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Phytotoxic effects of fresh and decomposing cover crop residues

TOR ARVID BRELAND
Agricultural University of Norway, Department of Biotechnological Sciences, Ås, Norway

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The occurrence of phytotoxicity was investigated 16 days after spring grain sowing on a loam soil where treatments with undersown Italian ryegrass, white clover or no cover crop had been introduced in the previous year. Tillage treatments included autumn rotovating, autumn ploughing, no tillage with killing of cover crops by herbicide in autumn, or spring rotovating. Effects of fresh plant materials and of soil incubated (15°C) for up to 28 days with plant materials were also studied. Phytotoxicity was bioassayed by the number of radish seeds germinating on filter paper with water extract from plant material or soil and expressed as a percentage of germination with deionized water. Ryegrass incorporated by spring rotovating reduced germination to 45%. The other treatments in the field trial were virtually without effect. Germination values in extracts from fresh ryegrass and white clover (13 mg plant dry matter ml^{-1}) were 64% and 15%, respectively. At double concentration of plant residues, the corresponding values were 27% and 1.3%. Wheat straw had no effect. Germination values in extracts from soil incubated with white clover were 63% and 66% on days 14 and 21, respectively. Ryegrass- and straw-amended soil did not differ significantly from unamended soil but tended to reduce germination on day 21. Plant residues had no effect on days 5 and 28. The results suggest that retarded germination observed in the field was mainly caused by phytotoxic substances indigenous to fresh residues and that these substances were degraded during 3–4 weeks of aerobic decomposition at 15°C.

Key words: Allelopathy, catch crop, cover crop, green manure, Italian ryegrass, no-till, phytotoxicity, reduced tillage, wheat straw, white clover.

Tor Arvid Breland, Agricultural University of Norway, Department of Biotechnological Sciences, P.O. Box 5040, N-1432 Ås, Norway

Cover crops have proved effective in reducing the risk of off-season nitrogen losses (Kyllingsbæk 1989; Sørensen 1992; Breland 1996b; Lyngstad & Børresen 1996) and may also reduce soil structure deterioration and erosion in arable farming systems (Morgan 1992; Breland 1995). When returned to the soil as green manure, cover crops also contribute to the pool of readily mineralizable organic nitrogen (Breland 1994a) and may increase subsequent crop yields (Breland 1996a). In conventional agriculture, chiefly non-legumes are used with the main purpose of preserving soil- and fertilizer-derived nitrogen (Sørensen & Thorup-Kristensen 1993). In low-fertilizer input systems, legumes are frequently applied to supply the soil with nitrogen derived from symbiotic fixation (Patriquin 1986).

To draw maximum benefit from this treatment on nitrogen fixation or conservation, cover crops should preferably be left undisturbed over the winter (Andersson 1986; Breland 1994b; Hansen et al. 1995; Lyngstad & Børresen 1996). In field trials with reduced tillage, however,

it has been observed that germination of spring grain sown shortly after incorporation of cover crop material by rotovating has been reduced compared with treatments without cover crop (Lyngstad & Børresen 1996). The reason for this may be physical, since surface-incorporated plant residues reduce the density of the seedbed and consequently, its susceptibility to drying. However, phytotoxic compounds indigenous to plant residues or microbial production of such substances may also be responsible (Elliott et al. 1978). A wide range of substances may be involved, such as phenols, plant growth regulators, organic acids, alcohols, hydrogen sulphide and antibiotics, but for many of these their actual roles under natural conditions have been difficult to identify (Elliott et al. 1978; Lynch 1985; Krogmeier & Bremner 1989). Microbial production of phytotoxins (mainly short-chain fatty acids) is closely related to the availability of easily decomposable substrates, and the subsequent toxin degradation depends on the rate of aerobic microbial metabolism as determined mainly by soil aeration and temperature (Harper & Lynch 1981).

The objective of this study was to investigate whether phytotoxic effects of straw and cover crop residues could explain impaired grain plant establishment in soil rotovated in spring (Lyngstad & Børresen 1996), and, if so, to determine the duration of the phytotoxicity in residue-amended soil incubated aerobically at field-proximate temperature.

Materials and methods

To investigate the possible occurrence of phytotoxicity under field conditions, material was collected from an experiment with cover crops in combination with different tillage treatments and N fertilizer levels on a loam soil at the Søråas site near the Agricultural University of Norway (59°40'N, 10°46'E). Field plan, soil properties and experimental treatments are described by Lyngstad & Børresen (1996). On 25 May 1990, which was 16 days after spring tillage and grain sowing and at the 1.5-leaf stage of the grain plants, soil samples were removed from the 0–6-cm layer with a soil sampling auger (diameter 2 cm, ten cores per plot, three replicates). From spring tillage until sampling, soil temperature (5 cm soil depth) ranged from 9.1 to 11.9°C and precipitation was 1.0 mm (Meteorological data for Ås, 1990. Department of Agricultural Engineering, Agricultural University of Norway). Selected cover crop treatments included no cover crop (120 kg N ha^{-1}), Italian ryegrass (*Lolium multiflorum* Lam.; 120 kg N ha^{-1}) and white clover (*Trifolium repens* L.; 0 kg N ha^{-1}). Tillage treatments comprised autumn ploughing, autumn rotovating, direct sowing (cover crops killed by herbicide in the autumn) and spring rotovating. After hand mixing of the soil, water up to water-holding capacity (W.H.C. = 57.8% w/w of dry soil) was added to subsamples corresponding to 115 g dry weight soil. Fifteen to 20 ml soil water was subsequently extracted by centrifugation (Beckman Model J2-21 M; 30 min; 739 G) through filter paper circles (Schleicher & Schuell 589[3] Blue Ribbon, diameter 55 mm) placed on a sieve that formed the lid of an extract collection chamber. A bioassay (modified after Wolf 1985) of possible phytotoxic effects of the extracts was carried out. Two parallel subsamples (5 ml) from each extract were pipetted into each of two petri dishes containing 50 radish (*Raphanus sativus* L. *var. radicula* cv. 'Non Plus Ultra')

seeds evenly distributed on a filter paper circle. Deionized water was applied as a control. The seeds were incubated at 21°C, and germinated seeds were counted when 50% of the seeds in the control had germinated (about 24 h). Radish was chosen because it is sensitive to phytotoxins and germinates rapidly, which is required to minimize the effect of microbial growth on the test result. The reaction of radish to phytoinhibitory effects has been found to be comparable to that of cereals (Wolf 1985).

To test whether a possible phytotoxicity could be caused by substances indigenous to plant material, a second experiment was carried out with extracts from pure, fresh plant residues. White clover and ryegrass material were minced separately in a mortar, while wheat (*Triticum aestivum* L.) straw was ground in order to pass through a 2-mm mesh. One portion of each plant material (2.27 g dry matter) was shaken (1 h, 21°C) with 175 ml deionized water (13 mg plant dry matter ml^{-1}), another with 87.5 ml (26 mg ml^{-1}). The samples were stored (3 h, 4°C) and shaken again (1 h, 21°C) before vacuum filtration (Whatman GF/C). Extract from an unamended sandy loam (described by Breland & Hansen 1996) was also included. Phytotoxicity was tested as described above in five parallel subsamples from each extract.

A third experiment was performed to test the duration of a possible phytotoxicity in soil incubated with plant residues. Fresh plant materials (2.27 g dry matter) were added to the sandy loam (500 g dry weight) and incubated in 0.5-L plastic trays for up to 28 days (15°C; 50% of W.H.C.; W.H.C. = 35% w/w of dry soil). The concentration of plant material corresponded to 500 g m^{-2} dry matter (0–20 cm depth). The treatments applied were unamended soil and soil with white clover, wheat straw and Italian ryegrass added, respectively. After 5, 14, 21 and 28 days of incubation, water up to W.H.C. was added to one tray from each of these treatments. The trays were stored for one day (4°C) before soil water (about 50 ml) was extracted by vacuum filtration (Whatman GF/C). Phytotoxicity was tested as described above in five parallel aliquots from each extract. Electrical conductivity and pH were measured in the extracts from fresh and incubated plant materials.

The results from the first experiment were tested statistically by analysis of variance (SYSTAT 1992) in a split-plot model with *tillage* as main plots and *cover crops* as subplots. Results from the second experiment were tested in a fully factorial model with *plant material* and *concentration* as variables. In the third experiment, a one-way analysis was applied for each sampling day. Orthogonal contrasts were used for testing differences between individual treatments.

Results and discussion

Germination of radish seeds was substantially inhibited in extracts from surface soil on ryegrass plots rotovated in spring ($p<0.001$; Table 1). This strongly suggests that phytotoxicity was an important factor in the reduced germination observed in these plots in the field (Lyngstad & Børresen 1996), although physical effects may also have contributed. Straw and white clover had no effect, and no phytotoxicity was recorded in soil from the other tillage treatments. The latter results also agreed with observations from the field.

Extracts from fresh ryegrass and, in particular, white clover material substantially reduced germination as assessed

Table 1. Germination of radish seeds after one day of incubation (21°C) on filter paper with soil water extracted from the 0–6-cm layer at Sørås on 25 May 1990 (number of germinated seeds as a percentage of germination with deionized water)

	Ryegrass	White clover	No cover crop
Spring rotovating	45 ±2.4[1)]	91 ±4.3	101 ±3.4
Direct sowing	98 ±2.9	94 ±6.8	81±3.6
Autumn rotovating	91 ±10.4	105 ±2.1	97 ±4.5
Autumn ploughing	76 ±9.0	94 ±4.6	97 ±7.3

[1)] Mean ± standard error (n = 3)

after 26 h ($p<0.001$; Fig. 1A). Under field conditions, seeds germinating close to fresh plant residues are probably subjected to fairly high concentrations of water-soluble material that leaks into the soil as plant cells disintegrate. Thus, the results indicate that phytoinhibitory substances present in plant material at incorporation contributed to the detrimental effect of ryegrass observed in soil from the field trial. The substantial effect of white clover conflicted with results from soil from the field trial (Table 1), but was in accord with results from a pot experiment where initial growth of ryegrass plants was significantly slower in clover-amended soil than in unamended soil, despite higher concentrations of soil mineral N in amended soil (Breland & Hansen 1996). The adverse effects of plant extracts were strongly dependent on concentration ($p<0.001$; Fig. 1). Consequently, the absence of effect in clover-amended soil from the field trial was probably due to a much smaller amount of fresh white clover than ryegrass material present at rotovating (not measured). In October, the above-ground yields were 134 and 193 g m^{-2} for white clover and ryegrass, respectively (T. Børresen, pers. comm.). The difference apparently increased until spring, as ryegrass continued growing during the relatively mild winter, whereas white clover stagnated or even declined.

There was no effect of straw extract (Fig. 1), which was in agreement with previous observations indicating that phytotoxicity associated with undecomposed, ripe straw is normally negligible (Elliott et al. 1978) and that

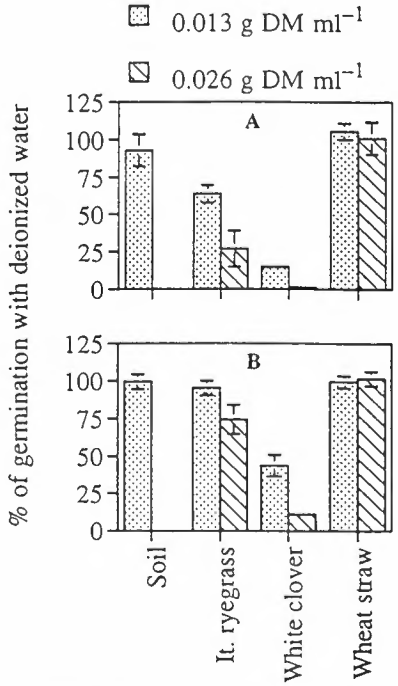

*Fig. 1. Germination of radish seeds after 26-h (**A**) and 40-h (**B**) incubation (21°C) on filter paper with water extracts from unamended soil and fresh plant residues (standard errors are indicated by vertical bars;* n = 5)

extracts from green material are more toxic than extracts from ripe material (Kimber 1973).

A comparison of germination as assessed after 26 h and 40 h (Figs. 1A and 1B) reveals that extracts from ryegrass and clover material had the effect of retarding germination rather than preventing it. Haugland & Brandsæter (1996) made a similar observation in a study of the effects of rape and rye plant extracts on germination of radish and ryegrass. Nevertheless, a delay may be detrimental to crop yield under field conditions. A retardation may render grain germs more susceptible to water stress and attack by pathogens and less competitive against perennial weeds and undersown crops for growth factors.

In incubated soil, there was no effect of plant residues on germination after five days (Fig. 2). At this stage, a large part of the residues still had a fresh appearance. Consequently, the yield of water-soluble substances in the extracts probably was low. After 14 and 21 days, significant phytotoxicity was detected in extracts from clover-amended soil ($p<0.01$), most likely because extraction efficiency increased as plant cell integrity deteriorated. The effect of ryegrass was weaker and not statistically significant. The last-mentioned results agreed qualitatively with those of pure plant extracts, although the effects were smaller for incubated residues. This must be attributed to dilution and adsorption of allelopathic agents in soil and the lack of mincing.

It seems that phytotoxicity in the incubation experiment was mainly derived from substances present in plant residues at incorporation in soil, although microbial toxin production cannot be ruled out. Accumulation of microbially produced toxins normally depends on anaerobic conditions (Elliott et al. 1978; Lynch 1985). If anaerobicity had occurred in the present incubation experiment, straw would have had a negative effect, since phytotoxin production is associated with degradation of cellulose and hemicellulose (Harper & Lynch 1981). More-

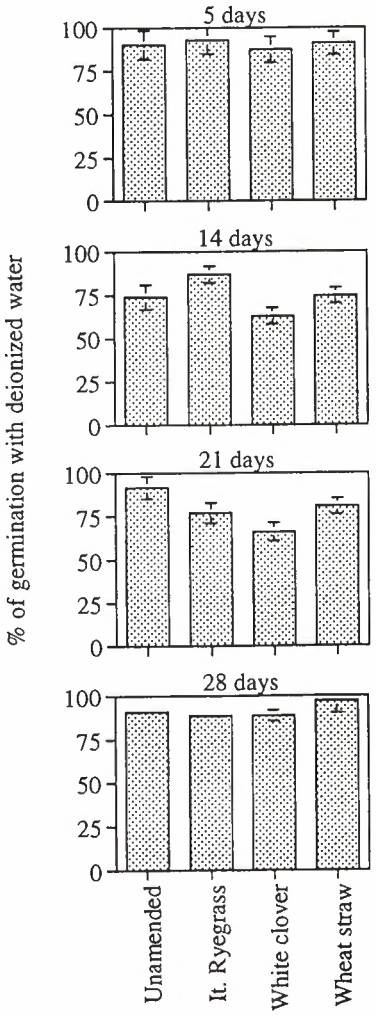

Fig. 2. Germination of radish seeds after one day of incubation (21°C) on filter paper with water extracted from soil incubated with plant residues for 5, 14, 21 and 28 days at 15°C (standard errors are indicated by vertical bars; n = 5)

over, Breland & Hansen (1996) found no indication of anaerobic metabolism in the same soil with white clover material added at the same concentration as that in the present experiment and incubated under similar conditions. In soil from the field trial, it seems unlikely that anaerobicity contributed significantly to the negative effect of ryegrass (Table 1). There was only 1.0 mm of precipitation from rotovating until sample removal, and soil was only removed from the upper 6 cm, where aeration is normally good.

After 28 days of incubation, extracts from amended soil had no phytotoxic effect (Fig. 2). In their pot experiment, Breland & Hansen (1996) observed growth inhibition of ryegrass plants ten days after addition of dried and ground white clover material, but on day 22 soil extracts were found to have no effect on germination of radish seeds. These observations concur with the absence of effect in soil from field plots where the green materials had been incorporated into the soil or killed by herbicide in the previous autumn (Table 1). They also agree with previous findings showing that phytotoxicity, regardless of whether it originates from plant- or microbially derived substances, is a temporary phenomenon that occurs for some time after incorporation of plant residues in soil (Kimber 1973; Elliott et al. 1978; Lynch 1985). The duration of this phase is extended by anaerobicity and low temperature (Harper & Lynch 1981).

In germination assays, phytotoxic effects may be confounded with effects of differences in osmotic potential. Haugland & Brandsæter (1996) studied the effect of polyethylene glycol (PEG) concentration (0–200 mg ml^{-1}) on germination of radish seeds (percentage of germination without PEG). When fitting a linear model to their data, the following relationship was obtained between speed of germination (y) and PEG concentration (x): $y = 95.8 - 0.5x$ ($r = 0.989$). Assuming that water-soluble material in clover and ryegrass amounts to 20–30% of total dry matter (T. M. Henriksen, Dep. Biotechnol. Sci., Agric. Univ. Norway, pers. comm.), the extracts from fresh plant material would contain a maximum of 8 mg ml^{-1} water-soluble material. Thus, it seems safe to conclude that differences in osmotic potential contributed little to the effects observed in the plant extracts (Fig. 1). As extraction efficiency was lower for incubated than for fresh plant residues, this conclusion is also valid for the incubation experiment (Fig. 2). Germination in extracts from fresh and incubated plant residues was not correlated with electrical conductivity (ranging from 0.2 to 3.6 mS cm^{-1}) nor with pH of the extracts (ranging from pH 5.6 to 6.4; results not presented), supporting the conclusion that the effects were caused mainly by phytoinhibitory substances. Conductivity was not measured in extracts from soil from the field trial, which was taken from both fertilized (control and ryegrass) and unfertilized plots (white clover). However, possible differences in salt concentration cannot explain the substantial effect of ryegrass rotovated in spring (Table 1) as ryegrass- and unamended samples were taken from the same fertilizer level (120 kg N ha^{-1}).

Conclusions

The results suggest that the impaired grain plant establishment observed after spring rotovating of a fresh ryegrass cover crop was caused by phytotoxic substances indigenous to ryegrass material. The bioassays showed that the phytotoxic potential of clover residues may be even

higher per unit of plant material than that of ryegrass. Relatively low amounts of fresh clover green matter may account for phytotoxicity not being observed in clover-amended soil from the field trial. Phytotoxicity was detected in residue-amended soil after 14 and 21 days of aerobic incubation at 15°C, but not after 28 days. No phytotoxicity was observed in soil from the field trial where residues were killed by tillage or herbicide in autumn. Consequently, spring sowing should be delayed by 3–4 weeks after fresh cover crop material has been mixed into the seedbed. As this is not a particularly popular practice, more acceptable options might be to use cover crops whose green matter is substantially reduced during winter, to kill cover crop material in autumn, or physically to separate cover crop material from germs, e.g., by ploughing.

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Flower yield and the content and quality of the essential oil of chamomile, Chamomilla recutita (L.) Rauschert, grown in Norway

STEINAR DRAGLAND[1], BERIT SMESTAD PAULSEN[2], JENS KRISTIAN WOLD[2] & TORUN HELENE ASLAKSEN[2]
[1]The Norwegian Crop Research Institute, Apelsvoll Research Centre Division Kise, Nes på Hedmark, Norway. [2]Institute of Pharmacy, University of Oslo, Oslo, Norway

Dragland, S., B.S. Paulsen, J.K. Wold & T.H. Aslaksen 1996. Flower yield and the content and quality of the essential oil of chamomile, *Chamomilla recutita* (L.) Rauchert, grown in Norway. Norwegian Journal of Agricultural Sciences 10: 363-370. ISSN 0801-5341.

Five chamomile cultivars were grown at a crop research centre in southeastern Norway in the summer of 1993. The yield of flowers and also the content and quality of the essential oil distilled from the flowers were found to be satisfactory. One of the cultivars was grown in the summer of 1994 at 42 locations in the southern, central and northern regions of Norway. The chamomile grown in the southern and central regions gave a reasonably high flower yield with acceptable oil quality. In northern Norway the yield was lower and the oil quality somewhat poorer.

Key words: Chamomile, climate, cultivars, essential oil, quality, yield.

Steinar Dragland, The Norwegian Crop Research Institute, Apelsvoll Research Centre Division Kise, N-2350 Nes Hedmark, Norway

Chamomile, *Chamomilla recutita* (L.) Rauchert, family *Asteraceae*, grows wild in a few districts of Norway. It has been grown in home gardens for several years, but there is no commercial production of any significance. A growing interest in herb production initiated the present experiments which are the first to study the potentiality for chamomile production in Norway. Five cultivars were tested at a research centre in 1993, and samples of one of the cultivars was grown on small plots in different districts of Norway the following year. Pharmacologically active substances in chamomile are concentrated mainly in the essential oil. This study is concerned with the content of oil components such as bisabolol and its oxides, chamazulene and spiroether, which have been shown to have antiphlogistic and spasmolytic effects.

Materials and methods

The growth experiments were carried out mainly at Apelsvoll Research Centre Division Kise, in southeast Norway (about 61°N10°E). In 1994 the growth of chamomile on small plots at 42 locations from 58 to 69° North was also investigated. The following five chamomile cultivars were grown in the experiment at Kise:

1. 'Budakalaszi-2' (tetraploid, Hungary)
2. 'Degumille'(diploid, Germany)
3. 'Dæhnfeldt'(seeds from Dæhnfeldt, Danmark)
4. 'Hungary'(seeds from B. Galambosi, Hungary)
5. 'Zloty Lan'(Poland)

Seeds were sown in plugs on April 20 (3-5 seeds per plug), and transplanted to the field on May 26, 1993. The plot size was 2.25 m^2 with three replications. The field was fertilized with 8-2-6.5 g/m^2 NPK compound at the time of soil preparation. Flowers were harvested with a hand harvester when in full bloom (July 5, July 21 and August 18). This gave 36 days from sowing to transplanting, and 40 days in the field until the first harvest. The flowers were dried at 35° C for 24 h and stored in paper bags at room temperature. Dry matter content is expressed relative to the fresh weight of flowers before such drying.

The cultivar 'Dæhnfeldt' was grown on 7 m^2 test plots at various locations in 1994.

Seeds were sown in plugs in April and transplanted to the fields in May or June. Fertilization varied because of several local factors. Harvesting of flowers was carried out by hand when most of the flowers were in full bloom. The flowers were dried at the farms, but it was not always possible to maintain the temperature between 30 and 40°C as planned.

Estimation of the content of essential oil in the chamomile flower heads was carried out using a modification by Aslaksen (1994) of the steam distillation procedure described in the European Pharmacopoeia (1980). After isolation, the essential oil was analysed by thin layer chromatography (TLC) for identification of the main constituents. Quantitative determination of oil components was carried out by gas chromatography (GC), and confirmation of the identity of the seven most important constituents was performed by gas chromatography in combination with mass spectrometry (GC/MS) (Aslaksen 1994).

Results

Five cultivars grown at Kise

The climatic conditions during the experimental period differed from those of the normal period 1961-90 (Table 1). The mean monthly air temperature in June-August 1993 was 1.0 -1.7 °C below normal, and during the harvesting period in July and August the number of

Table 1. Meteorological data for May-August at Kise as normals for the period 1961 - 90, and deviations from normal in 1993.

	May	June	July	Aug.
Normals over 30 years:				
Mean air temperature, °C	8.5	13.6	15.2	14.0
Precipitation, mm	44	59	66	76
Sunshine, hours	216	250	242	199
Deviations in 1993 from normal:				
Mean air temperature, °C	+ 2.1	- 1.7	- 1.0	- 1.6
Precipitation, mm	+ 28	- 23	+ 75	+ 29
Sunshine, hours	+ 12	- 24	- 124	- 43

sunshine hours was only 62% of the longterm normal.

The dry matter percentage of flowers varied from 16.8% in 'Hungary' to 19.6% in 'Degumille'. The average was 18.1%.

'Budakalaszi-2' had some flowers hidden among the leaves, but this presented no problem for the harvesting. The total accumulated yield of dry flowers reached 105.7 g/m^2 (Table 2). From the recorded weight of 100 flowers this amounts to 1950 flowers per m^2.

'Degumille' was easy to harvest because of thin, erect flower stems. The accumulated yield was low. The number of flowers was high, about 2450 per m^2, but the mean weight per flower was the lowest of all the cultivars.

'Dæhnfeldt' had some flowers hidden among the leaves, but erect flower stems made harvesting quite easy. The yield was about average. The number of harvested flowers was only 1740 per m^2, but each flower had a high weight.

'Hungary' was similar like 'Dæhnfeldt' in character. The yield was below average, as was the number of flowers (1880 per m^2).

'Zloty Lan' had curly stems, and the flowers were difficult to tear off by hand harvesting. The yield of dry flowers was high. Number of harvested flowers per m^2 reached 2060, and the mean weight per flower was above average. Flower heads from each of the five cultivars were analysed for content of essential oil and also for chamazulene, one of the pharmacologically active oil constituents. The data in Table 3, dem-onstrate a significant increase (P=0.05) in the percentage of essential oil from July 5 to July 21, and during the subseguent 4 weeks a slight decrease for the cultivars 'Degumille', 'Hungary' and 'Zloty Lan'. The same trend was also found also in the chamazulene content. This perhaps reflects a lower content of the precursor matricine in the flowers of these cultivars.

Table 2. Accumulated yield of dry chamomile flowers (g/m^2) harvested at Kise on dates as indicated. Average weight of 100 flowers in grams.

Cultivar	Harvesting dates July 5	July 21	Aug.18	Weight in g 100 flowers
'Budakalaszi-2'	11.3	57.0	105.7	5.41
'Degumille'	8.0	43.7	79.3	3.24
'Dæhnfeldt'	4.0	42.7	97.3	5.58
'Hungary'	8.0	46.0	93.0	4.95
'Zloty Lan'	16.3	68.7	109.0	5.29
$LSD_{0.05}$	3.2	9.1	16.3	1.25

Table 3. Essential oil (w/w%) and chamazulene (mg/100 g) in dry flowers of five chamomile cultivars grown at Kise in the 1993 season.

	Harvesting dates							
	July 5		July 21		Aug. 18		Mean	
Cultivar	E.oil	Cham.	E.oil	Cham.	E.oil	Cham.	E.oil	Cham.
'Budakalaszi-2'	0.4	60	0.7	78	0.7	78	0.6	72
'Degumille'	0.7	70	1.0	81	0.8	60	0.8	70
'Dæhnfeldt'	0.5	62	0.7	70	0.7	67	0.6	67
'Hungary'	0.5	45	0.9	81	0.8	70	0.7	65
'Zloty Lan'	0.5	65	0.8	76	0.7	65	0.7	69
Mean	0.6	60	0.8	77	0.7	68		

$LSD_{0.05}$ for E.oil = 0.1 for cultivars and for harvesting dates
$LSD_{0.05}$ for cham. = 9 for harvesting dates, and not calculated for cultivars because of non-significant effects of cultivars for the content of chamazulene.

Test plots from 58 to 69° North

In the local tests 42 farmers succeeded in growing chamomile 'Dæhnfeldt' and in harvesting most of the flowers. Daylength and normal temperature for some meteorological stations listed in Table 4, indicate a temperature level during the growing season ranging from 5 to 12°C in northern Norway and 10 to 16°C in the southern locations as an average per month during the season. In 1994 the southern part of Norway had temperatures above normal in June, July and August, while the months of May, June and July were cooler than normal in northern Norway that same year. In June and July the daylength is 24h in northern Norway, where as it is 18 to 19 h in southern Norway.

Yield of flowers, planting and harvesting date varied not only among the three regions of Norway, but even more within each of them (Table 5).

As shown in Table 5, the average content of essential oil in chamomile flowers grown in the northern region (64-69° N) was lower than in flowers grown in the southern (58-60° N) and central (61-63° N) regions of the country. The relative

Table 4. Normal temperature and daylength for some meteorological stations in Norway 1961-90.

		Temperature °C				Daylength, hours			
Station	Latitude	May	June	July	Aug.	May	June	July	Aug.
Landvik	58° 15' N	10.4	14.7	16.2	15.4	16.7	18.2	17.5	15.4
Kise	60° 45' N	8.5	13.6	15.2	14.0	17.2	19.0	18.2	15.8
Værnes	63° 45' N	9.4	12.6	13.9	13.4	18.1	20.5	19.4	16.3
Tromsø	69° 40' N	4.8	9.1	11.8	10.8	22.0	24.0	24.0	18.2

Table 5. First and last date 1994 for planting, flowering and harvesting in three regions of Norway. Yield of dried flowers and their essential oil content in the same regions.

Region		Southern	Central	Northern
Latitude		58-60° N	61-63° N	64-69° N
Number of trials		15	18	9
Planting date	earliest	May 10	May 26	May 30
	latest	June 8	June 30	June 21
First flowering	earliest	June 6	June 6	June 15
	latest	July 25	July 25	July 22
First harvesting	earliest	June 28	June 22	July 4
	latest	Aug. 1	Aug. 4	Sept. 5
Last harvesting	earliest	July 13	July 27	Aug. 17
	latest	Sept. 21	Oct. 10	Sept. 30
Yield of dried flowers g/m^2				
Lowest		17	36	12
Average		146	114	85
Highest		228	217	152
Essential oil in total dry matter				
Lowest		0.4	0.2	0.2
Average		0.8	0.9	0.6
Highest		1.2	1.2	1.0

proportions of the seven main essential oil components also varied with region (Table 6). It appears that the composition of oil from chamomile flowers produced in the southern and central Norway was very similar, but that it differed in some respects from the oil composition of chamomile from northern Norway. The proportion of chamazulene, bisabolol and bisabololoxide B was lower, while the proportion of farnesene was higher in essential oil from flowers produced in the northern region compared to the southern regions that year.

Discussion

The yield obtained in these experiments was relatively high even in the northern regions, as compared with 30-50 g/m^2 obtained in Czechia/Slovakia (Salamon 1992). In Hungary, yield is expected to be 50-200 g/m^2 fresh flowers, from which 10-50 g/m^2 dry drug may be produced (Svab 1992). In Finland Galambosi et al.(1991) did not find any relationship between flower yield and the temperature sum of the growing season. The main cause of variation in yield was the time of germination in early spring. Late

Table 6. Relative distribution in per cent of the seven main constituents of the essential oil of chamomile flowers produced in different regions of Norway in 1994.

Region	Farne-sene	Bisa-bolol	Bisa-bolol oxide A	Bisa-bolol oxide B	Bisa-bolon oxide A	Cham-azulene	Spiro-ether
Southern	4.7	3.5	10.5	15.2	7.4	17.2	41.4
Central	4.6	3.5	10.8	14.2	7.5	17.1	42.3
Northern	7.4	2.6	11.5	13.1	7.8	15.0	42.6

germination may allow only one harvest of flowers. On small plots the fresh flower yield in Finland varied between 177 and 699 g/m^2 averaged over four cultivars. This corresponds to about 30-130 g/m^2 dry weight.

Average yields of 80 - 150 g/m^2 in the test plots are not directly comparable to yields obtainable in commercial production. Harvesting the flowers with mechanical harvesters instead of by hand, lowers the yield. In commercial production the seed is usually directly sown in the field. This may give a lower yield than transplanting. On the other hand it should also be taken into account that most of the farmers who took part in these experiments had no experience in growing chamomile.

However, it can be concluded that chamomile can be grown in Norway with an acceptable yield of flowers.

The quality of chamomile flowers depend on the presence of several pharmacologically active substances. Some of these are water-soluble such as the flavonoids and polysaccharides, but these were not included in this study. However, the essential oil is considered to be most important and the European Pharmacopoeia standard requires a content of at least 0.4%. Table 3 shows that all of the five chamomile cultivars fulfilled this requirement. In particular, the flowers harvested in late July and August were rich in essential oil.

Since ancient times chamomile has been used in the treatment of wounds, stomach ache of children and inflammation, and it has been demonstrated in several pharmacological experiments that a number of the oil constituents possess anti inflammatory properties (Schilcher 1987). Bisabolol is the most active component, but its oxides A and B, chamazulene and, to a lesser extent, spiroether contribute to the effect. Thus, the quality of the essential oil is more or less determined by the total amount of these compounds.

Table 6 indicates that chamomile oil obtained from flowers grown in the North (64-69°N) was of somewhat inferior quality than that from flowers of the southern regions. There was a higher proportion of the inactive farnesene in the North Norwegian flowers, and also a lower bisabolol content. It may be that the cold summer in northern Norway had an influence on the amount and composition of the essential oil, and caused a lower yield of flowers, compared with what was obtained under the warmer conditions of central and southern Norway.

In order to compare the analytical data it was important that all the farmers included in the study should treat the flowers in the same way after the harvest.

There is some doubt about whether this was in fact done. Drying and storage of the plant material under unsuitable conditions can readily influence the content and quality of the essential oil. However, the present investigation indicates that chamomile grown in the southern regions of Norway gives essen-tial oil in a quantity and of a quality that are sufficiently high to justify further steps towards commercial production of chamomile on a larger scale.

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The Apelsvoll cropping system experiment VII Runoff losses of soil particles, phosphorus, potassium, magnesium, calcium and sulphur

RAGNAR ELTUN[1], OLE FUGLEBERG[2] & OLAV NORDHEIM[1]
[1] The Norwegian Crop Research Institute, Apelsvoll Research Centre, Kapp, Norway[2] Department of Mathematical Sciences, Agricultural University of Norway, Ås, Norway

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In the Apelsvoll Cropping System Experiment, the environmental side-effects and productivity of six cropping systems, involving conventional, integrated and ecological arable and forage systems, are being investigated. The systems differ with regard to crop rotation, fertilization, soil tillage and plant protection, and they are established on model farms, equipped as field lysimeters for measuring drainage and surface runoff. In the present paper the drainage and surface losses of soil particles, phosphorus, potassium, magnesium, calcium and sulphate-sulphur over the first four-year cropping period are presented. The average annual losses of these variables were 28, 0.32, 7, 12, 159 and 30 kg ha^{-1}, respectively. The results showed that arable cropping systems with autumn ploughing have higher erosion risks than arable systems with spring tillage or forage crop systems. It appeared that the losses of the present nutrients are less affected by the cropping systems than is nitrogen. However, crop management factors like time of soil tillage, time of manure application and type of plant cover in the autumn, affects the loss of phosphorus. Plant residues appeared to be importent sources for loss of phosphorus and potassium, while the loss of magnesium, calcium and sulphur seems to be primarely affected by fertilization. Because of variation in weather factors, there was a great annual variation in nutrient losses, which shows that long term observations are needed in order to obtain reliable data concerning nutrient losses from the various cropping systems.

Key words: calcium, cropping systems, fertilization, magnesium, phosphorus, potassium, soil tillage, sulphur, runoff, leaching

Ragnar Eltun, The Norwegian Crop Research Institute, Apelsvoll Research Centre, N-2858 Kapp, Norway

Runoff losses of phosphorus to watersheds are often the main pollution problem caused by farming in Norway (e.g. Rognerud et al. 1989; Røhr 1985). Since soil particles and plant residues are the most important sources of phosphorus (Krogstad & Løvstad 1987; Lundekvam & Mundahl 1986; Uhlen 1989a), phosphorus losses depend very much upon soil tillage practices (Skøyen 1988; Lundekvam 1993), fertili-zation (Krogstad 1987) and type of plant cover (Miller et al. 1994; Uhlen 1989b; Ulén 1984a). Potassium, magnesium and calcium are not considered to be major water pollutants in Scandinavia (Ulén 1984b). However, loss of these nutrients may lead to nutrient deficiencies and thus affect the need for liming and fertilization. The loss of sulphate, which is not a serious pollut-

ant either, is associated with the loss of cations. In this way sulphate losses may lead to soil acidification and increased need for liming (Karltun 1996). In addition, sulphur deficiency is on the increase in Norway (Repstad & Stabbetorp 1996), and losses will thus affect the need for sulphur application on soils with a low initial sulphur content. In most studies dealing with the loss of phosphorus and other nutrients, long- and shortterm crop rotations and lysimeter experiments have been used. It has been focused on the effect of soil tillage, fertilization, crop rotation etc. on soil properties, crop yields and nutrient losses (Eltun 1990). The Apelsvoll Cropping System Experiment which started in 1989 (Eltun 1994), is aimed to develope cropping systems which minimize the leaching of nutrients and pesticides, whilst providing farm products with a desirable nutritional value, and maintaining an economically viable yield. As opposed to previous experiments (Eltun 1990), the Apelsvoll Experiment is designed to measure nutrient leaching and runoff from entire cropping systems.

The results concerning runoff of nitrogen for the first four-year experimental period have been published by Eltun & Fugleberg (1996). The results from the same period (1990-93) concerning the runoff of soil particles, phosphorus, potassium, magnesium, calcium and sulphur are presented in the present paper.

Materials and methods

Cropping systems and nutrient loss measurements

The experimental design, management of the individual cropping systems and soil conditions on the model farms have been described by Eltun (1994) and by Riley & Eltun (1994). Only a brief resumé is given here. The experiment which is conducted at Apelsvoll Research Centre, Kapp, situated in the central part of south-

Table 1. Main differences between the cropping systems with regard to crop rotation, mineral nitrogen fertilizer, amount and time of slurry application, soil tillage and plant protection

	Cropping systems					
Management factors	Conv. arable	Integr. arable	Ecol. arable	Conv. forage	Integr. forage	Ecol. forage
Crop rotation	Cereals/ potatoes	Cereals/ potatoes	Cereals/ potatoes/ ley	Forages/ cereals	Forages/ cereals	Forages/ cereals
Mineral fertilizer, kg N ha $^{-1}$	120	70	0	110	60	0
Slurry, Mg wet weight ha $^{-1}$	0	0	10 (27) [1]	45 (121)	30 (81)	20 (54)
Time of slurry application			Spring	Autumn/ spring/ summer	Spring/ summer	Spring/ summer
Soil tillage	Autumn plough.	Spring harrow.	Spring plough.	Autumn plough.	Spring plough.	Spring plough.
Plant protection	Chemical	Integrated	Mechanical	Chemical	Integrated	Mechanical

[1] Total-nitrogen in the slurry, kg ha $^{-1}$

east Norway, is based both on traditional experimental methods and on a systems approach. The following six types of cropping systems are compared:

A. Conventional arable crop production without farmyard manure
B. Integrated arable crop production without farmyard manure
C. Ecological arable crop production with farmyard manure
D. Conventional forage crop production with farmyard manure
E. Integrated forage crop production with farmyard manure
F. Ecological forage crop production with farmyard manure

The main differences between the cropping systems concerning the management factors for the period 1990-94 are shown in Table 1, and the average amount of nutrients applied in mineral fertilizer and manure are presented in Table 2.

The dominant soil textures are loam and silty sand, with a topsoil containing 15% clay and about 7% humus. The contents of exchangeable cations (K^+, Mg^{2+}, Ca^{2+} and Na^+) in the upper 30 cm, are shown in Table 3. The determinations were made in the same soil samples, as described in Riley & Eltun (1994). The analyses were performed at the Agricultural Service Laboratory of the Norwegian Centre for Soil and Environmental Research by using Thermo Jarrell Ash Simultan ICP after extraction with 1M ammonium acetate. There were no differences between the cropping systems in the exchange capacity of any of the cations (Table 3).

Each cropping system is represented on two model farms of 0.18 ha each, randomly distributed within a 6 x 2 grid of 3.3 ha. Each farm has eight rotation plots. All crops in each rotation are pre-

Table 2. Annual average application of phosphorus, potassium, magnesium, calcium and sulphur in the period 1990-93

Cropping system	P kg ha^{-1}	K kg ha^{-1}	Mg kg ha^{-1}	Ca kg ha^{-1}	S kg ha^{-1}
Conventional arable	29	85	10	21	34
Integrated arable	18	52	6	13	21
Ecological arable	4	59	11	8	25
Conventional forage	30	193	20	56	24
Integrated forage	21	135	14	31	18
Ecological forage	12	86	9	23	9

Table 3. Content of the exchangeable cations potassium, magnesium, calcium and sodium in the topsoil (0-30 cm) at the start of the experiment in 1989

	K	Mg	Ca	Na
Cropping system	meq per 100 g air dry soil			
Conventional arable	0.129	0.840	11.6	< 0.033
Integrated arable	0.112	0.690	10.8	< 0.033
Ecological arable	0.115	0.852	12.2	< 0.033
Conventional forage	0.150	1.019	14.9	< 0.033
Integrated forage	0.133	0.856	13.2	< 0.033
Ecological forage	0.136	0.834	12.8	< 0.033
Std. error of difference	0.054	0.347	4.6	-
Mean	0.129	0.848	12.6	< 0.033

sent every year. Each farm has a separate drainage system from which leaching is measured continuously. Samples are taken for analysis of chemical composition in proportional to the runoff. Surface runoff water is collected by means of barriers placed at the lower end of each farm. It is measured and sampled in the same way as the drainage water.

Based on monthly records of runoff and analysis of nutrient concentrations, the results are presented on the basis of the «hydrological» year which is defined as the period from October to September. As explained in Eltun & Fugleberg (1996), the loss of the individual nutrients was calculated as the product of the average runoff from all systems and the nutrient concentrations in each system. The presented results are from the first four-year (October 1990-September 1994) runoff period, during which only minor changes were made in the management factors shown in Table 1.

The nutrient content and pH of the runoff water were analysed at The Norwegian Crop Research Institute, Holt Research Centre by means of standardized methods (Norwegian Standard[1]). Sulphate-sulphur was analysed by photometric titration, using a Thorin-barium perchlorate complex, the waveband 550 nm and a Technicon AutoAnalyzer II.

[1] Norwegian Standard 4720 1979. Water analysis, determination of pH; 4733 1983. Water analysis, determination of suspended solids in waste water and their loss on ignition; 4725 1984. Water analysis, determination of total phos-phorusdigestion by peroxo-disulphate; 4770 1994. Water analysis, determination of metals by atomic absorption spect-rometry, flame atomization, general principles and guidelines; 4775 1994. Water analysis, atomic absortion spec-trometry, special guidelines for sodium and potassium; 4776 1994. Water ana-lysis, atomic absorption spectrometry, special guidelines for calcium and magnesium. All issued by Norges Standardiseringsforbund, Postboks 7020, Homansbyen, 0306 Oslo.

Statistical method

Nutrient losses are assumed to be determined by climatic factors in interaction with soil processes and the cropping systems. Regression analysis were thus assumed to be the most suitable method to determine the relative influence of these factors on nutrient losses. The regression method used, and the models which are developed, are presented by Fugleberg & Eltun (1996) and Eltun & Fugleberg (1996).

Table 4. Days with ground frost at 10 cm depth, maximum snow depth, mean air temperature, total amount of precipitation and runoff in the runoff years 1990/91 - 1993/94

Runoff year	Ground frost days	Snow-depth cm	Air temp. °C	Preci-pitation mm	Drainage runoff mm	Surface runoff mm	Total runoff mm
1990/91	83	30	4.4	474	107	69	176
1991/92	74	35	5.8	462	115	27	142
1992/93	100	20	4.3	590	279	30	309
1993/94	0	72	2.9	690	506	16	522
1961-90 [1]			3.6	600			

[1] Normal 1961-90

Weather conditions and runoff

Annual weather data and runoff totals are presented in Table 4. More details about monthly temperatures and the distribution of precipitation and runoff during the year may be found in Eltun & Fugleberg (1996). In the first runoff year (1990/91) the temperature was close to normal throughout the year, but the precipitation was below normal most of the time. There was frost only in the upper 10 cm soil layer. The second year (1991/92) had a mild and dry winter, a warm and dry spring and early summer and a cool and wet autumn. As in the first year the ground frost was very shallow. The third year (1992/93) also had a fairly mild winter, but lack of snow resulted in deep ground frost. The growing season was unusually wet and cool that year. The final year (1993/94), had a very cold winter, but as there was a high precipitation and deep snow, there was hardly any ground frost. The early summer was warm and dry, but there was heavy rain in August and September.

Most of the runoff usually occurred in the periods October-December and March-April. Runoff only occurred during the growing season in months with unusually high precipitation, accompanied by water saturated soil and low evaporation. During the first three winters there were some cases of runoff due to fluctating temperature and repeated snow melt periods. On an average for the whole period (Table 4), 88% of the total runoff was drainage water. Most of the surface water came during the snow melt period March-April. The distribution of surface and drainage runoff in winter depended upon the ground frost conditions, but in most cases surface runoff dominated in the winter.

Results and discussion

Loss of soil particles

On an average for all cropping systems and years the annual losses of soil particles in the surface and drainage water was 28 kg ha^{-1} and, with the exception of the conventional arable system, the losses were as high or higher in the drainage water as in the surface water (Fig. 1).

As compared to most other measurements of soil and dry matter losses from arable land in the Nordic countries (e.g. Eltun 1990; Ludvigsen 1995; Lundekvam

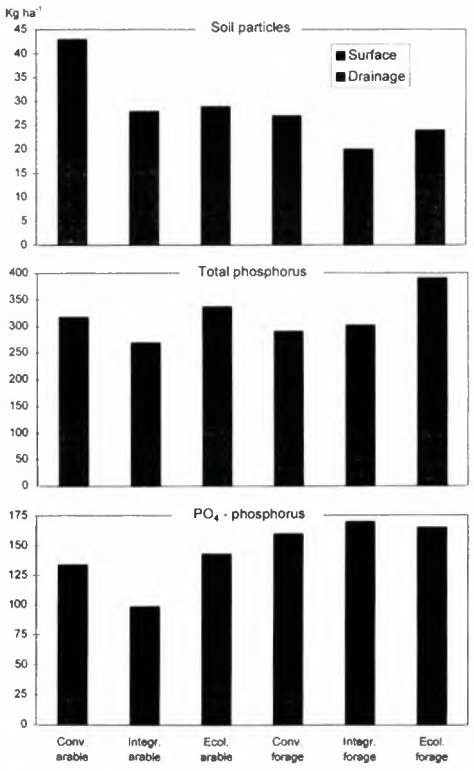

Fig. 1. Annual runoff losses in drainage and surface water of soil particles, total phosphorus and phosphate phosphorus for the six cropping systems averaged over the years 1990-94

1993) these losses are very small. However, the soil losses are in general small in this region (Ludvigsen 1995). In accordance with the «Universal Soil Loss Equation (USLE)» (Wischmeier & Smith 1987), the main reasons for the low surface erosion in this experimental period may be summarized as follows 1) the soil type has low erosion risk 2) no case with extreme precipitation intensity occured 3) the site has a short slope length (60 m) and a small angle of inclination (< 5%). Low surface erosion was also the main reason for the relatively high proportion of the soil particle losses in the drains as compared to the surface water. However, soil loosening during drain establishment may also have affected subsurface erosion in this early stage of the experiment. Soil cracks and earthworm channels also attribute to subsurface erosion in this soil type.

Despite the small losses by erosion, there were significant differences between cropping systems (Fig. 1 and Table 5). In Table 5 the regression parameters associated with the climatic variables expresses constant relative changes. For example, losses of soil particles in the drainage water increases with 0.55%, when precipitation increases with 1%, and this increase is significant with a t-value of 6.2. The regression parameters associated with the cropping system variables are

Table 5. Results of regression analysis of losses (g/daa $^{-1}$) of soil particles and potassium in drainage water and surface water and of magnesium, calium and sulphate-S in drainage water, based on monthly observations throughout the whole year in the period October 1990 - September 1994. The data for the cropping systems B-F are given relative to system A (conventional arable) and are presented as R-square and estimated regression parameters with t-values in paranthesis. An asteriks denotes a significant variable with a t-level of 2 or higher

	Soil particles				Potassium			
Regressor	Drainage		Surface		Drainage		Surface	
R-square	0.14		0.19		0.15		0.26	
P Precipitation	0.55	(6.2) *	-0.56	(-5.1) *	0.64	(7.4) *	-0.26	(-3.4) *
T. Air temperatire	0.04	(0.4)	1.32	(3.3) *	0.35	(3.1)	0.24	(1.1)
ST. Soil temperature	-0.07	(-2.0) *	-0.09	(-1.8)	-0.01	(-0.4)	0.15	(4.8) *
B. Integr. arable	0.24	(-1.2)	-0.67	(-2.3) *	-0.23	(-1.0)	-0.38	(-1.9)
C. Ecol. arable	-0.54	(-2.6) *	-0.29	(-1.0)	-0.27	(-1.3)	0.20	(0.9)
D. Conv. forage	-0.55	(-2.7) *	-0.55	(-2.0) *	-0.24	(-1.2)	0.23	(1.1)
E. Integr. forage	-0.59	(-2.9) *	-1.03	(-3.6) *	-0.42	(-1.9)	0.06	(0.3)
F. Ecol. forage	-0.45	(-2.2) *	-0.58	(-2.0) *	-0.05	-0.3)	0.37	(1.7)
	Magnesium Drainage		Calcium Drainage		Sulphate-S Drainage			
R-square	0.26		0.26		0.34			
P. Precipitation	0.67	(7.7) *	0.67	(7.6) *	1.57	(9,5) *		
T. Air temperature	0.15	(1.4)	0.16	(1.4)	0.31	(2.4) *		
ST. Soil temperature	-0.19	(-5.5) *	0.19	(-5.7) *	0.18	(2.7) *		
B. Integr. arable	-0.13	(-0.6)	-1.22	(-1.0)	-0.01	(-0.1)		
C. Ecol. arable	-0.17	(-0.8)	-0.25	(-1.2)	-0.01	(-0.1)		
D. Conv. forage	-0.00	(-0.1)	-0.14	(-1.2)	-0.87	(-3.3) *		
E. Integr. forage	-0.14	(-0.7)	-0.17	(-0.8)	-0.58	(-2.1) *		
F. Ecol. forage	-0.23	(-1.1)	-0.25	(-1.2)	-0.67	(-2.4) *		

the change in the logarithm of the concentration or losses by passing from conventional arable production (A) to any of the other systems. For example, passing from conventional arable production (A) to integrated arable production (B) entails a decrease in the logarithm of the amount of soil particles in the surface water of 0.67, and this is significant (t-value = 2.3).

The conventional arable system had higher losses of soil particles by surface water than the other systems. On the basis of many previous investigations (e.g. Njøs & Hove 1986; Skøyen 1988), the most obvious reason for this is that autumn ploughing was practiced in this system. The other systems had either spring tillage or perennial crops such as ley, which give better protection against soil erosion in the autumn, winter and spring. It is more difficult to explain the higher losses of soil particles found in the drainage water of the conventional and integrated arable systems than those found in the other systems. They may be related to the type of plants used in the crop rotation. It appears that cropping systems with ley (the ecological arable system and the forage systems) give a better protection against drainage losses than cropping systems with only cereals and potatoes (the conventional and the integrated arable system).

Loss of nutrients

Phosphorus

The concentrations and losses of total and soluble phosphorus are shown in Table 6 and Fig. 1 and the regression results in Table 7. The mean annual loss of total phosphorus in drainage and surface water was 0.32 kg ha^{-1} and the loss in surface water was twice as high as that in drainage water. The average concentration of total phosphorus in the drainage water was only 0.05 mg l^{-1}, as opposed to 0.65 mg l^{-1} in the surface water. Thus, it was a

Table 6. Mean concentrations of total phosphorus, phosphate phosphorus, potassium, magnesium, calcium and sulphate-sulphur[1)] in mg l^{-1}, and mean pH in the drainage and surface runoff of the cropping systems in the runoff years 1990/91 - 1993/94

	Tot.-P	PO_4-P	K	Mg	Ca	SO_4-S	pH
Drainage							
Conventional arable	0.07	0.02	3.30	6.0	81.3	36.0	7.4
Integrated arable	0.04	0.01	1.75	5.0	68.9	29.5	7.3
Ecological arable	0.05	0.01	1.93	5.1	70.7	33.5	7.4
Conventional forage	0.05	0.01	2.02	7.0	91.8	19.0	7.6
Integrated forage	0.05	0.01	1.52	4.7	68.6	18.0	7.4
Ecological forage	0.05	0.01	2.38	4.9	72.6	19.0	7.4
Mean	0.05	0.01	2.15	5.4	75.7	25.8	7.4
Surface							
Conventional arable	0.62	0.30	11.10	1.5	13.3	11.5	6.6
Integrated arable	0.52	0.21	7.30	1.0	9.1	10.0	6.6
Ecological arable	0.78	0.37	10.68	1.4	12.5	10.5	6.7
Conventional forage	0.61	0.41	10.13	1.6	12.9	7.0	6.8
Integrated forage	0.61	0.40	10.78	1.5	10.9	7.0	6.8
Ecological forage	0.89	0.40	14.48	1.4	10.7	7.0	6.8
Mean	0.67	0.35	10.75	1.4	11.6	8.8	6.7

[1)] SO_4-S in the years 1992/93 and 1993/94

higher drainage than surface runoff that accounted for the relatively high phosphorus losses in the drainage water. Soluble phosphorus constituted nearly 50% of the total phosphorus losses, and 73% of the soluble phosphorus was lost in the surface water.

The main sources for phosphorus losses are erosion of soil particles and plant residues (e.g. Krogstad & Løvstad 1987; Miller et al. 1994; Uhlen 1989a; Ulén 1984a). The small amount of soil losses in this experiment explains the fairly small phosphorus losses. They accord well with other measurements in areas with the same soil type and climate (Ludvigsen 1995). Plant residues have high contents of soluble phosphorus (Uhlen 1989a). Nearly half of the total losses were in this form, and thus it appears that plant residues was the source of a large proportion of the phosphorus lossed in this experiment.

The importance of plant residues as a source for phosphorus losses was confirmed by the fact that the forage crop systems, which have most plant residues on the soil surface outside the growing season, had significantly higher losses of dissolved phosphorus than the other systems. Similiar results have been reported by Uhlen (1989a) and Ylaranta et al. (1996). Ulén (1984a) showed that green plant material (ley) is a more important phosphorus source than straw (cereals). In the conventional forage system, the application of manure in the autumn (in the other systems all the manure was applied in the spring) probably also affected the loss of dissolved phosphorus, as demonstrated by Oskarsen et al. (1996). Uhlen (1989b) found a slight effect of phosphorus fertilization on surface losses from ley, but in the present experiment no such effect was found. This agrees well with the results of Yläranta et al. (1996), who found no consistent effect of fertilizer in experiments with low phosphorus losses. Also in an investigation concerning the phosphorus content of drainage water from cultivated land there was no difference due to variations in fertilization (Uhlen & Østerud 1992). The small effect of fertilizer in this experiment may also be expected since in all systems the amounts of phosphorus applied was well balanced against amounts removed in yields, with the exception of a substantial deficit in the ecological systems (Korsæth & Eltun 1996). As discussed in connection with soil particle loss, the higher concentration of total phosphorus in the conventional arable system than in the other systems, is probably related to subsurface erosion.

Potassium

The annual loss of potassium in drainage and surface runoff was 7.3 kg ha^{-1} (Fig. 2), whereof 56% was found in the drainage water. The concentration was 5 times as high in the surface water as in the drainage water (Table 6). Thus, the higher loss in the drainage than in the surface water is due to greater runoff in the drains.

According to Yläranta et al. (1996), the leaching losses of potassium depend very much upon the amount of exchangeable potassium in the soil. The importance of soil type for runoff losses of potassium has also been demonstrated in Norwegian experiments. At the Kvithamar field lysimeter, where the amount of potassium is very high (K soluble in HNO_3 = 1.4-3.7 g kg^{-1} air dry soil), the losses by drainage water were 42-80 kg ha^{-1} $year^{-1}$ (Myhr et al. 1996; Oskarsen et al. 1996). On the other hand at Ås, where the soil potassium status is more similiar to that of the Apelsvoll Experiment, the average annual loss was 10 kg ha^{-1} (Uhlen 1978;

Table 7. Results of regression analysis of concentration (µg l^{-1}) and losses (g daa^{-1}) of total-P and phosphate-P in drainage water and surface water, based on monthly observations throughout the whole year in the period October 1990 - September 1994. The data for the cropping systems B-F are given relative to system A (conventional arable) and are presented as R-quare and estimated regression parameters with t-values in paranteses. An asteriks dentotes a significant variable with a t-level of 2 or higher

	Drainage water				Surface water			
Regressor	Concentration		Losses		Concentration		Losses	
Total-P								
R-square	0.21		0.08		0.12		0.29	
P. Precipitation	0.14	(2.8) *	0.65	(6.9) *	-0.14	(-2.4) *	-0.40	(-4.9) *
T. Air temperature	0.49	(7.6) *	0.27	(2.3) *	0.57	(3.6) *	0.95	(4.2) *
ST. Soil temperature	0.21	(10.6) *	0.08	(2.1) *	0.08	(3.5) *	0.18	(5.3) *
B. Integr. arable	-0.33	(-2.9) *	-0.35	(-1.6)	-0.15	(-1.0)	-0.10	(-0.5)
C. Ecol. arable	-0.17	(-1.5)	-0.30	(-1.4)	0.15	(1.0)	-0.25	(-1.2)
D. Conv. forage	-0.15	(-1.3)	-0.31	(-1.5)	0.02	(0.1)	0.23	(1.0)
E. Integr. forage	-0.24	(-2.1) *	-0.15	(-0.7)	0.12	(0.8)	0.23	(1.1)
F. Ecol. forage	-0.29	(-2.6) *	-0.35	(-1.6)	0.27	(1.8)	0.43	(2.0) *
Phosphate-P								
R-square	0.07		0.05		0.33		0.38	
P. Precipitation	0.04	(0.6)	0.54	(4.9) *	0.14	(2.5) *	-0.13	(-1.5)
T. Air temperature	0.16	(1.7)	-0.14	(-1.0)	0.27	(1.7)	0.68	(2.9) *
ST. Soil temperature	0.16	(5.3) *	0.05	(1.1)	0.20	(8.6) *	0.30	(8.6) *
B. Integr. arable	-0.61	(-3.6) *	-0.62	(-2.4) *	0.18	(1.3)	0.19	(2.0) *
C. Ecol. arable	-0.10	(-0.6)	-0.19	(-0.8)	0.48	(3.3) *	0.57	(2.6) *
D. Conv. forage	0.03	(0.2)	-0.18	(-0.8)	0.52	(4.0) *	0.78	(3.4) *
E. Integr. forage	-0.25	(-1.4)	-0.04	(-0.2)	0.66	(4.6) *	0.75	(3.4) *
F. Ecol. forage	-0.21	(-1.2)	-0.23	(-0.9)	0.61	(4.2) *	0.81	(3.6) *

Uhlen 1989a) and in the subsurface drainage from five sandy loam soils in Denmark the annual losses were 2 kg ha^{-1} (Simmelsgaard 1996). The runoff losses in the Apelsvoll experiment are concidered representative for a soil type with a low content of plant available and acid soluble potassium (Riley & Eltun 1994). The much higher potassium concentrations in the surface than in the drainage runnoff are in accordance with the results of Uhlen (1989a), suggesting that plant residues are an important source for potassium losses as it is for phos-phorus.

Cropping system factors, such as the crops used in the rotation and the level of fertilization level, may affect potassium leaching (Hansen 1990; Uhlen 1989a; Yläranta et al. 1996), but in this experiment no significant effect of cropping system was found (Table 5). These results are not surprising, as the K-fixing capacity of the soil seems to be decisive for the effect of fertilization on potassium leaching, and since nutrient balance calculations (Korsæth & Eltun 1996) showed that there was no great surplus of potassium in any of the systems. Uhlen (1989a) found no effect of potassium fertilization on leaching from a clay soil, whereas on sandy soils Hansen (1990) and Yläranta et al. (1996) showed increased losses with increasing levels of K application. Uhlen & Østerud (1992) found

no effect of fertilizer level on potassium concentration in drainage water from cultivated land, while Uhlen (1989a) found higher potassium concentrations in surface water from row crops and ley than in that from cereal crops. In our model farms, with a mixture of different crops in each cropping system, the effect of individual crops on potassium losses is difficult to assess. The clear tendency toward higher concentration and losses of potassium in surface runoff in the ecological forage system is difficult to explain, neither from the soil or the fertilizer point of view. However, as this system has the highest degree of plant cover in autumn and winter, the losses may be related to K-relese from plant material.

Magnesium, calcium, sulphate-sulphur and pH

The total annual losses of magnesium, calcium and sulphate-sulphur on an average for all cropping systems in drainage and surface water, were 12, 159 and 30 kg ha^{-1}, respectively (Fig. 2).

In the investigation of Uhlen (1989a) the average annual amounts of runoff of these elements were 25, 89 and 30 kg ha^{-1}, respectively, and Simmelsgaard (1996) measured drainage losses of 11, 188 and 16 kg ha^{-1} $year^{-1}$ in Danish experiments. In the Finnish experiments (Yläranta et al. 1996) the annual average varied from 30 to 70 kg ha^{-1} for magnesium and from 50 to 150 kg ha^{-1} for calcium. The average annual loss of sulphate-sulphur in drainage and surface water of the Kvithamar field lysimeter was 39 kg ha^{-1} (Oskarsen et al. 1996). Thus, in the present experiment the losses of magnesium, calcium and sulphate were within the normal range of variation, which is determined by soil type, weather conditions and crop type.

Both magnesium, calcium and sulphate-sulphur are easily soluble in water and, in the same way as was found in the case of nitrogen (Eltun & Fugleberg 1996), the concentrations of all three components were much higher in the drainage than in the surface water (Table 6). The proportions in the drainage water, as compared to the total runoff losses, were 95%, 97% and 98% for magnesium, calcium and sulphate-S, respectively. There was no significant cropping system effect for either magnesium or calcium losses (Fig. 2 and Table 5), but a tendency towards greater losses in the conventional systems which had the highest level of fertilization.

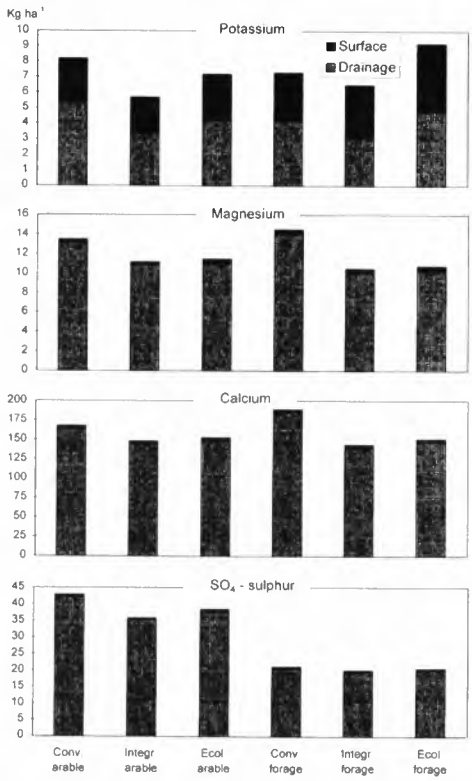

Fig. 2. Annual runoff losses in drainage and surface water of potassium, magnesium, calcium and sulphate sulphur for the six cropping systems averaged over the years 1990-94

Greater losses of magnesium and calcium as a result of increased fertili-zation is in accordance with the findings of Uhlen (1989a), who demonstrated that as these ions are the dominant ex-changeable cations, they are leached together with for example nitrate and sulphate. The higher loss of sulphate-S in the arable systems as compared to the forage systems (Tables 5 and 6 and Fig. 2), was probably also due to differences in fertilization level and nutrient balance. Uhlen (1989a) demonstrated higher losses of sulphur with increasing fertilizer application.

The pH was higher in the drainage than in the surface water, reflecting the greater concentration of calcium and magnesium in the former.(Table 6) There was no significant difference between the cropping systems in the pH of either drainage or surface water.

Annual variations in nutrient losses

Fig. 3 shows the losses of nutrients in each of the years 1990/91-1993/94. The total annual losses from drainage and surface water varied in the range of 0.3-0.5, 6-9, 4-22 and 44-297 kg ha^{-1} for total phosphorus, potassium, magnesium and calcium, respectively. This great variation in losses between years demonstrates clearly that the variation in weather and

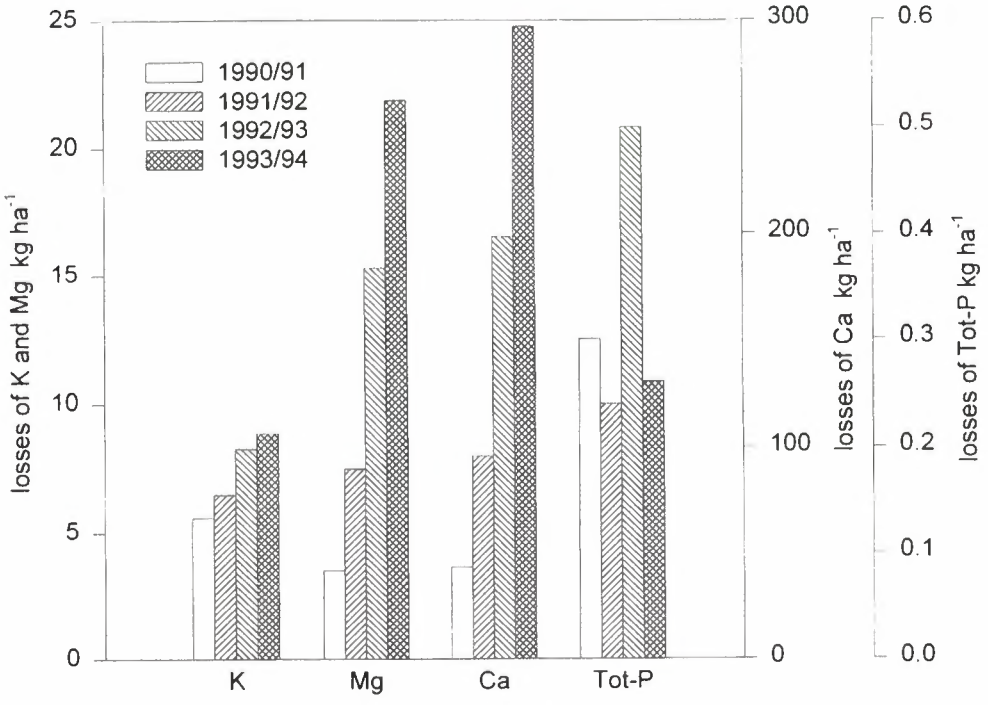

Fig. 3. Average losses of potassium, magnesium, calcium and total phosphorus in drainage and surface water for the six cropping systems in each of the years from 1990/91 to 1993/94

runoff conditions (Eltun & Fugleberg 1996) plays an important role in determining the level of runoff losses. Tables 5 and 7 show that the weather factors, and especially precipitation, are more important in determining the runoff variation than the management factors represented in the cropping systems.

There were differences between the nutrients in the amount of annual variation. The cations calcium and magnesium are easily leached, and the great annual variation therefore reflects the variation in drainage runoff (Eltun & Fugleberg 1996). Potassium had the smallest annual variation of the cations, probably because it is quantitatively less leachable than calcium and magnesium in the soil. Losses of phosphorus will depend upon the surface runoff and erosion, and the greater loss of phosphorus in 1992/93 than in the other years was due to especially high surface runoff during winter and spring of that year.

Conclusion

The great annual variation in losses of all nutrients necessitates long term observations to get a true picture of the nutrient losses from individual cropping systems. The weather factors, and especially precipitation, are more important in determining the runoff variation than the management factors represented in the cropping systems.

The experiment confirmed that arable cropping systems emploging autumn ploughing have higher erosion risks than arable systems with spring tillage or forage crop systems. Plant residue is probably the dominant source of phosphorus losses, and those cropping systems with the greatest amount of plant residues on the soil surface outside the growing season (the ecological arable system and all the forage systems) have the greatest concentration and the greatest losses of phosphorus. Thus, to avoid phosphorus losses the amount of plant residues in the fields in the autumn should be as small as possible. The fertilization level seems to have no significant effect on either phosphorus or potassium losses. For potassium the soil type seems to be more important in determining losses than fertilization. On the other hand, it appears that the losses of magnesium, calcium and sulphate-sulphur are dependent upon the amount of fertilizer applied in the systems.

It seems clear that the losses of soil particles, phosphorus, potassium, magnesium, calcium and sulphur are less affected by differences in the cropping system than is the nitrogen losses. However, crop management factors which reduce the risks of erosion and of leaching from farmyard manure and plant residues, will reduce the phosphorus losses. The losses of magnesium, calcium and sulphur have to be taken into consideration when determining the need for fertilization and liming.

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Correlations between current methods for determining reactivity of chalks and soft limestones, crystalline limestones, crystalline magnesian limestones, and crystalline dolomites for agricultural purposes

KARL-JAN ERSTAD[1], MARTIN REX[2], JUKKA PUTRO[3], JYRKI LINKE[4] & PETER RUNGE[5]

[1] The Norwegian Crop Research Institute, Fureneset Rural Development Centre, Hellevik i Fjaler, Norway
[2] Landwirtsch@ftliche Beratung Thomasdhünger, Versuchsanstalt Kamperhof, Mühlheim an der Ruhr, Germany
[3] Rautaruukki Research Center, Raahe, Finland
[4] Nordkalk OY AB, Pargas, Finland
[5] Sächsische Landesanstalt für Landwirtschaft, Leipzig, Germany

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Correlation studies were carried out in order to achieve a common European understanding of the reactivity of agricultural liming materials. Three methods of testing reactivity were compared: The Soil Incubation 1 year and 5 years, the Sauerbeck/Rietz method and the modified Finnish pH stat method. They were correlated by particle size classes for four groups of carbonate liming materials: chalk and soft limestones, crystalline limestones, crystalline magnesian limestones, and crystalline dolomites. Equations for the relationships were established, which make transformation of reactivity data possible. Care was taken to indicate minimum standard deviation values to be applied. A fourth method, the Runge method, was graphically compared with the other methods, and for most carbonates it yielded results very close to the Soil Incubation method 5 years.

Key words: Calcite, chalk, dolomite, fineness, liming materials, magnesian limestone, reactivity, rock carbonates

Abbreviations:
pH stat titration: pH monitored titration at fixed (static) pH level
NV: Neutralizing Value of liming materials (European standard, reaction with boiling 0.5 M HCl for 5 minutes)
ENV: Effective Neutralizing Value = Neutralizing Value x Dissolution in soil during a defined period (normally 1 and 5 years)
CEN: Comitè Europèen de Normalisation

Karl-Jan Erstad, The Norwegian Crop Research Institute, Fureneset Rural Development Centre, N-6995 Hellevik i Fjaler, Norway

It has proved difficult to find suitable methods for determining the reactivity of agricultural liming materials.

Different chemicals and methods have been proposed to test reactivity: 2 N acetic acid (Morgan & Salter 1923), treatment of the liming materials with 0.1 N oxalic acid and titration with 1 N $KMnO_4$ after heating and cooling (Barnes 1947, Thomas & Gross 1952), 0.07 N disodium ethylene-diaminetetraacetate (Gibaly & Axley 1955), dissolution in an ammonium chloride solution (Shaw & Robinson 1959), acetate buffer (Kjær & Jensen 1974), and pH stat titration method to rank liming materials at levels 2.00, 3.00, 4.00 and 5.00 (Jensen & Brink Pedersen 1977).

