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The Apelsvoll cropping system experiment VI. Runoff and nitrogen losses

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A cropping system experiment aimed at developing cropping systems which minimize nutrient leaching and maximize food quality and economy was started at Apelsvoll Research Centre in southeast Norway in 1990. The experiment includes arable and forage crop systems with conventional, integrated and ecological cropping. The systems differ in crop rotation, fertilization, soil tillage and plant protection, and are established on «model farms» which are equipped with field lysimeters for measuring drainage and surface runoff. Nitrogen runoff results for the first four-year experimental period revealed that on average for all cropping systems, the annual losses of total-N varied from 12 to 36 kg ha^{-1}. There were cropping system differences in nitrogen losses, and the losses were higher in the conventional and integrated arable system and in the conventional forage system than in the ecological arable system and the integrated and ecological forage system. It appears that crop rotation and management factors such as use of farmyard manure, fertilizer level and tillage system are the determinants in the risk of leaching. Weather factors, such as precipitation, had an even greater effect on nitrogen losses than the management factors, which differed between the cropping systems.

Key words: Conventional, ecological and integrated cropping, crop rotation, nitrogen concentration, nitrogen fertilization, nitrogen leaching, runoff, soil tillage.

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Investigation of nutrient leaching and runoff has been an important area of agricultural research in the 1980s and 90s (e.g. Davies & Sylvester-Bradley 1995; Haak & Lindén 1995; Simmelsgaard 1994; Torstensson et al. 1993a; Lyngstad 1990; Rognerud 1989; Uhlen 1989). Most of this research includes long- and short-term crop rotation and lysimeter experiments, with the focus on changes in soil and yields and nutrient losses as a result of, for instance, soil tillage, fertilization and crop rotation. The total effect of all the management factors composing an agricultural system on nutrient runoff has not been investigated in Norway. At Apelsvoll Research Centre a project was started in 1990 (Eltun 1994) based on traditional experimental methods as well as on a systems approach where one of the main aims was to study the effect of different cropping systems on nutrient runoff losses. Results of nitrogen runoff losses during the first four-year cropping period of the Apelsvoll Cropping System Experiment are presented here. The yield

results for this period have been published by Eltun (1996a and b).

Material and methods

Cropping systems

The experimental design, management of the individual cropping systems and soil conditions on the «model farms» are described in Eltun (1994) and Riley & Eltun (1994). Only a brief resumé is therefore given here. The experiment is being conducted at Apelsvoll Research Centre, Kapp, which is situated in the central part of southeast Norway. The major soil groups are well- or imperfectly drained brown earths, and the dominant soil textures are loam and silty sand, with a humus content of about 7% in the topsoil.

The experiment is based on both traditional experimental methods and a systems approach in which complete model farms are used as experimental units. Instead of using a fixed experimental layout, attention is paid to continuous improvement of the farming systems. The systems are adjusted every 4-5 years, depending on experience gained in the project and from other relevant sources. The experimental units are cropping systems which include six types of farming systems:

A. Conventional arable crop production, no farmyard manure.
B. Integrated arable crop production, no 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 for the period 1990-94

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

	Cropping systems					
Management	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-N in the slurry, kg ha^{-1}

are presented in Table 1. The farmyard manure consisted of aerated cattle slurry with 63% ammonium-nitrogen.

Each cropping system is represented on two «model farms» of 0.18 ha, randomly distributed within a 6 x 2 grid of 3.3 ha. Each «model farm» has eight rotation plots. All the crops in each rotation are thus present every year.

Runoff and nutrient concentration measurements

Each «model farm» has a separate drainage system, from which leaching water is measured continuously and sampled for chemical composition proportionally to the runoff. Analyses are performed on a monthly basis. The surface runoff water is measured in the same way. In addition, leaching water from separate rotation plots can be sampled, as desired, for chemical composition by means of access pipes. In autumn (early October) and spring (late April) the soil is sampled to a depth of 50 cm for measurement of mineral nitrogen content ($Nmin=NO_3$-N+NH_4-N) on selected rotation plots.

Based on the monthly measurements of runoff, the results are presented on a yearly basis as follows: October 1990-September 1991, October 1991-September 1992, October 1992-September 1993 and October 1993-September 1994. These «hydrological» years represent the first four-year cropping period, during which only minor changes were made in the management factors.

The nitrogen content of the runoff water was analysed at The Norwegian Crop Research Institute, Holt Research Centre. Total-N (organic-N + mineral-N) and nitrate-N were determined in accordance with the methods described in Norwegian Standard 4743 (1993) and Norwegian Standard 4745 (1991), respectively. Ammonium-N was analysed using Flow Injection Analysis (FIA).

The analyses of nitrate content in leaching water from individual plots and nitrate and ammonium (Nmin) contents in soil samples were performed at Apelsvoll Research Centre, Division Kise. The nitrate content of leaching water was analysed directly using a Tecator Aquatec flow injection instrument. The nitrate-N and ammonium-N in the soil samples were extracted by shaking 40 g crushed, frozen soil in 200 ml 1 M KCl for one hour. Both were analysed using a Tecator Aquatec flow injection instrument. The results are expressed on a dry matter basis by means of a 100 g subsample dried at 105°C and converted to absolute values (kg ha^{-1}) assuming dry bulk densities of 1.25 and 1.50 Mg m^{-3} in topsoil and subsoil, respectively.

Weather and runoff conditions

Important factors affecting the runoff conditions, such as temperature, precipitation, ground frost and snow depth and duration are presented in Figs. 1 and 2 and Table 2. The total normal (1961-90) annual precipitation is 600 mm, and the normal temperature over the whole year is 3.6°C. In the growing period May-September the normal temperature is 12.1°C. 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, dry winter, a warm, dry spring and early summer and a cool, wet autumn. As in the first year, 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 in that year. The final year (1993/94) had a very

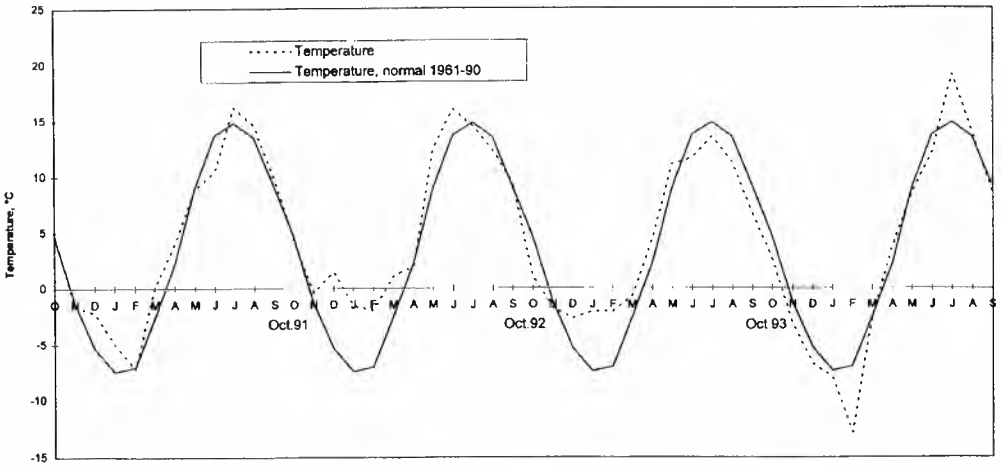

Fig. 1. Monthly mean air temperature 2 m above ground in the runoff years 1990/91-1993/94 and normal air temperature per month for the period 1961-90

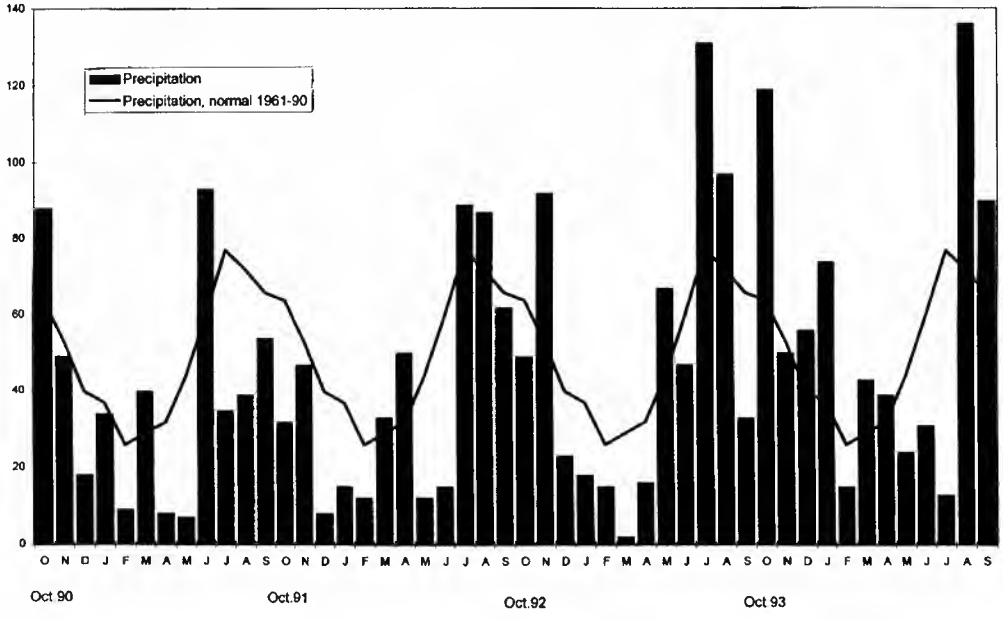

Fig. 2. Monthly precipitation in the runoff years 1990/91-1993/94 and normal precipitation per month for the period 1961-90

Table 2. Ground frost, period with snow cover, maximum snow depth, mean air temperature and total amount of precipitation and evaporation in the runoff years 1990/91 - 1993/94

Runoff year	Days with frost at 3 soil depths			Period with snow cover	Max. snow depth cm	Mean air temp-erature °C	Total precipi-tation mm	Potential [1] evapo-ration mm
	10 cm	20 cm	50 cm					
1990/91	83	0	0	26 Nov. - 3 April	30	4.4	474	309
1991/92	74	0	0	23 Des. - 10 April	35	5.8	462	369
1992/93	100	52	43	15 Oct. - 15 April	20	4.3	590	334
1993/94	0	0	0	6 Des. - 26 April	72	2.9	690	399

[1] Loss of water from a Thorsrud evaporation pan with a surface area of 0.25 m² at Apelsvoll Division Kise, 10 km distant, for the period May-Sept.

cold winter, but as there was 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.

These weather conditions resulted in the runoff pattern depicted in Fig. 3. Most of the runoff usually occurred in the periods October-December and March-April. Runoff during the growing season only occurred in months with unusually high precipitation, accompanied by water-saturated soil and low evaporation. During the first three winters there were

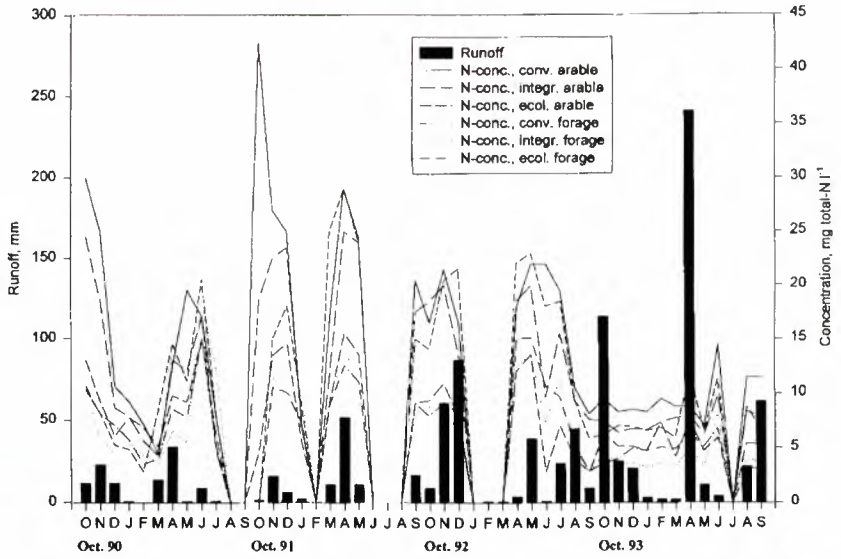

Fig. 3. Drainage runoff on average for all cropping systems and concentration of total-N in the drainage water of the six cropping systems on a monthly basis in the runoff years 1990/91-1993/94

some cases of runoff due to fluctuating temperature and repeated snowmelt periods. On average for the whole period (Table 3), 88% of the total runoff was by subsurface drainage. Most of the surface water came during the snowmelt period, March-April. The distribution of surface and drainage runoff in winter depended upon the ground frost conditions, but surface runoff usually dominated in the winter. The extremely high runoff in April 1994 was a result of the great snow accumulation during the winter (Table 2). Because of the many snow storms which occurred that winter, we cannot rule out that some snow was blown from outside the area onto the experimental field, thus affecting runoff. However, there was little variation in snow depth within the field, so that this effect was probably the same for all cropping systems.

As shown in Table 3, there were considerable differences in both drainage and surface runoff between the cropping systems. There was also variation between replicates within the same system. Owing to these variations two alternative methods of calculating the N losses have been evaluated (Table 4). A method where the measured runoff for each system was used to calculate N losses (alt. 1) is compared with a method of calculation in which average runoff for all systems was multiplied by N concentrations measured in individual systems (alt. 2). This shows that the calculated losses, especially in the two conventional systems, are affected by the method of calculation. Since the runoff differences between the cropping systems seem to be affected more by variation in groundwater conditions within the experimental area than by variation in the use of water between the systems (Haarstad 1996) and since there was no significant

Table 3. Drainage and surface runoff of the cropping systems in the runoff years 1990/91-1993/94

Cropping system	1990/91	1991/92	1992/93	1993/94	Mean 1990/94
Drainage, mm					
Conv. arable	148	164	339	587	309
Integr. arable	96	119	296	569	270
Ecol. arable	117	108	250	431	226
Conv. forage	86	97	225	424	208
Integr. forage	86	96	266	467	228
Ecol. forage	110	111	300	563	271
Mean	107	115	279	506	252
Surface, mm					
Conv. arable	67	16	20	19	30
Integr. arable	78	43	48	21	47
Ecol. arable	58	29	32	7	31
Conv. forage	58	20	14	15	26
Integr. forage	78	34	45	20	44
Ecol. forage	72	19	22	12	31
Mean	69	27	30	16	35

Table 4. Average losses of total-N in the drainage and surface runoff of the cropping systems for the runoff years 1990/91-1993/94 calculated both as (alt. 1) measured runoff per system multiplied by measured system concentration and as (alt. 2) average runoff for all systems multiplied by the measured system concentration

	Alternative 1				Alternative 2			
Cropping system	Drainage kg ha^{-1}	Surface kg ha^{-1}	Total kg ha^{-1}	Rel. %	Drainage kg ha^{-1}	Surface kg ha^{-1}	Total kg ha^{-1}	Rel. %
Conv. arable	43.2	1.6	44.8	100	35.7	1.9	37.6	100
Integr. arable	32.0	1.6	33.6	75	30.4	1.2	31.6	84
Ecol. arable	18.0	1.1	19.1	43	20.5	1.4	21.9	58
Conv. forage	27.5	1.2	28.7	64	34.3	1.7	36.0	96
Integr. forage	15.3	2.0	17.3	39	16.8	1.2	18.0	47
Ecol. forage	19.1	1.1	20.2	45	17.8	1.4	19.2	51

correlation between amount of runoff and nitrogen concentration, alternative 2 is used in the calculation of nutrient runoff losses.

Statistical method

Losses of nitrogen are assumed to be determined simultaneously by the climatic factors in interaction with processes in the soil, together with the impact of the cropping systems. On this assumption, we decided that regression analysis is the most suitable method to analyse the relative influence of these factors on nitrogen losses. The regression method used and the models which are developed are presented by Fugleberg & Eltun (1996). In this paper we focus on the results of the analyses, and give only a resumé of the methods.

The regression analyses are based on a Cobb-Douglas model; i.e a model with constant relative increment (elasticities). The model is:

$$Y=AP^{\beta_1}T^{\beta_2}ST^{\beta_3}e^{\tau_1 B}e^{\tau_2 C}e^{\tau_3 D}e^{\tau_4 E}e^{\tau_5 F}\mu \quad (1)$$

where the dependent variable Y denotes concentration or losses of nitrogen. By taking the logarithm on both sides of equation (1) the model is linearized as follows:

$$\ln Y=\beta_0+\beta_1\ln P+\beta_2\ln T+\beta_3\ln ST+\tau_1 B+\tau_2 C+\tau_3 D+\tau_4 E+\tau_5 F+\in \quad (2)$$

The variables in the models are as follows:

Dependent variables:

N_L: Losses of nitrogen in g daa^{-1} month^{-1};

N_C: Concentration of nutrient in g l^{-1}; where N=(N, NO_3, NH_4) for total-N, nitrate-N and ammonium-N, respectively;

L: Total runoff in l daa^{-1} month^{-1}

Explanatory variables:

Climatic variables:

P: Precipitation in mm month^{-1};

T: Mean monthly air temperature in °C;

ST: Number of days with soil temperature less than 0°C at 20 cm depth.

Qualitative dummy variables expressing effects of cropping systems:

B=1 if integrated arable crop production, else 0

C=1 if ecological arable crop production, else 0

D=1 if conventional forage crop production, else 0

E=1 if integrated forage crop production, else 0

F=1 if ecological forage crop production, else 0

The variable for cropping system enters into model (1) relative to the conventional arable crop production system (A) by using dummies for the remaining five levels. Incorporated in the variable levels related to cropping systems are factors such as, for example, N fertilization, percentage vegetation cover in the autumn, and time of soil tillage. Including these variables together with the system variables would probably entail interpretative problems and collinearity. For this reason they were excluded from the analyses.

Losses and concentration of nitrogen and surface and drainage runoff water should be estimated simultaneously. However, since the same explanatory variables are used in each equation, the simultaneous estimation may be reduced to yield a single ordinary least squares (OLS) equation. In additon, model (1) is based on a combination of cross-section with time series, where the units in the cross-section indicate the different levels of cropping systems. The evaluation of models based on such kinds of combined data is further discussed by Fugleberg & Eltun (1996).

The method of estimating models based on the combining of cross-section with time series depends on whether a fixed effect or a random effect approach is chosen for the units in the cross-section. However, it is of special interest to focus explicitly on cropping systems, and not to regard them as a random sample from a population. Consequently, the fixed effect model was chosen by using dummies for five of the six cropping systems. Then the equations for losses and concentration of nitrogen and total runoff could be estimated by OLS. However, if the error term in an equation is dependent on time, the equations should be modified for autocorrelation. Each of the equations was tested for autocorrelation by calculating the Durbin-Watson observator (Fugleberg & Eltun 1996). There seems to be no evidence of autocorrelation. Thus, also by assessing autocorrelation, this model may be reduced to yield a single OLS equation.

The most intensive periods for nitrogen leaching were found to be in autumn (September-November) and spring (March-April), and the model (2) is estimated on the basis of annual, autumn and spring samples. In connection with analyses for the autumn and spring samples respectively, model (2) is modified by including the following variables:

A_91, A_92 and A_93 as dummies for autumn 1991, 92 and 93 respectively. These dummies enter into the model relative to autumn 1990.

S_92, S_93 and S_94 as dummies for spring 1992, 93 and 94 respectively. These dummies enter into the model relative to spring 1992.

Results

Nitrogen runoff losses in complete cropping systems

Interpretation of the regression results

The statistical results for concentrations and losses of total-N, nitrate-N and ammonium-N for data based on monthly observations throughout the whole year can be found in Table 5, while Table 6 presents the results for concentration and losses of nitrate-N in the autumn and spring samples.

The coefficient (ß) associated with the climatic variables expresses constant relative changes; for example when precipitation increases by 1%, leaching of nitrogen (equation 1) increases by $ß_1$%. Thus, in Table 5 losses of total-N in

Table 5. Results of regression analysis of concentration ($\mu g\ l^{-1}$) and losses (g daa $^{-1}$) of total-N, nitrate-N and ammonium-N in drainage water and surface water respectively, based on monthly observations throughout the whole year from the period October 1990-September 1994. The data for the cropping systems B-F are given relative to system A (conv. arable) and are presented as R-square values and estimated regression parameters with t-values in parentheses

	Drainage water				Surface water			
Regressor	Concentration		Losses		Concentration		Losses	
Total-N								
R-square	0.21		0.11		0.12		0.20	
P [1]	-0.01	(-0.3) *[2]	0.56	(5.1) *	0.13	(2.3) *	-0.12	(-1.5)
T	0.27	(6.2)	0.11	(0.8)	0.86	(5.3) *	1.24	(5.3) *
ST	0.00	(0.2)	-0.13	(-3.0) *	0.11	(4.5) *	0.21	(6.1) *
B	0.03	(0.4)	-0.01	(0.0)	-0.21	(-1.4)	-0.16	(-0.7)
C	-0.46	(-5.9) *	-0.50	(-2.0) *	0.02	(0.1)	0.17	(0.8)
D	0.03	(0.4)	-0.17	(-0.7)	0.11	(0.7)	0.31	(1.4)
E	-0.53	(-6.7) *	-0.40	(-1.5)	-0.11	(-0.8)	-0.01	(-0.1)
F	-0.50	(-6.5) *	-0.53	(-2.1) *	0.01	(0.1)	0.17	(0.8)
Nitrate-N								
R-square	0.18		0.12		0.17		0.16	
P	0.03	(0.9)	0.60	(5.3) *	0.35	(3.8) *	0.10	(1.0)
T	0.23	(4.7) *	0.04	(0.3)	0.96	(3.7) *	1.37 *	(5.1) *
ST	-0.01	(-0.3)	-0.13	(-2.8) *	0.09	(2.3) *	0.20 *	(4.9) *
B	0.07	(0.7)	0.02	(0.1)	-0.24	(-1.0)	-0.21	(-0.8)
C	-0.50	(-5.7) *	-0.61	(-2.4) *	-0.06	(-0.3)	0.07	(0.3)
D	0.02	(0.2)	-0.20	(-0.8)	0.29	(1.2)	0.48	(1.9)
E	-0.58	(-6.5) *	-0.44	(-1.6)	-0.84	(-3.5) *	-0.75 *	(-3.2) *
F	-0.53	(-6.0) *	-0.58	(-2.2) *	-0.47	(-2.0) *	-0.27 *	(-1.0) *
Ammonium-N								
R-square	0.15		0.11		0.51		0.45	
P	0.55	(6.8) *	1.10	(8.4) *	-0.44	(-4.3) *	-0.7	(-4.8) *
T	0.49	(4.8) *	0.30	(1.8)	1.02	(3.5) *	1.42	(3.4) *
ST	0.31	(9.8) *	0.20	(3.7) *	0.45	(10.4) *	0.55	(8.8) *
B	-0.09	(-0.5)	-0.15	(-0.5)	0.34	(1.3)	0.40	(1.0)
C	-0.17	(-0.9)	-0.29	(-1.0)	0.49	(1.8)	0.63	(1.6)
D	0.06	(0.3)	-0.15	(-0.5)	-0.37	(-1.4)	-0.17	(-0.4)
E	-0.02	(-0.1)	0.13	(0.4)	0.68	(2.5) *	0.79	(2.0) *
F	-0.09	(-0.5)	0.15	(-0.5)	1.00	(3.6) *	1.21	(3.0) *

[1] As denoted in the chapter "Statistical method" P = precipitation, T = air temperature, ST = soil temperature and B-F = cropping systems

[2] * denotes a significant variable with a t-level of 2 or higher

drainage water increase by 0.56% when precipitation increases by 1%, and this increase is significant with a t-value of 5.1.

The interpretation of the coefficient associated with the cropping system variables is 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, τ_1 (equation 2) expresses the change in the logarithm of concentration or losses of nitrogen (positively or negatively) when passing from conventional arable production (A) to integrated arable production (B). Thus, in Table 5 passing from the conventional arable system (A) to the ecological arable system (C) entails a decrease in the logarithm of concentration of total-N of 0.46, and this decrease is significant (t-value = 5.9).