Collins & Speer (1939) studied the decomposition of dolomite samples of different degrees of fineness, incubating them in acid sandy soils (pH 4.50-5.60) for 65-75 days. Swartzendruber & Barber (1965) also used incubation results to verify their mathematical approach, and Kac-Kacas (1966) developed a rapid soil-KCl method reactivity determination.

Sverdrup & Warfvinge (1987) and Warfvinge & Sverdrup (1989) stressed that a mathematical model of dissolution in soil would be the best approach.

Since 1991 CEN delegates have worked intimately with the question of choosing a proper reactivity method for agricultural liming materials.

This study was carried out in an attempt to correlate certain methods for reactivity determination, and to establish regression equations.

Materials and methods

The attempt to correlate methods for assessing reactivity of carbonate liming materials was carried out in Norway, Germany and Finland during 1992-95. The following methods were employed:

The Soil Incubation method

The data were mostly taken from the tables of Erstad (1992). Data for natural crystalline magnesian limestones were found by interpolating between category III (coarsely crystalline limestone) and category IV (finely crystalline dolomite). In addition, from a current experiment individual results were available for 5 Danish and 3 German chalks and a soft limestone (Erstad 1997). These data included also parallel tests with the German Sauerbeck/Rietz method and partly the Finnish pH stat method.

The Sauerbeck/Rietz method

The currently adopted German method was a potentiometric titration of aqueous carbonate suspensions with HCl at pH 2.0 according to Sauerbeck & Rietz (1985). The pH stat titration period was 10 min.

In these experiments sieved particle size groups were tested, in contrast to normally mixed samples of liming materials.

Results were given as per cent dissolution of neutralizing value.

The Finnish method

This was described by the Finnish Dep. of Agr. Chem. as a 'Fast acting neutralizing capability of liming materials with the pH stat method.'

The method employs an automatic potentiometric titration, where each sample of liming material is leached for 24 hours in water, while pH is constantly kept at 5.0 by adding 0.4 M nitric acid (HNO_3) to the titration vessel.

A magnetic blender is used to avoid sedimentation during titration.The sam-

ples were placed in a cylinder net basket made of acid proof steel (mesh 0.15 mm). The cylinder was automatically subjected to a vertical movement which gave 30 impacts/min (impact length 50 mm) in the solution.

The neutralizing capability was measured by the consumption of HNO_3. The result is given as % dissolved Ca (*pHstatSF*). To obtain a reliable correlation with the results of the two other methods, the chemical purity of the liming materials was taken into account by the following modification:

pHmodSF = pHstatSF x 40.08/%Ca equiv.
where 40.08 = atomic weight of Ca
%Ca equiv. = % Ca + % Mg x 1.65

The Runge method

In the method by Runge (1992, 1995), 1.000 g liming material is shaken for half an hour at 22 °C in 1000 ml 0.025 M HCl, and a portion of the filtrate was titrated with 0.025 M NaOH using a phenolphtalein indicator. Before titration CO_2 was dispelled by careful heating.

This Runge method was tested for only a small range of liming materials. It is not an official standard method. Therefore, the results were not brought into statistical calculations, only evaluated graphically with the other methods.

Several liming materials from Nordic countries, Germany and Great Britain were tested with these methods (Table 1). Rather than to separate between calcites, magnesian limestones and dolomites according to mass % Mg, which does not consider the carbonate purity, it was decided to separate according to the Ca:Mg ratio. A calcite was defined to have a *mass ratio* Ca:Mg > 18.65, a magnesian limestone 2.62 < Ca:Mg ≤ 18.65 and a dolomite Ca:Mg ≤ 2.62. The latter will be a mixed Ca and Mg carbonate (dolomite as the dominating mineral), but will not include a pure $MgCO_3$ (magnesite).

These limits correspond to Mg contents <2% for calcites, 2%≤ Mg <10% for magnesian limestones and ≥10% for dolomites, if the liming materials were pure carbonates.

The distinction between the different calcites refers to the specifications in CEN/TC260 (European standardization). In practice a chalk is known as a calcium carbonate mudstone, formed by the planktonic calcareous algae coccoliths, and with a high primary porosity. A soft limestone has a reduced porosity due to secondary carbonate precipitation or

Table 1. Chemical analyses of liming materials tested for reactivity. Reactivity methods: Inc. = Soil Incubation method, Sa. = Sauerbeck/Rietz method, SFstat = Finnish pH Stat method, Run. = Runge method

Liming material	n	Ca:Mg ratio	NV	Reactivity method. Number of samples. Inc.	Sa.	SFstat	Run.
CALCITES (Ca:Mg>18.65)							
Chalks	9	119.2-641.2	50.9-55.0	9	9	3	1
Soft limestones	9	73.6-199.5	50.8-54.1	5	5	5	2
Crystalline limestones	14	18.7-219.7	46.8-56.0	14	14	4	4
MAGNESIAN LIMESTONES (2.62 < Ca:Mg ≤ 18.65)	3	3.84-4.82	41.2-50.7	3	3	-	-
DOLOMITES (Ca:Mg ≤ 2.62)	7	1.85-2.33	44.5-59.1	7	7	1	1

filling up of the cavities. A crystalline limestone is one with a very low porosity.

For exact physical identifications laboratory methods on porosity are available, e.g. in Boynton (1980) and Flügel (1982).

The following groups of particle size were used: <0.063, 0.063-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, 0.8-1.0, 1.0-1.4, 1.4-1.6, 1.6-2.0, 2.0-3.15, 3.15-5.0 and 5-20 mm. The complete range of these fractions was not available for all the liming materials.

The materials were sieved by means of a sieving machine. The chalks and the soft limestones were wet sieved, the crystalline materials, with two exceptions, only dry sieved. The relative mass in per cent of each particle size group was represented by the coefficients f_1-f_{12}, from the finest to coarsest material.

For the three first methods linear regressions were established by sum equations, where the coefficients f_1-f_{12} were multiplied with the regression coefficients from one method to the other:

Reactivity(*method2*) =
$(coef_1 * f_1 + coef_2 * f_2 + ... + coef_{12} * f_{12})$
x Reactivity(*method1*)

As a final step the total effect in soil of a liming material was found by the following equation:

ENV(method**Inc**) = NV x Reactivity(method**Inc**)

The regression coefficients were determined for all the four classes of liming materials.

To calculate the total dissolution of a liming material in soil by summarizing over the single fractions has been justified by previous studies (Ohlsson & Torstensson 1955, Erstad 1992).

All regression analyses were performed using the Statistical Analysis System (SAS), Release 6.03 (SAS INSTITUTE 1985, 1987 & 1988). Regression coefficients for particle size groups and their standard deviations for groups of liming materials were calculated by means of the procedure PROC SUMMARY.

Results and discussion

Tables 2-5 present the regression coefficients and their standard deviations for the four groups of liming materials.

The correlations were highest between the Soil Incubation and the Sauerbeck/Rietz method. The standard deviation (SD) was 10-20% of the regression coefficients for most of the materials, but clearly highest for the dolomites. The standard deviations increased when the modified Finnish pH stat method was involved.

The correlations would have been higher by further increases in the number of observations.

A critical particle size was that between 0.4 and 0.8 mm. Above this the diffusion in soil plays an important role, whilst in mineral acids only speed of dissolution is involved. Rapidly dissolving chalks and, in particular, limestones were overestimated for coarse particle sizes when comparing the Sauerbeck/Rietz method with the Soil Incubation method, whereas the crystalline dolomites were highly underestimated.

Two of the crystalline liming materials, Franzefoss Ringerike limestone and Franzefoss Ballangen dolomite, were tested with the Sauerbeck/Rietz method separately after both dry and wet sieving. Sieving procedure had no influence on the reactivity. Wet sieving is, however, required for chalks and soft limestones.

Table 2. Regression coefficients and their absolute standard deviations (SD) for *chalks and soft limestones*, obtained by comparing the Soil Incubation, the Sauerbeck/Rietz and the modified Finnish pH stat method. **n** = number of liming materials tested. Not all particle size groups were complete.

Particle size group, mm	coef.	SD	coef.	SD	coef.	SD	coef.	SD	coef.	SD
	Sauerbeck ->Inc. 1y		*Sauerbeck ->Inc. 5y*		*pHmodSF ->Inc. 1y*		*pHmodSF ->Inc. 5y*		*Inc. 1y-> Sauerbeck*	
<0.063	1.00	0.002	1.00	0.002	2.70	0.459	2.70	0.459	1.000	0.002
0.063-0.200	1.05	0.092	1.07	0.113	2.66	0.393	2.72	0.451	0.949	0.083
0.200-0.400	1.13	0.097	1.19	0.178	5.92	2.99	6.26	2.80	0.884	0.075
0.400-0.600	1.17	0.123	1.29	0.278	6.51	3.41	7.21	3.21	0.852	0.089
0.600-0.800	1.15	0.160	1.40	0.392	7.06	4.26	8.66	3.90	0.868	0.121
0.800-1.000	1.15	0.364	1.57	0.583	6.47	5.07	8.90	4.45	0.873	0.278
1.0-1.4	1.09	0.200	1.86	0.871	6.15	3.35	11.74	6.57	0.915	0.168
1.4-1.6	1.25	0.446	2.28	1.17	6.07	3.86	13.15	7.99	0.797	0.283
1.6-2.0	1.37	0.464	2.81	1.01	5.52	3.04	14.78	9.95	0.731	0.248
2.0-3.15	1.50	1.014	3.56	1.06	3.53	2.36	16.34	11.72	0.669	0.453
3.15-5.0	1.18	1.605	4.70	1.69	4.89	9.02	29.98	33.84	0.846	1.148
5-20	0	-	2.20	1.14	5.29	-	9.07	11.35	0	-
n	14		14		8		8		14	

Tab. 2. cont.

Particle size group, mm	coef.	SD	coef.	SD	coef.	SD	coef.	SD	coef.	SD
	Inc. 5y-> Sauerbeck		*Inc. 1y-> pHmodSF*		*Inc. 5y-> pHmodSF*		*pHmodSF-> Sauerbeck*		*Sauerbeck ->pHmodSF*	
<0.063	1.000	0.002	0.370	0.063	0.370	0.063	2.70	0.453	0.371	0.062
0.063-0.200	0.937	0.099	0.375	0.055	0.368	0.061	2.50	0.196	0.399	0.031
0.200-0.400	0.837	0.125	0.169	0.085	0.160	0.071	5.21	2.67	0.192	0.098
0.400-0.600	0.777	0.168	0.154	0.080	0.139	0.062	5.45	2.99	0.183	0.101
0.600-0.800	0.712	0.199	0.142	0.085	0.116	0.052	5.87	3.14	0.170	0.091
0.800-1.000	0.637	0.237	0.155	0.121	0.112	0.056	5.24	2.58	0.191	0.094
1.0-1.4	0.539	0.253	0.163	0.089	0.085	0.048	5.40	3.06	0.185	0.105
1.4-1.6	0.438	0.225	0.165	0.105	0.076	0.046	4.74	2.61	0.211	0.116
1.6-2.0	0.356	0.128	0.181	0.100	0.068	0.046	4.34	2.52	0.231	0.134
2.0-3.15	0.281	0.084	0.283	0.189	0.061	0.044	4.23	3.09	0.236	0.172
3.15-5.0	0.213	0.077	0.204	0.377	0.033	0.038	6.23	8.14	0.161	0.210
5-20	0.456	0.237	0	-	0.110	0.138	3.28	1.78	0.305	0.166
n	14		8		8		8		8	

Table 3. As for table 2, *crystalline limestones*.

Particle size group, mm	coef. *Sauerbeck ->Inc. 1y*	SD	coef. *Sauerbeck ->Inc. 5y*	SD	coef. *pHmodSF ->Inc. 1y*	SD	coef. *pHmodSF ->Inc. 5y*	SD	coef. *Inc. 1y-> Sauerbeck*	SD
<0.063	1.06	0.125	1.06	0.125	2.78	0.423	2.78	0.423	0.947	0.112
0.063-0.200	1.12	0.129	1.12	0.129	2.78	0.423	2.78	0.423	0.893	0.103
0.200-0.400	1.40	0.280	1.47	0.295	5.43	1.95	5.72	2.05	0.716	0.144
0.400-0.600	1.52	1.171	2.32	1.793	6.97	2.21	10.99	3.58	0.657	0.506
0.600-0.800	1.10	0.285	2.29	0.530	6.94	2.80	14.95	5.92	0.912	0.237
0.800-1.000	0.952	0.315	2.59	0.743	5.75	2.67	16.45	7.66	1.05	0.347
1.0-1.4	0.820	0.220	2.68	0.767	5.22	2.74	16.31	7.12	1.22	0.327
1.4-1.6	0.845	0.177	3.08	0.709	6.36	3.87	22.09	11.89	1.18	0.248
1.6-2.0	0.789	0.191	3.21	0.833	5.80	3.24	22.67	10.55	1.27	0.307
2.0-3.15	0.709	0.231	3.58	0.841	4.05	2.76	20.01	9.88	1.41	0.458
3.15-5.0	0.622	0.130	3.32	1.039	5.31	2.90	24.92	12.13	1.61	0.336
5-20	-	-	-	-	-	-	-	-	-	-
n	15		15		4		4		15	

Tab. 3. cont.

Particle size group, mm	coef. *Inc. 5y-> Sauerbeck*	SD	coef. *Inc. 1y-> pHmodSF*	SD	coef. *Inc. 5y-> pHmodSF*	SD	coef. *pHmodSF-> Sauerbeck*	SD	coef. *Sauerbeck ->pHmodSF*	SD
<0.063	0.947	0.112	0.360	0.055	0.360	0.055	2.78	0.423	0.360	0.055
0.063-0.200	0.893	0.103	0.360	0.055	0.360	0.055	2.64	0.491	0.378	0.070
0.200-0.400	0.680	0.136	0.184	0.066	0.175	0.063	4.37	1.86	0.229	0.097
0.400-0.600	0.432	0.334	0.144	0.046	0.091	0.030	6.81	3.22	0.147	0.069
0.600-0.800	0.437	0.101	0.144	0.058	0.067	0.026	7.42	3.69	0.135	0.067
0.800-1.000	0.386	0.111	0.174	0.081	0.061	0.028	8.05	5.61	0.124	0.087
1.0-1.4	0.373	0.107	0.192	0.101	0.061	0.027	7.12	4.06	0.141	0.080
1.4-1.6	0.325	0.075	0.157	0.096	0.045	0.024	7.74	4.68	0.129	0.078
1.6-2.0	0.312	0.081	0.172	0.096	0.044	0.021	8.16	5.65	0.123	0.085
2.0-3.15	0.279	0.066	0.247	0.168	0.050	0.025	6.25	3.43	0.160	0.088
3.15-5.0	0.301	0.094	0.188	0.103	0.040	0.020	7.96	4.52	0.126	0.071
5-20	-	-	-	-	-	-	-	-	-	-
n	15		4		4		4		4	

Table 4. As for table 2, *crystalline magnesian limestones.*

Particle size group, mm	coef. *Sauerbeck ->Inc. 1y*	SD	coef. *Sauerbeck ->Inc. 5y*	SD	coef. *Inc. 1y-> Sauerbeck*	SD	coef. *Inc. 5y-> Sauerbeck*	SD
<0.063	1.28	0.061	1.28	0.061	0.781	0.037	0.781	0.037
0.063-0.200	1.90	0.307	1.90	0.307	0.526	0.085	0.526	0.085
0.200-0.400	1.96	0.174	2.55	0.226	0.510	0.045	0.392	0.035
0.400-0.600	1.60	0.202	3.13	0.395	0.625	0.079	0.319	0.040
0.600-0.800	1.38	0.260	3.59	0.675	0.725	0.137	0.279	0.053
0.800-1.000	1.18	0.409	3.84	1.328	0.846	0.293	0.260	0.090
1.0-1.4	1.19	0.091	4.56	0.352	0.844	0.065	0.219	0.017
1.4-1.6	1.08	-	4.05	-	0.925	-	0.247	-
1.6-2.0	1.02	-	4.08	-	0.980	-	0.245	-
2.0-3.15	-	-	-	-	-	-	-	-
3.15-5.0	-	-	-	-	-	-	-	-
5-20	-	-	-	-	-	-	-	-
n	3		3		3		3	

Table 5. As for table 2, *crystalline dolomites.*

Particle size group, mm	coef. *Sauerbeck ->Inc. 1y*	SD	coef. *Sauerbeck ->Inc. 5y*	SD	coef. *pHmodSF ->Inc. 1y*	SD	coef. *pHmodSF ->Inc. 5y*	SD	coef. *Inc. 1y-> Sauerbeck*	SD
<0.063	2.70	1.03	2.70	1.03	7.32	-	7.32	-	0.371	0.141
0.063-0.200	5.36	2.67	5.36	2.67	7.32	-	7.32	-	0.187	0.093
0.200-0.400	4.83	4.31	8.70	7.75	8.79	-	15.81	-	0.207	0.184
0.400-0.600	4.19	2.81	10.47	7.03	6.45	-	16.14	-	0.239	0.160
0.600-0.800	3.06	1.96	9.94	6.38	4.30	-	13.98	-	0.327	0.210
0.800-1.000	2.48	1.45	9.08	5.32	3.29	-	12.08	-	0.404	0.237
1.0-1.4	2.03	1.03	10.16	5.16	2.34	-	11.71	-	0.492	0.250
1.4-1.6	2.55	0.83	10.18	3.33	2.70	-	10.81	-	0.393	0.129
1.6-2.0	3.21	1.63	9.63	4.88	2.70	-	8.11	-	0.311	0.158
2.0-3.15	1.91	0.71	9.55	3.54	1.60	-	7.99	-	0.523	0.194
3.15-5.0	2.27	0.60	6.81	1.80	1.70	-	5.10	-	0.441	0.116
5-20	-	-	-	-	-	-	-	-	-	-
n	8		8		1		1		8	

Tab. 5. cont.

Particle size group, mm	coef. *Inc. 5y-> Sauerbeck*	SD	coef. *Inc. 1y-> pHmodSF*	SD	coef. *Inc. 5y-> pHmodSF*	SD	coef. *pHmodSF-> Sauerbeck*	SD	coef. *Sauerbeck ->pHmodSF*	SD
<0.063	0.371	0.141	0.137	-	0.137	-	1.464	-	0.683	-
0.063-0.200	0.187	0.093	0.137	-	0.137	-	0.710	-	1.408	-
0.200-0.400	0.115	0.102	0.114	-	0.063	-	0.580	-	1.725	-
0.400-0.600	0.096	0.064	0.155	-	0.062	-	0.688	-	1.453	-
0.600-0.800	0.101	0.065	0.232	-	0.072	-	0.602	-	1.660	-
0.800-1.000	0.110	0.065	0.304	-	0.083	-	0.659	-	1.518	-
1.0-1.4	0.098	0.050	0.427	-	0.085	-	0.632	-	1.581	-
1.4-1.6	0.098	0.032	0.370	-	0.092	-	0.757	-	1.321	-
1.6-2.0	0.104	0.053	0.370	-	0.123	-	0.459	-	2.176	-
2.0-3.15	0.105	0.039	0.626	-	0.125	-	0.511	-	1.957	-
3.15-5.0	0.147	0.039	0.588	-	0.196	-	0.578	-	1.730	-
5-20	-	-	-	-	-	-	-	-	-	-
n	8		1		1		1		1	

Figure 1 show the results for all four methods for three liming materials, representing very different groups. It appears that the Runge method yields results very close to the that of the 5 years Incubation method. The exception was the crystalline dolomite, which reacted very slowly in solutions of mineral acids, but dissolved gradually in soil. An overestimation of the reactivity of coarse particles by the Incubation method at low soil pH was questioned, but was rejected by the fact that diffusion in soil is the limiting factor.

The regression tables may be used to assess the results obtained with other methods when we have the results of one, together with the particle size distribution of the liming material in question. Even if some reactivity measures are low, regressions are reliable because the methods are proven to be sensitive with respect to particle size groups.

In particular it will be useful to estimate the reactivity figures of the Soil Incubation method when we have data from one of the rapid laboratory pH stat methods.

A 'worst case study', which presumes that all deviations turn in the same direction, reveals that the standard deviation for the calculated value of a liming material could be quite high, but normally the single SD values of the fractions counteract each other. Thus, it is recommended to keep the *fixed SD value* of ±3 ENV units ('Effective Neutralizing Value') as practiced with the Soil Incubation method as suggested by Erstad (1992).

This fixed SD value corresponds to the magnitude of the compared reactivity figures:

Fixed SD values

- Soil Incubation method, ENV, neutralizing value corresponding to CaO equivalents in 100 kg material **3**
- Sauerbeck/Rietz method, reactivity of a total carbonate content (NV) in a liming material **6**
- Modified Finnish pH stat method, reactivity of Ca equivalents in the carbonate minerals of a liming material, corrected for impurities (other minerals) **2**

These fixed SD values are, however, only recommendations and should be used with care. They might be quite higher due to discrepancies between the methods and lack of data. Similarly the calculated reactivity must have an upper theoretical limit as an absolute maximum, i.e. the ENV of a liming material can not be higher than its NV.

To facilitate the understanding of the use of the equations, an example of calculation is shown in Appendix I.

Conclusions

Correlation equations are established to explain the relationship between reactivity methods for liming materials. We think in particular that it is helpful for practical agriculture to predict the effectiveness of liming materials in soil when data from pH stat methods are available.

On the other hand, the results must be critically applied, and we have indicated minimum standard deviations for the calculated figures. Liming materials with reactivity figures within the SD range must be considered as equal.

The dissolution kinetics of the crystalline dolomite is differing so much from the other carbonates that its charac-teristics have to be considered with alertness. Its slow dissolution is already regarded in current German fertilizer law, stating that its reactivity has to be R $\geq$10 according to the Sauerbeck/Rietz method. Still most of the German dolomites are more amorphous or naturally mixed with calcites (magnesian limestones) than the Nordic ones, and this promotes the dissolution speed.

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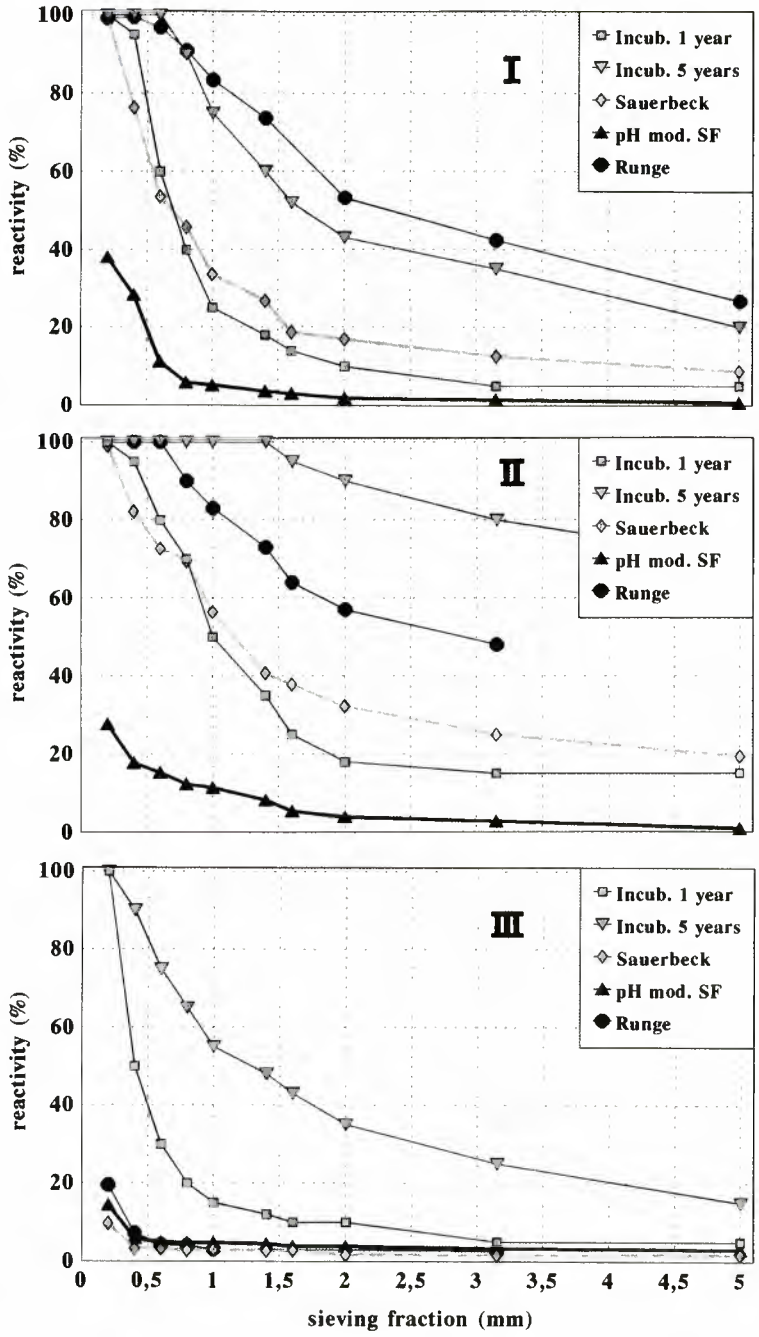

Fig. 1. Reactivity of liming materials as a function of fineness, tested by four different methods. I. Breivik crystalline limestone, II. Ignaberga soft limestone, III. Hammerfall crystalline dolomite.

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Example of calculation:

A **chalk** with NV=45 as delivered.

Particle size distribution in mass per cent:

<0.063 mm	20%
0.063-0.200 mm	10%
0.200-0.400 mm	10%
0.400-0.600 mm	5%
0.600-0.800 mm	5%
0.800-1.000 mm	5%
1.0-1.4 mm	5%
1.4-1.6 mm	2%
1.6-2.0 mm	5%
2.0-3.15 mm	8%
3.15-5.0 mm	10%
5-20 mm	15%

Reactivity determined according to the Sauerbeck/Rietz method: 45%

Calculation for ENV 1 year and 5 years (the Soil Incubation method):

ENV 1year = 45 x [1.00x0.20 + 1.05x0.10 + 1.13x0.10 + 1.17x0.05 + 1.15x0.05 + 1.15x0.05 + 1.09x0.05 + 1.25x0.02 + 1.37x0.05 + 1.50x0.08 + 1.18x0.10 + 0x0.15] x 0.45 = 45 x 0.978 x 0.45 = **20**

ENV 5years = 45 x [1.00x0.20 + 1.07x0.10 + 1.19x0.10 + 1.29x0.05 + 1.40x0.05 + 1.57x0.05 + 1.86x0.05 + 2.28x0.02+ 2.81x0.05 + 3.56x0.08 + 4.7x0.10 + 2.20x0.15] x 0.45= 45 x 2.003 x 0.45 = **40**

Fixed SD value: **±3**

Juvenility and flowering in *Festuca pratensis* Huds. 2.Effects of light intensity, defoliation and duration of primary induction treatments

LARS T. HAVSTAD
The Norwegian Crop Research Institute, Apelsvoll Research Centre, division Landvik, Grimstad, Norway

Havstad, L.T. 1996. Juvenility and flowering in *Festuca pratensis* Huds. 2. Effects of light intensity, defoliation and duration of primary induction treatments. Norwegian Journal of Agricultural Sciences 10: 397-412. ISSN 0801-5341.

Seedlings of *Festuca pratensis* Huds. (cv. Salten) were raised at three different light intensities (141, 85 or 28 mmol $m^{-2}s^{-1}$) for 7 weeks after emergence and then either left uncut or defoliated 40 or 80% of total leaf area (100, 60 or 20% of leaf area left), before transfer to primary induction (6°C, natural short days for 12, 15 or 18 weeks). Increasing light intensity enhanced tillering and leaf production during plant raising and elevated the content of water-soluble carbohydrates, in both shoots and roots, at the start of primary induction. Plants from the lowest light intensity continued to have the lowest tiller number also during primary induction. Defoliation at the start of induction reduced subsequent tillering and leaf production and regrowth was too slow for defoliated plants to overtake intact plants even after the longest induction period. Registration of flowering characters, after exposure to 15°C and continuous light (secondary induction), revealed that the percentage of heading plants generally was more affected by the duration of primary induction than by light intensity or defoliation prior to induction. Thus there was no significant effect of plant size at the start of induction on the flowering ability, no indication of a distinct juvenile stage were found in seedlings of *Festuca pratensis*. Defoliation had less influence on the number of panicles per plant than light intensity and, in particular, the duration of primary induction. An additional tagging experiment revealed that some tillers even developed after primary induction became reproductive, supporting suggestions from the first experiment in this series that tillers of *Festuca pratensis* lack or have an extremely short juvenile stage.

Key words: Carbohydrates, dry weight, defoliation, *Festuca pratensis*, flowering, induction, juvenility, leaf area, light intensity, meadow fescue.

Lars T. Havstad, The Norwegian Crop Research Institute, Apelsvoll Research Centre, division Landvik, N-4890 Grimstad, Norway

A juvenile stage, during which plants or tillers are insensitive to environmental conditions which later promote flowering, has been described in seedlings of *Dactylis glomerata* (Kozumplik & Christie 1972; Heide 1987), *Phalaris arundinacea* (Heichel et al. 1980), *Festuca pratensis* (Bean 1970), *Festuca arundinacea* (Bean 1970) and in tillers of *Poa pratensis* and *Festuca rubra* (Meijer 1984). The question whether the juvenile stage is a property of the entire plant or each individual tiller has been further discussed by Havstad (1996). Most authors relate juvenility to plant or seedling age or to morphological characters such as leaf number, leaf area or tiller size. Wellensiek & Higazy (1961) found that the length of the juvenile stage in the dicotyledonous species *Lunaria biennes*

was strongly influenced by light intensity, indicating that juvenility is controlled by the accumulation of carbohydrates within the plant.

The light intensity or irradiance influences plant growth through photosynthetic activity and developmental responses. Much research has been devoted to the effect of light intensity on vegetative growth in grasses. Allard et al. (1991) found that low irradiance reduced dry matter production in *Festuca arundinacea*, primarily due to fewer tillers produced per plant. The experiment also revealed that plants exposed to shading produced longer but thinner leaves than those grown at higher irradiance. Auda et al. (1966) reported that tillering, dry matter production and carbohydrates (percentage of dry weight) in plants of *Dactylis glomerata* dropped when light intensity was reduced to 75% of normal sunlight. Similar effects of light intensity on growth of grasses were demonstrated by Mitchell (1953) and Patel & Cooper (1961). However, less information is available on how variation in light intensity during the seedling stage affects subsequent stages of development.

Another factor that influences plant growth and development is defoliation. The rate of regrowth after defoliation is in particular affected by the reserves of carbohydrates present in plants at the time of defoliation. Carbohydrates located in stem bases or stubble are the most important of such reserves in grasses, and high levels can, according to Davidson & Milthorpe (1966) and Richards & Caldwell (1985), contribute to more rapid regrowth. Since juvenility has been associated with the level of carbohydrates, defoliation of seedlings might have an influence on the duration of the juvenile stage. However, current photosynthate soon becomes quantitatively more important as the carbon source for regrowth compared to carbohydrate reserves (Davidson & Milthorpe 1966). Current photosynthate continues to be preferentially allocated to regrowing shoot sinks until the demand of those sinks is satisfied. Only then is the allocation of photosynthate to roots increased (Bucher et al. 1987a, 1987b).

Alberda (1957) reported that the time needed for recovery after defoliation in *Lolium perenne* increased with decreasing light intensity and increasing night temperature. The author also revealed that tiller formation stopped immediately after cutting while uncut plants showed a linear increase in tiller number with time. The amount of carbohydrate in this experiment was negatively correlated with elevated night temperature. Although regrowth after defoliation is well understood, less information is available on how defoliation of small plants influences later stages of reproductive development.

The objective of the present research was to determine in more detail how different intensities of light and degrees of defoliation prior to primary induction influence juvenility, plant growth during induction and subsequent flowering. The north Norwegian cultivar 'Salten' was used because of its relatively high potential for carbohydrate storage (Havstad 1996).

Materials and methods

The experiment was carried out at the Norwegian Crop Research Institute, division Landvik and the Ås phytotron, during August 1994 through April 1995. Seeds of 'Salten' (origin 67°N) were obtained from the Basic Seed Centre

(Skjetten, Norway).

On 29 August 1994, 384 plastic pots (8 cm in diameter) were filled with a sandy soil (loss on ignition 4.1) that had been ground through a 3 mm mesh. After sowing three seeds per pot, the pots were allocated to three different growth chambers for germination and plant raising at 18-20°C. At seedling emergence the light intensities from TL-33 fluorescent tubes in the three growth chambers were regulated to 141 (L_1), 85 ($L_{0.6}$; 60% of L_1) or 28 ($L_{0.2}$; 20% of L_1) mmol $m^{-2}s^{-1}$ and the seedlings were thinned to 1 plant per pot.The plants were raised in continuous light and fertilized weekly with a standard nutrient solution (conductivity 1.7). On 25 October (7 weeks after seedling emergence) plants from each light intensity were divided into three equal groups, which were either left uncut (D_0) or defoliated by 40 ($D_{0.4}$) or 80% ($D_{0.8}$) of total leaf laminae area before transfer to primary induction.

Primary induction was accomplished in a phytotron compartment with natural daylight supplemented with 115 mmol $m^{-2}s^{-1}$ from high pressure mercury lamps (Philips HPI-T 400 W) for 8 h per day. The longest daylength during induction (10 h and 18 min) was recorded on 28 February (after 18 weeks of induction).

At the start of primary induction, 8 uncut plants from each light intensity were sampled destructively. After 12 and 18 weeks of induction, sampling was repeated with 8 plants from each combination of light intensity and defoliation treatment. The following characters were recorded for individual plants at each sampling :

1. The number of visible tillers with base diameter < 1 mm, 1-1.5 mm, 1.5-2 mm, 2-3 mm, 3-4 mm and > 4 mm. Tiller diameter was measured with a slide calliper 0.5-1 cm above tiller basis.
2. Number of leaves with laminae longer than 1 cm above sheath of preceding leaf.
3. Leaf area (laminae) (cm^2).
4. Dry weight of shoots and roots (g). Percentage of water-soluble carbohydrate (WSC) in the dry matter of shoots and roots.

Plants not subjected to destructive sampling were transplanted into 12-cm pots and transferred to secondary induction at 15°C and continuous light (200 mmol $m^{-2}s^{-1}$ from TL-33 fluorescent tubes) after 12, 15 or 18 weeks of primary induction. (3 light intensities * 3 defoliation treatments * 8 replicates = 72 plants per length of primary induction treatment.)

Percentage of flowering plants and the number of panicles per plant were used as the main criteria for flowering, while the number of days to heading of the first panicle was used as a criterion for the rate of flower development. The date of heading was recorded when the top of the panicle appeared above the ligule of the flag leaf. In addition, culm length, inflorescence length, spikelet number and floret number per spikelet were measured for the main reproductive tiller on each plant (one spikelet at the base, middle and top of each inflorescence were counted to estimate floret numbers).

For vegetative characters recorded before or during primary induction, separate analyses of variance were carried out for each length of induction treatment. For flowering characters, overall analyses were carried out to examine the main effects of length of induction treatment, light intensity and defoliation treatment, as well as their interactions. All analyses of variance were performed according to the procedure PROC GLM (Statistical

Analysis System 1987). Significant differences were separated by $LSD_{0.05}$.

An additional experiment with 15 plants from each of the three light intensities (5 from each defoliation treatment) was carried out simultaneously with the main experiment in order to explain the effect of tiller emergence date on flowering characters. Every tiller on each plant was tagged, using a different coloured wire ring, at the start of primary induction, halfway through and at the end of a 12-week induction treatment. Following primary induction, plants were transferred to secondary induction and tagging was discontinued. Flowering characters, as described for the main experiment, were registered for all tillers that became reproductive.

The total number of tagged vegetative tillers was only recorded at the start of primary induction. Percentage of fertility of tillers formed during and after induction, was therefore calculated by dividing the number of panicles tagged with a specific colour by the total tiller number formed during the respective period in the main experiment.

Data were analysed according to PROG GLM (Statistical Analysis System 1987) using an unbalanced one-way model, and significant differences were separated by $LSD_{0.05}$.

Results

Plant status at the start of primary induction

Number of tillers and tiller size

The highest number of tillers at the start of primary induction was found in plants which had received the highest light intensity (L_1). Approximately 35 and 85% more tillers had been produced in these highly illuminated plants compared to plants grown at medium ($L_{0.6}$) or low irradiance ($L_{0.2}$), respectively (Table 1).

Tiller base measurement showed that no tillers wider than 2 mm were developed

Table 1. Effect of light intensity[1)] on tiller number per plant, leaves per plant, leaves per tiller, leaf area per plant, leaf area per tiller (cm^2) and area per leaf (cm^2) at the start of primary induction. Means of 8 uncut plants per treatment.

Light intensity	Tillers per plant	Leaves per plant	Leaves per tiller (cm^2)	Leaf area per plant (cm^2)	Leaf area per tiller (cm^2)	Area per leaf
$L_{0.2}$	1.1	4.3	3.9	21.1	19.7	5.0
$L_{0.6}$	5.1	16.9	3.3	103.6	20.9	6.2
L_1	7.8	26.0	3.3	122.8	17.6	5.4
$LSD_{0.05}$	1.8	6.2	0.5	20.6	ns	ns

[1)] Light intensities during plant raising were 28, 85 and 141 mmol $m^{-2}s^{-1}$. The corresponding denominations $L_{0.2}$, $L_{0.6}$ and L_1 are used in this and other tables and figures.

in $L_{0.2}$-plants at the start of induction. In the $L_{0.6}$- and L_1-plants, 37 and 52% of the tillers were wider than 2 mm at the start of induction (Fig.1).

Leaf number and leaf area

Whereas an increase in light intensity from $L_{0.2}$ to $L_{0.6}$ dramatically increased leaf number and leaf area per plant, differences between $L_{0.6}$- and L_1-plants were generally less conspicuous (Table 1).

The leaf number per tiller was higher in $L_{0.2}$-plants than in plants from higher light intensities. Leaf area per tiller and area per leaf were not significantly affected by light intensity, but plants grown at the intermediate level ($L_{0.6}$) tended to have the highest values (Table 1).

Dry weight

Dry matter accumulation increased, both in shoots and in roots, with increasing light intensity (Table 2). The average total dry weight at the start of induction was 0.08, 0.7 and 1.4 g for plants grown at low, medium and high light intensity, respectively. Whereas only 12% of total plant dry weight was found in roots at the lowest light intensity, the corresponding figures for medium and high intensity were 33 and 48%, respectively.

Carbohydrate content

The concentration of water-soluble carbohydrates (WSC) in plant dry matter increased significantly, in both shoots and roots, with increasing light intensity (Table 2). Similar results were obtained for the total amount of WSC, both on plant (data not shown) and on tiller basis. Approximately 14% of the total amount of WSC in $L_{0.2}$-plants was found in the roots at the start of induction, compared with 23 and 47% in $L_{0.6}$ and L_1-plants.

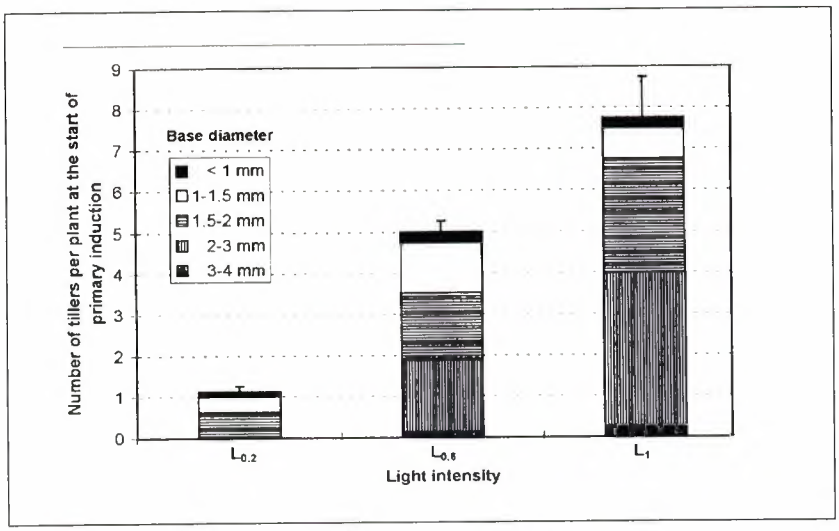

Fig. 1. The effect of light intensity during plant raising on the number and size distribution of tillers per plant at the start of primary induction. Average of 8 plants per treatment. Bars represent 1 SE for total tiller number.

Table 2. Effects of light intensity on dry weight in shoots and roots (g), percentage of water soluble carbohydrate (WSC) in shoot and root dry matter and the WSC content (total of shoots and roots) calculated per tiller (mg) at the start of primary induction. Means of 8 uncut plants per treatment.

Light intensity	Dry weight, shoot, g	Dry weight, root, g	WSC, shoot, %	WSC, root, %	WSC per tiller (mg)
$L_{0.2}$	0.06	0.01	3.9	3.8	2.8
$L_{0.6}$	0.5	0.2	6.0	5.8	8.5
L_1	0.7	0.7	21.1	12.0	34.4
$LSD_{0.05}$	0.2	0.1	1.5	1.1	9.4

Plant growth during primary induction

Tiller number and size

The total number of tillers per plant increased, on average for light and defoliation intensities, from 4.7 at the start of induction to 15.4 and 25.6 after 12 and 18 weeks of induction, respectively. Plants which had received low irradiance ($L_{0.2}$) prior to induction continued to have the lowest tiller number per plant throughout the induction treatment. No significant difference in tiller number between $L_{0.6}$ and L_1-plants was discovered after 12 and 18 weeks, but $L_{0.6}$-plants tended to have a higher tillering rate during the last 6 weeks of induction (Fig. 2a). Although less dramatic than the effect of light intensity, defoliation prior to induction reduced the development of new tillers. Uncut plants (D_0) had, on average for light intensities, approximately 35 and 40% more tillers than $D_{0.8}$-plants after 12 and 18 weeks of induction, respectively (Fig. 2b).

On average for light and defoliation intensities, approximately 35% of the tillers had base diameters greater than 2 mm after 12 and 18 weeks of primary induction. The lowest proportion of large tillers (> 2 mm) was always found in $L_{0.2}$-plants (Fig. 2a). Tiller size was also affected by defoliation prior to induction, especially after 12 weeks when 28% of the tillers in the uncut plants had base diameters wider than 3 mm. The corresponding figures for $D_{0.4}$ and $D_{0.8}$- plants were 6 and 4%, respectively (Fig. 2b).

Leaf number and leaf area

The leaf number and leaf area per plant increased with increasing duration of primary induction at all light and defoliation intensities. $L_{0.2}$- plants had, after both 12 and 18 weeks, significantly fewer leaves per plant and per tiller and less area per plant, tiller and leaf than $L_{0.6}$- and L_1-plants (Table 3).

Defoliation prior to induction led to reduced production of new leaves and slower leaf area development during induction. Uncut plants (D_0) had 30 and 57% more leaves than $D_{0.8}$-plants after 12 and 18 weeks, respectively. The corresponding figures for leaf area per plant were 87 and 54%. Undefoliated plants also had the highest leaf number per tiller after 18 weeks, whereas the negative effect of defoliation on leaf area per tiller or area per leaf was significant only after

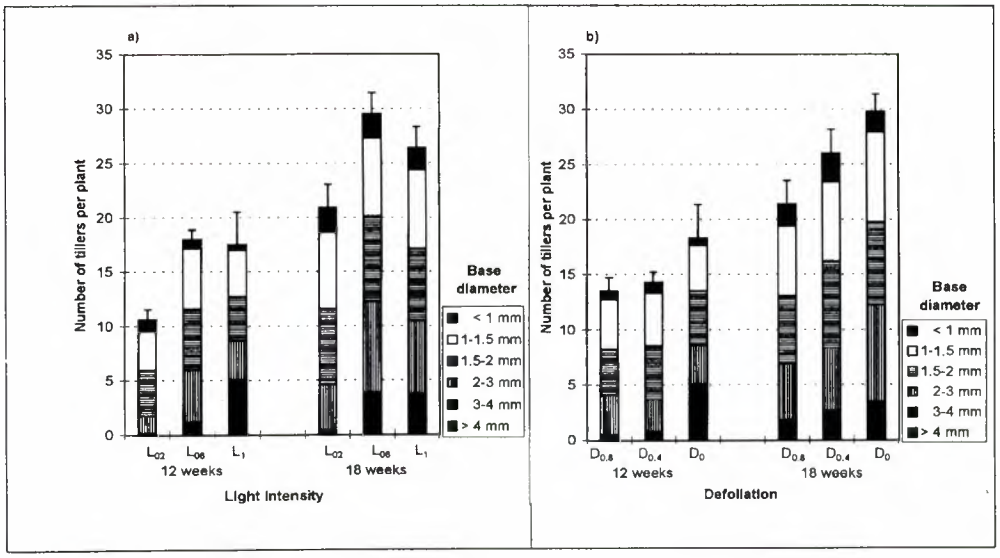

Fig. 2. Increase in total tiller number per plant as affected by (a) light intensity, and (b) defoliation prior to primary induction . Average of 24 plants per treatment. Bars represent 1 SE for total tiller number.

12, but not after 18 weeks. Defoliation of 40% of total laminae area generally hampered subsequent leaf development almost to the same extent as the more severe defoliation intensity.

The number of leaves per tiller became higher as the induction treatment was prolonged from 12 to 18 weeks (Table 3). On the contrary, the area per leaf was reduced, on average for light and defoliation intensities, from 2.2 cm^2 after 12 weeks to 1.4 cm^2 after 18 weeks of induction.

Dry weight

The total dry weight per plant increased, on average for light and defoliation intensities, from 0.7 g at the start of induction to 1.8 and 3.0 g after 12 and 18 weeks, respectively. By contrast, the corresponding shoot/root ratio was rather constant , only varying from 1.3 to 1.4. Shoot and root dry weight was lower in $L_{0.2}$-plants than in $L_{0.6}$- and L_1-plants throughout the induction period. L_1-plants had a significantly higher total dry weight than $L_{0.6}$-plants after 12 but not after 18 weeks (data not shown). The higher total dry weight in L_1-plants could be attributed to heavier root systems, as $L_{0.6}$-plants tended to have the highest shoot dry weight after both 12 and 18 weeks (Table 4). Increasing defoliation intensity prior to induction decreased both root and shoot dry weight during induction. However, differences in dry weight between $D_{0.4}$- and $D_{0.8}$-plants were not significant after 12 weeks.

Carbohydrate content

Plant total dry matter, on average for light and defoliation intensities, contained 13% of water-soluble carbohydrates (WSC) at the start of induction compared with 26 and 22% after 12 and 18 weeks. Of the total WSC content per plant 66, 50 and 47% were located in the shoots after 0, 12 and 18 weeks of induction, res-

Table 3. Effects of light intensity and defoliation[1] prior to induction on leaves per plant, leaves per tiller, leaf area per plant, leaf area per tiller (cm^2) and area per leaf (cm^2) after 12 and 18 weeks of primary induction. Means of 24 plants per treatment.

Primary induction (weeks)	Light int. / defoliation	Tillers per plant	Leaves per plant	Leaves per tiller	Leaf area per plant, cm^2	Leaf area per tiller, cm^2	Area per leaf, cm^2
12	$L_{0.2}$	10.6	24.9	2.3	36.4	3.1	1.3
	$L_{0.6}$	18.0	40.5	2.2	111.3	6.4	2.8
	L_1	17.5	35.1	2.3	90.4	6.0	2.5
12	$D_{0.8}$	13.5	29.2	2.2	59.5	3.9	1.8
	$D_{0.4}$	14.3	33.1	2.3	67.3	4.5	2.0
	D_0	18.3	38.1	2.4	111.3	7.2	2.9
$LSD_{0.05}$[2]		5.2	6.3	ns	19.3	1.2	0.4
18	$L_{0.2}$	20.9	69.4	3.4	68.4	3.2	1.0
	$L_{0.6}$	29.5	100.3	3.4	146.6	5.1	1.5
	L_1	26.5	112.9	3.7	161.0	6.4	1.6
18	$D_{0.8}$	21.4	76.0	3.6	100.7	4.6	1.3
	$D_{0.4}$	26.0	87.7	3.5	119.5	4.7	1.3
	D_0	29.8	119.4	4.0	155.6	5.3	1.4
$LSD_{0.05}$[2]		5.2	15.7	0.2	22.8	0.9	0.2

[1] The plants were either left uncut or defoliated 40 or 80% of total leaf area at the start of primary induction. The corresponding denominations D_0, $D_{0.4}$ and $D_{0.8}$ are used in this and other figures and tables.

[2] LSD for comparison of main effects of light and defoliation intensities.

pectively. The total amount of WSC was significantly lower, on both plant basis (data not shown) and tiller basis (Table 4), in $L_{0.2}$-plants than in $L_{0.6}$- and L_1-plants throughout the induction period. This was solely a result of lower dry weight as the $L_{0.2}$-plants had a significantly higher concentration of WSC in total dry matter

(data not shown) than plants from higher light intensities both after 12 and 18 weeks. Particularly the WSC concentration in roots was higher in $L_{0.2}$-plants than in $L_{0.6}$- and L_1-plants (Table 4).

The significantly highest amount of WSC after 12 and 18 weeks, both on plant (data not shown) and tiller basis (Table 4), was found in the uncut plants. However, the concentration of carbohydrates in roots was significantly lower in D_0-plants than in $D_{0.4}$- and $D_{0.8}$-plants after 12 weeks, and a similar tendency was recorded also after 18 weeks. No differen-

Table 4. Effects of light intensity and defoliation prior to induction on dry weight in shoots and roots (g), water soluble carbohydrates (WSC) in shoots and roots (% of dry matter) and WSC content (total of shoots and roots) calculated per tiller (mg) after 12 and 18 weeks of primary induction. Means of 24 plants per treatment.

Primary induction (weeks)	Light int. / defoliation	Dry weight, shoots, g	Dry weight, roots, g	WSC, shoots, %	WSC, roots, %	WSC per tiller, mg
12	$L_{0.2}$	0.4	0.3	26.2	40.4	20.8
	$L_{0.6}$	1.4	0.9	24.6	30.0	36.6
	L_1	1.2	1.2	21.2	28.8	39.1
12	$D_{0.8}$	0.8	0.6	23.6	35.2	27.5
	$D_{0.4}$	0.9	0.7	24.3	34.0	29.0
	D_0	1.3	1.1	24.2	30.0	40.0
$LSD_{0.05}$ [1]		0.2	0.2	0.9	2.0	7.0
18	$L_{0.2}$	0.8	0.6	18.5	32.2	15.8
	$L_{0.6}$	2.3	1.5	19.1	25.5	28.9
	L_1	2.1	1.8	18.1	28.2	31.6
18	$D_{0.8}$	1.2	1.0	16.7	30.5	22.9
	$D_{0.4}$	1.6	1.2	18.8	28.8	24.6
	D_0	2.3	1.7	20.4	26.5	28.8
$LSD_{0.05}$ [1]		0.3	0.2	0.5	4.3	1.4

[1] LSD for comparison of main effects of light and defoliation intensities.

ces in shoot WSC concentration between plants from the three defoliation groups were recognized after 12 weeks, but the uncut plants had a higher concentration at the end of induction.

The interactions between light intensity and defoliation intensity at the start and during induction were either insignificant or gave little information additional to that of main effects.

Flowering

Percentage of heading plants

Percentage of heading plants was significantly lower after 12 than after 18 weeks of induction (Table 5). Neither the main effects of light intensity or defoliation, nor the two-way interactions were significant for this character.

The number of panicles per plant

Increasing length of primary induction increased the number of panicles per plant significantly. On average for all light and defoliation intensities, approximately 110 and 65% more tillers became reproductive after 18 than after 12 and 15 weeks of induction (Table 5).

$L_{0.2}$-plants developed, on average for defoliation intensities and duration of primary induction, 62 and 58% fewer panicles than $L_{0.6}$- and L_1-plants (Table 5).

Table 5. Main effects of length of primary induction (12, 15 and 18 weeks), light intensity and defoliation prior to induction on percentage of heading plants, panicles per plant, days to heading, culm length (cm), inflorescence length (cm), number of spikelets per panicle and florets per spikelet. Means of 72 plants per treatment.

Treatments	Per cent heading plants	Panicles per plant	Days to heading[1]	Culm length, cm	Infloresc. length, cm	Spikelets per panicle	Florets per spikelet
12 weeks	86	6.2	39.0	127.9	21.8	54.9	7.1
15 weeks	93	7.9	33.9	137.2	20.4	48.0	7.1
18 weeks	97	13.0	32.7	134.0	19.6	44.5	7.0
$L_{0.2}$	89	6.4	33.8	133.4	20.3	45.0	7.3
$L_{0.6}$	93	10.4	36.1	133.3	20.7	50.1	6.8
L_1	94	10.1	35.3	132.9	20.6	51.4	7.1
$D_{0.8}$	94	8.4	34.9	135.8	20.7	49.5	7.1
$D_{0.4}$	93	8.6	35.4	131.6	20.4	49.6	7.0
D_0	89	10.1	34.9	132.0	20.5	47.4	7.1
$LSD_{0.05}$[2]	8.7	1.4	1.7	6.2	1.4	4.4	0.4

[1] Days to heading after transfer to secondary induction

[2] LSD for comparison of main effects of length of induction, light intensity and defoliation.

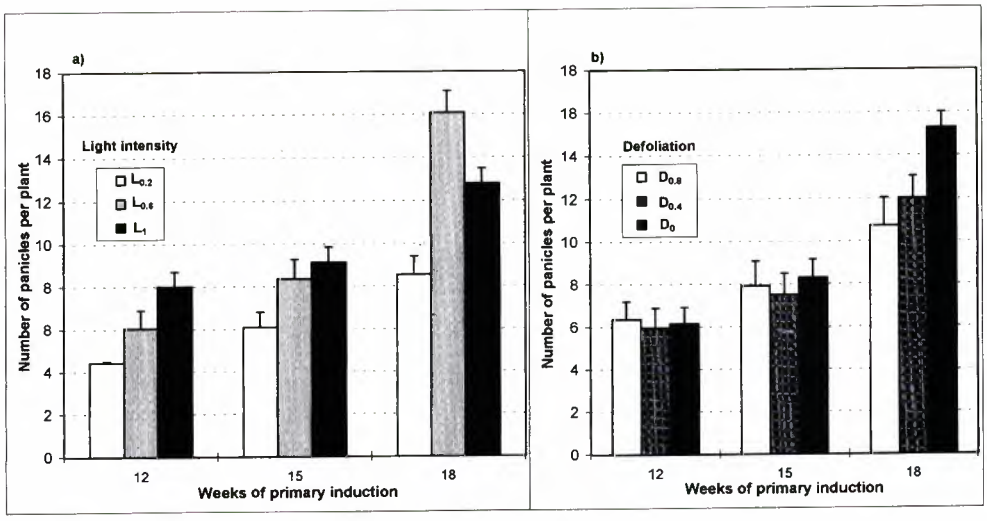

Fig. 3. The number of panicles per plant as affected by (a) light intensity, and (b) defoliation prior to primary induction . Average of 24 plants per treatment. Bars represent 1 SE.

Whereas L_1-plants produced more panicles than $L_{0.2}$- and $L_{0.6}$-plants after 12 and 15 weeks $L_{0.6}$-plants were superior to the other groups after 18 weeks of induction (Fig. 5a).

On average for light intensities and durations of primary induction, uncut plants (D_0) developed approximately 20 and 17% more panicles than $D_{0.8}$- and $D_{0.4}$-plants, respectively (Table 5). Uncut plants had significantly more panicles than defoliated plants only after the longest induction period (Fig. 5b). The interaction light intensity * defoliation intensity was not significant for this character.

Days to heading

On average for light and defoliation intensities, prolonged duration of primary induction from 12 to 18 weeks decreased the time to heading by approximately 6 days (Table 5). The shortest period to heading was usually recorded in the smallest $L_{0.2}$-plants. Neither defoliation nor its interaction with light intensity had any significant effect on the number of days to heading.

Culm length

The culm length increased significantly with increasing duration of induction from 12 to 15 weeks (Table 5). Neither the main effects of light and defoliation intensity nor the two-factor interactions were significant for this character.

Length of the inflorescence

The length of the inflorescence was significantly shorter after 18 than after 12 weeks of induction (Table 5). Other main effects or interactions were not significant.

Spikelets per panicle and florets per spikelet

On average for light and defoliation intensities, approximately 23% more spikelets were found per panicle after 12 than after 18 weeks of induction. The

number of florets per spikelet was generally little affected by length of primary induction (Table 5).

$L_{0.2}$-plants developed fewer spikelets per panicle but tended to have more florets per spikelet than the higher light intensities. Neither defoliation nor interactions were significant for these characters.

Effect of tiller emergence date on flowering characters (tagging experiment)

Forty-five plants used in the tagging experiment developed a total of 178 panicles. Of these 84 developed from tillers which had emerged prior to induction while 76 developed from tillers formed either during or after the induction treatment. Percentage fertility was much higher for tillers present at the start of primary induction than those formed during or after induction (Table 6).

Tillers which had emerged prior to induction headed approximately 3 and 8 days earlier than tillers emerging during and after the induction treatment, respectively. Tillers which had emerged prior to induction also developed longer culms and more spikelets per panicle. No difference in inflorescence length was discovered between the different tiller categories (Table 6).

The tagging experiment gave no information about the effect of light- or defoliation intensity in addition to that of the main experiment.

Discussion

Growth and development of seedlings of *Festuca pratensis* were strongly affected by light intensity prior to primary induction. Vegetative morphological characters such as tiller number, leaf number and leaf area per plant increased with increasing light intensity (Table 1). Similar responses were reported by Mitchell (1953) and Auda et al. (1966). The effects of high light intensity were

Table 6. The effect of tiller emergence date (prior to, during or after primary induction) on percentage of tillers becoming reproductive, days to heading, inflorescence length (cm), culm length (cm) and the number of spikelets per panicle after 12 weeks of primary induction. Means of all combinations of light- and defoliation intensities (45 plants in total).

Flowering characters	Tiller emergence period			$LSD_{0.05}$
	Prior to prim. ind.	During prim. ind.	After prim. ind.	
Percentage of tillers becoming reproductive	51.0	22.0	3.0	-
Days to heading[1)]	40.3	42.9	47.3	3.0
Inflorescence length (cm)	23.0	22.5	23.2	ns
Culm length (cm)	128.8	120.1	119.7	6.7
Spikelets per panicle	54.1	43.2	44.0	7.9

[1)] Days to heading after transfer to secondary induction.

probably associated with high rates of photosynthesis and carbohydrate accumulation (Table 2). Another characteristic feature associated with high light intensity was the ability of seedlings to develop a robust and heavy root system. The shoot/root ratios were 6.0, 2.5 and 1.0 for the $L_{0.2}$-, $L_{0.6}$ - and L_1-plants, respectively (Table 2). Also the specific leaf area ratio (i.e. leaf area per unit shoot dry weight) decreased with increasing light intensity (SLA= 0.35, 0.20 and 0.17 cm^2/mg at $L_{0.2}$, $L_{0.6}$ and L_1, respectively), indicating that highly illuminated plants had thicker leaves. Comparable shoot/root and leaf area ratios were also found by Allard et al. (1991) in plants of *Festuca arundinacea*. The higher leaf number per tiller in $L_{0.2}$- than in $L_{0.6}$- and L_1-plants (Table 1) demonstrates a lack of assimilates to utilize all tiller buds at the lowest light intensity as indicated by Mitchell & Coles (1955) and Davies & Thomas (1983).

Although L_1-plants produced significantly more tillers than $L_{0.6}$- and $L_{0.2}$-plants prior to induction, $L_{0.6}$-plants had a higher tillering rate during induction and tended to have the highest number of tillers after both 12 and 18 weeks (Table 3, Fig. 2). A relatively large leaf area, with a high photosynthetic potential, at the start of induction might explain the high tillering rate of $L_{0.6}$-plants during induction. In contrast, $L_{0.2}$-plants, which had a very small leaf area and a low photosynthetic capacity at the start of induction, never caught up with plants from the higher light intensities (Table 3).

In a defoliation experiment with *Lolium perenne*, Alberda (1957) found that tiller formation stopped immediately after cutting while leaf growth continued, albeit at a much slower rate than in uncut plants. Davies et al. (1972), working with the same species, reported that increasing height of cutting resulted in a greater amount of regrowth produced after defoliation. Similar results were obtained in the present experiment, plants which were defoliated most severely prior to induction ($D_{0.8}$) remained smaller in leaf area and developed fewer tillers and leaves per plant than $D_{0.4}$ - and D_0-plants. The negative effect of moderate cutting ($D_{0.4}$) on the number of tillers and leaves per plant was in fact more pronounced after 18 than after 12 weeks of induction, this complies with the differences in the amount of WSC per tiller after 12 weeks (Table 4). Alberda (1957) also found that the amount of stubble and root carbohydrates in *Lolium perenne* dropped considerably after defoliation, indicating that carbohydrate exhaustion was the main reason for reduced vegetative development after defoliation.

Bean (1970) suggested that seedlings of *Festuca pratensis* need approximately a 25 cm^2 leaf area in order to respond to inductive stimuli. This is in clear contrast to the present experiment in which the percentage of heading plants was not significantly affected by either light intensity or defoliation prior to primary induction (Table 5). Even plants from the combination $L_{0.2}$ /$D_{0.8}$, which had a leaf area of only 4-5 cm^2 at the start of primary induction, were apparently not restrained by insufficient leaf area as the number of heading plants after 12 weeks of induction was equal to or higher than in intact $L_{0.6}$- and L_1-plants, both of which had leaf areas greater than 100 cm^2 prior to induction (Table 1). In accordance with the first experiment in this series (Havstad 1996), the duration of primary induction was the most critical factor controlling the percentage of heading plants. Significantly more plants developed one or more reproductive tillers when the induction treatment was prolonged from 12 to 18

weeks, irrespective of light and defoliation intensities. These results lend no support to the existence of a juvenile stage in seedlings of *Festuca pratensis*.

Apart from the increase in percentage of heading plants, longer exposure to inductive conditions also enabled more tillers to enter a generative development (Table 5). A higher number of panicles was found in L_1-plants than in $L_{0.6}$- and, in particular, $L_{0.2}$ -plants after 12 weeks of induction. The same tendency was noticeable after 15 weeks, but as the induction period was prolonged to 18 weeks, the $L_{0.6}$-plants produced significantly more panicles than plants from the other two light intensities (Fig. 3a). This can be explained by the fact that $L_{0.6}$-plants produced most tillers during the induction treatment (Fig. 2), and some of these tillers were clearly able to respond to inductive stimuli. Lower tiller production during the latter part of the induction treatment (Table 3) also explains why defoliated plants produced fewer panicles than intact plants only after 18 weeks of induction (Fig. 3). However, as a main effect, defoliation had less effect on panicle production than light intensity prior to induction and, in particular, the duration of the primary induction treatment.

From the first experiment in this series Havstad (1996) reported that inflorescence length decreased with increasing exposure to inductive conditions. This conclusion is confirmed by the present material, which also shows an even more striking reduction in spikelet number per inflorescence with longer induction treatment (Table 5). A lower storage pool of WSC and smaller leaf area per reproductive shoot apex is the most likely explanation for these reductions in inflorescence length and spikelet number (more competition with an increasing number of panicles). The fact that spikelet number was lower in $L_{0.2}$- than in $L_{0.6}$- and L_1- plants whereas inflorescence length was unaffected by light intensity, shows that the former character is most sensitive to assimilate deficiency.

The tagging experiment revealed that a few tillers which emerged after the primary induction treatment became reproductive. Generative development of tillers unexposed to induction was also observed by Hare (1993, 1994) in *Festuca arundinacea*. Since *Festuca pratensis*, according to Heide (1988) has an extreme induction requirement (16-20 weeks at 6°C in 10 h photoperiod), these tillers must have been induced while still in the leaf sheath or as very young buds at the base of the parent shoot (Kleinendorst 1974). Alternatively, transmission of flowering stimuli from mother to daughter tillers, as further discussed by Havstad (1996), may have occurred. These results support the earlier suggestions (Havstad 1996) that tillers of *Festuca pratensis* lack or have an extremely short juvenile stage. In any case, juvenility in seedlings or tillers of *Festuca pratensis* can hardly be related to leaf area or carbohydrate status at the onset of primary induction.

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Non-beaked laying hens housed in aviaries I : Production performance in cages and three types of aviaries

JESSICA KATHLE* & NILS KOLSTAD
Department of Animal Science, Agricultural University of Norway, Ås, Norway
* Contact for correspondence and requests for reprints

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1. Production results, plumage condition and percentage of mislaid eggs are presented from three full laying cycles (20-75 weeks) of non-beak trimmed hens housed in three aviaries of the types Marielund (M), Laco-Volétage (V) and Tiered Wire Floor (TWF) and commercial three-tired battery cage system (C) installed in the same building. A total of 6000 hens were included per cycle with about 1500 hens per system. 2. As a mean of the three first cycles, C had the highest egg production per hen and day (50.2 g), followed by M (48.7 g), while hens in V and TWF produced 48.1 and 47.5 g, respectively. The mean feed conversion ratio (FCR) in TWF was significantly inferior than in C (2.63 vs. 2.17 kg of feed/kg of egg mass). There were no significant differences in egg quality traits (egg shell strength, albumen height and blood spots) between eggs from cages and aviaries. The average percentages of mislaid eggs ranged from 3.7 % (M) to 13.8 % (TWF), while the average cumulative mortality were 11.1 % in C, 12.6 % in M, followed by V (13.4 %) and TWF (21.7 %). About half of the mortality in TWF was due to cannibalism. 3. To conclude: The production varied greatly between aviaries within cycles and from one cycle to the next. Cages showed better and more stable results while the aviaries occasionally were at the same production level as cages. The main problems in aviaries recorded after three laying cycles were high number of mislaid egg, feather pecking and cannibalism.

Key words: Egg production, mislaid eggs, mortality, plumage, Marielund, Laco-Voletage, Tiered Wire Floor, Battery Cages.

Jessica Kathle, Department of Animal Science, Agricultural University of Norway, PO Box 5025 N-1432 Ås, Norway

It is generally accepted that both physiological and behavioural needs of poultry are relevant when discussing the birds welfare (Wegner, 1988). Traditional cages deprive the hens from some natural behaviour such as dust-bathing, roosting, brooding, flying and natural locomotion due to limited space (Hansen, 1994). In contrast, aviaries permit the hens to move freely; there are perches available for roosting, nest boxes for egg laying and litter material for dust-bathing. However, the success of an aviary in economic and welfare terms depends on avoiding undesired behavioural patterns among the hens, such as feather pecking and cannibalism as well as a high frequency of mislaid eggs (Tauson et al., 1992; Hansen, 1993). Frequencies of cannibalism and mislaid eggs are known to be influnced by the rearing condition (Hansen & Braastad, 1994), as well as breed

(Sørensen, 1992), type of aviary (Hansen, 1993; Abrahamsen & Tauson, 1995) and presence of cockerels in the flock (Bhagwat & Craig, 1979; Ylander & Craig, 1980).

It is reported that eggs from aviary systems increase the production cost in the order of 8 - 15 percent compared to eggs from battery cages, mainly because of extra labour involved and higher food consumption due to poor feather isolation and high activity. (Elson, 1992; Meierhans et. al., 1992; Tauson and Abrahamsson, 1992). However, in spite of higher prices, the market for eggs from non-cage systems is increasing (Simonsen, 1992; Klemm, 1994).

The main objective of the present experiment was to evaluate three types of aviaries for non-beak trimmed layers in three succeeding cycles focuses on the productivity of the hens. Results from the ethological, clinical and environmental studies included in the experiment have been published in previous articles by Lyngtveit, 1992; Engstrøm and Schaller, 1993; Hansen, 1994; Hansen and Braastad 1994, and Hansen et al., 1993.

Materials and methods

The present experiment was performed over a period of five years (1989 - 1993) and included three laying cycles. The aviaries chosen for the project were the Swedish Marielund (M), the Swiss Laco-Volétage (V) and the Dutch Tiered Wire Floor (TWF). A commercial three-tiered cage battery (C) served as a control. All systems were installed in the same laying house. The aviaries differed in total available ground area, in nest materials, in feeding systems and in light arrangements as described by Hansen (1994) and showed in Fig. 1. Some technical improvements of all the aviary systems were made after the first laying cycle, including replacement of fluorescent lamps with light bulbs and shielding dark corners attractive for egg laying. In order to accomplish a density experiment, described in Hansen and Braastad (1994), TWF and V were divided into six and four pens, respectively, before the start of the third cycle.

A commercial white-egg layer (N41) commonly used in Norway was applied for the study. N41 were simultaneously tested both in International and Norwegian Random Sample Tests (Nordli, 1991; Nordvoll, 1992; Valland, 1993) and in field tests in Norway (Nordli, 1993). At that time the breed was reported to have an average yearly egg production of 17.5 - 19.0 kg, a feed conversion ratio of 2.2 - 2.4 and a cumulative mortality of 5-11 %.

The hens were vaccinated against Marek's Disease. None of the chicks were beak-trimmed according to the regulation in Norway. In the two first laying cycles all chicks were reared on floor with a density of 13/m^2. In the third rearing period about 1/4 of the chicks, later placed in V, were reared in flocks with a density of 6.5/m^2 (Hansen and Braastad, 1994). Perches were available during all rearing periods. The pullets were moved to the aviaries at 15 weeks of age. All records from 20 to 75 weeks of age were included in the analyses.

The following lighting program was applied: full time light (24 h) for the first week, followed by nine hours per day until 24 weeks of age, thereafter an increase of half an hour per week to a maximum of 16 hours light per day, and a dusk of 15 minutes. The light intensity within the systems varied between 0.5 and 5 lux. The litter material was wood shavings for the first and second cycles and sand in the third.