Table 6. Results of regression analysis of concentration (µg l^{-1}) and losses (g daa^{-1}) of nitrate-N in drainage water and surface water respectively, based on monthly observations throughout the autumn (August, September, October) and spring (March, April) from the period October 1990-September 1994. The data for the cropping systems B-F are given relative to system A (conv. arable) and are presented as R-square values and estimated regression parameters with t-values in parentheses

	Drainage water				Surface water			
Regressor	Concentration		Losses		Concentration		Losses	
Autumn								
R-square	0.64		0.61		0.37		0.49	
P [1]	0.10	(1.0) *[2]	1.76	(6.9) *	(-) [3]	(-)	-	(-)
T	-0.41	(-3.9)	-2.28	(-8.3) *	(-)	(-)	-	(-)
B	0.14	(1.2)	0.13	(0.4)	0.76	(1.2)	0.76	(1.2)
C	-0.62	(-5.4) *	-0.60	(-2.0) *	0.99	(1.8)	0.99	(1.8)
D	-0.14	(-1.2)	-0.25	(-0.9)	0.45	(0.8)	0.45	(0.8)
E	-0.76	(-6.5) *	-0.72	(-2.3) *	0.02	(0.1)	0.02	(0.1)
F	-0.77	(-6.7) *	-0.76	(-2.5) *	0.13	(0.2)	0.13	(0.2)
A_91	-0.16	(-1.4)	-1.58	(-5.1) *	-	(-)	-	(-)
A_92	-0.04	(-0.4)	0.36	(1.3)	-	(-)	-	(-)
A_93	-1.11	(-10.7) *	-0.36	(-1.3)	-	(-)	-	(-)
Spring								
R-square	0.63		0.94		0.80		0.59	
P	0.21	(3.0) *	0.56	(6.8) *	0.70	(7.4) *	0.18	(1.8)
T	0.88	(4.0) *	7.73	(29.6) *	1.69	(2.9) *	1.73	(3.0) *
ST	-0.12	(-5.3) *	-0.12	(-4.5) *	0.01	(0.1)	0.30	(7.2) *
B	0.02	(0.2)	-0.08	(-0.6)	-0.29	(-1.7)	-0.29	(-1.7)
C	-0.25	(-2.0) *	-0.35	(-2.4) *	-0.12	(-0.7)	-0.12	(-0.7)
D	0.34	(2.9) *	0.29	(2.1) *	0.24	(1.3)	0.24	(1.3)
E	-0.51	(-4.2) *	-0.62	(-4.2) *	-0.69	(-3.9) *	-0.68	(-3.8) *
F	-0.31	(-2.5) *	-0.45	(-3.1) *	-0.32	(-1.8)	-0.32	(-2.0) *
S_92	0.59	(5.2) *	0.58	(4.3) *	1.81	(10.6) *	0.50	(2.9) *
S_93	0.70	(5.2) *	-2.03	(-12.6) *	2.70	(11.8) *	-0.68	(-3.0) *
S_94	-0.46	(-3.2) *	0.35	(2.0) *	-0.14	(-0.7)	-0.04	(-0.2)

[1] As denoted in the chapter "Statical method" P = precipitation, T = air temperature, ST = soil temperature, B-R = cropping systems, A_91-A_93 = autumn periods and S_92 - S_94 = Spring periods
[2] * denotes a significant variable with a t-level of 2 or higher
[3] - biased estimate due to collinearity

Total losses

As shown in Fig. 3 and Tables 7 and 8, there was considerable variation between years for both nitrogen concentrations and losses, and on the basis of the autumn and spring samples these variations were often significant (Table 6). The concentration of total-N in the drainage runoff on average for individual runoff years, varied from 7 mg l^{-1} in 1993/94 to 16 mg l^{-1} in 1991/92, while the average losses of total-N in the drainage water varied from 11.8 kg ha^{-1} in 1990/91 to 35.6 kg ha^{-1} in 1993/94.

Chemical composition of the runoff

Both the concentration measurements and runoff calculations showed that most of the nitrogen was lost as nitrate-N in the drainage water (Tables 7 and 8 and Fig. 4). On average for all years, 81% of the total nitrogen runoff was lost as nitrate-N in the drainage water, 2% as nitrate-N in the surface water, and 1% as ammonium-N in the surface water, while the drainage water contained very small amounts of ammonium-N. The remainder of the nitrogen losses (16%) was assumed to be organic nitrogen. While ammonium-N

Table 7. Mean concentrations of nitrate-N and ammonium-N in the drainage and surface runoff of the cropping systems in the runoff years 1990/91-1993/94

Cropping system	1990/91		1991/92		1992/93		1993/94		Mean 1990/94	
	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
Drainage, mg l^{-1}										
Conv. arable	11.63	0.04	18.72	0.06	15.41	0.03	8.83	0.01	13.65	0.04
Integr. arable	9.58	0.06	17.51	0.05	13.28	0.03	6.96	0.01	11.83	0.04
Ecol. arable	7.04	0.04	10.10	0.04	6.66	0.03	4.59	0.02	7.10	0.03
Conv. forage	7.56	0.03	18.02	0.03	15.81	0.03	6.91	0.01	12.08	0.03
Integr. forage	5.96	0.08	8.66	0.03	7.27	0.04	3.42	0.01	6.33	0.04
Ecol. forage	6.13	0.04	8.71	0.03	7.98	0.05	4.05	0.02	6.72	0.04
Mean	7.98	0.05	13.62	0.04	11.07	0.04	5.79	0.01	9.62	0.04
Surface, mg l^{-1}										
Conv. arable	0.76	0.53	8.48	0.51	6.04	1.91	1.45	0.08	4.18	0.76
Integr. arable	0.65	0.71	2.81	0.65	2.85	0.97	1.47	0.09	1.95	0.61
Ecol. arable	0.72	0.46	2.78	0.85	4.78	1.91	2.38	0.19	2.67	0.85
Conv. forage	0.88	0.44	6.04	0.57	6.60	1.12	1.31	0.13	3.71	0.57
Integr. forage	0.37	0.48	1.80	0.80	3.22	2.05	1.19	0.12	1.65	0.86
Ecol. forage	0.47	0.63	2.28	0.73	2.95	2.71	1.13	0.42	1.71	1.12
Mean	0.64	0.54	4.03	0.69	4.41	1.78	1.49	0.17	2.65	0.80

Table 8. Losses of nitrate-N and ammonium-N in the drainage and surface runoff of the cropping systems in the runoff years 1990/91-1993/94

Cropping system	1990/91		1991/92		1992/93		1993/94		Mean 1990/94	
	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
Drainage, kg ha^{-1}										
Conv. arable	14.6	0.07	22.4	0.05	43.3	0.11	41.7	0.06	30.5	0.07
Integr. arable	12.7	0.08	22.9	0.07	36.7	0.06	34.4	0.06	26.6	0.07
Ecol. arable	8.4	0.05	13.6	0.03	20.2	0.10	27.3	0.16	17.3	0.09
Conv. forage	10.4	0.05	25.3	0.04	47.4	0.07	40.5	0.09	30.9	0.06
Integr. forage	6.5	0.11	11.4	0.03	19.6	0.11	18.3	0.09	13.9	0.09
Ecol. forage	7.7	0.05	11.3	0.05	20.7	0.16	21.7	0.15	15.3	0.10
Mean	10.1	0.07	17.8	0.05	31.3	0.10	30.5	0.10	22.4	0.08
Surface, kg ha^{-1}										
Conv. arable	0.5	0.51	2.3	0.21	1.0	0.61	0.3	0.01	1.0	0.34
Integr. arable	0.5	0.72	0.7	0.24	0.6	0.29	0.2	0.01	0.5	0.32
Ecol. arable	0.5	0.49	0.6	0.33	0.7	0.56	0.3	0.03	0.5	0.35
Conv. forage	0.7	0.46	1.7	0.21	1.7	0.21	0.2	0.03	1.0	0.23
Integr. forage	0.3	0.51	0.4	0.30	0.5	0.64	0.2	0.02	0.3	0.37
Ecol. forage	0.3	0.64	0.5	0.27	0.5	0.79	0.2	0.07	0.3	0.44
Mean	0.5	0.56	1.0	0.26	0.8	0.52	0.2	0.03	0.6	0.34

accounted for less than 1% of the losses of total-N in the drainage runoff, it accounted for 25% of the total-N losses in the surface water.

As shown in Fig. 3, there was no clear relationship between amount of runoff and nitrogen concentration, but usually the peaks of the concentration curves were associated with periods with high runoff (October-December and March-April). An exception was the runoff year 1993/94, in which nitrogen concentration was fairly low throughout the year. Where there was runoff during the growing season, the concentration was also fairly high, but seldom reached the same level as that in the autumn and spring. On an annual basis, there tended to be a red-

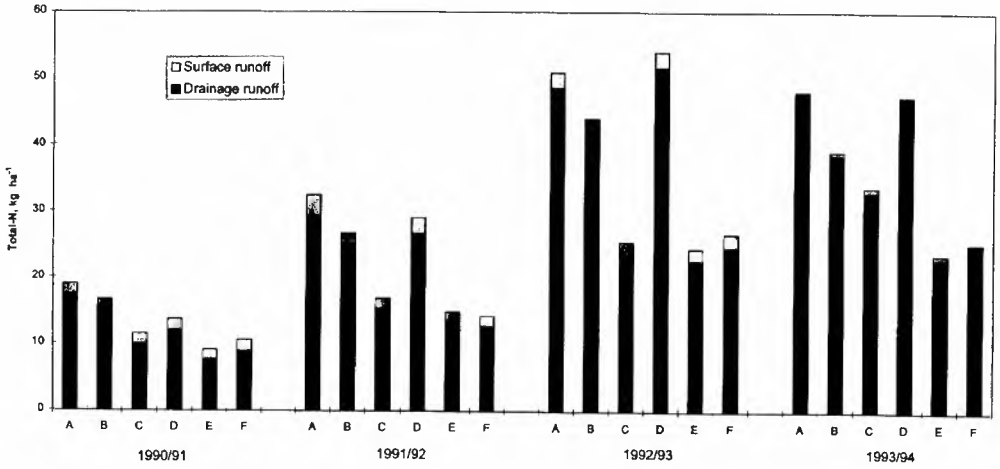

Fig. 4. Losses of total-N in the drainage and surface runoff of the conventional (A), integrated (B) and ecological (C) arable systems and the conventional (D), integrated (E), and ecological (F) forage systems in the runoff years 1990/91-1993/94

uction in concentration in the drainage water when runoff increased (r=-0.24), but this reduction was not significant at a 5% level.

The regression analysis showed that, in general, the climatic variables (precipitation, air and soil temperature) had higher t-values than the cropping system variables, and thus climate appeared to have a greater effect on the losses than cropping systems (Tables 5 and 6). Precipitation was the most important factor affecting the nitrogen losses. Losses of all types of nitrogen in the drainage water increased significantly with precipitation. The effect of temperature varied between seasons and forms of nitrogen, but usually there was an increase in nitrogen losses with increasing air and soil temperature. In the autumn there was, however, an increase in nitrogen losses with declining temperature, which reflects the greater runoff which occurred in the autumn.

Higher R-square values found by calculating the results for the autumn and spring samples separately (Table 6), as opposed to using the annual sample (Table 5), confirm that the regression model gives the best explanation of the climatic and cropping system differences when data from the most concentrated runoff periods are used.

Cropping system effects

The concentrations and losses of nitrogen from the cropping systems are shown in Figs. 3 and 4 and Tables 7 and 8 and the regression analyses in Tables 5 and 6. Both concentration and runoff of total-N and nitrate-N in the drainage water were higher in the two conventional systems and in the integrated arable system than in the two ecological systems and in the integrated forage system. The losses of nitrate-N in the surface water were also highest in the two conventional systems, while there were small differences between the other cropping systems. With regard to ammonium-N in the surface water, the concentrations and losses tended to be higher in the two ecological

systems and in the integrated forage system than in the two conventional systems and the integrated arable system. Losses of ammonium-N were nevertheless small.

The losses of nitrogen as compared to the dry matter produced per ha in food products or feed were 6.1, 5.7, 4.1, 4.2, 2.2 and 2.3 g total-N kg^{-1} dry matter for the conventional arable, integrated arable, ecological arable, conventional forage, integrated forage and ecological forage systems, respectively.

Mineral nitrogen in soil and leachate from individual crops

Effect of year and season

The mineral nitrogen in the soil (Nmin) in the autumn reflects the risk of nitrogen losses during the period without plant growth, and, as shown in Table 9, there was substantial variation between years in the content of Nmin in autumn. In the autumn of 1992 the Nmin content was more than double that found in 1993, and in 1991 more than three times as high as in 1993. In Table 9 the spring measurements are presented as the change that had occurred between autumn and the following spring. This shows that the changes in Nmin during the winter varied greatly between years. In the winter of 1992/93 there was, for example, in most crops an increase during the winter, whereas in 1991/92 there was a substantial reduction.

Effect of crops

There was considerable variation between crops concerning Nmin in the autumn, and a ranking of the crops based on average values for the cropping systems showed: ley < spring wheat < main-crop potatoes < fodder beet < early potatoes (Table 9). As nitrate is the most leachable fraction of the Nmin, the proportion of nitrate affects the risk of leaching. The percentage nitrate of total Nmin in the autumn was 23, 33, 53, 52, and 80 for ley, spring wheat, main-crop potatoes, fodder beet and early potatoes, respectively, averaged over all cropping systems and years. A ranking of the crops for content of nitrate in the drainage water in autumn gave roughly the same result with regard to leaching risk from the different crops as did the Nmin measurements in the soil (Table 9).

As is also shown in Table 9, there were differences between crops concerning the changes in Nmin which occurred during the winter. On average for all cropping systems there was a tendency for Nmin to increase in ley, in spring wheat there was very little difference between autumn and spring, whereas there were increasingly negative differences between autumn and spring for main-crop potatoes, fodder beet and early potatoes, indicating greater N losses from these crops.

Cropping system effects

With the exception of fodder beet, the differences between cropping systems for Nmin in the autumn were smaller than the differences between years and crops. With regard to system differences, it appeared that the decline in Nmin during winter could be ranked in the following order: ecological < integrated < conventional systems.

Discussion

Weather effects

In comparison with most other agricultural regions of Norway, the losses of nitrogen are small in this area (Ludvigsen 1995; Lundkvam 1993), and so also in this experiment (27.3 kg total-N ha^{-1} $year^{-1}$ on average for all years and cropping systems). The most obvious reason is the

Table 9. Nitrate-N and ammonium-N (Nmin) in the soil horizon 0-50 cm for different crops of the cropping systems in the autumn and spring of the years 1991/92-1993/94, and the nitrate concentration in the drainage water for the same crops on average for the whole period

Cropping system	Crop[1]	1991/92		1992/93		1993/94		Mean 1991/94		Nitrate-N in drainage water mg l^{-1}
		Autumn	Spring[2]	Autumn	Spring	Autumn	Spring	Autumn	Spring	
		Kg Nmin ha^{+1}		Kg Nmin ha^{+1}		Kg Nmin ha^{+1}		Kg Nmin ha^{+1}		
Conv. forage	Ley	27	− 3	27	− 1	12	+ 7	22	− 3	4
Integr. forage	"	32	+ 7	24	+ 9	9	+12	21	+10	4
Ecol. forage	"	42	+ 4	28	+ 5	8	+18	26	+ 9	5
Mean	"	34	+ 2	26	+ 5	10	+13	23	+ 7	4
Conv. arable	S. wheat	75	− 29	33	+ 9	7	+15	38	− 1	10
Integr. arable	"	44	− 8	31	− 2	10	+ 9	28	0	10
Ecol. arable	"	41	− 7	28	+10	16	+12	28	+10	7
Mean	"	53	− 9	31	+ 5	11	+12	32	− 1	9
Conv. arable	M. pot.	77	− 23	56	− 5	26	0	53	−10	18
Integr. arable	"	64	− 12	45	− 8	21	+ 1	43	− 6	14
Ecol. arable	"	66	− 17	45	− 6	19	+ 4	43	− 6	13
Mean	"	69	− 17	49	− 7	22	+ 2	46	− 7	15
Conv. forage	F. beet	179	−101	69	−18	20	+ 7	89	−37	11
Integr. forage	"	104	− 54	37	− 3	17	+11	53	−14	6
Ecol. forage	"	49	+ 1	45	+ 4	15	+21	36	+ 9	7
Mean	"	111	− 52	50	− 3	17	+13	59	−14	8
Conv. arable	E. pot.	190	−109	97	−42	46	−19	111	−57	42
Integr. arable	"	195	−145	67	−35	34	− 8	99	−63	29
Mean	"	192	−127	82	−39	40	−14	105	−60	35
Mean, all crops		92	− 41	48	− 8	20	+ 5	53	−15	

[1] 1st year ley, spring wheat, main-crop potatoes, fodder beet, early potatoes
[2] The spring results are presented as change in Nmin between autumn and spring

fairly dry climate and the fact that there are normally prolonged periods with ground frost and snow cover during the winter.

The nitrogen concentrations in drainage water were nevertheless rather high, compared with other measurements taken in Norway and in other Nordic countries (Ludvigsen 1995; Simmelsgaard 1994; Torstensson et al. 1993a; Uhlen 1989). In all cropping systems the concentrations were higher then 5 mg total-N l^{-1}, which is considered as an acceptable limit from a limnological point of view (Hoffmann & Uhlén 1994). Most measurements taken in Sweden have, however, indicated that this limit is very difficult to achieve (Hoffmann & Uhlén 1994). As compared to the Norwegian and European Union limit for good drinking water quality of 1 mg total-N l^{-1} the drainage or surface water from the experiment is not suitable for drinking. Almost all the nitrogen at risk of leaching during the autumn and winter seems to come from mineralization of organic N (Macdonald et al. 1989), and, as this soil is naturally high in organic matter (Riley & Eltun 1994), mineralization of organic matter may be the most important reason for the fairly high nitrogen concentrations found in this experiment.

Among others, Ellstrøm (1989), Hoffmann & Ulén (1994) and Gustafson (1987) have stated that weather factors such as precipitation, snow depth, ground frost and temperature are important factors affecting nitrogen leaching and

runoff, with precipitation as the most decisive. Our results confirm this conclusion, and in the experiment the annual variation in precipitation had a greater influence on nitrogen losses than the management factors represented by the cropping systems. The temperature variations probably influenced nitrogen losses by affecting the nitrogen mineralization rate, as has also been shown by Brandt et al. (1984).

These results confirm other workers' findings (Lundekvam 1993; Uhlen 1989) which show that nitrate-N in the drainage water is the dominant source of nitrogen losses under Norwegian conditions. On an annual basis the losses of total-N in the surface water runoff constituted 2-15% of the total losses. Most of the surface runoff came during the snowmelt period in the spring, and the annual variations were due to variation in the amount of snow and in the incidence of ground frost. Higher concentrations of ammonium-N in surface than in drainage water were probably partly caused by leaching from plant residues on the soil surface. In the soil the ammonium becomes tied to soil particles, and the part that reaches the drains is mostly nitrified, thus explaining the low content of ammonium in the drainage water.

Cropping system effects

Cropping systems dominated by forage crops and with spring ploughing (the integrated and ecological forage systems and the ecological arable system) were more favourable concerning nitrogen losses than systems dominated by arable crops (the conventional and integrated arable systems) and the forage crop system with autumn ploughing and autumn application of manure (the conventional forage system). These findings are in accordance with the results of Hansen & Kjellerup (1989), Søegaard (1988) and Uhlen (1989), which demonstrate that mixed cropping systems with a high proportion of leys have less nitrogen runoff than cereal-dominated cropping systems. The effect of the crops is also demonstrated by the content of Nmin in the soil and the nitrate concentrations in the leachate from separate crops, showing that the amount of leachable nitrogen is much higher after, for example, potatoes than in ley. Lindén & Wallgren (1989), among others, have shown that leys are effective utilizers of nitrogen, and Torstensson (1993a) has demonstrated that potatoes give a much greater leaching risk than ley. The Nmin after spring cereals was fairly low, but as there is a long period with nitrogen mineralization after harvest and no crops to utilize this nitrogen, the risk of losses nevertheless tends to be high after cereals. Thus, on the basis of variation in leaching risks in different crops, it is clear that the choice of crops in a cropping system is a very important factor in the risk of leaching. This was also stated by Alföldi et al. (1992).

Slurry application in the autumn compared with spring application is known to increase the risk of nitrogen leaching (Myhr & Oskarsen 1995; Torstensson et al. 1992) and may be an important reason for higher losses in the conventional forage system than in the other two forage systems. It is also known that autumn ploughing of leys and other catch crops gives rise to increased nitrogen mineralization and leaching (Gustafson & Torstensson 1988; Lindén et al. 1993). Thus the time of ploughing may be another reason for the high losses in the conventional forage system.

The time of ploughing does not seem

to have as great an effect on nitrogen leaching in cereal as in ley cropping, but in soils high in organic matter, as in this case, higher nitrogen losses have been measured following autumn ploughing than with spring tillage (Eltun 1995; Lundekvam 1993). Thus, higher N losses in the conventional system compared to the integrated and ecological arable systems can be explained partly by different times of ploughing.

In this experiment the nitrogen reserves at the end of the growing season give an indication of the possible effect of N-fertilization on leaching risk. Nmin measurements and nitrate analyses of the leachate revealed that the amount of leachable N in the autumn was somewhat less for the integrated and ecological cropping systems (low fertilizer input) than for the conventional systems (high fertilizer input). The differences between the fertilization intensity levels were in general smaller than the differences between crops, indicating that the type of crop affects the risk of leaching more than the level of fertilization. The differences between systems were, however, smaller for crops which displayed a balance between added and removed nitrogen (cereals) than for crops which received more fertilizer than the plants could utilize, and where there was no catch crop, as in the case of fodder-beet (Eltun 1993; Korsæth & Eltun 1996). These results suggest that provided fertilization is in harmony with plant requirements, the risk of leaching is low, but that leaching risk increases with the use of surplus fertilizer. These observations are in agreement with the results of Alföldi et al. (1992); Davies & Sylvester-Bradley (1995); Macdonald et al. (1989); Lyngstad (1990) and Uhlen (1989). However, according to this experiment, increasing levels of fertilization seem to give a general increase in the amount of leachable nitrogen in the soil, probably because of a higher nitrogen pool in the soil (Macdonald et al. 1989).

Comparisons of the cropping systems for nitrogen losses as compared to dry matter produced in food and feed showed that forage crop systems had smaller losses than arable cropping systems. The integrated and ecological forage system had the smallest nitrogen losses as compared to dry matter production.

Other measurements have shown no change, or only minor reductions in the risk of nitrogen leaching from ecological farming compared to conventional mixed farming (Alföldi et al. 1992; Kristensen et al. 1994; Torstensson et al. 1993b). Just as in this experiment, Kristensen et al. (1994) found that conventional cereal cropping gave higher losses than ecological farms cultivated with grass. It seems that it is the crop rotation and the interaction between rotation and the management factors composing each individual system that determine the risk of nitrogen leaching. The next challenge in this long-term experiment will be to investigate the possibilities for improvement of the individual cropping systems with regard to both maintaining productivity and reducing nutrient losses.

Summary

The idea behind the Apelsvoll Cropping System Experiment is to combine conventional experimental method with methodology for cropping system research aimed at the development of sustainable agriculture. Different cropping systems are represented on model farms in field lysimeters designed for the measurement of drainage and surface water. The aim is also to improve the sys-

tems gradually as new information becomes available. This experimental approach has been successful so far, and the experiment seems to be a good way of measuring system differences in, for example, leaching losses. We hope that it will also fulfil the aims with regard to system improvements. Nitrogen runoff results for the first four-year experimental period are presented here.

On average for all cropping systems there was a variation in the loss of total-N from 12 to 36 kg ha^{-1}, and 81% of the total-N runoff was lost as nitrate-N in the drainage water.

The results showed that there are cropping system differences in nitrogen runoff losses, and the concentration and losses of total-N were higher in the conventional and integrated arable systems and in the conventional forage system than in the ecological arable system and the integrated and ecological forage systems. The main reasons for the differences between the systems seem to be:

- Mixed cropping systems including leys and undersown crops have less leachable nitrogen in the soil in the autumn and spring than arable systems com-prising cereals and potatoes.
- Cropping management with the application of slurry during the growing season gives less risk of leaching losses than management with application of slurry in autumn.
- Surplus nitrogen fertilizer, relative to plant requirements, increases the risk of N losses. This poses little threat in the integrated and ecological systems, but it constitutes a problem for some crops in the conventional systems.
- Systems in which there is no soil tillage in autumn are more favourable concerning nitrogen leaching compared with systems with autumn ploughing.

It appears that it is the crop rotation and the management factors comprising each individual cropping system which determine the risk of nitrogen runoff losses. It seems that use of integrated management methods for fertilization and soil tillage will reduce the losses of nitrogen in both arable and forage crop systems, but the potential for reduction in losses is greatest in forage crop systems. The results also show that weather factors such as precipitation and temperature are even more important in determining the total nitrogen runoff than management factors.

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The Apelsvoll cropping system experiment V. Evaluation of statistical methods

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Estimation methods used in regression models to analyse nutrient loss are assessed for suitability in a number of wide-ranging lysimeter experiments based on combined cropping systems and replications with time series, such as for example the Apelsvoll Cropping System Experiment. The models are based on a three-component error term consisting of a replication or cropping-system specific effect, a period-specific effect and a remaining effect. An estimation method which «sweeps out» the first two components (the covariance estimation) is assessed together with a generalized least squares method (the Aitken estimation). Both estimation methods are unbiased and are asymptotically equivalent.

Simultaneous estimations are also assessed based on estimation procedures. If each equation has the same explanatory variables, simultaneous estimation based on the covariance estimation «collapses» to single equation estimation, but this does not generally deal with simultaneous estimation based on the Aitken estimation.

Key words: Aitken estimation, covariance estimation, nutrient leaching, estimation methods, lysimeter experiments, nutrient leaching, regression models, replications, simultaneous estimation, time series.

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The aim of the Apelsvoll Cropping System Experiment at Toten in central South-east Norway is to compare and develope cropping systems for environmental impact, productivity, yield quality and economy. This article focuses on assessment of regression models and estimation methods to analyse environmental impact from nitrogen and other nutrients. Thus, the models to be assessed should be appropriate for analysing nitrogen and other nutrients such as, for example, phosphorus, potassium, calcium and magnesium.

The Apelsvoll experiment exemplifies how the proposed regression models and the estimation methods generally could be suited to a number of wide-ranging lysimeter experiments.

The Apelsvoll experiment combines a traditional experimental design and a system research approach. Six different cropping systems established as «model farms» representing the combination of

two crop production systems and three levels of farming intensity were used. In recent years there has been increased interest in the use of a system research approach (an increased trend at commercial farm level) to develop sustainable agricultural methods (Hani & Vereijken 1990; Vereijken & Royle 1989; Vereijken 1992; Anderson 1992; Robbins 1989).