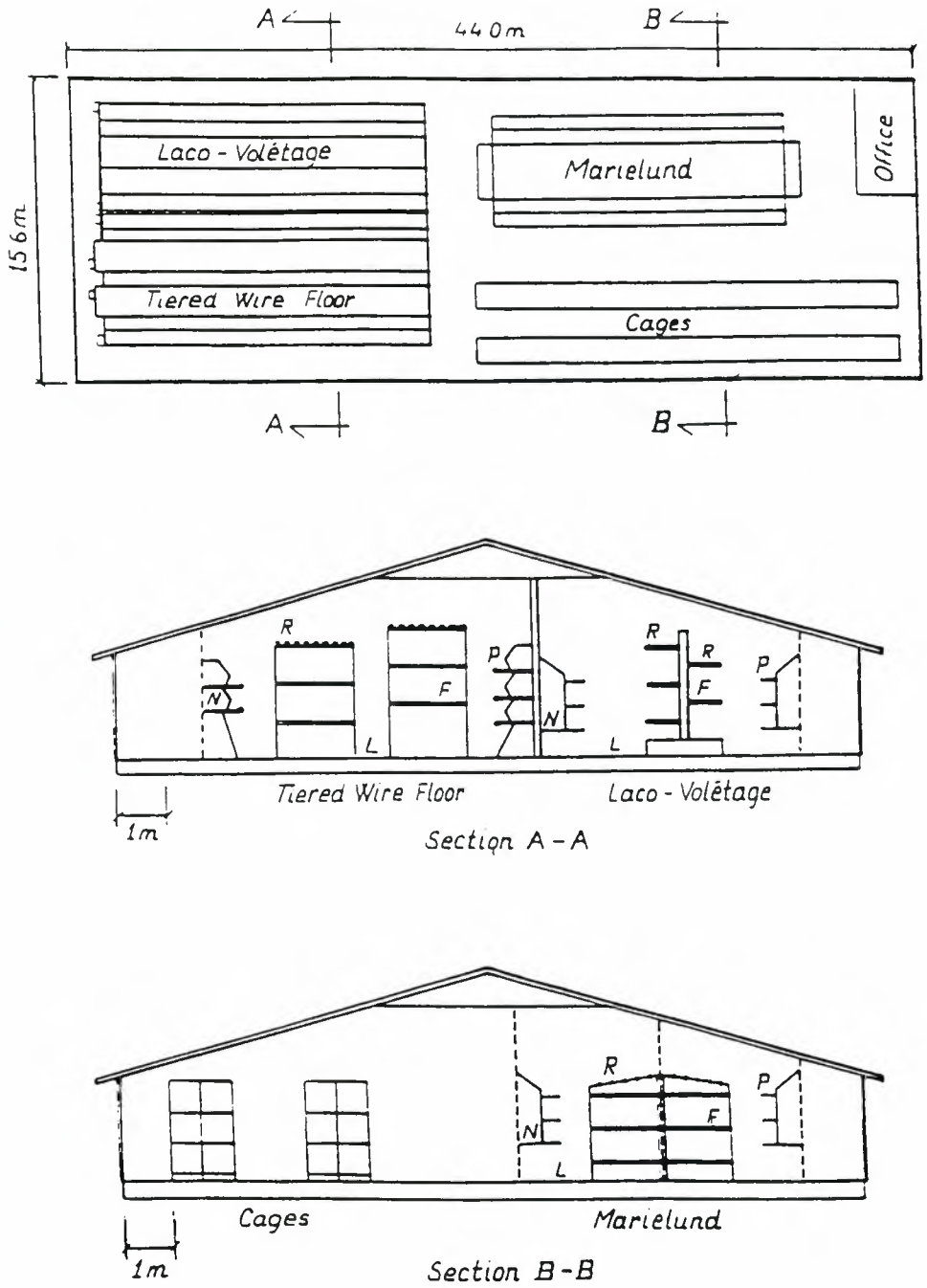

Figure 1. Layout and cross-section of the poultry house comprising a battery cage system and three types of aviary: the Marielund, the Tiered Wire Floor, and the Laco-Volétage (after Lyngtveit, 1992). L=litter, F=feeding floors, R=resting levels, N=nest boxes, P=perches in front of nests.

The density of hens per m² of ground floor was about 17 in all aviaries, while the densities per total available area in squared meter were 6.7 (TWF), 9.4 (M), and 11.2 (V). Three hens were placed in each cages with available ground area of 720 cm²/hen. Each system housed about 1500 hens per laying cycle.

The food consumption per system was recorded daily in all cycles, while daily water consumption was only recorded in the last cycle. The food given was a commercial complete mash diet, with a metabolisable energy of 11.1 kJ/kg, 13.8 % crude protein and 3.68 % Ca. One percent lysine was added to the diet. Samples from each delivery were analysed for N, fat, Na, Ca and P in order to insure normal ranges.

Floor eggs were collected four to five times a day from maturity to 30 weeks of age and once or twice a day thereafter. Every week 80 eggs per system were picked at random, weighed, and average egg weight calculated. Egg quality traits (shell strength, albumen height and blood and meat spots) were recorded six, three and two times during the laying periods in the first, second and third laying cycles, respectively. Feed was weighed out and recorded daily per system. Industry eggs were recorded weekly and included all dirty and cracked eggs (after candling).

All dead hens were sent for autopsy at the National Veterinary Institute (Engstrøm and Schaller, 1993.

The plumage condition was recorded on a random sample of 40 hens per system at 42 weeks of age by a method described by Tauson et al. (1984). Scores from 1 to 4 (best) were given for five areas of the bird; neck, breast, wings, tail and back, giving a maximum feather score of 20 points and a minimum of five. The birds were weighed at 42 and 75 weeks of age.

In the first and third laying cycles dust were recorded continuously in 8 hours in two successive days, repeated three times per cycle. In addition, personal exposure of dust was recorded six times during egg collection. The total dust was measured by gravimetry of filter samplers collected by pumps, described more in details by Lyngtveit (1992).

Statistical analyses

The production traits presented in Table 1 were recorded on a flock basis per laying cycle and housing system. The GLM-procedure (SAS, 1985) for analyses of variance was applied to test differences between the systems in the first three cycles. Model 1 below was used for the traits in Table 1, while egg quality traits, live weight and plumage score which were recorded on an individual basis, led to Model 2. In case of significant effect of the models, SNK-tests (SAS, 1985) were performed to separate between systems. Differences in dust records between the housing systems were tested by paired comparisons tests.

$$Y_{ij} = \mu + cycl_i + system_j + \varepsilon_{ij} \quad (1)$$

where:

Y_{ij} = registration per flock in cycle i and system j (i=3 and j=4)

ε_{ij} = random error

$$Y_{ijk} = \mu + cycle_i + system_j + \varepsilon_{ijk} \quad (2)$$

where:

Y_{ijk} = observation of a hen k in cycle i and system j (k=40-60, i=3 and j=4)

ε_{ijk} = random error

The significant level was set to 5 % if nothing else is mention.

Results

Egg production, food- and water consumption, mortality and mislaid eggs

During the first three laying cycles the average laying rates per hen day were 81.2 % in cages and 78.2 % for hens housed in the aviaries. However, the production varied greatly within aviaries and from one cycle to the next as seen in Fig. 2 and also as indicated by large standard errors in Table 1. Consequently, significant differences between the systems were easily masked in spite of an average higher egg production in cages compared to aviaries close to significant ($p = 0.7$). The system with the lowest average laying rate (TWF) produced the largest eggs (Table 1) and a recorded production of 50.0, 49.5 and 43.0 g/hen day in the first, second and third cycles versus 50.9, 49.6 and 50.1 g/hen day in C. Hens housed in V and M produced 49.0, 47.9 and 47.3 g/hen day and 50.2, 48.0 and 47.8 g/hen day in the three cycles, respectively. In general, the rate of lay was higher and more stable in cages than in the aviaries, but was occasionally on the same level (Fig. 2 A,B).

Generally, consumption per hen day was lower and food conversion ratio (FCR) better for caged hens than hens housed in aviaries, but only significantly between C and TWF (Table 1). FCR was recorded to be 2.10, 2.15 and 2.26 in cages vs. 2.51, 2.34 and 3.03 in TWF, for the three cycles respectively, while FCR in M was 2.19, 2.25 and 2.49 and in V 2.24, 2.32 and 2.49 in the respective cycles. Water consumption in the third cycle was on average per hen and day 142 ml, 198 ml, 193 ml and 133 ml for C, M, TWF and V, respectively.

The housing systems were not proved to have impact on the cumulative mortality after only three laying cycles (Table 1), due to great variations from one cycle to the next. However, the mortality in cages was in general lower than in aviaries (11.1 % versus 15.9 %), except for the second cycle when lower mortality rates were recorded in both M (8.6 %) and V (9.7 %) compared to C (11.9 %). In the third cycle the mortality rate was high in all systems (12.6, 16.7, 25.5 and 17.3 % for C, M, TWF and V, respectively) and Marek's Disease became then for the first time a significant death cause in all housing systems, ranging from 4.1 to 5.6 % (Engstrøm and Schaller, 1993). Hens in TWF had an extremely high mortality in two of the cycles due to cannibalism; accounting for 16.4 % of a total of 30.0 % in the first cycle and 14.8 % out of 25.5

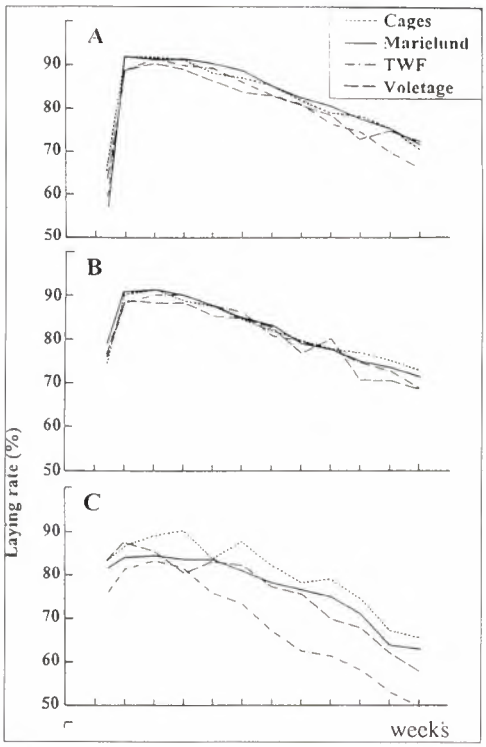

Figure 2. Egg laying rate per hen day in three laying cycles.

Table 1 . Average production of three laying cycles with standard errors from the four housing systems Cages (C), Marielund (M), Tiere Wire Floor (TWF) and Laco-Volitage (V).

Housing system	Laying rate %	Egg mass g/hen/day	Egg weight g	Food consump. hen/day	FCR	Mortality %	Mislaid egg %
C	81.2 ± .37	50.20 ± .38	61.6 ± .47^{a,b}	109 ± 2.0^{b}	2.17 ± .05^{b}	11.1 ± 1.17	-
M	80.2 ± 1.53	48.67 ± .77	61.0 ± .70^{b}	112 ± 3.4^{b}	2.30 ± .09^{a,b}	12.6 ± 2.34	3.7 ± .8
TWF	76.3 ± 3.98	47.50 ± 2.25	62.2 ± .67^{a}	124 ± 4.3^{a}	2.63 ± .21^{a}	21.7 ± 6 16	13.8 ± 8.5
V	78.3 ± 1.17	48.07 ± .50	61.3 ± .67^{a,b}	113 ± 2.5^{b}	2.35 ± .07^{a,b}	13.4 ± 2.38	10.3 ± 3.3

Differnt letters represent significant differences ($p<0.05$)

% in the third. Cannibalism was, however, not restricted to aviaries, but occurred in cages as well. For example, in the first cycle, e.g. the incidence of cannibalism was 1.3 % in C and 1.7 % in M (Engstrøm and Schaller, 1993).

As indicated by standard errors in Table 1, M had the most stable percentages of accumulated mislaid eggs, varying between 2.3 and 4.9 %, while the frequencies in TWF were from 1.7 to 30.1 %. Still, no significant differences were recorded between the aviaries. The percentages of mislaid eggs increased in all aviaries from the first to the third cycle.

Plumage, live weight, egg quality traits and dust records

Hens in cages were better feathered overall (average score of 15.8) than those in aviaries (average score of 13.0). However, there were no significant differences between hens in C and in M except for cycle 3 (Table 2). Hens housed in V scored significantly lower than those in M and C, while hens in TWF always scored lowest.

Body weights at 75 weeks of age were significantly higher in cages than in the aviaries, while only small differences between hens housed in the aviaries were found (Table 3). No significant differences were found between the systems at an earlier age (data not shown).

Somewhat more industry eggs (cracked or dirty) were recorded in the aviary systems compared to cages (6.4 % vs. 3.8 %). However, there were large differences between the aviaries with the lowest frequencies in M (4.2 %) and the highest in TWF (7.8 %). Frequency of blood spots in eggs from cages was 1.1 % and in aviaries 0.5 %. At 70 weeks of age TWF had in the third cycle significantly higher gravity (1.0975) than V (1.0861), C (1.0822) and M (1.0694). No significant differences were recorded between any of the systems in any of the egg quality traits before 70 weeks of age (data not shown). Specific weight and Haugh Unit varied between 1.069 - 1.098, and 72.9 - 79.4, respectively, which were within normal ranges.

The total dust concentration recorded from the stationary exposure during the first cycle, varied from 2.4 to 12 mg/m^3, with an average of 6.8 mg/m^3. The highest concentrations were found in the afternoon in the Voletage system. The exposure of dust recorded by the transportable equipment was in average 7.3 mg/m^3 with a variation from 2.4 to 17 mg/m^3 (Lyngtveit, 1992). The concentration of the dust reached a significant higher level in the afternoon than in the morning due to the hens dustbathing behaviour. Similar differences was not found in the department with battery cages. The amount of

Table 2. Total feather scores at 42 weeks of age of a random sample from the four housing systems, cages (C), Marielund (M), Tiere, Wire Floor (TWF) and Laco-Volétage (V). N= 40 hens per system and cycle. Means with SD in brackets

System	Laying cycle					
	1		2		3	
C	15.47	(2.52)[a]	15.73	(2.71)[a]	16.09	(2.80)[a]
M	5.23	(2.61)[a]	15.74	(3.09)[a]	13.91	(3.28)[b]
TWF	9.60	(1.97)[c]	11.56	(3.54)[c]	11.65	(3.11)[c]
V	13.29	(3.07)[b]	13.36	(3.53)[b]	12.53	(3.26)[c]

Different letters represent significant differences ($p<0.05$)

Table 3. Mean body weight (with SD in brackets) at 75 weeks of age of a random sample from the four housing systems, cages (C), Marielund (M), Tiere Wire Floor (TWF) and Laco-Volétage (V). N= 40 hens per system and cycle.

System	Laying cycle					
	1		2		3	
C	2.21	(.318)[a]	1.94	(.276)[a]	2.07	(.288)[a]
M	2.00	(.347)[b]	1.85	(.228)[a,b]	1.88	(.226)[b]
TWF	1.93	(.254)[b,c]	1.84	(.250)[b]	1.82	(.215)[b]
V	1.90	(.243)[c]	1.84	(.266)[b]	1.87	(.246)[b]

Different letters represent significant differences ($p<0.05$)

dust during collecting eggs in the morning were 1.6 mg/m^3 in the cage department, 2.1 mg/m^3 in M, 2.4 mg/m^3 in TWF and 3.0 mg/m^3 in V, while the values in the afternoon were 1.5 mg/m^3, 2.5 mg/m^3, 4.3 mg/m^3 and 6.6 mg/m^3 in the respective systems. In the last cycle with sand as litter material the dust records from the stationary exposure was in average 3.55 mg/m^3 (SD=1.82) with a minimum value of 0.82 mg/m^3 and a maximum of 8.3 mg/m^3. (Lyngtveit, 1993, pers. comm.).

Discussion

Egg production per hen day in aviaries was in general at an acceptable level compared to results from random sample tests (RST) and field tests in the same period and with the same hybrids (Nordli, 1991; 1993; Norvoll, 1992). However, many mislaid eggs were eaten by the hens or lost in the manure (Døving, per. comm.). Consequently, the egg laying rate might have been underestimated in those systems. The incidence of mislaid eggs

was highest during the first weeks of lay and may in particular explain some of the gap in the top laying between cages and aviaries. The increased number of mislaid eggs in the third cycle in TWF (30.1 %) and V (14.0 %) was partly caused by the division into small pens in that batch, and partly by the high incidence of cannibalism. The low light intensity which was used as a measure to prevent cannibalism also created many dark corners in the systems attractive for egg laying. To keep the incidence of mislaid eggs at an acceptable low level of 2.5 % requires skill and conscious management by the producer (Tauson et al. 1992). In the present study the same technician was responsible for the practical management, but his many assistants (students) varied for each cycle. The quality of their job is difficult to evaluate.

The genetic potential for egg production in the chosen hybrid was high. However, the great variation in egg production in aviaries due to undesired behaviour indicates an interaction between genotype and environment (housing system) as several authors have stated long ago (Gowe, 1956; Craig & Toth, 1969). Beak-trimming the birds is not allowed as a tool to reduce the damage of feather pecking behaviour according to Animal Welfare authorities in Norway. An alternative strategy to obtain more stable production in non-cage systems is further improvements of the environment combined with selection for relevant behaviour traits (Hansen, 1976; Gerken & Petersen, 1987; Sørensen, 1992; Flock, 1994; Abrahamsen & Tauson, 1995).

The mortality was in general somewhat higher and varied more in the present study (8.6 - 30.0 %) than recorded from RST (6 %) with the same hybrid during the same period of time. In the first cycle, the fluorescent light in TWF might have stressed the hens (Nuboer, 1992) and caused a high incidence of feather pecking and cloacal cannibalism. After changing to bulb lamps the mortality decreased tremendously, but rose again in cycle 3. The many small rooms in that batch might have led to more damage from feather pecking due to the reduced possibilities to escape from an attacker. Small group size has been stated (Guhl et al., 1945; Craig & Guhl, 1969; Hughes & Wood-Gush, 1977) to be favourable with regard to feather pecking and cannibalism, but neither feather pecking (Table 2) nor cannibalism were reduced in the third cycle with many pens and small flocks in TWF and V. Excluding cannibalism, no differences at all were found in mortality between aviaries and cages during the first three cycles.

Exercise is supposed to increase Ca absorption and thereby bone strength (Wise, 1977; Nestor et al. 1987; Classen, 1991). However, no influence of exercise or housing system (cages vs. aviaries) on shell strength was found in the present study and was very uncertain in the study by Abrahamsson and Tauson (1995). It might possibly be that the diet was insufficient in Ca content for the hens in aviaries because of their greater Ca requirement than hens in cages. However, this theory needs research investigation to be verified.

As expected, food consumption was lower for caged hens, mainly due to small possibilities for exercise (MacLeod et al., 1982; Braastad & Kathle, 1989) and a better plumage (Leeson and Morrison, 1978; Tauson & Svensson, 1980). In addition, high egg production decreases FCR per definition. As reported by Hansen (1994), the calmest hens were recorded to be in V and the most restless

in TWF, which was also indicated by the generally low plumage score in TWF (Table 2) and high water- and food consumption (Table 1). However, activity level and plumage condition were confounded as factors influencing on food consumption. Their relative importance is impossible to evaluate without individual records on food intake. It should also be taken into account that food consumption was recorded on a flock basis, while activity and plumage condition were recorded in random samples. Nevertheless, the tendency during all laying cycles clearly shows a significant effect of housing system on food consumption.

Results of dust measurements indicate that the concentration of total dust was not dependent of the area of straw bedding. In V, which had the highest dust concentration and least area with straw, the hens had a longer flying distance between the wire and the perches (Fig. 1). During most of the recording time in the first cycle the dust level was far above the Norwegian recommended hygienic level of 5 mg/m^3. According to the results in the third cycle sand seems to lower the total dust concentration in the aviaries.

So far, we may support the conclusion of Abrahamsen & Tauson (1995) that the egg production potential is the same in cages and aviaries, but as long as problems with mislaid eggs, feather pecking and cannibalism are not fully solved in the aviaries the systems can not be generally recommended. However, present results indicate that further ethological studies and more genetically adaptation material to non-cage systems are needed to control the production better.

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Non-beaked laying hens housed in aviaries II : Behaviour of cockerels and their effects on hen performance

JESSICA KATHLE,* BJARNE O. BRAASTAD & HÅKON LANGSTRAND
Department of Animal Science, Agricultural University of Norway, Ås, Norway
* Contact for correspondence and requests for reprints

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1. Non-beak trimmed white egg layers (Norbrid41) were housed in a three-tiered battery cage system (C) and in two aviaries of the types Marielund (M) and Laco-Volétage (V) for four laying cycles. About 1500 hens were included per system. In the first three cycles the aviary hens were without company of cockerels while the effect of two densities (1m / 30 ff vs. 1 m/ 130 ff) and two types of cockerels (Nordbrid41 vs. Jærhøns) were studied in the fourth cycle. The hens' production and the cockerels' behaviour were recorded. 2. Production results, plumage condition and percentage of mislaid eggs of the first three full laying cycles (20-75 weeks) from M, V and C were compared with the successive fourth cycle. In the last cycle the average egg production per hen and day was: 51.9 g (V), 51.8 g (M) and 51.3 g (C). The differences between C and M, and C and V in egg production were significantly changed in favour of aviaries compared to the mean of the first three cycles. The cumulative mortality rate was about 10 % in all systems and no cannibalism was recorded in contrast to the three first cycles. The cumulative percentages of mislaid eggs were 3.5 % (M) and 8.4 % (V). Pens with a high density of cockerels had somewhat lower frequency of mislaid eggs until 30 weeks of age than pens with few cockerels (16.3 % vs. 18.6 %). 3. Few differences in cockerels' behaviour related to cockerel type or density were observed. However, cockerels with high social rank crowed more, received more pecks from the hens, and had more interrupted mating than cockerels with low social rank. 4. To conclude: The presence of cockerels seems to have a favourable impact on production level, frequency of mislaid eggs and cannibalism. More knowledge about interactions between cockerels and hens may be applicable when improving aviary systems.

Key words: Cock density, cock type, social rank, production level, mislaid eggs, cannibalism.

Jessica Kathle, Department of Animal Science, Agricultural University of Norway, PO Box 5025, N-1432 Ås, Norway

National animal welfare legislation often require the fulfilment of both physiological and behavioural needs (Ministry of Agriculture 1982; MAFF, 1987). In contrast to traditional cages, aviaries stimulate the hens to show a larger behaviour repertoire and thereby presumably better welfare (Appleby et al., 1993; Hansen et al., 1993; Hansen, 1994). However, behaviour problems as feather pecking, cannibalism, and mislaid eggs can be pronounced in non-caged systems

(Tauson & Abrahamsen, 1992; Blokhuis & Metz, 1996 and Kathle & Kolstad, 1997). In order to reduce these problems the presence of males should be considered. Cockerels are an important factor of the social environment in domestic fowls. Reports from small flocks show that they may reduce aggression among hens and play a role in selecting nest sites (Guhl et al., 1945; McBride et al., 1969; Craig & Bhagwat, 1974; Ylander & Craig, 1980). However, few studies on the influence of cockerels on hens' performance in large flocks have been published (Craig & Guhl, 1969).

The objective of the present experiment was to study the effects of including males in a commercial flock of non-beak trimmed layers in two types of aviaries. Two breeds and two densities of cockerels were evaluated. The present paper focuses on the productivity of the hens compared to earlier results and ethological observations on the cockerels.

Materials and methods

The experiment lasted six years (1989 - 1994) and included four laying cycles. The first three cycles included only hens and served as a general background or contrast to the fourth with cockerels present. The same two-way commercial cross of White Leghorn hens, Norbrid41 (N41) was used in all cycles and the same aviaries were used: the Swedish Marielund (M) and the Swiss Laco-Volétage (V) in addition to a three-tiered cage battery (C). All systems were installed in the same layer house. The aviaries differed in many details as described by Hansen (1993). The cross-section of the layer house is given by Kathle & Kolstad (1997).

In the fourth cycle cockerels from two breeds were included, N41 and Jærhøns. The latter is an old, Norwegian, light type (1.6-2.0 kg for cockerels). It is sexually dimorphic, highly inbred over the years, and known to be somewhat aggressive.

Each sex was reared separately on the floor only intermingled with a few chicks of the opposite sex in order to stimulate their sexual behaviour and reduce aggression (Wood-Gush, 1958; Leonard et al. 1992; 1996). None of the chicks were beak-trimmed, as this is illegal in Norway. Perches were available during the rearing periods. The birds were moved to the aviaries at 15 weeks of age. All records from 20 to 75 weeks of age were included in the analyses.

The same light program, feeding regime and hen density were followed in all cycles as described by Kathle & Kolstad (1997). The density of hens per m^2 of ground floor was 17 in both aviaries, but differed per total available area with 9.4 hens/m^2 (M) and 11.2 hens/m^2 (V). There were three hens per cage with a available ground area of 720 cm^2/hen. Each system housed about 1500 hens per laying cycle. The litter material was wood shavings with whole wheat grain (1 g/hen and day) and shell sand added in the fourth cycle.

M was originally separated with wire in two compartments while V was build as one unit. In the third and fourth cycles V was divided into four compartments and M was additionally divided in two. All eight available pens were separated with solid walls so the cockerels were invisible from the neighbouring pens. It was decided to put cockerels in all eight pens, since crows from the cockerels anyway would have an impact on all hens in the layer house (Polley et al., 1974; Bhagwat & Craig, 1979). Two densities of cockerels were tested : one cock per

30 hens and one cock per 130 hens with two replicates for both system (M and V) and breed (N41 and Jærhøns). The cockerels were eight days older than the hens and placed in the aviaries one week earlier to settle their social hierarchy and reduce the probability of being attacked by the hens (McBride & Foenander, 1962). The number of fertilised eggs was recorded at 26 weeks of age when all eggs that week were sampled and incubated.

The floor eggs were collected after the same routine as earlier cycles i.e. four to five times a day from maturity to 30 weeks of age and one or two times a day thereafter. Every week 80 eggs per system were picked at random and weighed. Feed consumption per system was recorded daily.

The plumage condition was recorded on all cockerels and on a random sample of 50 hens per system at 54 weeks of age by a method described by Tauson et al. (1984). Scores from 1 to 4 (best) were given for five areas of the bird; neck, breast, wings, tail and back. The birds were simultaneously weighed.

Frequencies of cock behaviour were recorded by focal-animal sampling in M at 22 and 31 weeks of age. Each cock was collected and marked with spray (blue or green) one week before the observation periods. The focal animal was studied continuously for 10 min. during each of five three-hour periods of the day. The observer watched the aviary compartment from outside the entrance door in order to avoid disturbance of the birds. However, it was in some cases difficult to follow the cock within the aviary, which resulted in some missing data. Six behaviour patterns were recorded: agonistic behaviour towards other cockerels, mating (fulfilled or interrupted), crowing, pecking at hens (ranging from gentle pecking to feather removal), receiving pecks from hens and interfering with hens which were acting agonistically.

The social rank of the cockerels (X) was determined after a rank index given by Lee et al. (1982): $X = \frac{1}{2}(D - S + N + 1)$, where D is the number of cockerels dominated by the focal cock, S is the number of cockerels dominating the focal cock, and N is the group size. One third of the recorded cockerels was classified as having high social rank, while another third was classified as low rank.

Mobility of the cockerels was observed in M by recording the location of each cock every 10th second during a period of 10 minutes, repeated five times for each recording period. The start of the observation sequence always took place when the focal animal was on the litter. The numbers of cockerels on the litter and in front of the nests were recorded simultaneously.

Statistical analyses

The production traits were recorded on flock basis. In order to test possible impact of the cockerels, cages were regarded as a control within cycle and all traits (except for mislaid eggs) recorded in M and V were expressed as deviation from the control. Contrasts between the first three cycles and the fourth were constructed and GLM-procedure for variance analyses run (SAS, 1985) based on the model below. In case of significance, SNK-tests (SAS, 1985) were performed to separate within the effects.

$$Y_{ij} = \mu + \text{cycle}_i + \text{system}_j + \varepsilon_{ij}$$

where:

Y_{ij} = registration per flock in cycle i and system j (i=4 and j=2)

ε_{ij} = random error

For the fourth cycle factor variate analyses and t-tests were applied on ethological data, live weights and plum-age scores with a significance level of 5 %.

Results

Egg production, food consumption, mortality and mislaid eggs

The results from the first three laying cycles without cockerels present are presented in detail elsewhere (Kathle & Kolstad, 1997) and only summarised in the present paper (Table 1, upper part).

In the fourth cycle with cockerels present, the hens in both M and V attained a superior rate of egg laying per hen day compared to their earlier results, while the caged birds were at their average, but laid somewhat heavier eggs (Table 1). Considering the differences in egg mass between the two periods (1st - 3rd cycle vs. the 4th cycle), all systems obtained higher egg production in the last cycle. Food consumption and food conversion ratio (FCR) per hen day (not adjusted for the cockerels) in the fourth cycle were also higher (Table 1). No cloacal cannibalism was observed in the fourth cycle and the cumulative mortality was about 10 % in all systems.

Table 2 shows the part of the variation explained by the Model (R^2) and the significance level caused by system, cycle and contrast (cockerels). The contrasts were significant for egg laying rate, egg mass and FCR. In the three mentioned traits cycle also contributed significantly to the variation. No significant contrast differences in egg weight, food consumption, mortality rate or mislaid eggs were found. The only significant source of variation in mortality rate was cycle, while system (M vs. V) did not contribute significantly to the variation in any of the recorded traits.

The proportion of accumulated mislaid eggs decreased slightly (n.s.) compared to the average of earlier cycles (Table 1). Analysing within cycle four, V had an higher frequency of mislaid eggs than M (Fig. 1a) and in the period from 26 to 54 weeks of age, pens with breed Jærhøns had less mislaid eggs (7.7 %) than N41-cockerels (8.7 %). Until 30 weeks of age somewhat less eggs were mislaid in pens with many cockerels than in flocks with low

Table 1. Average production per system of the first three laying cycles (20 - 75 weeks). In the three bottom lines the production results of the fourth laying cycle are shown.

System & laying cycle	Laying rate %	Egg mass g/hen/day	Egg weight g	Food consump. g/hen/day	FCR	Mortality %	Mislaid egg %
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE
C / 1-3	81.2 ± .37	50.20 ± .38	61.6 ± .47	109 ± 2.0	2.17 ± .05	11.1 ± 1.17	-
M / 1-3	80.2 ± 1.53	48.67 ± .77	61.0 ± .70	112 ± 3.4	2.30 ± .09	12.6 ± 2.34	3.7 ± 0.8
V / 1-3	78.3 ± 1.17	48.07 ± .50	61.3 ± .67	113 ± 2.5	2.35 ± .07	13.4 ± 2.38	10.3 ± 3.3
C / 4	81.3	51.3	63.0	116	2.27	10.0	-
M / 4	82.9	51.8	62.3	121	2.34	11.6	3.5
V / 4	83.3	51.9	62.1	123	2.38	9.9	8.4

C = cages; M = Marielund; V = Laco-Volétage.

Table 2.Sources of variation and significant levels when all traits are expressed as deviation from control (cages). Contrasts are constructed between the first three cycles and the fourth.

Source of variation	Laying rate	Egg mass	Egg weight	Food consump.	FCR	Mortality	Mislaid egg
System (M vs.V)	ns	ns	ns	ns	ns	ns	ns
Cycle (1,2,3,4)	.027	.015	.085	ns	.021	.01	ns
R^2	.94	.96	.86	.80	.95	.97	.69
Contrast (cocks)	.013	.005	ns	ns	.026	ns	ns

cockerel densities (16.3 % vs. 18.6 %); thereafter no differences were recorded between cock density (Fig. 1b).

The frequency of fertilised eggs in pens with low density of cockerels was 45 % in V and 53 % in M, while in pens with high density, 92 - 94 % of the eggs were fertilised. There were no differences between the two aviaries or breeds of cockerels.

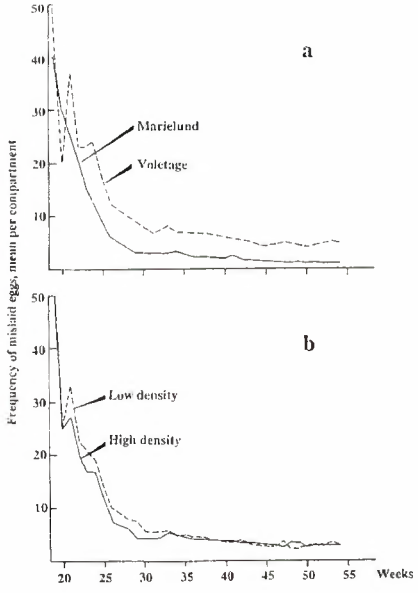

Figure 1. Frequency of mislaid eggs in Marielund and Volétage (a) and in compartments with high and low cock density (b).

Live weight, plumage and behavioural traits

Males of Jærhøns weighed 1.62 ± 0.14 g which was 500 g less than males of N41 (2.14 ± 0.28 g) and 200 g less than the average hen in the aviaries that cycle (1.84 ± 0.20 g). No significant differences were found between hens in M and V at 52 weeks of age, while the hens in cages were significantly heavier (1.90 ± 0.23 g).

Hens in cages were better feathered overall with an average score of 14.10 (SD=2.92) compared to those in M and V with 13.01 (SD=2.45) and 12.10 (SD=2.53), respectively. However, there was only significant difference between C and V hens. Cockerels of the Jærhøns breed had significantly lower average scores (15.8) than N41 (19.5), particularly for the back feather (1.1 and 4.0 for Jærhøns and N41, respectively).

Fig. 2a-d shows the frequency of behavioural events in cockerels classified after time of day, social rank, breed, and cock density. In general, due to large standard deviations in the behaviour traits, few significant differences between the groups were found. However, time of day had impact on the behaviour frequencies. The number of fulfilled matings increased during the day from 0.2 times to 1.4 ti-

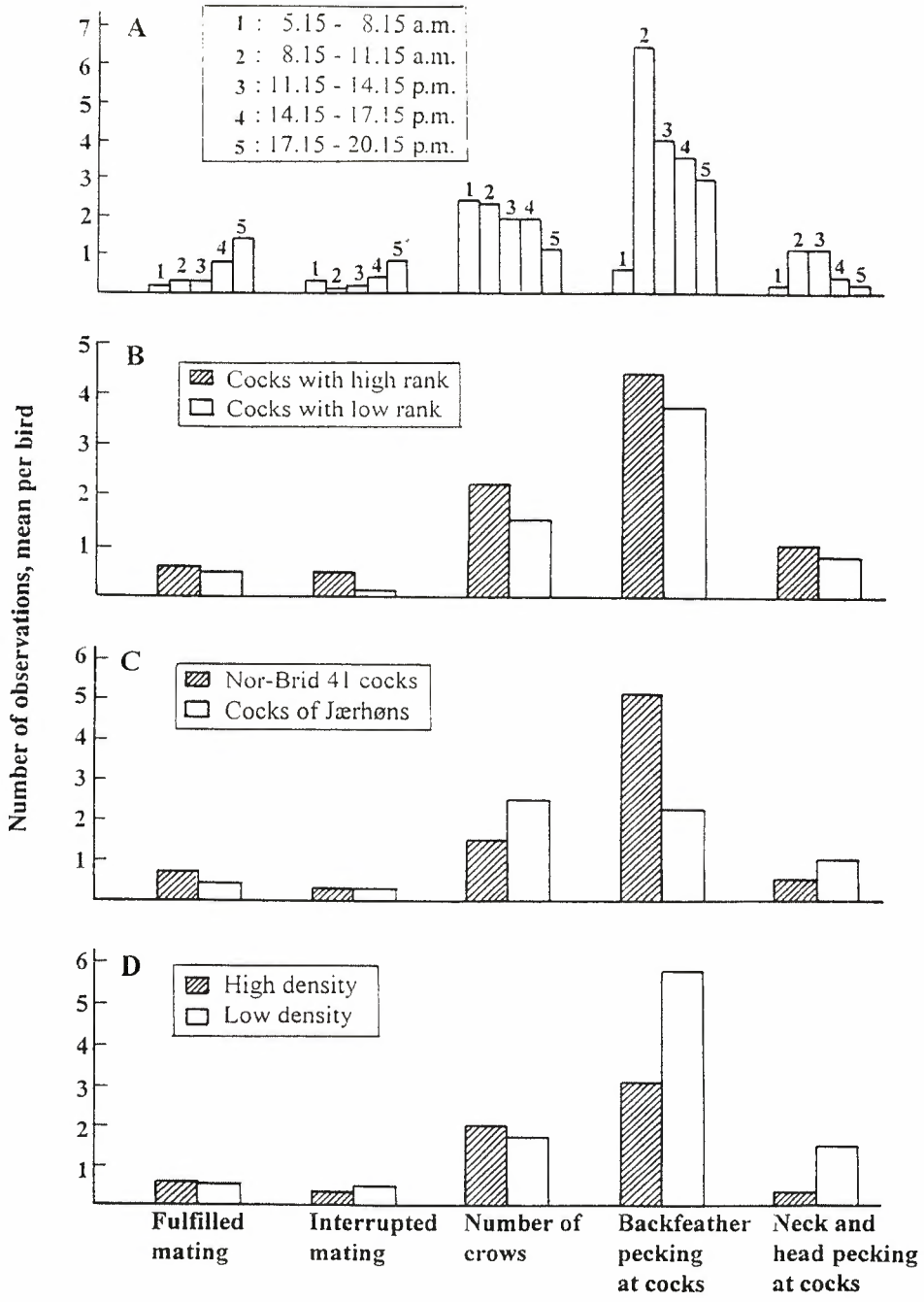

Figure 2. Behaviour observations on cockerels (fulfilled and interrupted mating and crowing) and number of feather pecking on cockerels by hens a: time of day; b: cockerels with low and high rank; c: two breeds and d: high and low cock densities.

during the day from 0.2 times to 1.4 times per hour and cock while interrupted mating increased from 0.3 to 0.8 in the same period (Fig. 2a). The cock crowed on average 2.4 times during the first observation period of 10 minutes in early morning and 1.1 times in late afternoon. Males of Jærhøns crowed on average 2.5 times while N41-males crowed 1.5 times during the observation period. At the most frequent time for egg laying (8.15 - 11.15 a.m.), the hens pecked most frequently on the cockerels, particularly on the back feather (6.5 pecks per cock). Cockerels with high rank received more pecks (4.4) than low ranked cockerels (3.7). This pecking behaviour by the hens decreased during the day. Number of matings did not change significantly with age or social class of the cockerels and was on average 0.6 matings per observation period. However, cockerels with low social rank had fewer interrupted matings than high ranked cockerels (0.1 times vs. 0.5) and crowed less (1.5 times versus 2.2). N41 cockerels received more tail feather pecks from hens (5.8) than Jærhøns (2.2), and cockerels in pens with few other cockerels seemed in general to receive more pecks from the hens (Fig. 2d).

Mobility and distribution of cockerels

At the start of the observation period the focal cock was located on the litter, and in 68.6 % of the cases he remained there during the whole observation session. In 24 % of the records the cock moved to the first wire floor, while only in 7.4 % of the cases he did fly further up in the system. Only cockerels belonging to the highest class of rank flew that far. The relative number of cockerels in front of the nests was highest (0.6 cockerels) around normal egg laying time (8.15 - 11.15 a.m.) compared to earlier or later in the day (0.45 cockerels).

Only minor differences were found between breed and density on the mobility pattern of the cockerels. They moved evenly over the whole floor area except for Jærhøns in the pens with low cock density. In these pens the cockerels were represented in 66 % of all observations in the half of the total area closest to the observer.

Discussion

In the fourth cycle with cockerels present, mean egg production per hen day was for the first time higher in aviaries than in cages. The cockerels' possible impact on the production is confounded with system and cycle since no traditional control (pens without cockerels) was run in the fourth cycle. Besides a limited number of pens, which did not allow replicates of M and V without cockerels, crows would be heard by all hens in the layer house which probably would influence hens in pens without cockerels as well (Polley et al., 1974; Ylander & Craig, 1980). However, in the contrast analyses one has to accept cages (which remain without cockerels) as a general control. In order to test if the results were due to year variation or a possible effect of cockerels, all traits were recorded as deviations from C and contrasts between the first three cycles and the fourth were constructed. The highly significant effect of contrast on egg production and FCR (Table 2) strongly indicates that cockerels had a favourable impact on the hens' performance.

The model applied for variance analyses explained from 69 to 97 % of the total variance recorded (R^2).Including interaction between cycle and system as a variate factor did not increase R^2 significantly and was therefore omitted from the model.

Another technician scored the hens' plumage in the fourth cycle than in the three foregoing and the scoring was done at 10 weeks older birds. The scores, which were generally low in cycle four, may have become biased compared to earlier evaluations. Analysing plumage score within cycle four confirms, however, the general tendency toward poorer feathering on hens in aviaries than in cages. In the same cycle the food consumption increased both in cages and aviaries, which can be explained by higher egg production, poorer plumage (Leeson & Morrison, 1978; Tauson & Svensson, 1980), but also partly by a colder environment, due to an extremely cold winter during that cycle in combination with a 25% decrease in the total number of hens in the layer house (one aviary in the layer house was empty).

The food consumption was not adjusted for the presence of cockerels. A cock of breed N41 has been recorded to eat somewhat less than a productive N41 hen (Kathle & Nordli, 1992). The extra food consumed by the cockerels is calculated to be 0.8 g per hen and day with the low cock density (1:130) and 3.5 g per hen and day with a density of 1: 30. The adjusted food consumption in the aviaries in the fourth cycle increased with 2.12 g per hen and day compared to the first three cycles without cockerels. Consequently, the adjusted FCR becomes 2.29 in M and 2.33 in V, which are very similar to earlier results (Table 1). Differences in FCR between C and M, and C and V in the fourth cycle compared to earlier cycles are then reduced from -0.13 to -0.02 (M) and from -018 to -0.06 (V). In the last cycle after adjusting for the cockerels, only C showed any significant increase in FCR. The results in Table 2 are not adjusted for the food consumption of cockerels, but still support that cockerels contributed significantly to the variation in FCR, which, however, could be a secondary effect of increased egg production in M and V relative to C.

Fertile eggs in Norway have the same market value as infertile eggs and are not considered to be inferior by consumers. A high percentage of fertile eggs indicates a cock dominance (Ylander & Craig, 1980; Duncan et al., 1990). In the present study about 50 % of all eggs was fertile when the male density was 1: 130. Every second hen then has to be mated at least once a week or each cock has to mate minimum nine hens a day. In the flocks with high cock density (30 hens per cock) the average cock has to mate at least five times (hens) a day. This is comparable to the results of Craig et al. (1977) who reported an average of about 5 matings per cock in pens with 24 hens per male. High ranked cockerels had more interrupted matings than low ranked, seldom because of interaction by other males, but due to low self-motivation. No observation of agonistic behaviour between males was recorded which indicate that even in compartments with high cock density there were enough hens (or room) available for all cockerels. The high mating activity and the observations of more crows by high ranked cockerels support earlier reports of mating and crowing as indicators of dominance (Guhl et al. 1945; Ylander & Craig, 1980). Even the light cock breed Jærhøns dominated the hens very well by their mating and crowing behaviour.

Hens are generally attracted towards cockerels (Wood-Gush, 1958) while cockerels are active in selecting nest places for the hens (McBride et al. 1969). The higher concentration of cockerels in front of the nests around laying time might

have led to higher frequency of nest laying in spite of many small compartments in the fourth cycle. A high density of cockerels also seems to be favourable for the frequency of nest eggs in the early laying period.

The two breeds of cockerels tested did not seem to differ in their impact on the hens in spite of Jærhøns' very small size. However, differences between breeds in hens' behaviour in aviary systems have been reported (Abrahamsson & Tauson, 1995). One might expect differences in male behaviour between breeds as well , which should be tested in order to choose the best fitted cockerels for alternative systems. Cockerels of Jærhøns received less pecks from hens than the bigger N41-cocks which was expected to dominate the hens more. This is, however, in contrast to the plumage records, but in accordance with the observation of more pecks at high ranked cockerels in the present study which might be a part of the hens' courtiers towards cockerels. No observation was recorded of any pecking by cockerels at hens.

It is quite possible to include cockerels in aviaries without serious drawbacks and our results indicate higher egg production, increased number of nest eggs and reduced vent pecking. However, to keep cockerels in alternative systems like modified cages with small flocks of 5-6 hens (Appleby et al., 1993) would be expensive due to the considerable number of cockerels then needed and the extra food they would consume.

A possible strategy to obtain a more successful and economical egg production in alternative systems is to combine improvement of the environment with selection for relevant behaviour traits (Hansen, 1976; Gerken & Petersen, 1987; Flock 1994, Craig & Muir, 1996) including further genetic and ethological studies of hens' and cockerels' behaviour in general and in interaction.

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Thinning apples and pears in a nordic climate I. The effect of NAA, ethephon and lime sulfur on fruit set, yield and return bloom of four pear cultivars

MEKJELL MELAND AND BRITA GJERDE
The Norwegian Crop Research Institute,Ullensvang Research Centre,
Lofthus, Norway

Meland, M. & B. Gjerde 1996. Thinning apples and pears in a nordic climate. I.The effect of NAA, ethephon and lime sulfur on fruit set, yield and return bloom of 4 pear cultivars. Norwegian Journal of Agricultural Sciences 10:437-452. ISSN 0801-5341.

A field experiment examined the effect of using naphthalene acetic acid (NAA), lime sulfur and ethephon to thin four pear cultivars. NAA at three concentrations; 10, 20 and 30 mg/l and 5 % lime sulfur with or without the addition of 150 mg/l ethephon were applied at petal fall and full bloom to the same trees for a period of three years, respectively. The effects of NAA were largely additive; fruit set ,yield and fruit number decreased with increasing concentration. Neither thinning nor return bloom were promoted of a low dosage of ethephon. All cultivars, except 'Amanlis', became biennial during the experiment. At heavy bloom density 10 mg/l NAA thinned 'Amanlis', 20 mg/l 'Keiserinne' and 'Moltke' and 20 -30 mg/l 'Clara Frijs' adequately. Lime sulfur produced some thinning on 'Amanlis' and 'Moltke'. The thinning had little impact on return bloom. Minor phytotoxic symptoms of the highest concentrations of NAA were observed.

Key words: Thinning, NAA, ethephon, lime sulfur, yield, fruit size, yield efficiency, return bloom, *Pyrus communis L.*

Mekjell Meland, Norwegian Crop Research Institute, Ullensvang Research Center, N-5774 Lofthus, Norway

The Norwegian pear industry is located to the fjord district of western Norway. Due to the Gulf stream, the winter climate is mild and the pear trees rarely suffer from any winterfrost. The cultivars grown are old, vigorous and adapted to Norwegian growing conditions.

Biennial bearing is a major problem in the pear industry. Due to overcropping in the 'on-year', fruit size and quality are reduced. The trees will likely move into a pattern with high and low yield every second year. This inconsistant yield pattern provides problems both for the growers and the market.

The main horticultural control of biennial bearing is reneweal pruning, growth control and thinning. In Norway, thinning of flowers or fruitlets in pears is not a common horticultural practice. In apples, however, chemical fruit thinning is a standard procedure to improve fruit size, increase return bloom and promote regular bearing like elsewhere in apple producing countries (Jonker 1979, Looney 1993). For apples literature on crop

adjustment is volumnious, while only few papers are dealing with the thinning of pears.

The thinner naphthalenacetic acid (NAA) is widely used in the apple industry around the world. Thinning results with NAA are often variable and is seriously influenced by spray volume, weather around application time and additives. Both concentration and timing also have a major impact on the thinning results in apples (Jones et al.1992; Williams and Edgerton 1981).

In Europe, ethephon is used as a flower thinner for biennial-bearing apple trees. In general it is not considered useful due to the risk of overthinning (Jonkers 1979). In Tasmania many studies were conducted with ethephon, dealing with timing and concentration before and after bloom, but also developing models for predicting of thinning effects (Koen & Jones 1985; Jones et al. 1983, 1989, 1990). Positive results have been obtained with ethephon as a flower promoter (Buban et al. 1976; Patzold et al. 1981, 1983).

Only few reports are published on the combined use of NAA and ethephon as thinners. Kongsrud (1991) thinned the apple cultivar 'Summerred' with a mixture of ethephon and NAA, and found the effect of NAA reduced. In Tasmania Jones et al.(1994) found no advantage in adding NAA to ethephon to thin the apple cultivar 'Golden Delicious' at full bloom. Katzfuss & Schmidt (1986), however, reported thinning effect with a single spray of ethephon and NAA.

The thinning agent lime sulfur has a caustic effect on the flowers and is mainly used at full bloom on plums (Kvåle & Ystaas 1969). Lime sulfur applied at full bloom produced some thinning on the apple cultivar 'Summerred' (Grauslund 1992).

Øhlers (1966) thinned many pear cultivars with NAA after bloom. He found differences in thinning sensivity between cultivars. Higher concentration of NAA caused phytotoxic symptoms on the leaves.

The main purpose of this investigation was to examine the thinning effects of combining ethephon with lime sulfur and different concentrations of NAA to reduce fruit set and increase return bloom.

Materials and methods

One field trial with the four pear cultivars 'Keiserinne', 'Clara Frijs', 'Amanlis' and 'Moltke' was conducted in the experimental orchard of Ullensvang Research Centre, Lofthus at 60° North over the years 1990-1993.

The experiment was carried out on mature trees, all grafted on seedling rootstock and planted in 1980. The trees were trained as free spindle and kept at about 2.5 m of height by pruning and spaced 3x5 m. The soil was a loamy sand with about 4 % organic matter. Soil management combined frequently mown grass in the alleyways with 1 m wide herbicide strips along the tree rows. Irrigation was not provided. Fertilizer application was monitored by chemical soil analysis.

The experimental design was randomized blocks with four replicates for all cultivars except 'Clara Frijs' with three replicates. Unsprayed control trees were compared with trees sprayed with NAA at 10, 20 or 30 mg/litre, 5 % lime sulfur, and with and without 150 mg/litre ethephon as a tank mix. All sprays were applied to run off (about 2000 litres/ha) with a hand gun sprayer. The lime sulfur was applied at full bloom and NAA at petal fall during three years (Table 1). The experiment was repeated for 3 years using

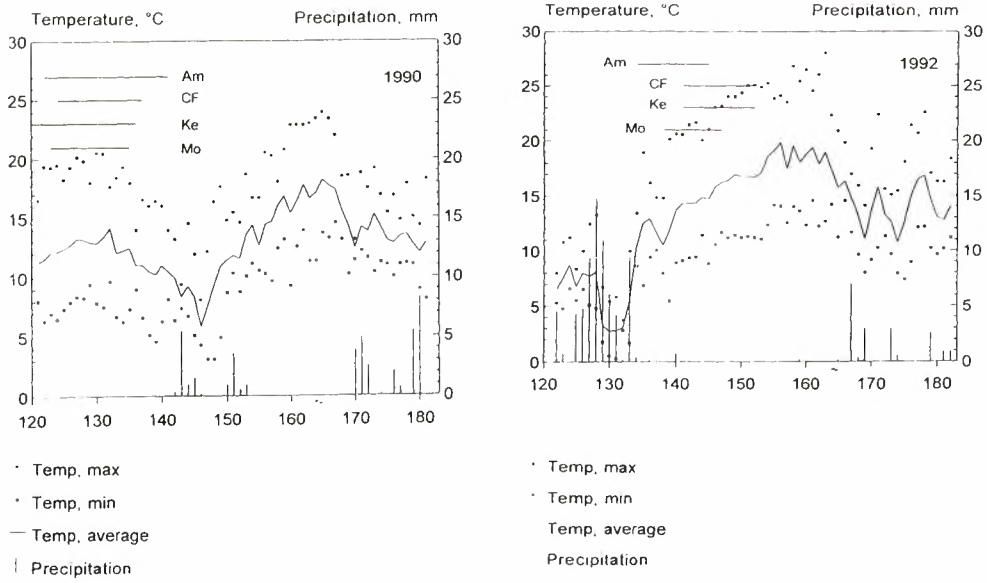


Fig. 1. Daily maximum, average and minimum temperature and precipitation in May and June (Julian day) in the years 1990, 1991 and 1992. Bloom period for the four cultivars 'Amanlis' (Am), 'Clara Frijs' (CF), 'Keiserinne' (Ke) and 'Moltke' (Mo).

the same treatments on the same trees.

Total flowering and non-flowering spurs were counted each year at pink bud on whole trees. The fruits on each tree were harvested at commercial harvest time (Table 2), counted and weighed. The fruit characteristics will be discussed in another paper (Meland & Gjerde 1996).

Trunk circumference was measured each year following leaf drop at 25 cm above the graft union, and the trunk cross-sectional areas (TSCA) calculated. Fruit set was expressed in terms of numbers of fruits/100 flower clusters (bloom density) and numbers/cm^2 TCSA (tree size).

All data were subjected to analysis of variance using the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) program package (SAS Institute Cary, N.C., USA). Fitted regression lines are used in the Figures. Average of measured values and their variation are not shown due to many observations.

Results

Main effects on productivity, bloom and harvest

Flowering of the trees of all 4 cultivars during the experiment was uniform. The average number of flower clusters per tree of the the four cultivars 'Keiserinne', 'Clara Frijs', 'Amanlis' and' Moltke' were 238, 231, 221 and 374, respectively. Percent bloom is a measure of inflorescence as related to the total growing points of the whole plant. There was no significant difference between the trees in percent bloom. The percentage was 45, 42, 52 and 67 for the four cultivars, respectively.

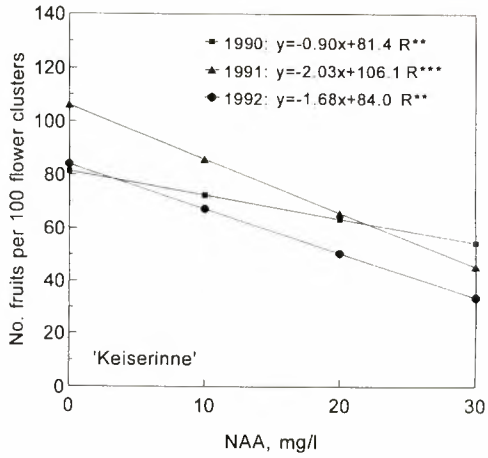
In 1990 the pear trees bloomed early (Fig. 1) and the thinning applications were conducted May 5 and 10 for lime sulfur, ethephon and NAA, respectively. The maximum temperature was around 20°C at the applications dates. The bloom period was short. The following years, 1991 and 1992, the trees bloomed in the second half of May. The maximum temperature was 23°C in 1991 and 25°C in 1992 when the NAA application was made. The spraying conditions should therefore be favourable.

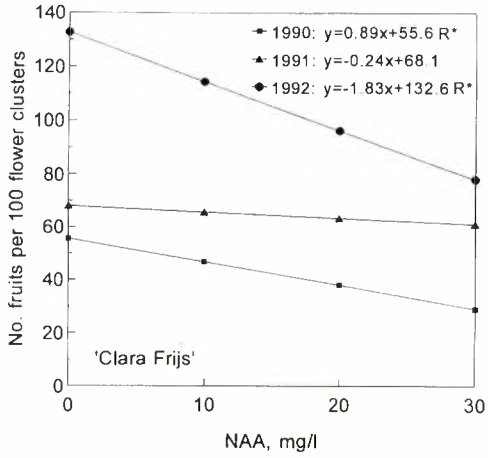
As no significant interaction between the thinning chemicals were found, the effects of NAA, ethephon and lime sulfur will be discussed separately.

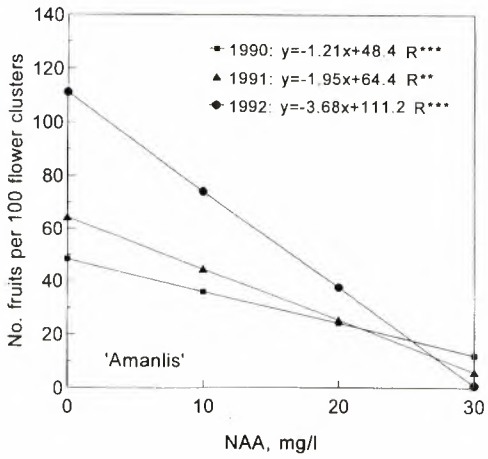
The cultivar 'Keiserinne' was picked during the last half of August all three years. The other cultivars were harvested during the first half of September the first two years and at the end of August the third year (Table 2).

NAA

The fruit set and number of fruits per tree were reduced significantly and linearly in response to increased concentration of NAA, except for 'Clara Frijs' in 1991.







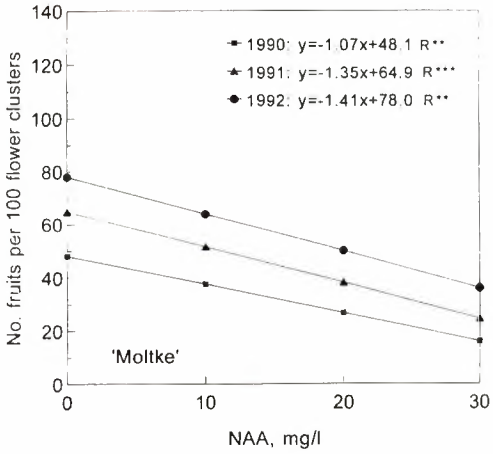


Fig. 2. Effects of different thinning concentrations (0, 10, 20 and 30 mg/l) of NAA on fruit set (number of fruits per 100 flower clusters) of the four pear cultivars 'Keiserinne', 'Clara Frijs', 'Amanlis' and 'Moltke' in 3 years.

Fruit set differed between years and between cultivars (Fig. 2). Unthinned fruit set differed from 50 to 110 fruits per 100 hundred flower cluster for 'Amanlis' and from 55 to 132 for 'Clara Frijs'. The fruit set was lowest in 1990 and highest in 1992 for all cultivars with an intermediate value in 1991, except for 'Keiserinne' which showed minor differences between years.

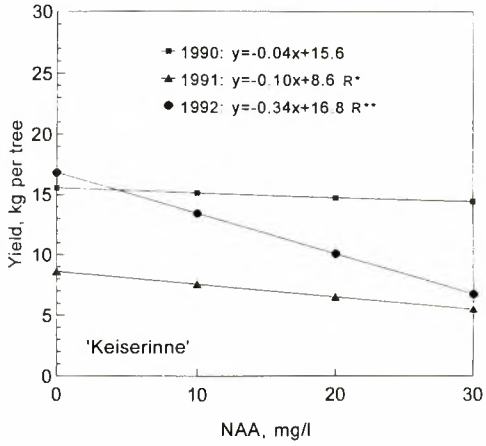
The data for yield per tree confirmed the fruit set. Fruit load at harvest decreased significantly and linearly with increasing concentration of NAA except for 'Keiserinne' in 1990, 'Clara Frijs' in 1990 and 1992 and 'Moltke' in 1991 (Fig. 3). 'Clara Frijs' had a light total yield in 1991 with only 3 kg/tree on the control trees. The yield in the second year was lower than the first and third year for 'Keiserinne' too. The thinning response of increasing concentration of NAA was strongest for 'Amanlis' and the pattern was the same during three years. Fruit number was reduced significantly with increasing concentration of the thinner for all cultivars except 'Clara Frijs' (Tables 3, 4, 5 and 6). The reaction was even stronger for 'Amanlis' where the yield and fruit number became reduced to 1/3 when the concentration was raised from 10 to 20 mg/l, and caused overthinning. 'Moltke' was also tolerant to the thinner, but the highest concentration reduced the fruit number to half of the control. Small phytotoxic symptoms on the pear leaves were observed of the highest concentration of NAA.

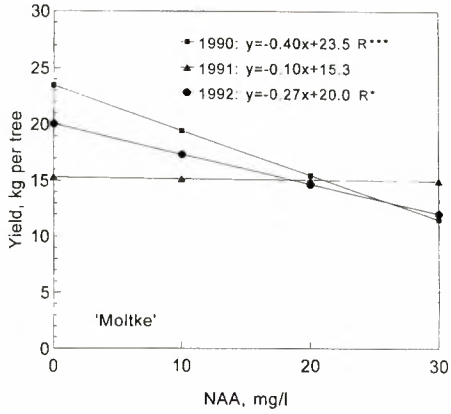
Obviously the efficiency expressed as number of fruit/cm^2 TCSA decreased in accordance with the thinning effects and confirmed the fruit set, yield and fruit number results. 'Moltke' showed the highest yield efficiency and 'Amanlis' the lowest.

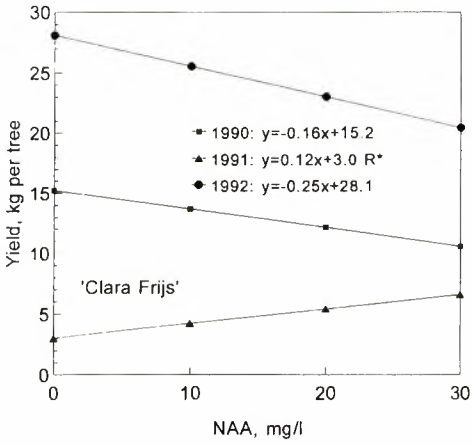
The number flower clusters per tree the year after application was positively correlated to increased NAA concentration, but not significant for any of the cultivars on the average for the three thinning years. The cultivars reacted, however, differently in individual years (Fig. 4). For 'Moltke' return bloom increased significantly with increased thinning effect the year before in 1991 and 1993. Similar results was found for 'Keiserinne' in 1993 and 'Clara Frijs' in 1991. 'Amanlis' showed no sign to promoted return bloom even after strong thinning effect the year before.

Ethephon

Adding ethephon to NAA and lime sulfur had no thinning effect except for 'Moltke'. When 150 mg/liter ethephon was added to NAA at all levels, the thinning was increased significantly only for 'Moltke', reducing the yield and fruit number. Adding ethephon in the same tank mix did not influence return bloom significantly.







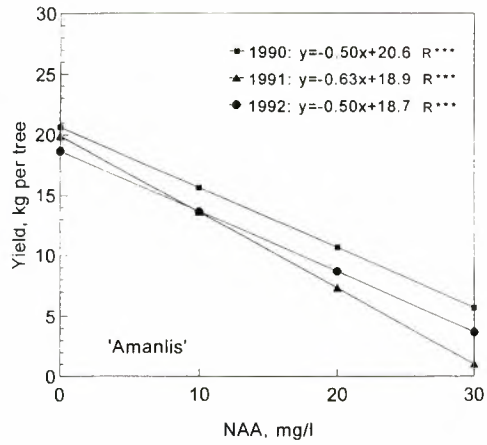


Fig. 3. Effects of different thinning concentrations (0, 10, 20 and 30 mg/l) of NAA on yield (kg/tree) of the four pear cultivars 'Keiserinne', 'Clara Frijs', 'Amanlis' and 'Moltke' in 3 years.

Lime sulfur

Lime sulfur thinned 'Amanlis' and 'Moltke' significantly. The yield reduction was 44 % and 42 % and the fruit number reduction 66% and 42 % for the two cultivars, respectively. Return bloom was not affected by this thinner.

Effects on individual cultivars

'KEISERINNE'

The harvest date for this cultivar is normally the end of August (Table 2). Fruit set was reduced linearly and significantly with increasing NAA concentration; 30 mg/l reduced the fruit set to about the half of the control trees. The yield pattern reacted similary, except in 1990 when the thinning did not produce any significant yield reduction. The thinning was conducted right before petal fall that year. The timing might have influenced the results. The biennial pattern

Table 1. Dates of thinning applications of four pear cultivars in three years

Cultivar	Chemical	Year		
		1990	1991	1992
'Keiserinne'	NAA, ethephon	May 10	May 29	June 1
	Lime sulfur, ethephon	May 05	May 15	May 29
'Clara Frijs'	NAA, ethephon	May 11	May 29	June 1
	Lime sulfur,ethephon	May 05	May 15	May 29
'Amanlis'	NAA, ethephon	May 10	May 29	June 1
	Lime sulfur,ethephon	May 05	May 15	May 29
'Moltke'	NAA, ethephon	May 05	May 29	June 1
	Lime sulfur,ethephon	May 07	May 15	May 29

Table 2. Dates of harvest for four pear cultivars in three years

Cultivar	Year		
	1990	1991	1992
'Keiserinne'	August 21	August 29	August 18
'Clara Frijs'	September 10	September 16	August 27
'Amanlis'	September 11	September 17	September 1
'Moltke'	September 5	September 17.	August 26

was strong. Both bloom number and total yield per tree were reduced to the half the intermediate year. This pattern is well illustrated in Fig. 4. The number of flower clusters per tree after a light yield are tripled compared to the year after. The return bloom was significantly increased in 1993, the year after the strongest thinning effect.

Lime sulfur or adding ethephon had no thinning or any effect on number of return bloom.

'CLARA FRIJS'

Over the concentration range used, NAA consistently reduced fruit set, fruit number and yield. The tendency to alternate bearing was strong. Number flower clusters the second year (data not shown) were less than 1/3 of the year before. The variation in fruit set between years was also striking (Fig. 2). The yield both in 1990 and 1992 was too heavy to promote an adequate amount of return bloom. Neither lime sulfur nor ethephon had any thinning effect.

'AMANLIS'

This cultivar was the most sensitive to increased NAA concentration. Both fruit set and yield were significant reduced every year, but return bloom was unaffected. Even the strongest thinning, which in fact was overthinning, did not have any positive effect on the amount of bloom the year after. NAA concentrations

Table 3. Effects of NAA, ethephon and lime sulfur applications on flowering, fruit set, yield, fruit number and return bloom of 'Keiserinne' pear trees. Average of three cropping years.

Treatment (mg·liter^{-1})		No. flower clusters per tree	Percent bloom	No. fruits per 100 flower clusters	Yield, kg per tree	No. fruits per tree	No. fruits per cm^2 TCSA[1]	Return bloom No. flower clusters per tree
NAA	**ethephon**							
0	0	243	32	88	13.2	199	3.74	110
10	0	255	52	69	10.8	163	3.41	163
20	0	246	46	73	12.9	169	2.69	161
30	0	251	45	35	5.6	73	1.60	190
0	150	221	40	87	12.7	173	3.22	211
10	150	265	55	80	13.5	203	4.75	183
20	150	241	43	62	11.6	150	2.32	191
30	150	245	50	44	10.0	115	2.07	207
Lime sulfur	**ethephon**							
5%	0	187	43	81	10.4	166	2.96	161
5%	150	200	35	78	10.6	152	2.26	106
Significance								
NAA		NS	NS	***	* *	* * *	* * *	NS
ethephon		NS	NS	NS	NS	NS	NS	NS
lime sulfur		NS	NS	NS	NS	NS	NS	NS

[1]TCSA = trunk cross sectional area
*,**,***,NSMain effects within columns significant at P = 0.05, 0.01 or 0.001 or nonsignificant, respectively

Table 4. Effects of NAA, ethephon and lime sulfur applications on flowering, fruit set, yield, fruit number and return bloom of 'Clara Frijs' pear trees. Average of three cropping years.

Treatment (mg·liter^{-1})		No. flower clusters per tree	Percent bloom	No. fruits per 100 flower clusters	Yield, kg per tree	No. fruits per tree	No. fruits per cm^2 TCSA[1]	Return bloom No. flower clusters per tree
NAA	**ethephon**							
0	0	240	49	72	15.0	160	3.66	60
10	0	186	38	68	10.3	96	2,64	97
20	0	212	39	80	16.6	169	3.21	74
30	0	250	41	54	12.0	123	2.43	131
0	150	182	35	80	12.9	138	4.24	92
10	150	290	43	93	19.7	242	4.98	64
20	150	224	40	76	15.2	149	3.49	125
30	150	266	41	49	12.3	118	2.43	152
Lime sulfur	**ethephon**							
5%	0	232	42	40	11.7	114	2.96	105
5%	150	243	57	50	9.4	95	3.65	57
Significance								
NAA		NS	NS	NS	NS	NS	*	NS
ethephon		NS	NS	NS	NS	NS	*	NS
lime sulfur		NS	NS	*	NS	NS	NS	NS

[1]TCSA = trunk cross sectional area
*,**,***,NSMain effects within columns significant at P = 0.05, 0.01 or 0.001 or nonsignificant, respectively

Table 5. Effects of NAA, ethephon and lime sulfur applications on flowering, fruit set, yield, fruit number and return bloom of Amanlis pear trees. Average of three cropping years.

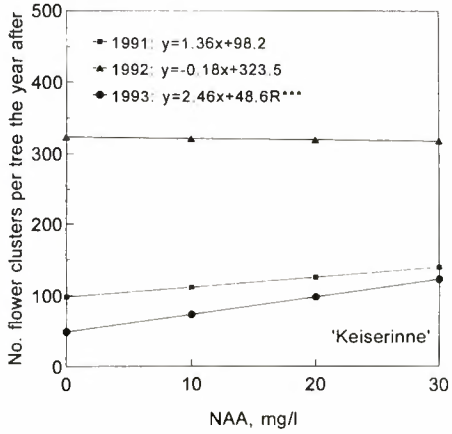
Treatment (mg·liter^{-1})		No. flower clusters per tree	Percent bloom	No. fruits per 100 flower clusters	Yield, kg per tree	No. fruits per tree	No. fruits per cm^2 TCSA[1]	Return bloom No. flower clusters per tree
NAA	**ethephon**							
0	0	218	65	68	17.9	142	1.70	127
10	0	243	56	49	17.2	120	1.48	209
20	0	197	45	21	5.6	42	0.83	136
30	0	235	47	14	4.8	33	0.48	209
0	150	265	56	60	21.2	159	2.40	174
10	150	267	59	35	13.6	94	1.52	182
20	150	211	57	17	4.9	35	0.40	141
30	150	232	49	15	5.4	34	0.51	153
Lime sulfur	**ethephon**							
5%	0	162	47	30	6.1	48	0.76	134
5%	150	190	44	40	10.1	75	1.19	167
Significance								
NAA		NS	NS	***	* * *	* * *	* * *	NS
ethephon		NS	NS	NS	NS	NS	NS	NS
lime sulfur		NS	NS	**	* * *	* * *	* *	NS

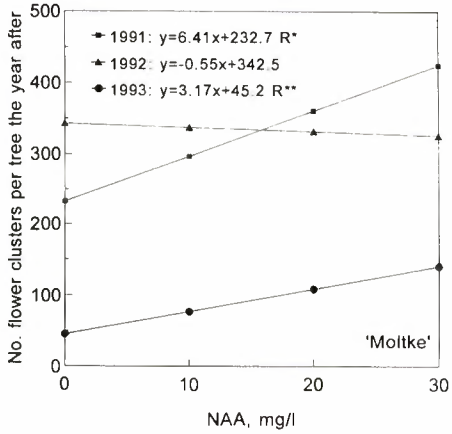
[1]TCSA = trunk cross sectional area
*,**,***,NSMain effects within columns significant at P = 0.05, 0.01 or 0.001 or nonsignificant, respectively

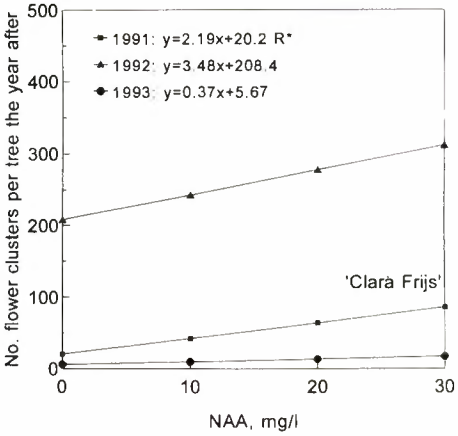
Table 6. Effects of NAA, ethephon and lime sulfur applications om flowering, fruit set, yield, fruit number and return bloom of 'Moltke' pear trees. Average of three cropping years.