Environmental impact in this article is comprehended as explaining the variability of leaching and concentration of nitrogen and other nutrients by cropping systems opposite climatic factors.

First we have the layout of the Apelsvoll Cropping System Experiment, where special attention is given to relationships that are are assumed important concerning regression analysis of leaching and concentration of nitrogen and other nutrients (hereafter denoted as analyses of nutrients). The intention is to construct a regression model that reflects the mechanisms of the process behind leaching and concentrations behind nutrients, in turn reflecting the interactions between nutrients, climatic factors and farming-related factors.

Concerning application of the proposed regression models, analyses of nitrogen based on data from the Apelsvoll cropping system experiment are executed and discussed in Eltun (1994).

B. Experimental layout

B.1. The Apelsvoll Cropping System Experimental layout

The experimental layout of the Apelsvoll Cropping System Experiment is described in Eltun (1994). In this article the framework of this layout is presented.

Each of six cropping systems is replicated once and is represented on two trial blocks or model farms of 0.18 ha randomly distributed within a 6 x 2 grid of 3.3 ha. The cropping systems represent the combination of two crop production systems - arable crop production without farmyard manure and forage crop production with farmyard manure - and three levels of farming intensity - conventional, integrated and ecological. Each model farm has eight rotation plots, such that all the crops in a particular rotation are present each year. The three levels of farming intensity represent differences in fertilization, soil tillage and plant protection.

Each model farm has a separate drainage system, from which leached water is measured continuously, and sampled monthly for total-N, nitrate-N and ammonium-N in proportion to the runoff. The surface runoff is measured in the same way. In correspondence with these measurements monthly observations of climatic factors, respectively precipitation, temperature and soil temperature, are carried on.

The measurement period for these analyses is October 1990-September 1994. Since there have only been minor changes in the agricultural management factors in these years, this is deemed a natural period for these analyses.

B.2. General experimental layout

In general, we assess regression models and the estimation method are assessed with the aim of analysing leaching and concentration of nutrients in a lysimeter experiment consisting of

- N cropping systems (or N crop rotation and fertilization plots)
- R replications
- T time period measurements for each cropping system and replication.

In order to explain the variability of the dependent variables (leaching and concentration of nutrients and eventually total leaching) the explanatory variables should be climatic variables (preci-

pitation, temperature and soil temperature) and variables related to types of farming (N-fertilization, manure, soil tillage, percentage green fields, etc.).

C. Assessment of regression models

Based on the above-mentioned general experimental layout and variables, regression analysis seems to be the most suitable method of analysing leaching and concentration of nutrients.

Firstly, a basic regression model is formulated, constituting the foundation for assessments of different estimation methods. Then the model is modified and extended depending on statistical assumptions, which reflect unequal relationships with regard to the experimental layout and the mechanisms behind nutrient leaching.

C.1 A general basic model

Concerning the above mentioned experimental layout, the periodic effects are understood as random. Where there are no replications the cropping systems can also be used as random effects. If the model includes effects of both cropping systems and replications, then using both as random effects becomes complicated. On the other hand we should be specially interested in the influence exerted by the cropping system units, rather than appreciating them as a sample from a population. They could then be comprehended as fixed effects by using dummies for the individual cropping system units. Therefore, as a general basic model we use cropping systems as fixed effects and replications and period-specific effects as random effects. But the structure of the model should be about the same if the cropping systems are used as random effects where there are no replications. We formulate the following basic model:

$$Y_{rt}=\alpha_0+\alpha_2 D_2+\ldots+\alpha_N D_N+\tau_1 Z_{1rt}+\ldots+\tau_K Z_{Krt}+\epsilon_{rt} \quad r=1,\ldots,R \quad t=1,\ldots,T \qquad (1)$$

$$\epsilon_{rt}=U_r+V_t+W_{rt}, \qquad (2)$$

where the variables are defined as follows:

Y_{rt}: Nutrient leaching or concentration or total leaching in replication r and period t.

D_i: Dummy variable for cropping system i; i.e $D_i=1$ if cropping system i, else 0 (i=2,..,N). N-1 dummies are used for N cropping systems units.

Z_{krt}: Independent variable k (a climatic variable or farming-related variable) in replication r and period t. k=1,...,K.

The three component model for the error term represents the following effects:

U_r: The replication specific-effect.

V_t: The periodic specific-effect.

W_{rt}: The remaining effects, neither replication nor periodic specific effect.

We assume that the error components U_r, V_t and W_{rt} have zero means, are independent of each other and

$$EU_rU_{r'}=\sigma_v^2 \text{ for } r=r' \text{ and } 0 \text{ for } r\neq r'$$

$$EV_tV_{t'}=\sigma_v^2 \text{for } t=t' \text{ and } 0 \text{ for } t\neq t' \qquad (3)$$

$$EW_{rt}W_{r't'}=\sigma_w^2 \text{ for } r=r' \text{ and } t=t' \text{ and } 0 \text{ for } r\neq r' \text{or } t\neq t'.$$

yielding

$$\text{Var}(\epsilon_{rt})=\sigma^2=\sigma_u^2+\sigma_v^2+\sigma_w^2 \qquad (4)$$

On matrix form we write the model (1)-(3) as

$$Y=R\alpha+Z\tau+\epsilon=X\beta+\epsilon \qquad (5)$$

where $X=R+Z$, $\beta=(\alpha', \tau')'$ and

$$Y=(Y_{11},Y_{12},\ldots,Y_{1T},\ldots,Y_{R1},\ldots,Y_{RT})'$$

$$Z=\begin{vmatrix} Z_{1,11} & \cdots & Z_{K,11} \\ Z_{1,12} & \cdots & Z_{K,12} \\ \vdots & & \vdots \\ Z_{1,1T} & & Z_{K,1T} \\ \vdots & & \vdots \\ Z_{1,R1} & & Z_{K,R1} \\ \vdots & & \vdots \\ Z_{1,RT} & & Z_{K,RT} \end{vmatrix}$$

R is a matrix of ones and zeros reflecting the constant terms and the dummies for the cropping system units.

$\alpha=(\alpha_0,\alpha_1,...,\alpha_N)'$
$\tau=(\tau_1,...,\tau_K)'$

$\in=(U+V+W)$
$=(U_1+V_1+W_{11}, U_1+V_2+W_{12},...,U_1+V_T+W_{1T},...,U_R+V_1+W_{R1},...,U_R+V_T+W_{RT})'$ (6)

C.2. Assessment of estimation methods

Assessments of the different estimation methods are described, but for an analytical and more detailed presentation, see the given references.

The structure of the components of the error term $\in$ in (3), leads to a violation of the standard assumptions of the ordinary least squares (OLS) regression. In fact OLS, applied on a model with cross-section (the replications are the cross-section in this case) combined with time series have unbounded asymptotic variances. See Wallace (1969).

The covariance estimators

The idea behind the covariance estimators is to find a transformation matrix Q, which when applied to the model (5), «sweeps out» the replication-specific effect and the periodic-specific effect.

$$QY=QX\beta+Qw \qquad (7)$$

where we have taken it that
$Q(\in)=Q(U+V+W)=Q(W)$.

It can be shown that $Q=I_{RT}-(1/T)A+(1/R)B+(1/RT)J_{RT}$, where I_{RT} is the RTxRT identity matrix and J_{NT} is the RTxRT matrix of ones. Furthermore, $A=I_N \oplus J_T$ and $B=J_N \oplus I_T$, where $\oplus$ is the Kronecker product.

Applying the OLS procedure to the transformed model (7) gives the covariance estimator of β

$b=(X'Q'QX)^{-1}X'Q'QY=(X'QX)^{-1}XQY$ (8)

where we have assumed that the covariance matrix Q is idempotent; i.e that $Q=Q'$ and $Q^2=Q$.

It may readily be seen that b is unbiased.

The deduction of the covariance estimation method is presented in detail in Wallace (1969).

The Aitken procedure estimation

The Aitken procedure estimation is a generalized least squares estimation based on a two-stage procedure. In the first stage the estimator of â is expressed by the inverse of the covariance matrix Ó of the error term å. Then unknown parameters in this inverse covariance matrix $Ó^{-1}$ are replaced by estimates.

The Aitken procedure estimation can be used to obtain the efficient estimates of â as

$$\beta=(X'\Sigma^{-1}X)^{-1}(X'\Sigma^{-1}Y) \qquad (9)$$

The problem is to obtain Σ^{-1}. This is solved by trial, error and generalization in Wallace (1969). However, in Nerlove (1971) Σ^{-1} is derived analytically, and this method is used by Avery (1977).

The covariance matrix contains the parameters

$$\rho_U = \frac{\sigma_u^2}{\sigma^2} \quad \rho_V = \frac{\sigma_v^2}{\sigma^2} \quad \sigma^2$$

These parameters as they enter into Σ^{-1}, are then replaced by estimates that obtain the efficient estimates of β as

$$\beta = (X'\Sigma^{-1}X)^{-1}(X'\Sigma^{-1}Y) \quad (11)$$

where is Σ^{-1} replaced by estimates of the parameters in (10).

It can be shown that both the covariance estimators and the Aitken estimators are unbiased and are asymptotically equivalent. However, the Aitken estimators are more efficient in small samples. On the other hand, the covariance estimator is more readily obtained, since no iterative estimation is required.

Simultaneous estimation

Since leaching and concentration of a nutrient and total leaching are probably correlated, they should be estimated simultaneously. Nitrogen leaching and concentration of nitrate-N and ammonium-N along with total leaching should be estimated simultaneously.

Instead of the single equation (5) we postulate a set of J linear equations:

$$Y_1 = X_1\beta_1 + \epsilon_1$$
$$\vdots \quad (12)$$
$$Y_j = X_j\beta_j + \epsilon_j$$

where Y_j, X_j, β_j and ϵ_j are defined analogously to their counterparts in (5). The equations, however, need not have the same explanatory variables. Thus, K_j is the number of independent variables in the jth equation. In a simultaneous estimation, experiment Y_1, Y_2 and Y_3 may denote leaching and concentration of a nutrient and total leaching respectively

Simultaneous estimation based on covariance estimation

The set of equations should be estimated using the following two-stage procedure:

Stage 1: Transform each single equation in (12) by the same transformation matrix Q, which «sweeps» out all the error components with the exception of the components of W_j.

$$QY_1 = QX_1\beta_1 + Q(W_1)$$
$$\vdots \quad (13)$$
$$QY_j = QX_j\beta_j + Q(W_j)$$

Stage 2: Estimate the set (13) of transformed equations by seemingly unrelated estimation.

Simultaneous estimation based on the Aitken estimation procedure

We let the error term of the rt observation of the j equation be defined as before

$$\epsilon_{jrt} = U_{jr} + V_{jt} + W_{jrt} \quad (14)$$

with variance

$$E(\epsilon_{jrt}\epsilon_{jrt}) = \sigma_{jj}^2 = \sigma_{Ujj}^2 + \sigma_{Vjj}^2 + \sigma_{Wjj}^2 \quad (15)$$

It is reasonable to assume that the covariance between error terms for two observations defined for two equations can be written as

$$E(\epsilon_{jrt}\epsilon_{j'rt}) = \sigma_{jj'}^2 = \sigma_{Ujj'}^2 + \sigma_{Vjj'}^2 + \sigma_{Wjj'}^2 \quad (16)$$

We observe that the covariance structure between two equa-tions is the same as that within an equation.

We write the set of equations in (12) in compact form as

$$Y = X\beta + \epsilon \quad (17)$$

where

$Y=(Y_1',....,Y_J')'$, $\beta=(\beta_1',...,\beta_J')'$, $\in=(\in_1',...,\in_J')$ and

$$X=\begin{vmatrix} X_1 & & 0 \\ & \ddots & \\ 0 & & X_J \end{vmatrix}$$

The variance-covariance matrix of the whole system can be written as

$$\Omega=\begin{vmatrix} \sigma_{11}^2\Sigma_{11} & \cdots & \sigma_{1J}^2\Sigma_{1J} \\ \vdots & & \vdots \\ \sigma_{J1}^2\Sigma_{J1} & \cdots & \sigma_{JJ}^2\Sigma_{JJ} \end{vmatrix} \qquad (18)$$

Then the Aitken estimators of regression parameters β of the entire system are

$$\beta=(X'\Omega^{-1}X)^{-1}X'\Omega^{-1}Y \qquad (19)$$

As in single equation estimation, the parameters in Ω^{-1} are replaced by estimates obtaining the efficient estimates of β as

$$\beta=(X'\Omega^{-1}X)^{-1}X'\Omega^{-1}Y \qquad (20)$$

where Ω^{-1} is Ω^{-1} replaced by estimates of the unknown parameters.

Simultaneous estimation in the case of the same explanatory variables in each equation

If each single equation in the set (13) of equations has the same explanatory variables, then $X_1=...=X_J=X$, and the set (12) can be written as

$$\begin{aligned} Y_1&=X\beta_1+\in_1 \\ Y_J&=X\beta_J+\in_J \end{aligned} \qquad (21)$$

If the simultaneous estimation is based on the covariance estimation, the simultaneous estimation of the transformed set (21) «collapses» to single by single equation estimation.However, in the Aitken estimation procedure, the simultaneous estimation generally does not «collapse» to single by single equation estimation. This is unlike the standard, seemingly unrelated, regression problem (where the error term does not include components), where the coefficient estimates in general equal single equation estimates, when each equation has the same explanatory variables (see Avery 1977).

In Eltun & Fugleberg (1996) the same explanatory variables are used in regression equations of leaching and concentration of nitrate-N and ammonium-N, and dummies are used for effects of the cropping systems. Consequently, these forms of nitrogen are estimated by single equation estimation.

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Factors affecting determination of selenium in biological materials by using HG-AAS

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A dry ash digestion method was employed for determination of selenium in reference materials and fish flesh with $Mg(NO_3)_2 \cdot 6H_2O$ and 69% HNO_3. The sample solutions were heated to dryness, and ashed, prepared by dissolving dry ash in 6 M HCl on a hot plate and then analyzed using HG-AAS. Selenate was reduced to selenite by heating at 80°C for 1 h. Different concentrations of hydrochloric acid in the final solution were tested. The results indicated that a high concentration of acid tends to suppress the absorption signal. The sample size, the time of digestion, and the temperature program were also critical factors.

Key words: Selenium, Hcl concentration, biological materials.

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In recent years selenium has received increased attention. The chemical properties of selenium can be reassembled as -II, 0, +II, +IV, and +VI. With the exception of +II, all the oxidation states are commonly found in nature (Wang 1994). The usual concentration of selenium in plants is about 0.1-0.5 µg/g (Campbell 1984) and 0.1 µg/g in earth crust (Toei & Shimoshi 1981). There is sufficient evidence today to support the assumption that selenium may have a beneficial effect on the growth of plants, and, depending on concentration level, it is both an essential and a toxic trace element for animal and man (Raptis et al. 1983).

Because only extremely low concentrations of selenium exist in nature, reliable methods are needed for determination of this element. Robberecht & Grieken (1982) have described various methods of determination of selenium. Hydride-generation atomic absorption spectrophotometry for determination of selenium is one of the most sensitive methods (Campbell 1992, Fcorino et al. 1976, Ihnat & Miller 1977a). It has been reported that high concentrations of nitric, sulfuric, and perchloric acid can suppress the absorption signals and result in a significant reduction in sensitivity (Tinggi et al. 1992, Ihnat 1976).

A review of the literature indicated that quantitative recovery of endogenous selenium from biological materials using open system dry ashing with $Mg(NO_3)_2$ has been revealed for both NBS bovine

liver and fish tissue (Pettersson et al. 1986). The dry ashing method appears simple, safe and is less variable compared with a method using perchloric acid. Several reports have been published on the determination of selenium in biological samples by using the dry ashed method (May 1982, Tam & Lacroix 1982, Brumbaugh & Walther 1989). Mechanical aspects of hydride generation are important considerations for optimum performance (Ihnat & Miller 1977a).

The digestion procedure for determination of selenium in biological materials is a key factor compared with analysis facilities. This factor includes digestion time and temperature (Campbell 1984, Mailer & Pratley 1983) and also sample size. The choice of digestion method is highly dependent on sample type (Pettersson et al. 1986). The concentration of HCl plays a critical role in the determination of selenium by using HG-AAS. Increasing acid concentrations in the solution resulted in a decrease in absorbance signal by a batch type method. Low concentrations of acid give lower reproducibility due to incomplete reduction by sodium borohydrate (Julshamn et al. 1982). However, higher concentrations of acid in the final solution suppress the signal owing to reactions with other foreign ions.

The aim of this study was to investigate both the reliability of a dry ash digestion method for the determination of selenium in biological materials and the various factors influencing the determination.

Material and methods

Apparatus

1. Spectrophotometer: Perkin-Elmer Model 400.
2. Hydride generation: Varina VGA-76.
3. Inert gas supply: Ar, 340 KPa.
4. Muffle furnace: Heraeus Mr170.
5. Hot plate: Ori-Block 08-3H.

Reagents

1. Nitric acid: Reagent grade, 70-72%.
2. Hydrochloric acid: Reagent grade, 37%.
3. Magnesium nitrate hexahydrate: Reagent grade, (purity>97.0%).
4. Magnesium nitrate solution: Prepared for every analysis by dissolving 80 g $Mg(NO_3)_2 \cdot 6H_2O$ in 200 ml deionized water.
5. Sodium borohydride: A solution of 0.6% w/v of $NaBH_4$ was prepared for every analysis by dissolving 3 g $NaBH_4$ and 2.5 g NaOH in 500 ml flask with deionized water.
6. Selenium standard solution: (1) Stock solution -- 1000 mg/l, 1.000 g Se was dissolved in HCl (2 M) and diluted to 1 L with deionized water. (2) Selenium standard solutions -- 4.0, 8.0, 20.0 and 40.0 ìg/l.

Sample digestion

About 0.5 g bovine liver, 0.2-0.5 g cod and 2 g fish flesh were accurately weighted into quartz crucibles. Ten milliliters nitric acid and 10 ml 40% (w/v) magnesium nitrate hexahydrate were added to each sample. The samples were covered with the watch glasses, placed on a hot plate, and kept at different temperatures (60-110°C) for 6-18 h. The temperature was then increased to about 200°C, and the watch glass tipped to speed evaporation. The dried samples were then transferred to a cold muffle furnace, ramp temperature set to 500°C over 4 h, and kept there for 2-4h, after which the samples were cooled to room tempera-ture.

Reduction of Se(VI) to Se(IV)

Twenty milliliters 6 M HCl was added to the digested samples. The watch glasses were replaced and the samples were gently boiled for 1 h on a hot plate until the ashed residues were solubilized. The digested solutions were quantitatively transferred to the 25 ml volumetric flask and diluted to volume with deionized water. Finally, the solutions were transferred to the conventional polyethylene bottle and kept at +4°C in the dark.

Determination

The setting up of the spectrophotometer was done in accordance with the manufacturer's recommendations and the burner position was optimized for maximum sensitivity. Hydride generation apparatuses were installed and the rates of reductant, acid and samples by bumping system were adjusted. Instrumental conditions are presented in Table 1.

A 10 ml sample solution was pipetted into a test tube and solutions of 10 ml HCl with different concentrations of 10 M, 6 M, 3 M were added respectively. The solutions were heated in an oven at 80°C for 1 h to form Se(IV) state for determination and then cooled to room temperature.

Standard solutions of 0, 4, 8, 20, and 40 ìg/g Se were pipetted into test tubes. Standards were treated in the same manner as the samples. Concentrations of selenium were calculated using the standard curve.

Results and discussions

Effects of acid

The effect of hydrochloric acid concentration on the Se determination value is shown in Table 2. It is clear that a high concentration of hydrochloric acid has a suppression effect on the determination of selenium by using HG-AAS. The analytical results show that the absorption signal was reduced by 20% in the 6 M HCl final sample solution compared with 4.5 M. There were two different HCl concentrations in our study. The acid which was used for the reduction of

Table 1. Instrumental conditions

Instrument model	Absorbance
Calibration model	Concentration
Measurement model	Integration
Lamp current (mA)	10
Slit width (mn)	1.0
Slit height	normal
Wavelength (nm)	196.0
Delay time (s)	40
Time constant	0.05
Measurement time	10.0
Replicates	2
Background correction	on
Purge gas, pressure	Ar, 325 kpa
Reductant	0.6% $NaBH_4$; 0.5% NaOH
Acid	10M HCl
Flame	Air-acetylene

Table 2. Effect of different concentrations of hydrochloric acid on recovery of selenium

Materials[a]	Se concentration (µg/g) Hydrochloric acid concentration (Mol/l) 3.0	4.5	6.0	8.0	Certified value
Bovine liver[b]	0.667±0.001	0.674±0.032	0.531±0.075	0.347±0.110	0.71± 0.07
Cod[c]	1.420±0.002	1.675±0.028	1.179±0.084	0.663±0.102	1.63± 0.07
Fish flesh	0.148±0.005	0.152±0.012	0.130±0.016	0.071±0.012	

a: No. of samples used was 6 for each material. b: BNS1577a c: CRM244

Se(VI) to Se(IV) was 6 M. The other concentrations of HCl were 3.0, 4.5, 6.0, and 8.0 M in the final sample solution respectively.

The concentration of HCl in the final solution was the main factor affecting the determination of selenium by using hydride generation. The highest value of Se was found in 4.5 M HCl and the lowest in 8 M.

The low recovery of selenium in sample solutions with a high HCl concentration may be explained by a reaction between strong acid and other foreign ions. Selenium hydrogen (SeH_2) is usually produced by reducing Se(IV) with borohydride ($NaBH_4$) in hydrochloric acid solution. The SeH_2 formed can readily be evaporated from the solution with an inert gas (N_2) and transferred to a heated quartz cuvette for atomization. The interference occurs from frequently used quartz cells that were contaminated by sample components or excess sample concentrations of hydride-forming elements. These elements may form a layer on the cuvette surface even after only one measurement (Mayer et al. 1992) and will be reacted by hydrogen selenite in a high HCl concentration. The interference effects of ions under high acidity must be taken into consideration when using hydride generation.

It is necessary to distinguish between the HCl concentrations when carrying out a reduction of Se(VI) to Se(IV) and in the final sample solution. Several reports revealed that the presence of 6 M HCl at about 80°C for 30 min can effectively reduce Se(VI) to Se(IV) (Reamer & Veillon 1981, Micheal Siu & Berman 1984, Hocquellet & Candillier 1991). However, when using such concentrations for the determination of selenium, a suppression effect will be observed.

Effect of sample size

The recovery of Se in reference material was reduced from 1.681 to 1.36 :g/g Se when the samples were weighted from 0.2004 to 0.400 g material. Large amounts of sample material may cause incomplete destruction of organic matter, and thus result in poor recovery of selenium. We studied different amounts of certified cod (CRM) samples. The volume of the sample used in the hydride generation is a critical factor. The result indicates that about 8 mg/ml cod samples (dry weight basis) gives a good recovery of selenium.

Detection limits included are usually of two types: method detection limits and instrumental detection limits. The limit of detection for sensitivity in HG-AAS analysis is reported to be < 1.0-10 ng/ml (Tölg 1984), and 0.02 ng/mg (Mayer et al. 1992) in batch type. This requires that the operator has to pay attention to sample size. In addition, a large amount of sample material increases the possibility of a loss during the dry ash procedure.

Effects of digesting temperature

In analysis of biological materials the digesting temperature has an impact on the recovery of selenium directly. The temperature effect in digesting fish flesh is shown in Fig. 1. The residue takes on a somewhat light yellow appearance in dried samples and a white puffy "cake" character in the final products. When the evaporation temperature is kept low, the material contains a red green gas, which results in low recovery of selenium. By contrast, a high temperature leads to severe bumbling, particularly foward the end of the drying procedure, which causes a physical loss of samples. Great care has to be taken to prevent excessive foaming.

It is suggested that when drying biological materials optimal temperatures should be 100°C for digestion, 120°C-250°C for drying, and 500°C for ashing in a muffle furnace.

From the temperature effect study we stress that in the destruction of biological materials, a high temperature is needed in order to decompose organic matter, particularly organic matter containing fat. Very acid-resistant organoselenium compounds are often not fully decomposed, thus resulting in low recovery (Welz & Melcher 1985, Hansson et al.1989). When we digested NBS reference materials using the optimized procedure, the values agreed closely with those of the certified value. In this heating program, no charring was found. In order to remove nitric acid from the digested solution, the samples should be heated to complete dryness.

Effect of digesting time

The effect of digestion time on recovery of Se in fish flesh is shown in Fig. 2. It is obvious that the digestion time is also an important factor in the determination of selenium. The results show that digesting the sample for 18 h at 100°C gives the highest value of selenium content. When the digestion time was less than 12 h, the recovery of Se was low due to incomplete destruction of biological material. In addition, it was found that an incompletely digested sample heated in a muffle furnace will cause charring.

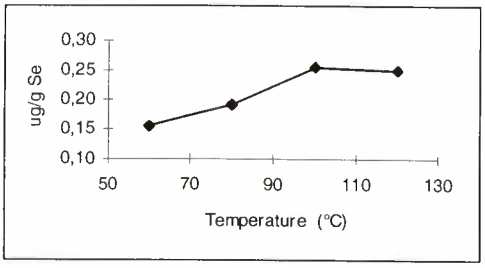

Fig. 1. Effect of digesting temperature for 18 h

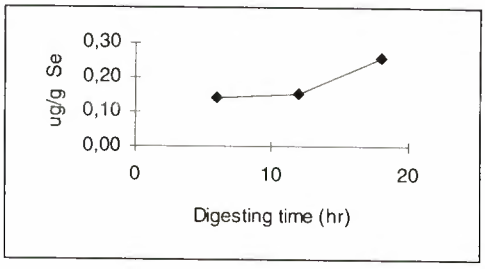

Fig. 2. Effect of digesting time at 100°C

The digestion time is dependent on the temperature program, reflex condensers and volume of the digesting solution. A literature survey revealed few references that report the time factor. Many analytical methods used in the determination of selenium in biological materials assume complete destruction of the organic constituent.