Treatment (mg·liter^{-1})		No. flower clusters per tree	Percent bloom	No. fruits per 100 flower clusters	Yield, kg per tree	No. fruits per tree	No. fruits per cm^2 TCSA[1]	Return bloom No. flower clusters per tree
NAA	**ethephon**							
0	0	338	57	75	20.7	229	4.93	177
10	0	361	66	68	21.9	227	5.46	226
20	0	376	60	42	15.5	142	3.47	246
30	0	441	78	30	13.6	115	2.51	292
0	150	390	64	47	16.3	177	3.95	232
10	150	398	68	38	13.9	137	3.93	283
20	150	401	72	42	15.4	138	3.40	260
30	150	390	77	15	8.4	62	1.00	311
Lime sulfur	**ethephon**							
5%	0	329	65	33	12.1	105	2.49	201
5%	150	316	61	50	13.7	150	4.32	156
Significance								
NAA		NS	NS	***	* * *	* * *	* * *	NS
ethephon		NS	NS	**	* *	*	NS	NS
lime sulfur		NS	NS	**	* *	* *	*	NS

[1]TCSA = trunk cross sectional area
*,**,***,NSMain effects within columns significant at P = 0.05, 0.01 or 0.001 or nonsignificant, respectively







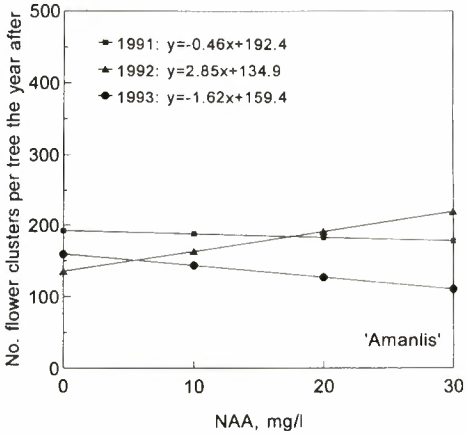


Fig. 4. Effects of different thinning concentrations (0, 10, 20 and 30 mg/l) of NAA on number of flower clusters per tree the year after (return bloom) of the four pear culitivars 'Keiserinne', 'Clara Frijs', 'Amanlis' and Moltke' in 3 years.

20 and 30 mg/l thinned the trees too heavily. Adding ethephon had not any thinning effect. Lime sulfur, however, reduced fruit set and halfed the yield, but did not influence the amount of return bloom.

'MOLTKE'

Fruit set decreased significantly with NAA concentration. Yield per tree showed similar pattern except in 1991 when no yield reduction was registered. When any thinning effect was obtained, return bloom increased significantly. 'Moltke' was the only cultivar which reacted positively with increased thinning effect when with ethephon was added. Lime sulfur significantly reduced fruit set and yield.

Discussion

Natural fruit set and chemical thinning results may be quite variable from year to year. The success of fruit thinning is

affected by several factors like cultivar, tree vigour, foliage condition, pollination and climatic conditions. The application cost of a chemical thinner is generally modest, but the consequences of success or failure can be major (Looney 1986). Temperature is the most important single factor; growth regulator-type thinners will be relatively ineffective at temperatures below 20° C (Forshey 1986). Increasing the concentration will not compensate for low temperature. The thinning effect of apples with 400 mg/l ethephon at petal fall increased linearly from 12° C to 24° C (Jones & Koen 1985). Lime sulfur is more temperature independent. In a nordic climate the temperature during the bloom period and right after is often too low to conduct chemically thinning efficiently; it is important to choose a warm day within the optimal thinning time.

From the results obtained it is evident that NAA is an active thinner of all four cultivars. With the concentrations used, NAA consistently reduced the fruit set, fruit number and yield. The thinning obtained is in accordance with results obtain in apples (Jonkers 1979). The cultivars reacted, however, differently; 'Amanlis' was the most sensitive and 'Clara Frijs' was the more tolerant cultivar. A thinning target proposed for apples is to reduce fruit numbers to 30 - 60 fruits per 100 flower clusters (Jones et al. 1994). In years with heavy bloom, 20 mg/l NAA will thin the cultivars 'Keiserinne' and 'Moltke' to this target under favourable spraying conditions. But the concentration should be reduced when bloom density is less. Under normal circumstances, 10 mg/e NAA will thin 'Amanlis' sufficently, but the concentrations can be raised in case of application at the stage of snowball bloom to 20 mg/l. 'Clara Frijs is difficult to thin, and it is important to evaluate bloom density and bloom strength.

The thinning performance by the addition of 150 mg/l ethephon lacked a positive response, except for 'Moltke'. Both Basak et al (1988) and Katzfuss & Schmidt (1986) found these joint use effective in apples, but Kongsrud (1989) and Jones et al. (1994) did not. The concentration of 150 mg/l ethephon is too low to expect any thinning effect. Kvåle (1977) thinned several apple cultivars adequately with 400 ppm ethephon at early bloom. Return bloom was not promoted by addition of low concentration of ethephon. This result is in contrast to results obtained elsewhere with apples (Buban et al. 1976, Patzold et al. 1981, 1983).

Thinning pears with lime sulfur is not reported, only on plums (Kvåle & Ystaas 1969) and apples (Grauslund 1988). In this study lime sulfur thinned 'Amanlis' and 'Moltke' adequately.

A general aspect of crop regulation is that heavy thinning will result in higher amount of return bloom or number of flower clusters per tree the year after. The four pear cultivars reacted differently. The yield of 'Amanlis' was strongly reduced by thinning, but no significant return bloom registered. On the other side 'Moltke' reacted with increased amount of flowers two out of three thinning years. All cultivars, except 'Amanlis', became biennial during the experiment. This finding support earlier work on apples that thinning earlier than petal fall is necessary to obtain return bloom sufficient for a normal yield (Meland 1992). Further investigatons should explore the effect of thinning earlier than petal fall.

Conclusions

In years with high bloom density thinning with NAA at petal fall 10 mg/l is recommened for 'Amanlis', 20 mg/l for 'Keiserinne' and 'Moltke' and 20-30 mg/l for 'Clara Frijs'. A concentration of 5 % lime sulfur will thin 'Amanlis' and 'Moltke' adequately at full bloom.

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Thinning apples and pears in a Nordic climate II. The effect of NAA, ethephon and lime sulfur on fruit quality of four pear cultivars

MEKJELL MELAND AND BRITA GJERDE
The Norwegian Crop Research Institute,Ullensvang Research Centre,
Lofthus, Norway

Meland, M. & B. Gjerde 1996. Thinning apples and pears in a nordic climate. II. The effect of NAA, ethephon and lime sulfur on fruit quality of four pear cultivars. Norwegian Journal of Agricultural Sciences 10: 453-468. ISSN 0801-5341.

Postbloom sprays of NAA over 3 years thinned 'Keiserinne', 'Amanlis' and 'Moltke', but not 'Clara Frijs' pears. NAA increased fruit size, Grade 1 percentage and soluble solids concentrations. Flesh firmness of 'Keiserinne' and 'Amanlis' was reduced by NAA, but had little impact on the seed number. Lime sulfur applied at full bloom had no benifical effect on pear quality. A low dosage of ethephon in the same tankmix as NAA and lime sulfur did not influence the fruit quality either. It is concluded that the market quality of 'Amanlis' and 'Moltke' pears is questionable.

Key words: Thinning, NAA, ethephon, lime sulfur, fruit quality, fruit size, seed count, soluble solids, flesh firmness, *Pyrus communis L.*

Mekjell Meland, Norwegian Crop Research Institute, Ullensvang Research Centre, N-5774 Lofthus, Norway

Main objectives of crop regulation is to achieve annual yield of high quality fruit. Thinning agents like NAA (1-naphthaleneactic acid) and ethephon reduce fruit set in pears (Kvåle 1982, Knight 1982, 1986, Meheriuk & Looney 1985, Williams & Edgerton 1981 and Øhlers 1966) and lime sulfur in plums (Kvåle & Ystaas 1969). Meland & Gjerde (1996) reported on thinning responses of four pear cultivars. The data reported here evaluate storage and quality responses to thinning of NAA, ethephon and lime sulfur to the four pear cultivars 'Keiserinne', 'Clara Frijs', 'Amanlis' and 'Moltke' in the same experiment.

Materials and methods

A field trial with the four pear cultivars 'Keiserinne', 'Clara Frijs', 'Amanlis' and 'Moltke' was conducted in the experimental orchard of Ullensvang Research Centre, Lofthus, at 60° North, over the years 1990-1993.

The experiment was carried out on mature trees, all grafted on seedling rootstock and planted in 1980. The trees were spaced 3x5 m and trained as free spindle. They were kept at about 2.5 m of height by pruning. The soil was a loamy sand with about a content of 4 % organic matter. Soil management combined

frequently mown grass in the alleyways with 1 m wide herbicide strips along the tree rows. Irrigation was not provided. Fertilizer application was monitored by chemical soil analysis.

The experimental design was randomized blocks with four replicates for all cultivars, except the 'Clara Frijs' cultivar with only three replicates. Unsprayed control trees were compared with trees sprayed with NAA at 10, 20 or 30 mg/litre, 5 % lime sulfur and with and without 150 mg/litre ethephon as a tank mix. All sprays were applied to run off (about 2000 litres/ha) with a hand gun sprayer. The lime sulfur was applied at full bloom and NAA at petal fall. The experiment was repeated for 3 years using the same treatments on the same trees.

The fruits on each tree were harvested at commercial harvest time, counted and weighed. The total yield of each plot and each cultivar was graded into to classes, Grade I marketable fruit according to Norwegian general requirements to quality, packaging and marketing (1986) and lower. Random samples of 10 pears from each plot were kept in cold storage at 0° C and about 90% RH for about 3 weeks ('Keiserinne'), 2 months in 1990, 1 week in 1991 and 2-4 weeks in 1992 for the 3 other cultivars before postharvest evaluations.

Flesh firmness was recorded using a penetrometer (Effegi pressure tester) with an 8 mm diameter tip. Each fruit was sectioned equatorially to count total number of seeds. The content of soluble solids was measured at 20° C by an Abbe digital refractometer.

The meteorological data were obtained from the weather station located at Ullensvang Research Centre.

All data were subjected to analysis of variance using the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS) program package (SAS Institute Cary, N.C., USA). Fitted regression lines are used in the Figures. Average of measured values and their variation are not shown due to many observations.

Results

Main effects on post harvest quality

NAA

The thinning response to NAA was linear with increasing concentration (Tables 1-4). Excessive thinning occurred at the highest concentration. The fruit weight increased with reduced fruit load and number of fruits per tree. For all cultivars the fruit weight increased linearly with NAA concentration the first cropping year in 1990 (Fig. 1). The intermediate year the cultivars 'Keiserinne' and 'Amanlis' only responded significantly, while the cultivar 'Amanlis' reacted positivly with increased fruit weight throughout the experimental period.

The percentage of Grade 1 was raised from untreated to the highest level NAA with 37 %, 0 %, 3 % and 37 % in average for the three years for the cultivars 'Keiserinne', 'Clara Frijs', 'Amanlis' and 'Moltke', respectively. As for the fruit quality, as measured by the content of soluble solids, the thinning degree highly affected the sugar content of the pears. For all cultivars, increasing NAA concentration lowered the yield and raised the soluble solids content for all the cultivars, except for 'Clara Frijs' during these three years.

There was no relationship between seed count and thinning degree except for the cultivar 'Amanlis', where the seed number decreased with increasing fruit size.

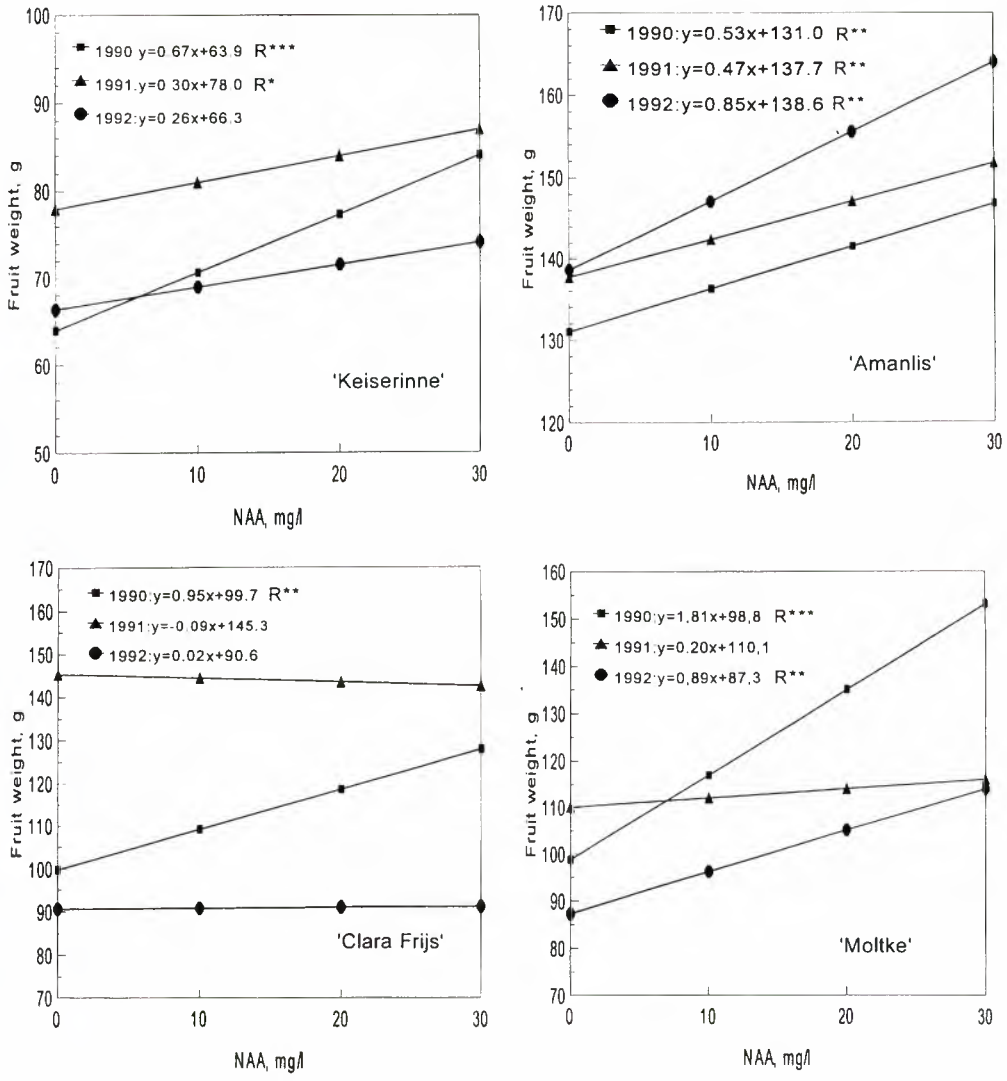


Fig. 1. Effects of different thinning concentrations (0, 10, 20 and 30 mg/l) of NAA on fruit weight of the four pear cultivars 'Keiserinne', Clara Frijs', 'Amanlis' and 'Moltke during 3 years.

For all cultivars except 'Amanlis' flesh firmness was reduced with increasing NAA concentrations.

Ethephon

Adding ethephon to NAA and lime sulfur as a combination had almost no effect on

the fruit quality. Neither seed number, the content of soluble solids nor flesh firmness were affected by the joint use. Only fruit weight of the 'Keiserinne' pears were significantly improved by ethephon without having any effect on reducing the fruit load.

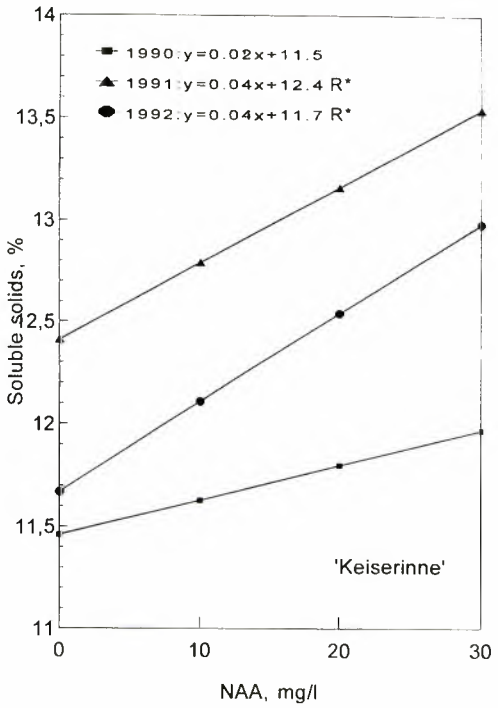
Lime sulfur

Lime sulfur significantly reduced the crop load of the cultivars 'Amanlis' and 'Moltke'; the only quality factor affected was flesh firmness. Lime sulfur treated pears had firmer flesh than the untreated control trees.

Individual effects on the cultivars

'KEISERINNE'

Increasing NAA concentration significantly thinned and increased fruit weight, Grade 1 percentage and the soluble solids concentration the first and third year (Table 1, Fig. 1, 2, 3). Both the seed number and flesh firmness, however, was reduced by NAA application (Fig. 4, 5). Neither ethephon nor lime sulfur had any effect on the fruit quality.

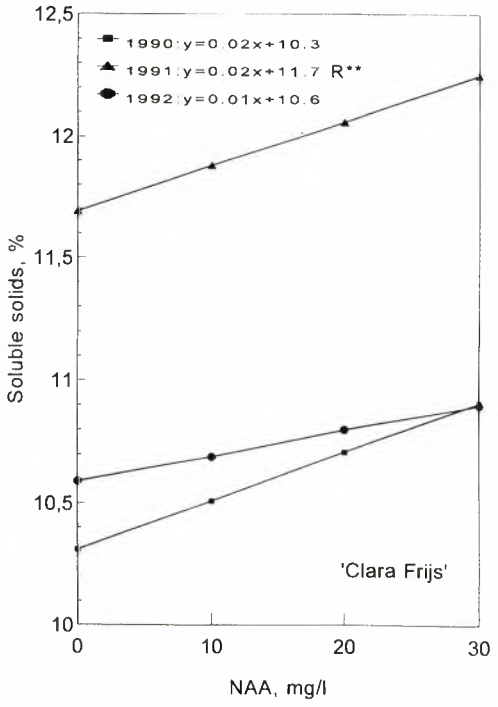


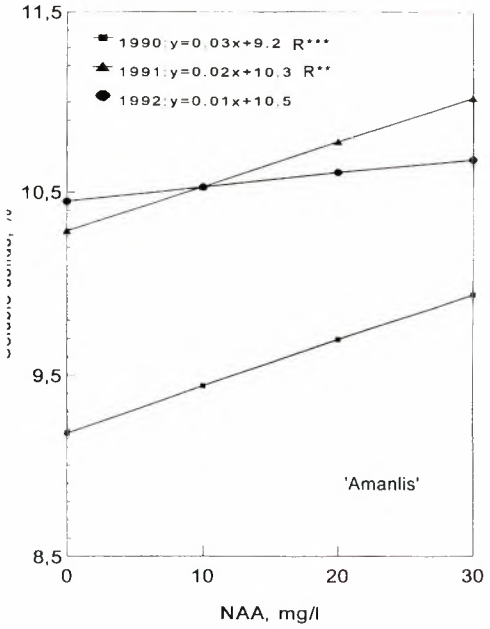
'CLARA FRIJS'

The chemical thinning had little impact on fruit quality (Table 2, Fig. 1-5). Fruit weight and percent soluble solids increased significantly only one year when yield was reduced. Flesh firmness was reduced with increased NAA concentration. Lime sulfur and ethephon had not any influence on fruit quality.

'AMANLIS'.

The thinning response was strong with significant relationship between reduced crop load and increased fruit quality (Table 3). Increasing NAA concentration increased fruit weight, soluble solids and flesh firmness, but seed number was





reduced (Fig. 1-5). Grade I percentage was high and independent of degree of thinning. Lime sulfur reduced the fruit number. Fruit quality was apparently not improved, but did not meet the demand of significance. Ethephon had no influence on the quality parameters.

'MOLTKE'

Increasing NAA concentration improved fruit quality significantly; increased fruit size, higher content of soluble solids and Grade I percentage (Table 4). In years of normal crop load, the trees responded in the same way, in contrast to the intermediate year with less crop load (Fig.1-3). Seed number and flesh firmness were not significantly affected by thinning (Fig.4,5). Neither ethephon nor lime sulfur had any influence on the fruit quality, except for higher flesh firmness on the fruits treated with lime sulfur.

Discussion

Like apples, the pears have the same tendency to set more fruit than the trees can mature to commercial size with acceptable fruit quality. A chemical thinning agent is the most cost-effective bioregulator a fruit grower can apply. This cultural management decision, however, is often difficult and unpredictable to make (Miller 1988). Thinning pears either chemically or by hand is not a common practise in Norwegian orchards. Both yields and quality vary from year to year. In order to maintain an accceptable annual fruit quality, crop adjustment is necessary.

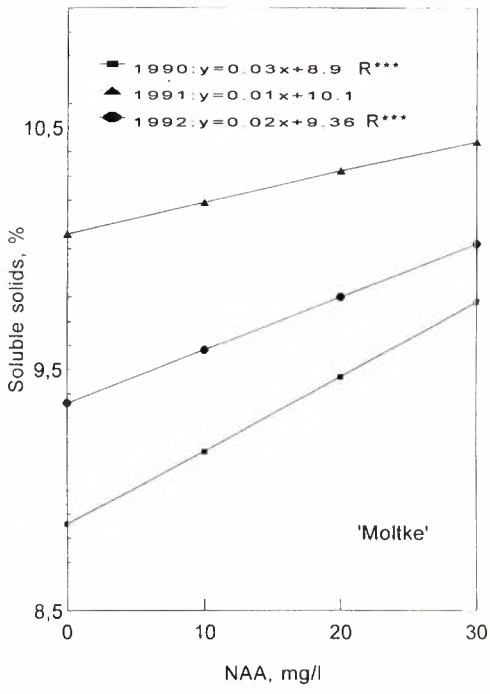


Fig. 2. Effects of different thinning concentrations (0, 10, 20 and 30 mg/l) of NAA on percent soluble solids of the four pear cultivars 'Keiserinne', 'Clara Frijs', 'Amanlis' and 'Moltke' during 3 years.

Table 1. Effects of NAA, ethephon and lime sulfur applications on fruit characteristics of 'Keiserinne' pear trees. Average of three cropping years.

Treatment (mg·liter^{-1})		No. fruits per tree	Fruit weight, g	Fruits ›45 mm, %	Seed count per fruit	Soluble solids, %	Flesh firmness, kg
NAA	**ethephon**						
0	0	199	72	68	9.3	11.8	5.6
10	0	163	67	77	8.9	12.5	4.9
20	0	169	77	86	9.3	12.0	5.2
30	0	73	78	90	9.0	13.6	4.9
0	150	173	77	77	9.8	12.1	5.3
10	150	203	69	76	9.2	12.5	4.9
20	150	150	80	91	9.2	12.1	4.7
30	150	115	90	95	9.4	12.4	5.0
Lime sulfur	**ethephon**						
5%	0	166	67	65	9.7	12.1	5.6
5%	150	152	74	81	9.3	11.3	5.9
Significance							
NAA		***	***	***	NS	**	*
ethephon		NS	*	NS	NS	NS	NS
lime sulfur		NS	NS	NS	NS	NS	NS

*,**,***,NS Main effects within columns significant at P = 0.05, 0.01 or 0.001 or nonsignificant, respectively

Table 2. Effects of NAA, ethephon and lime sulfur applications on fruit characteristics of 'Clara Frijs' pear trees. Average of three cropping years.

Treatment ($mg \cdot liter^{-1}$)		No. fruit per tree	Fruit weight, g	Fruits ›50 mm, %	Seed count per fruit	Soluble solids, %	Flesh firmness, kg
NAA	**ethephon**						
0	0	160	108	93	8.6	10.7	6.6
10	0	96	118	97	9.8	11.2	5.9
20	0	169	107	96	9.8	10.5	6.0
30	0	123	118	94	9.1	11.4	5.9
0	150	138	113	95	9.5	10.8	6.3
10	150	242	105	92	9.7	10.8	5.8
20	150	149	116	94	9.0	11.2	6.1
30	150	118	123	94	9.5	11.5	5.8
Lime sulfur	**ethephon**						
5%	0	114	105	94	8.8	10.8	6.4
5%	150	95	128	92	9.0	11.5	6.2
Significance							
NAA		* * *	NS	NS	NS	NS	* *
ethephon			NS	NS	NS	NS	NS
lime sulfur		NS	NS	NS	NS	NS	NS

*,**,***,NS Main effects within columns significant at P = 0.05, 0.01 or 0.001 or nonsignificant, respectively

Table 3. Effects of NAA, ethephon and lime sulfur applications on fruit characteristics of 'Amanlis' pear trees. Average of three cropping years.

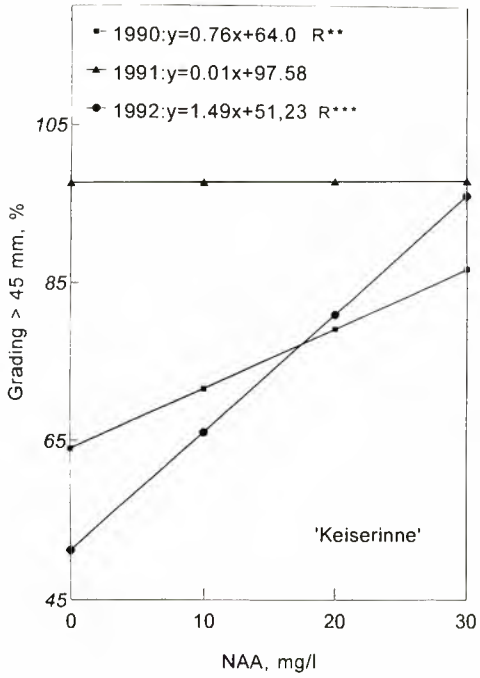
Treatment (mg·liter^{-1})		No. fruit per tree	Fruit weight, g	Fruits ›55 mm, %	Seed count per fruit	Soluble solids, %	Flesh firmness, kg
NAA	**ethephon**						
0	0	142	127	95	7.9	9.9	6.0
10	0	120	143	99	7.0	10.4	5.7
20	0	42	133	98	5.4	10.8	5.9
30	0	33	145	97	6.4	10.2	7.0
0	150	159	133	96	7.6	9.9	6.0
10	150	94	145	99	7.4	10.1	6.1
20	150	35	140	100	6.9	10.6	6.1
30	150	34	159	99	6.5	10.4	6.0
Lime sulfur	**ethephon**						
5%	0	48	127	94	6.7	9.9	7.0
5%	150	75	135	98	7.3	10.0	6.6
Significance							
NAA		* * *	*	* * *	*	*	*
ethephon		NS	NS	* *	NS	NS	NS
lime sulfur		* * *	NS	NS	NS	NS	* * *

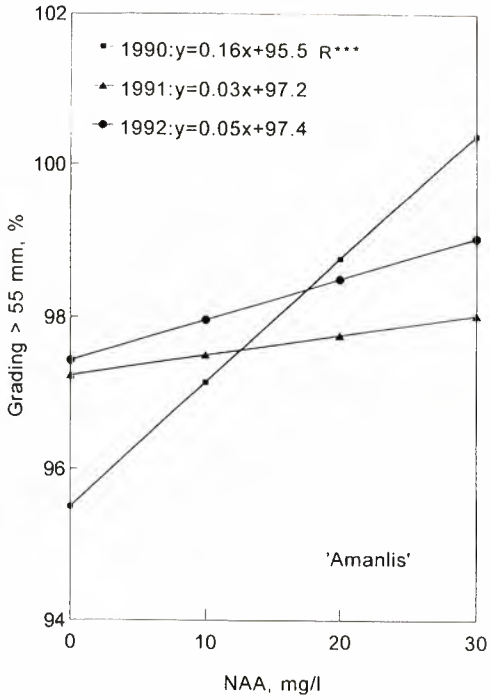
*,**,***,NSMain effects within columns significant at P = 0.05, 0.01 or 0.001 or nonsignificant, respectively

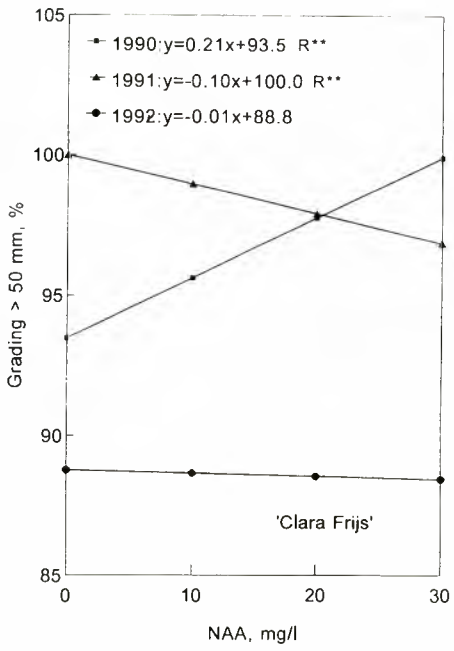
Table 4. Effects of NAA, ethephon and lime sulfur applications on fruit characteristics of 'Moltke' pear trees. Average of three cropping years.

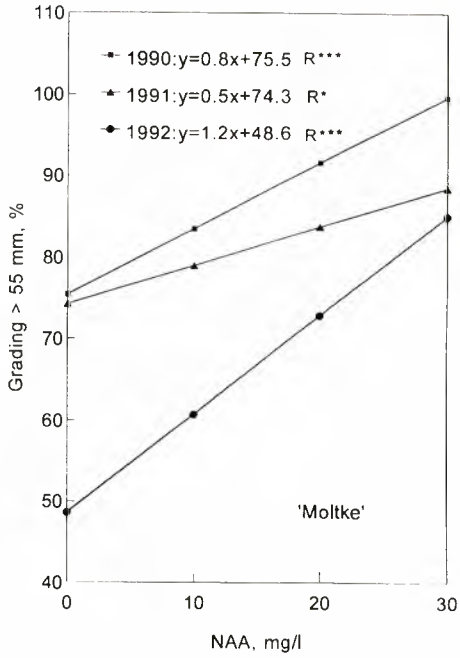
Treatment (mg·liter^{-1})		No. fruit per tree	Fruit weight, g	Fruits ›55 mm, %	Seed count per fruit	Soluble solids, %	Flesh firmness, kg
NAA	**ethephon**						
0	0	229	103	65	7.4	9.5	8.0
10	0	227	100	78	7.7	9.4	7.6
20	0	142	112	83	7.4	9.8	8.1
30	0	115	122	88	7.8	10.1	7.9
0	150	177	93	68	7.7	9.6	8.1
10	150	137	100	69	7.9	9.9	8.4
20	150	138	115	83	7.8	9.7	8.0
30	150	62	147	94	7.9	10.4	7.9
Lime sulfur	**ethephon**						
5%	0	105	115	72	7.7	9.5	8.8
5%	150	150	96	70	7.9	9.3	8.5
Significance							
NAA		* * *	* * *	* * *	NS	* *	NS
ethephon		*	NS	NS	NS	NS	NS
lime sulfur		* *	NS	NS	NS	NS	* *

*,**,***,NSMain effects within columns significant at P = 0.05, 0.01 or 0.001 or nonsignificant, respectively


1990:y=0.76x+64.0 R**
1991:y=0.01x+97.58
1992:y=1.49x+51,23 R***
Grading > 45 mm, %
105
85
65
45
0
10
20
30
NAA, mg/l
'Keiserinne'


1990:y=0.16x+95.5 R***
1991:y=0.03x+97.2
1992:y=0.05x+97.4
Grading > 55 mm, %
102
100
98
96
94
0
10
20
30
NAA, mg/l
'Amanlis'


1990:y=0.21x+93.5 R**
1991:y=-0.10x+100.0 R**
1992:y=-0.01x+88.8
Grading > 50 mm, %
105
100
95
90
85
0
10
20
30
NAA, mg/l
'Clara Frijs'


1990:y=0.8x+75.5 R***
1991:y=0.5x+74.3 R*
1992:y=1.2x+48.6 R***
Grading > 55 mm, %
110
100
90
80
70
60
50
40
0
10
20
30
NAA, mg/l
'Moltke'

In this investigation maximum thinning response was achieved with the highest rate of NAA. Fruit size increased by lowering fruit count and the content of soluble solids of the fruits was raised. These findings are in accordance with the general aspects of apple thinning (Williams & Edgerton 1974); Early removing of excess fruit reduces the competition for metabolites and nutrients.

The main objective of adding ethephon to NAA in the same tankmix was to promote annual bearing. The low dosage applied did not affect fruit quality, which was expected. In apples higher concentrations of ethephon are necessary in order to achieve any thinning effect (Kongsrud 1991, Kvåle 1974, 1977) in a nordic climate. The climatic conditions when ethephon was applied were optimum all three years with temperatures above 20°C. (Meland & Gjerde 1996). The temperature dependence of ethephon which causes variability of response had apparently no influence in this study (Jones & Koen 1983, Knight 1982). In Tasmania ethephon combined with NAA at the same concentrations thinned 'Golden Delicious' apples very effectively (Jones et al. 1994). Fruit firmness was not altered by ethephon application in this experiment. Kvåle (1974) reported advanced maturity of ethephon treatments in apples based of iodine tests, respiration activity and ethylene production of the fruit. In pears there are a year to year variation in fruit firmness in Norway (Kvåle 1986). Consequently this parameter is likely to be less reliable as a maturity index. In this case the low dosage of ethephon had apparantly no influence on the maturity.

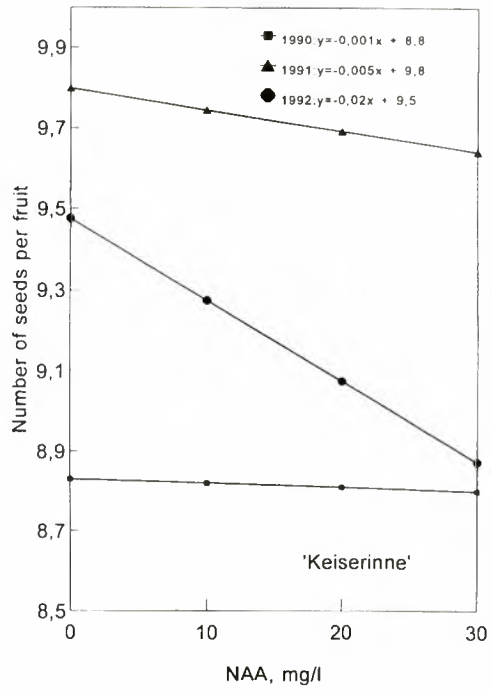
Lime sulfur reduced the crop load of two of the cultivars, but did not influence the quality to any extent. This chemical is recommended to thin plums (Grauslund 1978, Kvåle & Ystaas, 1969). The sensitivity of lime sulfur is variable between plum cultivars. Similar reaction is likely to occur in pears.

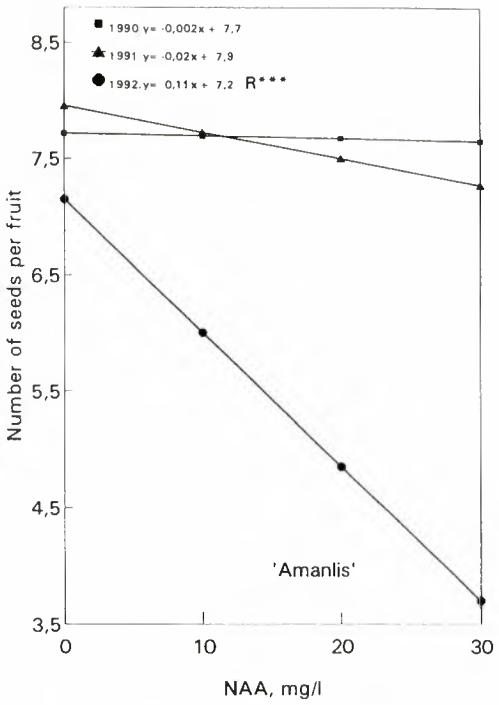
The percentage of Grade 1 affected by NAA thinning became positively improved for the cultivars 'Keiserinne' and 'Moltke', but not for 'Clara Frijs' and 'Amanlis'. The grade out parameter is only based on size. In the pear industry an overall objective of orcharding is to produce high quality pears where both external and internal quality factors are taken into account.

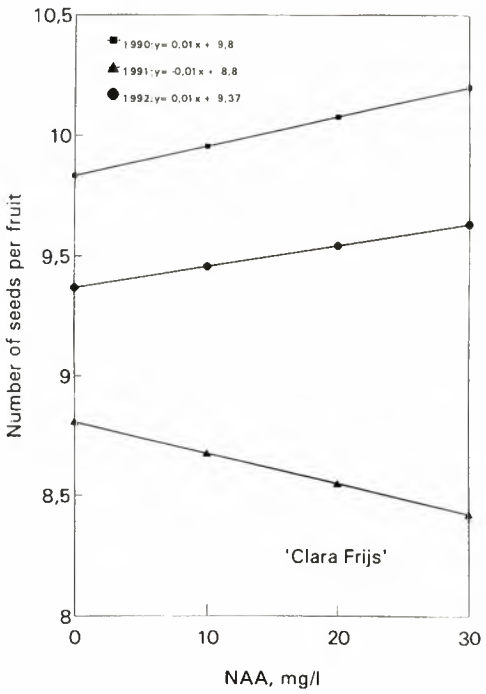
According to Vangdal (1982), flavour quality was strongly correlated with the soluble solids content of the fruit. Pears with soluble solid content above 11.3 % and firmness between 5 and 2 kg had acceptable eating quality. In this study both thinned and unthinned trees of 'Keiserinne' and 'Clara Frijs' passed the minimum quality level; internal quality was improved significanly by thinning (Fig. 2). Flesh firmness was recorded to the upper limit for eating quality for both cultivars.

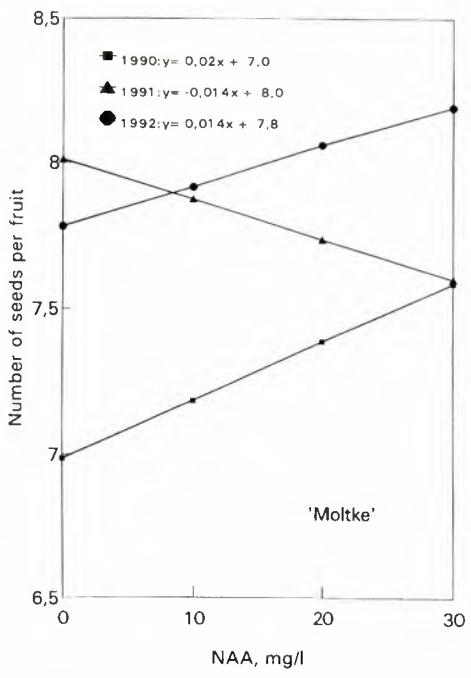
The soluble solids content of 'Amanlis' and 'Moltke' was low and below acceptable quality. This pattern mainly occurs in years with a heavy crop load. Neither low yield nor heavy thinning did bring these two cultivars up to the quality threshold desired. The strongest thinning degree brought the yields of these two cultivars to less than 10000 kg per ha (Meland & Gjerde 1996). Kvåle (1986) found that at the onset of the climateric, the percentage area of starch contents is 35% and 18 % for 'Amanlis' and 'Moltke', respectively. In 1990 the postharvest

Fig. 3. Effects of different thinning concentrations (0, 10, 20, and 30 mg/l) of NAA on percent Grade 1 of the four cultivars 'Keiserinne', 'Clara Frijs', 'Amanlis' and 'Moltke' during three years.


1990 y=-0,001x + 8,8
1991 y=-0,005x + 9,8
1992 y=-0,02x + 9,5
Number of seeds per fruit
9,9
9,7
9,5
9,3
9,1
8,9
8,7
8,5
'Keiserinne'
0
10
20
30
NAA, mg/l


1990 y= -0,002x + 7,7
1991 y= -0,02x + 7,9
1992 y= 0,11x + 7,2 R***
Number of seeds per fruit
8,5
7,5
6,5
5,5
4,5
3,5
'Amanlis'
0
10
20
30
NAA, mg/l


1990 y= 0,01x + 9,8
1991 y= -0,01x + 8,8
1992 y= 0,01x + 9,37
Number of seeds per fruit
10,5
10
9,5
9
8,5
8
'Clara Frijs'
0
10
20
30
NAA, mg/l


1990 y= 0,02x + 7,0
1991 y= -0,014x + 8,0
1992 y= 0,014x + 7,8
Number of seeds per fruit
8,5
8
7,5
7
6,5
'Moltke'
0
10
20
30
NAA, mg/l

quality was registered 2 months after harvest. It is likely that the degradation of the starch content was completed at that stage. The temperature in the growing season (May-September) these three years was 0.2° C below average (12.9° C) the two first years and 13° C the last year. According Kvåle (1977) accumulated heat units (summation of the averages of maximum and minimum temperatures) and number of days from full bloom to the preclimateric stage of development seemed to be a fairly good maturity index. For 'Moltke' pears the averages were 126 days and 1758 degree days. The corresponding heat units for the same years were 1740, 1821 and 1460 degree days.

The soluble solid content for 'Moltke' was highest the intermediate year. But still an accumulation of more heat units than Kvåle (1977) recommended, it appears that the quality was not satisfactory. Nevertheless, the last year 'Moltke' likely became picked slightly too early.

Low content of soluble solids is documented from other studies of mainly 'Moltke' pears, and there is a relative large year to year variation (Ystaas 1971, 1972, 1990, Vangdal & Ystaas 1984). Hjeltnes and Ystaas (1993) regarded the quality of 'Moltke' as acceptable only in October. Based on results from this study and elsewhere, it is questionable if the quality of 'Amanlis' and 'Moltke' is good enough for marketing in the long run due to large quality differences from year to year.

Diploid pear cultivars have a higher seed content than triploids (Frimanslund 1983). The diploid 'Clara Frijs' had higher seed count than the other cultivars which are triploid. The thinning had no influence on the seed count except for 'Amanlis' where increased NAA dosage reduced the number of seeds in the fruits (Fig 4).

Fig. 4. Effects of different thinning concentrations (0, 10, 20, and 30 mg/l) of NAA on seed number per fruit of the four cultivars 'Keiserinne', 'Clara Frijs', 'Amanlis' and 'Moltke' during three years.

Conclusions

Increased NAA concentration improved fruit weight, Grade 1 percentage and soluble solids content of the cultivars 'Keiserinne', 'Amanlis' and 'Moltke'. The quality of 'Clara Frijs' pears was little influenced. The market quality of 'Amanlis' and 'Moltke' is questioned.

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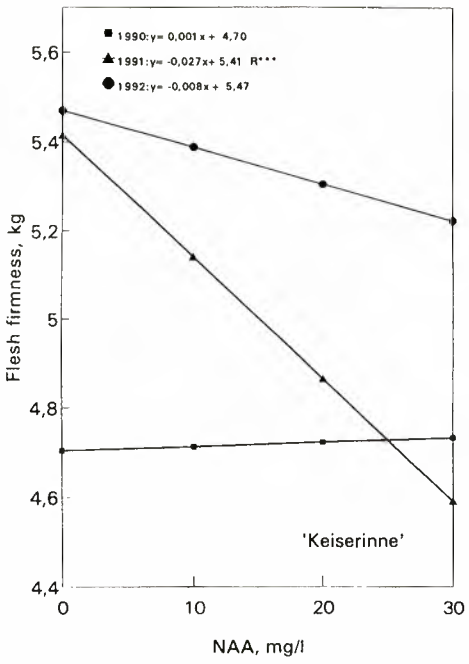
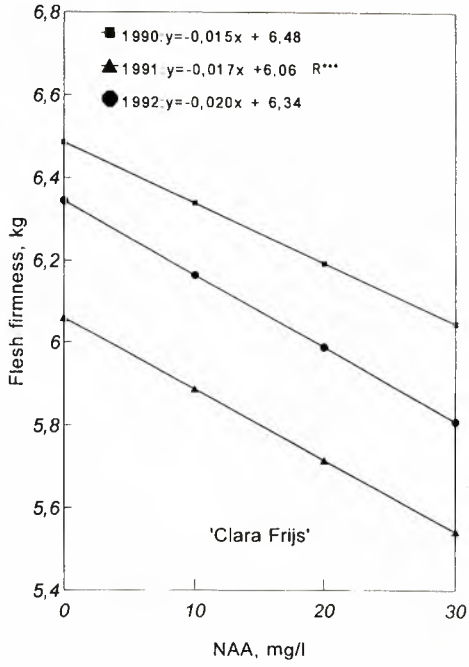
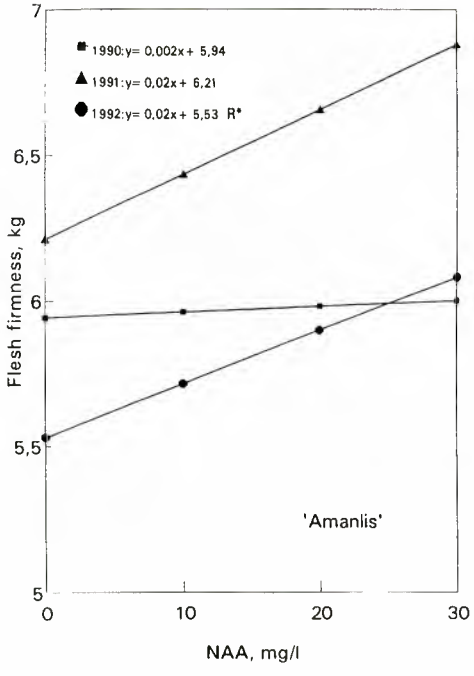

1990: y= 0,001 x + 4,70
1991: y= -0,027x+ 5,41 R***
1992: y= -0,008x + 5,47
'Keiserinne'
Flesh firmness, kg
NAA, mg/l


1990: y=-0,015x + 6,48
1991: y=-0,017x +6,06 R***
1992: y=-0,020x + 6,34
'Clara Frijs'
Flesh firmness, kg
NAA, mg/l


1990: y= 0,002x + 5,94
1991: y= 0,02x + 6,21
1992: y= 0,02x + 5,53 R*
'Amanlis'
Flesh firmness, kg
NAA, mg/l

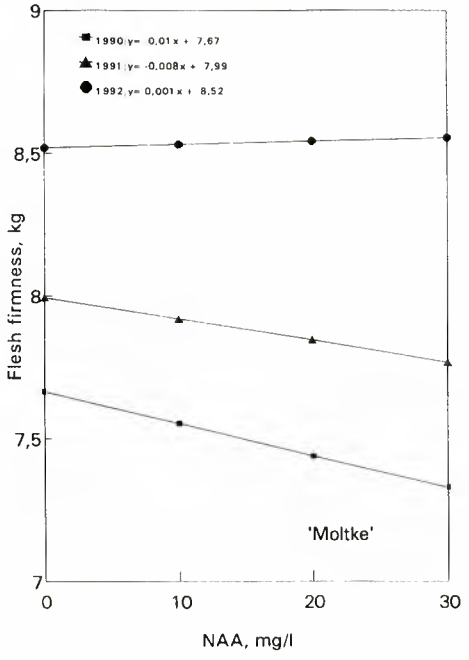

1990: y= 0,01 x + 7,67
1991: y= -0,008x + 7,99
1992: y= 0,001 x + 8,52
'Moltke'
Flesh firmness, kg
NAA, mg/l

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Fig. 5. Effects of different thinning concentrations (0, 10, 20 and 30 mg/l) of NAA on flesh firmness, kg per fruit, of the four cultivars 'Keiserinne', 'Clara Frijs', 'Amanlis' and 'Moltke'.

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The Kvithamar field lysimeter
III. Barley yield and nutrient balance

KRISTEN MYHR[1], TROND K. HARALDSEN[2] & HELGE OSKARSEN[1]
[1]The Norwegian Crop Research Institute,Kvithamar Research Centre, Stjørdal, Norway [2]Jordforsk, Centre for Soil and Environmental Research, Ås, Norway

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Productivity of barley grain, yield quality, nutrient leaching and nutrient balances were investigated at the Kvithamar field lysimeter at Stjørdal, central Norway. The experiment included investigation of the results of autumn and spring ploughing, application of pig slurry in autumn and spring, application of mineral fertilizer, and treatment with no fertilizer, as a control. Averaged for four seasons, ploughing-in of pig slurry in the autumn gave a crop yield of only 57% compared with the same amount of slurry applied in the spring. No significant differences in barley grain yields between autumn and spring ploughing were found. Treatments with pig slurry and mineral NPK fertilizer gave the same yield when the same amounts of mineral N were supplied. Autumn ploughing gave higher N concentrations in the grain and heavier leaching of N compared to spring ploughing. Ploughing-in of pig slurry in the autumn proved to be hazardous with regard to greater losses of plant nutrients to adjacent watercourses. The nutrient balances for N and P were positive in the fertilized treatments, whereas for K, Mg, Ca and S the balances proved to be negative. An annual drainage loss of 40 kg SO_4-S/ha/year is explained by recent draining into a deeper horizon of the marine deposit.

Key words: Barley, field lysimeter, nutrient balances, nutrient leaching, nutrient uptake, pig slurry, yields, yield quality.

Kristen Myhr, Kvithamar Research Centre, N-7500 Stjørdal, Norway

From a farmer's point of view it is convenient to spread animal slurry on the fields after harvest, and to plough it in during the autumn when labour and machinery are usually available. For clay, clay loam and silty clay loam soils autumn ploughing is thought to promote a more suitable soil structure, and thereby to provide possibilities for increased yields. A short growing season, variable climatic conditions in the spring, and limited storage capacity for animal manure are also factors that are conductive to ploughing during the autumn. On the other hand, application of slurry and ploughing during the autumn bring with them the risk of plant nutrient losses, pollution of adjacent watercourses and erosion hazards.

Nutrient balance studies can be used to investigate the sustainability of cropping systems, and how soil productivity is influenced by different treatments. Several nutrient balance studies have been carried out in the Nordic countries (e.g. Uhlen 1978, 1989; Hansen 1990; Uhlen & Tveitnes 1995). A complete nutrient balance study requires measurement of

input and output of all relevant plant nutrients, and information about sorption processes in the soil and immobilization/ mineralization related to organic matter. In most of the published studies fertilizer input, removal of nutrients by plants and leaching have been measured, while gaseous nitrogen losses to the atmosphere have not been measured (Uhlen 1989; Hansen 1990).

The Kvithamar field lysimeter at Stjørdal, central Norway, was established in order to investigate crop productivity, yield quality, nutrient balances and environmental impact in a spring barley monoculture. The experiment included investigation of autumn and spring ploughing, application of pig slurry in autumn and spring, application of mineral fertilizer, and treatment with no fertilizer, as control.

In the present paper we aim to address: The fate of plant nutrients with regard to plant uptake and yield, leaching losses and soil absorptions at different fertilizing regimes and ploughing times.

Materials and methods

The Kvithamar field lysimeter was established in 1989-90 on a gently sloping (1-2%) field, which had been cultivated for 95 years. The main soil type on the experimental site is a poorly drained silty clay loam (Typic Cryaquept), with an average of 6% sand, 62% silt and 32% clay. Loss of ignition in the topsoil was 11.7%. Organic matter content from ignition loss and the average clay content was calculated as (Riley & Eltun 1994) being an average of 7.6%, varying from 4.6% to 11.7%.

Field lysimeter installation, site, soil type and cropping history are described by Myhr et al. (1996). Kvithamar has a humid continental climate with long, cold winters and cool summers. Oskarsen et al. (1996) has reported temperature, precipitation, pipe drainage and surface runoff in millimeters per month for each of the four years of experimentation. Loss of soil, concentrations of plant nutrients in water, and losses of plant nutrients in pipe drainage water and surface runoff are reported in the same paper.

Experimental design

Six treatments for ploughing and fertilizing were defined:

1. Autumn ploughing, pig slurry supplied before ploughing (Ap-ps-bp),
2. Autumn ploughing, pig slurry supplied in the spring (Ap-ps-s),
3. Autumn ploughing, NPK-fertilizer supplied in the spring (Ap-NPK-s),
4. Spring ploughing, pig slurry supplied in the spring (Sp-ps-s),
5. Spring ploughing, NPK-fertilizer supplied in the spring (Sp-NPK-s),
6. Spring ploughing, no plant nutrients supplied (Sp-no nutr.).

Three replications of each treatment were arranged in a randomized block design (Myhr et al. 1996). Each of the 18 plots measured 36 x 8 m. A uniformity trial, when all plots were supplied with equal amounts of mineral fertilizer with NPK dosages as described for the experimental years, was performed in 1990 and has been reported by Myhr et al. (1996). The experimental treatments started after harvest, in the autumn of 1990.

Nutrients supplied

Pig slurry was supplied as 40 tonnes per hectare, each year. The quantities of plant nutrients supplied, based on chemical analyses of the slurry, and declarations of the mineral fertilizers used, are presented in Table 1. Ammonium-N amounted to 64% of the Kjeldahl-N in the pig slurry.

Nutrient exchange with the atmosphere was not studied, and will not be included in the balance accounts.

Table 1. Nutrients supplied in pig slurry and in mineral fertilizer, kg/ha/year

Nutrient	Pig slurry	Mineral fertilizer
Kjeldahl-N in pig slurry [1]	112	0
Fertilizer-N [2]	0	75
Phosphorus	27	27
Potassium	50	50
Calcium	34	29
Magnesium	13	0
Sulphur	6	0

[1] Ammonium-N 64% + 36% organic-N
[2] Ammonium-N 59% + 41% nitrate-N

Crop and growing time

Six-row spring barley ('Bamse' 1990-91 and 'Arve' 1992-94) was used as the experimental crop. The grain was sown simultaneously in all treatments, and harvested at maturity on the same day. The grain yields were adjusted to a water content of 15%. At the foot of Table 2 the actual dates for sowing, and for growing time are listed for the separate years.

Dicotyledonous weeds were controlled each year with appropriate herbicides. Once per season, in 1993 and 1994 scald *(Rhynchosporium secalis)* attacks were controlled with an appropriate fungicide. The barley straw was chopped up and ploughed in on the respective plots, without yield registration.

Chemical analyses

Chemical analyses of soil samples, pig slurry, plant material and of water were conducted according to standard methods, at the laboratory of analytical chemistry, Holt Research Centre, Tromsø.

For nutrient losses in leaching through drain water and surface runoff, the total contents of all elements are used in the estimates of nutrient balances; with the exception of sulphur, where SO_4-S was determined and applied in the balance account.

Statistical methods

The experiment was treated as a random block design in the analysis of variance. The LSD-method was used to determine significant differences between treatments. Level of significance is denoted by * for 95%, ** for 99% and *** for 99.9% probability, and ns for not significant.

Results

Grain yields

Pig slurry ploughed in during the autumn gave a significantly larger grain yield compared with unfertilized plots. On the other hand, application of pig slurry ploughed in during the autumn, gave a significantly much lower yield compared with pig slurry applied in the spring. On spring-ploughed plots, pig slurry gave a significantly larger grain yield than mineral fertilizers. On the autumn-ploughed plots no corresponding difference was observed. No significant overall differences were detected between yields on autumn-ploughed and spring-ploughed plots, when treatments 2 and 3 were compared with treatments 4 and 5.

The interaction between treatment and experimental year was significant ($p<0.05$), due to relatively large grain

Table 2. Grain yields in kg/ha with 15% moisture, in four experimental years (1991-94)

Treat-ment	Experimental years 1991	1992	1993	1994	Average 1991-94
1. Ap-ps-bp [1]	1780	2110	2860	1320	2020
2. Ap-ps-s	3370	3550	3910	3330	3540
3. Ap-NPK-s	2920	3560	4030	3470	3500
4. Sp-ps-s	2860	3850	4470	3150	3580
5. Sp-NPK-s	2700	3580	4030	2760	3270
6. Sp-no nutr.	1080	2080	2110	910	1540
Mean	2450	3120	3570	2490	2910
$LSD_{5\%}$	260	310	470	290	260
Level of sign.	***	***	***	***	***
CV %	10	10	11	12	9
Date of sowing in May	3rd	21th	11th	11th	11th
Days of growing	115	102	122	106	112

[1] Abbreviation: Ap: autumn ploughing, Sp: spring ploughing ps: pig slurry, NPK: mineral fertilizer, bp: spread before ploughing in autumn, s: spring spread and harrowed in, no nutr.: no nutrient

yields on unfertilized plots in 1992 and 1993.

Moisture in grain at harvest showed only minor differences, although pig slurry applied in the autumn gave significantly drier grain compared with fertilizing in the spring (Table 3). Lodging was not a problem, but mineral fertilizer applied on spring-ploughed land resulted in less lodging compared with corresponding autumn-ploughed plots. For invasion of couchgrass *(Elytrigia repens),* a strong interaction between treat-ment and experimental years was registered. Barley plant height was significantly enhanced after supply of plant nutrients in the spring.

Table 3. Moisture in grain at harvest, lodging and couchgrass in per cent, and barley plant height at harvest, average of four experimental years (1991-94)

Treatment	Moisture in grain	Lodging	Couch-grass	Barley plant height cm
1. Ap-ps-bp [1]	21.3	1	25	56
2. Ap-ps-s	22.6	10	8	79
3. Ap-NPK-s	22.7	13	7	83
4. Sp-ps-s	22.1	10	11	82
5. Sp-NPK-s	22.9	6	10	83
6. Sp-no nutr.	22.0	0	32	46
$LSD_{5\%}$	1.1	3	9	6
Level of sign.	*	***	***	***

[1] Abbreviations as indicated in Table 2

Chemical composition of barley

Autumn ploughing resulted in a small, but significantly higher nitrogen concentration in barley grain, compared with spring ploughing (Table 4). On spring-ploughed plots the nitrogen concentration in the grain was not significantly enhanced by fertilization. The NO_3-N concentrations in barley grain were <5 mg/100 g DM in all samples.

The potassium concentration in the barley grain was significantly enhanced by spring fertilization (Table 4).

The concentrations of phosphorus (0.39 g/100 g DM), calcium (0.04 g/100 g DM), magnesium (0.12 g/100 g DM) and sulphur (0.11 g/100 g DM) in the grain showed no significant differences between treatments.

Table 4. Nitrogen and potassium in barley grain (percentage of dry matter), average of four experimental years (1991-94).

Treatment	Kjeldahl- N	K
1. Ap-ps-bp [1]	1.50	0.45
2. Ap-ps-s	1.53	0.49
3. Ap-NPK-s	1.52	0.49
4. Sp-ps-s	1.46	0.48
5. Sp-NPK-s	1.45	0.48
6. Sp-no nutr.	1.42	0.43
$LSD_{5\%}$	0.05	0.02
Level of sign.	*	**

[1] Abbreviations as indicated in Table 2

Nutrients removed by the grain

Since the fertilizing treatments influenced only the nitrogen and potassium uptake in the grain, the barley yield was the major factor for nutrient removal by the crop.

The grain crop removed 40-45 kg nitrogen/ha/year when supplied with mineral fertilizers or pig slurry in the spring (Table 5). When pig slurry was ploughed in during the autumn the nitrogen removal was 25 kg/ha/year; the corresponding figure for unfertilized spring ploughed land was 19 kg/ha/year. There was a tendency toward more nitrogen being removed by the grain grown on autumn-ploughed plots, compared with spring-ploughed fields, on average for four experimental years. For the first and last experimental years (1991 and 1994) the difference in favour of autumn ploughing was significant ($p<0.05$). Pig slurry and mineral fertilizer contributed almost equally to the nitrogen content in the grain. On spring-ploughed plots, however, there was a tendency of greater N removals where pig slurry was applied.

Phosphorus removed by the grain crop amounted to 11 kg/ha/year when mineral fertilizer or pig slurry was applied in the spring (Table 6). Owing to lower barley yield when pig slurry was ploughed in during the autumn, the phosphorus removal was reduced comparatively. The smallest amount of P removed in grain was found for unfertilized spring-ploughed land. For phosphorus, too, there was a tendency toward greater removals from autumn-ploughed land, and this was especially true in the first experimental year (1991).

The grain crop removed 14 kg potassium/ha/year when mineral fertilizer or pig slurry was applied in the spring (Table 7). On spring-ploughed plots there was a tendency toward enhanced K content in the grain crop where pig slurry was applied, in relation to mineral fertilizer. The smallest amount of removed potassium in grain was found in unfertilized spring-ploughed plots (Table 7).

For magnesium, calcium and sulphur (Table 8) the removals by the grain yields at spring fertilized plots were scarcely

Table 5. Nitrogen removed by grain, kg/ha, in four experimental years (1991-94)

Treat-ment	Experimental years 1991	1992	1993	1994	Average (1991-94)
1. Ap-ps-bp [1]	25.7	24.5	32.8	17.7	25.2
2. Ap-ps-s	47.7	43.8	47.7	41.2	45.1
3. Ap-NPK-s	40.8	47.1	46.8	44.0	44.7
4. Sp-ps-s	37.6	46.9	54.6	37.9	44.3
5. Sp-NPK-s	33.9	43.3	49.9	34.6	40.4
6. Sp-no nutr.	15.4	23.5	24.0	11.2	18.8
Mean	33.5	38.2	42.6	31.1	36.4
$LSD_{5\%}$	6.5	6.9	11.3	6.8	4.1
Level of sign.	***	***	***	***	***

[1] Abbreviations as indicated in Table 2

Table 6. Phosphorus removed by grain, kg/ha, in four experimental years (1991-94)

Treat-men	Experimental years 1991	1992	1993	1994	Average (1991-94)
1. Ap-ps-bp [1]	6.6	6.2	9.5	4.8	6.8
2. Ap-ps-s	12.1	10.9	12.2	11.5	11.7
3. Ap-NPK-s	10.5	11.1	11.9	11.5	11.3
4. Sp-ps-s	9.9	11.3	13.8	10.9	11.5
5. Sp-NPK-s	9.4	10.4	12.8	9.7	10.6
6. Sp-no nutr.	3.9	6.1	7.1	3.3	5.1
Mean	8.7	9.3	11.2	8.6	9.5
$LSD_{5\%}$	1.7	1.4	2.3	1.4	1.0
Level of sign.	***	***	***	***	***

[1] Abbreviations as indicated in Table 2

Table 7. Potassium removed by grain, kg/ha, in four experimental years (1991-94)

Treatment	Experimental years 1991	1992	1993	1994	Average (1991-94)
1. Ap-ps-bp [1]	7.5	6.9	11.1	5.3	7.7
2. Ap-ps-s	14.9	13.2	15.6	14.6	14.6
3. Ap-NPK-s	12.9	14.7	15.6	14.5	14.4
4. Sp-ps-s	12.8	14.2	17.8	13.7	14.6
5. Sp-NPK-s	11.3	13.9	16.2	12.2	13.4
6. Sp-no nutr.	4.5	6.9	8.3	3.6	5.8
Mean	10.7	11.6	14.1	10.6	11.8
$LSD_{5\%}$	2.1	2.3	3.5	2.0	1.3
Level of sign.	***	***	***	***	***

[1] Abbreviations as indicated in Table 2

Table 8. Magnesium, calcium and sulphur removed by grain, kg/ha/year. Mg and Ca in four experimental years (1991-94). S for three years (1992-94).

Treatment	Magnesium Average 1991-94	Calcium Average 1991-94	Sulphur Average 1992-94
1. Ap-ps-bp [1)]	2.1	0.7	2.0
2. Ap-ps-s	3.6	1.3	3.3
3. Ap-NKP-s	3.5	1.3	3.5
4. Sp-ps-s	3.5	1.3	3.5
5. Sp-NKP-s	3.3	1.1	3.1
6. Sp-no nutr.	1.6	0.6	1.6
Mean	2.9	1.1	2.8
$LSD_{5\%}$	0.3	0.1	0.3
Level of sign.	***	***	***

[1)] Abbreviations as indicated in Table 2

influenced by time of ploughing or source of nutrient. Fewer nutrients (Mg, Ca, S) were removed from unfertilized plots and plots with slurry applied in the autumn.

Nutrient balances

Balances for the macro-nutrients are presented in the Table 9. Amounts of nutrients added, and removed by the grain, can be obtained from earlier tables in this report. Data for leached nutrients through drainage discharge and surface runoff have already been published by Oskarsen et al.(1996). Chemical analyses of topsoil samples have been reported earlier by Myhr et al. (1996), but the main results with regard to nutrient balances are nevertheless reviewed in Table 10. Nutrient exchanges between soil and atmosphere, and nutrients supplied from the pool of minerals and organic matter in the soil are not included in the balance accounting, but will be commented on, in a subsequent chapter.

The nitrogen balances were positive for all treatments where pig slurry or mineral fertilizers were applied. The organic N content in the pig slurry (40 kg/ha/year) enhanced the positive balance by approximately an equal quantity; from 20 kg/ha/year for mineral fertilizer to 60 kg/ha/year for pig slurry. For unfertilized spring-ploughed soil the N balance showed a negative reading.

The phosphorus balances were positive for all fertilized treatments, but for the unfertilized treatment the balance was negative.

For potassium, negative balances were registered on all treatments. Autumn ploughing resulted in greater deficits than spring ploughing, due to increased leaching losses during the winter season. Heavy leaching losses caused negative balances for magnesium, calcium and sulphur for all treatments.

Discussion

Viewed in light of results from the present investigation, ploughing-in of animal slurry during the autumn cannot be recommended in central Norway. Because

Table 9. Balances of nitrogen, phosphorus, potassium, magnesium and calcium on an average for the four experimental years 1991-94, and sulphur in three years 1992-94, kg/ha/year

Components	Treatment					
	Ap-ps bp [1]	Ap-ps s	Ap-NPK s	Sp-ps s	Sp-NPK s	Sp no nutr.
N added	112.0	112.0	75.0	112.0	75.0	-
N in grain	25.2	45.1	44.7	44.3	40.4	18.8
N leached	26.8	13.5	14.9	7.7	12.3	8.5
Balance	+60.0	+53.4	+15.4	+60.0	+22.3	-27.3
P added	27.0	27.0	27.0	27.0	27.0	-
P in grain	6.8	11.7	11.3	11.5	10.6	5.1
P leached	2.4	1.5	1.8	1.0	1.2	1.1
Balance	+17.8	+13.8	+13.9	+14.5	+15.2	-6.2
K added	50.0	50.0	50.0	50.0	50.0	-
K in grain	7.7	14.6	14.4	14.6	13.4	5.8
K leached	84.1	64.0	77.1	44.6	56.9	45.8
Balance	-41.8	-28.6	-41.5	-9.2	-20.3	-51.6
Mg added	13.0	13.0	-	13.0	-	-
Mg in grain	2.1	3.6	3.5	3.5	3.3	1.6
Mg leached	61.4	51.6	56.4	50.7	59.3	45.2
Ca added	34.0	34.0	29.0	34.0	29.0	-
Ca in grain	0.7	1.3	1.3	1.3	1.1	0.6
Ca leaching	152.3	129.0	138.8	116.4	142.1	110.1
Balance	-119.0	-96.3	-111.1	-83.7	-114.2	-110.7
S added	6.0	6.0	-	6.0	-	-
S in grain	2.0	3.3	3.5	3.5	3.1	1.6
S leaching	40.5	37.2	47.5	35.4	36.9	36.3
Balance	-36.5	-34.5	-51.0	-32.9	-40.0	-37.9

[1] Abbreviations as indicated in Table 2

of increased nutrient leaching, the grain yields dropped by approximately 45%, in relation to application of an equivalent quantity of slurry after ploughing in the following spring. In practical management the falling off in yield is prevented by supplementation with mineral fertili-zers during the spring. Yield responses of autumn ploughing in relation to spring ploughing were negligible in the mean of four years.

At Kvithamar, pig slurry applied in the spring resulted in a grain yield equal to that from mineral fertilizers with the same amount of mineral N. Good agreement between yield of arable crops and ammonium-N in slurry was also found by Lyngstad (1993). Some nitrogen in the slurry might have been lost by ammonia emission at application, but this loss is more important when slurry is applied to leys.

Table 10. Plant-available nutrients in the topsoil at start of the experiment (1990) and changes in nutrial status at termination (1994) four years later. All parameters in mg per 100 g of dry soil. The symbol + indicates a positive balance, and - a negative balance. Analyses of variance on 1994 data only

Para-meter	Start 1990	Treatment,data for 1994 Ap-psbp [1]	Ap-sps	Ap-NPKs	Sp-pss	Sp-NPKs	LSD Spno n	5%	Level of sign.
K-HNO_3	138	+38	+61	+57	+70	+54	+45	40	ns
K-AL	7.8	-0.9	+0.9	+0.4	+1.7	+1.2	-0.2	1.6	*
P-AL	9.2	-4.1	-3.2	-1.0	-2.8	-3.9	-2.8	2.4	ns
Mg-AL	14	-1.3	-0.3	0.0	+0.3	-2.0	1.0	3.1	ns
Ca-AL	268	-105	-97	-62	-78	-79	-83	58	ns

[1] Abbreviations as indicated in Table 2

The statistical analyses showed a significant interaction ($p<0.05$) between treatments and experimental year. On spring-ploughed land the grain yields were considerably higher in the last two years where pig slurry was applied than in the first two years, compared with the yields from mineral fertilizer. This might be an indication of residual effects from the organic part of nitrogen in the slurry applied. Variable climatic conditions and differences in length of growing season can also contribute to the interaction with years. In 1992 it was warm in June, which might have initiated an early and comprehensive mobilization of nitrogen associated with organic compounds in the topsoil. The long growing season in 1993, with late harvesting of the grain, might also have resulted in a beneficial of mineralization of nutrients in the soil. The relatively enhanced yields on unfertilized soil (treatment 6) in both 1992.and 1993, compared with 1991 and 1994, might support this assumption.

Unfertilized land and plots with autumn-applied slurry exhibited slow plant development in the early growth stages of the spring barley crop, probably due to lack of nutrition. No visible delayed development was registered in the barley where pig slurry (112 kg Kjeldahl-N/ha/year) was applied in the spring, in relation to mineral fertilizer. This result fits well with Eltun (1996), who noticed a slower start of growth in an ecological cropping system than in a system using mineral fertilizer at Apelsvoll Research Centre in eastern Norway.

During the four year barley monoculture, couchgrass *(Elytriga repens)* successively invaded unfertilized plots and plots with autumn-applied pig slurry. This was obviously a result of a thin and short barley stand, with an abundance of light for volunteer weeds.

The mean for four experimental years indicate that the nitrogen concentration in barley grain was slightly, but significantly, higher on autumn-ploughed compared with spring-ploughed land. This was especially true where pig slurry was applied. This result can be explained by a looser structure and higher temperature in the autumn-ploughed soil, with better possibilities for the inherent microorganisms to mineralize organic nitrogen.

The nitrogen balance was positive for all fertilized treatments. After application of pig slurry the N balance was as much higher as the content of organic N in the slurry (Table 9). Where no nutrients were

supplied the N balance was negative, due to grain removals and leaching. In addition to the negative N balance in unfertilized plots, Uhlen (1989) found negative N balance in spring grain plots treated with 100 kg N/ha/year. Negative N balances were found in all crop rotations when only moderate amounts of mineral fertilizers were applied (Uhlen & Tveitnes 1995). In a review Gustafson (1996) pointed out that under-fertilization with nitrogen did not reduce N leaching. Normal fertilization gave a weak positive N balance, showing a sustainable system, while over-fertilization resulted in considerable N losses. Hansen (1990) found that the N leaching was enhanced when applications of phosphorus and potassium were omitted, such that some essential plant nutrients were in demand.

The phosphorus concentration in barley grain was not significantly influenced by fertilizing or time of ploughing. The phosphorus balances were positive for all fertilized treatments. On the other hand, the content of readily plant-available phosphorus in the soil had decreased significantly for all treatments during the four years of experimentation. Between the separate treatments no significant difference in P-AL decrease could be found. Leaching of phosphorus on spring fertilized plots accounted for only 5% of added P. One explanation for this is that the P supply during the experimental period was less than that in the previous years, and therefore the P-AL values decreased. The positive P balance might be explained by fixing to the soil mineral particles (Uhlen 1989). According to Krogstad & Løvstad (1988), only 10-20% of the total P in the soil is revealed by the P-AL analyses. A partial explanation might therefore be that the surplus application of phosphorus has built up a larger pool of P in the underground biomass.

For potassium, a significantly increased concentration of K in the grain as a result of fertilizing was found, either as pig slurry or mineral fertilizer. The potassium balance was negative for all treatments. On autumn-ploughed plots the leaching of potassium was greater than K added. On spring-ploughed plots the leaching equalled the supply. The leaching amounted to 45 kg K/ha/year on unfertilized plots. The great resource of potassium on this site can be explained by the high clay content (Myhr et al. 1996). Readily plant-available potassium had slightly increased on fertilized plots. The 1 M HNO_3 soluble potassium in the soil (Reitemeier et al. 1947), increased significantly during the experimental period, but the differences between treatments were not significantly altered. Uhlen & Tveitnes (1995) also registered large negative balances and increasing values for exchangable potassium in a long-term crop rotation and fertilizer experiment on a clay loam soil at Ås, Norway.

The sulphur balances calculated for three years were negative, due to leaching. The largest amount of leached sulphur, 47.5 kg SO_4-S/ha/year, was registered on autumn-ploughed plots with spring application of mineral fertilizer. Eriksen et al. (1995) found a very low plant uptake of slurry-S. The high content of organic matter in the soil at the actual site represents a great source of sulphur. But, in addition, mineral sulphur may be present in this marine deposit, because pyrite is often found in the subsoil of marine clay soils. Bærug & Uhlen (1982) have reported leaching of 267.5 kg SO_4-S /ha/year at a site in the same region. Recent draining to a deeper horizon with inherent composition might explain the large sulphur losses. Jeng

(1991) has studied the weathering of sulphide-bearing rocks, and that process in the soil might also contribute to the heavy leaching of sulphur at Kvithamar. Myhr & Stabbetorp (1994) have reported on an increasing frequency of sulphur deficiency in crop production, particularly in central Norway. On the field lysimeter plots sulphur deficiency symptom was not visually diagnosed. The sulphur concen-tration in the grain samples was, however, well below the S content usually expected (Myhr & Stabbetorp 1994).

The concentrations of calcium and magnesium in the grain were not influenced by ploughing time or fertilizer treatments. The balances for both these elements were negative, due to leaching. For calcium the adding:leaching proportion was approximately 1:3, and the same proportion was registered for magnesium on plots where pig slurry was supplied in the spring. Our results support the findings of both Uhlen (1989) and Yläranta et al. (1996), who reported predominantly negative nutrient balances for calcium, magnesium and potassium.

Conclusion

In conclusion, autumn ploughing cannot gererally be recommended on sloping land in districts with a humid winter climate. Ploughing-in of animal slurries during the autumn resulted in severely decreased spring barley yields, as well as great leaching losses of plant nutrients through leaching, and appeared to be a hazard with regard to water pollution. Utilization of mineral-N in pig slurry and in NKP fertilizer was similar when the nutrients were supplied in the spring. Spring application of animal slurry should therefore be practised.

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Chemical composition and voluntary intake of effluent as affected by silage additive and time of flow following ensiling

ÅSHILD T. RANDBY
Agricultural University of Norway, Department of Animal Science, Ås, Norway

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The feeding of silage effluent to livestock minimizes ensiling losses and increases total feed resources from grasslands. The voluntary intake of effluent, however, may depend on its chemical composition, which varies considerably. The influence of nine commercial silage additives on the composition of effluent tapped from the silages at various stages of fermentation was investigated in this study. In an effluent feeding experiment, dairy cows were fed effluent from silage treated with either an inoculant (*Natuferm*) or a formic-acid-based additive (*Maxgrass*). Although all silages were well fermented, considerable variation was observed in the chemical composition of resulting effluents. Effluents from silage treated with inoculants or *Howden*, as well as those from untreated silages, exhibited the highest lactic acid concentrations, whereas silages treated with-formic-acid based additives yielded effluents with the highest sugar content. Sugar and ash content decreased with time following ensiling, while the content of dry matter, crude protein, organic acids, and ethanol increased. The daily intake for cows fed effluent from *Natuferm*-treated silage was determined to be 43.6 kg, compared to 57.4 kg for cows fed effluent from *Maxgrass*-treated silage. Effluent intake decreased rapidly with time following ensiling. A significant positive correlation was observed between effluent sugar content and intake.

Key words: Acids, additive, chemical composition, cows, effluent, fermentation, intake, silage, sugar.

Åshild T. Randby, Agricultural University of Norway, Hellerud Research Station, P.O. Box 115, N-2013 Skjetten, Norway

Silage effluent has been successfully fed to pigs (Saue 1975; Patterson & Walker 1979b), beef cattle (Pestalozzi & Matre 1975, 1976, 1977; Clarke et al. 1984; Steen 1986; O'Kiely & Flynn 1988), and dairy cows (Davies & Clench 1988; Randby 1997b). The chemical composition of effluent has been shown to vary considerably, being affected by properties related to the crop, and the harvesting technique employed (Brown 1961; Mo 1975; Patterson & Walker 1979a; McDonald et al. 1991; Jones 1993). It is also affected by the use of silage additives (Weddell 1993), as well as the time following ensiling when the effluent drains off (Randby 1997a). O'Kiely & Flynn (1988) reported an intake of 45 l/day for steers fed effluent from a well-fermented silage, as opposed to only 5 l/day for effluent from a poorly fermented silage. The choice of silage additive during harvesting may be critical in determining effluent composition, and

thus in ensuring the success of effluent feeding to livestock. Since the concentrations of sugar, lactic acid, acetic acid, and ammonia nitrogen (NH_3-N) in silage are important fermentation characteristics related to silage intake in livestock (Selmer-Olsen 1989; Huhtanen 1993), it is likely that these components also influence the intake of silage effluent. In this study the chemical composition and the intake of effluent as affected by various silage additives and time of flow following ensiling were investigated.

Materials and methods

Crops and ensiling

Experiments 1 and 2

In late August 1990 (expt. 1) and early October 1991 (expt. 2) crops consisting of timothy, meadow fescue and red clover were direct cut, divided into 10 kg loads, and emptied into 1-m^3 silos. Current recommended levels of several commercial silage additives were applied. A total crop mass of 400 kg was added to each silo in expt. 1, and 330 kg in expt. 2. Crops used in expts. 1 and 2 contained 178 and 248 g dry matter (DM)/kg, 158 and 70 g crude protein (CP)/kg DM, and 58 and 103 g total sugar/kg DM respectively. Table 1 provides information on type of additives and application rates. In each experiment, each additive was used in only one silo, with the exception of *Foraform*, which was used in two silos at different rates in expt. 2. The silos were kept indoors at 15-20°C in expt. 1 and at 10-15°C in expt. 2. Accidental damage to the plastic cover on the *Kofa plus* silo in expt. 1 led to leakage from the water basin used as pressure, and the effluent was diluted by about 50 l of water.

Experiment 3

Three wooden tower silos were simultaneously filled with direct cut, flail-harvested crop on 10-11 June 1991. Forty tonnes of a crop consisting primarily of timothy and meadow fescue was ensiled in each silo, with the addition of 3.7 l/tonne *Natuferm*, 4.0 l/tonne *Foraform*, and 5.3 l/tonne *Maxgrass* respectively. The crop contained 177 g DM/kg, 174 g CP/kg DM, and 121 g sugar/kg DM.

Chemical analyses

Samples of crop, silage and effluent were analysed for DM, ash, total nitrogen (TN) and total sugar. Silages and effluents were also analysed for pH, lactic-, formic-, acetic-, propionic-, and butyric acids, ethanol, and NH_3-N. All samples were treated and analysed as described by Randby (1997a). Concentrations of TN and NH_3-N in silages and effluents were corrected for NH_3 derived from *Foraform* and *Maxgrass*, and for NH_3 derived from hexamethylene-tetramine in *Kofa plus* by subtracting, on a per kilo sample basis, 0.0492, 0.0328, and 0.048 g N per kg additive per tonne crop respectively. Concentrations of acetic acid in silages and effluents were corrected by subtracting, per kilo sample, 0.2 g acetic acid per kilo *Ensimax* per tonne crop. Crude protein was calculated as corrected TN x 6.25.

Effluent collection

Effluent was tapped at 2, 14 and 49 days following ensiling in expt. 1, and at 2, 12, 21, and 63 days following ensiling in expt. 2. Owing to a high crop DM content in expt. 2, effluent appeared from only 5 of the 11 silos at 2 days following ensiling. Effluent was continually drained off from the high tower silos and collected in outdoor storage tanks in expt. 3. Effluents from the *Natuferm* and *Foraform* silages were collected in gas-tight tanks with a

Table 1. Silage additives, compositions, and application rates in experiments 1 and 2

Silage additive		Application rate, l/tonne	Additive composition
Control	(C)		
Howden	(H)	5.0	8.5% NaCl, 1.7% KCl, 3.5% molasses, 3.3% Na-benzoate, 0.8% sugars, 0.5% malt extract
Natuferm	(N)	3.5[2)]	*Lactobacillus plantarum*, *Lactobacillus* spp., *Pediococcus* spp.
Lactisil Plus	(L)	4.0[3)]	*Lactobacillus plantarum*, *Pediococcus acidilactici*, *Streptococcus faecium* M 74, cellulase
Biomax E	(B)	2.0-3.6[4)]	*Lactobacillus plantarum*, *Pediococcus pentosaceus*, cellulase, hemicellulase
Kofa plus	(K)	2.5[5)]	23% $NaNO_2$, 13% hexamethylentetramine, 5% Ca-formate, 55% NaCl
Ensimax	(E)	4.0	21.3% formic acid, 20% acetic acid, 50% Finfermex (lignosulphonates, sugars, Ca, P, S)
Foraform	(F4)	4.0	64% formic acid, 6% NH_3
Formic acid	(FA)	3.0	85% formic acid
[1)]Foraform	(F6)	6.0	64% formic acid, 6% NH_3
[1)]Maxgrass	(M)	6.0	64.4% formic acid, 10% propionic acid, 2% caprylic acid, 4% NH_3

[1)] Only used in expt. 2
[2)] Giving 6 x 10^5 cfu per g crop
[3)] 32 g bac-pac + 32 g enz-pac per tonne, giving 6 x 10^4 cfu per g crop
[4)] 2.0 l in expt. 1 and 3.6 l in expt. 2, because of different dilutions. In both expts.: 50 g dry powder per tonne, giving 10^6 cfu per g crop
[5)] Kg per tonne

5-mm oil layer floating on the effluent surface to ensure oxygen-free storage. Effluent from the *Maxgrass* silo was collected in an open tank in which a floating lid of styropor provided an effective seal against air. Mean temperatures were 11°C in the remaining days of June, 17°C in July and August until the end of the experiment.

Effluent feeding experiment (expt. 3)

Effluents from the tower silos were utilized in an experiment with 12 dairy cows designed to determine the voluntary intake of effluents with different chemical compositions. The animals had an average milk yield of 24 kg/day, ranging from 17 to 39 kg at the start of the experiment, and from 16 to 32 kg at the

Table 2. Chemical composition of the silages in experiments 1-3

Silage additive[1]	DM g/kg	g/kg DM							NH_3-N, g per kg TN		pH
		CP	Sugar	Lactic acid	Form. acid	Acetic acid	Prop. acid	Ethanol	Uncorr	Corr	
Expt.1											
C	190	172	25	126	1	21	0	8	63	63	3.97
H	199	165	31	124	1	21	0	19	69	69	3.91
N	198	157	40	122	1	14	0	6	50	50	3.85
L	197	168	51	120	1	14	2	7	45	45	3.86
B	192	165	39	128	1	18	2	8	59	59	3.92
K	174	181	83	82	1	11	0	0	62	39	4.16
E	188	164	36	104	7	16[2]	0	6	47	47	3.87
F4	179	179	44	93	23	17	0	4	80	35	3.89
FA	191	170	43	84	21	17	0	4	33	33	3.87
Expt.2											
C	225	96	44	93	0	28	0	22	76	76	3.77
H	234	83	59	95	0	28	0	18	74	74	3.75
N	232	90	90	92	0	12	0	35	54	54	3.70
L	236	90	61	82	0	17	0	38	74	74	3.76
B	228	88	80	71	0	15	0	28	62	62	3.82
K	240	88	164	44	1	13	0	16	91	59	4.16
E	226	84	77	77	5	24[3]	0	14	69	69	3.75
F4	232	85	92	78	13	25	0	14	109	44	3.80
FA	242	79	129	44	14	19	0	14	65	65	3.78
F6	238	80	98	55	19	23	0	10	135	36	3.86
M	232	94	121	38	27	16	3	6	108	49	3.86
Expt.3											
N	222	162	33	100	0	5	0	20	18	18	3.71
F4	242	157	37	58	8	18	0	6	43	3	3.82
M	234	160	54	49	13	16	2	3	62	22	3.85

[1] See Table 1
[2] Uncorrected value: 20
[3] Uncorrected value: 27

end of the experiment. All animals were fed roughage *ad libitum*, as well as restricted quantities of concentrate, 3-11 kg/day depending on milk yield. In the adaptation period (first 2 weeks), alkali-treated straw was provided in the morning, and fresh grass in the afternoon. During the 6 weeks' experimental period, round bale silage was fed at both meals.

The experiment started immediately following ensiling. Since only one type of effluent could be given at any time, different effluents were presented to the animals at various stages of the experiment. To adapt animals to effluent, *Foraform* effluent was provided during the adaptation period. Fermentation was expected to be most extensive in *Natuferm* effluent, and most restricted in *Maxgrass* effluent, for which reason these effluents were selected for feeding during the experimental period. The *Natuferm* and *Maxgrass* effluents were provided in alternate weeks, *Natuferm* in weeks 3, 6,

and 7, and *Maxgrass* in weeks 4, 5, and 8. Effluents were fed *ad libitum* via nipple-drinkers, and intakes were recorded daily for individual animals. Water was given *ad libitum*, the joint intake of pairs of cows sharing a water bowl being recorded daily. Milk yields were recorded at the beginning and at the end of the experiment.

Statistical analyses

In expts. 1 and 2, the effect of time following ensiling on the chemical composition of effluents was tested within experiments using the nine and eleven silages in expt. 1 and 2 respectively as replicates in two-way variance analyses.

For expts. 1 and 2, correlation analyses were performed to demonstrate any relationships between final silage quality and the chemical composition of effluents tapped from that silage at various times following ensiling.

Differences between the two types of effluent investigated in expt. 3 were assessed by comparing regressions of effluent intake against time following ensiling. Relationships between chemical compositions and intake of effluents were tested by way of multiple regression. All statistical analyses were performed using NM software (Nissen 1990).

Results

Chemical composition of silages

The chemical composition of silages was determined after unloading the silos 51, 65, and about 150 days following ensiling in expts. 1, 2 and 3 respectively. These data are presented in Table 2. All silages, including controls, were well fermented with no butyric acid detected, indicating that the crops were easy to ensile. Nevertheless, the degree of silage fermentation differed considerably between experiments, and between silages within experiments. The inoculated silages exhibited a higher content of lactic acid and ethanol, but a lower content of acetic acid than silages treated with acids. The sugar concentrations observed in *Kofa plus* silage in expts. 1 and 2, and in *Formic acid* and *Maxgrass* silages in expt. 2, were higher than the corresponding crop values, and this may have resulted from hydrolysis of fructan and hemicellulose.

Chemical composition of effluent

Chemical compositions of the effluents from expts. 1 and 2 are presented in Fig. 1 and 2 respectively. With the exception of propionic acid derived from *Maxgrass*, propionic and butyric acids were not detected in effluents. Significant changes occurred for all effluent components with time following ensiling, with the exception of ethanol in expt. 1 and CP in expt. 2. Sugar and ash concentrations decreased with time following ensiling, while the contents of DM, CP, organic acids, and ethanol all increased.

Differences in effluent composition as affected by silage treatment were observed as early as 2 days following ensiling. The silages treated with formic-acid-based additives or *Kofa plus* produced effluents with higher sugar levels and lower concentrations of lactic and acetic acids than did the other silages. Silages treated with inoculants or *Howden,* as well as untreated silages, gave rise to effluents with the highest content of lactic acid. Although silage treated with *Ensimax* yielded effluent with a high sugar content during the first days of fermentation, sugar levels decreased over time, and acid concentrations increased rapidly. After 20-30 days, effluent from the *Ensimax* silage resembled effluents from inoculant-treated silages more closely than those from silages treated with acid-based

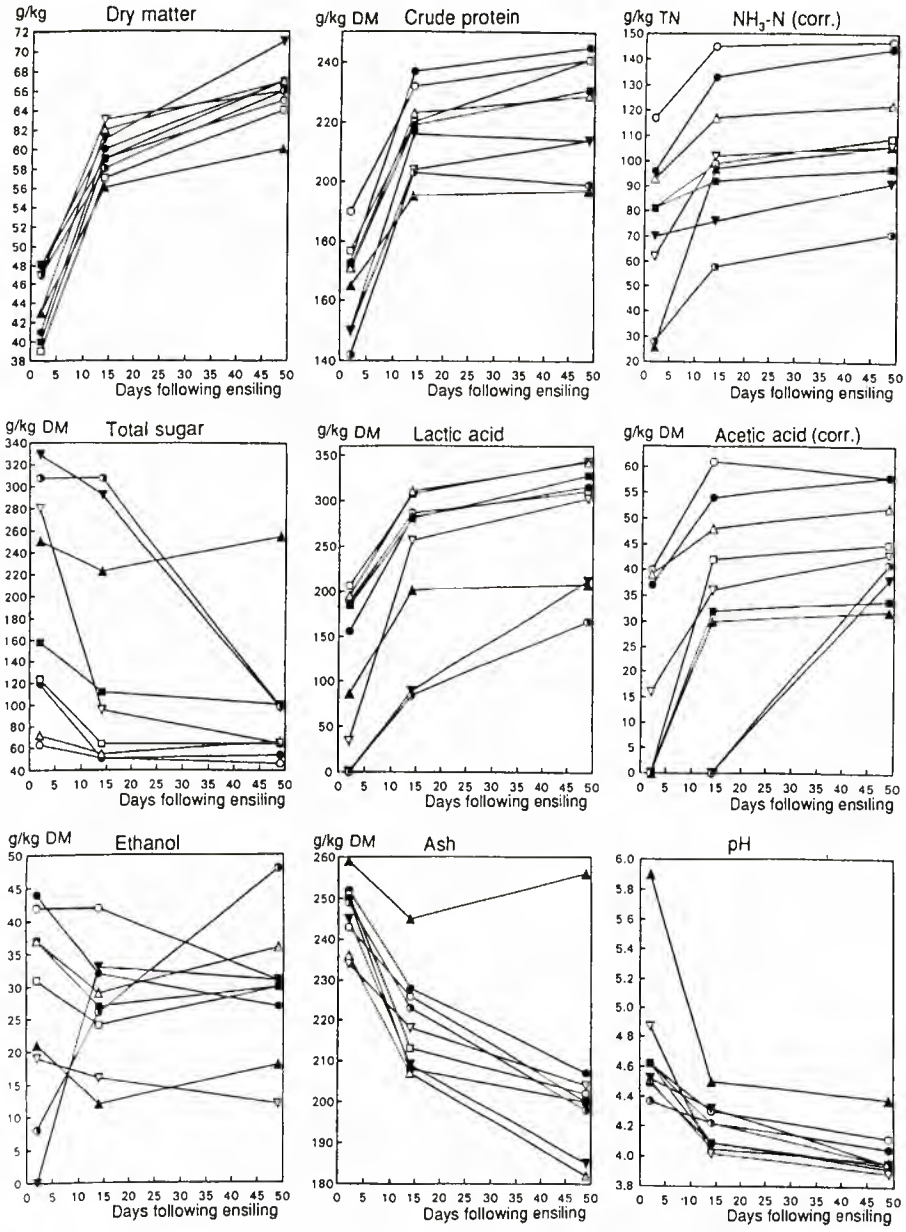

Fig. 1. Chemical composition of effluent tapped at various times following ensiling in expt. 1.
Silage additives (for explanation, see Table 1): ○ C ● H □ N ■ L △ B ▲ K ▽ E ▼ F4 ◑ FA

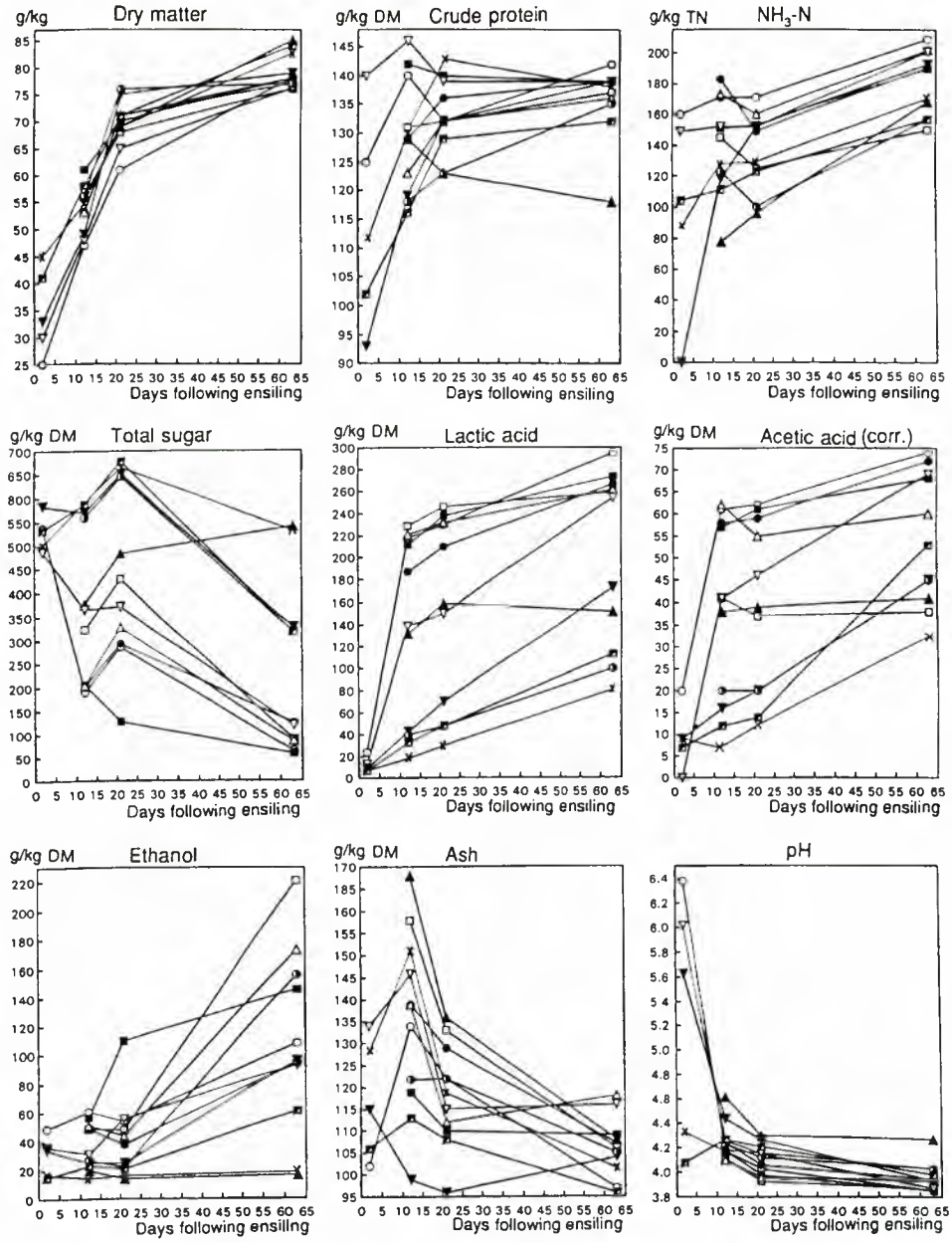

Fig. 2. Chemical composition of effluent tapped at various times following ensiling in expt. 2.
Silage additives (for explanation, see Table 1): ○ C ● H □ N ■ L △ B ▲ K
▽ E ▼ F4 ◑ FA ◪ F6 X M

additives. Throughout both experiments pH values remained higher in effluent from *Kofa plus* silage than in effluent from all the other silages.

Data for total effluent productions at 49, 63, and 56 days in expt. 1, 2, and 3 respectively are presented in Table 3. It should be noted that these data represent only single observations.

In expt. 3, effluent draining from the silos was continuously collected in storage tanks, from which the animals were fed. Compositions of effluents when drained from the silos, and when fed from the storage tanks to the cows, are presented in Fig. 3. Effluent tapped from the storage tanks and fed to the animals consisted of a mixture of the effluent that had drained off earlier (in weeks 1-3). Therefore the composition differed from that of the final samples of effluent flowing from the silos. Changes in effluent composition from week 3 onwards were mainly due to fermentation in the storage tanks. At that stage effluent production was fairly low (70-120 kg/day) in relation to the large volumes stored in the tanks (5-10 tonne). Ethanol fermentation occurred to a major extent in the tanks. Between week 3 and 4, a marked increase in ethanol level was detected in effluent from *Maxgrass*-treated silage, followed by decreases in DM and sugar levels.

The changes over time in composition of flowing effluent corresponded to the changes in composition of effluent from pilot-scale silos when tapped at various stages following ensiling (expts. 1 and 2). Differences in composition of effluents as affected by silage additive were also in agreement with the results of expts. 1 and 2, but the drop in sugar content in effluent from *Foraform*-treated silage was steeper and occurred earlier in expt. 3 than in expts. 1 and 2.

Table 3. Effluent production in experiments 1-3

Silage additive [1]	Kg effluent per tonne crop ensiled		
	Expt. 1	Expt. 2	Expt. 3
C	113	103	
H	145	91	
N	124	95	281
L	163	82	
B	126	100	
K	ND[2]	86	
E	92	99	
F4	119	110	284
FA	91	88	
F6		112	
M		111	316

[1] For explanation, see Table 1.
[2] ND = not determined because of accidental dilution of effluent by leakage from the water pressure

Effluent intake in the feeding study

Two of the twelve cows consumed only 2-3 kg effluent per day during the first week of the adaptation period, and were therefore replaced by two other cows. In the second week of adaptation, the mean intake of *Foraform* effluent was 74.3 kg per day. The intakes of effluent, chemical components of effluent, and drinking water are presented in Fig. 4. The mean intake of *Natuferm* effluent throughout the experiment was 43.6 kg/day, and 57.4 kg/day for *Maxgrass* effluent. Regressions performed on effluent intake against time following ensiling, based on individual daily intakes, indicated significant differences between the two types of effluent in both slope and intercept. Intake of *Maxgrass* effluent was higher than that of *Natuferm* effluent, but decreased more

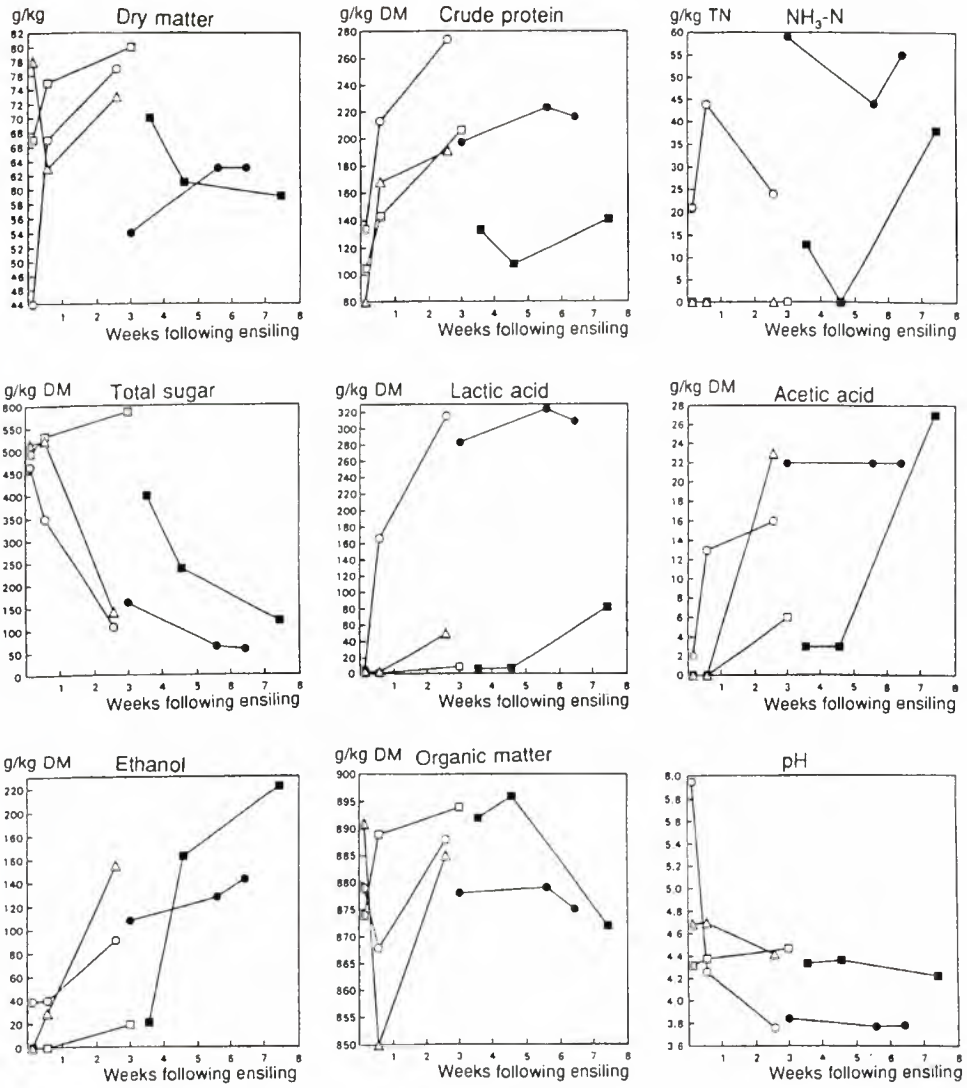

Fig. 3. Chemical composition of effluent when draining off and when fed from the storage tanks to experimental animals in expt. 3. ○ *Natuferm* effluent (N) when flowing from the silo; ● N when tapped from the storage tank and fed; □ *Maxgrass* effluent (M) when flowing from the silo; ■ M when tapped from the storage tank and fed; △ *Foraform* effluent when flowing from the silo and fed

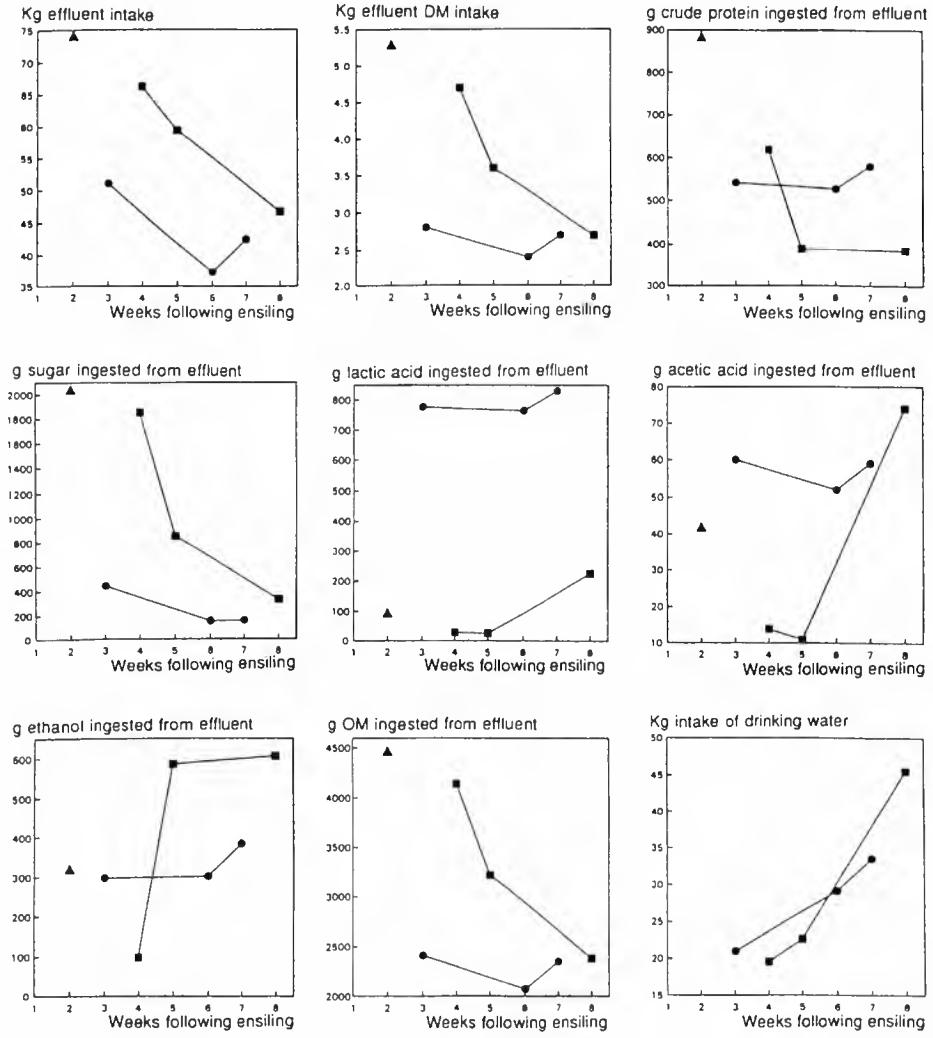

Fig. 4. Daily intake of effluent produced by *Natuferm* (●) or *Maxgrass* (■) treated silage at various times following ensiling, and from *Foraform* (▲) treated silage during the adaptation period in expt. 3. The different effluents were fed to the same animals in alternate weeks

rapidly over the experimental period. Intake of *Natuferm* effluent did not decrease significantly with time after ensiling. The intake of chemical components in *Natuferm* effluent remained relatively constant at approximately 2.6 kg DM/day, of which 250 g as sugar, 330 g as ethanol, and 790 g as lactic acid. Between week 4 and 8 the intake of *Maxgrass* effluent decreased from 4.7 to 2.7 kg DM/day, of sugar from 1860 to 330 g/day, while ethanol and lactic acid intake increased from 100 to 610 g/day and 30 to 220 g/day respectively.

Individual daily intake, averaged over the experimental period and over the two types of effluent, ranged from 31.1 to 73.2 kg. The cow with the highest milk yield consumed an average of 69.0 kg effluent per day. Water intake during the experimental period increased at a rate corresponding to the mean rate of decrease of effluent intake. However, water intake did not vary according to the weekly changes in effluent intake when one or the other type of effluent was fed. No health problems occurred in the course of the experiment.

Discussion

The contents of DM, CP and sugar in the crop ensiled in expt. 1 were typical for direct cut grass in Norway. The low protein content of the crop used in expt. 2, and the high sugar content in expts. 2 and 3 were reflected in their respective silage effluents.

All silages prepared in this study were of good fermentation quality. The chemical composition of effluents resulting from these silages, however, showed considerable variation. The composition of effluents from poorly fermented silages may deviate considerably from those observed in this study.

Changes in the composition of effluent drained at various times after ensiling agreed well with those of effluent from tower silos (Randby 1997a). Patterson & Walker (1979a), however, observed no relationship between the chemical composition of effluent and the time of draining following ensiling. Since effluent is the surplus liquid not retained by the silage, its composition reflects the fermentation process occurring within the silo (Shiels et al. 1993).

Lactic acid content and pH value were the silage fermentation characteristics which could best be predicted from their concentrations in effluent in expts. 1 and 2. Even in the earliest drained effluent, as well as in subsequent effluents, significant correlations were found between the contents of these components in effluent and silage (r=0.74-0.97). Sugar content in silage could be predicted from its content in effluent drained from day 12 onwards in expt. 2 (r=0.62-0.87), but in expt. 1 predictions were not valid prior to the last effluent sampling before emptying the silos (r=0.97). Ammonia-N in silage (g/kg TN, corrected) could be successfully predicted from its concentration in effluent throughout expt. 1 (r=0.82-0.94), as could ethanol throughout expt. 2 (r=0.76-0.81). Acetic acid concentrations in silage could be successfully predicted in both experiments from concentrations in effluent drained no earlier than at the last sampling date prior to emptying the silos (r=0.68-0.89).

When feeding effluent for the first time, it has previously been observed that animals spontaneously consume the effluent if feeding is initiated a few days following ensiling. If starting later, however, farmers have experienced that

animals may refuse the effluent (Harbo 1975). These observations are probably related to the marked decline in sugar content with time following ensiling, but may also be related to the simultaneous increase in levels of fermentation products.

Peak effluent flow usually occurs during the first week following ensiling. Ensiling of a wet crop can result in as much as 90% of total effluent production occurring during the first 20 days (Bastiman 1976). Weddell (1993) observed that peak effluent flow from a clamp silo was greater and occurred earlier, and that total flow was also greater, when the crop was treated with *Formic acid 85%* than when it was treated with *Natuferm* or left untreated. During the first 20 days in expt. 3, approximately 80% of the effluent from the *Natuferm*-treated silage, and approximately 86% from the *Maxgrass*-treated silo drained off. When studying Figs. 1-3, it should be noted that the chemical compositions of effluents during the first 20 days represent the largest effluent volumes.

The cows obviously preferred the sugar-rich effluent produced in the first few weeks by the *Maxgrass*-treated silage. Consequently, as is the case with silage, the intake of effluent was influenced by its fermentation quality. Regression analyses performed on effluent intake against effluent sugar content yielded the following equation :

$$y = 1.9 + 0.0076\,x, \quad r^2_{total} = 0.39, \quad r^2_{within\ animals} = 0.61$$

y = effluent intake, kg DM/day
x = effluent sugar concentration, g/kg DM

Effluent sugar content accounted for 39% of total variation in effluent intake, and for 61% of intake variation within animals. The prediction of effluent intake was not significantly improved by incorporating its DM, lactic acid, acetic acid, or ethanol contents into a multiple regression analysis.

Compared with the results of previous studies (Saue 1975; Davies & Clench 1988; Randby 1997b) the cows in the present experiment consumed large quantities of effluent. Bearing in mind that the animals were fed forage *ad libitum* in addition to concentrate, the high intakes in this study must have been due to superior effluent quality. The superior quality and high intakes of effluents can primarily be attributed to the fact that the experiment was begun shortly following the onset of ensiling. The rapid decrease in effluent intake observed in the course of the experiment, however, indicated that effluent composition moved towards more typical values towards the end of the experiment, as confirmed by chemical analyses of the effluent. One pertinent question is whether the extensive ethanol fermentation observed in tank-stored effluent could have been avoided. Several acids and food preservatives are known to inhibit microbial growth (Woolford 1975a, 1975b). It is possible that the addition of such an inhibitor to the effluent could have maintained a high sugar content and high palatability, so that effluent intakes did not decrease as rapidly with time following ensiling. Further research is required in order to explore this possibility.

When effluent is to be fed, farmers should be aware of the large differences, not only in silage quality, but in effluent composition as well, resulting from the choice of silage additive. During the first 2-3 weeks of effluent drainage, in which effluent flow was at a peak, silage treated with formic-acid-based additives gave rise

to effluents with the highest sugar levels and the lowest levels of lactic and acetic acids. The untreated silage and those treated with inoculants and *Howden* all produced effluents with a lower sugar content and higher lactic acid content. In addition to the effect on intake, the protein feeding value may be higher in sugar-rich than in extensively fermented effluent, since sugar is a greater source of energy for rumen microbes than products of fermentation (Chamberlain & Choung 1993; Beever & Cottrill 1994).

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Effects of silage additive, time of flow following ensiling, and storage conditions on the quality of silage effluent intended for animal feeding

ÅSHILD T. RANDBY[1] & IDA SKAAR[2]
[1] Agricultural University of Norway, Department of Animal Science, Ås, Norway
[2] Central Veterinary Laboratory, State Veterinary Laboratories of Norway, N-0033 Oslo, Norway

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Three experiments were conducted to investigate methods of storage for silage effluent intended for animal feeding. Fifty-two different types of effluent, derived from silages treated with various silage additives and collected at increasing lengths of time following ensiling, were assessed. The effects of surface sealing of the effluent and application of preservatives during storage were studied. Surface fungi were identified. The quality of most effluents deteriorated seriously over time when stored with neither sealing treatment nor preservative. The use of surface layers of liquid paraffin or waste deep-fat as sealing treatments, as well as lids, reduced surface moulding and storage losses, and dramatically improved the fermentation quality of stored effluent. Preservation of effluent with formic acid increased the sugar content in stored effluent by restricting the fermentation of sugar to acetic, propionic, and butyric acids, and ethanol. As compared to effluent draining from silage at later stages, effluent draining over the first days following ensiling was of superior quality, but more susceptible to deterioration if not properly stored. When preserved with levels of formic acid sufficient to restrict ethanol fermentation, effluents from silages treated with formic acid based additives were of better fermentation quality than effluents from silages treated with other additives. The mixing of preservatives into the surface layer of paraffin improved the quality of long-term stored effluent.

Key words: Ethanol, fermentation, fungi, moulding, preservatives, storage losses, surface sealing.

Åshild T. Randby, Agricultural University of Norway, Hellerud Research Station, P.O. Box 115, N-2013 Skjetten, Norway

The successful use of silage effluent as feed for pigs and cattle has been well documented (Patterson & Walker 1979; Clarke et al. 1984; Steen 1986; Randby 1997b). Owing to the flow of large volumes of effluent over a short period of time, effluent must be stored from the time of drainage until feeding. In experiments performed over a three-year period, the storage of effluent within the silo (i.e. together with silage) resulted in the production of high-quality silage and effluent (Randby 1997a). However, since existing silos are usually not sufficiently tight to retain the effluent, storage of effluent in separate tanks is more common.

Silage effluent contains nutrients that

are readily consumed by micro-organisms (Pedersen 1976), and thus effluent stored in tanks will quickly lose its high nutritive value and palatability if not properly preserved. Studies on preservation of silage effluent intended for animal feeding have earlier been carried out by Pestalozzi (1975) and Patterson & Walker (1981). These previous reports did not, however, take into account the great compositional variation of fresh effluent, depending on the silage additive used and the time of drainage following ensiling.

Three laboratory experiments were performed to investigate the storage stability of various types of fresh effluent (i.e. effluent at the time of drainage from the silo, irrespective of time following ensiling). The effect of various sealing treatments and preservatives on the quality of stored effluent was studied.

Materials and methods

Ensiling and effluent collection

Experiment 1

A grass crop consisting of meadow fescue and timothy was direct cut in June 1990 and simultaneously ensiled in 1-m^3 silos without additive (control), or treated with *Formic acid 85%* or *Biomax E* (containing enzymes and lactic acid bacteria). At ensiling the crop contained 167 g dry matter (DM) per kg, and per kg DM: 153 g crude protein and 84 g total sugar. The chemical composition of silages, presented in detail by STIL (1990), showed that *Formic acid* and *Biomax E*-treated silages were of good fermentation quality with higher sugar content and lower acetic acid and ammonia nitrogen contents than the control silage. Three different effluents used in the storage experiments were tapped two days following ensiling and bulked, from three control silos (C), from two silos to which was applied 3.0 and 4.5 l/tonne of *Formic acid* (FA), and from two silos to which was applied 2.0 and 4.0 l/tonne (25 and 50 g powder giving 5 x 10^5 and 10^6 cfu/g) of *Biomax E* (B), respectively. The compositions of fresh effluents can be found in Table 1. Butyric and propionic acids were not detected.

Experiments 2 and 3

Experiment 2 was performed in August 1990 using effluents tapped 2, 14, and 49 days following ensiling, from untreated silage (C), and silage added recommended rates of *Howden* (H) 5 l/t, *Natuferm* (N) 6 x 10^5 cfu/g, *Lactisil Plus* (L) 6 x 10^4 cfu/g, *Biomax E* (B) 10^6 cfu/g, *Kofa plus* (K) 2.5 kg/t, *Ensimax* (E) 4.0 l/t, *Foraform* (F4) 4.0 l/t, and *Formic acid 85%* (FA) 3.0 l/t.

Experiment 3 was carried out in October 1991 using effluents tapped 12 and 21 days after ensiling from 11 different silages, 9 of which had received the same treatments as those used in expt. 2. In addition, two silages treated with a higher dose of formic acid were included in the experiment, using *Foraform* (F6) 6 l/t and *Maxgrass* (M) 6 l/t respectively. Ensiling procedures, compositions of silage additives, and determination of the composition of crops, silages, and effluents in the two experiments have been previously described (Randby, 1996). Chemical compositions of the fresh effluents used in expts. 2 and 3, as means for each silage additive treatment averaged over times of tapping, and as means for each time of tapping averaged over all silos, are presented in Table 1. Butyric and propionic acids were not detected, with the exception of propionic acid derived from *Maxgrass*.

Effluent storage

In all three experiments, batches of 500 g

Table 1. Chemical compositions of fresh effluents used in experiments 1, 2 and 3

Days after ensiling	Effluent type[1]	DM g/kg	g/kg DM							NH_3-N, g/kg TN		pH
			OM	CP	Sugar	Lactic acid	Formic acid	Acetic acid	Ethanol	Uncorr.	Corr.	
Expt.1												
	C	42		233	131	181	7	26	36	110	110	4.37
2	B[2]	43		239	195	205	2	14	37	49	49	4.27
	FA[3]	51		210	349	4	176	0	14	18	18	3.86
Expt.2												
	C	57	777	221	53	262	2	53	38	136	136	4.35
Aver-	H	56	771	218	75	251	2	50	34	124	124	4.30
age	N	53	778	213	84	286	2	29	28	96	96	4.17
of	L	55	781	207	123	264	1	22	31	90	90	4.21
2,	B	57	792	208	64	282	1	46	34	111	111	4.17
14	K	53	747	186	243	165	4	21	17	145	76	4.93
and	E	59	781	189	147	197	30	48[4]	16	90	90	4.26
49	F4	60	787	193	240	100	83	13	21	191	79	4.26
	FA	57	777	181	238	84	87	14	27	52	52	4.18
LSD5%		4	16	13	101	51	13	17	NS	32	19	0.37
2	Aver-	44	753	165	189	117	29	17	27	101	73	4.72
14	age	59	780	217	139	233	23	35	27	119	102	4.20
49		66	796	223	94	281	19	46	29	125	110	4.02
LSD5%		2	10	7	58	30	7	10	NS	18	11	0.21
Expt.3												
	C	54	872	136	239	224	0	61	57	171	171	4.10
	H	62	866	132	248	198	0	58	43	166	166	4.15
Aver-	N	62	855	131	377	237	0	39	48	135	135	4.02
age	L	65	886	141	167	225	0	59	83	152	152	4.07
of	B	62	875	127	267	226	0	58	47	166	166	4.03
12	K	62	848	126	431	145	3	38	17	166	87	4.46
and	E	56	870	142	369	144	19	60[5]	43	152	152	4.20
21	F4	62	903	125	611	56	69	18	25	276	135	4.35
	FA	66	878	120	602	44	66	20	24	111	111	4.17
	F6	64	890	122	633	40	97	13	22	311	117	4.24
	M	61	866	136	627	23	101	9	15	256	126	4.16
LSD5%		NS	20	13	91	11	13	6	30	26	31	0.12
12	Aver-	54	865	129	379	134	36	39	37	196	139	4.25
21	age	70	882	133	451	151	29	40	41	179	137	4.11
p		<0.001	0.002	NS	0.002	<0.001	0.02	NS	NS	0.007	NS	<0.001

[1] Silage additives used: Control (C), *Howden* (H), *Natuferm* (N), *Lactisil Plus* (L), *Biomax E* (B), *Kofa plus* (K), *Ensimax* (E), *Foraform* 4l/t (F4), *Formic acid* (FA), *Foraform* 6 l/t (F6), *Maxgrass* (M)
[2] Means of 2 and 4 l/t *Biomax E*
[3] Means of 3 and 4.5 l/t *Formic acid 85%*
[4] Value corrected for applied acetic acid: 32
[5] Value corrected for applied acetic acid: 43

Table 2. Effects of preservation (control (C) or 0.26% formic acid (F)) and surface sealing (control (C), average of 2 and 4 mm liquid paraffin (P), or lids) on composition and storage losses of the three types of effluents in experiment 1

Effluent type [1]	Stored with		n	DM g/kg	g/kg DM								NH_3-N, g/kg TN		pH	% losses				% of surface covered by mould
	Formic acid	Sealing			CP	Sugar	Lactic acid	Formic acid	Acetic acid	Prop. acid	Butyric acid	Ethanol	Uncorr.	Corr.		Mass	DM	Sugar	CP	
C	C	C	1	38	229	24	95	13	68	55	11	18	288	288	5.36	32.0	37.7	88.3	39.0	100
	C	P	2	42	228	29	293	7	59	0	0	36	147	147	3.98	4.5	2.8	78.5	5.3	15
	F	C	1	42	235	111	141	57	57	36	7	26	417	331	4.84	30.6	37.0	33.2	29.5	100
	F	P	2	48	207	100	187	99	25	4	2	39	231	119	3.88	4.4	-4.2	12.5	1.9	5
	C	Lid	1	38	236	26	258	8	64	5	0	29	134	134	4.22	0.3	9.6	81.1	8.5	100
B	C	C	2	36	227	26	295	7	70	37	0	25	243	243	5.01	28.2	40.0	91.7	43.1	100
	C	P	4	44	211	36	263	1	37	0	0	41	108	108	3.96	11.4	10.1	82.2	20.5	34
	F	C	2	41	205	23	200	60	59	27	0	28	287	166	4.45	30.2	39.3	91.9	42.2	100
	F	P	4	48	190	99	221	101	3	0	0	46	196	69	3.87	6.2	1.4	45.6	16.3	6
	C	Lid	2	41	199	31	322	3	50	3	0	68	120	120	4.05	0.3	5.2	84.2	21.1	55
FA	C	C	2	46	193	242	139	75	12	6	0	0	170	170	4.48	24.9	32.4	51.4	38.0	100
	C	P	4	49	183	416	4	128	0	0	0	8	30	30	3.99	4.0	6.4	-12.2	18.7	8
	F	C	2	68	175	379	2	213	0	0	0	2	165	64	3.75	24.0	4.1	-9.9	15.3	3
	F	P	4	55	164	373	2	225	0	0	0	9	165	31	3.72	4.5	2.2	-10.5	19.1	4
	C	Lid	2	48	180	418	4	136	0	0	0	5	37	37	3.96	0.2	6.0	-12.2	19.2	5
C	Mean		7	43	224	60	207	41	51	15	3	32	228	183	4.30	11.5	11.6	54.9	13.0	49
B			14	43	204	50	255	39	37	9	0	42	179	126	4.16	13.4	15.3	74.8	25.7	48
FA			14	53	177	374	22	162	2	1	0	6	108	56	3.94	9.5	8.5	-2.3	21.1	19
Mean	C	C	5	40	213	112	192	35	46	28	2	13	223	223	4.87	27.6	36.5	74.9	40.2	100
	C	P	10	46	203	187	165	53	27	0	0	27	84	84	3.97	7.1	7.2	43.7	16.7	20
	F	C	5	52	199	183	109	120	35	18	1	17	264	158	4.25	27.8	24.8	39.4	28.9	61
	F	P	10	51	183	209	127	150	6	1	0	30	190	64	3.81	5.2	0.6	16.6	14.5	5
	C	Lid	5	43	199	185	182	58	33	2	0	35	89	89	4.05	0.2	6.4	45.0	17.8	44
Stat. sign. p	Effluent type			0.01	<0.001	<0.001	<0.001	<0.001	0.002	NS	NS	<0.001	0.002	0.001	NS	0.06	NS	<0.001	0.08	NS
	Storage			0.08	0.002	NS	NS	<0.001	0.06	0.05	NS	0.1	<0.001	0.003	0.006	<0.001	0.006	0.06	0.01	0.02
	Interaction			<0.001	NS	0.04	0.03	<0.001	<0.001	<0.001	<0.001	0.09	<0.001	<0.001	<0.001	NS	<0.001	0.006	0.001	0.02

1) For explanation, see Table 1

effluent were stored at 15-20°C in glass jars with an open surface area of 58 cm^2. The jars were weighed at the beginning and end of the storage period. In expts. 1 and 2 the jars were not covered. A considerable proportion of effluent evaporated during the storage period when not sealed with paraffin or a lid. In expt. 3, lids were placed loosely on the jars to reduce evaporation, and to restrict the contamination of neighbouring jars from effluents with extensive mould growth. The lids were not tightened, however, and were removed 2-3 times a week to expose the effluent to a normal atmosphere.

Experiment 1

For three types of effluent, formic acid was tested as a preservative at two doses, and liquid paraffin layers were tested as sealing treatments at two thicknesses. The following factorial design was used, with two replicates per treatment :

Type of effluent :	C, B, FA
Preservative :	0, 0.13%, 0.26% formic acid (0, 0.2% and 0.4% *Foraform*)
Sealant :	0,2mm,4mm paraffin

The quantity of C effluent available was too small and hence one complete replicate, in addition to the 0.13% dose of formic acid of the other replicate, was omitted. In addition to the factorial design above, one jar was filled with C effluent, and two jars with B and FA effluent respectively, and sealed with lids as an alternative sealing treatment. The experiment comprised a total of 47 jars of effluent stored for 25 days.

Experiment 2

Formic acid *(Foraform)* was investigated as a preservative, and liquid paraffin layers as sealing treatments, with 27 types of fresh effluent (effluent tapped 2, 14, and 49 days after ensiling from 9 silages treated with different additives). The following factorial design was used :

Type of effluent :	C, H, N, L, B, K, E, F4, FA
Tapped following ensiling :	2 d, 14 d, 49 d
Preservative :	0 and 0.26% formic acid (0, 0.4% *Fora form*)
Sealant :	0, 4 mm paraffin

A total of 108 jars of effluent, tapped at 2, 14 and 49 days following ensiling, were stored for 33, 28, and 29 days, respectively.

Experiment 3a

The combined use of 0.13% formic acid (0.15% *Formic acid 85%*) and surface sealing with 4 mm of liquid paraffin was compared with the control treatment (no preservative or sealing) for 22 types of fresh effluent (effluent tapped 12 and 21 days following ensiling from 11 silages treated with different additives). The following factorial design was used :

Type of effluent :	C, H, N, L, B, K, E, F4, FA, F6, M
Tapped following ensiling :	12 d, 21 d
Preservative and sealant :	none (C), both (F+P)

A total of 44 jars of effluent, tapped 12 and 21 days following ensiling, were stored for 33 and 32 days, respectively.

Experiment 3b

Potassium sorbate was compared with formic acid as an effluent preservative. As a surface sealing treatment, waste deep-fat (vegetable oil, used for frying potatoes, etc.) was compared with liquid paraffin.

Effluents from two silages, tapped at two times, were used according to the following factorial design :

Type of effluent : N, FA
Tapped following ensiling :12 d, 21 d
Preservative :C, 0.13% formic acid (0.15% *Formic acid 85%*), 0.01% K-sorbate
Sealant :C, 4 mm paraffin, 4 mm waste deep-fat

A total of 36 jars (8 of which were used in both expts. 3a and 3b) were stored as in expt. 3a.

Experiment 3c
Sorbic acid and the propyl ester of parahydroxy benzoic acid (PHB), both widely used as food preservatives, were investigated as components of the paraffin surface layer. Three different doses of the two preservatives were mixed into the paraffin prior to pouring it onto effluent surfaces in the jars. *Natuferm* and FA effluent tapped 12 days after ensiling, and C and F4 effluent tapped 21 days after ensiling, were used in this experiment according to the following factorial design :

Type of effluent - tapped at day :
N-12, FA-12, C-21, F4-21
Preservative (mixed into paraffin) :
Sorbic acid, PHB-propylester
Preservative dose : 1, 5, 10 g/l paraffin

A total of 24 jars of effluent, tapped 12 and 21 days following ensiling, were stored for 215 and 206 days, respectively.

Identification and quantification of moulds and yeasts

In all experiments the surface of jar-stored effluent was appraised 2-3 times weekly, and the proportion of surface area covered with fungal growth was recorded as a measure of extent of moulding. In expt. 3 the appearance (colour and texture) of the various growth areas on the surface was noted, and the fungi were subcultured. The surface mould colony was gently touched with a heat-sterilized platina loop, and a three-point inoculation was prepared on maltose/yeast sucrose medium (MYSA) (Stenwig et al. 1992). All plates were incubated for 7 days at 25°C.

The following media were used for subcultures: malt extract agar (MEA), according to Blakeslee (Pitt 1979), Czapek yeast extract agar (CYA) (Pitt 1979), yeast extract sucrose agar (YES) (Samson & van Reenen-Hoekstra 1988), creatine sucrose agar (CREA) (Frisvad 1981), nitrite sucrose agar (NO_2) (Frisvad 1981), potato dextrose agar (PDA) (Booth 1971), and yeast glucose peptone agar with chloramphenicol (modified Sabourauds medium) (SAB) (Barnett et al. 1983).

Penicillium spp. were subcultured on MEA, CYA, and YES at 25°C, and on CREA and NO_2 at 20°C, at normal atmosphere for 7 days. Some isolates were inoculated in apples according to Frisvad (1981). The isolates were identified according to Pitt (1979), Frisvad (1981, 1985), and Frisvad & Filtenborg (1983). *Aspergillus/Eurotium* spp. were subcultured on MEA and CYA with 2% and 40% glucose at 25°C for 7 days at normal air atmosphere, and were identified at group level according to Raper & Fenell (1977). *Mucorales* (*Mucor* spp. and *Rhizopus* spp.) were subcultured on MEA and PDA and identified by genus according to Samson & van Reenen-Hoekstra (1988). *Geotrichum* spp. were subcultured on MEA and SAB at 25°C for 7 days at normal air atmosphere, and were identified according to Barnett & Hunter (1972) and Samson & van

Table 3. Effects of different levels of formic acid and different thicknesses of the surface sealing on composition and storage losses of effluent from *Biomax E* silage in experiment 1

% formic acid	Paraf-fin, mm	n	DM, g/kg	g/kg DM							NH_3-N, g/kg TN		pH	% losses				% of surface covered by mould
				CP	Sugar	Lactic acid	Formic acid	Acetic acid	Prop. acid	Etha-nol	Un-corr.	Corr.		Mass	DM	Sugar	CP	
0	0	2	36	227	26	295	7	70	37	25	243	243	5.01	28.2	40.0	91.7	43.1	100
0.13	0	2	36	199	18	163	34	66	21	29	315	243	5.19	29.4	44.5	94.4	51.1	100
0.26	0	2	41	205	23	200	60	59	27	28	287	166	4.45	30.2	39.3	91.9	42.2	100
		LSD5%	NS	NS	NS	NS	12	NS	NS	NS	20	37	NS	NS	NS	NS	NS	NS
0	Mean	4	44	210	37	263	1	37	0	41	107	107	3.95	11.4	10.1	82.1	20.5	34
0.13	of 2	4	48	188	77	221	43	18	0	48	141	68	3.88	6.4	-0.4	57.7	18.7	5
0.26	and 4	4	48	189	99	221	101	3	0	45	195	69	3.87	6.2	1.4	45.6	16.3	6
		LSD5%	4	NS	NS	NS	15	13	NS	NS	27	26	0.04	2.2	6.9	NS	NS	NS
0	0	2	36	227	26	295	7	70	37	25	243	243	5.01	28.2	40.0	91.7	43.1	100
0	2	2	45	203	34	287	1	34	0	38	114	114	4.01	15.9	12.8	84.2	25.8	58
0	4	2	43	219	39	240	0	41	0	45	101	101	3.91	6.9	7.4	80.2	15.3	10
		LSD5%	NS	NS	NS	NS	4	21	14	7	80	80	0.45	8.7	9.3	4.6	5.1	NS
Mean	0	4	39	201	20	181	47	62	24	28	301	204	4.82	29.7	41.9	93.1	46.6	100
of 0.13	2	4	49	187	70	230	76	09	0	48	171	73	3.88	8.5	1.2	61.9	18.8	6
and	4	4	47	190	107	213	67	12	0	45	165	64	3.86	4.1	-0.3	41.1	16.3	5
0.26		LSD5%	4	NS	55	NS	16	19	8	15	20	17	0.29	2.4	7.9	31.3	8.2	3

Table 4. Effects of preservation (control (C) or 0.26% formic acid (F)) and surface sealing (control (C) or 4 mm paraffin (P)) on composition and storage losses of effluent tapped at various times following ensiling in experiment 2

Days after ensiling	Stored with		n	DM, g/kg	g/kg DM											pH	% losses					% of surface covered by mould
															NH_3-N, g/kg TN							
	Formic acid (F)	Paraffin (P)			OM	CP	Sugar	Lactic acid	Formic acid	Acetic acid	Prop. acid	Butyr. acid	Ethanol	Uncorr.	Corr.		Mass	DM	OM	CP	Sugar	
2	C	C	9	57	581	153	33	52	6	65	36	20	10	297	265	7.47	62.1	50.8	60.0	52.9	88.2	89
	C	P	9	49	737	163	57	171	38	79	4	0	41	158	136	4.57	13.1	4.1	6.7	5.8	68.3	0
	F	C	9	90	743	171	169	84	126	24	7	3	1	304	233	4.62	50.8	7.6	11.1	-2.8	7.4	17
	F	P	9	52	771	141	165	123	122	29	0	2	21	272	103	4.15	4.9	-4.2	-4.0	5.0	9.8	0
14	C	C	9	112	688	230	52	105	37	43	20	3	3	157	143	6.36	65.6	33.7	39.2	28.3	63.2	67
	C	P	9	61	779	211	47	271	26	57	2	0	37	134	118	4.14	3.0	-0.1	0	2.7	49.9	0
	F	C	9	151	785	221	105	241	102	31	0	0	0	227	187	3.99	59.8	3.8	4.7	-3.5	14.2	0
	F	P	9	66	798	191	73	237	104	43	0	0	24	214	110	3.94	1.6	-4.5	-5.4	3.4	26.1	0
49	C	C	9	68	761	239	50	182	24	59	32	12	5	203	190	5.05	27.8	25.4	28.2	20.9	49.0	71
	C	P	9	67	805	227	59	295	23	51	2	1	32	121	106	4.03	2.8	1.2	0.2	0.1	27.0	12
	F	C	9	88	806	227	72	294	83	40	1	2	0	242	177	3.93	25.2	5.6	5.5	-0.4	15.6	11
	F	P	9	72	824	209	68	282	95	46	0	2	29	205	114	3.87	1.3	-2.2	-4.8	0	14.7	0
Stat. sign. p	Time after ensilage			<0.001	<0.001	<0.001	<0.001	<0.001	0.004	NS	NS	0.03	NS	<0.001	0.02	<0.001	<0.001	0.03	0.003	0.02	0.001	NS
	Formic acid			<0.001	<0.001	0.002	<0.001	0.001	<0.001	<0.001	<0.001	0.009	<0.001	0.001	NS	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Paraffin			<0.001	<0.001	<0.001	NS	<0.001	NS	0.06	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.03	<0.001
	Interaction T x F			NS	0.008	NS	<0.001	0.009	0.001	0.002	NS	NS	0.09	NS	NS	0.03	<0.001	0.05	0.04	0.04	<0.001	NS
	Interaction T x P			<0.001	0.01	NS	0.006	NS	NS	NS	NS	0.08	NS	0.06	0.05	0.01	<0.001	0.06	0.05	NS	NS	NS
	Interaction F x P			<0.001	<0.001	0.005	0.003	<0.001	NS	NS	0.002	0.003	NS	0.02	NS	<0.001	0.01	<0.001	<0.001	<0.001	0.002	<0.001

Reenen-Hoekstra (1988). The presence of yeasts was verified microscopically, but not identified.

Chemical analyses

Samples of fresh and stored effluent were analysed for dry matter (DM), total nitrogen (TN), NH_3-N, total sugar, lactic, acetic, formic, propionic and butyric acids, ethanol and pH, and DM content corrected for volatiles, as described by Randby (1997a). Corrections in NH_3-N and TN were made for NH_3 derived from *Foraform, Maxgrass*, and *Kofa plus* as described by Randby (1996). Corrected and uncorrected values for NH_3-N (g/kg TN) are presented in the tables. Corrections were not made for acetic acid derived from *Ensimax*, or for propionic acid derived from *Maxgrass*, except where indicated in the tables.

Calculation of storage losses

Effluent weight loss, and losses of DM, organic matter (OM), crude protein (CP), and sugar were calculated by weighing and by chemical analyses. The quantity of preservative was added to the initial value, such that losses were estimated for effluent including preservative. The fat surface seal was excluded from calculation of losses by excluding it from samples of stored effluent, and by subtracting its weight at the end of the storage period. However, small quantities of the fat may have been mixed into the effluent samples, which may have been responsible for the calculation of some losses as negative.

Statistical analyses

The NM software package (Nissen 1990) was used for all statistical analyses. Since probability levels between 0.05 and 0.1 were considered to indicate trends, probabilities up to $p=0.1$ are presented. NS is used for $p>0.1$. Results were considered to be statistically significant at $p<0.05$.

In expt. 1, the effects of the three types of effluent and the five storage treatments were tested by two-way analysis of variance, with unequal but proportional subclass numbers (Snedecor & Cochran 1967). The mean square of the interaction between effluent types and storage treatments was tested against the within-subclasses mean square, and was observed to be highly significant for most parameters. The main effects of effluent types and storage treatments were therefore tested using interaction mean square as the error term.

All other data in the three experiments were tested by two-way or factorial analyses of variance. The highest level of interaction in factorial variance analyses was used as the error term for all main effects and lower levels of interaction. Least significant differences were calculated only when the analysis of variance showed significant results at the 0.05 level (LSD5%).

Results

In assessing the quality of different types of effluent after storage, it should be noted that the compositions of initial fresh effluents varied (Table 1), and so differences between treatments cannot be completely attributed to changes occurring during storage.

Experiment 1

The effects of different storage conditions on chemical composition and losses are presented in Table 2. Formic acid effluent had the highest overall quality and C effluent the poorest, although significant interactions with storage conditions were apparent. Butyric acid was produced only

in C effluent, primarily when effluent was stored without a sealing treatment. Propionic acid was produced predominantly in C and B effluents when stored without paraffin sealing. Almost no changes occurred in FA effluent during the storage period except when stored with neither sealing nor preservative. Sugar contents remained high, and ammonia levels were low for all other storage treatments.

For all three effluents, DM losses were within acceptable limits when stored with a sealing treatment. Dry matter losses were also small in FA effluent stored without paraffin sealing when 0.26% formic acid was added. Compared to C and B effluents, microbial growth on the surface of FA effluent was retarded. The use of lids and also liquid paraffin markedly improved effluent quality compared with no seals. The production of acetic, propionic, and butyric acids was strongly reduced, as were proteolysis and effluent surface moulding. Dry matter losses increased along with increase in the extent of moulding, except in lid-sealed jars. Sealing generally reduced proteolysis and DM losses, while the addition of formic acid reduced sugar losses.

In evaluating different levels of formic acid and liquid paraffin, only B effluent was studied (Table 3). Control effluent was excluded because of missing observations, and FA effluent was omitted since fermentation and moulding occurred only to a negligible extent during storage. Effluent stored without sealing treatments was generally of poor quality, and the addition of formic acid at the lowest dose did not significantly improve effluent quality. Addition of the highest dose of formic acid, however, significantly reduced ammonia formation. In effluents stored with paraffin, addition of the lowest dose of formic acid clearly improved quality, and appeared to be sufficient. An increase in dose of formic acid, however, increased average sugar content.

Storage with the thinnest paraffin layer improved effluent quality and was observed to be sufficient, irrespective of whether formic acid was added or not. Increased thickness of the surface layer did reduce evaporation and CP losses, but increased ethanol fermentation in effluent stored without formic acid.

Experiment 2

The effects of preservatives, surface sealing, and time of tapping following ensiling are presented in Table 4. Effluent stored with formic acid, but with no surface sealing treatment, decreased in weight as a result of evaporation, at a rate of 1.3 kg per m^2 per day, resulting in near-doubling of DM concentrations. When stored with neither additive nor surface sealing treatment, weight losses were equivalent to 1.5 kg per m^2 per day. This loss, however, was also due to serious deterioration and DM losses caused by moulding and poor fermentation, and resulted in only small increases in DM concentrations.

Lactic acid concentrations were stable throughout the storage time when formic acid was added. When formic acid was not added, however, lactic acid concentrations increased in effluent stored with surface sealing, and decreased in effluent stored without sealing treatments. Preservation with formic acid generally restricted fermentation to acetic, propionic, and butyric acids, and ethanol, and a high sugar content was maintained in the stored effluent. Mould growth and storage losses were also reduced.