Our results indicate that the digestion time influences the analysis accuracy due to the degree of decomposition of the biological material. An incompletely digested solution gives poor recovery of selenium (Verlinden 1982, Alfthan 1984). On the other hand, an over-digestion program consumes time and indeed, may cause contamination. The possibility of contamination by dust in the laboratory environment has to be considered when using an open system (Galgan & Frank 1993). When we used the optimal time, i.e. 18 h at 100°C, for digestion of reference materials, the values closely agreed with the certified value.

Acknowledgments

The authors express their gratitude to Professor Martin Lodenius for his suggestions and patient guidance.

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Selection response for dry matter yield in white clover (*Trifolium repens* L.) using different selection methods

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The between and within population variations for primary and secondary quantitative characters were studied among some 90 local populations of white clover (*T. repens*). Thereafter, four different selection methods were compared in order to select the most valuable populations for dry matter (DM) yield. In the initial screening method (S1), the observed phenotypic values and their economic weights of the following five characters were used: winter hardiness 0.2, plant height 0.1, leaf length 0.1, flower density 0.1, and DM yield 0.5. However, a method (S2) using heritabilities, in addition to the observed values and their economic weights, for only the two secondary characters winter hardiness and plant height, and a method (I2) using also the phenotypic correlation between DM yield and the two secondary characters, showed the best correlation with the observed gain for fodder yield in the official variety test.

Key words: Selection methods, white clover.

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White clover (*Trifolium repens L.*) is one of a few herbage plants adapted to northern areas that are able to produce protein using nitrogen from the air in association with the N-fixing bacteria *Rhizobium trifolii*. In the coming years, white clover may be of great importance in producing low-cost protein for animals in a sustainable way.

The varieties of white clover on the market today are, however, not winter hardy enough for fodder production based on perennial crops in most parts of Norway. In the climatically more favourable areas of Norway foreign varieties can be used.

Following the use of foreign white clover varieties over a long period of time, a genetic adaptation among genotypes within populations to different regions of Norway has taken place. Some of the populations may be native. Thus the adapted differences among populations today are primarily a result of a natural selection for winter survival, and secondly, a genetic drift between populations in interaction with the environment. It was therefore of interest to collect local populations from the main districts of Norway as a base for our breeding.

The breeding programme reported upon here was started in 1987 with some 90 local populations collected throughout the country.

The aim of the programme is to develop varieties with a stable dry matter production, good fodder quality, and good seed production. To reach this goal, the ability to survive the winter is a decisive factor. However, breeding and testing programmes in other plant species have revealed that it is difficult to combine good winter hardiness and high production potential (Andersen 1971). It may also be difficult to combine high production potential and good seed maturity in northern areas with a short summer (Flovik 1942; Østgård 1976).

For the breeding process, the problem is to find a procedure that in the shortest possible time leads to a desirable combination of primary and secondary characters.

Material and methods

Plant material and characters

Geographic origin and designation of local populations, following a collection scheme introduced by Schjelderup (1973), and extended by Marum (1981), are presented in Table 1. For each population, seeds of 50-100 different plants were collected and sown in a greenhouse. The Danish variety Milkanova was used as a reference population. After germination, 50 seedlings were sampled from each population, and planted in «jiffypots» for a preculture. The 50 genotypes were cloned, and 25 clones were planted 20 cm x 30 cm apart into plots. The plots were randomly distributed within two replications in open field trials at Holt Research Centre (69°N, 19°E) and Apelsvoll Research Centre (60°N, 11°E) in June 1988.

The following characters were observed at Holt (1989 and 1990) and Apelsvoll (1989): Winter hardiness, plant height, leaf length, and flower density. The dry matter production (DM yield) was observed for one year in both locations. Flower density was used as an indicator for the seed production capacity. Chemical analyses, using the NIRS (Marum 1990) and the Kjeldahl-N methods, were carried out for all populations at Holt in

Table 1. Collected local populations of white clover

District no.	County	Population nos.	District no.	County	Population nos.
01	Finnmark, Troms	1-12	07	Sogn & Fjordane, Hordaland, Rogaland, Vest-Agder	71-78
02	Nordland	13-24			
05	Trøndelag, Møre og Romsdal	25-34 36-40 86-90	08	Aust-Agder, Telemark (coast)	79-80
			09	Hedmark (south), Vestfold, Oslo, Akershus, Østfold	81-85
06	Hedmark (north) Oppland, Buskerud, Telemark (inland)	41-70			

No. 35 is Milkanova.

1990. Further descriptions of characters and observation procedures can be found in Table 2.

To estimate the population heritability for plant height, the observations on two replications over two years at Holt were used. To estimate the population heritability for winter hardiness, a total of four different observations on two replications after three winters at Holt (1989-91) and one winter at Apelsvoll (1989) were used. For the other characters, there were insufficient observations on replications to estimate acceptable heritabilities.

Construction of selection indices

In order to study the use of index selection and the use of secondary characters in indirect selection for the primary character DM yield, four different methods were compared.

The first procedure, which seeks to combine several characters including DM yield, is a simple one, using the phenotype observed combined with an «economic» value in a total score (S1). In the second procedure, the phenotype observed, its heritability and «economic» value are used indirectly on two secondary characters to fodder yield in a total score (S2). In the third and fourth procedures, the phenotype observed, its heritability and «economic» value, and the correlation between the secondary characters and DM yield are used indirectly in an index for one (I1) and for two (I2) secondary character(s), (see Table 3).

The economic values used in this material do not have the same import as the economic values used in animal breeding, where such values are based primarily on the price of products of each character on the market. In fodder crop breeding, the economic values are based on several factors, and are therefore more difficult to determine.

In the present study, the economic values are based, first, on the value that each character is expected to have on DM yield; second, on the effect that the characters (for example the content of protein and ash) are expected to have on the production of milk and meat; and, third, on the value of the seed production.

According to the field plot design mentioned above, the model for the analysis of variance was as follows:

$$Y_{ijk} = y + g_i + r_j + e_{ijk},$$

where:

y is the general mean,

Table 2. Description of characters

Character	Abbreviation	No.	Observation description
Winter hardiness	WH	X1	surviving plants, 0-100 %/plot
Plant height	PH	X2	cm of 15 genotypes/plot
Leaf length	LL	X3	mm of mid-leaflet, 15 plants/plot
Flower density	FD	X4	0 - 9 scale/plot
Dry matter yield	DM	X5	kg dry matter yield/plot
Crude fibre	Cf	(x3)	% of dry matter
Ash	Ash	(x3)	% of dry matter
Kjeldahl-N	KN	(x3)	% of dry matter

g_i is the effect of the i-th genotype (assumed to be normally distributed with a variance of Vg), r_j is the effect of the j-th replication, and e_{ijk} is the experimental error (assumed to be normally distributed with a variance of V_e).

The broad sense heritability (h_b^2) of characters is the ratio of genetic variance (Vg) to phenotypic variance (Vg + Ve):

$$h_b^2 = Vg/(Vg + Ve).$$

According to Falconer (1970) an index («H») using two characters, x, primary and y, secondary (in «indirect» selection) may be represented by the equation:

$$H = Ax + wAy,$$

where A = b Ap P = the breeding value of the character, and w is an additional value («economic» value) of the secondary character y related to the primary one x.

Furthermore, b Ap is the regression coefficient (b) of the genetic variance (Vg) on the phenotypic variance (Vg + Ve), which is similar to the heritability, and P is the phenotypic observed value of the character.

If working with parent-offspring material, the heritabilities and the phenotypic and genotypic correlation between characters are based on co-variance/variance analyses, as used for example in studies of timothy by Aastveit, A. H. (1988). In the present material, however, the estimation of heritability and the calculation of correlation coefficients are based on cloned material. The phenotypic correlation between the primary character (DM yield) and the secondary characters (winter hardiness and plant height) is calculated using the observed phenotypic values, because the observed DM yield did not have replications of genotypes to evaluate the environmental factor.

When using two secondary characters in the present material, an «economic» value Q is ascribed to both (equations 2 and 4 below). A similar model is used in a selection index for breeding Christmas trees (Arnold et al. 1994, a, b). In addition, a phenotypic correlation between the primary character DM yield and the two secondary characters are calculated for the index I2 (equation 4).

The four procedures of selection in the present material are described according to the following equations:

1. Score S1 = X1 Q1 + X2 Q2 + ...+ X5 Q5 = score when using five characters

Table 3. Economic weights for characters used in selection methods S1, S2, I1, I2, and S12

Method	WH Q1	PH Q2	LL Q3	FD Q4	DM Q5	Cf (q3)	Ash (q3)	KN (q3)
S1	0.2	0.1	0.1	0.1	0.5			
S2	0.5	0.5						
I1	1.0							
I2	0.5	0.5						
S12	0.2	0.1	——	0.1	0.5	0.02	0.03	0.05

Q3 used for LL in S1 is substituted with q3 for Cf, Ash, and KN in S12.

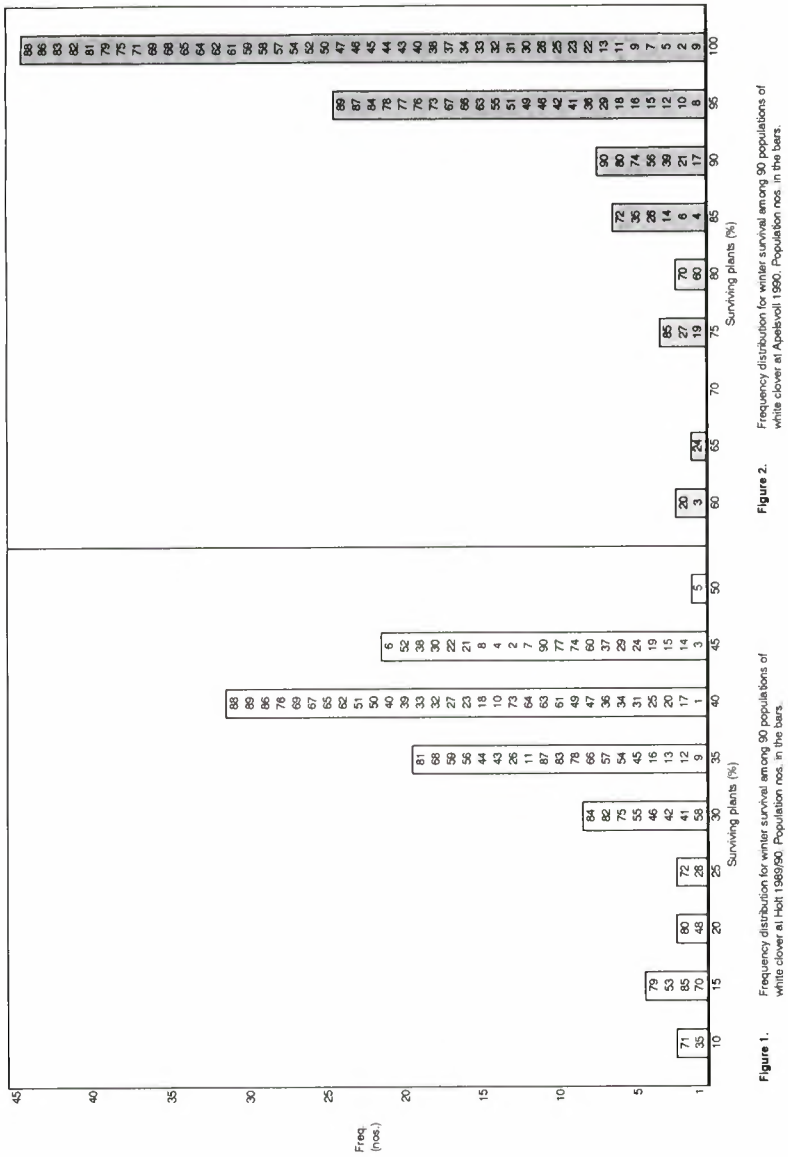

Figure 1. Frequency distribution for winter survival among 90 populations of white clover at Holt 1989/90. Population nos. in the bars.

Figure 2. Frequency distribution for winter survival among 90 populations of white clover at Apelsvoll 1990. Population nos. in the bars.

including the DM yield.

2. Score S2 = (X1 Q1 h1) + (X2 Q2 h2) = score when using two secondary characters.
3. Score I1 = (X1 Q1 h1) rpx1x5 = index when using one secondary character.
4. Score I2 = ((X1Q1h1)rpx1x5 + (X2Q2h2)rpx2x5 = index when using two secondary characters, where:

X1 - X5 are the phenotypic values of characters 1 to 5,

Q1 - Q5 are the «economic» values of characters 1 to 5, h1 and h2 are the broad-sense heritability of characters 1 and 2,

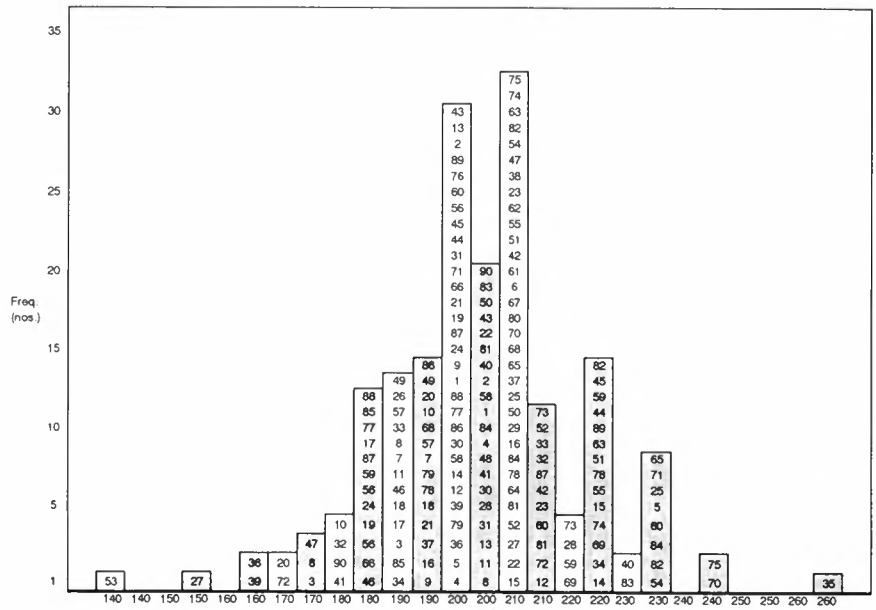

Figure 3. Frequency distribution for plant height among 90 populations of white clover at Holt 1989/90 (white bars) and at Apelsvoll 1990 (grey bars). Population nos. in the bars.

and rpx1x5 and rpx2x5 are the phenotypic correlations between the two secondary characters winter hardiness (X1) and plant height (X2), respectively, and the primary character DM yield (X5).

The «economic» values for the characters used in S1, S2, I1, I2, and S12 are presented in Table 3, in accordance with the selection procedures stated above. In an alternative score to S1 (the S12), leaf length was replaced with a secondary index score for fodder quality (see Table 3) as proposed by Aastveit, K. (1983a). This secondary score was calculated as the S1, but using chemical analyses of dry matter from all populations (Rapp 1993).

Based on these S1 and S12 scores, the first screening of the «best 10» populations was undertaken. The «top 6» of the 10 best selected populations and the reference variety Milkanova were then submitted for the official variety testing. Results from the first year of this testing have been used to compare the more practical related gain of the selection methods in the present material.

The initial screening was done to save time in the first part of the breeding programme. After a while, heritabilities and correlation coefficients were assessed for use in the different selection methods.

Statistical analyses and graphs were produced using the NMSTAT program package (Nissen et al. 1993).

Results

Variation between populations

Frequency distribution among 90 populations, including the reference variety Milkanova (no. 35), for winter survival,

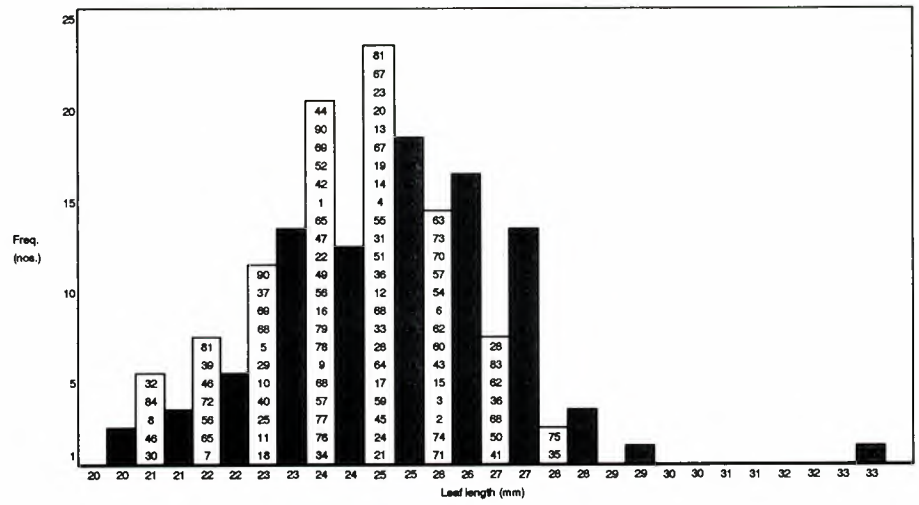

Figure 4. Frequency distribution for leaf length among 90 populations of white clover at Holt 1989/90 (white bars) and at Apelsvoll 1990 (grey bars). Population nos. in the bars.

plant height, leaf length, flower density, and DM yield at Holt (white bars) and Apelsvoll (grey bars) is presented in Figs 1-6, respectively.

For winter survival (Figs. 1, 2) it is shown that the climatic difference between Holt and Apelsvoll has resulted in a quite different distribution among populations at the two sites. At Holt (Fig. 1), populations from northern Norway are among the most winterhardy, whereas at Apelsvoll (Fig. 2), several populations from southern districts of Norway displayed a winter survival rate equal to that of populations from northern districts. At both sites, the Danish reference variety Milkanova (no. 35) was at the very lowest end of the scale.

For plant height, Fig. 3 demonstrates an approximately normal distribution among populations. Populations from the North and from marginal areas in the South were smallest and placed mostly to the left of the figure. However, the variety Milkanova was highest at Apelsvoll, and lowest at Holt. The reason is that the few surviving plants of Milkanova at Holt were very small throughout the whole summer.

For leaf length, too (Fig. 4), the distributions among populations are close to normal, and quite similar to those for plant height. Populations from southern districts generally have larger leaves compared with those from the North. However, some of the populations from marginal areas in the South also have small leaves. Many of the populations which are among the highest (Fig. 3) also have the largest leaves. Winter survival has therefore not greatly affected the leaf size, as seems to be the case for plant height. Milkanova has, for example, the largest leaves at both research locations.

Concerning flower production (Fig. 5), the distribution among populations does not differ markedly between the two research locations. At Apelsvoll, more than 50% of the populations had a flower density of 80-100%, while at Holt about

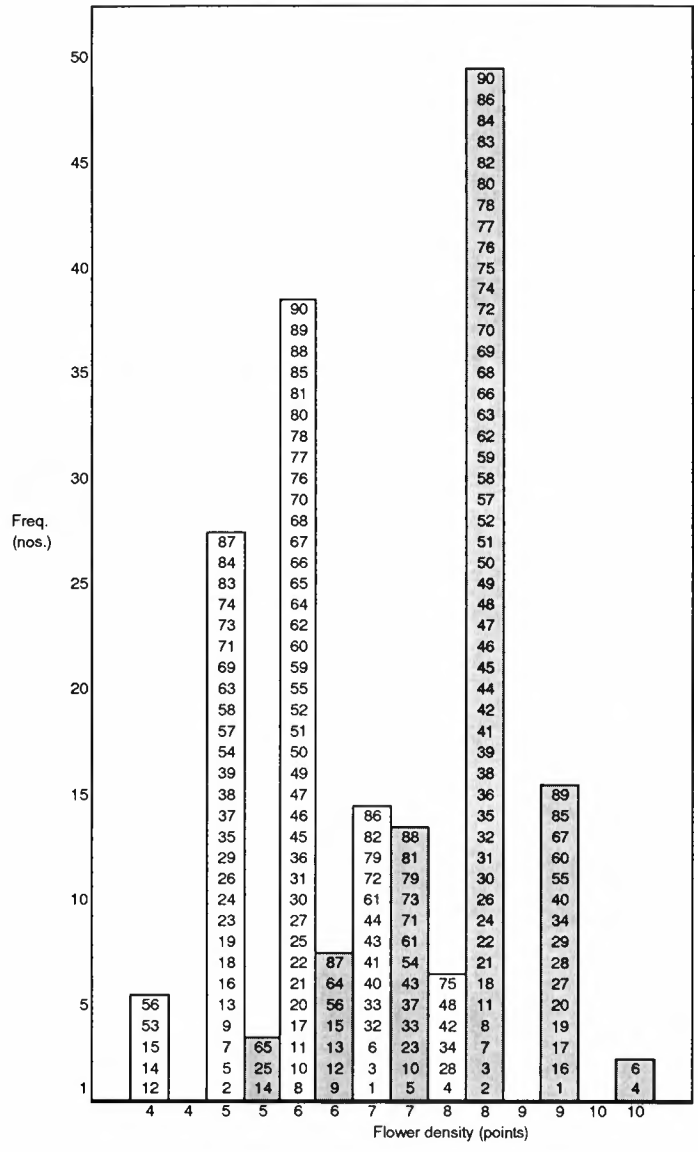

Figure 5. Frequency distribution for flower density (1-10) among 90 populations of white clover at Holt 1989/90 (white bars) and at Apelsvoll 1990 (grey bars). Population nos. in the bars.

25% of the populations had a flower density of 75-80%. However, northern populations were among the best flowering plants. For example, at Apelsvoll populations 04 and 06 from Finnmark were the best, while at Holt population no. 04 was among the five best.

For DM yield (Fig. 6) the distribution among populations was broader than for any of the other characters. DM yield is

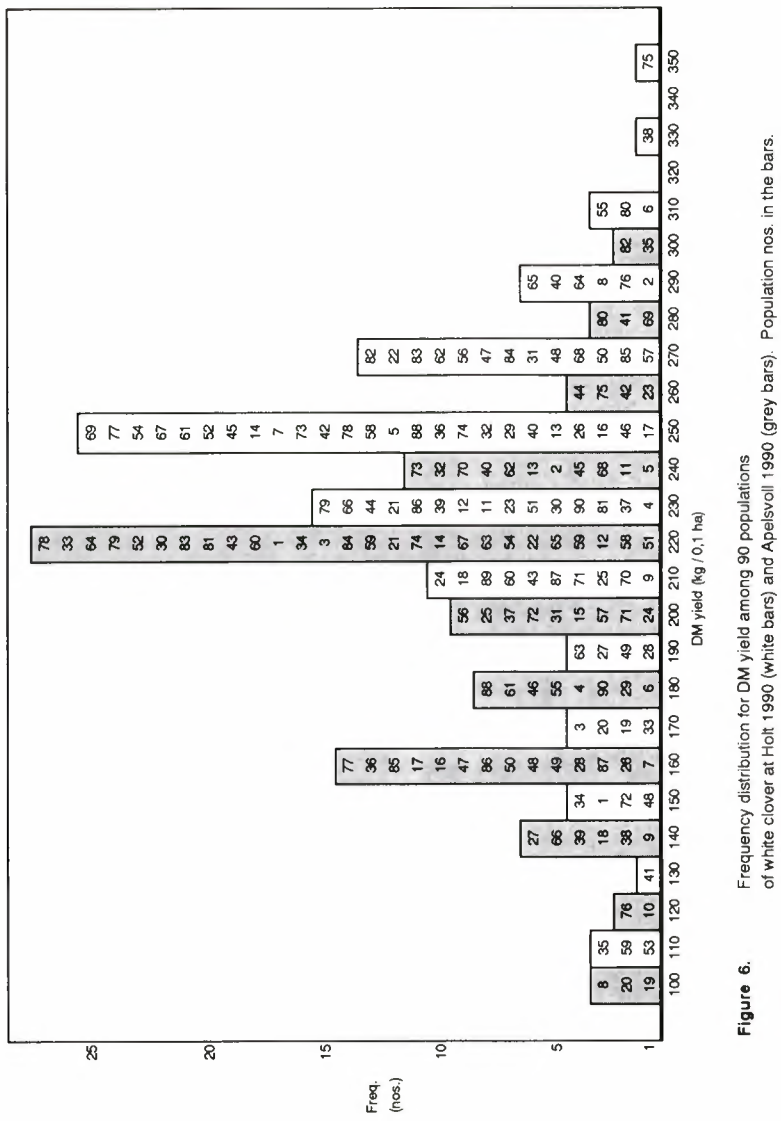

Figure 6. Frequency distribution for DM yield among 90 populations of white clover at Holt 1990 (white bars) and Apelsvoll 1990 (grey bars). Population nos. in the bars.

based on a complexity of other characters, and the distribution is therefore difficult to explain. One such secondary character for DM yield is, for example, winter hardiness. After some time, populations with a low winter survival will accumulate more weeds on the plots, often resulting in a high but incorrect DM yield, and therefore confounding the true yield and make the explanation difficult.

Selection using between- and within population variabilities

The variations in S1 scores, S2 scores, and the alternative S12 scores among 90 populations, mean of Holt and Apelsvoll, are presented in Table 4.

The variations in heritabilities for

Table 4. Variations in scores for selection methods S1, S2, and S12

Selection method	Mean score	Range of scores	Population ranking Lowest	Highest
S1	- 96 -	30 - 140	35,53,59,41,48,12	75,40,42, 6, 1,61,38
S2	- 54 -	0-90	58,35,85,64,53,71	77,88,7,18,37,40
S12	- 95 -	35 - 135	59,41,53,71,72,28	40,62,38,75,61,69

Table 5. Variations in heritability for winter hardiness (WH) and plant height (PH).

Character	Mean	Range	Population ranking Lowest	Highest
WH	0.6	0.1 - 0.9	59, 5, 8,58, 55,31	88, 3, 33, 87, 49, 80
PH	0.5	0.2 - 0.9	80, 35,64, 58, 53,43	38, 37, 77, 18, 30, 11

Table 6. Scores for S1 and S12, heritabilities (h^2) for winter hardiness (WH) and plant height (PH), scores for S2, correlation coefficients (rp) between DM yield and WH and DM yield and PH, and index scores for I1 and I2, among seven populations of white clover

Pop. nos.	Scores S1	S12	h^2 WH	PH	Scores S2	rp. between DM vs. WH	PH	Index I1	I2
6	119	124	0.27	0.78	104	0.50	0.66	48	64
22	107	105	0.66	0.76	127			49	76
38	127	119	0.60	0.85	156			57	121
40	138	131	0.92	0.67	174			49	125
62	128	115	0.77	0.57	149			36	102
75	125	140	0.83	0.24	69			17	47
35	40	79	0.66	0.75	81			44	51

winter hardiness and plant height among the 90 populations can be found in Table 5.

The scores for S1 and S2, the heritability for winter hardiness and plant height, the correlation coefficients between DM yield and winter hardiness and plant height, and the indices I1 and I2 of the six top-ranking populations and the variety Milkanova are presented in Table 6.

Results for winter survival and DM yield from the official variety testing in North- and South Norway for one year of the six top-ranking populations and Milkanova can be found in Table 7.

Finally, the correlation coefficients between scores of S1, S2, I1, and I2 (Table 6) and DM yield in North- and South Norway (Table 7) are recorded in Table 8.

Comments on the results

The «best 10» populations selected on the basis of the S1/S12 scores were ranked as follows: nos. 75, 40, 38, 06, 62, and 22 (with scores of 110-140), and nos. 50, 82, 83, and 86 (with scores of 105-110). The

Table 7.DM yield (kg/0.1 haa) and percentage of white clover from variety testing in North Norway (NN), + mountain districts (FJ), South Norway (SN) and means for the country among seven populations of white clover (Marum et al. 1995)

Pop. Nos.	DM Yield bto. NN	Fj	SN	Mean	DM Yield nto. NN	Fj	SN	Mean	Per cent white clover NN	Fj	SN
6	598	564	745	655	319	226	313	270	55	40	42
22	652	612	783	698	424	306	360	333	65	50	46
38	669	631	808	720	401	316	364	340	60	50	45
40	641	636	834	735	385	318	393	355	60	50	47
62	634	658	824	741	444	395	413	404	70	60	50
75	616	572	850	711	370	257	425	340	60	45	50
35	529	508	913	710	159	127	456	310	30	25	50
Lsd10%	84	63	61								

Table 8. Correlation coefficients between S1, S2, I1 and I2 (from the clone experiments) and DM yield (from the variety testing) among seven populations of white clover

	Selection scores				DM yield bto.				DM yield nto.			
	S1	S2	I1	I2	NN	Fj	SN	Mean	NN	Fj	SN	Mean
Y/X	2	4	5	6	7	8	9	10	11	12	13	14
2		0.45	-0.07	0.58	0.04	0.40	0.61	0.61	-0.03	0.03	0.46	0.42
4			0.71	0.97	0.66	0.85	0.08	0.56	0.48	0.68	-0.02	0.45
5				0.65	0.51	0.33	-0.56	-0.13	0.04	0.11	-0.69	-0.24
6					0.69	0.84	0.21	0.63	0.44	0.65	0.07	0.47
7						0.69	0.26	0.58	0.70	0.57	0.15	0.46
8							0.38	0.83	0.83	0.96	0.39	0.83
9								0.83	0.42	0.42	0.95	0.73
10									0.75	0.83	0.81	0.94
11										0.90	0.52	0.86
12											0.51	0.92
13												0.81
14												

first six populations mentioned are the «top 6», also submitted for the official variety testing. The last four populations were chosen also in order to obtain a better geographical distribution and a more diverse genetic pool among the material selected for further breeding. Instead of having many populations from Mid-Norway (districts 05 and 06), e.g. nos. 61, 64, 65 and 69 in addition to no. 62, and instead of nos. 73 and 77 in addition to no. 75 from West Norway (district 07), all of which were among the highest S1/S12 scores, nos. 50, 82, 83, and 86 from other districts were chosen.

Later on, population no. 22 was replaced with no. 16, while no. 06 was replaced with no. 02 from the same districts, in order to a give a higher priority to winter hardiness.

In the variation range of S2 scores (Table 4), several populations other than the «best 10» selected on the basis of S1/S12 are also among the highest scoring. However, taking into account the district moment used in the first screening, and that nos. 06 and 22 are replaced with nos. 02 and 16, the place in the ranking in S2 is acceptable, with the exception of population no. 75.

In the variation range of heritability for winter hardiness (Table 5) there were 11 populations from districts South of Trøndelag and Møre og Romsdal among the 30 populations with the highest heritabilities, and only one of the top six selected (the northern no. 40) is among these 30.

The «top 6» ranking populations using S1/S12, have the following ranking in S2 (Table 6): nos. 40 (174), 38 (156), 62 (14+9), 22 (127), 06 (104), and 75 (69). Population no. 75 from district 07 (West Norway), which had the highest S1/S12 scores, is among the lowest in S2 scores due to its weak winter survival at Holt.

In the I1 index (Table 6), using only the secondary character plant height, population no. 38 (57) is at the top, followed by populations 40, 22, 06, 62, and 75. Population no. 35 (Milkanova) has a relatively high score (44) because of its superior plant height at Apelsvoll.

In the I2 index (Table 6), populations 40 (125), 38 (121), and 62 (102) are at the top, followed by nos. 22 (76), 06 (64), and 75 (47). No. 35 (Milkanova) (51) is second lowest.

When studying the nto. DM yield from the variety testing in open field plots (Table 7), the ranking is: nos. 62 (404), 40, 75, 38, 22, 35, and 06. Populations 35 (465) and 75 (425) are the best yielding in South Norway, and population 62 is the best yielding in the North (444) as well as in mountain districts (395).

Finally, the correlation coefficients (Table 8) clarify the results given above. First, the weak correlation between the S1 and S2 scores ($r = 0.45$), followed by the almost perfect correlation between the S2 and I2 ($r = 0.97$). These two methods also show a good correlation with the DM yields in northern Norway and the mountain districts ($r = 0.85$, and $r = 0.84$, respectively), and also an acceptable correlation with the mean DM yield ($r = 0.56$, and $r = 0.63$, respectively.

Discussion

The between population variability

The between population variability and the very normal distribution among populations for all characters, with the exception of winter survival, observed at the two research sites (Figs. 1-6), provide good information and a realistic background for selection.

Generally, populations from northern districts are not particularly high and also tend to have smaller leaves, but they are more winter hardy than populations from southern districts. This general rule has previously been reported for foreign white clover material, for example by Eagles & Othman (1986), and for parts of the present material (Junttila et al. 1990; Aasmo 1996). Caradus et al. (1989) found that large-leaved, erect cultivars tended to be more frost sensitive than smalleaved, prostrate cultivars. However, in the present material there are also some relatively high growing and broad leaved populations showing a good winter hardiness. This exception to the general rule provides hope for finding high value for the first priority characters assembled in one and the same population.

Selection among populations

Index scores based on more than one character have not been used so much in practical plant breeding as has been the case with animal breeding, despite the fact that the theory of index selection was first presented over fifty years ago (Smith 1936; Hazel & Lush 1942; Hazel 1943). In Norway, for example, the discussion concerning index selection in plant breeding has just started (Aastveit, K. 1983a, 1983b; Aastveit A.H. 1988), whereas in animal breeding index selection has been in practical use since the 1950s (Skjervold 1980).

One reason for this is that up until now there has been a good response in plant breeding with selection using the simplest procedures, often for only one population and one character at a time, or stepwise for one population and one character, a sort of «tandem» method (Hazel & Lush 1942). The varieties on the commercial market have also been accepted. The gain in breeding white clover (1940-90) for the western world is accordingly as high as 6% per decade (Woodfield & Caradus 1989).

Another reason is that more costly experiments are required in order to calculate heritabilities for-and correlation coefficients between several important characters. A third reason is the problem of determining good «economic» value for characters in plant breeding compared to animal breeding.

For animals, the open market prices have primarily been used to settle economic values in breeding programmes. In fodder crops, however, the «economic» value of different characters must be related to the DM yield as a sort of market. Economic values in fodder crops will as a consequence always be different from those economic values used in animal breeding, and also different from such values in cash crops. However, the latter point is not a sufficient reason for not using index selection in fodder plant breeding.

Meanwhile, a manual for use of indices in plant breeding will soon be published (Aastveit, K. personal inf.). The present work is an example showing how index selection may be used in selection processes to achieve better varieties in a fodder crop.

The present material has demonstrated the importance of using widely adapted populations when starting a plant breeding programme. Among the 90 populations tested, about 10% are primarily selected for further testing, and these will be used as a base for composing synthetic populations.

The S1 (and S12) procedure(s), including five characters and their «economic» values, seems to be satisfactory as a first screening, and has in the present case given an acceptable first ranking among the selected populations (75, 40, 38, 06, 62, and 22).

However, with indirect selection based only on the two secondary characters winter hardiness and plant height and their heritabilities (the S2 method), the ranking (40, 38, 62, 22, 06, and 75) corresponds better with the mean DM yield in the official variety testing (Table 7).

In addition, inclusion of the correlations between DM yield and the secondary characters winter hardiness and plant height (the I2 proceduer) (which leads to the ranking 40, 38, 62, 22, 06, and 75), corresponds better to the DM yield in the field experiments — also in the case of southern Norway.

The I2 index threfore provides the best indication of what are the most promising populations to be included in a final variety testing programme based on practice.

Indirect selection using only the character plant height (the I1 method) has the lowest correlation with the results of the variety testing DM yield, and is not an acceptable procedure.

The present results indicate clearly that the final selection should always be based on open field variety testing in different districts. In this project the final ranking for DM yield based on the variety testing in South- and North Norway is populations: 62, 40, 38, 75, 22, and 06.

There are, however, some considerations that must be kept in mind when discussing selection methods in fodder crops.

First, the characters or items used in this material, primarily winter hardiness and plant height, are not necessarily the most obvious ones in other materials. For example, the leaf/straw percent and seed production capacity may have the highest priority for other materials.

Secondly, the economic values used in the present material may very well be changed, and this factor should be more seriously discussed among plant breeders. Thirdly, is the background for estimation of the heritability components of a material as large as the present one. Are there any alternatives — less environmentally influenced methods — to conducting field experiments?

When this breeding programme in white clover started, the intention was to select for turf types,too. In the first screening, selection of turf types in addition to fodder grass was included among the populations. Instead of plant height, leaf length, and/or chemical analyses used in the present

S1/S12 method(s), an alternative characteristic for a «general performance» was used. As a result of this turf type screening, the best populations were nos. 62, 22, and 06 (Rapp 1992). As these populations were also among the best selected for fodder production, the characteristics of turf types are well taken care of among the populations selected for fodder production in the present material. However, when starting the selection for synthetic populations, special genotypes for turfs will be considered.

A practical related conclusion that can be drawn from this breeding programme, so far, is that population no. 62, indigenous to district 06 in central Norway, and no. 40, from district 05 in Mid-Norway, are the two most promising populations for an official variety of white clover in Norway.

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Quality evaluation of apple cultivars

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In a first screening in Norway, 31 apple cultivars and selections were evaluated for fruit quality. 'Astramel' and 'Geneva Early' were the best summer cultivars (harvested in August and early September). Of the later ripening cultivars (harvested in late September and October), ARX 49-18, BM 55196, 'Delcorf', 'Elan', 'Elstar', 'Sampion' and 'Sunrise' are considered the most promising.

Key words: Apple, cultivars, fruit quality, fruit size.

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In Norway, the first screening of new apple cultivars has been performed at the Agricultural University of Norway. Results are published by Redalen (1977, 1984, 1985, 1986, 1987, 1988) and Redalen et al. (1996). In this paper we present results from screening of new cultivars in the period 1990-94.

Material and methods

A total of 31 cultivars and selections were tested (Table 1). Two trees of each genotype were planted from 1986 to 1991, and the cultivars were included in quality tests as soon as the yield was sufficient. Standard cultivars were 'Julyred', 'Qui-nte' and 'Vista Bella' for summer apples, 'Aroma', 'Gravenstein' and 'Summerred' for later ripening cultivars.

Methods for quality tests of apples at the Agricultural University of Norway are described by Redalen (1977, 1986, 1988), and procedures are only briefly mentioned here. Every week during the ripening period, summer cultivars were harvested on Monday, and kept at room temperature until sensory evaluation on Tuesday and Friday by a panel of 4-8 trained persons. Later ripening cultivars were harvested when considered mature, and stored at 4°C until quality evaluation around the 20th of September, October, November and December. On every day of evaluation, 2 apples of each cultivar were scored for ground colour (scale 0-9, 9 = completely yellow) and red colour (scale 0-9, 0 = no red colour, 9 = completely covered) by each member of the panel. Thereafter the apples were cut in sectors and scored for taste (scale 0-9, 5 = acceptable, 9 = superior). By every day of evaluation, firmness was measured by a hand penetrometer (7/16" plunger) on 4 peeled apples, 3 measurements per fruit. Each apple was then halved, one half being scored for starch content by the starch-iodine test. An 0-5 scale was used, where 0 = no starch (no staining), and 5 =

Table 1. The selections and cultivars tested.

Cultivar / selection	Parentage	Origin	Introduced
ARX 48-38	'Aroma' x open-pollinated	Norway	
ARX 49-18	'Aroma' x open-pollinated	Norway	
BC 8B-20-73	'Golden Del.' x 'Spartan'	Canada	
'Astramel'	'Roter Astrachan' x ('James Grieve' x 'Melba')	Germany	1986
'Belrene'	Mutant of 'Reine des Reinettes'	France	1976
'Blairmont'	QH 11-75 ('York Imperial' x 'Minjon') x 'Grove'	USA	1982
BM 46722	'Stark's Earliest' x 'Transparente Blanche'	Sweden	
BM 47612	'Golden Del.' x 'Ingrid Marie'	Sweden	
BM 55196	'Golden Del.' x 'Pate'	Sweden	
'Delcorf'	'Stark Jongrimes' x 'Golden Del.'	France	1974
'Early Cortland'	'Cortland' x 'Lodi'	USA	1982
'Egri 'Piros"		Hungary	
'Elan'	'Golden Del.' x 'James Grieve'	Netherlands	1984
'Elstar'	'Golden Del.' x 'Ingrid Marie'	Netherlands	1972
'Geneva Early'	'Quinte' x 'Julyred'	USA	1982
'Helios'	'Oldenburg' x open-pollinated	Germany	1969
'Jester'	'Worcester Pearmain' x 'Starkspur Golden Del.'	United Kingdom	1981
KS 56B-26	'Katja' x 'Sävstaholm'	Norway	
'Make'	'Atlas' x 'Yellow Autumn Kallvill'	Finland	1981
'Mantet'	'Tetofsky' x open-pollinated	Canada	1929
'Pikant'	'Undine' x 'Carola'	Germany	1988
'Piros'	'Helios' x 'Apollo'	Germany	1985
'Primgold'	'Stark Goldenspur' x 'Stark Jongrimes'	France	
'Primula'		Poland	1974
'Sampion'	'Golden Del.' x 'Cox's Orange Pippin'	Czech Republic	
'Shamrock'	'McIntosh' 10C-8-43-1 x 'Starkspur Golden Del.'	Canada	1986
'Sumac'	Complex pedigree incl. 'Vista Bella' and 'Jonamac'	Canada	1987
'SummerTreat'	NJ 109055 x 'Mollie's Delicious'	USA	1980
'Sunrise'	10C-10-19 ('McIntosh' x 'Golden Del.') x PCF3-120 (unknown origin)	Canada	1991
'Tuscan'	'Wijcik' x 'Greensleeves'	United Kingdom	1989
'Wijcik'	Mutant of 'McIntosh'	Canada	1969

high starch content (completely stained). Content of soluble solids and titratable acids were analysed on filtrated fruit juice from the remaining fruit halves. For summer apples, evaluations included scores for taste and colour only.

Estimation of optimal harvest date for summer apples is based on flavour and ground colour scores. Estimation of optimal consumption period of later ripening apples is mainly based on taste scores, but development of ground colour, firmness, starch content and sugar/acid ratio is also taken into consideration.

In the years 1990-94 there was considerable variation in climatic conditions. In all tables, the results are corrected for variation between years, as not all cultivars were included in all years. The standard cultivars (pooled) were used for

calculation of a yearly correction value for each character, by subtracting the yearly mean from the total mean of the 5 years. Results for each cultivar were then adjusted by these yearly correction values. For summer apples, the harvest date is also corrected, as the test period included rather late and extremely early years.

Results

Results for summer cultivars are presented in Tables 2 and 3 and show that in the first part of the season, 'Geneva Early' tasted better than any other cultivar. The fruits were attractive with good colour, but were quite small. The cultivar was observed to be rather susceptible to powdery mildew. 'Astramel' had very large, attractive fruits with fairly high scores for flavour, but the fruits tended to crack. 'Make' and BM 47622 had a fairly good taste in early September. KS 56B-26, 'Sumac' and 'Primula' had small, well-coloured fruits. Flavour scores for KS 56B-26 and 'Primula' were low, while 'Sumac' achieved flavour scores at the same level as the standard cultivars, but ripened a week later. This cultivar is very productive, but has to be picked several times to avoid preharvest drop. Observations on unsprayed trees indicated that 'Sumac' is tolerant to apple scab. The quality of 'Mantet', 'Helios' and 'Piros' was below acceptable level.

In the later part of the season, flavour scores at the level of those for 'Aroma' were observed for ARX 48-38, ARX 49-18, BM 55196, 'Delcorf', 'Elan', 'Elstar', 'Sampion', 'Summer Treat', 'Sunrise' and 'Tuscan' (Tables 4 and 5). Flavour scores of ARX 49-18 were very high in some years, mediocre in others. Both ARX 49-18 and ARX 48-38 have a shorter period with maximum taste score compared with 'Aroma'. 'Summer Treat' tasted well in September, but had a shorter consumption

Table 2. Development of flavour scores for summer cultivars of apple, corrected means for 1990-94. Scale 0-9, where 5=acceptable, 9=superior

Cultivar/ selection	Week nr. (mean harvest date) 33 (Aug. 13)	34 (Aug. 20)	35 (Aug. 27)	36 (Sep. 2)	37 (Sep. 9)
'Geneva Early'	6.4	6.0			
'Vista Bella'	4.9	4.9	5.0		
'Quinte'	5.5	5.2	5.3	4.7	
'Julyred'	5.1	5.3	4.5	4.5	
KS 56B-26	3.8	4.1	4.2	4.8	4.5
'Astramel'		5.4	5.4	5.6	
'Sumac'		4.7	5.1	4.9	3.5
BM 47622		4.2	4.9	5.1	5.6
'Mantet'			4.7	4.8	4.5
'Helios'			4.3	4.8	4.5
'Piros'			4.7	4.9	4.6
'Make'			5.2	5.3	5.6
'Primula'				3.6	3.9
$LSD_{5\%}$	0.7	0.5	0.6	0.6	0.7

Table 3. Quality evaluation of summer cultivars of apple, corrected means for 1990-94

Cultivar/ selection	Number of years in test	Fruit weight (grams)	Estimated optimal date of harvest	Quality parameters at estimated optimal harvest date		
				Flavour scores (0-9)	Ground colour (0-9)	Red colour (0-9)
'Geneva Early'	4	92	Aug 13	6.4	8.0	6.5
'Vista Bella'	4	120	Aug 13	4.9	6.7	6.0
'Quinte'	5	129	Aug 13	5.5	6.2	5.0
'Julyred'	5	132	Aug 20	5.3	6.5	6.8
'Astramel'	4	196	Aug 20	5.4	7.4	6.7
KS 56B-26	4	90	Aug 27	4.2	6.4	6.7
'Sumac'	4	97	Aug 27	5.1	6.4	7.5
'Mantet'	2	135	Aug 27	4.7	6.8	4.2
'Helios'	5	111	Sep 2	4.8	7.1	2.4
'Piros'	5	138	Sep 2	4.9	7.2	5.7
'Primula'	3	87	Sep 2	3.6	7.5	6.8
BM 47622	4	144	Sep 9	5.6	7.5	0.4
'Make'	4	130	Sep 9	5.6	8.0	4.0
$LSD_{5\%}$		18		-	-	-

period compared with 'Summerred'. 'Delcorf' is an attractive apple with high scores for taste, but has a strong alternate bearing habit, and only yielded enough fruits for testing every other year. 'Tuscan' and 'Wijcik' are the two cultivars of columnar tree type that have been tested in Norway, where only 'Tuscan' matures satisfactorily in the Norwegian climate. BC 8B-20-73, 'Belrene', BM 47612, 'Egri Piros' and 'Shamrock' achieved low scores for taste, while 'Blairmont', 'Deljeni Primgold', 'Early Cortland', 'Jester' and 'Pikant' were considered acceptable only for a short period.

The highest contents of soluble solids (more than 15%) were found in 'Jester', 'Belrene' and ARX 48-38, while 'Wijcik' was the only cultivar with less than 11% soluble solids (Table 5). Contents of titratable acids ranged from above 1% in 'Jester' and ARX 48-38 to 0.5% in 'Deljeni Primgold'. 'Sampion' and 'Deljeni Primgold' were the only cultivars with sugar/acid ratios above 25.

Discussion

Most of the cultivars included in this report have not been previously tested in Norway. At the start of the apple season, 'Geneva Early' was the best cultivar. This is in accordance with another Norwegian apple test (Redalen et al. 1996). Unpublished results from Ullensvang Research Station, Division Njøs (Western Norway) indicate less red colour and poorer taste of 'Geneva Early' than the results in the present report (from eastern Norway). It seems that 'Geneva Early' is better adapted to the climate of eastern Norway than to that of the western part of the country. Similar differences in adaptation

Table 4. Development of flavour scores of apple cultivars, corrected means for 1990-94. Scale 0-9, where 5 = acceptable, 9 = superior

Cultivar / selection	Mean flavour scores			
	September	October	November	December
ARX 48-38	5.0	5.6	5.0	4.5
ARX 49-18	-	5.7	5.0	4.9
'Aroma'	-	6.0	5.8	5.0
BC 8B-20-73	-	4.7	4.4	3.3
'Belrene'	-	4.4	4.4	3.6
'Blairmont'	5.1	5.2	4.3	4.1
BM 47612	-	3.8	4.7	3.9
BM 55196	5.5	5.7	5.0	4.7
'Delcorf'	5.7	4.9	5.8	4.4
'Deljeni Primgold'	-	5.0	3.5	4.0
'Early Cortland'	5.1	4.1	4.9	4.3
'Egri 'Piros''	-	3.7	4.0	3.6
'Elan'	-	5.4	5.4	5.1
'Elstar'	-	5.2	5.8	5.3
'Gravenstein'	5.0	4.7	4.6	4.1
'Jester'	-	4.9	5.1	4.9
'Pikant'	3.9	4.9	5.1	5.0
'Sampion'	-	5.7	5.7	4.6
'Shamrock'	-	4.6	4.0	3.9
'Summerred'	5.3	5.3	5.5	4.7
'Summer Treat'	5.5	5.2	4.7	4.2
'Sunrise'	6.0	6.1	5.0	4.2
'Tuscan'	-	5.9	5.2	5.1
'Wijcik'	-	3.9	3.7	3.8
$LSD_{5\%}$	0.6	0.6	0.8	0.7

were previously observed for 'Julyred' (Redalen 1989; Meland & Hovland 1992) and 'Lobo' (Husabø 1962), with poorer development of red colour and flavour in western Norway. Observations made at Njøs confirm the susceptibility of 'Geneva Early' to powdery mildew. At Njøs, 'Elstar' tasted better than is indicated in this paper, with high flavour scores from December to February. The flavour scores for ARX 49-18 varied between excellent and intermediate in both the eastern and western parts of Norway. This selection has been considered promising as a result of high flavour scores in some years and less observed *Gloeosporium* rot than in 'Aroma'. ARX 49-18 is now undergoing further evaluation at several sites.

It remains to be seen whether the cracking found in the fruit of 'Astramel' continues as the trees mature. This problem is usually most severe on large fruits on young trees.