Sealing of the effluent surface with 4 mm paraffin markedly reduced evaporation, storage losses, and mould growth. Fermentation quality was

Table 5. Quality and losses of various types of effluents after poor (C) and good (0.26% formic acid (F) + 4 mm paraffin (P)) storage conditions in experiment 2. Means of effluent tapped at 2, 14 and 49 days following ensiling

Storage	Effluent type[1]	n	DM, g/kg	g/kg DM										NH_3-N, g/kg TN		pH	% losses					% of surface covered by mould
				OM	CP	Sugar	Lactic acid	Formic acid	Acetic acid	Prop. acid	Butyr. acid	Etha-nol	Un-corr.	Corr.			Mass	DM	OM	CP	Sugar	
C	C	3	68	717	244	38	78	12	87	44	21	8	274	274	6.63		47.2	41.3	45.8	35.2	55.6	100
	H	3	85	703	265	41	86	4	61	25	3	3	192	192	6.46		53.3	34.1	39.9	20.3	56.2	100
	N	3	64	602	220	39	64	13	35	47	10	3	225	225	7.19		53.7	48.3	56.4	45.9	68.3	100
	L	3	58	615	201	37	65	3	37	45	6	25	209	209	7.16		53.5	54.5	63.8	55.1	85.4	100
	B	3	80	709	227	45	97	15	80	42	20	10	240	240	6.23		53.7	40.0	46.1	34.8	58.9	100
	K	3	57	559	153	34	51	1	43	25	12	0	309	246	8.08		55.9	54.3	64.4	59.8	93.8	100
	E	3	116	776	187	56	315	29	48[2]	0	7	0	122	122	3.99		48.2	3.8	4.6	4.5	46.6	13
	F4	3	95	708	189	61	141	59	53	14	14	0	237	124	5.50		51.0	26.7	30.1	25.1	64.9	33
	FA	3	88	704	180	56	120	64	56	22	12	4	162	162	5.41		50.0	27.0	30.9	25.6	71.4	33
		LSD5%	35	119	47	NS	118	42	NS	NS	NS	NS	NS	NS	2.07		NS	NS	33.2	NS	27.0	47
F+P	C	3	62	794	204	44	264	91	56	2	1	28	237	147	4.05		2.7	-0.2	-0.7	2.5	13.5	0
	H	3	62	787	193	70	239	88	47	0	0	27	235	136	4.01		1.9	-2.3	-2.7	3.6	-0.8	0
	N	3	61	798	186	60	277	79	42	1	0	20	215	104	3.90		1.7	-6.3	-6.5	3.9	14.9	0
	L	3	61	797	186	120	251	84	30	0	0	23	204	94	3.97		1.1	-4.2	-4.6	2.2	-5.4	0
	B	3	64	801	186	47	288	100	50	0	2	25	223	121	3.92		1.5	-4.1	-3.9	2.9	21.3	0
	K	3	63	769	170	164	146	91	22	0	0	37	281	132	4.29		9.7	-1.9	-2.9	0.6	29.8	0
	E	3	64	816	172	97	238	108	52[3]	0	3	11	205	96	3.87		1.8	-2.0	-5.0	2.2	19.7	0
	F4	3	68	808	167	172	124	163	28	0	1	20	289	92	3.94		1.3	-6.5	-8.0	4.2	22.8	0
	FA	3	64	810	159	143	97	161	28	0	2	29	183	61	3.92		1.5	-5.4	-8.3	3.1	36.0	0
		LSD5%	NS	21	20	92	30	28	13	NS	NS	NS	30	15	0.13		2.3	NS	NS	NS	NS	NS
C	Mean	27	79	677	207	45	113	22	56	29	12	6	219	199	6.29		51.8	36.6	42.4	34.0	66.8	76
F+P	Mean	27	63	798	180	102	214	107	39	0	1	24	230	109	3.99		2.6	-3.6	-4.7	2.8	16.9	0
Stat. sign. p	Effluent type		0.03	0.02	<0.001	0.05	<0.001	<0.001	NS	NS	NS	0.07	NS	NS	0.02		0.01	NS	0.05	0.09	0.02	0.002
	Storage		0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.02	<0.001	0.003	<0.001	NS	0.002	<0.001		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Interaction		0.07	NS	0.01	NS	<0.001	NS	NS	NS	NS	0.08	NS	NS	0.06		NS	NS	0.08	0.07	0.05	0.002

[1] For explanation, see Table 1
[2] Value corrected for applied acetic acid: 40
[3] Value corrected for applied acetic acid: 37

Table 6. Quality and losses of various types of effluents after poor (C) and good (0.13% formic acid (F) + 4 mm paraffin (P)) storage conditions in experiment 3a. Means of effluent tapped at 12 and 21 days following ensiling

Stor-age	Effluent type [1]	n	DM, g/kg	g/kg DM									NH_3-N, g/kg TN		pH	% losses					% of surface covered by mould
				OM	CP	Sugar	Lactic acid	Formic acid	Acetic acid	Prop. acid	Butyr. acid	Etha-nol	Un-corr.	Corr.		Mass	DM	OM	CP	Sugar	
C	C	2	37	825	146	35	270	2	89	14	17	51	97	97	4.26	10.6	38.8	52.3	33.8	91.6	100
	H	2	40	775	164	32	242	2	65	18	13	45	85	85	4.47	14.1	43.3	57.3	29.6	93.2	100
	N	2	35	772	157	36	203	3	61	34	39	59	114	114	4.76	12.2	50.4	65.0	40.4	95.3	100
	L	2	41	776	158	47	219	3	62	31	15	53	91	91	4.61	19.3	49.6	64.9	43.3	85.8	100
	B	2	39	827	149	37	182	4	137	14	7	34	81	81	4.56	12.9	44.8	58.3	35.4	92.4	100
	K	2	38	746	157	33	100	7	36	25	85	34	192	93	5.77	14.2	46.6	62.3	33.4	96.0	100
	E	2	37	807	157	46	284	23	68[2]	12	3	61	148	148	4.24	10.3	40.9	55.2	34.7	92.9	100
	F4	2	33	774	180	36	81	19	60	41	69	38	287	113	6.23	14.0	53.6	69.4	34.8	97.4	100
	FA	2	22	708	189	49	34	20	47	54	14	40	257	257	7.48	13.9	69.9	80.9	56.0	97.8	100
	F6	2	42	792	168	44	135	23	57	50	23	18	262	56	5.57	17.5	45.1	58.3	27.6	96.4	100
	M	2	50	818	157	156	269	49	41	13[4]	0	6	170	39	4.05	12.4	28.3	39.6	16.3	82.2	100
		LSD5%	NS	61	NS	NS	NS	15	31	NS	NS	NS	140	NS	NS	4.3	16.0	16.6	16.8	NS	NS
F+P	C	2	60	881	131	96	272	30	72	0	0	62	188	188	3.81	1.0	-6.5	10.7	-6.1	61.2	1
	H	2	66	865	138	158	209	28	66	0	0	61	148	148	3.99	2.4	-1.9	14.8	-9.0	31.4	2
	N	2	59	869	136	102	265	28	48	0	0	127	127	127	3.93	7.1	12.6	31.8	6.9	75.1	55
	L	2	68	873	138	86	229	23	60	0	0	98	152	152	3.92	1.8	-0.7	20.6	-1.0	43.8	1
	B	2	65	880	131	126	244	25	69	0	0	68	148	148	3.88	1.1	-2.6	14.4	-8.7	54.2	2
	K	2	66	860	130	431	135	30	37	0	0	19	200	130	4.24	0.8	-3.0	5.5	-8.8	-1.8	0
	E	2	63	870	144	134	169	49	69[3]	0	0	111	177	177	4.03	6.5	-1.5	23.9	-5.3	64.1	4
	F4	2	60	856	151	96	86	94	38	0	0	197	300	187	4.24	8.8	11.7	47.6	-9.9	86.7	13
	FA	2	64	874	134	384	45	104	21	0	0	130	105	105	4.07	2.9	5.7	30.8	-6.6	35.7	20
	F6	2	69	885	130	344	70	115	31	0	0	62	294	118	4.09	4.6	0	21.7	-8.9	41.9	18
	M	2	69	890	136	608	23	133	10	9[5]	0	13	276	165	4.03	0.8	-9.9	4.4	-13.1	-0.8	0
		LSD6%	NS	NS	NS	301	49	32	20	2	NS	NS	48	NS	0.09	NS	NS	21.8	NS	NS	NS
C	Mean	22	38	784	162	50	184	14	66	28	26	41	162	107	5.09	13.8	46.5	60.3	35.1	92.8	100
F+P	Mean	22	65	873	137	233	159	60	48	1	0	86	192	150	4.02	3.4	0.3	20.6	-6.4	44.7	10
Stat. sign. p	Effluent type		0.03	0.01	NS	0.02	0.008	<0.001	<0.001	NS	NS	NS	0.003	NS	0.04	NS	0.05	0.003	0.02	NS	NS
	Storage		<0.001	<0.001	<0.001	<0.001	NS	<0.001	<0.001	<0.001	0.005	0.008	0.07	0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Interaction		NS	0.08	NS	NS	NS	<0.001	0.01	NS	NS	NS	NS	0.08	0.09	0.08	NS	NS	NS	NS	NS

[1] For explanation, see Table 1
[2] Value corrected for applied acetic acid: 43
[3] Value corrected for applied acetic acid: 53
[4] Value corrected for applied propionic acid: 2
[5] Value corrected for applied propionic acid: 0

significantly improved, as shown by reduced contents of propionic and butyric acids, and reduced NH_3-N values. Ethanol fermentation increased, however, when the surface was sealed with paraffin, especially if formic acid was not added.

Fresh effluents tapped at two days following ensiling were of good quality, with a high sugar content and low concentrations of organic acids and NH_3-N. However, good storage conditions were required for the maintenance of high quality. As shown in Table 4, effluents tapped at two days following ensiling maintained higher quality (higher sugar content and lower concentrations of fermentation products) than other effluents when stored with preservative and sealed. Effluent tapped at later stages was otherwise better.

The storage quality of the nine effluent types, following storage under poor (C) or good (preservative + sealing) conditions, is presented in Table 5. *Ensimax* effluent maintained surprisingly good quality, with OM losses of only 5%, when exposed to the control treatment. All other types of effluent deteriorated seriously, with OM losses exceeding 30% in such storage conditions. However, effluents drained from silages treated with formic-acid-based additives were less susceptible to moulding than other effluents.

When stored with both preservative and surface sealing, all effluents were well preserved, and no moulding occurred. Large differences in composition were observed, but these could be attributed to compositional differences in the initial fresh effluent. Effluents with a high initial sugar content (K, F4 and FA effluent) stored with surface sealing, but without preservative, were subject to extensive ethanol fermentation during storage.

Experiment 3

A total of 170 fungal isolates were examined from the effluent surfaces. Thirty-four of the isolates were verified microscopically as yeasts, but not identified. The distribution of the isolates was as follows:

No	Genus/species
65	*Penicillium roquefortii*
6	*Penicillium atramentosum*
4	*Penicillium puberulum*
2	*Penicillium fellutanum*
1	*Penicillium chrysogenum*
1	*Penicillium crustosum*
1	*Penicillium griseoroseum*
1	*Penicillium implicatum*
1	*Penicillium melanochlorum*
1	*Eurotium amstelodami (Aspergillus hollandicus)*
4	*Mucor* spp.
3	*Rhizopus* spp.
46	*Geotrichum* spp.
34	Yeasts

Geotrichum or yeasts were often the first organisms detected on the effluent surface. Their appearance usually resembled a thin membrane covering the entire surface and growing thicker with time. Colonies of *Penicillium* spp., initially white but gradually changing to green or blue, were usually detected later.

Experiment 3a

The qualities of the 11 different types of effluents following storage under poor (C) and good (preservative + sealing) conditions are presented in Table 6, and the corresponding moulds and yeasts identified on the surfaces are listed in Table 7. Mould growths on effluents appeared as early as 1-2 days when stored under poor conditions. After one week, growth had begun in all effluent types, including M, K, and FA effluents, in

which the onset of moulding was longest delayed. *Penicillium roquefortii* and yeasts were most frequently identified in effluents from *Foraform, Formic acid* and *Maxgrass* treated silages, whereas *Geotrichum* was most frequently found in the other effluents. *Maxgrass* was the only type of effluent that maintained acceptable fermentation quality after poor storage conditions, but its surface moulded as other effluents, and an OM loss of nearly 40% was unacceptably high.

The effects of adding 0.13% formic acid and 4 mm liquid paraffin to the effluents were highly significant for all parameters apart from lactic acid content. Averaged over all effluents, relative to untreated controls, DM content increased from 38 to 65 g/kg, and OM losses decreased from 60% to 21%, when both preservative and paraffin were added. Moulding was absent or delayed compared to the control treatment, and all effluent types maintained acceptable quality.

Marked differences in composition were observed between various effluents, but these differences were largely attributed to compositional differences already present in fresh effluent. The composition of *Maxgrass* and *Kofa plus* effluents remained almost unchanged during storage when both formic acid and paraffin were added. Effluent from silages treated with the other formic-acid-based additives also maintained acceptable quality, although ethanol fermentation was too extensive. The contents of acetic acid or ethanol in the other effluents were higher than desired.

Storage losses were lower in effluent tapped 12 days than in effluent tapped 21 days following ensiling. Otherwise, differences between effluent from the two periods of tapping were small.

Experiment 3b

Comparisons between formic acid and K-sorbate as preservatives, and between liquid paraffin and waste deep-fat as surface sealing treatments, are presented in Table 8. Formic acid effluent deteriorated seriously when stored without surface sealing, a situation not prevented by either of the two additives. The quality of *Natuferm* effluent was better than that of *Formic acid* effluent when no sealing treatment was used, and was improved when preserved with formic acid, but not with K-sorbate.

Formic acid, but not K-sorbate, preserved a high sugar content and restricted ethanol fermentation in FA effluent stored with sealing. Both preservatives had similar effects on N effluent when stored with a sealing treatment.

As shown in Table 7, *Geotrichum*, yeasts, and *Penicillium roquefortii* were identified in similar numbers from effluents preserved with K-sorbate and formic acid. From FA effluent preserved with formic acid *Penicillium puberulum* was also identified, and from N effluent preserved with K-sorbate *Penicillium atramentosum*, *Penicillium implicatum*, and *Penicillium griseoroseum* were identified. Apart from *P. atramentosum*, these species covered only minor parts of the effluent surfaces.

During transportation to the storage place, effluent tapped at 12 days following ensiling was shaken, and the added surface layers were disturbed. The soft paraffin immediately levelled out, and again covered the entire surface. Crevices remained in the harder waste deep-fat, however, creating susceptible points for fungal attack. As a possible result, the waste-fat sealed effluent had somewhat poorer quality than paraffin-sealed effluent, for effluent tapped at 12 days

Table 7. Moulds and yeasts identified in experiment 3

Effluent type 1)	Stored with: Preservation 2)	Stored with: Sealing 3)	Total jars	Jars with moulding: n	Jars with moulding: Days to onset of mould growth	No. of identified moulds and yeasts: Total	Distribution: *Geotrichum* Yeasts	Distribution: *P. roqueforti*	Distribution: Others
Expt. 3a									
C	C	C	2	2	2	5	4		1
H			2	2	2	7	5	1	1
N			2	2	2	6	4	1	1
L			2	2	1	6	2	2	1	1
B			2	2	3	7	3	1	1	2
K			2	2	5	4	3	1		
E			2	2	3	3	3			
F4			2	2	4	5	2	1	1	1
FA			2	2	6	7	1	1	4	1
F6			2	2	3	6		2	1	3
M			2	2	6	3		2		1
C	F	P	2	1	23	1			1	
H			2	2	20	1		1		
N			2	2	10	3	2	1		
L			2	1	7	1		1		
B			2	2	28	0				
K			2	0		0				
E			2	2	19	2				2
F4			2	2	13	2		1	1	
FA			2	1	12	1			1	
F6			2	1	19	1			1	
M			2	0		0				
Average	C	C	22	22	3	59	27	12	8	12
average	F	P	22	14	17	12	2	4	4	2
Expt. 3b									
N+FA	F	4)	12	9	9	15	4	5	5	1
	Ks		12	9	10	20	4	5	6	5
N+FA	5)	P	12	10	10	14	4	3	7	
		WF	12	6	13	9	1	2	3	3
Expt. 3c 6)										
FA-12	7)	P	6	6	15	17	2		15	
N-12			6	6	78	14	6	1	7	
C-21			6	6	129	7		1	6	
F4-21			6	6	9	21		5	11	5
Average	S	P	12	12	92	33	5	4	22	2
average	PHB		12	12	24	26	3	3	17	3
	g/l 8)									
Average	1	P	8	8	46	27	7	2	16	2
average	5		8	8	62	18		2	14	2
	10		8	8	65	14	1	3	9	1

1) For explanation, see Table 1
2) C=Control; F=0.13% formic acid; Ks=0.01% K-sorbate; S=sorbic acid and PHB=PHB-propylester, both mixed into paraffin
3) C=Control; P=4 mm liquid paraffin; WF= 4 mm waste deep-fat
4) Average of effluent without sealing or sealed with P or WF
5) Average of effluent without preservation or preserved with F or Ks
6) Storage period prolonged to approx. 210 d
7) Average of effluent preserved with 1, 5 and 10 g S or PHB per l paraffin
8) g S or PHB per l paraffin

Table 8. Effects of 0.13% formic acid (F) and 0.01% K-sorbate (Ks) as preservatives, and of 4 mm liquid paraffin (P) and waste deep-fat (WF) as surface sealing for effluent in experiment 3b

Preservation	Sealing	n	DM, g/kg	g/kg DM									NH_3-N, g/kg TN	pH	% losses					% of surface covered by mould
				OM	CP	Sugar	Lactic acid	Formic acid	Acetic acid	Prop. acid	Butyr. acid	Ethanol			Mass	DM	OM	CP	Sugar	
F	1)	12	53	833	141	181	159	43	37	9	4	97	144	4.67	12.0	26.9	44.7	20.1	69.7	53
Ks		12	51	809	151	67	161	26	45	14	9	137	175	4.86	12.2	27.9	49.4	19.7	87.2	39
Stat. sign. p			NS	0.002	NS	0.01	NS	0.003	NS	NS	NS	0.05	0.02	0.07	NS	NS	NS	NS	0.03	0.08
2)	P	12	60	862	136	131	183	48	44	1	1	166	141	4.06	6.4	11.8	36.5	4.1	74.6	27
	WF	12	61	856	130	125	187	40	40	2	1	166	148	4.05	9.1	13.8	38.2	11.6	78.6	20
Stat. sign. p			NS	NS	NS	NS	NS	0.09	NS	NS	NS	NS	NS	NS	0.01	NS	NS	0.01	NS	NS

1) Average of C, 4 mm paraffin and 4 mm waste deep-fat
2) Average of C, 0.13% F and 0.01% K-sorbate

following ensiling. However, effluent tapped at 21 days following ensiling was not shaken, and so no moulding occurred, and the fermentation quality of that effluent tended to be better when waste fat was used as compared to paraffin. The overall results indicated no differences between the two types of fat used for surface sealing.

Experiment 3c

The effects of mixing preservatives into the surface layer of paraffin are presented in Tables 7 and 9. Since no effluent was stored without a sealing treatment in this part of the experiment, and the treatments were expected to be effective, the storage period was prolonged. Acetic acid content was extremely high in effluent stored for such a prolonged period. F4 effluent stored successfully only when its surface layer had received the highest dose (10 g/l) of sorbic acid. When 1 g/l sorbic acid, or 1 or 5 g/l PHB propylester was applied, F4 effluent was subject to butyric acid fermentation, as was also N effluent when the lowest dose (1 g/l) of sorbic acid was applied. Sorbic acid tended to be better than PHB propylester in maintaining sugar contents, and was significantly better in restricting ethanol fermentation and in reducing DM and OM losses.

Mould growth was diffuse in this experiment, being located partly under the paraffin layer, and was therefore difficult to quantify. *Penicillium roquefortii* was most frequently identified in all four types of effluents and by the use of both preservatives at all three levels. *Penicillium atramentosum* and *Penicillium fellutanum* were isolated from F4-21 effluent when stored with sorbic acid, and when the same effluent type was stored with PHB, three isolates were all identified to be *Rhizopus* spp. Moulding started at a later stage when sorbic acid was used as compared to PHB propylester, but the total areas of fungal growth were of the same size for the two preservatives at the end of the experiment. An increasing dose of both preservatives delayed mould growth, improved effluent quality, and reduced storage losses.

Discussion

Effluent types (silage additives), and time of tapping following ensiling

The significant influence of silage additives on chemical composition of effluent was apparent in fresh effluent as early as two days following ensiling (Randby 1996c). When effluent was well preserved, these differences were diminished, but were to a large extent still noticeable in the stored effluent. Effluent draining at later stages following ensiling was already fermented when collected. Lower sugar content and higher organic acid content in such effluent, as compared with levels in effluent draining in the first days following ensiling, may explain why it was easier to preserve. Effluent draining shortly after ensiling, however, was of superior quality with a high sugar content and low concentrations of fermentation products when well preserved.

The use of formic-acid-based additives or *Kofa plus* during ensiling resulted in a markedly increased sugar content in both fresh and stored effluents as compared with effluents from silages treated with other additives. A high effluent sugar content has been shown to increase effluent palatability (Randby 1996), and, in addition, the effluent would be expected to contribute to higher N retention, since sugars provide rumen microbes with more energy than do organic acids

(Chamberlain & Choung 1993).

Effluents from silages treated with inoculants or *Howden*, as well as those from untreated silages, tended to be more susceptible to moulding than effluents from silages treated with *Kofa plus* or formic-acid-based additives. When stored with surface sealing and with sufficient levels of preservative, however, all effluents were well preserved and were generally resistant to moulding.

Although most effluents deteriorated seriously when stored with neither preservative nor surface sealing treatment, there were some exceptions. Possibly because of its high content of formic acid, 176 g/kg DM, FA effluent in expt. 1 maintained an acceptable fermentation quality under poor storage conditions. *Ensimax* effluent in expt. 2 and *Maxgrass* effluent in expt. 3 also became subject to lactic acid fermentation for some reason, and maintained low pH and acceptable quality under poor storage conditions. These cases, however, were clearly exceptions.

Low pH in the initial fresh effluent did not guarantee successful storage. The pH in effluent tapped at 12 days and onwards following ensiling was lower in effluents from inoculant-treated silages than in effluents from silages treated with formic-acid-based additives. Effluents from inoculant-treated silages nonetheless were never found to store successfully under poor storage conditions.

Surface sealing treatments

All three experiments clearly showed the necessity of storing effluent with some form of surface sealing treatment, in accordance with previous experiments (Pestalozzi 1975; Patterson & Walker 1981). The most obvious effects of surface sealing were reductions in mould growth, proteolysis, as indicated by ammonia content, butyric acid fermentation, and storage losses. Organic matter losses were reduced from 42 to 2% when liquid paraffin was added in expt. 2.

Preliminary studies have suggested that various types of fat can be used for surface sealing of effluent. This was also concluded from expt. 3b, in accordance with Patterson & Walker (1981). The thickness of the surface layer was of secondary importance provided the added amount was sufficient to cover the whole surface. Patterson & Walker (1981) obtained good results by using 6 and 12 mm paraffin or maize oil, whereas 3 mm was too little since it covered only parts of the surface. The waste deep-fat investigated in expt. 3b also worked perfectly when it covered the entire surface, but surface points susceptible to moulding developed because of the hardness of deep-fat. The hardness of the fat at the actual storage temperature may then determine the required amount. Even when scattered moulding occurred on the surface, the fat layer was not ineffective; mould growth was still depressed and effluent quality was by far superior to effluent stored with no sealing treatment.

The two methods of surface sealing, namely liquid paraffin and lids, showed similar effects in expt. 1, in agreement with Pestalozzi (1975) and Patterson & Walker (1981). It is probable that the unoccupied space between the effluent surface and the lid must be small, since the headspace supplies microbes with oxygen during the initial storage period.

Preservatives

The main effect of formic acid (*Foraform* or *Formic acid 85%*) as an effluent preservative was the maintenance of high sugar levels in stored effluent. As an effluent component, formic acid generally restricted fermentation, especially the

Table 9. Effects of sorbic acid (S) and PHB propylester as preservatives, when mixed into the paraffin surface sealing of long-term stored effluent in experiment 3c

Effluent type [1]	Preservative mixed into paraffin		n	DM, g/kg	g/kg DM										NH_3-N, g/kg TN	pH	% losses					% of surface covered by mould
	Type	g/l			OM	CP	Sugar	Lactic acid	Formic acid	Acetic acid	Prop. acid	Butyr. acid	Ethanol	Uncorr.	Corr.		Mass	DM	OM	CP	Sugar	
FA-12			6	58	851	133	55	187	60	89	0	0	81	135	135	3.90	8.0	8.0	10.9	-4.5	90.6	10
N-12	Average	Average	6	45	827	175	33	110	1	218	41	22	103	214	214	4.55	7.5	28.6	30.2	2.0	92.2	33
C-21			6	57	863	166	36	216	0	244	18	0	118	179	179	4.10	3.5	12.8	14.8	-12.7	89.6	2
F4-21			6	56	790	266	34	69	7	197	23	40	40	439	382	5.70	33.1	51.3	57.3	4.1	97.2	33
LSD5%				6	24	24	9	77	3	39	15	NS	34	132	135	0.38	7.3	6.6	7.5	6.2	1.7	3
Average	S	Average	12	54	832	183	42	159	17	191	21	14	67	236	220	4.47	12.4	21.9	24.8	-3.8	92.0	19
	PHB		12	53	833	187	37	133	17	184	20	17	104	247	235	4.65	13.6	28.5	31.8	-1.9	92.8	20
Stat. sign. p				NS	NS	NS	0.09	NS	NS	NS	NS	NS	0.01	NS	NS	NS	NS	0.01	0.02	NS	NS	NS
Average	Average	1	8	47	803	220	32	103	18	181	24	25	112	298	287	5.04	18.0	39.1	43.9	-2.2	94.7	35
		5	8	55	840	178	41	139	14	207	23	22	65	234	221	4.51	11.7	21.2	23.7	-4.0	91.9	16
		10	8	59	855	157	44	196	19	172	15	0	80	193	174	4.14	9.2	15.3	17.3	-2.2	90.6	7
LSD5%				5	20	20	8	66	2	NS	NS	NS	29	NS	NS	0.35	NS	5.7	6.5	NS	1.5	2

[1] FA-12 Effluent from *Formic acid 85%*- treated silage, tapped at 12 days following ensiling
N-12 Effluent from *Natuferm*-treated silage, tapped at 12 days following ensiling
C-21 Effluent from control silage, tapped at 21 days following ensiling
F4-21 Effluent from *Foraform*-treated silage, tapped at 21 days following ensiling

undesirable fermentation of sugar to acetic, propionic, and butyric acids, and ethanol. The high sugar content achieved in effluent by using formic-acid-based additives during ensiling necessitated the addition of sufficient levels of formic acid directly into the effluent, otherwise the sugar rapidly fermented to ethanol. Wet, sugar-rich environments are conducive to yeast growth (Deacon 1984). Under aerobic conditions, yeasts have a high growth capacity and can utilize a variety of substrates, including lactate, acetate, citrate, propionate and ethanol. Under acidic, anaerobic conditions, in contrast, the presence of sufficient quantities of sugar is essential for yeast survival (McDonald et al. 1991). In the present experiments, effluents with a sugar content above 200 g per kg DM were prone to ethanol fermentation. Ethanol fermentation in effluent is undesirable for a number of reasons: firstly, sugar is consumed by the micro-organisms thereby reducing palatability of effluent; secondly, sugar consumed by yeasts would otherwise have fermented to lactic acid, which, in contrast to ethanol, reduces pH and contributes to the preservation of effluent; thirdly, sugar is a better energy source for the rumen microbes than fermentation end-products (Chamberlain & Choung 1993), and so ethanol fermentation may reduce effluent protein value; fourthly, ethanol ingestion may adversely affect animal health; and finally, high ethanol intake in dairy cows may cause milk taint (Rogers & Poole 1993). A multiple regression was performed on data from effluent stored with surface sealing in expts. 2 and 3. This showed that ethanol fermentation increased as sugar content increased, and decreased as formic acid content increased :

$y = -1.34 + 0.014x_1 - 0.0426x_2^2$, $n=84$, $R^2 = 0.50$, $P = 0.01$

y = g ethanol produced per kg effluent
x_1 = g sugar per kg DM in fresh effluent
x_2 = g formic acid per kg fresh effluent, added amount included

Effluents with sugar contents in the range 46 to 649 g/kg DM, and with formic acid contents up to 8 g/kg were included in the regression. The concentration of formic acid required to suppress ethanol fermentation was predicted to be 6 g/kg at an effluent sugar content of 200 g/kg DM, and 13 g/kg at a sugar content of 600 g/kg DM. The fresh effluent contained 3-5 g formic acid per kg when the crop was ensiled with 3 l *Formic acid 85%* per tonne. Further required amounts should then be added directly to the effluent, but it may not be necessary to suppress ethanol fermentation completely, since low ethanol levels are not necessarily harmful to livestock. Woolford (1975) reported 75 mmol formic acid (approx. 3.5 g/kg) to be sufficient to suppress yeast growth at pH=4, and 200 mmol (approx. 9.2 g/kg) to be insufficient at pH=5. Preservation with 0.26% formic acid was sufficient to restrict ethanol fermentation in expt. 2. In expt. 3, however, where the sugar content in the ensiled crop was double that in expt. 2 (103 vs. 58 g/kg DM), 0.13% formic acid was not sufficient to restrict ethanol fermentation in most effluents during storage.

Ethanol fermentation is temperature sensitive. The present laboratory experiments were carried out at 15-20°C, close to the optimum temperature range, 20-25°C, of the vast majority of yeasts (Phaff et al. 1978). When collecting effluent produced from the ensiling of regrowth swards, however, temperatures

can be much lower, and thus the risk of ethanol fermentation is markedly reduced. At a mean daily temperature of 9°C, Patterson & Walker (1979) successfully preserved effluent for 300 days from a crop ensiled with a sulphuric acid/formalin/urea additive by adding 3 l formalin per tonne effluent.

Preservation with formic acid also improved the quality of effluents from control silage and silages treated with inoculants or *Howden* by restricting the fermentation of sugar to acetic and propionic acids. Thus for all effluents draining shortly following the onset of ensiling, the use of preservatives was necessary to ensure good effluent fermentation quality. The use of preservatives was of reduced importance, however, in effluents draining as late as 49 days following ensiling.

When effluent is to be stored and fed to livestock, one possible approach is to ensile crops with high levels of formic-acid-based additives, as recommended in Finland (Heikkilä et al. 1993), and to some extent in Great Britain (Unsworth & Mayne 1993). Application of 5-6 l/t of a predominantly formic-acid-based additive will produce silages of the restricted-fermentation type, which are associated with high feed intake (Kennedy 1990) and a high content of milk fat and milk protein (Chamberlain & Choung 1993). Furthermore, the effluent will exhibit high sugar and formic acid concentrations, and will therefore be highly palatable and still easy to preserve. In the present study, this type of effluent was represented by FA effluent in expt. 1, and by F6 and M effluents in expt. 3. Pestalozzi (1975) also recommended the use of a high level of formic acid during ensiling when the effluent was intended to be stored for feeding, since it not only made effluent storage easier, but also improved silage quality.

Addition of 0.01% K-sorbate was as effective as 0.13% formic acid in preserving N effluent, but was inferior in preserving FA effluent. On average, no advantages were gained by using K-sorbate as compared to formic acid as an effluent preservative at the application rates used in this study.

The quality of long-term stored effluent was clearly improved by increasing doses of sorbic acid or PHB propylester from 1 to 10 g/l paraffin. Follow-up studies revealed, however, that these preservatives did not completely remain in the paraffin layer, but to some extent diffused into the effluent. The concept of mixing an antifungal preservative into a surface layer of fat is probably a good one, but cannot completely replace the addition of preservatives into the effluent, unless the preservative partly diffuses into the effluent. The current costs of using sorbic acid and PHB propylester are high, however, compared with the costs and benefits of using formic acid.

Moulds and yeasts identified

There are several reasons why fungal growth on effluent surfaces is undesirable. Moulds are aerobic heterotrophs which effectively consume organic nutrients and raise storage losses to unacceptable levels. In the present experiments, heavily moulded effluents lost approximately 60% of organic nutrients and were thus unusable for feeding.

Several mould species may produce toxic secondary metabolites which are probably the most serious consequence of fungal growth. A variety of different mycotoxins have been described, but adequate analytical methods do not always exist (Pohland & Wood 1987). Without extensive analytical investigations it is impossible to determine

whether or not mycotoxins have been produced in moulded feeds. The general prevention of mould growth is therefore the only practical and secure method for avoiding problems caused by mycotoxins.

The most prevalent micro-organisms in this study, *Penicillium roquefortii, Geotrichum* spp., and yeasts, have been isolated from silage effluent in previous studies (Patterson & Walker 1981). In general, 70-80% of *Penicillium* species are thought to produce mycotoxins (Pohland & Wood 1987). *P. roquefortii* is known to produce a variety of toxins: patulin, PR-toxin, penicillic acid, citrinin, roquefortine C, isofumiga-clavines, and mycophenolic acid (Pohland & Wood 1987; Northolt & Soentoro 1988). In addition, *Geotrichum* spp. and *Mucorales* are known to produce mycotoxins (Frisvad 1988). Infections with *Mucorales* are associated with abortion in livestock (Andrews et al. 1992). Yeasts have not yet been shown to produce mycotoxins (Moss 1987).

The present experiments indicate that it is generally possible to avoid moulding on effluent surfaces by using proper surface sealing treatment. In addition, the use of formic-acid-based additives during ensiling and the application of preservatives to effluent were shown to delay the onset of mould growth.

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Impact of reduced tillage on the weed flora in spring cereals

ROLF SKUTERUD[1)], KIRSTEN SEMB[1)], JORALV SAUR[1)] & SOLFRID MYGLAND[2)]

[1)] The Norwegian Crop Research Institute, Plant Protection Centre, Department of Herbology, Ås, Norway

[2)] The Norwegian Crop Research Institute, Apelsvoll Research Centre, Kapp, Norway

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In 38 large scale experiments in cereal growing areas in Norway, different systems of reduced tillage were compared with conventional autumn ploughing and spring ploughing. Registrations of weeds both before spraying in the early summer and before harvesting in the autumn showed that reduced tillage caused an increase in weeds compared to autumn ploughing. Spring harrowing only, or direct drilling or rotavating in the spring, caused most weeds. Winter annuals, biennials and the perennials increased more than summer annuals, and monocots increased more than dicots when tillage was reduced. The number of weeds in early summer increased rapidly over years, most after reduced tillage. The biomass of weeds assessed visually before harvest did not increase over the years.

Key words: Direct drilling, reduced tillage, soil type, spring cereals, weeds, yield.

Rolf Skuterud, The Norwegian Crop Research Institute, Plant Protection Centre, Fellesbygget, N-1432 Ås, Norway

To reduce costs in the cereal production, there is a great interest in reduced tillage in Norway. Reduced tillage is also a way to decrease soil erosion and loss of plant nutrients to the sea. In order to fullfill the goal in the North Sea Convention, the farmers in areas where soil erosion is a problem are stimulated economically to reduce stubble cultivation and mouldboard ploughing in the autumn. However, by changing the tillage practice, the weed flora will also change. The results of several investigations indicate that grass weeds and perennial weeds increase in a reduced tillage system compared to a system including mouldboard ploughing (Andersen 1987, Bachtaler 1974, Cussans 1976, Legere et al. 1990, Nielsen & Pinnerup 1982 and Schwerdtle 1977). To get more experience about the use of reduced tillage in spring cereal production, long term large scale experiments were started in 1988. In the following years similar experiments were laid out in most of the cereal growing areas in Norway. Some experiments were run up to 1995. The project was directed by Apelsvoll Research Centre, but the plant protection aspects were handled by the Plant Protection Centre. The effect of reduced tillage on the grain yield is published elsewhere (Korsæth et al.1996). The results from the weed registrations are presented in the present report.

Materials and methods

Thirty eight experiments were performed according to the main plan, which had five different tillage treatments as shown below.

Conventional autumn ploughing, treatment 5, was used as a control. In some of the mentioned experiments other tillage treatments were added to the plan. The stubble cultivation was usually performed with a tine stubble cultivator. The ploughing depth was 20-25 cm. Except for plots with direct drilling in some fields, all plots in each field were tilled with the same type of harrow, usually a tine harrow, in the spring. The farmers, who owned the field where the experiment was laid out, performed the tillage according to the plan. To make it possible to use the machinery on the farm, the plot size was set to approximately 1000 m^2, and there were no replications within each experiment. The farmers also sprayed the experimental fields against weeds early in the summer in the same way as they treated the surrounding field. With an exception for the first year, when only a few experiments were sprayed with glyphosate, about half of the experiments were sprayed each year with glyphosate in the stubble. In some instances only the most weed infested plots were sprayed at this moment.

The weed population was assessed twice a year, the first time just before normal time for weed control in cereals in early summer. The number of weeds was then counted on a 1/4 m^2 area at 8 different places on each plot. The second assessment was done 2 - 3 weeks before harvest. The biomass of the weeds was then visually judged in percent of the total biomass on 3 places on each plot. Because of some changes in the main plan, the number of assessments in 1993 and later were 4 and 2 respectively. The first calculation of weed biomass was performed 1990, corresponding to the second year of cropping. Weed countings started in early summer 1991. The duration over years for each experiment varied. Of the total number of 38 experiments, only 6 were carried out for five succeeding years.

The diversity of weed species is expressed as Simpson's Dominance Index (Whittaker 1975):

$C = \sum_{i=1}^{s} \left(\frac{n_i}{N}\right)^2$, where C is diversity, s the number of species in a sample, n_i the number of species $_i$ and N the sum of numbers of all species. C may vary between 0 and 1. Small values express large diversity.

The observations were analysed statistically according to SAS (SAS Institute Inc. 1988). Analysis of variance were performed in two different ways: 1.The analysis was based on a randomized complete block design, with different tillage as treatments and number of observations (year x experiment) considered as replications. 2. For the 6 experiments following the main plan for five succeeding years, the factors year and field were tested against the interaction year x field. In this case the tillage factor, the two

Treatment	*1*	*2*	*3*	*4*	*5*
Stubble cultivation:	*No*	*Yes*	*No*	*Yes*	*Optional*
Ploughing:	*No*	*No*	*Spring*	*Spring*	*Autumn*
Spring harrowing:	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*

factor interactions tillage x year and tillage x field were tested against the rest. If variance analyses gave significant differences, LSD-values were used to detect the actual differences. A regression analysis was carried out in order to determine the relationship between number of weeds or weed biomass and the yield of grain. A significance level of P = 0.05 was used in all tests. Not significant differences are given by LSD 5% = NS.

Results

Development of weeds - sum of all species

During the experimental period 47 different weed species were found in early summer and 62 before harvest. On an average of all the observations (year x experiment) autumn ploughing gave a significant lower total number of weed plants in early summer than all the other tillage treatments (Fig. 1a). Spring ploughing caused also significantly less number of weeds than no ploughing. Stubble cultivation, however, gave only a slight reduction in weed number.

Assessed before harvest the treatment with stubble cultivation on unploughed plots caused a significant reduction of weed biomass (Fig. 1b). The differences between the other treatments were almost the same as that for the early summer countings.

In the observations of the weed flora for five succeeding years the relative effect on the weed occurence of the diffe-

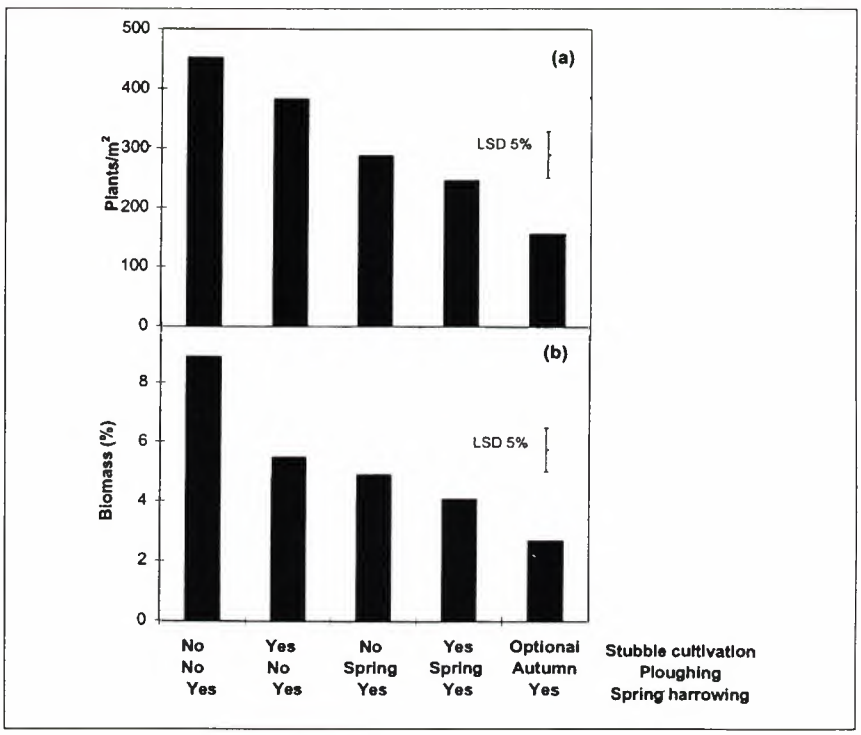

Fig. 1. Occurrence of weeds after different tillage treatments. Average of all weed species of (a) 114 observations (experiment x year) of number of plants/m² before spraying in early summer, and (b) for 120 observations of weed biomass in % of total biomass before harvest

rent tillage treatments was almost the same each year. Therefore, an average of the four treatments with changed tillage compared with autumn ploughing was used. There was a significant increase in the number of weeds over time, most for reduced tillage, but also for autumn ploughing (Fig. 2). For the biomass, however, there was a nonsignificant reduction from the third to the fourth year after start. Later on less differences between years were found.

The effect of the different tillage treatments on weed infestation was almost the same in the different counties, both with respect to the number of weeds and to the biomass (Table 1). However, both Akershus, Telemark and Nord-Trøndelag, which had only a few number of weeds on autumn ploughed plots in early summer, showed up with most weed biomass before harvest in all tillage treatments.

When grouped according to soil type, the highest number of weeds in early summer was found on silt + sandy soils, and the lowest on loam soils (Fig. 3). Before harvest the level of weed biomass increased most on silt + sandy soils and on loam after reduced tillage. In experiments performed on clay spring ploughing alone gave a significant increase in weed biomass compared to autumn ploughing. No stubble cultivation in combination with no ploughing gave most weed biomass on all soil types.

The effect on weeds of other tillage treatments than those included in the main plan can be seen in Table 2. Direct

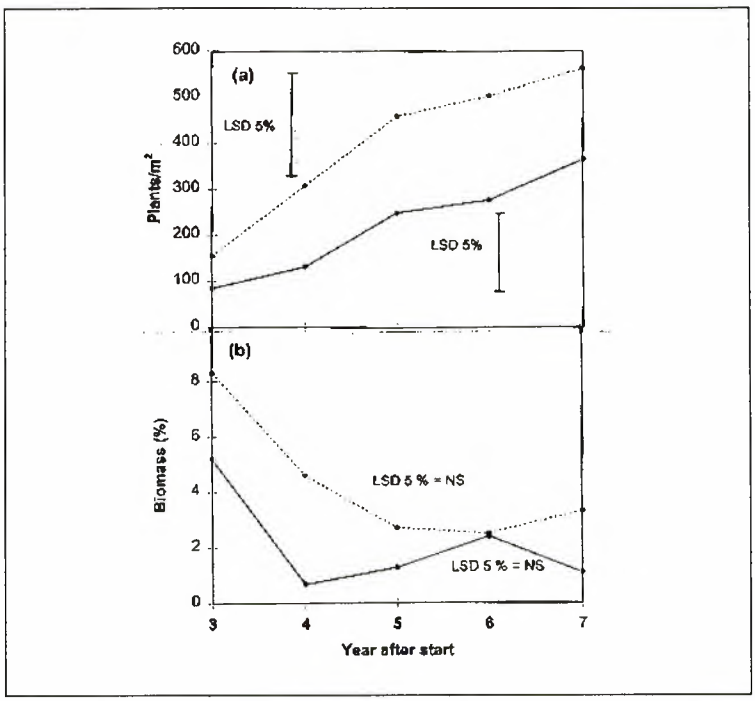

Fig. 2. Development of weed infestation over five years on plots with autumn ploughing (——) compared to average of the four reduced tillage treatments (·····): (a) Number of plants/m² before spraying in early summer and (b) weed biomass in % of total plant biomass before harvest. LSD 5% for year is shown. 6 experiments which were assessed every year are included

Table 1. Effect of tillage treatments on weed infestation in different counties before spraying in early summer (number of plants/m^2) and before harvest (weed biomass in % of total biomass). Average of all weed species for all observations (experiment x year)

Stubble cultivation Ploughing Spring harrowing	No No Yes	Yes No Yes	No Spring Yes	Yes Spring Yes	Optional Autumn Yes	LSD 5%	No. of obs.	Year of start
No. of plants/m^2								
Akershus	276	240	249	191	73	102	20	88
Oppland	433	348	249	294	207	150	26	90
Telemark	673	153	129	87	96	262	7	88
Østfold	503	481	342	268	173	126	60	88
Hedmark	1296	-	302	-	433	NS	3	89
Nord-Trøndelag	111	-	76	-	22	NS	5	90
Vestfold	140	-	66	-	68	NS	7	89
Biomass (%)								
Akershus	23.2	18.2	15.2	12.6	3.8	9.1	12	88
Oppland	7.4	3.5	2.2	2.0	1.4	1.6	26	90
Telemark	17.1	8.4	6.0	4.0	3.9	NS	6	88
Østfold	6.4	3.9	4.1	3.4	2.9	1.5	75	88
Hedmark	11.5	-	3.7	-	1.1	NS	3	89
Nord-Trøndelag	15.6	-	10.3	-	5.7	NS	5	90
Vestfold	2.8	-	0.5	-	0.7	NS	6	89

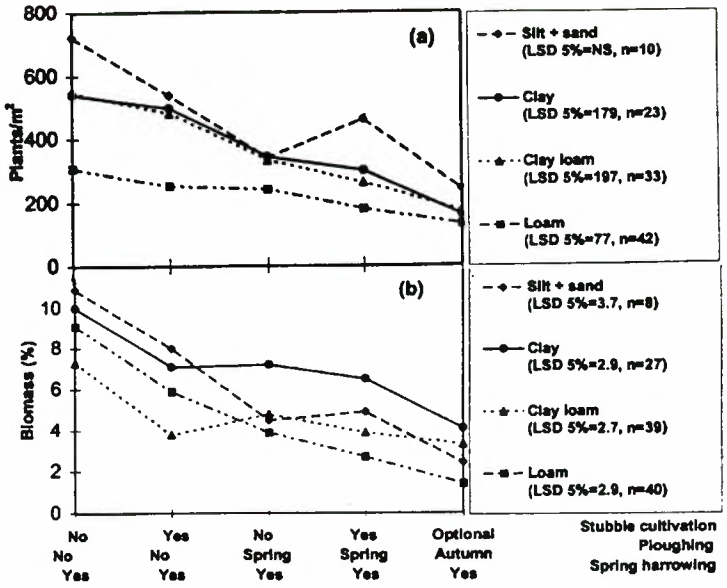

Fig. 3. Development of weed infestation on different soil types after different tillage treatments: (a) Number of plants/m^2 before spraying in early summer and (b) weed biomass in % of total biomass before harvest. Average of all observations (n=experiment x year). LSD 5% for tillage is shown

Table 2. Effect of different tillage equipment used in spring on weed infestation before spraying in early summer (number of plants/m^2) and before harvest (weed biomass in % of total biomass). Average of all weed species for all observations (experiment x year).

Assessed in	*Early summer*			*Before harvest*		
	No. of plants/m^2	LSD 5%	No. of obs.	Biomass (%)	LSD 5%	No. of obs.
Direct drilling	295			22.3		
		113	28		NS	25
Ploughing + harrowing in spring	156			12.3		
Rotavator	354			14.6		
		NS	7		NS	7
Tine harrow	180			8.7		
Friction driven harrow [1)]	553			5.8		
		NS	19		NS	19
Tine harrow	622			6.9		
Ploughing in spring + soil packer	72			4.0		
		NS	13		NS	14
Ploughing in spring - soil packer	91			4.1		

[1)] Trade name = Dynadrive

drilling, compared to spring ploughing, caused a significant increase in the number of weeds in early summer. A similar tendency was observed for the weed biomass in the autumn. Cultivation with a rotavator gave a tendency to more weeds than cultivation with a tine harrow. There was, however, no differences in weed occurance between a tine harrow and a friction driven harrow (Dynadrive), and between spring ploughing with or without soil packer.

Development of different weed groups and species

The dicots dominated the weed population (Fig. 4). During the experimental period 43 and 51 different dicot species were found in early summer and before harvest respectively. For the dicots there was an increase in the number of plants proportional to the reduction in tillage intensity. For the total number of monocot plants, 4 species were observed in early summer and 11species before harvest. The combination of no stubble cultivation and no ploughing gave significantly more monocot weeds than the rest of the treatments. Relatively more monocots were found before harvest than in early summer.

During the experimental period 21 species of summer annuals, 12 species of winter annuals + biennials and 14 species of perennials were found in early summer, grouped according to Korsmo et al. (1986) and Fykse & Karlsen (1987). Before harvest the number of species mentioned in the same order were 23, 13 and 26. The total number of summer annuals were less influenced by reduced tillage than winter annuals + biennials and perennials, both in early summer and before harvest (Fig. 5). The winter annuals + biennials dominated in plots without ploughing at both times of assessment. The perennials dominated more before harvest than in early summer, especially on plots with spring harrowing only.

When looking at the individual spe-

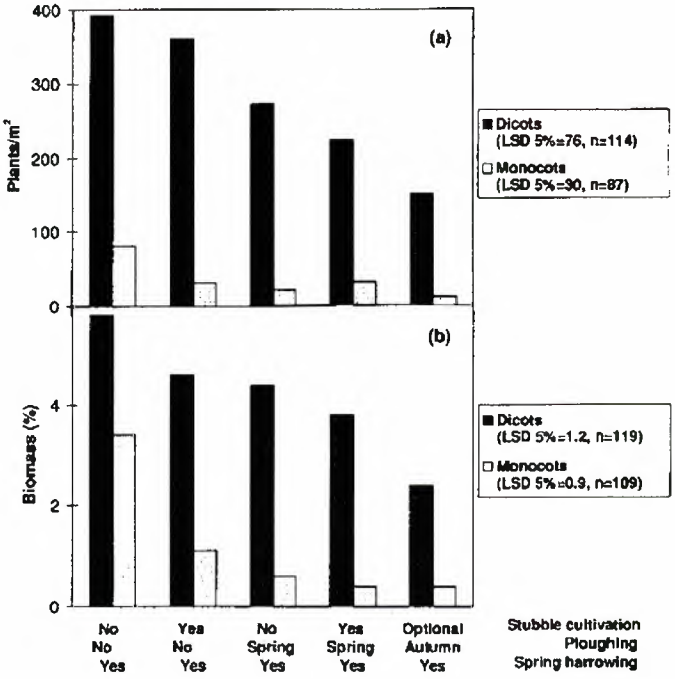

Fig. 4. Occurrence of weed species divided in dicots and monocots after different tillage treatments: (a) Number of plants/m² before spraying in early summer and (b) weed biomass in % of total biomass before harvest. Average of all observations (n=experiment x year). LSD 5% for tillage is shown

cies, only the frequent occuring species are mentioned. In general little differences in the occurrence of summer annuals between the different tillage treatments were found (Table 3). *Viola arvensis* Murr., *Sonchus asper* (L.) Hill. and *Fumaria officinalis* L.were the dominating weed species. Only the number of *S. asper* and *Polygonum aviculare* L. increased significantly when soil tillage was reduced. Both for *F. officinalis* and *Galeopsis* spp. the heaviest infestation was found after spring ploughing, especially on plots without stubble cultivation. *Spergula arvensis* L. was the only summer annual that decreased significantly in number when tillage was reduced. Before harvest this species as well as the different *Polygonum* species were found only in a sparse amount.

Among the winter annuals or biennials, *Lamium purpureum* L., *Stellaria media* (L.) Vill., *Poa annua* L. and *Matricaria perforata* Merat. were the dominating species (Table 4). In general, the heaviest infestation was found on plots without both stubble cultivation and ploughing. *L. purpureum*, however, was found in high amount on all tillage treatments. *Thlaspi arvense* L. was the only species which had the highest count for conventional autumn ploughing. *Alopecurus geniculatus* L. was more frequent at harvest than in early summer in most experiments. Assessed before harvest this weed increased dramatically on unploughed plots. Both *T. arvense*, *Senecio vulgaris* L. and *Myosotis arvensis* (L.) Hill. were easy to control in all tillage systems.

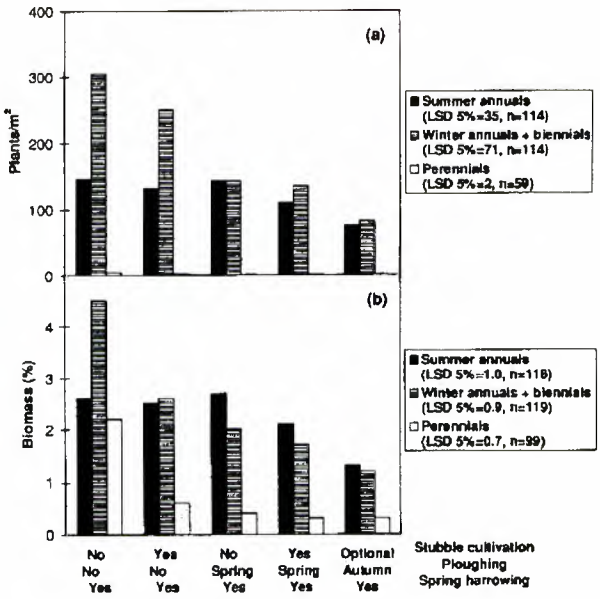

Fig. 5. Occurrence of weed species in different biological groups after different tillage treatments: (a) Number of plants/m² before spraying in early summer and (b) weed biomass in % of total biomass before harvest. Average of all observations (n=experiment x year). LSD 5% for tillage is shown

The effect of the treatments on the main perennials is presented in Table 5. Again no stubble cultivation in combination with no ploughing caused most weeds. For *Sonchus arvensis* L. no significant differences were found. In general there was a relatively small population of perennials in these experiments.

Species diversity

In average for each field more species were found in early summer than before harvest (Table 6). Stubble cultivation reduced the number of species on unploughed and spring ploughed plots at both assessment times. The smallest number of species was found after autumn ploughing and spring ploughing in combination with stubble cultivation, and the highest number after spring harrowing alone.

In early summer the Simpson's Dominance Index was larger (i.e. species diversity was smaller) on only harrowed plots than on ploughed plots (Table 6). Autumn ploughing caused the lowest index. Before harvest, however, there were no differences in species diversity between the tillage treatments. In a separate test, no differences in diversity between years for the 6 experiments lasting for five years were found (data not shown).

Effect of grain yield on weed occurance

The regression of weed occurence vs. yield showed a nonsignificant relationship between increase in weed number in early summer and increase in yield (Fig. 6). However, before harvest the assessment of the biomass showed a significant decrease with increase in yield.

Table 3. Occurrence of some dominating summer annual weeds after different tillage treatments. Assessment time 1 = plants/m^2 before spraying in early summer, and time 2 = weed biomass in % of total biomass before harvest. Average of all observations (experiment x year).

Stubble cultivation Ploughing Spring harrowing	Ass. time	No No Yes	Yes No Yes	No Spring Yes	Yes Spring Yes	Optional Autumn Yes	LSD 5%	No. of obs.
Chenopodium album L.	1	15	16	12	10	7	NS	104
« «	2	0.8	0.9	0.6	0.6	0.2	NS	60
Fumaria officinalis L.	1	22	20	38	22	12	13	91
« «	2	0.7	0.7	1.0	0.7	0.4	NS	88
Galeopsis spp.	1	10	13	21	18	11	6	102
« «	2	0.3	0.4	0.9	0.7	0.2	NS	72
Galium aparine L.	1	8	9	3	1	2	NS	33
« «	2	0.3	0.3	0.1	0	0	NS	30
Polygonum aviculare L.	1	5	4	3	3	2	1	86
« «	2	0.2	0.1	0.2	0.1	0.1	NS	69
Polygonum convolvulus L.	1	2	1	2	2	1	NS	40
« «	2	0.1	0.1	0.1	0.1	0.1	NS	51
Polygonum persicaria L.	1	1	1	2	1	1	NS	40
« «	2	0.1	0	0	0	0	NS	21
Sonchus asper (L.) Hill.	1	75	61	29	26	12	36	69
« «	2	1.0	0.7	0.5	0.4	0.6	NS	92
Spergula arvensis L.	1	3	2	5	5	7	3	72
« «	2	0.1	0.1	0.1	0.1	0.1	NS	16
Viola arvensis Murr.	1	52	46	62	47	35	NS	107
« «	2	0.4	0.5	0.5	0.5	0.3	NS	103

Discussion

The results in this report point out the main weed problems which arise when practising traditional weed control associated with autumn ploughing in a system with reduced tillage in a monoculture of spring cereals. In general, the weed infestation increased when soil tillage was decreased. This was most obvious for winter annual, biennial and perennial weeds. Similar results have been found by Andersen (1987), Bachthaler (1974) and Schwerdtle (1977). The infestation of summer annuals also increased, but not to the same extent as for the other weed groups. In this respect, the present findings differ from those of Andersen (1987), Bachthaler (1974), Cussans (1976) and Schwerdtle (1977). They found on a whole a reduced occurence of summer annuals when practising reduced tillage, especially direct drilling. In the present study, only one summer annual, *S. arvensis,* was less frequent after reduced tillage than after conventional tillage.

Among the winter annuals only *T. arvense* decreased after reduced tillage. This is in accordance with the findings of Schwerdtle (1977).

Dicots dominated the weed flora, especially in early summer. Before harvest the amount of monocots increased drastically on plots with harrowing in the spring as the only tillage treatment. The dominating species were *Elytrigia repens* (L.) *Gould., A. geniculatus* and *P. an-*

Table 4. Occurrence of some dominating winter annual + biennial weeds after different tillage treatments. Assessment at time 1 = plants/m^2 before spraying in early summer, 2 = weed biomass in % of total biomass before harvest. Average of all observations (experiment x year).

Stubble cultivation Ploughing Spring harrowing	Ass. time	No No Yes	Yes No Yes	No Spring Yes	Yes Spring Yes	Optional Autumn Yes	LSD 5%	No. of obs.
Alopecurus geniculatus L.	1	9	1	1	0	0	NS	4
« «	2	3.4	1.3	0.7	0.2	0.2	2.2	30
Lamium purpureum L.	1	51	44	51	53	38	11	98
« «	2	0.6	0.7	0.8	0.8	0.5	NS	100
Lapsana communis L.	1	32	10	4	3	2	NS	50
« «	2	0.8	0.3	0.1	0.1	0.1	0.4	40
Matricaria perforata Merat.	1	22	8	5	3	4	8	82
« «	2	1.3	0.3	0.1	0.2	0.1	0.5	76
Myosotis arvensis (L.) Hill.	1	9	6	4	5	2	3	75
« «	2	0.1	0.2	0.1	0.1	0	0.1	71
Poa annua L.	1	98	30	30	49	16	46	54
« «	2	1.6	0.6	0.4	0.3	0.3	0.5	77
Senecio vulgaris L.	1	18	9	17	5	1	NS	21
« «	2	0.2	0.1	0.1	0	0	NS	11
Stellaria media (L.) Vill.	1	158	173	67	52	30	67	111
« «	2	1.2	1.2	1.0	0.9	0.7	0.4	83
Thlaspi arvense L.	1	1	1	4	6	6	4	31
« «	2	0	0	0	0.1	0.1	NS	10
Veronica agrestis L.	1	15	17	10	8	5	NS	28
« «	2	0.6	0.1	0.1	0.1	0.1	NS	19

nua. Similar findings are reported by Schwerdtle (1977) and Bachthaler (1974).

Although the smallest number of species was found after autumn ploughing, this treatment caused the largest species diversity (lowest Simpson's Dominance Index) indicating that there were more equal numbers of each species after this treatment, and that no species was dominating. This is in accordance with the findings of Andersen (1987) and Gill & Arshad (1995). Anderson (1987) also found that species diversity on only harrowed plots decreased with years. No such development was detected in the present experiments.

Spring ploughing caused more weeds than autumn ploughing. One reason for this may be that spring ploughing causes a poor soil structure on heavy soils (Njøs & Børresen 1991). Another reason may be seasonal variation in germination (Håkansson 1983) and that some weed species can produce viable seeds in late autumn or early spring. In addition, the location of the seeds during the winter, whether it is on the surface or buried in the soil, may affect the germination. For the winter annuals, biennials and the perennials, reduced mechanical disturbance means improved survival. In general, differences in requirements for germination, growth and seed production are the basic reasons why some species increases, some decreases and some are not affected by changing the tillage

Table 5. Occurence of some dominating perennial weeds after different tillage treatments. Assessment at time 1 = plants/m^2 before spraying in early summer, 2 = weed biomass in % of total biomass before harvest. Average of all observations (experient x year).

Stubble cultivation Ploughing Spring harrowing	Ass. time	No No Yes	Yes No Yes	No Spring Yes	Yes Spring Yes	Optional Autumn Yes	LSD 5%	No. of obs.
Cirsium arvense (L.) Scop.	1	2	1	0	0	0	1	15
« «	2	0.9	0.4	0	0	0	0.6	31
Elytrigia repens (L.) Gould.	1	7	2	1	0	0	NS	6
« «	2	1.5	0.4	0.2	0.1	0.1	0.7	76
Sonchus arvensis L.	1	6	4	2	1	1	NS	23
« «	2	0.7	0.2	1.0	0.8	0.8	NS	19
Taraxacum spp. .	1	2	1	0	0	0	1	27
« «	2	0.6	0.2	0	0	0	0.3	45

practice. Also the distribution of plant nutrients and differences in soil moisture caused by different tillage systems may cause changes in the weed flora (Espeby 1989, Froud-Williams et al. 1981).

In a monoculture of spring cereals, as practiced in the present experiments, the possibility to control weeds is smaller than when a crop-herbicide rotation is practiced. Derksen et al. (1993) and Bräutigam (1990) found that weeds caused no large problems in a reduced tillage system when spring cereals were grown in rotation with crops such as winter cereals and/or broadleaved crops.

A possible reason for the rapid increase in weed numbers over years may be that the knowledge about how to control weeds at reduced tillage was limited at the early stage of this investigation. It was unexpected , however, that the number of weeds increased also on autumn ploughed plots, although not to the same extent as for reduced tillage. Con-tamination from neighbouring plots may be one reason for this. Different climatic conditions, giving different conditions for germination in the different years, may also have caused differences in the development of the weeds over time (Andersen 1987, Derksen et al. 1993).

The amount of weed biomass before

Table 6. Number of species and Simpson's Dominance Index after different tillage treatments at two assessment times. Average for all observations (experiment x year).

Stubble cultivation Ploughing Spring harrowing	No No Yes	Yes No Yes	No Spring Yes	Yes Spring Yes	Optional Autumn Yes	LSD 5%	No. of obs.
Early summer:							
No. of species	10.4	9.9	10.1	9.5	9.8	0.4	114
Simpson's Dominance Index	0.43	0.45	0.39	0.38	0.35	0.04	113
Before harvest:							
No. of species	8.4	7.6	7.2	6.9	6.8	0.4	120
Simpson's Dominance Index	0.34	0.34	0.36	0.36	0.32	NS	118

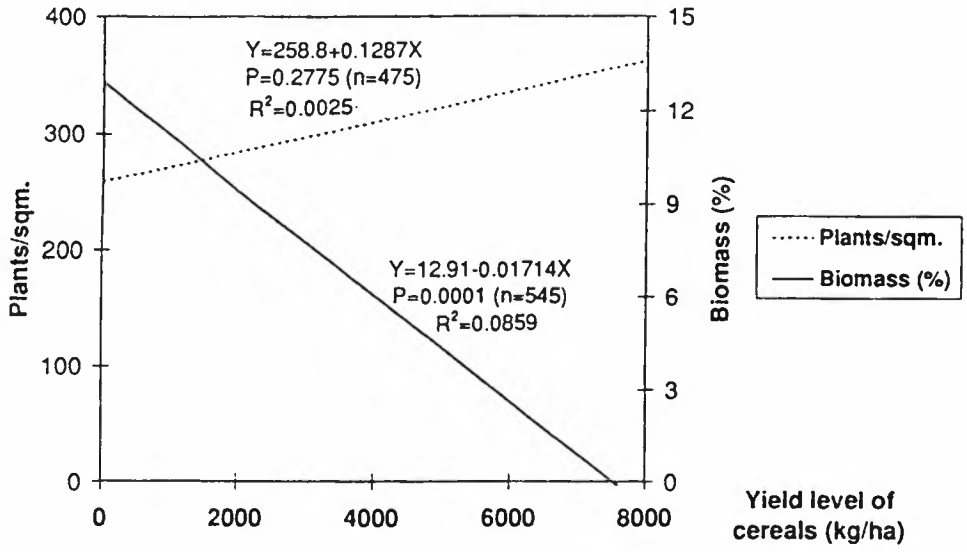

Fig. 6. Regression of occurrence of weeds vs. grain yield: Number of plants/m² before spraying in early summer (·····) and weed biomass in % of total biomass before harvest (——). Regressions are based on all tillage treatments (=5), experiments and years (n=tillage x experiment x year). Significance level (=P) and R^2 of regression are included

harvest tended to decrease in the first years. Use of more effective herbicides in early summer during the experimental period may be one reason for this.

Korsæth et al. (1996) reports the yield responses from the different treatments in these experiments. However, the occurrance of weeds at different grain yield is presented in this report. On average the biomass of the weeds was reduced in high yielding experiments. Low yield in the experiments in Akershus, Telemark and Nord-Trøndelag is probably the main reason why the percentage of weed biomass was so high in these counties. In a high yielding field the competition from a dense crop is stronger than in a low yielding one (Håkansson 1986). This competition from the crop is finally more important for the production of weed biomass during the summer than the number of the weeds per m² in early summer.

Spraying with glyphosate against weeds in the stubble in these experiments was performed according to requirement. The type of selective herbicide used in early summer varied. The effect of these treatments was not included as part of the investigation. Therefore it is not possible to evaluate the effect they might have. However, when the amount of weeds increases after reduced tillage, it means more spraying with herbicides, both in the stubble and in the growing season. For spraying in the stubble, glyphosate is the only recommended herbicide today. This is not a desirable situation because of the possibility for developing glyphosate resistent weeds. So far such resistance has not been reported, but repeated application of the same herbicide is a danger (Froud-Williams et al. 1981, Røyneberg 1993). In general, it is risky to use a strategy for soil tillage and seed drill-

ing technology which completely has to rely on one single herbicide.

Acknowledgements

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Observations on wood scab caused by Venturia inaequalis and V. pirina in apple and pear in Norway

ARNE STENSVAND, TERJE AMUNDSEN & LARS SEMB
The Norwegian Crop Research Institute, Plant Protection Centre, Department of Plant Pathology, Fellesbygget, Ås, Norway

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Shoot infections (wood scab) caused by *Venturia inaequalis* and *V. pirina*, the apple and pear scab fungus, respectively, have been investigated in various apple and pear cultivars. Generally, scab lesions were found as mycelial pustules in bark splits. In second season shoots, in both apples and pears, scab lesions were also detected growing superficially on the bark, often at the base of buds. In apples, lesions containing viable conidia (viable lesions) were detected in August (only time examined) in new shoots, and from February to September in second season shoots. No viable lesions were found in third season apple shoots. In pears, viable lesions were detected from June to November in new shoots, from February to November in second season shoots, and from February to September in third season shoots.

Key words: Shoot infections, *Venturia inaequalis*, *Venturia pirina*, wood scab.

Arne Stensvand, The Norwegian Crop Research Institute,Plant Protection Centre, Department of Plant Pathology,Fellesbygget, N-.1432 Ås, Norway

The ascomycetes *Venturia inaequalis* (Cke.) Wint. (anamorph *Spilocaea pomi* Fr.) and *Venturia pirina* Aderh. (anamorph *Fusicladium pyrorum* (Lib.) Fuckel) are the causal organisms for apple and pear scab, respectively. The scab fungi overwinter as fruiting bodies (pseudothecia) in leaf litter on the ground, or as mycelium and conidia (the anamorphic stage) in shoots and buds. Overwintering as mycelium in the bark of young shoots (wood scab) has been described from many countries throughout the world. In Norway, wood scab is common in several apple and pear cultivars. The importance of wood scab seems to vary between countries and regions, and is more common in pears than in apples.

From England, two early reports described the infection process and the growth of the two fungi in shoots (Marsh & Walker 1932; Marsh 1933). According to these reports, infections in shoots can only occur close to the tip in young, growing shoots. As soon as the epidermal cells start to form the phellogen, which gives rise to cork cells of the primary bark, infections of the apple scab fungus are made impossible. The pear scab fungus, on the other hand, seems to be able to penetrate the epidermal layer some time after it has started to form the phellogen. Most of the infections will occur from June to August. Throughout the growing season, the young shoots will develop cork cell barriers to prevent the fungal

growth by sloughing off the fungal tissue. From the primary site of infection, subsidiary pustules of fungal stromata will develop peripherally under the bark. In spring and early summer the bark in the second season shoots splits open, and conidia are spread during wet periods from the subsidiary stromata. Formation of new cork cells and secondary growth of the wood will slough off most of the infected tissue in second season shoots in May and June.

Cook (1974) and Hill (1975) in England studied release of apple scab conidia from shoot infections in the cultivar 'Cox's Orange Pippin'. Hill (1975) found that the release started soon after infections became established in August, reaching a maximum in October and continuing throughout November. Conidial release continued at a low level during December, January, and February. In one year, large numbers of conidia were collected from shoot lesions in January. Conidial release was high in March, April, and May, and decreased in June. Cook (1974) reported conidial release in early March, 2-3 weeks before bud-burst, and in the three years of the investigation most conidia were released in April and May.

A study of the time when release of conidia from shoot infections starts in spring and is checked in the summer and autumn has not previously been carried out in Norway. Thus the objective of this research was to investigate at which time of the year it is possible to find viable conidia of the apple and pear scab fungi in shoot infections.

Materials and methods

Infections were investigated in new, second season, and third season shoots of apples and pears at different times of the year, from early spring 1991 to early spring 1993. Shoots from various cultivars were collected at two locations in south-eastern Norway (Ås in Akershus County and Sauherad in Telemark County) and at two locations in western Norway (Hjelmeland in Rogaland County and Norddal in Møre og Romsdal County). The names of the various cultivars can be found in Tables 1 and 2. The following pear cultivars have a Norwegian synonym in parentheses: 'Bonne lucrative' ('Herrepære'), 'Doyonné Boussoch' ('Philip'), 'Épargne' ('Keiserinne'), 'Grise bonne' ('Gråpære'). The other apple and pear cultivars have Norwegian names similar to or close to those listed in the tables.

The shoots were sent by mail from western Norway to Ås. They were wrapped in dry newspapers and sealed in plastic bags packed in cardboard boxes. It took 2-3 days from collecting the shoots until they were examined. Samples from Ås were collected and examined on the same day, but the one sample from Sauherad was examined the day after collection. The dates given in Tables 1 and 2 are the dates of examination at the Plant Protection Centre at Ås.

For each sample, 1-15 lesions were examined. Conidia were suspended in distilled water, and suspension droplets were placed on microscope slides in moist chambers at 100% relative humidity and 20-25°C. After ca. 24 h the slides were examined in a light microscope. For each sample 50-100 conidia in each of 2-4 suspension droplets were assessed for germination (viability).

Table 3 shows the 30-year normal values for mean monthly temperature and precipitation for the period 1961-90 at Hjelmeland (Fister met. station) and Ås (Ås met. station). The data for Norddal (Linge met. station) are mean values for the period 1961-74. The data were

Table 1. Viability (% germination) in conidia of *Venturia inaequalis* in new (1) and second season (2) shoots of the apple cultivars 'Gravenstein' (Gs), 'Ingrid Marie' (IM), 'Lobo' (Lo), 'Quinte' (Qu), 'Summerred' (Su), 'Torstein' (To), and 'Vista Bella' (VB) at Hjelmeland, Norddal, Sauherad, and Ås 1991-92 (- = not examined). Dates are given as day/month

Location	Cultivar	Year/ Date	1	2
		1991		
Ås	Lo	15/3		40.0
Ås	To	20/3		10.0
Ås	Lo	20/3		25.0
Sauherad	VB	23/7	-	1.8
Ås	Su	15/8	20.0	-
Ås	To	15/8	48.0	48.0
Ås	Lo	15/8	0.0	40.0
		1992		
Norddal	Gs	18/2		0.0
Ås	Lo	14/2		27.0
Norddal	Gs	4/3		44.2
Ås	Lo	9/3		25.3
Ås	IM	9/3		26.0
Norddal	Gs	26/3		30.9
Hjelmeland	Qu	6/5		36.6
Norddal	Gs	21/5	-	18.7
Norddal	Gs	14/8	-	18.7
Sauherad	VB	4/9	-	8.0

provided by the Norwegian Meteorological Institute (Oslo).

Results

Scab lesions were usually observed as mycelial pustules in bark splits. The mycelium contained several cell layers. The oldest conidia were in the centre of the lesions, and mycelium still covered with bark had few, often immature conidia. Infections were more readily detected in pear shoots, which had more frequent and larger lesions than apple shoots. In both apples and pears, scab lesions were observed several times growing superficially on the bark of second season shoots, mostly around buds. The mycelium was dense and readily visible, and in several instances it grew directly from the second season shoots to the newly formed, green shoots. This was observed in the apple cultivar 'Vista Bella' and in the pear cultivars 'Doyenné Boussoch' and 'Épargne'.

In green, new shoots in June and July, the scab fungi grew sub-cuticularly, similar to the growth in leaves. We investigated viability of pear scab in first season shoots during this period, but not in apple scab.

In apples (Table 1), infections in new shoots were investigated only in August 1991, when viable conidia were found. In second season shoots, viable conidia were found from mid-February to early September. Of the two samples collected

Table 2. Viability (% germination) in conidia of *Venturia pirina* in new (1), second season (2) or third season (3) shoots of the pear cultivars 'Bonne lucrative' (Bl), 'Épargne' (Ép), 'Doyenné Boussoch' (DB), 'Fleskepære' (Fl), 'Grev Moltke' (GM), 'Grise bonne' (Gb), and 'Précoce de Trévoux' (PT) at Hjelmeland, Norddal, and Ås 1991-93 (- = not examined, o = not found). Dates are given as day/month

Location	Cultivar	Year/ Date	1	2	3
		1991			
Ås	Bl	27/2		50.0	-
Norddal	Ép	7/3		41.3	-
Hjelmeland	Fl	8/3		60.3	54.7
Ås	Gb	11/3		45.0	-
Hjelmeland	Fl	21/3		-	48.0
Hjelmeland	DB	26/6	36.8	38.7	-
Hjelmeland	Fl	22/7	69.6	5.9	22.5
Norddal	Ép	22/7	52.9	54.1	40.7
Ås	Bl	15/8	82.0	24.0	-
Norddal	Ép	2/9	42.0	5.5	2.5
Norddal	Ép	12/11	30.5	o	-
Hjelmeland	Fl	13/11	30.5	19.0	-
		1992			
Ås	Gb	17/2		44.7	-
Norddal	Ép	18/2		30.3	11.0
Hjelmeland	DB	20/2		43.0	2.0
Norddal	Ép	3/3		60.7	37.0
Ås	Bl	9/3		46.3	4.4
Hjelmeland	DB	12/3		36.7	0.6
Norddal	Ép	26/3		41.0	52.3
Norddal	Ép	21/5	-	41.5	10.5
Norddal	Ép	13/8	o	21.0	o
Hjelmeland	PT	17/8	o	2.0	-
Hjelmeland	DB	20/8	o	33.7	-
Hjelmeland	Fl	4/9	73.0	6.0	0.0
Hjelmeland	Fl	4/9	22.5	1.6	o
Hjelmeland	GM	4/9	67.0	6.5	-
		1993			
Hjelmeland	Fl	24/2		18.0	17.6
Norddal	Ép	24/2		30.5	38.0

in February, only one had viable conidia. Samples taken in March all had conidia which germinated readily. Viability was still high in August, but in the sample investigated in September only 8% of the conidia germinated, and all of them had short germ tubes. At no time were conidia in third season apple shoots observed.

In pears (Table 2), infections in new shoots were found from late June to November, with high viability throughout the period. In second season shoots, viable conidia were found from February to November, while third season pear shoots

Table 3. Normal values for mean monthly temperature (°C) and percipitation (mm) at Hjelmeland and Ås 1961-90. Data for Norddal are monthly means for the period 1961-74

	Ås		Hjelmeland		Norddal	
Month	Temp.	Prec.	Temp.	Prec.	Temp.	Prec.
January	-4.8	49	0.5	120	0.8	136
February	-4.8	35	0.4	90	1.0	101
March	-0.7	48	2.5	110	2.9	106
April	4.1	39	5.5	65	5.5	75
May	10.3	60	9.7	75	10.2	46
June	14.8	68	12.7	90	13.0	53
July	16.1	81	14.3	110	14.3	75
August	14.9	83	14.3	125	13.9	77
September	10.6	90	11.5	180	10.6	144
October	6.2	100	8.5	185	7.9	149
November	0.4	79	4.5	170	3.7	153
December	-3.4	53	1.5	155	1.5	175

had viable conidia from February to September. In two samples from July the viability was high in third season shoots, but in September it was found that few conidia had germinated. The lesions in third season shoots were found frequently in the bark in areas surrounding scab lesions that had sporulated the previous year. Despite a great variation within each month, the ability to germinate seemed to be reduced towards the end of the growing season in second and third season pear shoots.

Discussion

In this work, we have investigated the viability of shoot infections of *V. inaequalis* and *V. pirina* at various times during the year. In both apples and pears, we observed scab lesions containing viable lesions in second season shoots from several weeks before bud-break and more or less throughout the entire growing season. Several authors from the UK and Ireland state that most of the scab lesions in second season shoots, in both apples and pears, cease to produce conidia during June and early July (Marsh & Walker 1932; Marsh 1933; McKay 1938; Swinburne 1965; Cook 1974). Occasionally, scab lesions will remain attached to the shoots and contain viable conidia beyond July (Marsh & Walker 1932). In eastern England, Dillon Weston & Petherbridge (1933) found conidia from May until August in apple spur shoots. A few lesions have also been detected in third season shoots in apples (Swinburne 1965) and pears (Kienholz & Childs 1937). In both apples and pears in our investigations, conidia were found readily after mid-summer in second season shoots.

In pears, the difference between our observations and most others where wood scab has ceased growing in the summer can probably be explained partly by the aggressive growth of the fungus observed in the three most examined cultivars; 'Doyenné Boussoch', 'Épargne', and 'Fleskepære'. The fungus could probably

readily overcome growth barriers in second season shoots, since viable lesions were found until November and lesions in third season shoots continued to produce conidia.

We made no attempts to quantify the production of conidia at various times during the season. Thus, even though we readily detected lesions with viable conidia, in order fully to understand the importance of the spread of conidia in late summer and autumn, further studies are needed on the seasonal distribution of release.

We observed a decline in the ability to germinate towards the end of the season. This is in agreement with Marsh (1933) and Cook (1974), who found that a decline in production of conidia in apple shoots in June was accompanied by a decrease in viability of conidia. The viability of the conidia was in general somewhat lower than that previously observed in conidial suspensions from leaves, which was usually around 70% (Stensvand 1993). However, the viability varied greatly in both conidia from leaves and those from shoots.

The superficial growth of scab on the bark of second season shoots has previously been studied by Kennel (1981), Moosherr & Kennel (1986) and Kennel (1990). What they called superficial scab («superfizieller Schorf») was described as mostly macroscopically invisible, and occurred at shoot tips and at shoots that developed after a too early summer pruning. The symptoms we observed were more similar to what Kennel (1990) called shoot basal scab («Triebbasisschorf»), which had a visible mycelium growing directly from second season shoots to the basis of new, emerging shoots and leaves.

Conidia from shoot infections and other anamorphic sources may play a very important role in early infections of the apple and pear scab fungi. Ascospores released from pseudothecia in apple and pear leaf litter during spring and early summer are considered the main source of primary scab inoculum in Norway. This is true, especially in apples and in well-managed orchards. From southwestern England, Hill (1975) suggested that the mild climate during winters in that region causes rapid decomposition of leaves, lessening the role of the ascospores in providing primary inoculum. Dillon Weston & Petherbridge (1933) found that initial infections in spring were brought about by conidia from shoot infections and not from ascospores produced in leaf litter on the ground.

During mild winters in coastal fruit-growing regions of Norway, such as for example at Hjelmeland and Norddal, most of the apple and pear leaf litter often degrades before spring. Table 3 shows that at these two locations the mean temperature does not fall below freezing in the winter, and precipitation is frequent, especially during autumn and early winter. The climatic conditions, with their subsequent effect on leaf degradation are similar to the conditions described by Dillon Weston & Petherbridge (1933) and Hill (1975) in England. In particular if scab management has been partly out of control in the preceding year, shoot infections might thus be the overall source of primary inoculum in the spring.

In southeastern Norway, e.g. at Ås, temperature is lower during late autumn and winter, and precipitation is lighter (Table 3). Furthermore, leaves are covered with snow for a longer time. Leaf degradation is thus much slower than in western Norway, and the importance of ascospores as primary inoculum in spring is higher.

Conidia in great numbers from shoot infections are close to and can quickly

reach the new, emerging apple and pear tissue. If shoot infections do occur, it is important to prevent early infection by means of cover sprays with protectant fungicides. Kennel (1987) studied the phenological development of apple buds in early spring. The first green parts exposed in spring consist of sepals. Sepals are thus the first organs susceptible to infections, and infections in sepals are a very important source for scab on young fruits. In trees containing shoot infections, Dillon Weston & Petherbridge (1933) found conidia in the unfolding flower buds. Water is readily held in the grooves of expanding buds, providing excellent conditions for infection. In Hjelmeland and Norddal, the first green tissue in the expanding flower buds of pear trees has been observed as early as late January and early February in some years. We have observed that inoculum coming from shoot infections in high numbers can cause serious damage to flower parts such as sepals and flower stalks when they are first exposed. Such infections caused serious yield loss in the pear cultivar 'Épargne' at Norddal in 1990.

Even if shoot infections are observed, early spraying around bud-burst is often made difficult by frequent spring rains and steep, slippery orchard floors. It is thus important to prevent the establishment of shoot infections during the preceding summer and autumn. By the end of June, the spread of ascospores usually ceases in Norway (Stensvand 1993), and scab spraying more or less ends if growers manage to prevent the establishment of scab in the orchards. If wood scab occurs, our findings indicate that spraying programmes should be continued for another 1-2 months in apples, and for even longer in pears. Furthermore, to prevent the establishment of infections in new shoots, growers should consider spraying until terminal growth ceases in problem cultivars. Finally, growers should not ignore the infection potential from wood scab in third season pear shoots even if no viable scab lesions develop in second season pear shoots for one year.

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Prediction of field occurrence of the cabbage moth, Mamestra brassicae (Lepidoptera: Noctuidae): Pheromone traps and degree-day model

NINA SVAE JOHANSEN
Norwegian Crop Research Institute, Plant Protection Centre,Department of Entomology and Nematology, Fellesbygget, Ås, Norway

Johansen, N.Svae, 1996. Prediction of occurrence of the cabbage moth, Mamestra brassicae (Lepidoptera: Noctuidae): Pheromone traps and degree-day model. Norwegian Journal of Agricultural Sciences 10: 541-554. ISSN 0801 5341.

Pheromone traps for monitoring flight of the cabbage moth, *Mamestra brassicae* (L.), were tested in commercial cabbage and cauliflower fields in different localities in south-eastern Norway during 1989-91. Trap catches were very low in all localities and years, and the traps could therefore not be recommended for practical monitoring. A degree-day model for prediction of occurrence of adults, eggs and small larvae in the field was developed and validated. Agreement between predicted and observed occurrence was good. An automatic voice board response system for prognosis and advice for the growers was developed and implemented. The growers get information on present status of *M. brassicae* in the field, prognosis for development for the nearest days, when to record eggs for assessment of the need for control, and favourable spraying time. Advice on insecticide use is also given. The system has been evaluated.

Key words: Cabbage crops, degree-day model, *Mamestra brassicae*, monitoring, Noctuidae, pheromone traps, prediction, prognosis.

Nina Svae Johansen, Norwegian Crop Research Institute, Plant Protection Centre,Department of Entomology and Nematology, Fellesbygget, N-1432 ÅS, Norway

The cabbage moth, *Mamestra brassicae* (L.) is an important pest on cabbage crops in Norway, south of 62°N, where it has one generation a year. Overwintering takes place as pupae in the soil, and the adults emerge in late spring or early summer. Eggs are deposited on the underside of the leaves in clusters of up to 70-80 eggs. The larvae feed in colonies the first day after hatching. Later they spread to the neighbouring plants, and the older larvae feed directly on the marketable product of different cabbage crops (Rygg & Kjos 1975).

Chemical insecticides are almost the only control method used against *M. brassicae* in Norway today. To be effective, insecticides must be applied when the larvae are small and are feeding on the outer leaves of the cabbage plants. The larvae should preferably be smaller than 12 mm (larval instar I-III). From instar V they enter the crown of the cabbage plants and become protected from insecticides (Rygg & Kjos 1975). Also, older larvae tend to be more tolerant to insecticides (Rygg & Kjos 1975, Van de Steene 1994). Many growers do not sample, but follow a prophylactic spraying scheme with one treatment in the middle of July and

perhaps another one 14 days later. In some years this is too late to get full effect from the treatment.

Development of *M. brassicae* is strongly temperature dependent (Øgaard 1983, Johansen unpublished). Thus, the occurrence of the different developmental stages in the field will vary between years and localities. For example the peak occurrence of larval instar I and II of *M. brassicae* in one field in southern Norway varied up to five weeks over a seven year period, and this makes correct timing of control treatments difficult (Johansen 1994).

Information to the growers about flight times of adult *M. brassicae* in Norway has previously been based on records from emergence cages placed outdoors at The Norwegian Crop Research Institute, Plant Protection Centre, at Ås in southern Norway. However, the climatic variations in southern Norway are great, and there is a need for more local predictions.

Pheromone traps have been tested for monitoring *M. brassicae* with variable results (Hommes 1983 Pelerents & Van de Veire 1985, Terytze & Adam 1980, Terytze et al. 1987, Van de Veire and Dirinck 1986).

Several degree-day models with good agreement between predicted and observed field occurrence of insects have been developed, e.g. emergence models of *Helicoverpa* zea (Boddie) and *Heliothis virescens* (F.) (Rummel & Hatfield 1988; McCann et al. 1989). Kobro (1988) has shown that emergence of *M. brassicae* adults can be predicted from degree-day calculations based on historical records of spring emergence. Lower developmental thresholds and thermal requirements for all life stages of native *M. brassicae* have been established (Johansen 1996). A network of automatic weather stations exists throughout Norway, and local meteorological data throughout the distribution area of *M. brassicae* are easily available.

The objective of this study was to test pheromone traps to monitor flight, to construct and validate a degree-day model to predict occurrence of different developmental stages in different regions of Norway, and to develop a practical decision-support system for the growers.

Materials and methods

2.1 Pheromone traps

Pheromone traps were placed in commercial fields of white cabbage and cauliflower at 3-5 different locations in south-eastern Norway during 1989-1991. Aluminium tray traps (width 40 x 20 x height 11 cm) with a changeable sticky insert were used. Similar tray traps gave good catches of *M. brassicae* in field trials in Germany (Terytze & Adam 1981, Terytze et al. 1987). A polythylene capsule with a mixture of 0.8 mg (Z)-11-hexadecenyl acetate (Z 11-16:Ac), 0.1 mg (Z)-11-heptadecenyl acetate (Z 11-17:Ac) and 0.1 mg hexadecenyl acetate (16:Ac) was placed on the sticky insert. Inorder to avoid catches of *Ochropleura plecta* (L.) 0.05 mg (z)-9-hexadecenyl acetate (z 9-16:Ac) was added (Van de Veire and Dirinck 1986). The pheromone capsules were replaced every 21 days, and the sticky insert was changed when needed to maintain the stickiness. As recommended by Terytze & Adam (1981) the traps were placed 1.20 m above ground level.

Trapping was started well in advance of the expected emergence of adult M. brassicae. In 1989 a system of two traps was used. One trap was placed at the edge, and the other 30 m into the field.

In 1990 and 1991 a system of three

traps per field in an equilateral triangle with sides of 30-40 m was used. Two of the traps were placed at the edge of the field. One of the traps was oriented towards the prevailing wind direction. Z 9-16:Ac was not included in the pheromone blend as this compound did not prevent trapping of *O. plecta* in 1989.

All fields were situated in landscapes with a mixture of small fields, hedgerows, woods and ridges.

2.2 Degree-day model

Lower developmental thresholds and thermal requirements for the immature stages and the preoviposition period of native *M. brassicae* have previously been established using linear regression technique (Johansen 1996).

To calculate the number of degree-days (DD) accumulated for each day, the following equation was used:

$$DD = (T_{mean} - T_b) * t/24 \; T_{mean} > T_b$$

$$DD = 0 \quad T_{mean} <= T_b$$

T_b is the lower develop-mental threshold for the life stage in question. T_{mean} is the mean temperature of the hours when temperature exceeded T_p the previous day, and t is the number of hours during the previous day with temperature higher than T_b. The model accumulates degree-days until the average thermal requirement for the particular life stage in question is reached. *M. brassicae* pupates in soil at 3-5 cm depth (Rygg & Kjos 1975). But for technical reasons soil temperature at 10 cm depth was chosen to calculate emergence of adults. Temp-erature data from Department of Agricultural Engineering (1984-1994) show that there are no significant differences between the monthly mean temperatures at 5 and 10 cm soil depth for the period from 1st of April to 30th of June . Air temperature measured 2 m above ground level was used to estimate the occurrence of eggs and larvae.

2.4 Model validation

The accuracy of the prediction model was checked using data from natural populations of *M. brassicae* in 7 different regions in southern Norway during 1992-1994. Eggs and larvae were counted weekly on 50 plants systematically sampled throughout cabbage fields. In addition, data on the occurrence of eggs and larvae of M. brassicae were available for Ås during the period 1984-1985 and

Table 1. Males of *M. brassicae* trapped in pheromone traps in commercial cabbage fields at 5 different locations in south-eastern Norway 1989-91. (- = no experiment.)

Locality	No. of males trapped 1989	1990	1991	Surrounding vegetation near the edge trap
Ås	0	0	3	Fruit trees
Rygge	0	1	0	Deciduous wood
Ski	-	11	2	Mixed coniferous and deciduous wood
Lier	0	-	-	Hedgerows
Notodden	-	1	-	Deciduous wood

1988-1992 (Johansen & Hougsnæs 1986, Johansen unpublished). The sample size was 20 plants in 1984 and 1985, and 100 plants during 1988-1992.

Predicted first occurrence of eggs and larvae were compared with the observed occurence of eggs and larvae in the field. The "first event" approach was chosen to give the farmers time to respond to the advice provided by the model.

The simulation model was run using temperature data from the locally situated automatic weather stations. Which measured temperature on an hourly basis. The weather stations were calibrated once a year in spring, and the data were continuously validated during the prediction period.

Accumulation of degree-days was started 1st of April. Historical data from the automatic weather station network show that the soil temperature at 5 or 10 cm depth in the distribution area of *M. brassicae* in Norway very rarely exceeds the lower temperature threshold for pupae before this date.

Results and discussion

3.1 Pheromone traps

The trap catches at all locations and years were very low. (Table 1) 93% of the total amount of males trapped were caught in the traps placed at the field edges.

At all locations high numbers of *O. plecta* and *Discestra trifolii* (Hufn.) and small numbers of other noctuids were trapped. Thus, the specificity of the pheromone blend was low, as also found by Van de Veire & Dirinck (1986) and Pelerents & Van de Veire (1988). In Germany, tray traps baited with 1 mg Z 11-16:Ac trapped *D. trifolii* and *Diarsia rubi* (View.) in addition to M. *brassicae*. (Terytze & Adams 1981, Terytze et al. 1987).

Different pheromone dialects might exist in different geographical populations of *M. brassicae*, as is shown for European, western Asian and African populations of *Agrotis segetum* (Schiff.) (Lofstedt et al. 1986, Hansson et al. 1990, Toth et al. 1992). The pheromone blend in the present experiment was based on the pheromone compounds isolated from a Belgian laboratory rearing of *M. brassicae*, and might not be optimal for Norwegian *M. brassicae* populations. However, the density of *M. brassicae* in all locations were low during 1989-1991. In the experimental field in Ås low numbers of eggs were found although no males were trapped in 1989 and 1990, and in 1991 eggs were found before the first male were caught in the traps. The low trap catches probably reflected the low population density, but conclusions on the efficiency of the traps could not be drawn.

So far the pheromone traps are concidered as too uncertain for monitoring flight in a practical monitoring system. More research is needed on the pheromone compound, especially with respect to possible pheromone dialects, and on trap design and trapping system. The relationship between trap catches and actual population density in field should be established if possible. The behaviour of adult *M. brassicae* in field during migration, mating and nutrition should be investigated as well.

3.2 Validation of the degree-day model

As the reliability of the pheromone traps was uncertain, a prediction system based solely on degree-day calculations was developed.

Using the lower developmental thres-

hold ($T_{b(Pupae)}$) of 7.5°C and the thermal requirement ($DD_{(Pupae)}$) of 304 degree-days for pupae found by Johansen (1996) gave too late predictions of adult emergence. This was also the case when $T_{b(Pupae)}$ (5.2°C) and $DD_{(Pupae)}$ (363) found by Øgaard (1983) for Danish populations were used. The late pred-ictions is probably be inherited in the degree-day model. The relationship between temperature and pupal development show an exponential pattern for temperatures between 10 and 23 °C (Johansen 1996). Thus the linear extrapolation towards $T_{b(Pupae)}$ in the model underestimates development at temperatures near $T_{b(Pupae)}$. During the post-diapause period in the spring in Norway the soil temperature stays near to $T_{b(Pupae)}$ for long periods of time (Depart-ment of Agricultural Engineering 1984-94).

Instead a thermal requirement of 129 degree-days for pupal development ($T_{b(Pupae)}$=7.5°C) based on historical observations of egg occurrence in Ås during the period 1984-85 and 1988-92 was used. The onset of emergence was set to be 5 days before the first occurrence of eggs. This was done to provide the growers with constant information on the phenology of *M. brassicae* in field.

Comparison between predicted and observed occurrence of first eggs and larvae are given in table 2. As the field occurrence was recorded once a week, the first eggs and larvae must have occurred at the sampling date or up to six days before. The agreement between predicted and observed occurrence of the first *M. brassicae* eggs was good in most locations and years. However, in Ås, in 1984 and 1991, the predicted onset of oviposition was more than one week too late. In Ås, in 1988, the predicted onset of oviposition seemed to be too early, but some of the first eggs found in the field hatched within one day and must have been laid at least one week before they were found. In 1992 the first records of eggs were made at Julian date 167 in Stokke, Jæren and Nordfjord. Eggs were present in these three locations that day.

Expect for Ås, in 1994, the agreement between predicted and observed occurence of the first larvae was good in all locations and years. In Ås, in 1991, and in Stokke, in 1992, the predicted occurrence of the first larvae seemed to be too early. However, in both years some of the first larvae observed were already older than instar I, and must have been present in the field for several days. Thus, the predictions are in agreement with the observed occurrence also for these years. The predictions of occurrence of both eggs and larvae were acceptable to good also in years with extreme temperatures, as in 1988 and 1992, when May and June were very warm, and in 1991, when the temperatures were very low in June. Temperature data for Ås are provided in table 3.

For the practical model the favourable period for egg recording was set from the day of predicted onset of oviposition and three weeks ahead, and favourable spraying time was set from one week after prediction of the first larvae and until the first larvae had completed instar IV. The comparisons between the predicted favourable period for egg recording and observed development of the egg population, and between the favourable spraying time, and observed development of the larval population in Ås during 1984-1992, are shown in figure 1. For all years, the predicted favourable period for egg recording covered periods with high egg density, making a rough assessment of the need for control possible. This was also

Table 2. Comparison between predicted and observed occurrence of first eggs and larvae of *M. brassicae* at seven locations in Norway 1984-1994. Eggs were recorded weekly. In 1992 the first records in Stokke , Jæren and Nordfjord were done at Julian date 167. Julian date 153 = 1 June.

Site (Region)	Year	Predicted / Observed (Julian dates)		Deviation (Days)	
		First eggs	First larvae	First eggs	First larvae
Rygge (Southeast)	1992	169 / 169		0	
	1994	174 / 171		+3	
Ås (Southeast)	1984	168 / 158	182 / 179	+10	+3
	1985	165 / 170	176 / 184	-5	-8
	1988	161 / 174 [1)]	169 / 174	-13 [1)]	-5
	1989	169 / 172	177 / 179	-3	-2
	1990	162 / 164	173 / 171	-2	+2
	1991	178 / 170	188 / 198 [2)]	+8	-10 [2)]
	1992	157 / 155	165 / 162	+2	+3
	1993	158 / 160	177 / 181	-2	-4
	1994	168 / -	183 / 174		+9
Ski (Southeast)	1992	157 / -	165 / 169		-4
Lier (Southeast)	1994	176 / 171		+5	
Stokke (South)	1992	156 / <167	163 / 174 [3)]		-11 [3)]
	1993	153 / -	173 / 175		-2
Jæren (Southwest)	1992	153 / <167			
Nordfjord (West)	1992	162 / <167			

[1)] Some of the eggs hatched within one day.

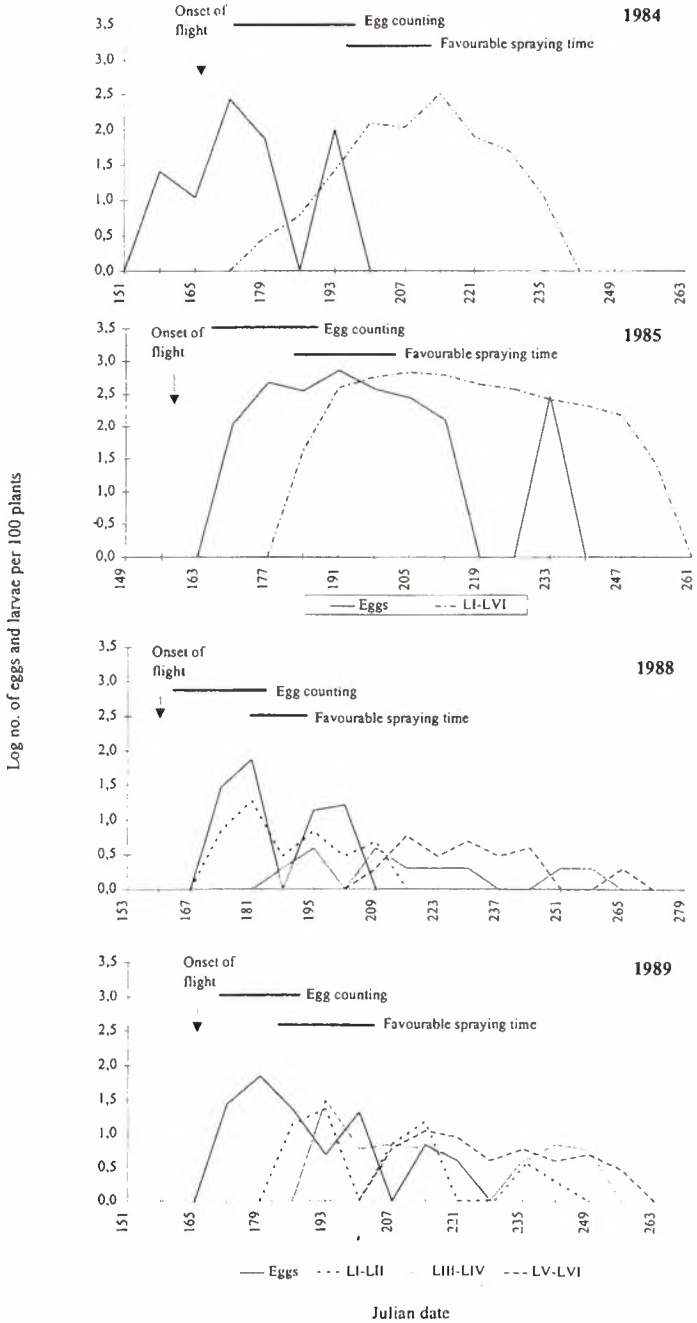
[2)] Larval instar II and III.

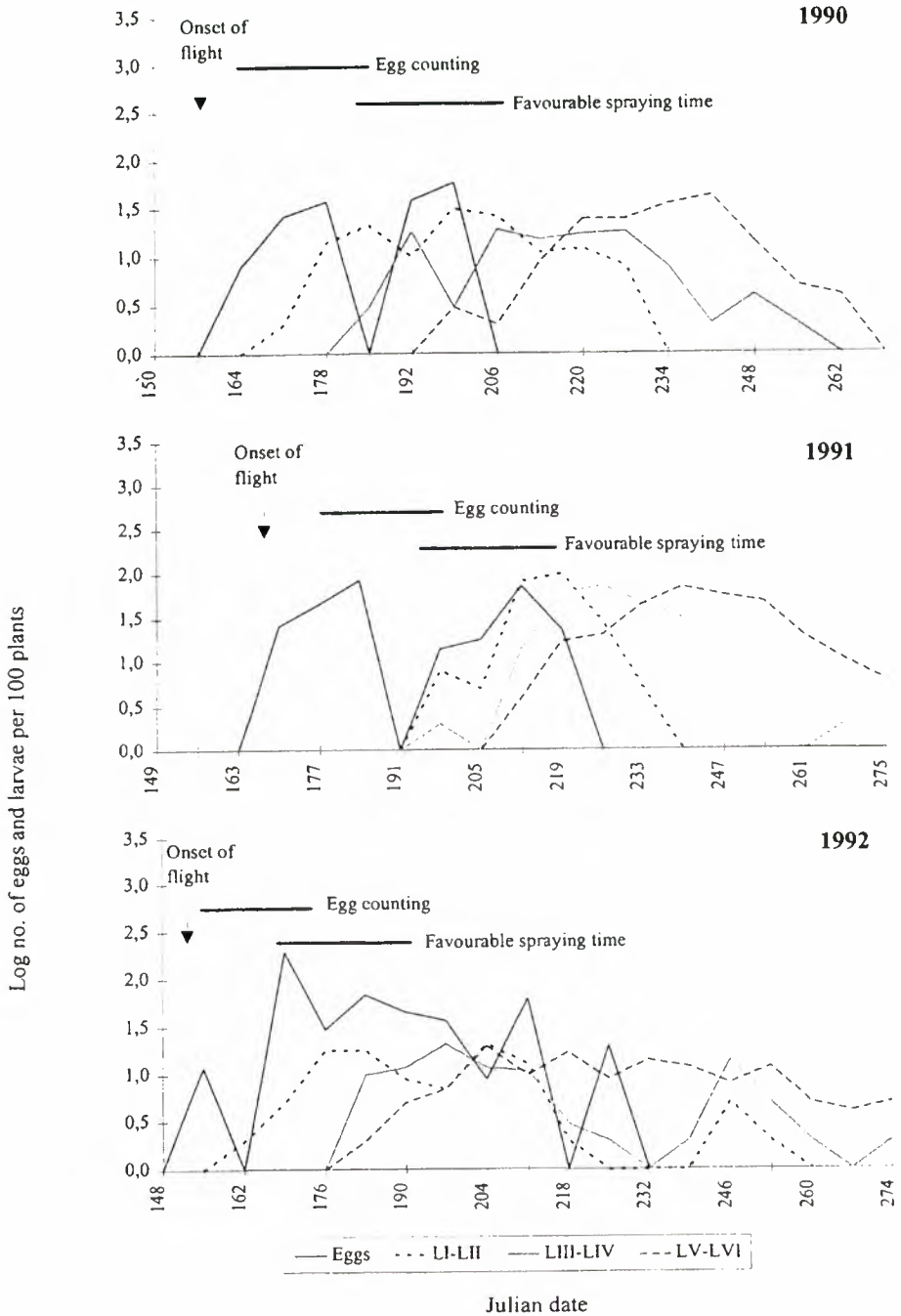
[3)] Larval instar I and II.

Table 3. Mean monthly air temperatures in Ås for May and June 1984-1994, and deviation from the normal air temperature. The normal temperature is the mean monthly air temperature for the period 1961-1990). (Department of Agricultural Engineering 1984-1994).

Year	Temperature (deviation from normal)	
	May	June
1984	12.2 (+1.9)	14.5 (- 0.3)
1985	11.0 (+0.7)	13.6 (- 1.2)
1988	12.2 (+1.9)	17.7 (+2.9)
1989	10.6 (+0.3)	14.5 (- 0.3)
1990	11.8 (+1.5)	14.6 (- 0.2)
1991	10.3 (0.0)	11.3 (- 3.5)
1992	12.8 (+2.5)	17.3 (+2.5)
1993	12.6 (+2.3)	13.4 (- 1.4)
1994	10.7 (+0.4)	13.5 (- 1.3)

Fig. 1. Comparison between predicted favourable period for egg recording and observed egg population development, and between predicted favourable spraying time and observed larval population development in Ås during 1984-1985 and 1988-1992. Julian date 153=1 June.




1990
Onset of flight
Egg counting
Favourable spraying time
1991
Onset of flight
Egg counting
Favourable spraying time
1992
Onset of flight
Egg counting
Favourable spraying time
Log no. of eggs and larvae per 100 plants
Eggs
LI-LII
LIII-LIV
LV-LVI
Julian date

the case in 1984 and 1991, when the predicted occurrence of the first eggs were too late. The predicted favourable spraying time covered the period when the larval population shifted from a population of individuals in instar I and II towards a population of individuals in instar III and IV, and , except for 1992, included the peak density of larvae in instar I and II. Application of insecticides in this period would have ensured a good effect of the treatment, as larvae are most susceptible to insecticides in instar I-III. The results show that the degree-day model was able to give acceptable predictions of the favourable period for egg recoding and

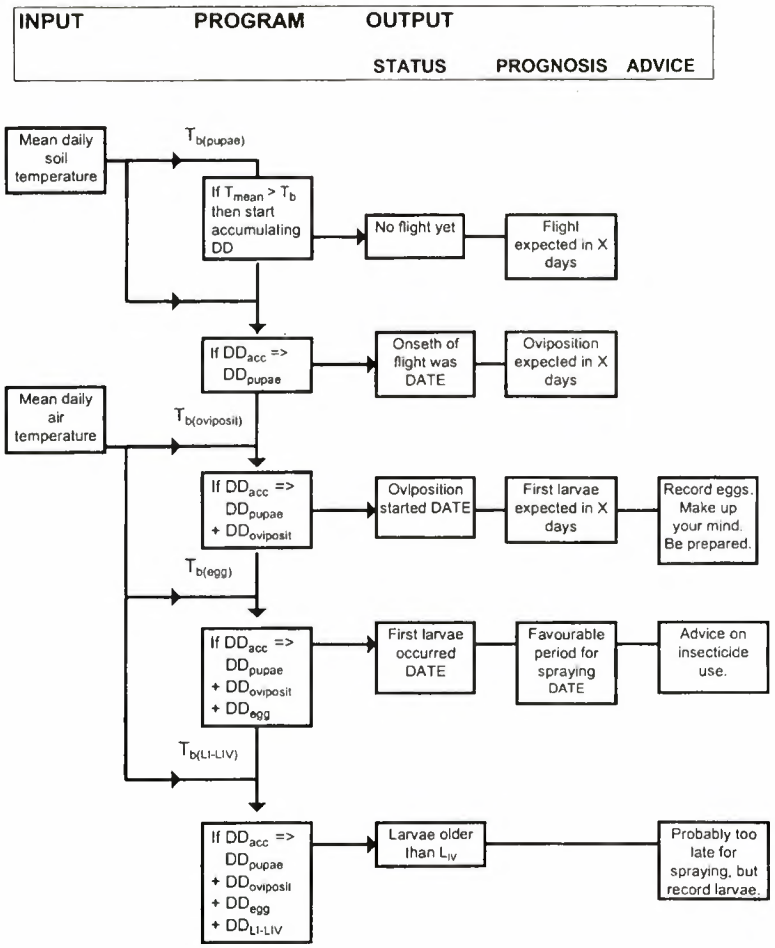


Fig. 2. Flow diagram showing the structure of the model used in the automatic voice board response system for practical warning, prognosis and advice on M. brassicae. *DD_{acc} is accumulated degree-days. DD_{pupae}, DD_{egg}, DD_{LI-LIV} and $DD_{oviposit}$ are number of degree-days required to complete the pupal, egg and larval stages, and the preoviposition period, respectively. $T_{b(pupae)}$, $T_{b(oviposit)}$, $T_{b(egg)}$ and $T_{b(LI-LIV)}$ are the lower developmental threshold for pupae, the preoviposition period, eggs and larval instar I IV. T_{mean} is the mean temperature in the soil in a depth of 10 cm.*

good predictions of the favourable time for insecticideapplications.

An automatic voice board response system for prognoses of development of *M. brassicae* and advice for the growers was developed and implemented. The structure of the prediction model is given in figure 2. The growers get local information on phenology at the present time, prognosis for development for the next 14 days, when and how to record eggs in the field to assess the need for control, and when to spray if needed. Because of the prolonged period over which *M. brassicae* eggs and larvae are normally found in the field, the growers are advised to assess the need for a second insecticide application later in the season. Advice on the use of insecticides is also given.

The model is now part of TELEWISE, an automatic plant protection and weather forecast service for growers, developed by The Norwegian Crop Research Institute, Plant Protection Centre, in co-operation with the Instrument Service.

Conclusion

The dgree-day model presented here provides a good method to predict occurrence of eggs and small larvae of *M. brassicae* on a local scale. In Norway the need for control of *M. brassicae* varies between years and locations. The prediction model will help the growers to find the right time for assessment of the need for control, and unnecessary insecticide applications may be saved. Correct timing of insecticide application is essential to achieve an effective control of *M. brassicae,* and the favourable spraying time predicted by the model should lead to an increased effect of the treatments. Biological control with *Trichogramma* or microbial insecticides may be used to control *M. brassicae* in the future, and the model can most likely be adjusted to predict the right time for the application of these biological control agents as well.

Due to low populations of *M. brassicae* during the experimental period, the efficiency of the pheromone traps was difficult to assess. Thus, this method is so far considered as too unreliable to be used in practical monitoring of *M. brassicae* flight. However, the use of reliable pheromone traps would most likely increase the precision of the prognosis model, and further research should be done.

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Leaching of plant nutrients in drainage water as influenced by cropping system, fertilization and climatic factors

S. TVEITNES[1], O. FUGLEBERG[2] & S.L. ØPSTAD[3]
[1]Department of Soil and Water Sciences, Agricultural University of Norway, Ås, Norway. [2]Department of Mathematical Sciences, Agricultural University of Norway, Ås, Norway. [3]Fureneset Rural Development Centre, Hellevik i Fjaler, Norway

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In a lysimeter study, carried out in Western Norway on a location having an oceanic climate and an annual rainfall of 2010 mm, leaching of mineral nutrients and their concentration in the drainage water was recorded during the periods 1973-79 and 1984-86 by means of monthly analyses of drainage water. Two sites were chosen for the study, the one located on a sandy soil rich in organic matter, the other on a purely organic soil (peat). On each site 5 different crop rotation and fertilizing programs were compared. On average the amount of drainage water recorded corresponded to 39-64% and 24-45% of the rainfall on the two fields respectively. The concentration of Nmin and nitrate-N in the leachate were higher on the plots with tilled land the two first years of each 4 year rotation period than on plots with permanent grassland. Nmin in the leachate amounted to 2-4.5 kg daa^{-1}, while the concentration and leaching of P were small, especially on mineral soil. Precipitation significantly affected the leaching of mineral N. On basis of data collected over the year, it was observed that an increase in precipitation caused a relatively large increase in the loss of Nmin by leaching. Also an increase in temperature caused increased leaching of the N-fractions, but only in the case of data collected over the year or during autumn. In the spring, leaching of both Nmin and nitrate-N decreased with increase in temperature.On basis of data collected over the year, it was found that leaching of both Nmin and nitrate-N was larger in the case of the sandy loam than in the case of peat. In the autumn and spring the leaching of the N fractions was significantly larger than in the summer and winter. However, in the spring leaching was less affected by precipitation than in the rest of the year. Regression analyses further showed that precipitation was a highly significant variable with regard to leaching of phosphorus, but generally not a significant variable with regard to the concentration of P in the drainage water. Temperature was generally not a significant variable in the case of phosphorus. Both total leaching and concentration of P was significantly larger in peat than in the sandy soil. The concentration of phosphorus in the drainage water depended more on crop rotation and fertilizing practice than did the total leaching of phosphorus. Both precipitation and temperature seemed to influence significantly both leaching and concentration of K, Ca, Mg, SO_4-S, Na and Cl. Crop rotation and fertilizing practice did also to a large extent influence both concentration and the amount of leaching of these elements. On the whole, leaching increased significantly with increase in precipitation, while the concentration of these elements in the drainage water decreased. Both concentration and leaching increased with increase in temperature for all the elements, except for chlorine.

Key words: Calcium, cattle slurry, chlorine, cropping rotation, field lysimeter, leaching, magnesium, manure, nitrogen, phosphorus, sulphate sulphur, sodium

Steinar Tveitnes, Agricultural University of Norway, Department of Soil and Water Sciences, P.O.Box 5028, N-1432 Ås, Norway

The loss of plant nutrients from cultivated land depends strongly on fertilization and crop rotation practice, on weather conditions and on soil type. (Røyset 1947, 1954, Tveitnes 1988, Øyen 1993).

Lysimeter experiments are widely used in studies of nutrient losses, BASF (1984) cites 1800 references. The advantage of a field lysimeter experiment is that the soil profile is kept undisturbed, while the disadvantage is the small possibility of controlling soil water movement and environmental conditions.

A considerable variation in the concentration of nutrients in drainage water and surface runoff from agricultural fields, and thus also in amounts of nutrients lost, has been reported in Norway (Uhlen 1978, 1989, Lundekvam 1993). Uhlen, Haugen and Kolnes (1992) found in South East Norway that manure applied in the autumn resulted in a good yield the following year, and caused no large additional leaching, except for Cl. Heavy yields and correspondingly high uptake of nutrients contributed to rather small losses of nitrate-N by leaching. Oskarsen (1993) reported a substantial loss of NO_3-N, especially from sites in coastal areas when manure was given in the autumn, while Myhr et al (1996) demonstrated that plowing in of slurry in the autumn increases the loss of nutrients compared with spring application of slurry.

The purpose of the present study was to provide further information about loss of nutrients, in the drainage water, in order to evaluate the effect of fertilization on the pollution hazard in a humid, oceanic climate (Western Norway). Emphasis was laid on nitrogen and phosphorus, since these nutrients are considered to be the main reason for eutrophication in fresh water. Losses of gaseous nitrogen and fixation of nitrogen in organic components in the soil have not been measured. Due to incomplete records results concerning surface runoff are not included.

Materials and methods

Experimental design

Two field lysimeters (F21 and F22) were constructed at Fureneset Research Station in Western Norway, situated at latitude 61°18'N 5°4'E, 10 m above sea level. Average annual rainfall at Fureneset is 2010 mm, season of growth (>5°C) for 1961-1990, 208 days, and temperature sum (>5°) 1129°C.

The F21 site was situated on a sandy loam (Podzolic) with 9 per cent organic matter and a pH of 5.9. The volume weight was close to 1.0 in the upper 20 cm soil layer, and 1.3 in the 40-60 cm layer. The content of P-AL was 3-7 mg 100 g^{-1} dry soil and K-AL 5-15 mg 100 g^{-1}, i.e. moderate content of both phosphorus and potassium.

Site F22 was on a peat soil with 46 per cent organic matter. The volume weight was 0.6 in the top soil. The content of P-AL was 7-13 mg 100 g^{-1} and K-AL 5-11 mg 100 g^{-1}, which indicates a soil rich in phosphorus and medium rich in potassium.

The sandy loam (site F21) was rich in acid soluble potassium (K-HNO_3), while the peat soil (site F22) had a moderate content. The content of magnesium was high on site F21, and low to medium on site F22.

Each site consisted of five plots, each of the size (5 x 20) m^2. Along the middle of each plot drain pipes were placed at a depth of 80 cm. In the lower end of the plots, the pipes were attached to plastic

pipes which were connected to tilting buckets in a small hut where the amount of drainage water was recorded. Around the site, ditches were dug in order to cut off water from the outside. Within the site, the top soils of the plots were separated by vertical boards.

Samples of surface and drainage water were collected at regular intervals in periods with runoff and leaching. The analyses were carried out at Laboratory of Analytical Chemistry, N-1432 Ås, in accordance with standard methods (Norges Standardiseringsforbund 1980).

The slope of the sites F21 and F22 were 11% and 2% respectively.

The periods of experimentation were 1973 -1979 and 1984 -1986.

Crop rotation and fertilization plan

On both sites the following crop rotation and fertilization plan was conducted. Both cattle slurry and fertilizer were broad spread.

Plot a. Crop rotation: 1st year, green fodder rape. 2nd year, sown grassland without cover crop. 3rd year, grassland. 4th year, grassland. Fertilization: 1st and 2nd year: In spring: Cattle slurry, 100 t ha^{-1}. After 1st cut (2nd year): Calcium nitrate (15.5% N), 300 kg ha^{-1}. 3rd and 4th year: In spring: NPK-fertilizer 16-3-15, 750 kg ha^{-1}. After 1st cut: NPK-fertilizer 16-3-15, 500 kg ha^{-1}, topdressed.

Plot b. Crop rotation as a. Fertilization: 1st and 2nd year: In spring: NPK-fertilizer 14-6-16, 1500 kg ha^{-1}. After 1st cut (2nd year): Calcium nitrate, 300 kg ha^{-1}. 3rd and 4th year: In spring: NPK-fertilizer 16-3-15, 750 kg ha^{-1}. After 1st cut: NPK-fertilizer, 500 kg ha^{-1}.

Plot c. Crop rotation: Permanent grassland. Fertilization: Every year: In spring: NPK-fertilizer 16-3-15, 750 kg ha^{-1}. After 1st cut: NPK-fertilizer 16-3-15, 500 kg ha^{-1}.

Plot d. Crop rotation as c. Fertilization: Every year: In spring: Cattle slurry, diluted with water 1:1, 80 m^3 ha^{-1}. After 1st cut: NPK-fertilizer 16-3-15, 500 kg ha^{-1}.

Plot e. Crop rotation as c. Fertilization: Every year; on frozen soil or within the end of February: Manure, 40 t ha^{-1}. From 1974: plus Calcium ammonium nitrate, 200 kg ha^{-1}. After 1st cut: NPK-fertilizer 16-3-15, 500 kg ha^{-1}.

The heaviest application of cattle slurry and mineral fertilizers was thus given to plots a and b. Plot d received a high potassium application, plot c a low P and K, while plot e received the least N. The third and fourth year of the rotation period the application of P and K was higher on plots d and e which received cattle slurry and manure respectively, than on plots a, b and c, which received mineral fertilizers (Table 1).

The application of nutrients was almost identical at the two sites and in the two first rotation periods. Neither between sites nor between rotation periods were significant differences found in nutrient application versus recovery in crop yield. For the two first years of both periods recovery of nutrients was higher than in the last two years. Table 2 shows the differences found between the various cultivation systems.

The amount of nutrients given seemed to be well balanced with crop demand. On plot c; with mineral fertilizer only, applied phosphorus was about the same as was removed in grass yield. On the other plots, application of phosphorus was 12 to 27 kg ha^{-1} higher than that removed by the crop, due to the high application of P in the cattle slurry and manure.

The application of mineral-N was adequate on plots a, b and d, and a little short on plots c and e. However, the

Table 1. Application of Nmin, P and K in cattle slurry, manure and mineral fertilizers during the experimental period (kg ha^{-1}).

	Crop rotation*				
Part of rotation period	a	b	c	d	e
1st and 2nd year					
Nmin	224	257	200	181	151
P	121	90	38	48	64
K	332	240	188	283	208
3rd and 4th year					
Nmin	200	200	200	215	195
P	38	38	38	43	67
K	188	188	188	230	215

* For explanation, see text

application of total N in cattle slurry and manure gave a surplus on plots a, d and e.

The application of potassium was less than the recovery of potassium in crop yields, especially on plots a and b. Only on plot d, with mineral fertilizer combined with permanent grassland did the potassium application balance the recovery. However, K-shortage did not occur, since the availability of soil potassium was adequate.

Statistical analyses

It was of special interest to examine the effects of crop rotation and fertilization programs versus the effects of climatic factors. Regression was used to analyse the effects.

This is due to the above mentioned design, the mingling of quantitative variables (climatic factors) and qualitative variables (soil and topographical conditions, crop rotation and fertilizat-

Table 2. Difference between nutrients applied in mineral fertilizers, cattle slurry and manure and nutrients recovered in crop yields (kg ha^{-1}). Average for both sites and for all years and crops.

	Crop rotation*				
Nutrients	a	b	c	d	e
N-tot	82	29	-31	47	53
N-min	1	19	-31	-17	-53
P	26	20	3	12	27
K	-111	-104	-92	-6	-71
Ca	28	-8	-29	10	21
Mg	14	1	-1	12	13

* For explanation, see text.

ion). The basis for this approach is that leaching and concentration of nutrients in the drainage water and total leaching are simultaneously determined by the processes in the soil on the one side and by the field lysimeter factors and the climatic factors on the other.

The influence of the factors which can be controlled (crop rotations and fertilization), was compared with the influence of factors which are not controllable (climatic factors). The climatic factors are influencing leaching, concentration of nutrients in the leachate and total leaching independently and in interaction with crop rotation and fertilization practice.

Therefore, a simultaneous regression model to analyse concentration of nutrients in leachate together with total leaching was chosen. This is based on an assumed statistical dependence between the equations of leaching and concentration of element in leachate and the equation of total amount of drainage water.

The simultaneous regression model

The variables for the simultaneous regression model are:

Dependent variables

N_C, P_C, K_C, Ca_C, Mg_C, SO_4_C, Na_Cl and Cl_C where C stands for concentration of element in leachate in mg l^{-1}, and N_L, P_L, K_L, Ca_L, Mg_L, SO_4_L, Na_L and Cl_L, where L stands for total amount leached in g daa^{-1}.

TR: Total leachate, l daa^{-1}

Independent variables

Climatic variables

P: Precipitation, mm per month

T: Monthly mean temperature, C°

Soil and topographic factors

F: Dummy variable for field (F = 1 if field F21, else F = 0, i.e. if field F22).

Crop rotation and fertilization

B: Dummy variable for crop rotation and fertilization plot b

C: Dummy variable for crop rotation and fertilization plot c

D: Dummy variable for crop rotation and fertilization plot d

E: Dummy variable for crop rotation and fertilization plot e

B = 1 if crop rotation and fertilization plot b, else 0. Correspondingly for the dummies C, D and E respectively. There is no dummy for plot a. The dummies B-E are calculated relatively to plot a.

The simultaneous regression model of concentration and leaching of nutrients and total runoff is formulated as follows:

$$Y_k = A_k P^{\beta_{k1}} T^{\beta_{k2}} e^{\tau_{k1}F} e^{\tau_{k2}B} e^{\tau_{k3}C} e^{\tau_{k4}D} e^{\tau_{k5}E} \mu_k;\ k=1,\ldots,7 \quad (1)$$

where Y_1=Nmin_L, Y_2=NO_3_L, Y_3=NH_4_L, Y_4=Nmin_C, Y_5=NO_3_C, Y_6=NH_4_C, Y_7=TR.

Taking the natural logarithm on both sides of each equation gives

$$\ln(Y_k) = \alpha_k + \beta_{k1}\ln(P) + \beta_{k2}\ln(T) + \tau_{k1}F + \tau_{k2}B + \tau_{k3}C + \tau_{k4}D + \tau_{k5}E + \varepsilon_k;\ k=1,\ldots,7 \quad (2)$$

where $\alpha_k = \ln(A_k)$ and $\varepsilon_k = \ln(u_k)$

The model is of log-log type. Therefore the variable «temperature» is transformed in order to avoid negative values. The parameters in these equations have an appropriate interpretation as relative increment. For example in the equation for Y_1=Nmin_L, the coefficient $ß_{11}$ means per cent increment in concentration of Nmin_L by one per cent increment in precipitation (P); i.e. the elasticity of Nmin_L with respect to P is $ß_{11}$. The interpretation of $ß_{12}$ associated with temperature is correspondingly. By comparing field F22 with F21, log Nmin_L increases with τ_{11}, and by comparing crop rotation and fertilization plot a with crop rotation and fertilization plot b log Nmin_L increases with τ_{12}. Besides this appropriate interpretation, analyses of the log-log model showed a better adaption than analyses of both the linear model and the exponential model.

Estimation of the simultaneous regression models

This deals with estimation of a simultaneous model based on combined cross section with time series data. In that respect we distinguish between

1) Single-equation estimation based on cross section with time series.
2) Estimation of simultaneous models.
3 Estimation of simultaneous models based on combined cross section with time series.

Point 1) and 2) are well dealt with in litterature, for instance by Maddala (1971) or Wallace & Hussain (1969) concerning point 1). For point two see Judge et al (1980), where seemingly unrelated regression (SUR) are dealt with, conditioned on the interdependence between the equations. Point 3) is infrequently dealt with, but two references are Avery (1977) and Baltagi (1981). However in this case the estimation is simplified of the following reasons:

i) Point 1 «collapses» to single-equation estimation when each equation in a simultaneous model has the same regressors. ii) Point 2) simplifies to estimation with dummies in the fixed effects approach.

The fixed effects approach means to focus only on the units in cross section, and not to appreciate these as a sample from a population. In this case it is natural to appreciate the crop rotation and fertilization plots as fixed effects. This simplifies the estimation procedure to single equation estimation and the use of dummies for the crop rotation and fertilization plots. Based on the proposed estimation methods, regression analyses of leaching and concentration of mineral nitrogen were executed from monthly measurements based on the following samples:

The year recordings:

Sample Y1: Monthly recording throughout the year from the periods 1973-1979 and 1984-1986.

Sample Y2: Monthly recording throughout the year from the period 1973-1979.

The autumn recordings:

Sample A1: Monthly recording throughout September, October and November from the periods 1973-1979 and 1984-1985.

Sample A2: Monthly recording throughout September, October and November from the period 1973-1979.

Sample A3: Monthly recording throughout September, October and November from the period 1984-1986.

The spring recordings:

Sample S: Monthly recording throughout

March, April and May from the period 1973-1979.

The analyses of the autumn and spring are not based on equidistant recording. Then we use dummies for autumn/year and spring/year as follows:
A74 = 1 if autumn 74, else 0
S75 = 1 if spring 75, else 0

Correspondingly for A75, A76, A77, A78, A79 and S76, S77, S78, S79 based on the analyses from the period 1973-1979 and for A85 and A86 based on the period 1984-1986.

In the analyses based on sample Y1 and Sample A1, a dummy variable for decade is used:

DEC = 1 if recorded in the 1984-1986 period, else 0.

The analyses based on the year samples reflect the intensive periods of nutrient loss with dummies for spring and autumn respectively, together with interactions between climatic factors and the seasons as follows:

A = 1 if autumn (September, October and November), else 0
S = 1 if spring (March, April and May), else 0

P *A = interaction between precipitation and autumn
P *S = interaction between precipitation and spring

T *A = interaction between temperature and autumn
T *S = interaction between temperature and spring

Results

General

Drainage water

As expected did the amount of drainage water depend on precipitation. In the experimental periods 1973-1979 and 1984-86 did the amount of drainage water on F21 (sandy loam) vary between 39% and 64% of precipitation per annum. On F22 (peat) did the drainage water amount to 24-45 %. In 1984-1986 was the amount of drainage water far greater than in the 1973-1979 period on both fields. In 1986 the amount of drainage water was almost the same as the precipitation, especially on field F21. No obvious reason for this change can be seen. In table 3 mean values and standard deviation of the amounts of drainage water recorded on each field and plot are presented.

The regression analyses of total runoff based on the remaining samples show approximately the same results. This means that total runoff increased significantly with precipitation, by comparing field F22 (peat soil) with F21 (sandy loam) or by comparing plot a with one of the other plots.

Erosion

The surface runoff transported some soil and manure particles, especially from plots with arable crops. Erosion was especially noticable on sandy loam (F21) in 1973, when an amount corresponding to 3.6 tons of soil per hectare was removed with the runoff water from plot b. From plot a, only 1.0 ton was removed. In 1974 and 1975, erosion was also less from plots where cattle slurry was applied, than from plots with mineral fertilizer. It is likely that erosion was reduced due to the application of slurry. More soil eroded from plots with arable crops than from

grassland plots. Erosion was also less from the F22 site where the slope was less than on site F21.

Botanical analyses

On plots c and d, with permanent grassland fertilized with mineral fertilizer and cattle slurry respectively, did timothy, *Phleum pratense*, constitute 45-50% during the 1st four year period and 50-53% during the second period. Other grasses, most of which was *Meadow fescue* and *Festuca pratensis*, decreased from about 40-45% in the first, to only 18% in the second period. The weed percentage increased substantially from the 1st until the 2nd period, from below 5% to above 30%. There were only small differences between 1st and 2nd cut. There were no significant differences in botanical composition between the three plots with permanent grassland.

On plots a and b with two years of tilled field during the four year cropping rotation, a seed mixture was sown the 2nd year. The content of timothy was on the average 30% in the 1st cropping rotation and 50% in the 2nd. *Meadow fescue* was dominating among other grasses, while weeds constituted 30-35% of the sward.

There were only small differences between the sites regarding botanical composition.

Nitrogen

At both fields the concentration of total-N and nitrate-N in the leachate were highest on plots a and b with tilled land the first two years of each crop rotation period. The highest values were found on plot a, where cattle slurry was applied. On plots with permanent grassland there were only minor differences in the concentrations of N in the drainage wa-

Table 3. Drainage water, mm year^{-1}, mean and SD (in parenthesis) of the experimental periods 1973-1979 and 1984-1986.

Field	a	b	c	d	e	Mean
F21	790 (713)	1063 (1308)	1286 (1654)	1029 (1198)	1006 (1122)	1034 (1267)
F22	472 (593)	810 (1021)	679 (977)	712 (1037)	900 (1224)	715 (997)

Measurements of surface water were incomplete, but available records indicate that surface runoff was rather small.

Regression analyses of total leaching (TR) are performed and the results from the period 1973-1979 are given below with t-values in parantheses.

$$TR = \underset{(17.6)}{2.85P} + \underset{(3.6)}{0.34T} + \underset{(5.9)}{0.54F} + \underset{(2.9)}{0.43B} + \underset{(2.0)}{0.29C} + \underset{(2.6)}{0.39D} + \underset{(3.4)}{0.48E} +$$
$$\underset{(6.9)}{8.83A} + \underset{(7.5)}{9.72S} - \underset{(-6.8)}{1.46P*A} - \underset{(-7.4)}{1.82P*S} - \underset{(-1.7)}{0.35T*A} + \underset{(0.0)}{0.01T*S}; \; R^2 = 0.58$$

ter. The concentration of total N, NH_4-N and NO_3-N, mean of the periods 1973-1979 and 1984-1986, are shown i table 4.

At field F21 (sandy loam) the amounts of total N varies from about 3.0 (plot a) to 4.5 kg daa^{-1} (plot e), while at F22 (peat soil) the corresponding values are about 2.0 and 4.2 kg daa^{-1}. The Nmin values were also lowest on plot a, while plot c has the highest value, approximately 4.0 kg daa^{-1}.

Results of the regression analyses are given in Table 5.

Precipitation

Based on all sets of observation, leaching of NH_4-N, NO_3-N and Nmin increased significantly with precipitation (although not so strongly in the spring recordings). The elasticity of leaching of Nmin with precipitation was highest in the year samples with 1.73 and 2.26 in Sample Y1 (monthly recordings throughout the year for the periods 1973-1979 and 1984-1986) and Sample Y2 (monthly recordings throughout the year for the period 1973-1979, respectively. This elasticity was lowest in Sample S (spring recordings 1973-1979) with 0.80. In the three autumn samples this elasticity was about 1.1-1.4. The elasticities of leaching of both nitrate-N and ammonium-N with precipitation follow the same pattern by samples.

Based on the year samples concentration of both Nmin and nitrate-N decreased significantly with precipitation, and the corresponding elasticities varied from -0.41 to -0.75. In Sample A2 (autumn recording for the period 1973-1979) concentration of both Nmin and nitrate-N increases significantly with precipitation with elasticities 0.25 and 0.53 respectively.

Precipitation was not at all a significant variable in the analyses of concentration of ammonium-N.

Temperature

Based on the whole year samples and Sample A1 (autumn recordings for the periods 1973-1979 and 1984-1986) and A3 (autumn recordings for the period 1984-1986), leaching of both Nmin and nitrate-N increased significantly with temperature. The corresponding elasticities in these samples were about 0.3-0.4. In Sample S leaching of both Nmin and nitrate-N decreased significantly with temperature with an elasticity about 1.0. The analyses of leaching of ammonium-N show that the leaching (Sample Y2)

Table 4. Total N, NH_4-N and NO_3-N in the drainage water, mean and SD (in parenthesis) of the periods 1973-1979 and 1984-1986, mg kg^{-1}.

	a	b	c	d	e	Mean
F21 (sandy loam)						
N-total	5.8 (5.9)	5.4 (7.2)	3.3 (4.2)	3.7 (3.6)	3.6 (3.3)	4.3 (5.1)
NH_4-N	0.11 (0.16)	0.10 (0.15)	0.10 (0.12)	0.10 (0.13)	0.11 (0.12)	0.11(0.14)
NO_3-N	4.5 (4.8)	4.7 (6.6)	3.0 (4.19	3.2 (3.3)	3.1 (3.1)	3.7 (4.6)
F22 (peat soil)						
N-total	7,5 (7.7)	5.6 (5.2)	5.1 (4.1)	5.0 (3.4)	5.3 (4.0)	5.7 (5.2)
NH_4-N	0.14 (0.17)	0.10 (0.13)	0.11 (0.07)	0.14 (0.09)	0.14 (0.10)	0.13 (0.12)
NO_3-N	5.9 (6.8)	4.5 (4.6)	3.9 (3.7)	3.5 (3.0)	3.8 (3.6)	4.3 (4.6)

increased significantly with temperature with the elasticity 0.27. In Sample S ammonium-N decreased sign-ificantly with temperature with the elasticity -0.81.

Based on Sample Y1, Sample A1 and A3 concentration of both Nmin and nitrate-N increased significantly with temperature. The corresponding elasticities in these samples were about 0.3-0.5. Temperature was not a significant variable in the analyses of concentration of ammonium-N in drainage water.

Field

In the year samples leaching of both nitrate-N and ammonium-N were significantly higher on site F21 (sandy loam) than on site F22 (peat soil).

Crop rotation and fertilization

In Sample Y1 comparing plot a with one of the other four plots entailed a significant increment of leaching of ammonium-N. In sample Y2 comparing plot a with d or e entailed a significant increment in ammonium-N. In Sample S comparing plot a with d entailed a significant decrement of leaching of both Nmin and nitrate-N.

In Sample A1 comparing plot a with d or e entailed a significant increment of leaching of both Nmin and nitrate-N. In addition passing to c entailed a significant increment in nitrate-N, while comparing plot a with one of the other plots entailed a significant decrement of leaching of ammonium-N.

In Sample A3 comparing plot a with one of the other plots entailed a significant increment of leaching of mineral nitrogen.

Season

The leaching loss of nitrogen was highest in the autumn and least during summer and winter.

In the whole year samples, comparing summer or winter with autumn or spring, entailed that leaching of nitrogen increased significantly less intensively by precipitation. This comparison also entailed that concentration of both Nmin and nitrate-N decreased less significantly by precipitation.

Year

In the autumn and spring samples both leaching and concentration of mineral nitrogen seemed to depend on year.

In Sample Y1 and Sample A1 a comparison of period 1973-1979 with 1984-1986 entailed a significant decrement in both leaching and concentration in both types of mineral nitrogen.

Table 5: Results of regression analyses, based on a log-log model, to determine the effect of precipitation, temperature, soil type, crop rotation and fertilizing programme on the leaching of plant nutrients in the drainage water as observed in a lysimeter experimet. Leaching is given both as total amount in g daa^{-1} (L in table), and as concentration in mg l^{-1} of drainage water (C in table). R-squared and estimated regression parametres are given with t-values in parenthesis. t-values > 2.0 are indicated by *. Data for nitrogen (NO_3-N, NH_4-N and their sum Nmin).

Symbols: P=Precipitation, T=Monthly mean temperature, F=dummy variable for field, B,C,D and E are dummies for crop rotation and fertilization on plot b, c, d and e respectively (see text for treatments). A and S are dummies for autumn and spring respectively, DEC is dummy for the period 1984-1986. P*A, P*S, T*A and T*S = interactions.