It is possible that fruit size and quality of 'Sumac' may be acceptable if regular thinning is carried out. However, production costs are high in cultivars with a strong demand for thinning. The uneven

Table 5. Quality evaluation of apple cultivars, corrected means of 1990-94

Cultivar/ selection	Number of years in evaluation	Fruit weight (grams)	Optimal consumption period	Starch content in Oct. (Scores 0-5)	Mean values of quality parameters for the first two months of the optimal consumption period[1] Flavour scores (0-9)	Soluble solids (%)	Titratable acid(%)	Sugar/ acid ratio	Fruit firmness (kg/cm^2)	Ground colour (0-9)	Red colour (0-9)
ARX 48-38	3	113	Oct-Nov	0.2	5.3	15.5	1.00	16	6.5	7.9	7.2
ARX 49-18	4	119	Oct-Nov	0.5	5.4	13.6	0.77	18	7.4	7.2	5.0
'Aroma'	5	129	Oct-Nov	0.1	5.9	13.5	0.71	19	7.1	7.2	4.7
BC 8B-20-73	3	143	Oct-Nov	0.0	4.6	13.1	0.82	16	5.2	7.5	1.6
'Belrene'	2	131	Oct-Nov	0.8	4.4	16.2	0.89	18	9.8	7.5	4.9
'Blairmont'	3	107	Sep-Oct	0.0	5.2	13.3	0.59	23	8.4	7.9	7.3
BM 47612	2	146	Nov-Dec	2.5	4.3	11.6	0.84	14	6.1	5.3	2.0
BM 55196	4	127	Sep-Oct	0.4	5.6	14.3	0.71	20	7.9	7.5	1.1
'Delcorf'	3	148	Sep-Nov	0.0	5.8	13.7	0.59	23	7.2	8.0	2.5
'Deljeni Primgold'	2	118	Oct	0.0	5.0	13.7	0.51	27	8.2	7.1	1.4
'Early Cortland'	3	175	Sep-Nov	0.0	5.0	11.7	0.70	17	6.1	7.1	4.2
'Egri Piros'	2	99	Oct-Dec	0.0	3.9	13.1	0.83	16	5.9	7.4	6.9
'Elan'	4	105	Oct-Dec	2.3	5.4	13.8	0.79	17	8.6	8.4	4.2
'Elstar'	4	131	Nov-Dec	2.5	5.6	14.0	0.91	15	7.2	7.2	3.3
'Gravenstein'	5	173	Sep-Nov	0.1	4.9	13.1	0.78	17	7.9	6.7	2.3
'Jester'	2	154	Oct-Dec	0.3	5.0	16.5	1.06	16	7.9	7.7	5.7
'Pikant'	3	238	Oct-Dec	2.5	5.0	14.3	0.94	15	8.6	7.5	6.4
'Sampion'	4	152	Oct-Nov	0.0	5.7	14.1	0.55	26	7.1	8.1	5.4
'Shamrock'	2	122	Oct	0.0	4.6	13.5	0.60	23	9.2	4.8	2.2
'Summerred'	5	132	Oct-Nov	0.0	5.4	12.3	0.69	18	6.1	7.7	7.4
'Summer Treat'	4	121	Sep	0.0	5.5	11.9	0.57	21	8.2	7.5	7.6
'Sunrise'	4	153	Sep-Oct	0.0	6.1	13.0	0.64	20	7.1	7.5	6.0
'Tuscan'	3	136	Oct-Dec	1.0	5.6	13.6	0.80	17	6.7	5.2	1.4
'Wijcik'	2	103	Oct-Nov	0.0	3.8	10.6	0.64	17	6.3	5.7	5.9
$LSD_{5\%}$		42		1.2	-	-	-	-	-	-	-

[1] Mean of September and November for 'Delcorf' and 'Early Cortland', only September for 'Summer Treat', only October for 'Deljeni Primgold' and 'Shamrock'.

ripening observed in 'Sumac' is quite common in summer cultivars, and represents a problem for the grower. 'Make' and BM 47622 tasted good in the first part of September, with the same ripening time as 'Discovery', but they are not likely to compete with 'Discovery' because of their poorer appearance and taste. Owing to the longer consumption period and higher flavour scores of 'Sunrise' compared with those of 'Summer Treat', the former should be preferred.

The small fruit size of 'Elan' compared with 'Elstar' is surprising, as 'Elan' is normally regarded as having larger fruits than 'Elstar' (Grauslund 1989, 1990; Kellerhals et al. 1991). The good performances from 'Delcorf', 'Sampion' and 'Sunrise' are in accordance with results from Denmark (Grauslund 1993), and in the case of 'Delcorf', also with Swedish results (Goldschmidt-Reischel 1987). Poor performances from 'Deljeni Primgold', 'Early Cortland', 'Pikant', 'Piros' and 'Shamrock' are in accordance with Danish and Dutch results (Grauslund 1990; Goddrie & Kemp 1993).

Somewhat sourish as well as rather sweet apples were given high scores for flavour by this testing panel. In the cultivars and selections recommended for further testing, the ratios between contents of soluble solids and titratable acids ranged from 15 in 'Elstar' to 26 in 'Sampion', with a mean ratio just below 20. This mean ratio is well in accordance with Nybom (1962), who suggested an optimum ratio of 18, and with the optimum of 18-20 suggested for summer apples by Redalen (1984). Grauslund (1990) classified apples by sugar/acid ratios as sour (below 12), acidic (12-15), balanced (15-

20) and sweet (above 20).

Owing to the change from the earlier 1-10 scale to a 0-9 scale, taste scores for the standard cultivars are generally lower in this paper than in reports published before 1990 (Redalen 1977, 1984 and 1986). However, this does not fully explain the low scores for 'Gravenstein', as 5 was used as the lower limit for acceptable quality in both scales. 'Gravenstein' is the main cultivar in Norway, but flavour is scarcely found acceptable by this panel. 'Julyred' also had a shorter optimal consumption period than expected when compared with previous results (Redalen 1984). A difference was noted between ages in the testing panel, with the younger members tending to prefer the less ripe apples. The inclusion of more young members in the panel may be one explantion for a shift towards an earlier optimal consumption period of standard cultivars than in former reports.

Conclusions

The summer cultivars 'Astramel' and 'Geneva Early, and the later ripening selections and cultivars ARX 49-18, BM 55196, 'Delcorf', 'Elan', 'Elstar', 'Sampion', 'Sunrise' and 'Tuscan' are recommended for a more thorough testing in Norway. ARX 48-38, BC 8B-20-73, 'Belrene', 'Blairmont', BM 47612, BM 47622, 'Deljeni Primgold', 'Early Cortland', 'Egri Piros', 'Helios', KS 56B-26, 'Jester', 'Make', 'Mantet', 'Pikant', 'Piros', 'Primula', 'Shamrock', 'Sumac', 'Summer Treat' and 'Wijcik' are not suitable for the Norwegian growing conditions.

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Growth of spring barley (*Hordeum vulgare* L.) and five weed species under different irradiance levels outdoors

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Semb, K. 1996. Growth of spring barley (*Hordeum vulgare* L.) and five weed species under different irradiance levels outdoors. Norwegian Journal of Agricultural Sciences 10: 289-300. ISSN 0801-5341.

As part of a broader study on growth characteristics of weeds with different competitive ability in spring cereals, an outdoor experiment with individual plants of spring barley (*Hordeum vulgare* L.), *Brassica rapa* L. ssp. *oleifera* (DC.) Metzger, *Chenopodium album* L., *Galeopsis tetrahit* L., *Stellaria media* (L.) Vill., and *Viola arvensis* Murray was conducted in May/June 1992 at Ås, under 14, 24, and 100% daylight for four weeks. On average, irradiance had no effect on the number of leaves, plant length, leaf area, dry weight, and shoot/root ratio, but the species responded differently to irradiance level. Net assimilation rate (NAR) increased and leaf area ratio (LAR) decreased with increasing irradiance, whereas relative growth rate (RGR) was unaffected. Barley and *B. rapa* had the largest values for leaf area and dry weight, followed by *G. tetrahit*/*C. album*, *S. media*, and, finally, *V. arvensis*. Similarities in results from growth chamber experiments are discussed.

Key words: *Brassica rapa*, *Chenopodium album*, dry matter, *Galeopsis tetrahit*, growth analysis, *Hordeum vulgare*, irradiation, leaf area, *Stellaria media*, *Viola arvensis*

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Economic thresholds and reduced doses are valuable tools in reducing herbicide usage in spring cereals in Norway (Fykse 1991). Fykse (1991) found that different species had different threshold values, e.g. *Galeopsis* spp. had lower values than *Chenopodium album* L., which in turn had lower values than *Viola arvensis* Murray. These different economic thresholds of the weed species are mainly caused by different growth and competitive ability and corresponded well with dry weight and leaf area differences between individual weed seedlings in growth chamber studies (Semb 1996a & b). The early growth of spring barley (*Hordeum vulgare* L.) and selected weed species responded differently to different irradiance levels or temperature regimes in the same growth chambers. This indicates that outdoor variations in temperature during the growing season may influence growth and competitive ability. Furthermore, light quantity (and quality) in an outdoor plant stand may be different from that in the growth chambers, due to different shading of the crop. To study the effect of light quantity on growth of weed species outdoors, shading cages can be used.

The purpose of this investigation was to study the effect of different irradiances outdoors on the growth of spring barley

and the same five weed species studied in growth chambers (Semb 1996a & b) and to test whether the results from the growth chambers have relevance to outdoor conditions. This is part of a study aimed at revealing the growth characteristics and species which are of major importance to economic thresholds in cereals.

Material and methods

Plant material

Seeds from *C. album*, *Galeopsis tetrahit* L., *Stellaria media* (L.) Vill., and *V. arvensis* were collected at Ås in 1991 and placed in dry, cool storage until the start of the experiment. In addition, spring barley (cv. Bamse) and spring turnip rape (*Brassica rapa* L. ssp. *oleifera* (DC.) Metzger, cv. Emma) were used. Seed treatments, raising of seedlings and transplanting were all performed as described by Semb (1996a).

Experimental conditions

The experiment was carried out at Ås in May and June 1992, with three irradiance levels and two repetitions. On the day of planting the pots were placed on wooden boards covered with felt (3 mm thick) and perforated plastic. To obtain reduced irradiances compared to daylight, the pots were placed inside white painted wooden cages (1.2 m length x 1.0 m width x 1.0 m height) made of laths with varying spacing. On average, the three irradiance levels corresponded to 14, 24, and 100% daylight with minor differences between the two repetitions, based on measurements of photosynthetic photon flux (PPF) taken in the middle of the day with a sunfleck ceptometer (Model SF-80, Decagon Devices, Inc.). The pots were watered daily from below by drip nipples and from above when needed. Temperature, relative humidity (RH), and PPF (PAR Quantum sensor, type QS, Delta-T, Cambridge, UK) were measured and recorded each hour by a datalogger.

During daytime, PPF reached its maximum at noon as expected (Fig. 1a). There was, however, an unexpected drop at about 10 a.m. at 24 and 100% daylight, probably because of shading from other cages. Averaged over daytime (≈18 h) the PPF level was approximately 120, 230, and 670 μ mol m^{-2} s^{-1} for the different irradiance levels. Expressed as a percentage of full daylight, the values for low and medium irradiance levels were higher than those recorded by the sunfleck ceptometer in the middle of the day, probably because the wooden laths at low solar elevation angles caused more light to enter the cages. At sunrise RH reached its maximum level and temperature its minimum level, while in the middle of the day and a few hours later the opposite trend was found (Figs. 1b & 2c). There

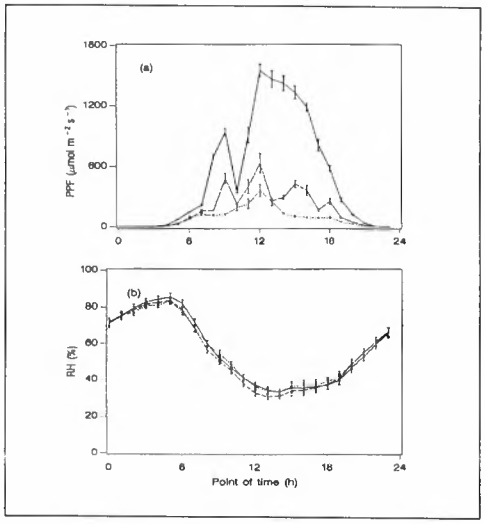

Fig. 1. (a) Photosynthetic photon flux (PPF) and (b) relative humidity (RH) at 14 (.....), 24 (------), and 100% daylight (_____) during daytime. Average over experimental period. Vertical bars indicate ± standard error of means

were only small differences in temperature and RH between the different shading cages, with average temperatures of 18-20°C and an average RH of 55-56%. The main trend, however, was for RH to decrease and temperature to increase during the experimental period. PPF increased slightly, except for 100% daylight, which showed a minor decrease in June (Fig. 2).

Measurements

Two randomly selected plants of each species were harvested 7, 14, 21, and 28 days after planting at each irradiance level and repetition. For each species, the number of leaves, flowering (defined as observed generative plant parts, i.e. flowers, flowers buds, and awns (barley)), plant length, and leaf laminae area, and for barley the developmental stage also, were determined as previously described (Semb 1996a). The soil was removed from the roots by gentle washing. Owing to the labour-intensive situation, the pots with roots had to be stored before washing either at 2°C for periods of up to one week or in a deep freezer when longer periods were necessary. The dry weights of shoots and roots were determined after drying for 48 h at 60-65°C. Dry weight and shoot/root ratios on a per plant basis were derived from dry weights of shoots and roots.

Relative growth rate (RGR), net assimilation rate (NAR), and leaf area ratio (LAR) were calculated as in Evans (1972). The plants were paired to allow for statistical analysis.

Statistical analyses

Variance analysis was performed by using the statistical package SAS (SAS Institute Inc. 1988). A split-plot model was used with irradiance levels on the main plots and species and harvest times on the subplots. Before analysis, the values for number of leaves, leaf area, and dry weight were transformed to the common logarithm ($\log_{10}$) to stabilize variance. LSD-tests were conducted to detect the actual differences. In all tests a significance level of $p \leq 0.05$ was used, except in LSD-tests on species and harvest times,

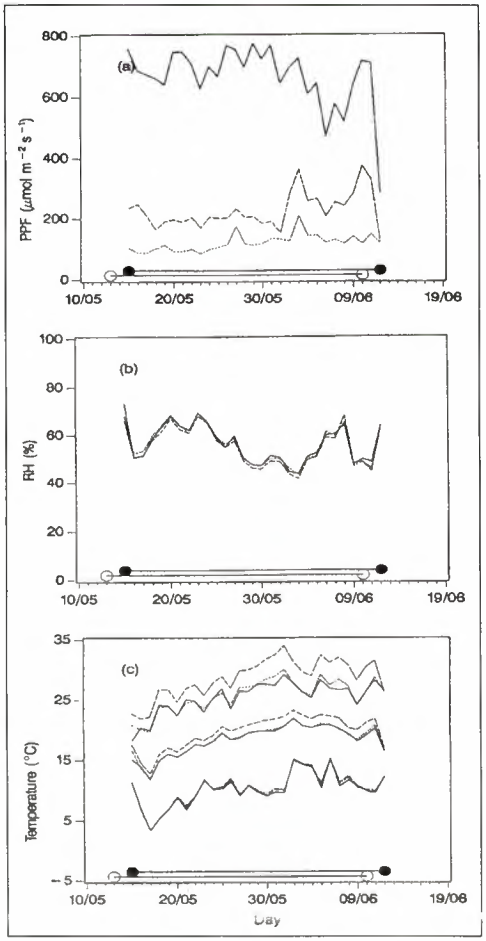

Fig. 2. Average daily climate during the experimental period at 14 (.....), 24 (-----), and 100% daylight (_____): (a) PPF (average over photoperiod ≈18 h), (b) RH, (c) maximum, average, and minimum temperature. The experimental period of repetition 1 and 2 is indicated by o——o *and* ●——● *, respectively*

where a significance level of $p \leq 0.01$ was chosen in order to gain more control over the type I error.

Results and discussion

Developmental characteristics

G. tetrahit and *S. media* were at vegetative stage during the whole experimental period, while barley had a trace of awns at the last harvest time when grown under 24% daylight (Table 1). *B. rapa* and, to some extent, *C. album* reached the generative stage 14 days after planting. *V. arvensis* flowered one week later than *B. rapa* and *C. album*. When and how much the species flowered corresponded well with the results of the growth chamber studies with the same average temperature (ca. 18°C, Semb 1996b). In the growth chambers with a lower average temperature (14-15°C), however, the flowering started later than in this study. On the other hand, the differences between the species were almost the same, with the exception of *G. tetrahit,* which did flower and barley, which did not flower, in the growth chambers (Semb 1996a). Irradiance level had very little influence on onset of flowering. *C. album* and *V. arvensis*, however, flowered about one week later at 100% daylight compared with 14 and 24% daylight. In the growth chamber experiments with irradiances comparable to 14 and 24% daylight, *B. rapa*, *C. album*, and *V. arvensis* showed a greater variation in the time of flowering at different irradiance levels (Semb 1996a & b).

The developmental stage and the number of tillers of barley naturally increased with harvest time, and the number of tillers increased with increasing irradiance level (Fig. 3) as found in the growth chambers (Semb 1996a & b). The developmental stage was little affected by irradiance, as found in one of the growth chamber studies (Semb 1996a), whereas the interaction between harvest time and irradiance level was significant, showing a slight increase from 14 to 24% and a decrease from 24 to 100% daylight at the last harvest time. The former increase corresponded well with the other growth chamber study (Semb 1996b).

Growth characteristics

The number of leaves, plant length, leaf area, and dry weight increased with harvest time for each species (Table 2). The exponential growth of leaf area stopped earlier in *B. rapa* than was found in Semb (1996a), probably because of a higher temperature in the cages and hence a

Table 1. Percent flowering plants of each irradiance regime during the experimental period. A plant was considered as flowering when generative plant parts were observed

% daylight	14				24				100			
Days after planting	7	14	21	28	7	14	21	28	7	14	21	28
Barley	0	0	0	0	0	0	0	50	0	0	0	0
B. rapa	0	75	100	100	0	100	100	100	0	100	100	100
C. album	0	100	100	100	0	100	100	100	0	0	100	100
G. tetrahit	0	0	0	0	0	0	0	0	0	0	0	0
S. media	0	0	0	0	0	0	0	0	0	0	0	0
V. arvensis	0	0	100	100	0	0	100	100	0	0	25	100

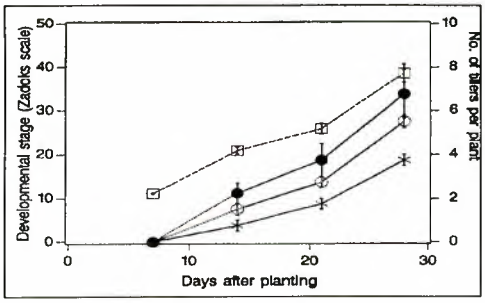

Fig. 3. Developmental stage of barley (Zadoks et al., 1974, average over irradiance levels,---□ --- and number of tillers at 14 (——), 24 (—o—), and 100% (—●—) daylight during the experimental period. Vertical bars indicate ± standard error of means*

greater developmental rate.

The number of leaves was of the same magnitude and the species differences were the same as found in Semb (1996a & b). The plant length was of the same magnitude as that in Semb (1996a & b) for barley, *G. tetrahit*, and *S. media*, whereas *B. rapa*, *C. album*, and *V. arvensis* were longer in this study, resulting in the following decreasing order of length: barley > *B. rapa* > *C. album* > *G. tetrahit* > *V. arvensis*. *S. media* did not differ from either of the two later species. The red/far-red ratio in unshaded places outdoors is about 1-1,2 at noon (Holmes & Smith 1977), while that of the growth chambers was 2-6 (Semb 1996a & b). Reduced red/far-red ratios are known to cause further stem elongation (e.g. Morgan & Smith 1981) and probably explain why three of the species were longer in this study than in the growth chambers.

For leaf area and dry weight, barley and *B. rapa* had the largest and *V. arvensis* the smallest values of the species, while *G. tetrahit* did not differ significantly from *C. album*, which in turn had larger values than *S. media*. These differences were similar to those in the growth chambers (Semb 1996a & b), except that in the growth chambers *G. tetrahit* had larger values than *C. album*, which was of the same size as *S. media* (Semb 1996a).

The shoot/root ratio varied significantly with species and harvest times, and the interaction between species and harvest times was significant, too (Table 2). A decrease with time, reaching a minimum 14 (*B. rapa*) or 21 days after planting (*C. album, G. tetrahit, V. arvensis*) was followed by an increase. The shoot/root ratio of barley and *S. media* showed no clear response with time. In the growth chambers, however, Semb (1996a) found a more or less clear decrease during the whole experimental period, especially for *B. rapa*.

None of the growth characteristics were significantly affected by the irradiance alone. The irradiance, however, played a part in some significant interactions.

In contrast to the former study in growth chambers (Semb 1996a), the number of fully developed leaves showed a significant interaction between irradiance and species, with *S. media* and *V. arvensis* having the highest number at 24% daylight and the other species having the same or an increasing number when the daylight increased from 24 to 100% (Fig. 4a).

For plant length, there was a significant interaction between irradiance and species. Barley and *V. arvensis* revealed a decreased length with increasing irradiance, *B. rapa*, *C. album*, and *S. media* showed an optimum at 24% daylight, while *G. tetrahit* was unaffected by the irradiance (Fig. 4b). This indicates that the species adapt to different irradiance levels in different ways. However, the light quality in a plant stand (red/far-red ratio) as well as quantity, are likely to influence stem elongation (e.g. Morgan

Table 2. Growth characteristics of each species during the experimental period. Average over irradiance regimes ± standard error of mean are shown

Growth characteristics	Days after planting	Barley	*B. rapa*	*C. album*	*G. tetrahit*	*S. media*	*V. arvensis*
No. of leaves	7	0.05 ±0.03	0.28±0.03	0.19±0.11	-1.00±0.00	0.30±0.00	-0.31±0.15
(no. plant^{-1}, $\log_{10}$)[1]	14	0.54±0.03	0.57±0.02	0.60±0.03	0.40±0.04	1.14±0.03	0.42±0.04
	21	0.91±0.03	0.92±0.05	1.13±0.07	0.78±0.02	1.71±0.05	0.70±0.05
	28	1.28±0.04	1.19±0.04	1.58±0.04	1.22±0.07	2.24±0.04	1.12±0.06
Plant length	7	14.1±0.7	5.4±0.4	4.2±0.1	3.2±0.1	3.3±0.2	1.8±0.1
(cm plant^{-1})	14	29.0±2.7	11.3±1.0	10.3±1.0	7.3±0.3	7.6±0.7	4.9±0.4
	21	40.1±4.0	32.9±3.0	21.7±1.8	12.9±0.7	13.8±1.2	9.6±1.0
	28	54.5±4.4	62.3±4.5	41.4±2.4	22.9±1.6	19.4±1.6	16.0±1.7
Leaf area	7	1.12±0.02	0.93±0.04	0.58±0.03	0.61±0.05	0.38±0.04	0.30±0.08
(cm^2 plant^{-1}, $\log_{10}$)	14	1.71±0.04	1.65±0.07	1.28±0.08	1.46±0.03	1.09±0.06	0.87±0.06
	21	2.16±0.06	2.21±0.04	1.95±0.08	1.97±0.06	1.85±0.07	1.40±0.07
	28	2.50±0.06	2.44±0.05	2.38±0.05	2.50±0.06	2.45±0.07	1.86±0.12
Dry weight	7	-1.14±0.04	-1.50±0.04	-1.97±0.06	-1.76±0.05	-2.19±0.04	-2.15±0.06
(g plant^{-1}, $\log_{10}$)	14	-0.53±0.07	-0.67±0.07	-1.11±0.08	-0.93±0.08	-1.32±0.06	-1.39±0.07
	21	0.03±0.05	0.02±0.08	-0.36±0.13	-0.40±0.11	-0.56±0.06	-0.88±0.07
	28	0.49±0.06	0.44±0.09	0.30±0.08	0.19±0.11	0.08±0.06	-0.36±0.11
Shoot/root ratio	7	0.97±0.07	2.90±0.24	3.45±0.57	1.83±0.27	2.13±0.27	2.34±0.27
	14	1.50±0.19	1.91±0.25	3.27±0.57	1.58±0.22	2.49±0.44	1.52±0.44
	21	1.22±0.16	2.33±0.52	2.28±0.35	1.15±0.14	1.96±0.20	1.37±0.18
	28	1.67±0.17	3.82±0.46	3.17±0.50	1.58±0.20	2.58±0.23	3.06±0.78

[1])The number of leaves were set to 0.1 if the permanent leaves were not fully developed.

1981), and hence plant length and adaptation to irradiance level. The interaction of plant length between harvest time and irradiance was also significant. On average, the length of the plants growing at 24% daylight increased more during the whole experimental period than those at 100% daylight, and during the last part of the period also more than those at 14% daylight (Fig. 5a).

The leaf area showed an optimum at 24% daylight for most species, while *G. tetrahit* and *C. album* were less affected by irradiance (Fig. 4c), hence revealing a significant interaction between irradiance and species.

The dry weight responded similarly to leaf area, even though in more species (*G. tetrahit*, *C. album*, *B. rapa*) the dry weight increased with daylight levels between 24 and 100% (Fig. 4d). This corresponded well with the growth chamber studies, which showed a growth in dry weight and a smaller growth or an optimum in leaf area with increased irradiance (Semb 1996a & b). Other experiments outdoors have revealed an increase in dry weight (Bubar & Morrison 1984) or an increase to a certain optimum while raising irradiance levels (Fogelfors 1973). In this study the dry weight of *S. media* decreased slightly, while that of *C. album*

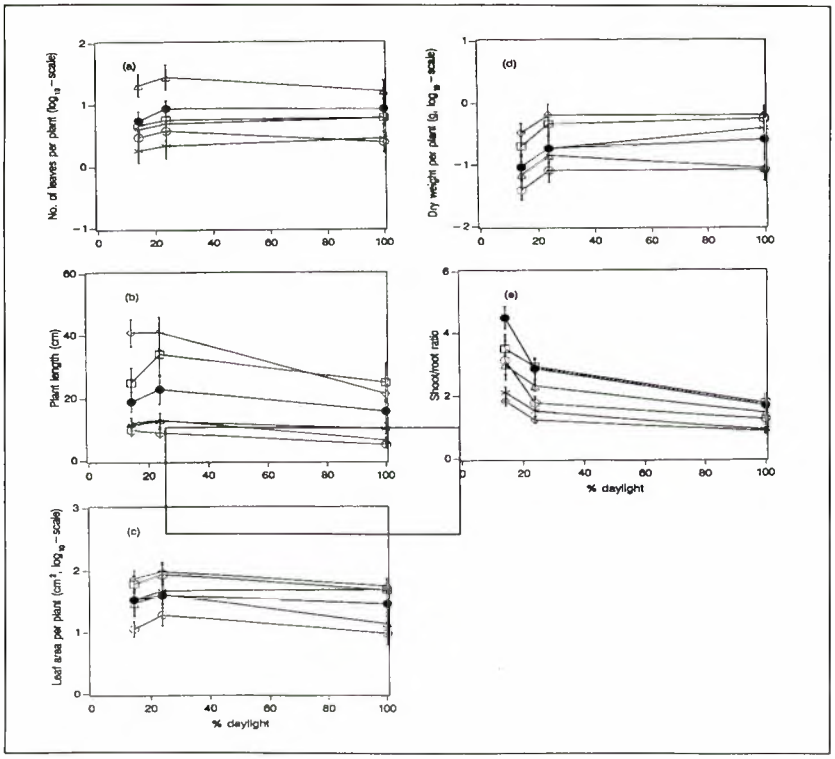

Fig. 4. (a) Number of leaves, (b) plant length, (c) leaf area, (d) dry weight, and (e) shoot/root ratio of B. rapa (□), C. album (•), G. tetrahit (*), S. media (△), V. arvensis (o), *and spring barley* (◊) *at different irradiance levels. Vertical bars indicate ± standard error of means. Average over experimental period*

increased from 24 to 100% daylight. These results are supported by the growth chamber studies, where *C. album* had a larger dry weight than *S. media* at the high irradiance compared with that at the medium irradiance level (Semb 1996a & b), and also by Fogelfors (1973), who found that the dry weight of *S. media* had an optimum at a lower light level than *C. album*.

For leaf area and dry weight, the interaction between irradiance level and harvest time was significant. Between 7 and 14 days after planting the leaf area showed the largest increase at 24% daylight compared to 14 and 100% daylight, and between 21 and 28 days after planting the increase was smaller at 100% daylight compared with 12 and 24% daylight (Fig. 5b). For dry weight, the plants at 24% daylight increased the fastest between 7 and 14 days after planting, resulting in only minor differences from 14 to 28 days inclusive between 24 and 100% daylight (Fig. 5c). Hence the tendency was for the largest value for leaf area to be reached at 24% daylight and that for dry weight at 24 and/or 100% daylight. As previously reported (Semb 1996a & b), there was a close correlation between leaf area and dry weight. The leaf area, however, adjusted more to shade than dry weight,

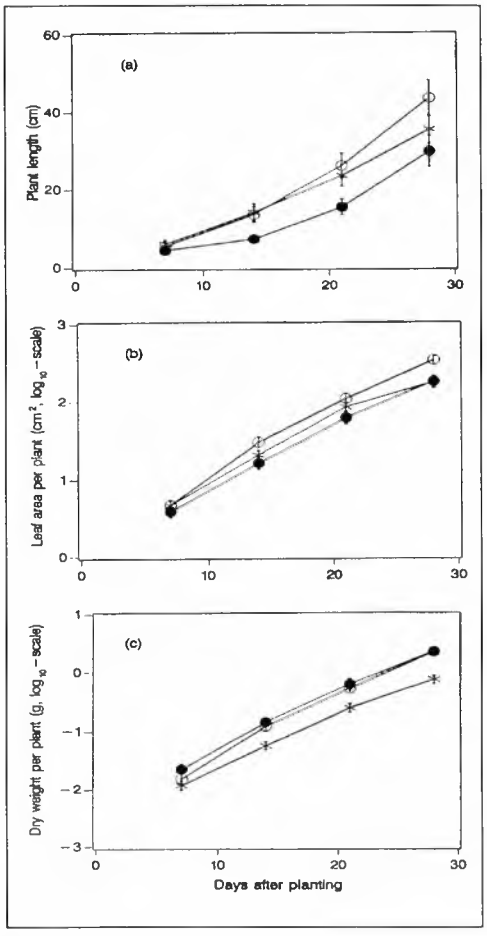

Fig. 5. (a) Plant length, (b) leaf area, and (c) dry weight at 14 (*), 24 (○), and 100% (•) daylight during the experimental period. Vertical bars indicate ± standard error of means. Average over species

by increasing LAR (see below).

The shoot/root ratio tended to decrease with increasing irradiance, and the interaction between irradiance and species was significant with the greatest decrease for *C. album*, *V. arvensis*, and *B. rapa* (Fig. 4e). This result was poorly correlated with that from the growth chambers (Semb 1996a & b). Altogether, there was, however, considerable variations in the material, probably because of difficulties with the root washing procedure and/or because some roots were stored cool and some deep frozen before washing.

Growth analysis

RGR and LAR decreased with increasing harvest interval (Fig. 6). NAR increased and LAR decreased with irradiance level, as expected (Fig. 7), while RGR was unaffected by irradiance level (not shown) as previously found (Regnier et al. 1988; Semb 1996a).

The species differed in that *C. album* and *S. media* had a larger RGR than *V. arvensis* and barley, while the other species were more or less similar (Fig. 6a). This corresponds with Semb (1996a),

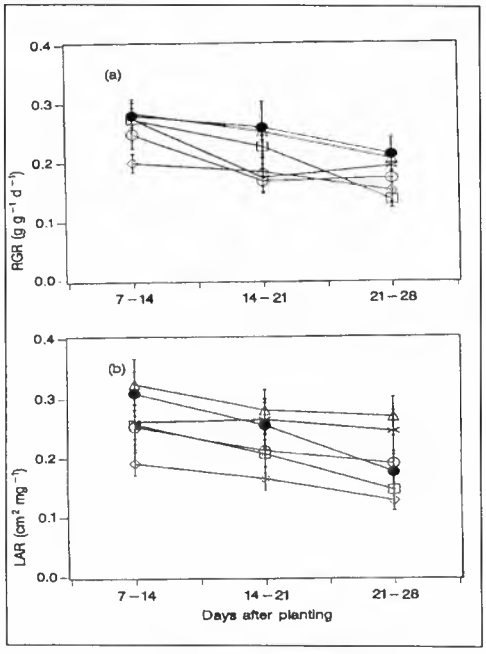

Fig. 6. (a) Relative growth rate (RGR) and (b) leaf area ratio (LAR) of B. rapa (□), C. album (•), G. tetrahit (*), S. media (Δ), V. arvensis (○), *and spring barley (◊) at each harvest interval. Vertical bars indicate ± standard error of means. Average over irradiances*

except that *B. rapa*, instead of *S. media* was among the species with the largest RGR.

With regard to NAR there were small differences between species, with only *C. album* having significantly larger values than *S. media* (Fig. 7a). In the growth chambers there were larger species differences, but *S. media* and *C. album* had some of the lowest and largest values, respectively, for NAR (Semb 1996a), as was also found in this study.

S. media reached the largest and barley the smallest LAR. Among the other species, *G. tetrahit* had a significantly larger LAR than *V. arvensis* and *B. rapa*, and *C. album* a larger LAR than *B. rapa* (Figs. 6b & 7b). These differences, with the exception of the low LAR for *B. rapa*, correspond well with the growth chamber studies (Semb 1996a).

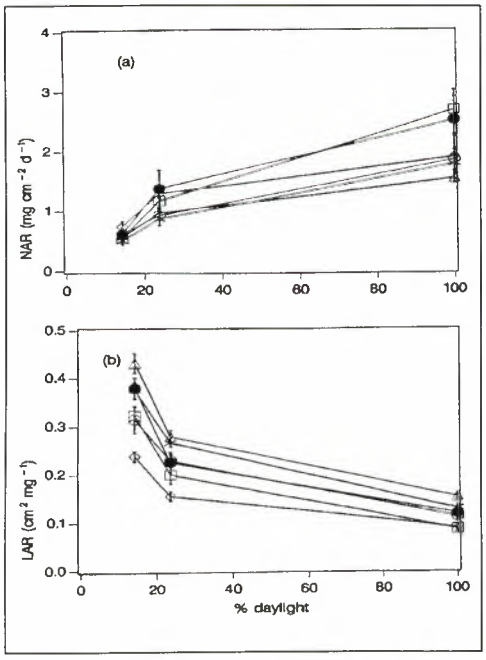

Fig. 7. (a) Net assimilation rate (NAR) and (b) LAR of B. rapa (□), C. album (•), G. tetrahit (*), S. media (Δ), V. arvensis (O), *and spring barley (◊) at different irradiance levels. Vertical bars indicate ± standard error of means. Average over harvest intervals*

The above results indicate that values for RGR, NAR, and LAR for the species at different irradiance levels were more or less similar under controlled conditions and outdoors at comparable irradiances. These results corresponded well with those of Regnier et al. (1988), where RGR, NAR, and LAR seemed to be the same under field and controlled conditions at comparable irradiances for soybean (*Glycine max* (L.) Merr.) and three broadleaf weeds.

For LAR, but not for RGR and NAR, the two-factor interactions were all significant, with LAR of *G. tetrahit* being almost unaffected by harvest interval, whereas that of *C. album* and *B. rapa* showed the fastest decrease with time (Fig. 6b). For all irradiance levels LAR decreased with increasing harvest interval (not shown).

Concluding discussion

Leaf area, plant density and height in the plant stand are likely to influence irradiance level. According to Skuterud (1977), 14 and 24% daylight may occur at ground level, when the plant stand is at the most shaded stage.

The plant characteristics of the species responded in a variety of ways to irradiance. The plant length responded differently to raised irradiance level, showing a decrease (barley, *V. arvensis*), an optimum (*B. rapa*, *C. album*, *S. media*), or being unaffected (*G. tetrahit*). This means that for some species the plant length increased under shading, resulting in plants becoming exposed to higher irradiance. In addition, shading in a plant stand, but not in the shading cages in this

study, would cause reduced red/far-red ratio, which promotes stem elongation and hence longer plants (Morgan 1981).

When irradiance was increased, the leaf area of most species showed an optimum value or was unaffected, while the RGR was unaffected. In spite of this, the dry weight of three species (*B. rapa*, *C. album*, *G. tetrahit*) increased when irradiance increased. The reason for this may be that when irradiance was raised, assimilation rate (NAR) was also increased, and, especially for *B. rapa* and *C. album*, more dry weight was allocated to root compared to shoot (decrease in shoot/root ratio). The dry weight of *S. media* and *V. arvensis* reached an optimum at 24% daylight. This would be of advantage in a dense compared to a sparse plant stand, or at low levels in the stand compared to the upper levels. These species are well adapted to living in a plant stand. They also had small plant lengths. Other weeds, which increased dry weight when irradiance was increased (*B. rapa*, *C. album*, *G. tetrahit*), may have an advantage in a sparse stand or when growing high in the stand. Since *B. rapa* and *C. album* were relatively tall species, increased dry weight with increasing irradiance may add to the significance of these species in a plant stand. However, different red/far-red ratios in the plant stand may influence height of the species differently. Regarding the dry weight, leaf area, and plant length of the weed species obtained in this study, they can be ranged as follows in descending order: *B. rapa*, *C. album*, *G. tetrahit*, *S. media*, *V. arvensis*.

On average, the plant characteristics responded to irradiance in the same way as those in the growth chambers (Semb 1996a), except that the dry weight and RGR were unaffected in this study. Only the low and medium irradiance levels in the shading cages were comparable to the irradiance levels in the growth chambers (Semb 1996a & b). The species differences with regard to number of leaves, leaf area, and dry weight were the same in the outdoor shading cages as in the growth chambers at comparable irradiances, except that *G. tetrahit* and *C. album* in this study had a similar dry weight and leaf area. In the outdoor experiment, some species (*B. rapa*, *C. album*, *V. arvensis*) were longer than those in growth chambers, probably due to a lower red/far-red ratio, and the shoot/root ratios varied compared to growth chambers studies. Growth analysis results were to some extent similar to those of the growth chambers. This means that the comparison between the shading cages and the growth chambers indicates some similarities and some discrepancies. However, taking into account the full effect of temperature and irradiance in a comparison of the shading cage and the growth chamber results, a simulation model can be used (Semb 1995).

Acknowledgements

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Effectiveness of partially acidulated and beneficiated Minjingu rock phosphate as sources of phosphorus for maize and sorghum in three acid soils of Tanzania

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Pot and field experiments were conducted to compare the agronomic effectiveness(yield and P uptake, of partially acidulated rock phosphate (25% PARP and 50% PARP) and beneficiated Minjingu rock phosphate(BMRP)to triple superphosphate(TSP, reference fertilizer) as sources of P for maize and sorghum. Two pot studies and field experiments were conducted. Maize was the test crop in the initial pot study and in the field experiments while sorghum in pot experiments was used to evaluate residual phosphate(P).Three soils, Magadu(Oxic Haplustult), Gate(Tropeptic Eustrustox) and Mlama (Volcanic derived soil - not classified), varying widely in properties were used.Results from an initial pot experiment indicated that all the P carriers had similar effectiveness to the test fertilizer in the strongly acidic Mlama soil but were inferior to TSP in the less acidic Magadu and Gate soils. In the residual P pot study results indicated that all the P amendments were equally effective to TSP in the Mlama and Gate soils and generally superior to TSP in the Magadu soil indicating that over time the P sources underwent considerable dissolution. Field experiments revealed trends similar to the initial pot experiment in the Magadu and Gate soils. The PARPs and BMRP were generally inferior to the reference fertilizer. Results of these experiments therefore established that the Minjingu rock phosphate products may be effective sources of P for the Mlama soil and other soils with similar characteristics. The PARPs could be attractive P alternatives to soils which are not very acidic.

Key words: Acid soils, agronomic effectiveness, maize, P uptake, partially acidulated phosphate rock, residual P effect, sorghum, Tanzania.

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The use of conventional phosphate-(P)fertilizers has drastically decreased in Tanzania over the years due to increases in prices of the same. With the continuing decreases in fertilizer subsidies, tangible alternatives must be worked out to increase fertilizer affordability to farmers. Efforts are now being directed to the use

of low cost indigenous fertilizer materials such as phosphate rock. In general, results of the experiments carried out in Tanzania have shown that the use of local Minjingu rock phosphate(MRP)is most effective when the soil is acidic and deficient in P(Mnkeni *et al.*, 1986; Ikerra *et al.*, 1994). Results from these experiments have shown that in most cases beneficiated Minjingu rock phosphate (BMRP) was as effective a source of P as triple superphosphate (TSP). The BMRP is obtained through sieving, drying and concentration of P in the rock material. This product is also currently been used for the production of TSP and NPK fertilizers at the Tanga factory in Tanzania.

Partial acidulation of rock phosphate has been employed in many parts of the world as an alternative way to increase solubility of the rock phosphate. Interest in the partially acidulated rock phosphate(PARP)has been mainly due to its favorable economics of production compared to superphosphate production as the former uses less acid (Friesen *et al.*, 1987). Compared to rock phosphate(RP), PARP is expensive due to acidulation but more beneficial due to enhanced solubility. In Tanzania, no work has been done to evaluate effectiveness of PARP. The PARP could be an attractive alternative product especially in areas with soils which are not very acidic. Studies conducted by Singh and Uriyo (1978) indicated the occurrence of acid soils in every district in Tanzania. Use of MRP and/or PARPs could reduce the problem of P deficiency in most parts of the country. Glasshouse and field experiments were therefore conducted to evaluate the agronomic effectiveness of PARP and BMRP in comparison to TSP as sources of P to maize and also to determine their residual P effectiveness using sorghum as a test crop.

Materials and methods

Soil samples were collected from three sites which were acidic and low in P and Ca levels. These were taken randomly from the top 20 cm to represent the experimental sites. The soil samples were air dried, thoroughly mixed and crushed to pass a 2 mm screen. Laboratory analyses of these soils included determinations of organic C (OC), pH, total N, exctractable P, CEC and exchangeable amounts of Ca, Mg, Na K, H, and Al. Organic C was determined by the wet combustion method (Nelson and Sommers, 1982), total N by Micro-Kjeldahl digestion method (Bremner and Malvaney, 1982) and available P by the Bray and Kurtz No.1 method (Bray and Kurtz, 1945). Exchangeable H and Al were determined by the KCl method (Barnihisel and Bertsch, 1982) whereas pH was electrochemically measured in water (1:1 w/v). Cation exchange capacity (CEC) was determined by the ammonium acetate saturation method (Chapman, 1965). Sodium and K were measured by flame photometry while Ca and Mg were measured by atomic absorption spectrophotometry. The results of these analyses are summarized in Table 1.

Phosphate amendments

All the P sources used in this study originated from the MinjinguRP mine situated in Arusha, Tanzania. The PARPs were made from MinjinguRP by the International Fertilizer Development Center. Acidulation levels were 50% and 25% of the proportion of phosphoric acid required to convert the calcium phosphate in the rock phosphate into monocalcium phosphate monohydrate. The proportion of the acid added is expressed as a percentage of the stoichiometric quantity of the acid required to fully acidulate the

Table 1. Some chemical properties of the soils used in the study

Soil	pH	OC (%)	P mg/kg	CEC	Ca ------(cmol/kg)----	Al
Mlama	4.7	4.8	3.9	3.6	1.35	1.0
Magadu	4.9	1.3	5.9	5.6	2.50	0.6
Gate	5.8	1.2	5.8	6.9	3.90	

rock phosphate. The TSP was made from MinjinguRP acidulated with phosphoric acid at Tanga, Tanzania. The chemical composition of the P sources used in the studies is shown in Table 2.

Pot experiments

Initial pot experiment

This study involved three soils and maize as a test crop. Four kg air dried soil was weighed into plastic pots and the following treatments were applied: Control (no P source applied), TSP, Minjingu 50% PARP, Minjingu 25% PARP and BMRP. Each of the P sources was applied at the rate of 80 Kg/ha P (recommended rate for most soils in Tanzania) by mixing thoroughly with the soil samples after which the pots were watered to approximately field capacity and incubated for one week. A two factor factorial design was used with soil as one factor, the other being P sources. The treatments were arranged in a randomized complete block design with three replicates. Five maize (*Zea mays* L. staha) were then planted in each pot. Thinning was done to two plants per pot one week after emergence. Further watering was done to maintain the soil moisture at approximately field capacity. Two weeks after emergence, sulfate of ammonia was applied at the rate of 80 kg/ha N. In addition, each pot received Zn, Cu, Mo and B equivalent to 12, 12, 1 and 2.4 $mgkg^{-1}$ of the soil weight. The nutrient carriers were $ZnSO_4.7H_2O$, $CuSO_4.5H_2O$, $(NH_4)_4Mo_7O_{24}.4H_2O$ and $Na_2B_4O_7.10H_2O$, respectively. The maize was harvested after six weeks of growth. The plants from each pot were cut 1 cm above the soil level, rinsed in distilled water and dried to constant weight at 65 °C for determinations of DM yield and tissue P concentration. The plant samples were ashed according to Juo(1979) and the P content determined by the Venado - Molybdate method (Jackson, 1958).

Table 2.Composition (by weight) of major elements in MinjinguPR products

Phosphate material	WS	Total P	CaO (%)	SO4
TSP	18.3	20.8	19.3	NA
PARP 50 %	11.2	10.0	30.0	25.3
PARP 25 %	6.3	11.7	34.0	18.0
BMRP	0	13.5	50.6	NA

WS = Water solubility NA = Not analyzed

Residual pot experiment

After harvest of maize, the soils of each pot were air dried, ground and mixed. Maize roots from the previous experiment were removed. Sorghum (*Sorghum bicolor* L. serena) was sown into the potted soils in order to evaluate the residual effectiveness of the P carriers. Harvesting was done after six weeks of growth.

Field experiments

Field experiments were conducted during the 1989/90 growing season in Magadu and Gate sites. The experimental sites were ploughed and harrowed and the study design was similar to that of the pot studies except that the treatments were

replicated four times. Plot size was 3 M x 5 M and the P sources were applied at the rate of 80 kg/ha P by broadcasting followed by incorporation into the soil before sowing. The rate of sowing was three maize seeds per hill at a spacing of 75 cm x 30 cm. Thinning was done to one plant per hill two weeks after emergence. Sulfate of ammonia was applied at 80 kg/ha N at "knee height" stage and the plots were maintained weed free throughout the growing season. Harvesting was done at maturity.

Statistical analysis

Data from each experiment was statistically analyzed as a two way factorial design. General linear model (GLM) was employed using ANOVA procedures described by Reza (1994). The least significant difference (LSD) procedure was used to compare differences between treatment means. The relative agronomic effectiveness (RAE) values were computed using grain yield from the field experiments. The formula used was as described by Engelstad *et al.*, (1974), that is :

$$RAE = \frac{YF - YC}{YR - YC} \times 100$$

where:

YR = yield due to references fertilizer
YF = yield due to tested source
YC = yield in the control treatment

Results and discussions

Pot experiments

Effect of P sources on maize yield

Maize yield and P uptake results are shown in Table 3. There was a significant ($P < 0.05$) P source x soil type interaction. This shows that the effect of the P fertilizers differed from soil to soil. The three soils varied widely in productivity as reflected by their control yield data. The basic fertility was highest in Gate soil followed by Magadu and Mlama soils. Differences in productivity were generally maintained even after P fertilization. This may be related to soil test results (Table 1) in which, for example, P levels and CEC of these soils followed a decreasing pattern similar to that of maize yields indicating a corresponding trend of decreasing fertility status.

The PARP and BMRP materials increased the yields and P uptake to the same level as TSP in the highly acidic volcanic Mlama soil. This show that the plant availability of P in PARP and BMRP were equal to that of TSP when applied to the Mlama soil. In Magadu and Gate soils TSP was generally superior to PARP and BMRP and the PARPs were superior to the BMRP. This trend was also somewhat reflected by the corresponding P uptake data, indicating differential P availability in the three soils.

The highest magnitude of response to P fertilization was observed in the Mlama soil which could be due to the lowest initial P and the highest OM content in this soil. Ikerra *et al.*, (1994) found that application of farm yard manure and compost increased effectiveness of BMRP due to increased levels of OM. The fact that even BMRP resulted in yields which were comparable to TSP and the PARPs, points to the possibility of adequate P dissolution when the soil is highly acidic. These results somewhat agree with those of Chien (1978) who observed that in acid soils some PARPs could have effectiveness similar to TSP due to reduced efficiency of P in TSP caused by its tendency to revert to less soluble P forms in the soil through fixation reactions. These reactions are less pronounced for PAPRs compared to TSP (Friesen *et al.*, 1987).

Table 3. Effect of the P sources on maize dry matter yield and P uptake in the glasshouse experiment

PR Source	Mlama		Magadu		Gate	
	DM (g/pot)	P uptake (mg/pot)	DM (g/pot)	P uptake (mg/pot)	DM (g/pot)	P uptake (mg/pot)
Control	5.7	5.3	14.4	17.4	12.4	17.2
TSP	11.8	13.4	21.4	29.2	17.9	31.4
PAPR 50%	11.2	15.1	19.2	28.4	16.0	27.1
PAPR 25%	11.7	15.3	16.4	21.8	16.1	25.9
BMPR	11.0	14.7	20.0	25.6	15.1	22.9

DM yield LSD (0.05) = 0.67 g/pot
P uptake LSD (0.05)= 0.23 mg P/pot

The superior effectiveness of the PARPs over BMRP observed in the Gate soil is probably due to the fact that the PARPs are more soluble than the BMRP (Table 2). In addition, the inherently low acidity levels of these soils compared to Mlama soil could have contributed to the lower responses observed.

Residual P pot experiment

Sorghum DM yields and P uptake results are shown in Table 4. Yields on these three soils were increased by each of the residual P treatments. The trends of these results were similar to those observed for the initial pot experiment suggesting that the responses were possibly due to increases in soil P status. For the Mlama and Gate soils, all the P sources had comparable residual effects to TSP. In the contrary, superior residual effectiveness of the PARPs relative to the test fertilizer was observed in the Magadu soil. The yield results corresponded to those of the P uptake. These results are similar to those obtained by Rajan and Watkinson(1992) and Rajan *et al.*,(1994) who reported superior residual effectiveness of the PAPRs and PRs over that of TSP.

Field experiments

The results of grain yield of maize and the amount of P in grain are shown in Table 5. The TSP fertilizer was superior

Table 4. Residual effect of P sources on sorghum yield and P uptake in the glasshouse experiment.