Regr.	Nmin_L	NO_3-N_L	NH_4-N_L	Nmin_C (2)	NO_3-N_C	NH_4N_C
Monthly observations for the periods 1973-1979 and 1984-1986						
R-square	0.49	0.44	0.57	0.27	0.24	0.04
P	1.73 (10.5)*	1.60 (8.5)*	2.11 (14.2)*	-0.41 (-3.9)*	-0.54 (-3.7)*	-0.03 (-0.5)
T	0.45 (5.2)*	0.45 (4.6)*	0.14 (1.8)	0.27 (4.8)*	0.26 (3.5)*	0.05 (-1.3)
F	0.08 (0.9)	0.27 (2.7)*	0.34 (4.3)*	-0.42 (-7.5)*	-0.24 (-3.0)*	-0.16 (-4.6)*
B	0.25 (1.8)	0.27 (1.7)	0.38 (3.0)*	-0.20 (-2.2)*	-0.19 (-1.5)	-0.07 (-1.3)
C	0.03 (0.2)	0.15 (1.0)	0.28 (2.2)*	-0.33 (-3.7)*	-0.21 (-1.7)	-0.08 (-1.4)
D	0.17 (1.2)	0.25 (1.6)	0.39 (3.1)*	-0.22 (-2.5)*	-0.14 (-1.2)	-0.00 (-0.0)
E	0.22 (1.6)	0.26 (1.6)	0.45 (3.6)*	-0.25 (-2.9)*	-0.21 (-1.7)	-0.01 (-0.4)
A	3.57 (3.0)*	2.87 (2.1)*	4.76 (4.4)*	-2.07 (-2.7)*	-2.78 (-2.7)*	-0.89 (-1.9)
S	4.42 (3.3)*	3.79 (2.5)*	5.92 (4.9)*	-1.71 (-2.0)*	-2.34 (-2.0)*	-0.21 (-0.4)
P*A	-0.56 (-2.7)*	-0.47 (-2.0)*	-0.72 (-3.9)*	0.33 (2.5)*	0.42 (2.3)*	0.17 (2.0)*
P*S	-0.66 (-2.6)*	-0.50 (-1.7)	-1.10 (-4.7)*	0.45 (2.8)*	0.62 (2.7)*	0.01 (0.1)
T*A	-0.26 (-1.6)	-0.25 (-1.4)	-0.25 (-1.8)	-0.00 (-0.0)	0.01 (0.1)	0.00 (0.1)
T*S	-0.23 (-1.1)	-0.21 (-0.9)	0.10 (0.6)	-0.21 (-1.7)	-0.19 (-1.1)	0.12 (1.5)
DEC	-1.81(-18.7)*	-2.07 (-18.7)*	-1.31(-14.9)*	-0.42 (-6.7)*	-0.68 (-8.0)*	0.08 (2.2)*

Table 5 continued
Monthly observations for the period 1973-1979

R-square	0.32	0.22	0.51	0.28	0.22	0.05
P	2.26 (11.2)*	2.11 (9.0)*	2.78 (15.3)*	-0.59 (-5.0)*	-0.75 (-4.3)*	-0.07 (-0.8)
T	0.42 (3.5)*	0.33 (2.4)	0.27 (2.5)*	0.07 (1.0)	-0.01 (-0.1)	-0.07 (-1.5)
F	0.02 (0.2)	0.23 (1.8)	0.31 (3.0)*	-0.51 (-7.8)*	-0.30 (-3.2)*	-0.23 (-4.8)*
B	0.11 (0.6)	0.10 (0.5)	0.31 (1.9)	-0.32 (-3.0)*	-0.33 (-2.1)*	-0.12 (-1.6)
C	-0.21 (-1.2)	-0.07 (-0.3)	0.14 (0.9)	-0.50 (-4.8)*	-0.36 (-2.3)*	-0.15 (-2.0)*
D	-0.02 (-0.1)	0.06 (0.3)	0.35 (2.2)*	-0.39 (-3.8)*	-0.32 (-2.1)*	-0.02 (-0.3)
E	0.07 (0.4)	0.10 (0.5)	0.43 (2.7)*	-0.41 (-3.9)*	-0.38 (-2.5)*	-0.05 (-0.6)
A	5.54 (3.5)*	4.71 (2.5)*	7.92 (5.5)*	-3.28 (-3.5)*	-4.11 (-3.0)*	-0.90 (-1.3)
S	7.27 (4.5)*	6.16 (3.3)*	9.37 (6.4)*	-2.44 (-2.6)*	-3.56 (-2.6)*	-0.35 (-0.5)
P*A	-0.98 (-3.7)*	-0.90 (-2.9)*	-1.27 (-5.3)*	0.48 (3.0)*	0.56 (2.4)*	0.19 (1.7)
P*S	-1.27 (-4.1)*	-0.04 (-2.9)	-1.80 (-6.5)	0.55 (3.1)*	0.77 (3.0)*	0.01 (0.1)
T*A	-0.09 (-0.4)	-0.02 (-0.1)	-0.41 (-1.7)	0.25 (1.7)	0.32 (1.5)	-0.06 (-0.6)
T*S	0.01 (0.1)	0.15 (0.5)	0.19 (0.8)	0.01 (0.0)	0.15 (0.7)	0.18 (1.7)

Monthly observations for the autumn during the period 1973-1979

R-square	0.52	0.50	0.52	0.57	0.57	0.03
P	1.39 (8.9)*	1.67 (8.1)*	1.26 (7.9)*	0.25 (2.3)*	0.53 (3.3)*	0.13 (1.1)
T	0.21 (1.3)	0.06 (0.3)	-0.14 (-0.8)	0.16 (1.5)	0.02 (0.1)	-0.18 (-1.5)
F	-0.31 (-2.5)*	-0.29 (-1.8)	0.37 (2.9)*	-0.94(-10.9)*	-0.92 (-7.2)*	-0.26 (-2.7)*
B	0.07 (0.4)	0.12 (0.5)	0.30 (1.5)	-0.32 (-2.3)*	-0.27 (-1.3)	-0.09 (-0.6)
C	-0.04 (-0.2)	0.23 (0.8)	0.27 (1.4)	-0.38 (-2.7)	-0.11 (-0.5)	-0.06 (-0.4)
D	0.22 (1.1)	0.51 (2.0)*	0.33 (1.7)	-0.13 (-0.9)	0.16 (0.8)	-0.02 (-0.1)
E	0.27 (1.4)	0.55 (2.2)*	0.43 (2.2)*	-0.33 (-2.4)*	-0.05 (-0.3)	-0.17 (-1.2)
A74[1)]	1.03 (4.6)*	1.18 (4.1)*	0.10 (0.5)	0.99 (6.4)*	1.14 (5.0)*	0.06 (0.4)
A75	0.91 (4.0)*	1.65 (5.7)*	0.14 (0.6)	0.89 (5.7)*	1.63 (7.1)*	0.12 (0.7)
A76	0.47 (1.8)	1.76 (5.3)*	-0.61 (-2.4)*	1.26 (7.1)*	2.55 (9.7)*	0.18 (0.9)
A77	1.21 (5.3)*	1.98 (6.8)*	0.17 (0.7)	1.25 (7.9)*	2.01 (8.7)*	0.19 (1.1)
A78	-0.47 (2.0)*	-0.52 (-1.7)	-0.18 (0.8)	-0.00 (-0.0)	-0.06 (-0.3)	0.28 (1.6)
A79	0.74 (2.2)*	0.61 (1.4)	0.86 (2.5)	0.28 (1.2)	0.14 (0.4)	0.39 (1.5)

[1)] Dummies for the autumn of 1974 and correspondingly for the remaining years

Table 5 continued
Monthly observations for the spring during the period 1973-1979

R-square	0.62	0.60	0.61	0.49	0.51	0.10
P	0.80 (2.2)*	0.72 (1.9)	0.89 (2.6)*	-0.28 (-1.4)	-0.36 (-1.8)	-0.19 (-0.9)
T	-1.00 (-3.0)*	-0.94 (-2.7)*	-0.81 (-2.6)*	-0.17 (-0.9)	-0.11 (-0.6)	0.02 (0.1)
F	-0.29 (-1.3)	-0.23 (-1.0)	0.07 (0.3)	-0.66 (-5.1)*	-0.60 (-4.7)*	-0.30 (-2.4)
B	-0.09 (0.3)	-0.06 (-0.1)	-0.05 (-0.1)	-0.44 (-2.2)*	-0.41 (-2.0)*	-0.39 (-2.0)*
C	-0.60 (-1.8)	-0.62 (-1.8)	0.14 (0.4)	-0.98 (-5.1)*	-1.01 (-5.4)*	-0.25 (-1.3)
D	-0.84 (-2.5)*	-0.90 (-2.6)*	0.23 (0.7)	-1.14 (-6.0)*	-1.20 (-6.5)*	-0.07 (-0.4)
E	-0.21 (0.8)	-0.26 (-0.7)	0.01 (0.1)	-0.49 (-2.6)*	-0.49 (-2.7)*	-0.22 (-1.2)
S75[2)]	-0.44 (-1.4)	0.44 (-1.3)	0.06 (0.2)	-0.29 (-1.6)	-0.29 (-1.6)	0.20 (1.2)
S76	-0.31 (-1.0)	-0.31 (-0.9)	-0.14 (-0.5)	-0.16 (-0.9)	-0.15 (-0.9)	0.01 (0.1)
S77	-0.22 (-0.5)	-0.24 (-0.5)	-0.34 (-0.8)	-0.02 (-0.1)	-0.04 (-0.2)	-0.14 (-0.6)
S78	-3.07 (-4.3)*	-3.22 (-4.4)*	-2.44 (-3.7)*	-0.88 (-2.2)*	-1.03 (-2.6)*	-0.24 (-0.6)

[2)] Dummies for the spring 1975 and correspondingly for the remaining years

Monthly observations for the autumn during the period 1973-1979 and 1984-1986

R-square	0.70	0.68	0.65	0.48	0.53	0.04
P	1.28 (11.7)*	1.45 (10.5)*	1.26 (11.6)*	0.11 (1.3)	0.28 (2.3)*	0.08 (1.1)
T	0.28 (2.9)*	0.24 (2.0)*	-0.14 (-1.5)	0.33 (4.3)*	0.28 (2.7)*	-0.09 (-1.4)
F	-0.22 (-2.4)*	-0.16 (-1.3)	0.32(3.4)*	-0.73 (-9.8)*	-0.67 (-6.4)*	-0.20 (-3.0)*
B	0.27 (1.8)	0.34 (1.8)	0.38 (2.6)*	-0.15 (-1.2)	-0.08 (-0.5)	-0.03 (-0.3)
C	0.27 (1.8)	0.50 (2.7)*	0.39 (2.7)*	-0.13 (-1.1)	0.10 (0.6)	-0.01 (-0.1)
D	0.48 (3.3)*	0.73 (4.0)*	0.38 (2.7)*	0.11 (0.9)	0.36 (2.2)*	0.01 (0.1)
E	0.51 (3.4)*	0.74 (4.0)*	0.46 (3.2)*	-0.06 (0.5)	0.17 (1.0)	-0.11 (-1.1)
A74[3)]	0.97 (4.8)*	1.06 (4.2)*	0.10 (0.5)	0.90 (5.6)*	0.98 (4.4)*	0.02 (0.2)
A75	0.90 (4.5)*	1.63 (6.4)*	0.14 (0.7)	0.85 (5.3)*	1.57 (7.1)*	0.09 (0.6)
A76	0.35 (1.6)	1.51 (5.4)*	-0.62 (-2.9)	1.09 (6.1)*	2.25 (9.2)*	0.12 (0.7)
A77	1.16 (5.6)*	1.89 (7.3)*	0.17 (0.8)	1.15 (7.0)*	1.87 (8.2)*	0.16 (1.1)
A78	-0.46 (-2.2)*	-0.55 (-2.1)*	-0.18 (-0.9)	-0.02 (-0.1)	-0.11 (-0.5)	0.26 (1.8)
A79	0.71 (2.3)*	0.53 (1.4)	0.84 (2.8)*	0.24 (0.9)	0.05 (0.2)	0.36 (1.7)
A84	0.35 (1.5)	0.55 (1.9)	0.02 (0.1)	0.13 (0.7)	0.32 (1.3)	-0.21 (-1.3)
A85	1.02 (4.8)*	1.14 (4.3)*	-0.11 (-0.5)	0.81 (4.8)*	0.93 (4.0)*	-0.32 (-2.1)*
DEC	-1.60 (-7.9)*	-2.34 (4.3)*	-1.11 (-5.5)*	-0.76 (-4.7)*	-1.50 (-6.6)*	-0.26 (-1.9)

[3)] Dummy for the autumn of 1974 and correspondingly for the remaining years

Table 5 continued
Monthly observations for the autumn of the period 1984-1986

R-square	0.73	0.68	0.66	0.36	0.30	0.23
P	1.12 (9.6)*	1.11 (8.1)*	1.24 (9.6)*	-0.12 (-0.9)	-0.13 (-0.8)	0.01 (0.1)
T	0.35 (4.0)	0.41 (4.0)*	-0.14 (-1.4)	0.48 (4.9)*	0.54 (4.6)*	-0.01 (-0.3)
F	-0.05 (-0.5)	0.09 (0.7)	0.21 (1.7)	-0.35 (-2.9)*	-0.20 (-1.4)	-0.09 (-1.8)*
B	0.64 (3.7)*	0.75 (3.7)*	0.52 (2.7)*	0.19 (1.0)	0.31 (1.3)	0.08 (1.0)
C	0.85 (4.9)*	0.99 (4.8)*	0.61 (3.2)*	0.30 (1.6)	0.44 (1.9)	0.06 (0.8)
D	0.97 (5.6)*	1.14 (5.6)*	0.48 (2.5)*	0.55 (2.9)*	0.72 (3.1)*	0.06 (0.8)
E	0.94 (5.4)*	1.07 (5.2)*	0.52 (2.7)*	0.42 (2.2)*	0.55 (2.3)*	0.00 (0.0)
A85[4)]	0.81 (5.0)*	0.90 (4.7)*	-0.11 (-0.6)	0.92 (5.1)*	1.00 (4.5)*	-0.01 -0.10)
A86[4)]	-0.17 (-1.0)	-0.18 (-0.8)	0.00 (0.0)	0.12 (0.6)	0.12 (0.5)	0.27 (3.5)*

[4)] *Dummy for autumn 1985 and 1986*

Phosphorus

The concentration of total phosphorus in the drainage water was very low, especially at field F21 (sandy loam). The values tended to be higher on plots a and b, with tilled land the two first years of each 4 year rotation period, than on the other plots with permanent grassland (table 6).

The average amounts of total phosphorus in the drainage water for the experimental period were 40 - 45 g daa^{-1}.

The estimated equations of leaching and concentration of phosphorus for the above mentioned periods are given in table 7. The main results of the analyses in table 7 are presented in the following.

Precipitation

Based on the autumn samples and the whole year samples, with the exception of the period 1984-1986, leaching of phosphorus increased significantly with precipitation (R). In the period 1973-1979 the elasticity of phosphorus leaching (P_L) with respect to precipitation was 2.39. The concentration of phosphorus did not generally depend on precipitation.

Temperature

The temperature was a significant variable for leaching of phosphorus in the period 1984-1986 and for the concentration of phosphorus in the autumn 1984-

Table 6. Total P in the drainage water, mg kg^{-1}, mean and SD (in parenthesis) of the experimental periods 1973-1979 and 1984-1986.

	a	b	c	d	e	Mean
F21	0.06 (0.07)	0.06 (0.07)	0.04 (0.05)	0.05 (0.05)	0.05 (0.05)	0.05 (0.06)
F22	0.27 (0.52)	0.07 (0.08)	0.14 (0.13)	0.15 (0.08)	0.13 (0.06)	0.15 (0.25)

86 sample. In the period 1973-1979, leaching and concentration of phosphorus was not significantly influenced by temperature.

Field

With few exceptions, both concentration and leaching of phosphorus were significantly higher at the peat soil site than in the sandy loam soil site.

Crop rotation and fertilization

Based on both the whole year samples and the autumn samples, concentration of phosphorus in the leachate decreased strongly and significantly by comparing plot a (which received cattle slurry,) with plot b (where only mineral fertilizer was used).

Generally, in permanent grassland where NPK-fertilizer was used (plot c), the concentration of phosphorus was significantly less than in plot a.

In the period 1973-1979, the concentration of total phosphorus in the drainage water was significantly lower on permanent grassland, where manure was spread in the winter (plot e) than in plot a. Generally there was a tendency to decrease in the concentration of phosphorus by comparing of plot a with the other plots. Also leaching of phosphorus decreased by comparing plot a to the other plots. Spreading of manure on permanent grassland in the winter did not increase phosphorus leaching significantly compared with plot c and d where fertilizer and cattle slurry respectively, were spread in the growing season.

Season and interaction between season and climatic factors

In the period 1973-1979 leaching of phosphorus was significantly higher in autumn and spring than during the summer period. However, in autumn and spring phosphorus leaching increased less intensively with precipitation than in the summer period.

Generally, there were few cases with significant influences of season and interaction between season and climatic factors. Based on the autumn samples, concentration and leaching of phosphorus were influenced by the autumn/year (climatic) effects.

Table 7: Results of regression analyses as explained in table 5. Data for phosphorus (P_C and P_L) based on monthly observations during the periods indicated.
Symbols as for table 5.

Period	1973-79		1984-86		1973-79 and 1984-86	
Regressor	P-C	P-L	P-C	P-L	P-C	P-L
R-squar	0.29	0.45	0.53	0.49	0.45	0.41
P	-0.05(-0.5)	2.39(11.6)*	0.15(0.6)	-0.42(-1.4)	-0.02(-0.2)	1.83(10.0)*
T	-0.04(-0.6)	0.03(0.1)	-0.17(-1.6)	-0.57(-4.5)*	-0.10(-2.0)	-0.07(-0.7)
F	-0.80(-13.4)*	-0.14(-1.2)	-1.57(-12.2)*	-1.08(-7.3)*	-0.9(-17.3)*	-0.37(-3.8)*
B	-0.54(-5.8)*	-0.13(-0.8)	-0.97(-4.8)*	-0.51(-2.2)*	-0.63(-7.2)*	-0.22(-1.4)
C	-0.31(-3.3)*	-0.05(-0.3)	-0.62(-3.1)*	-0.08(-0.3)	-0.38(-4.3)*	-0.06(-0.3)
D	-0.16(-1.7)	0.18(1.0)	-0.22(-1.1)	0.14(0.6)	-0.17(-1.9)	0.18(1.1)
E	-0.19(-2.0)	0.24(1.3)	-0.13(-0.6)	0.35(1.5)	-0.17(-2.0)*	0.26(1.7)
A	0.20(0.2)	6.88(4.3)*	-0.19(-0.1)	-8.53(-4.4)*	-0.45(-0.6)	3.69(2.8)*
S	-0.82(-1.0)	5.54(3.5)*	-11.80(-0.5)	-18.76(-0.7)	-0.79(-1.0)	2.64(1.8)
P*A[1)]	0.01(0.1)	-0.14(-4.2)*	-0.15(-0.5)	1.50(4.3)*	0.02(0.1)	-0.63(-2.8)*
P*S	0.16(1.1)	-1.18(-4.0)*	2.15(0.5)	3.61(0.7)	0.10(0.7)	-0.60(-2.2)*
T*A	-0.05(-0.4)	-0.14(-0.5)	0.48(2.9)*	0.75(3.9)*	0.24(2.4)*	0.13(0.7)
T*S	-0.04(-0.3)	0.26(1.0)	1.06(0.6)	1.13(0.6)	0.05(0.4)	0.27(1.2)
DEC	- -	- -	- -	1.03(15.5)*	-0.32(-2.8)*	

[1)] Interactions

Period	Autumn:1973-79		Autumn:1984-86	
Regressor	P_C	P_L	P_C	P_L
R-square	0.38	0.42	0.67	0.59
P	0.18 (1.8)	1.24 (8.5)*	0.01 (0.1)	1.24 (6.8)*
T	-0.16 (-1.5)	-0.11 (-0.7)	0.31 (2.9)*	0.20 (1.4)
F	-0.80 (-9.6)*	-0.21 (-1.8)	-1.63 (-11.7)*	-1.32 (-7.2)*
b	-0.35 (-2.6)*	0.03 (0.2)	-0.89 (-4.1)*	-0.48 (-1.6)
c	-0.11 (-0.9)	0.18 (0.9)	-0.81 (-3.7)*	-0.27 (-0.9)
d	-0.12 (-0.9)	0.19 (1.0)	-0.26 (-1.2)	0.13 (0.4)
e	-0.19 (-1.5)	0.32 (1.7)	-0.27 (-1.2)	0.25 (0.8)
A74[2)]	0.17 (1.1)	0.18 (0.8)	- -	- -
A75	0.46 (2.8)*	0.49 (2.1)*	- -	- -
A76	0.83 (4.5)*	-0.04 (-0.2)	- -	- -
A77	0.15 (0.9)	0.14 (0.6)	- -	- -
A78	-0.04 (-0.3)	-0.55 (-2.4)*	- -	- -
A79	0.09 (0.6)	0.55 (2.4)*	- -	- -
A85	- - - -		-0.02 (-0.1)	-0.11 (-0.4)
A86	- - - -		-0.02 (-0.1)	-0.47 (-1.5)

[2)] A74 is dummy for autumn 1974 and correspondingly for the remaining years

Potassium, calcium, magnesium, sulphur, sodium and chlorine

Mean concentration of K, Ca, Mg, SO_4-S, Na and Cl in the drainage water is shown in table 8. The concentration of K, Mg and Cl in the leachate seemed to be lower on plot c (permanent grassland and mineral fertilizer) than on the other plots at both fields. The differences between plots are insign-ificant due to considerable variation in the data.

The Ca and SO_4-S concentrations were higher on F22 (peat soil) than on F21 (sandy loam), while there were only small and insignificant differences between the fields in the concentration of K, Mg, Na and Cl.

The estimated equations of leaching and concentration of potassium, calcium, magnesium, sulphate sulphur, sodium and chlorine are given in table 9 for the year periods 1979 and 1984-1986, and in table 10 for the autumn months in the same periods.

Precipitation

Based on all five samples, except the 1984-86 sample, leaching of all these nutrients increased strongly significant with precipitation. For example, based on the 1973-79 sample, leaching of potassium increased with 2.57 percent by one per cent increment in precipitation.

Based on the autumn sample of 1984-86, concentration of calsium, magnesium, sulphate sulphur and sodium decreased significantly with precipitation. Based on the 1973-79 sample, concentration of calsium, sodium and chloride decreased significantly with precipitation.

Temperature

Based on all these samples except the 1984-86 sample both concentration and leaching of calsium, magnesium, sulphate sulphur and sodium increased strongly significant with temperature. For example based on the 1973-79 sample, concentration of sulphate sulphur increased with

Table 8. K, Ca, Mg, SO_4-S, Na and Cl in the drainage water, mg kg^{-1}, mean and SD (in parenthesis) of the experimental periods 1973-1979 and 1984-1986.

	a	b	c	d	e	Mean
F21 (sandy loam)						
K	2,7 (1,5)	2.2 (1.4)	1.1 (0.6)	2.6 (0.9)	2.5 (1.1)	2.2 (1.3)
Ca	13.9 (16.0)	15.9 (10.9)	15.3 (6.9)	13.5 (6.0)	11.4 (5.3)	14.0 (8.1)
Mg	3.0 (2.0)	2.8 (1.5)	2.0 (0.7)	2.6 (1.1)	2.9 (2.9)	2.6 (1.8)
SO_4-S	5.8 (5.2)	6.7 (4.6)	7.5 (4.9)	5.3 (3.5)	5.4 (3.5)	6.2 (4.4)
Na	7,6 (8.6)	6.5 (2.5)	6.0 (1.6)	7.0 (2.1)	6.7 (1.8)	6.8 (4.2)
Cl	10.7 (11.3)	9.0 (6.2)	7.9 (4.8)	10.4 (6.4)	10.2 (6.9)	9.6 (7.5)
F22 (peat soil)						
K	2,7 (2,6)	1.5 (1.8)	0.7 (0.6)	1.9 (0.8)	1.1 (0.7)	1.6 (1.7)
Ca	19.8 (9.8)	19.6 (9.6)	19.1 (8.7)	14.4 (5.8)	15.7 (6.1)	17.7 (8.5)
Mg	2.3 (1.2)	2.6 (3.6)	1.9 (0.9)	2.0 (1.0)	2.3 (1.2)	2.2 (1.9)
SO_4-S	8.0 (6.1)	9.5 (6.0)	11.2 (8.1)	8.1 (4.8)	8.8 (5.9)	9.1 (6.4)
Na	6,1 (1.8)	4.9 (1.6)	5.2 (1.7)	6.4 (1.8)	5.7 (1.8)	5.6 (1.8)
Cl	10.6 (8.8)	9.2 (6.5)	8.0 (5.4)	10.0 (5.9)	9.6 (6.2)	9.5 (6.7)

0.48 percent by one percent increment in temperature. Concerning potassium this applies to the 1973-79 sample and the 1984-86 sample. Concerning chlorine this applies to the autumn decade 80 sample, while concentration of chlorine decreased with temperature for the decade 70 sample.

Field

Except for the 1984-86 sample both leaching of magnesium, sulphate sulphur and sodium increased significantly by temperature. This applies to all samples with the exception of the autumn 1973-79. On the other hand, in 1973-79 and in the autumn 1984-86 sample leaching of chloride decreased significantly by temperature.

Crop rotation and fertilization

Plot b compared with plot a:

For all the six samples (samples Y1, Y2, A1, A2, A3 and S, see page 7) comparing plot a with plot b entailed that con-centration of potassium decreased significantly, and that both leaching of magnesium and calsium increased significantly. Furthermore in 1973-79 and 1984-86 this comparison entailed that both concentration and leaching of sulphate sulphur increased significantly.

Plot c compared with plot a:

For all the six samples comparing plot a with plot c entailed that both concentration and leaching of potassium decreased significantly, while both concentration and leaching of sulphate sulphur increases significantly. Based on the 1984-86 period and the autumn sample 1984-86 this comparison entailed that both concentration and leaching of calsium increased significantly. The comparison also entailed that concentration of magnesium decreased significantly. Finally based on the autumn 1973-79 sample and the autumn 1984-86 sample, concentration of sodium decreased significantly.

Plot d compared with plot a:

For all the six samples comparing plot a with plot d entailed that leaching of both sulphate sulphur and sodium increased significantly. In the 1973-76 period, the 1984-86 period and both periods this comparison entailed that leaching of chlorine increased significantly. Furthermore, in the 1973-79 period and the 1984-86 period leaching of potassium increased significantly by this comparison. In the autumn 1973-79 and in the autumn 1984-86 period leaching of magnesium increased significantly by this comparison.

Plot e compared with plot a:

For all the six samples comparing plot a with plot e entailed that leaching of magnesium, sulphate sulphur, sodium and chlorine respectively increased significantly. Except for the 1973-79 period, this passing entailed that concentration of potassium decreased significantly and leaching of calsium increased significantly.

Year and interaction with climatic factors

The year effect seemed to be most significant in the analyses based on the autumn samples. Concerning the interaction between year and climatic factors there were few significant cases.

Table 9. Results of regression analyses as explained in table 5. Data for potassium (K_C and K_L), calcium (Ca_C and Ca_L), magnesium (Mg_C and Mg_L), sulphur (SO_4_C and SO_4_L), sodium (Na_C and Na_L) and chlorine (Cl_C and Cl_L), based on monthly observations during the periods indicated.

Symbols as for table 5.

Period	1973-1979		1984-1986		1973-79 and 1984-86	
Regressor	K_C	K_L	K_C	K_L	K_C	K_L
R-square	0.45	0.51	0.45	0.62	0.41	0.51
P	0.14 (1.6)	2.57 (13.6)*	-0.31 (-1.7)	-0.89 (-4.1)*	0.03 (0.5)	1.89 (11.4)*
T	0.11 (2.2)*	0.17 (1.6)	0.00 (0.0)	0.40 (-4.5)*	0.08 (2.0)*	0.12 (1.4)*
F	0.55 (11.9)*	1.20 (11.5)*	0.30(3.4)*	0.78 (7.5)*	0.49 (11.5)*	1.09 (12.3)*
B	-0.30 (-4.2)*	0.10 (0.6)	-0.69 (-4.9)*	-0.23 (-1.4)	-0.39 (-5.8)*	0.02 (0.1)
C	-1.00(-13.8)*	-0.74 (-4.5)*	-1.35 (-9.6)*	-0.80 (-4.9)*	-1.08(-16.6)*	-0.76 (-5.4)*
D	0.09 (1.2)	0.43 (2.6)*	-0.51 (-3.7)*	-0.15 (-0.9)	-0.05 (-0.8)	0.29 (2.1)*
E	-0.14 (-2.0)*	0.28 (1.7)	-1.03 (-7.3)*	-0.55 (-3.4)*	-0.35 (-5.2)*	0.09 (0.6)
A	0.65 (1.0)	7.33 (5.0)*	-2.90 (-2.5)*	-11.23 (-8.2)*	-0.28 (-0.5)	3.86 (3.2)*
S	0.58 (0.9)	6.94 (4.8)*	-9.96 (-0.6)	-16.93 (-0.9)	0.03 (0.1)	3.46 (2.6)*
P*A	-0.19 (-1.7)	-1.34 (-5.4)*	0.47 (2.3)*	2.11 (0.0)	-0.01 (-0.1)	-0.66 (-3.2)*
P*S	-0.09 (-0.8)	-0.43 (-5.3)*	1.77 (0.6)	3.23 (0.9)	-0.03 (-0.2)	-0.73 (-2.9)*
T*A	0.02 (0.2)	-0.07 (-0.3)	0.11 (1.0)	0.38 (2.9)*	0.04 (0.5)	-0.07 (-0.5)
T*S	-0.02 (-0.2)	0.28 (1.2)	0.74 (0.6)	0.82 (0.6)	0.03 (0.3)	0.24 (1.2)
DEC	- -	- -	- -	- -	0.16 (3.2)*	-1.19(-11.3)*

Table 9 continued

Regressor	Ca_C	Ca_L	Ca_C	Ca_L	Ca_C	Ca_L
R-square	0.26	0.44	0.61	0.62	0.31	0.50
P	-0.17 (-2.8)*	2.27 (12.5)*	0.42 (3.9)*	-0.15 (-0.9)	-0.06 (-1.2)	1.79 (11.7)*
T	0.20 (5.8)*	0.27 (2.5)*	0.56 (12.4)*	0.16 (2.4)	0.30 (10.5)*	0.34 (4.3)*
F	-0.30(-8.9)*	0.35(3.5)*	-0.14 (-2.6)*	0.34 (4.3)*	-0.27 (-8.8)*	0.34 (4.1)*
B	0.00 (0.1)	0.41 (2.6)*	0.31 (3.7)*	0.77 (6.1)*	0.07 (1.6)	0.49 (3.8)*
C	0.01 (0.3)	0.27 (1.8)	0.22 (2.6)*	0.76 (6.0)*	0.06 (1.3)	0.38 (3.0)*
D	-0.14 (-2.6)*	0.20 (1.3)	0.11 (1.3)	0.47 (3.7)*	-0.08 (-1.7)	0.27 (2.0)*
E	-0.16 (-3.0)*	0.27 (1.8)	-0.00 (-0.0)	0.48 (3.8)*	-0.12 (-2.6)*	0.32 (2.5)*
A	-0.87 (-1.8)	5.81(4.1)*	3.11 (4.5)*	-5.22 (-5.0)*	0.00 (0.0)	4.14 (3.8)*
S	-0.81 (-1.8)	5.54 (4.0)*	-4.40 (-0.5)	-11.36 (-0.8)	-0.14 (-0.3)	3.29 (2.7)*
P*A	-0.14 (1.7)	-1.01 (-4.2)*	-0.54 (-4.3)*	1.11 (5.9)*	0.00 (0.0)	-0.65 (-3.4)*
P*S	0.19 (2.2)*	-1.15 (-4.4)*	0.91 (0.5)	2.38 (0.8)	0.08 (1.0)	-0.62 (-2.7)*
T*A	-0.01 (-0.1)	-0.09 (-0.4)	-0.36 (-5.3)*	-0.09 (-0.9)	-0.11 (-2.0)*	-0.22 (-1.5)
T*S	-0.14 (-1.8)*	0.17 (0.7)	0.06 (0.1)	0.14 (0.1)	-0.22 (-3.3)*	-0.13 (-0.1)
DEC	- -	- -	- -	- -	0.01 (-0.4)	-1.37(-13.9)*

Regressor	Mg_C	Mg_L	Mg_C	Mg_L	Mg_C	Mg_L
R-square	0.26	0.48	0.52	0.63	0.31	0.52
P	- 0.12 (-1.9)	2.32 (13.8)*	0.23 (1.8)	-0.34 (-2.0)*	-0.06 (-1.0)	1.79 (12.4)*
T	0.27 (7.9)*	0.33 (3.4)*	0.45 (8.3)*	0.05 (0.7)	0.31 (10.5)*	0.35 (4.7)*
F	0.12(3.6)*	0.77 (8.3)*	0.29 (4.6)*	0.78 (9.3)*	0.16 (5.3)*	0.76 (9.8)*
B	-0.07 (-1.5)	0.32 (2.2)*	0.12 (1.2)	0.58 (4.4)*	-0.03 (-0.7)	0.38 (3.1)*
C	-0.21 (-4.0)*	0.05 (0.4)	-0.48 (-4.8)*	0.06 (0.5)	-0.27 (-5.6)*	0.05 (0.4)
D	-0.06 (-1.2)	0.28 (1.9)	-0.13 (-1.3)	0.24 (1.8)	-0.08 (-1.6)	0.27 (2.2)*
E	0.07 (1.3)	0.49 (3.4)*	-0.14 (-1.4)	0.33 (2.5)*	0.02 (0.4)	0.46 (3.7)*
A	-0.04 (-0.1)	6.64 (5.0)*	2.41 (2.9)*	-5.93 (-5.4)*	0.58 (1.4)	4.72 (4.5)*
S	-0.29 (-0.6)	6.06 (4.7)*	-7.31 (-0.6)	-14.26 (-0.9)	0.02 (0.1)	3.45 (3.0)*
P*A	-0.03 (-0.4)	-1.18 (-5.3)*	-0.40 (-2.7)*	1.25 (6.4)*	-0.10 (-1.4)	-0.75 (-4.1)*
P*S	0.14 (1.6)	-1.20 (-5.0)*	1.45 (0.6)	2.91 (1.0)	0.07 (0.8)	-0.63 (-2.9)*
T*A	0.03 (0.4)	-0.05 (-0.2)	-0.30 (-3.7)*	-0.03 (-0.3)	-0.11 (-1.8)	-0.21 (-1.5)
T*S	-0.16 (-2.2)*	0.14 (0.7)	0.31 (0.4)	0.39 (0.3)	-0.20 (-2.9)*	0.01 (0.1)
DEC	- -	- -	- -	- -	0.16 (5.3)*	-1.21(-13.1)*

Table 9 continued

Regressor	SO_4_C	SO_4_L	SO_4_C	SO_4_L	SO_4_C	SO_4_L
R-square	0.45	0.52	0.51	0.67	0.46	0.52
P	-0.14 (-1.7)	2.30 (12.9)*	0.21 (2.0)*	-0.36 (-2.2)*	-0.06 (-0.8)	1.80 (11.8)
T	0.48 (10.2)*	0.54 (5.3)*	0.34 (7.9)*	-0.06 (-0.8)	0.42 (11.6)*	0.46 (5.8)
F	-0.45 (-9.9)*	0.20 (2.1)*	-0.32 (-6.3)*	0.16 (2.0)*	-0.41(-11.0)*	0.18 (2.3)
B	0.20 (2.8)*	0.60 (3.9)*	0.40 (4.9)*	0.86 (6.7)*	0.24 (4.1)*	0.66 (5.1)
C	0.37 (5.2)*	0.63 (4.1)*	0.30 (3.7)*	0.85 (6.7)*	0.35 (6.0)*	0.67 (5.2)
D	0.09 (1.3)	0.43 (2.8)*	0.23 (2.8)*	0.59 (4.7)*	0.12 (2.1)*	0.47 (3.6)
E	0.13 (1.9)	0.56 (3.6)*	0.14 (1.7)	0.61 (4.8)*	0.13 (2.2)*	0.57 (4.4)
A	-1.18 (-1.9)	5.49 (4.0)*	1.79 (2.7)*	-6.54 (-6.2)*	-0.10 (-0.2)	4.00 (3.7)
S	-0.92 (-1.5)	5.43 (4.0)*	-5.99 (-0.6)	-12.94 (-0.8)	-0.63 (-1.1)	2.80 (2.3)
P*A	0.16 (1.4)	-1.00 (-4.2)*	-0.27 (-2.2)*	1.38 (7.3)*	0.03 (0.4)	-0.62 (-3.2)
P*S	0.14 (1.2)	-1.20 (-4.7)*	1.17 (0.6)	2.63 (0.9)	0.08 (0.7)	-0.62 (-2.7)
T*A	0.18 (1.7)	0.09 (0.4)	-0.17 (-2.6)*	0.09 (0.9)	-0.04 (-0.6)	-0.15 (-1.0)
T*S	-0.14 (-1.3)	0.17 (0.8)	0.43 (0.6)	0.50 (0.5)	-0.09 (-1.1)	0.12 (0.7)
DEC	- -	- -	- - -	-	0.41 (9.1)*	0.18 (2.3)
Regressor	Na_C	Na_L	Na_C	Na_L	Na_C	Na_L
R-square	0.28	0.48	0.62	0.67	0.31	0.53
P	-0.21 (-5.0)*	2.23 (-12.7)*	0.21 (3.1)*	-0.37 (-2.6)*	-0.14 (-3.6)*	1.72 (11.7)*
T	0.13 (5.2)*	0.19 (1.9)	0.28 (10.2)*	-0.12 (-2.1)*	0.16 (8.0)*	0.19 (2.5)*
F	0.14 (6.0)*	0.79 (8.2)*	0.17(5.4)*	0.65 (9.4)*	0.15 (7.3)*	0.75 (9.4)*
B	-0.14 (-3.9)*	0.26 (1.7)	-0.13 (-2.5)*	0.33 (3.0)*	-0.14 (-4.3)*	0.27 (2.2)*
C	-0.11 (-3.1)*	0.15 (1.0)	0.25 (-4.9)*	0.29 (2.7)*	-0.15 (-4.6)*	0.18 (1.4)
D	0.10 (2.7)*	0.43 (2.9)*	-0.07 (-1.5)	0.29 (2.6)*	0.06 (1.8)	0.41 (3.2)*
E	0.03 (0.7)	0.45 (3.0)*	-0.18 (-3.5)*	0.30 (2.7)*	-0.02 (0.6)	0.42 (3.4)*
A	-0.76 (-2.3)*	5.91 (4.3)*	2.20 (5.2)*	-6.14 (-6.7)*	-0.08 (0.3)	4.06 (3.8)*
S	-1.10 (-3.5)*	5.25 (3.9)*	-3.40 (-0.6)	-10.35 (-0.8)	-0.71 (-2.4)*	2.72 (2.3)*
P*A	0.12 (2.2)*	-1.03 (-4.5)*	-0.40 (-5.3)*	1.24 (7.6)*	0.01 (0.2)	-0.64 (-3.4)*
P*S	0.25 (4.2)*	-1.08 (-4.4)*	0.66 (0.6)	2.12 (0.9)	0.17 (3.0)*	-0.53 (-2.4)*
T*A	0.03 (0.6)	-0.05 (-0.2)	-0.15 (-3.5)*	0.12 (1.4)	-0.02 (-0.5) -	0.13 (-0.9)
T*S	-0.08 (-1.6)	0.22 (1.0)	0.15 (0.3)	0.22 (0.2)	-0.10 (-2.1)*	0.11 (0.6)
DEC	- -	- -	- -	- -	0.03 (1.4)	-1.32(-13.9)*

Table 9 continued

Regressor	Autumn: 1973-1979 K_C	K_L	Autumn: 1984-1986 K_C	K_L
R-square	0.70	0.71	0.74	0.74
A76	-0.41 (-3.2)*	-1.27 (-6.0)*	- -	- -
A77	-0.75 (-6.7)*	-0.77 (-4.1)*	- -	- -
A78	-1.25 (-11.1)*	-1.75 (-9.3)*	- -	- -
A79	-0.97 (-8.8)*	-0.53 (-2.8)*	- -	- -
A85	- -	- -	0.52 (3.7)*	0.43 (2.6)*
A86	- -	- -	0.81 (5.0)*	0.37 (1.9)

Regressor	Ca_C	Ca_L	Ca_C	Ca_L
R-square	0.47	0.53	0.54	0.82
P	0.01 (0.2)	1.07 (9.3)*	-0.21 (-3.3)*	1.02 (13.1)*
T	0.14 (2.2)*	0.20 (1.6)	0.33 (7.1)*	0.22 (3.7)*
F	-0.42 (-8.4)*	0.17 (1.8)	-0.22 (-3.6)*	0.09 (1.1)
B	-0.05 (-0.7)	0.33 (2.2)*	0.35 (3.6)*	0.76 (6.1)*
C	-0.00 (-0.0)	0.29 (1.9)	0.39 (4.0)*	0.93 (7.5)*
D	-0.07 (-0.9)	0.24 (1.6)	0.23 (2.4)*	0.63 (5.0)*
E	-0.19 (-2.3)*	0.33 (2.2)*	0.10 (1.0)	0.61 (4.9)*
A74	-0.11 (-1.1)	-0.09 (-0.5)	- -	- -
A75	0.21 (2.1)*	0.23 (1.3)	- -	- -
A76	0.38 (3.5)*	-0.49 (-2.4)*	- -	- -
A77	0.57 (5.9)*	0.55 (3.0)*	- -	- -
A78	0.14 (1.5)	-0.36 (-2.0)*	- -	- -
A79	-0.25 (-2.6)*	0.19 (1.1)	- -	- -
A85	- -	- -	0.50 (5.8)*	0.41 (3.7)*
A86	- -	- -	0.15 (1.4)	-0.30 (-2.3)*

Regressor	Mg_C	Mg_L	Mg_C	Mg_L
R-square	0.54	0.61	0.29	0.70
P	0.00 (0.1)	1.07 (10.0)*	-0.28 (-3.0)*	0.95 (9.4)*
T	0.20 (3.8)*	0.25 (2.3)*	0.26 (3.6)*	0.14 (1.9)
F	0.14 (3.3)*	0.73 (8.4)*	0.23 (2.4)*	0.54 (5.3)*
B	-0.03 (-0.5)	0.35 (2.6)*	0.24 (1.6)	0.65 (4.0)*
C	-0.08 (-1.2)	0.21 (1.5)	-0.30 (-2.0)*	0.24 (1.5)

Table 9 continued

Regressor	Cl_C	Cl_L	Cl_C	Cl_L	Cl_C	Cl_L
R-square	0.28	0.37	0.55	0.59	0.21	0.48
P	-0.29 (-2.7)*	2.14 (10.5)*	0.46 (4.1)*	-0.11 (-0.7)	-0.17 (-1.8)	1.68 (9.7)*
T	-0.37 (-6.1)*	-0.31 (-2.7)*	0.41 (9.0)*	0.01 (0.2)	-0.13 (-2.6)*	-0.09 (-1.0)
F	-0.05 (-0.7)	0.61 (5.4)*	-0.08(-1.4)	0.41 (5.3)*	-0.05 (-1.0)	0.54 (5.9)*
B	-0.05 (-0.5)	0.35 (2.0)*	0.09 (1.1)	0.55 (4.6)*	-0.02 (-0.2)	0.40 (2.7)*
C	-0.15 (-1.6)	0.12 (0.7)	-0.09 (-1.0)	0.46 (3.8)*	-0.13 (-1.6)	0.19 (1.3)
D	0.19 (2.0)*	0.52 (2.9)*	-0.08 (-1.0)	0.28 (2.3)*	0.12 (1.4)	0.47 (3.2)*
E	0.16 (1.8)	0.59 (3.4)*	-0.14 (-1.6)	0.34 (2.8)*	0.10 (1.2)	0.53 (3.7)*
A	-0.81 (-1.0)	5.87 (3.7)*	3.56 (5.0)*	-4.78 (-4.8)*	-0.44 (-0.6)	3.70 (3.0)*
S	-1.97 (-2.4)*	4.39 (2.8)*	-1.78 (-0.2)	-8.73 (-0.6)	-0.94 (-1.2)	2.49 (1.8)
P*A	0.17 (1.2)	-0.98 (-3.7)*	-0.69 (-5.5)*	0.95 (5.3)*	0.04 (0.3)	-0.61 (-2.8)*
P*S	0.40 (2.6)*	-0.94 (-3.2)*	0.32 (0.2)	1.78 (0.7)	0.23 (1.5)	-0.48 (-1.8)
T*A	-0.18 (-1.4)	-0.27 (-1.0)	-0.22 (-3.1)*	0.05 (0.5)	-0.01 (-0.2)	-0.13 (-0.8)
T*S	0.29 (2.2)*	0.59 (2.4)*	-0.02 (-0.0)	0.06 (0.1)	0.09 (0.7)	0.30 (1.4)
DEC	- -	- -	- -	- -	0.59 (-9.5)*	-1.94(-17.6)*

Table 10. Results of regression analyses as explained in table 5. Data for potassium (K_C and K_L), calcium (Ca_C and Ca_L), magnesium (Mg_C and Mg_L), sulphur (SO_4_C and SO_4_L), sodium (Na_C and Na_L) and chlorine (Cl_C and Cl_L), based on monthly observations during autumn (September, October and November) of the years indicated.

	Autumn: 1973-1979		Autumn: 1984-1986	
Regressor	K_C	K_L	K_C	K_L
R-square	0.70	0.71	0.74	0.74
P	-0.02 (-0.2)	1.05 (8.7)*	-0.15 (-1.6)	1.07 (9.1)*
T	0.25 (3.3)*	0.30 (2.4)*	0.19 (2.5)*	0.08 (0.9)
F	0.65 (11.2)*	1.24 (12.7)*	0.35 (3.5)*	0.66 (5.5)*
B	-0.24 (-2.6)*	0.14 (0.9)	-0.58 (-3.7)*	-0.16 (-0.9)
C	-1.00 (-10.9)*	-0.72 (-4.6)*	-1.20 (-7.6)*	-0.66 (-3.5)*
D	0.13 (1.4)	0.44 (2.8)*	-0.27 (-1.7)	0.12 (0.6)
E	-0.24 (0.1)	0.28 (1.8)	-0.89 (-5.7)*	-0.38 (-2.0)*
A74	-0.60 (-5.3)*	-0.59 (-3.1)*	- -	- -

Table 10 continued

Regressor R-square	Mg_C 0.54	Mg_L 0.61	Mg_C 0.29	Mg_L 0.70
D	0.03 (0.5)	0.34 (2.5)*	0.02 (0.1)	0.41 (2.6)*
E	0.07 (1.0)	0.58 (4.2)*	-0.06 (-0.4)	0.45 (2.8)*
A74	0.45 (5.7)*	0.47 (2.8)*	- -	- -
A75	0.48 (6.0)*	0.51 (3.0)*	- -	- -
A76	0.74 (8.3)*	-0.13 (-0.7)	- -	- -
A77	0.72 (9.1)*	0.70 (4.2)*	- -	- -
A78	0.25 (3.2)*	-0.26 (-1.5)	- -	- -
A79	-0.06 (-0.8)	0.38 (2.3)*	- -	- -
A85	- -	- -	0.45 (3.4)*	0.36 (2.5)*
A86	- -	- -	0.21 (1.4)	-0.23 (-1.4)
Regressor R-square	SO_4_C 0.56	SO_4_L 0.59	SO_4_C 0.52	SO_4_L 0.74
P	0.14 (2.0)*	1.20 (10.3)*	-0.12 (-2.0)*	1.11 (11.1)*
T	0.59 (8.1)*	0.64 (5.2)*	0.26 (5.7)*	0.15 (1.9)
F	-0.33 (-5.8)*	0.27 (2.8)*	-0.37 (-6.1)*	-0.06 (-0.6)
B	0.30 (3.4)*	0.68 (4.5)*	0.36 (3.8)*	0.78 (4.9)*
C	0.44 (5.0)*	0.73 (4.9)*	0.34 (3.6)*	0.88 (5.6)*
D	0.22 (2.4)*	0.52 (3.5)*	0.28 (2.9)*	0.67 (4.3)*
E	0.21 (2.4)*	0.73 (4.8)*	0.16 (1.7)	0.67 (4.2)*
A74	0.28 (2.6)*	0.30 (1.6)	- -	- -
A75	0.17 (1.5)	0.20 (1.1)	- -	- -
A76	0.59 (4.8)*	-0.28 (-1.3)	- -	- -
A77	0.89 (8.3)*	0.87 (4.8)*	- -	- -
A78	0.39 (3.6)*	-0.12 (-0.6)	- -	- -
A79	-0.10 (-1.0)	0.34 (1.9)	- -	- -
A85	- -	- -	0.34 (4.0)*	0.25 (1.8)
A86	- -	- -	0.13 (1.3)	-0.32 (-1.9)

Table 10 continued

Regressor	Na_C	Na_L	Na_C	Na_L
R-square	0.61	0.66	0.52	0.75
P	0.06 (1.7)	1.13 (11.1)*	-0.12 (-2.9)*	1.11 (12.9)*
T	0.11 (2.8)*	0.16 (1.5)	0.16 (4.9)*	0.04 (0.7)
F	0.19 (6.1)*	0.78 (9.4)*	0.16 (3.7)*	0.47 (5.5)*
B	-0.19 (-4.0)*	0.19 (1.4)	-0.09 (-1.3)	0.33 (2.4)*
C	-0.11 (-2.1)*	0.18 (1.4)	-0.16 (-2.4)*	0.38 (2.8)*
D	0.17 (3.4)*	0.48 (3.6)*	0.05 (0.8)	0.45 (3.3)*
E	-0.02 (-0.4)	0.50 (3.8)*	-0.08 (-0.3)	0.42 (3.1)*
A74	0.06 (1.0)	0.07 (0.4)	- -	- -
A75	0.25 (4.2)*	0.28 (1.8)	- -	- -
A76	0.64 (9.6)*	-0.23 (-1.2)	- -	- -
A77	0.61 (10.4)*	0.59 (3.7)*	- -	- -
A78	0.13 (2.3)*	-0.37 (-2.4)*	- -	- -
A79	0.15 (2.6)*	0.60 (3.8)*	- -	- -
A85	- -	- -	0.01 (0.1)	-0.08 (-0.7)
A86	- -	- -	-0.22 (-3.2)*	-0.67 (-4.7)
Regressor	Cl_C	Cl_L	Cl_C	Cl_L
R-square	0.64	0.56	0.30	0.78
P	0.11 (1.3)	1.17 (8.4)*	-0.10 (-1.2)	1.13 (15.0)*
T	-0.95 (-10.3)*	-0.91 (-6.2)*	0.23 (3.8)*	0.12 (2.1)*
F	-0.21 (-2.9)*	0.38 (3.4)*	-0.10 (-1.2)	0.21 (2.8)*
B	-0.14 (-1.2)	0.24 (1.3)	0.11 (0.9)	0.53 (4.4)*
C	-0.26 (-2.3)*	0.03 (0.2)	-0.00 (-0.0)	0.54 (4.5)*
D	0.03 (0.3)	0.34 (1.9)	-0.03 (-0.2)	0.36 (3.0)*
E	-0.08 (-0.7)	0.44 (2.4)*	-0.11 (-0.9)	0.40 (3.4)*
A74	1.15 (8.2)*	1.16 (5.3)*	- -	- -
A75	1.68 (11.9)*	1.71 (7.8)*	- -	- -
A76	2.23 (14.2)*	1.37 (5.6)*	- -	- -
A77	1.79 (12.9)*	1.77 (8.2)*	- -	- -
A78	1.97 (14.1)*	1.47 (6.7)*	- -	- -
A79	1.57 (11.4)*	2.02 (9.4)*	- -	- -
A85	- -	- -	-0.03 (-0.3)	-0.12 (-1.1)
A86	- -	- -	-0.39 (-3.0)*	-0.84 (-6.7)*

Discussion

Drainage water

There is no unambigious explanation of the uneven drainage from the different plots. A possible reason may be that some water originates from the surrounding areas and from the underground (artesian water). At the start of the experiment on field F21 (sandy loam) there was a 30 cm soil layer with high content of organic matter covering gravelly and coarse sandy loam. At the end of the experimental period this layer had shrinked to only 10-12 cm. This may have influenced the water storing ability of the soil.

Nitrogen

The leaching as well as the concentration of mineral nitrogen are influenced especially by precipitation, but also by temperature. On the whole precipitation entails an increment of leaching of mineral nitrogen. But crop rotations and fertilization seem to be essential in the sense of influencing concentration and leaching of mineral nitrogen. In years when the soil is ploughed and harrowed, the soil erosion may become considerable, as was the case in 1973. Oskarsen et al (1996) found that the loss of nitrogen increased when pig slurry was applied before ploughing in the autumn. Finally the influence from season (year) and the interaction between precipitation and year are considerable. This implies that with a given increment of precipitation, leaching of mineral nitrogen is less in spring and autumn than in the summer period. Oskarsen et al (1996) also demonstrated an increased runoff off the growing season. This is in both investigations due to a higher precipitation off the growing season, low temperature and thereby negligible evaporation and removal of water by crops. At Særheim (South-West Norway) Øyen (1993) observed a higher loss of nitrogen from a sandy soil than from a loamy soil. The major reason for this is probably good conditions for nitrogen mineralization off the growing season in that area, especially on the sandy soil. Mild winters and heavy precipitation increased the leaching loss.

Phosphorus

In both the 1973-79 and the 1984-86 periods, the precipitation was a significant variable with regard to leaching of total phosporus, but generally not a significant variable with regard to concentration of phosphorus. In both periods temperature was generally not a significant variable, while leaching and concentration of phosphorus decreased strongly by passing from site F22 (peat soil) to site F21 (sandy loam soil).

In the 1973-79 period concentration of phosphorus seemed to depend more on crop rotation and fertilization practice than was the case for the analyses in the 1984-86 period. However, in the 1984-86 period the interaction between precipitation lagged and crop rotation and fertilization plots seemed to influence both leaching and concentration of phosphorus.

In both periods leaching and concentration of phosphorus decreased strongly by passing from site F22 (peat soil) to site F21 (sandy loam soil). This is in accordance with results published by Øyen (1993). Loss of phosphorus and potassium especially takes place off the growing season and from sandy soils with less ion fixation capacity than loam soil.

Other nutrients

Both precipitation and temperature seem to influence significantly both leaching and concentration of potassium, calsium,

magnesium, sulphate sulphur, sodium and chlorine in the drainage water. But crop rotations and fertilization are also essential in the sense of influencing concentration and leaching of all these nutrients. Leaching of these nutrient increases significantly with precipitation, while concentration decreases. At Kvithamar, Oskarsen et al (1996) found a pronounced dilution of potassium in drainage water.

Concentration and leaching of all nutrients increases with temperature, with the exception of chlorine, where both concentration and leaching seems to decrease. Concerning the influences from crop rotation and fertilization, the influences on chlorine frequently seems to be opposite that of the other nutrients.

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Autumn growth and seed-producing capacity of tillers of *Poa pratensis* 'Lavang' and 'Leikra'

TRYGVE SVEEN AAMLID
The Norwegian Crop Research Institute, Apelsvoll Research Centre, Division Landvik, Grimstad, Norway

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Plant height, tillering, leaf development, dry weight and rhizome formation of *Poa pratensis* L. were monitored in spaced plant trials at Landvik (58°N) at fortnightly intervals during the autumn of 1987 and at monthly intervals during the autumn of 1988. The 1988 experiment also included labelling of tillers on 1 September, 1 October and 1 November in order to determine which tillers would produce panicles the following year. Compared with the subarctic cv. Lavang (origin 69°N), plants of the temperate cv. Leikra (origin 61°N) were taller and their height growth less influenced by sampling date. In both cultivars vigorous tillering and rhizome formation continued until the last sampling on 15 October 1987 and 1 November 1988, and there was no indication of a period with reduced tillering but with growth of already existing tillers. While 47-55% of the late summer and autumn-formed tillers of 'Lavang' developed panicles irrespective of month of formation, fertility in 'Leikra' decreased from 75% for tillers formed before September to 65% for tillers formed in September and 52% for tillers formed in October. In the latter cultivar, intravaginal tillers also had a much lower fertility rate (average:48%) than tillers developed from rhizomes (average: 70%). The results are discussed in relation to primary induction requirements and light competition in the two cultivars.

Key words: Juvenility, leaf development, panicles, *Poa pratensis*, rhizomes, seed production, smooth meadow grass, tillers.

Trygve Sveen Aamlid, The Norwegian Crop Research Institute, Apelsvoll Research Centre, Division Landvik, 4890 Grimstad, Norway

Like other dual induction grasses, *Poa pratensis* L. requires short days and/or low temperatures (primary induction) in autumn and long days with moderate temperatures (secondary induction) in spring in order to produce panicles (Heide 1980, 1994). *Poa pratensis* probably also has a juvenile stage during which plants are not receptive to flower induction stimuli (Borg 1974, 1982; Meijer 1984). An implication of juvenility and the dual induction requirement is that each plant has to reach a certain size in autumn in order to become fertile in the subsequent year. Since flower induction stimuli can be transferred to some extent from mother to daughter tillers, it remains unclear whether juvenility and the size requirement are properties not only of the plant, but also of each individual tiller (Havstad 1996).

Experiments involving labelling of tillers as they appear in the field have revealed that in nearly all temperate grasses, most fertile tillers are produced before winter, i.e. during the previous growing season (e.g. Langer & Lambert 1959; Lambert & Jewiss 1970; Nordestgaard

1988; Hare 1994). In Danish trials, fertile tillers were mostly produced later in *Poa pratensis* than in *Dactylis glomerata, Festuca pratensis* and *Lolium perenne*, but nevertheless, more than 50% of the fertile tillers had been produced by 1 September and more than 90% by 1 November (Odgaard 1970). In Dutch seed crops of *Poa pratensis* sown on 22 May, 85% of the tillers that produced seed in the first harvest year had been produced before the end of October (Meijer 1984).

The subarctic cultivar Lavang and the temperate cultivar Leikra are both grown for seed in SE Norway. As a very winter-hardy cultivar, 'Lavang' utilizes most of its late summer and autumn assimilates for underground storage rather than for leaf production, and it initiates floral primordia as early as September/October (Aamlid 1996). By contrast, 'Leikra' often gives a good dry matter yield in late autumn, and no floral initiation can be observed until spring. After spring sowing without cover crop the proportions of tillers present on 15 November that produced panicles in the first seed harvest year averaged 33 and 30% in 'Lavang' and 'Leikra', respectively (Aamlid 1993). However, in those experiments no attempt was made to determine when the panicle-producing tillers were formed during the autumn months.

The objectives of the present research were (1) to examine in more detail the growth and tillering pattern of 'Lavang' and 'Leikra' during autumn in SE Norway, and (2) to determine in which period tillers have to be formed in order to become fertile in the subsequent year.

Materials and methods

Typical clones of 'Lavang' and 'Leikra' were propagated vegetatively in a greenhouse during the winters of 1987 and 1988 and transplanted into the field at Landvik (58°N) on 11 June 1987 and 24 June 1988. Plant distances were 1.0 m X 1.0 m in 1987 and 1.35 m X 1.50 m in 1988. After establishment and (when necessary) irrigation, propachlor was applied at a rate of approximately 6 kg a.i. ha^{-1} in order to prevent germination of *Poa annua* and other weeds.

In both years the experimental fields were located on sandy soils (72-83% sand, 5-6% clay). In 1987 40 kg N ha^{-1} was applied as NPK 16-7-12 before planting and 50 kg N ha^{-1} as $Ca(NO_3)_2$ on 4 September. The 1988 experiment, which did not receive any fertilizer before planting, included plots with no autumn nitrogen and with applications of 50 kg N ha^{-1} as $Ca(NO_3)_2$ on 1 August, 1 September or 1 October. However, probably because of mineralization of nitrogen from the rather high organic matter content in the soil (9.5%), differences in plant development between the various nitrogen treatments were not significant, and only the average values for each sampling date will therefore be reported

At approximately biweekly intervals from 1 August until 15 October 1987, and at monthly intervals from 1 August to 1 November 1988, nine plants of each cultivar (and in 1988 for each nitrogen treatment) were excavated, washed and taken to the laboratory for registration. These records included plant height (to the top of the youngest fully expanded leaf) and the number of tillers and rhizomes. Leaf number (in 1987 only) and dry weight were also recorded and calculated per tiller. While intravaginal tillers were always separated from tillers from rhizomes in 'Leikra', such a distinction was impossible in 'Lavang', which had hardly any intravaginal tiller development.

In order to obtain additional data, tiller number in 1987 was also recorded on nine fixed plants of each cultivar in the field. Since these countings took place on approximately the same dates as the destructive samplings, tiller numbers presented for this year (Fig. 1) represent an average of eighteen plants.

In addition to the tiller countings, the 1988 experiment included labelling of tillers on four fixed plants of 'Lavang' and five fixed plants of 'Leikra'. Labelling was carried out by sliding coloured plastic rings, 2-3 mm in diameter, over newly emerged tillers on 1 September, 1 October and 1 November. Of a total of 780 and 1084 rings attached in 'Lavang' and 'Leikra', respectively, 84 and 88% were reclaimed at seed harvest in 1989. Based on reclaimed tillers, the proportions of tillers produced before September, during September and during October that were dead, vegetative or fertile at seed harvest were compared by chi-square analyses.

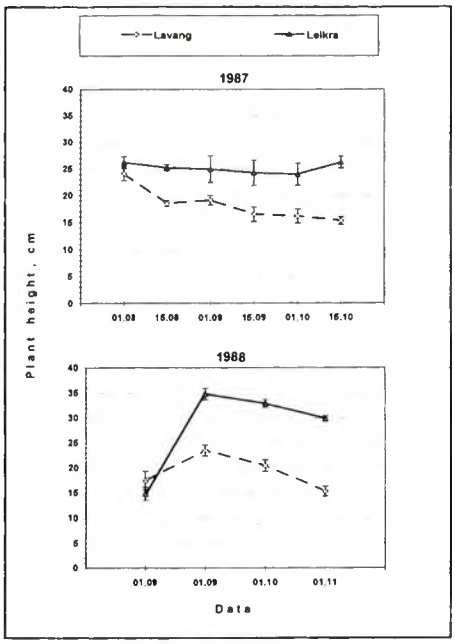

Fig. 1. Plant height (= height of youngest fully developed leaf) of Poa pratensis 'Lavang' and 'Leikra' at Landvik during the autumn of 1987 and 1988. Vertical bars denote ± 1 SEM.

Results

Plant height

From 1 August to 15 October 1987, plant height dropped significantly in 'Lavang' but remained fairly constant in 'Leikra'. In 1988 neither cultivar reached its maximal height until 1 September, but after that, height declined more strongly in 'Lavang' than in 'Leikra'.

Tillers

While tiller number in 'Lavang' showed a marked rise after 15 September 1987, it increased almost linearly throughout the autumn of 1988. In 'Leikra' the number of intravaginal tillers levelled off after 1 October 1987, but both intravaginal tillers and tillers from rhizomes continued to increase until 1 November 1988. The total tiller number in 'Leikra' (intravaginal tillers plus tillers from rhizomes) was in both years less than half the total tiller number in 'Lavang'.

Leaves per tiller

In 1987, leaf number increased at the same rate as tiller number in both cultivars. The average number of leaves per tiller was 2.3 in 'Lavang', while in 'Leikra' it was 3.0 for intravaginal tillers and 2.7 for tiller from rhizomes.

Dry weight per tiller

No significant difference in dry weight per tiller could be observed among sampling dates in either year. On average for sampling dates in 1988, the dry weight per tiller was 45 mg in 'Lavang', 121 mg for

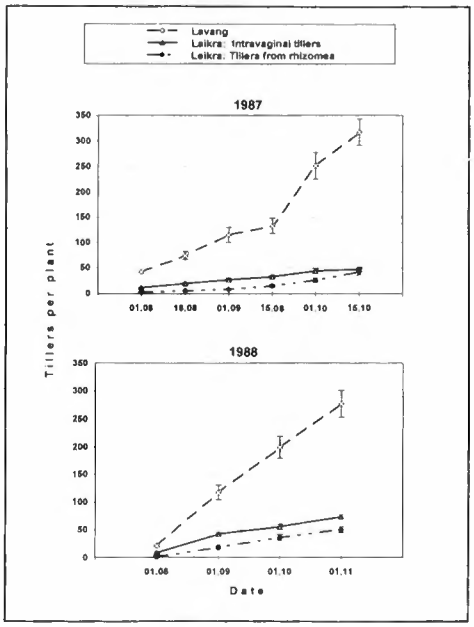

Fig. 2. Tiller number of Poa pratensis *'Lavang' and 'Leikra' at Landvik during the autumn of 1987 and 1988. Vertical bars denote ± 1 SEM*

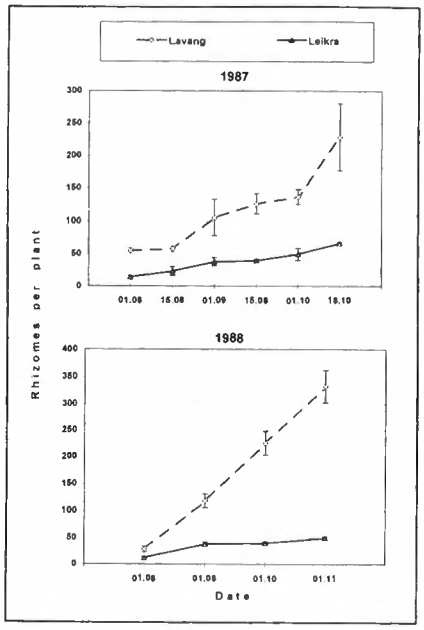

Fig. 3. Rhizome number of Poa pratensis *'Lavang' and 'Leikra' at Landvik during the autumn of 1987 and 1988. Vertical bars denote ± 1 SEM*

intravaginal tillers in 'Leikra' and 99 mg for tillers from rhizomes in 'Leikra'.

Rhizomes

Rhizome number increased until the last sampling date in both years and in both cultivars. The percentage of rhizomes which had developed aerial tillers showed a steady increase until 15 October 1987, but was fairly stable during September and October 1988 (Table 1). Rhizomes in 'Leikra' were generally longer and not nearly as ready to turn upward and develop aerial tillers as those in 'Lavang'.

Fertility of tillers

Of a total of 655 'Lavang' tillers found tagged with coloured rings in 1989, 52% were fertile, 29% vegetative and 19% dead. While the chi-square test revealed no significant relationship between tiller fertility and period of tiller formation in this subarctic cultivar, fertility declined and mortality increased with later formation in 'Leikra'. In the latter cultivar there was also a marked difference between intravaginal tillers and tillers from rhizomes, fertility being much higher in the latter group.

Table 1. Percentage of rhizomes which had developed aerial tillers on various sampling dates in 1987 and 1988.

	1 Aug.	15 Aug.	1987 1 Sept.	15 Sept.	1 Oct.	15 Oct.
Lavang	38	54	57	61	67	91
Leikra	11	14	17	22	24	43
	1 Aug.	1 Sept.	1988 1 Oct.	1 Nov.		
Lavang	43	64	57	63		
Leikra	6	32	34	37		

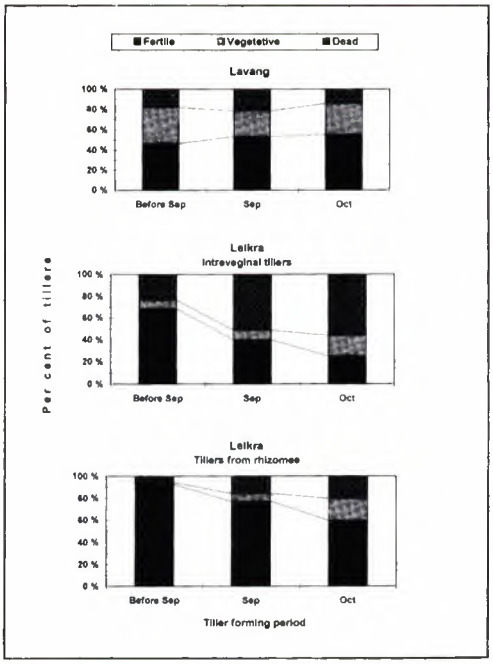

Fig. 4. Percentage of tillers formed in various periods during the autumn of 1988 that were fertile, vegetative or dead at seed harvest in 1989.

Discussion

The plant height measurements (Fig. 1) in these trials substantiate the general experience (e.g. Håbjørg 1976; Rognli & Staver 1979; Aamlid 1990) that subarctic cultivars (here represented by 'Lavang') react more strongly than temperate cultivars (e.g. 'Leikra') to decreasing daylength in autumn. In light of the almost 2.5 h drop in photoperiod from 1 August to 1 September at Landvik, the fact that both cultivars reached their maximal height one month later in 1988 than in 1987 can be explained by later planting in 1988 than in 1987 (24 June vs. 11 June), lack of nitrogen fertilization before planting in 1988 and a higher average temperature during August in 1988 than in 1987 (14.9°C vs. 13.2°C). In ordinary *Poa pratensis* seed crops sown in early spring, maximal leaf length would normally be attained before 1 August, and certainly before 1 September.

Although daylength on the experimental site was only 10.3 h on 15 October and a mere 8.9 h on 1 November, tillering in 'Lavang' continued at an undiminished rate until these dates in 1987 and 1988, respectively (Fig. 2). This observation is compatible with phytotron experiments showing decreasing daylength from 16 to 12 h to stimulate tillering in 'Lavang' (Aamlid 1990), and by field experiments showing an increase in tiller number from 15 August to 15 October in a spring-sown seed crop (Aamlid 1996). However, in the

latter report, there was a small drop in tiller number from 15 October to 15 December; and it is therefore unlikely that tillering in the present experiments continued for very much longer than the last registration dates. Håbjørg (1976) stated that the optimal photoperiod for tillering in arctic ecotypes of *Poa pratensis* is around 18 h, but this statement was based mainly on experiments with the cultivar 'Holt', which appears to be a more extreme arctic ecotype than 'Lavang'. This conclusion is in agreement with Solhaug (1991), who found a stronger long-day stimulation of dry matter production in 'Holt' than in 'Lavang' at low temperature, and by Håbjørg (1979), who in a later paper reported great variations among 'Holt' and other (sub)arctic ecotypes in generative development in autumn. The fact that 'Lavang', unlike 'Holt', is fairly resistant to leaf rust in autumn, further explains why tillering may go on longer in the former cultivar.

Based on literature studies and experiences with Swedish cultivars of *Poa pratensis*, Borg (1974) suggested that there is a period in late autumn which is characterized by no or very limited formation of new tillers, but with vigorous growth of already existing ones. The present results lend no support to this notion, as tillering continued until the last registration date, whereas both leaf number and dry weight per tiller remained constant. Borg's (l.c.) hypothesis can also be discounted on the grounds of phytotron experiments showing leaf number per tiller to decrease rather than to increase with falling daylength and temperature (Aamlid 1990). On the other hand, the deduction made by Borg (1974), namely that seed yields would be higher after a late than after an early application of nitrogen in autumn, has been verified by Danish (Nordestgaard 1976, 1989) as well as by Norwegian (Aamlid 1993) experiments comparing dressings on either (approximately) 1 September or 1 October. In 'Leikra' the superiority of the 1 October dressing was in fact accompanied by a lower tiller number on 15 November, but, in light of both the present and Dutch (Meijer & Vreeke 1988) results, any positive effect of such a moderate tiller number on seed yield seems more likely to have been mediated by lower tiller mortality in spring than by greater average tiller size in autumn.

In spite of the fact that floral primordia are initiated as early as September-October (Aamlid 1996), no relationship could be found between tiller-forming period and fertility in 'Lavang' This, at first glance, rather surprising result, was probably due to the short requirement for primary induction in the arctic cultivar. Too long an exposure to short photoperiod, low light intensity and rather high temperatures during winter may have resulted in 'overinduction' with concomitant tiller death or at least degeneration of floral primordia in many of the first-formed 'Lavang' tillers. This interpretation is in good agreement with earlier results (Håbjørg 1979; Rognli & Staver 1979; Heide 1980; Aamlid 1996), and it is validated by the unusually mild winter at Landvik in 1988-89 (mean temperature in November-March was 3.4°C as opposed to a normal temperature of 0.2°C). Nowadays, most seed of 'Lavang' is produced in continental areas of eastern Norway where overinduction is less of a problem and the fertility of early-formed tillers probably higher than at Landvik.

Unlike the situation in a number of other Norwegian ecotypes (Håbjørg 1976, 1979; Heide 1980), the primary induction

requirements have not been studied closely in 'Leikra'. The results of these trials suggest that this rather untypical Norwegian ecotype requires long exposure to short days and low temperatures, and that seed production therefore ought to be located in areas with a long and mild winter. This corroborates the results from joint Scandinavian trials showing seed yields of 'Leikra' to be highest at Roskilde, Denmark, the southernmost of eleven experimental sites (Nordestgaard 1983).

Since tillers from rhizomes are usually produced later in the sowing year than intravaginal tillers, Borg (1982) assumed that fertility in the first seed harvest year would be greater in the former group. In the present experiments, however, the average fertilty in 'Leikra' was 70% for tillers from rhizomes vs. 48% for intravaginal tillers, despite the fact that the intravaginal ones had, on average, 10% more leaves and 18% higher weight. Bearing in mind that 'Leikra' develops long rhizomes which do not turn upward until they are 8-12 cm outside the mother tufts, the high fertility of many of the late-formed tillers from rhizomes indicates that they, unlike their intravaginal counterparts, were subjected to no or very moderate competition for light. This was also reflected in tiller shape, tillers from rhizomes generally being shorter and less etiolated than intravaginal tillers in late autumn. The high mortality of intra-vaginal tillers in 'Leikra' is compatible with Ong (1978), who found that light competition is the most common reason for tiller death in grasses.

On the assumption that tillers formed after 1 November did not become fertile, calculations based on tiller countings and fertility ratings in the 1988/89 season show that 53 and 83% of the fertile tillers had been formed by 1 October in 'Lavang' and 'Leikra', respectively. As far as 'Leikra' is concerned, this proportion is comparable to Danish (Odgaard 1970) and Dutch (Meijer 1984) results, but for 'Lavang', it is considerably lower. About 50% of the 'Leikra' panicles were produced outside the tufts.

Since these experiments were conducted with single plants, the results are not immediately transferable to ordinarily sown stands. Earlier calculations have shown that the average fertility of autumn-formed tillers seldom exceeds 30-35% in first-year seed crops, and in older crops it is usually much lower (Aamlid 1993, 1994). Again, competition for light seems to be the most important reason for this low fertility in dense stands, and since the smallest tillers are most vulnerable to competition (Ong 1978), it might be assumed that the fertile tillers are formed relatively earlier in dense than in open stands. To some extent this assumption is validated by Meijer (1984), who found that tillers formed before September contributed 24 and 43% of the panicle population in seed crops of *Poa pratensis* sown in July at rates of 3 and 24 kg ha^{-1}, respectively.

In conclusion, the present results shows that (1) tillering and rhizome formation in seed crops of *Poa pratensis* 'Lavang' and 'Leikra' in SE Norway continue until at least 1 November in the planting year; (2) the fertility of early-formed tillers is no higher than that of late-formed tillers in 'Lavang' grown for seed in mild winter climates; (3) the fertility of 'Leikra' tillers decreases with later period of formation in autumn; (4) intravaginal tillers of 'Leikra' have lower fertility than tillers from rhizomes emerging during the same period.

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Ås Science Park Ltd., Sagabygget, N-1432 Ås, Norway

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