PR source	Mlama		Magadu		Gate	
	DM (g/pot)	P uptake (mg/pot)	DM (g/pot)	P uptake (mg/pot)	DM (g/pot)	P uptake (mg/pot)
Control	0.4	0.3	2.3	2.5	2.2	2.3
TSP	1.0	1.0	6.3	7.6	6.6	7.6
PAPR 50%	1.2	1.1	7.2	8.9	6.7	8.0
PAPR 25%	1.1	1.2	7.0	8.4	6.4	7.0
BMPR	1.1	1.2	7.3	7.7	6.8	7.7

DM yield LSD (0.05) = 0.3 g/pot
P uptake LSD (0.05) = 0.38 mg P/pot

to the other P sources in the Magadu and Gate sites. The PARPs were generally superior to BMRP and there was no significant difference ($P < 0.05$) between 25% and 50% levels of acidulation in the Gate soil. Grain P uptake indicated similar trends suggesting that part of the observed response was due to enhanced P nutrition. This observation is supported by the results in Table 6 which indicate that there were increases in soil exctractable P levels relative to the controls. Application of PARPs for example, nearly doubled P levels in the two soils indicating that the PARPs underwent considerable dissolution compared to BMRP in the two locations, hence the observed increases in grain P uptake and consequently grain yield. Hammond *et al.* (1980) also found PARPs to increase soil P levels relative to ground RP in P deficient soils.

Field experiment results were generally consistent with those obtained in the initial pot experiment. These materials could thus be good TSP substitutes in this soil. In view of its relatively low cost, direct application of BMRP is recommended for this and other soils with similar properties.

In the Gate and Magadu soils the agronomic effectiveness generally followed the order TSP > PAPRs > BMPR in the initial pot study and field experiments. This was mainly due to the relatively high pH of these soils compared to the Mlama soil. However, given the appreciable effectiveness shown by these materials, they could be used as TSP alternatives in these soils if found to be economically feasible. The PARPs and BMRP indicated equal/or superior residual effectiveness to TSP in the Mlama, Magadu and Gate soils. This may suggest that the PARPs and BMRP can be useful in supplying P for a substantial period of time to sustain crop yields on these soils. Based on the results of this study, partial acidulation of MRP could be an attractive P source to soils which are not very acidic.

Acknowledgements

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Table 5. Effect of P sources on grain yield, grain P uptake and relative agronomic effectiveness (RAE) in maize

PR material	Magadu			Gate		
	Yield (Kg/ha)	P uptake (KgP/ha)	RAE (%)	Yield (Kg/ha)	P uptake (KgP/ha)	RAE (%)
Control	2033	3.4	-	2133	3.3	-
TSP	3607	6.6	100	3483	7.2	100
PAPR 50	3400	7.0	87	3383	6.9	93
PAPR 25	3227	6.6	79	3333	6.5	89
BMPR	3082	5.7	67	3167	5.6	77

Grain yield LSD (0.05) = 99.6 Kg/ha
Grain P uptake LSD (0.05) = 0.13 Kg /ha P

Table 6. Effect of P sources on soil P and Ca levels after harvest in the field experiment.

PR source	Magadu		Gate	
	P (mg/kg)	Ca (cmol/kg)	P (mg/kg)	Ca (cmol/kg)
Control	4.93	2.47	5.16	3.47
TSP	8.31	4.73	9.33	6.94
PAPR 50	7.75	4.28	8.24	6.80
PAPR 25	8.07	4.31	7.78	6.20
BMPR	7.67	4.15	8.14	6.19

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Fungicide treatments against apple scab (Venturia inaequalis)

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In eight experiments fungicides were applied after infection, based on predictions from KMS-P electronic scab warning devices. Bitertanol mixed with tolylfluanid, penconazol mixed with tolylfluanid, difenoconazol, and the strobilurine analogue kresoxim-methyl provided very good scab control. Bitertanol mixed with wettable sulphur in a normal or low dose, low doses of either bitertanol or penconazol mixed with tolylfluanid, and dodine were less effective in some experiments, while in others, there were no differences in level of control, compared to the best treatments. Lowering the doses of bitertanol or penconazol according to the time between predicted infection and fungicide application reduced the chemical rates by 33-75%. In one experiment with a 7-14-day protective spray programme, kresoxim-methyl, difenoconazol, dithianon, and tolylfluanid provided very good scab control, whereas a low dose of wettable sulphur was slightly less effective.

Keywords: Bitertanol, difenoconazol, ditihanon, dodine, kresoxim-methyl, penconazol, scab warning, strobilurine, sulphur, tolylfluanid, *Venturia inaequalis*.

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Apple scab is caused by the fungal pathogen *Venturia inaequalis* (Cooke) Winter (anamorph *Spilocaea pomi* Fries). Ascospores, spread during rain from pseudothecia overwintering in apple leaf litter on the ground, are the main inoculum source for primary infections in spring and early summer. In Norway, the season for ascospore release in the apple scab fungus usually lasts 6-10 weeks from the time of apple bud break, with the main spore release from the tight cluster stage to 1-2 weeks after petal fall of the apple flower (Stensvand 1993). This is in agreement with observations made in other countries (Hirst & Stedman 1962, Szkolnik 1974, Brook 1976, Gadoury & MacHardy 1982). The most important period in which to apply fungicides against apple scab is within the main period of spore release. In Norway, the season for ascospore release in *V. inaequalis* usually comes to an end in mid or late June (Stensvand 1993).

Postinfection fungicide treatments against apple scab are based on the use of electronic scab warning devices and curative fungicides. Mills's table (Mills & Laplante 1951) indicates the time needed with moist apple tissue at different

temperatures for infections to occur. Mills's table or revised forms of it (MacHardy & Gadoury 1989), incorporated into the scab warning devices, is the basis for disease prediction.

In recent years, the main curative fungicides in Norway have been the demethylation inhibiting fungicides (DMI fungicides) and dodine. Currently, the most important DMI fungicides for scab control in Norway are bitertanol and penconazol. DMI fungicides inhibit a demethylation step in the fungal sterol biosynthesis, while dodine affects the permeability of the cell membrane and inhibits respiration (Sijpesteijn 1982).

A new group of fungicides, the strobilurines, has recently been developed (Beautement *et al.* 1991, Ammermann *et al.* 1992, Godwin *et al.* 1992). These are synthetically developed fungicides, based on chemical structures of secondary metabolites of the basidiomycete *Strobilurus tenacellus* (Persoon ex Fries) Singer. The strobilurines inhibit the mitochondrial respiration (Brandt & von Jagow 1991), and has both a curative and protective effect against the apple scab fungus (Creemers 1994).

Growers in Norway usually tank-mix a curative and a protective fungicide when spraying after infection against apple scab. This can reduce the number of sprayings if infection periods are frequent. The most common protectant fungicides for apple scab management in Norway are tolylfluanid, wettable sulphur, and mancozeb.

Because of an increasing demand for a reduction in pesticide use and the high cost of fungicides, many Norwegian apple growers lower the doses of DMI fungicides, depending on the time from the predicted infection until application.
Eight experiments have been conducted to evaluate fungicides in different mixes and doses, applied after infection, based on predictions from an electronic scab warning device. Furthermore, the effects of fungicides were tested in one experiment in a 7-14 day-protective spray schedule. Preliminary results from these experiments have already been reported (Amundsen *et al.* 1991, Stensvand *et al.* 1993), as well as having been presented in a doctoral thesis (Stensvand 1993).

Materials and methods

The experiments were carried out at two locations in southeastern Norway in 1990-93; at Sauherad with the cultivar 'Vista Bella', and at Ås with the cultivar 'Lobo'. Both cultivars are very susceptible to apple scab. The dates of different phenophases of the apple flower buds are recorded in Table 3.

In the postinfection programme, no fungicides were applied prior to the 1 cm green stage, which occurs between the green tip and tight cluster stages. After this stage, fungicides were applied, as soon as the weather permitted after an infection was predicted, usually within 1-3 days. The shortest interval between applications was 7 days until 1-2 weeks after petal fall, and 10 days later in the season. This means that if an infection period was predicted within 7 or 10 days after the previous application, no fungicides were applied.

In one experiment in 1993, various fungicides were compared in a protective 7-14-day interval spray programme.

An overview of the fungicides tested is presented in Table 1. Dodine was withdrawn from the Norwegian market in 1995, difenoconazol and dithianon have not yet been approved in Norway, and the

Table 1. The fungicides,product, g active ingredient (a.i.) per kg or L, and manufacturing company

Fungicide	Product	a.i.	Manufacturer
1-3. DMI fungicides:			
1. Bitertanol	Baycor 25 WP	250g/kg	Bayer AG, Leverkusen, Germany
2. Penconazol	Topas 100 EC	100g/L	Ciba-Geigy, Basel, Switzerland
3. Difenoconazol	Score	250g/L	"
4. Dodine	Melprex	650g/kg	Cyanamid International, Wayne, New Jersey, USA
5. Kresoxim-methyl	BAS 490 02 F (test fungicide)	500g/kg	BASF AG, Ludwigshafen am Rhein, Germany
6-8. Protectant fungicides:			
6. Tolylfluanid	Euparen M	500g/kg	Bayer AG, Leverkusen, Germany
7. Wettable sulphur	Bayer Svovel	800g/kg	"
8. Dithianon	Delan SC 750	750g/L	Shell International Chemical Co., Ltd, London, England

strobilurine analogue kresoxim-methyl was in a test formulation.

The highest bitertanol dose mixed with tolylfluanid was used as a standard for comparison with the other fungicides in all experiments with postinfection applications.

The assumed amount of time required following a prediction of infection to give a sufficient curative effect at different doses and temperatures for bitertanol and penconazol, is based on advisory service recommendations for growers (Anonymous 1995). In three of the treatments, one with bitertanol mixed with tolylfluanid, one with bitertanol mixed with sulphur, and one with penconazol mixed with tolylfluanid, the doses of bitertanol and penconazol varied according to Table 2. Thus, as the time between predicted infection and application was shortened, fungicide doses were reduced.

The doses of difenoconazol, dodine, kresoxim-methyl, and dithianon were applied as recommended by the manufacturers. To prevent damage to pubescent fruit, the dodine dose was reduced by 50% after bloom. The tolylfluanid concentration was 50% of the highest dose recommended by the manufacturer. The doses of wettable sulphur in the postinfection treatments were as recommended by the manufacturer in one treatment, and reduced to 1/3 in two other treatments.

Table 2. Curative effect against apple scab for bitertanol and penconazol, in hours since predicted infection at different temperatures. Concentrations (doses) of fungicides in g or ml per 100 L as recommended for growers in Norway (Anonymous 1995). Product and g active ingredient are presented in Table 1

Fungicide	g or ml product per 100 L	Curative effect in hours			
		<8°C	9-12°C	13-15°C	>15°C
Bitertanol	50 g	84	60	48	48
	25 g	60	54	42	36
	12.5 g	48	48	36	24
Penconazol	25 ml	120	96	72	72
	12.5 ml	60	48	36	36

Table 3. Dates (day/month) of phenophases 1990-93 assessed in the cultivars 'Vista Bella' at Sauherad and 'Lobo' at Ås

Location and year	Green tip	Tight cluster	Pink	Bloom	Petal fall
Sauherad					
1990	25/3	20/4	30/4	4/5	7/5
1991	15/4	10/5	18/5	22/5	27/5
1992	15/4	10/5	19/5	22/5	25/5
1993	23/4	30/4	10/5	19/5	23/5
Ås					
1990	4/4	25/4	4/5	7/5	10/5
1991	23/4	10/5	20/5	27/5	3/6

In the protective spray programme the dose of wettable sulphur was 1/3 of the normal dose, which was in accordance with the Norwegian guidelines for integrated apple production (Hesjedal & Edland 1991).

The trees were sprayed to run off, with handgun and high-pressure sprayers. The amount of fungicide applied varied with tree size and time of the season. At Sauherad the variation was between 500 and 1500 L/ha, while at Ås it varied between 1000 and 2500 L/ha.

Weather data were obtained from KMS-P electronic scab warning devices (Anton Paar KG, Graz, Austria, manufactured 1989). The data provided hourly records of precipitation, temperature, relative humidity, and leaf wetness. Predicted infection periods from the green tip stage to the end of July are listed in Table 4. Postinfection fungicide applications were based on Mills's table for light infection (Mills & Laplante 1951). In 1990 at Ås (Table 7), there were two occasions, April 17 and May 14, when the water on the leaf wetness sensors dried 1-2 h prior to a calculated infection and 3-4 h before the apple foliage was dry. Fungicides were applied on April 19 and May 15. The scab warning device at Sauherad was located in an orchard app-

Table 4. Dates (day/month) of infection periods from the green tip stage to the end of July, predicted by KMS-P electronic scab warning devices at Sauherad and Ås 1990-93. The severity of the infection periods in parentheses, as according to Mills & Laplante (1951), L = low, M = medium, S = severe

	Dates of predicted infections							
Sauherad								
1990	16/4(M), 23/6(S),	19/4(M), 25/6(S),	22/4(S), 2/7(S),	24/5(M) 5/7(S),	2/6(S), 9/7(S),	8/6(S), 17/7(L),	19/6(S), 29/7(L),	21/6(S), 31/7(L)
1991	4/6(L), 17/7(S),	11/6(L), 21/7(S),	12/6(S), 25/7(L),	17/6(S), 28/7(L)	23/6(S),	26/6(M),	12/7(S),	14/7(S),
1992	15/4(L), 18/7(S),	28/4(S), 20/7(M),	2/5(M), 22/7(S),	13/6(S), 25/7(S),	1/7(S), 26/7(S),	11/7(S), 31/7(L)	13/7(S),	15/7(L),
1993	25/4(L), 20/6(L), 24/7(M),	3/5(S), 25/6(S), 27/7(M),	15/5(L), 27/6(L), 29/7(L),	21/5(L), 9/7(L), 30/7(S)	23/5(S), 11/7(M),	24/5(L), 13/7(S),	1/6(L), 15/7(S),	15/6(L), 22/7(S),
Ås								
1990	3/4(L), 21/6(S), 29/7(M),	17/4(L), 23/6(M), 31/7(M)	23/5(S), 26/6(M),	3/6(S), 28/6(M),	5/6(M), 2,7(S),	7/6(L), 6/7(S),	17/6(L), 8/7(S),	19/6(S), 22/7(S),
1991	8/6(L), 12/7(M),	12/6(S), 14/7(L),	15/6(M), 17/7(S),	19/6(L), 19/7(L),	21/6(M), 21/7(S)	23/6(S),	26/6(M),	29/6(M),

roximately 1 km from the experimental site, while at Ås it was located at the experimental site.

The spray plots were in randomized blocks. At Sauherad each treatment had three replications and at Ås two replications.

At Sauherad, two different plantings were used, both within the same commercial orchard, and with slender spindle trees grafted on rootstock M26. The trees in the 1990 and 1991 experiments were planted in 1987 in double rows on 2.5 m x 4+1 m, while the trees in the 1992 and 1993 experiments were planted in 1990 in single rows on 1.5 m x 4 m. Each treatment plot consisted of a row of five trees, with one additional untreated tree on each side within the row.

At Ås, the planting was 3-4 m tall crown trees grafted on rootstock M2, planted in 1963 on 2 m x 4 m. The experimental plots were within a research plot consisting of rows with different cultivars, but with the same cultivar in each row. Each treatment plot consisted of 8-10 trees in a row, with an open area of approximately 5 m between each plot.

Disease assessments were made on the three trees in the middle of the plot, and were made once towards the end of the primary inoculum season and once at harvest time.

On the foliage, the number of lesions found on all leaves of 30 shoots on each of the three trees was recorded in each

Table 5. Reduction in fungicide use by varying bitertanol and penconazol doses according to time of application, in percent of the standard dose

Location and year	Bitertanol	Penconazol
Sauherad		
1990	75%	-
1991	50%	-
1992	50%	33%
1993	61%	36%
Ås		
1990	33%	-
1991	50%	-

- = not tested

treatment plot. In 1992, only 20 shoots were recorded on each of three trees. In the first assessment in the season, lesions on both spurs and terminal shoots were recorded (approximately half of each). In the last assessment mostly terminal shoots were recorded. Spur leaves and terminal leaves were not separated in the statistical analysis.

In the first assessment of the season, the number of lesions on 90 fruits was recorded for each treatment plot, with the exception of plots where the number of fruits was less, and from Sauherad 1992, where no fruits were recorded. In the last assessment, the numbers of fruits recorded at Ås were 90 and 200 per treatment plot in 1990 and 1991, respectively, while at Sauherad all fruits were recorded per treatment plot. The number of fruits in each plot varied between approximately 50 and 500 at Sauherad.
F-tests were run by using mean numbers from each treatment plot of leaf lesions per shoot and percentage of fruits with scab. Because of the great difference between treated and untreated plots, and thus a high standard deviation, two F-tests (á=0.05) were run for each experiment, one with and one without the untreated control. The level of significance in the F-tests is indicated in the tables as follows:
n.s. = no significant difference,
* = $p \leq 0.05$
** = $p \leq 0.01$
*** = $p \leq 0.001$
Least significant difference (LSD 5%) was calculated.

Results

When DMI fungicides applied after infection were not mixed with a preventive fungicide, bitertanol (Table 7) and penconazol (Tables 11 and 12) provided poor control, while difenoconazol (Tables 6, 8, 11, 12) gave excellent control. In all of these experiments difenoconazol gave as good a control as bitertanol or penconazol mixed with a protective fungicide. In the protective 7-14-day spray programme in 1993, difenoconazol gave excellent control (Table 14).

The standard dose of bitertanol mixed with tolylfluanid (Tables 6-13) gave good to excellent control in all experiments. In 3 of 5 trials the low dose of bitertanol in mixtures with tolylfluanid gave very good control (Tables 6, 7, and 12). In two experiments, scab control was reduced in the fruits at harvest, compared to the full dose (Tables 8 and 11), but was significantly different in the fruits in one experiment only (Table 8).

In the two experiments where bitertanol and wettable sulphur were mixed in various doses (Tables 9 and 10), the scab control was not significantly reduced compared to the results with standard doses of bitertanol and tolylfluanid. In one of the experiments (Table 10), however,

the mean values for scab attack on both foliage and fruits were relatively high for all the sulphur treatments.

The highest dose of penconazol mixed with tolylfluanid gave as good an effect as the standard bitertanol mixed with tolylfluanid in 1992 (Table 11). In 1993 (Table 12) the scab control on the foliage at harvest was slightly reduced. There were no significant differences between the high and low penconazol doses, although the mean values for scab attack at the lowest dose in 1992 (Table 11) were much higher.

Dodine proved to be very effective in one experiment (Table 6). In two of the experiments (Tables 7 and 8), the control was slightly less on the foliage at harvest than in the best treatment. The mean values for fruit infections (Tables 7 and 8) were high, but not significantly different from the best treatment.

Kresoxim-methyl showed excellent control, both for applications after infection and in a 7-14-day protective spray schedule (Tables 13 and 14).

Both dithianon and tolylfluanid gave excellent control in the protective spray schedule, while the low dose of wettable sulphur was slightly less effective (Table 14).

The number of fungicide applications against apple scab per season in the postinfection programme varied between two and seven, with a mean of 4.25. In the protective spray programme in 1993, fungicides were applied eight times.
By varying the bitertanol and penconazol doses according to the time between predicted infection and application, 33-75% bitertanol and 33-36% penconazol was saved compared to the normal doses (Table 5).

Table 6. Control of apple scab (*Venturia inaequalis*) on cultivar 'Vista Bella' with fungicides applied after infection at Sauherad in 1990. Product and g active ingredient are presented in Table 1. Dates of application (day/month): 17/4, 24/4, 8/6

Fungicide	g or ml product per 100 L	13 June		7 August	
		Leaf lesions per shoot	% fruits with scab	Leaf lesions per shoot	% fruits with scab
Untreated		0.17	12.15	9.41	53.80
Bitertanol + tolylfluanid	50 g 75 g	0.03	0.00	0.10	1.50
Bitertanol + tolylfluanid	12.5-50 g 75 g	0.00	0.00	0.52	2.70
Difenoconazol	30 ml	0.02	0.00	0.35	0.00
Dodine	30-60 g	0.01	1.65	0.75	1.83
F-test with untreated	**	*	***	***	
LSD 5%		0.05	5.30	2.98	7.83
F-test without untreated	n.s.	n.s.	n.s.	n.s.	
LSD 5%		(0.05)	(3.71)	(0.51)	(2.82)

Table 7. Control of apple scab (*Venturia inaequalis*) on cultivar 'Lobo' with fungicides applied after infection at Ås 1990. Product and g active ingredient are presented in Table 1. Dates of application (day/month): 19/4, 15/5, 25/5, 4/6, 18/6, 27/6, 9/7

Fungicide	g or ml product per 100 L	19 June Leaf lesions per shoot	19 June % fruits with scab	20 September Leaf lesions per shoot	20 September % fruits with scab
Untreated		0.53	23.90	16.51	70.00
Bitertanol + tolylfluanid	50 g 75 g	0.21	7.75	0.25	6.15
Bitertanol + tolylfluanid	12.5-50 g 75 g	0.22	3.30	0.10	1.65
Bitertanol	50 g	0.30	9.45	0.72	17.80
Dodine	30-60 g	0.20	10.55	1.20	10.00
F-test with untreated		n.s.	n.s.	**	**
LSD 5%		(0.30)	(13.91)	4.95	17.88
F-test without untreated		n.s.	n.s.	*	*
LSD 5%		(0.38)	(14.25)	0.45	8.81

Table 8. Control of apple scab (*Venturia inaequalis*) on cultivar 'Vista Bella' with fungicides applied after infection at Sauherad 1991. Product and g active ingredient are presented in Table 1. Dates of application (day/month): 4/6, 14/6

Fungicide	g or ml product per 100 L	22 May Leaf lesions per shoot	22 May % fruits with scab	22 August Leaf lesions per shoot	22 August % fruits with scab
Untreated		0	0	5.82	86.37
Bitertanol + tolylfluanid	50 g 75 g	0	0	0.01	1.60
Bitertanol + tolylfluanid	12.5-50 g 75 g	0	0	0.02	16.43
Difenoconazol	30 ml	0	0	0.00	0.00
Dodine	30-60 g	0	0	0.04	7.17
F-test with untreated		-	-	***	***
LSD 5%		-	-	1.65	8.27
F-test without untreated		-	-	*	**
LSD 5%		-	-	0.03	8.13

Table 9. Control of apple scab (*Venturia inaequalis*) on cultivar 'Vista Bella' with fungicides applied after infection at Sauherad 1991. Product and g active ingredient are presented in Table 1. Dates of application (day/month): 4/6, 14/6, 25/6

Fungicide	g or ml product per 100 L	22 May Leaf lesions per shoot	22 May % fruits with scab	26 August Leaf lesions per shoot	26 August % fruits with scab
Untreated		0	0	2.64	47.80
Bitertanol + tolylfluanid	50 g 75 g	0	0	0.00	0.27
Bitertanol + sulphur	50 g 450 g	0	0	0.01	0.07
Bitertanol + sulphur	50 g 150 g	0	0	0.01	1.03
Bitertanol + sulphur	12.5-50 g 150g	0	0	0.05	2.70
F-test with untreated		-	-	*	**
LSD 5%		-	-	2.31	17.67
F-test without untreated		-	-	n.s.	n.s.
LSD 5%		-	-	(0.04)	(3.02)

Table 10. Control of apple scab (*Venturia inaequalis*) on cultivar 'Lobo' with fungicides applied after infection at Ås 1991. Product and g active ingredient are presented in Table 1. Dates of application (day/month): 9/6, 17/6, 28/6

Fungicide	g or ml product per 100 L	9 July Leaf lesions per shoot	9 July % fruits with scab	27 September Leaf lesions per shoot	27 September % fruits with scab
Untreated		7.36	2.20	25.32	71.00
Bitertanol + tolylfluanid	50 g 75 g	0.09	0.00	0.75	2.50
Bitertanol + sulphur	50 g 450 g	0.38	0.55	5.62	9.25
Bitertanol + sulphur	50 g 150 g	0.19	0.55	2.56	9.50
Bitertanol + sulphur	12.5-50 g 50 g	0.19	0.55	3.48	10.50
F-test with untreated		n.s.	*	***	**
LSD 5%		(9.14)	1.18	4.73	24.40
F-test without untreated		n.s.	n.s.	n.s.	n.s.
LSD 5%		(0.57)	(1.24)	(4.59)	(14.97)

Table 11. Control of apple scab (*Venturia inaequalis*) on cultivar 'Vista Bella' with fungicides applied after infection at Sauherad 1992. Product and g active ingredient are presented in Table 1. Dates of application (day/month): 29/4, 15/6, 1/7

Fungicide	g or ml product per 100 L	25 June Leaf lesions per shoot	25 June % fruits with scab	7 August Leaf lesions per shoot	7 August % fruits with scab
Untreated		2.47	-	12.68	83.80
Bitertanol + tolylfluanid	50 g 75 g	1.02	-	1.23	8.93
Bitertanol + tolylfluanid	12.5-50 g 75 g	0.86	-	2.60	15.23
Difenoconazol	30 ml	0.24	-	0.28	3.10
Penconazol	25 ml	3.68	-	7.35	29.80
Penconazol + tolylfluanid	25 ml 75 g	1.23	-	2.45	3.90
Penconazol + tolylfluanid	12.5-25 ml 75 g	1.12	-	5.52	18.77
F-test with untreated		**	-	n.s.	***
LSD 5%		1.25	-	(8.51)	17.31
F-test without untreated		**	-	n.s.	*
LSD 5%		1.34	-	(5.95)	18.37

Discussion

We have shown that several chemicals can provide effective control against the apple scab fungus when sprayed after predicted infections. Difenoconazol, the strobilurine analogue kresoxim-methyl, and bitertanol or penconazol mixed with tolylfluanid gave the best effect. In one experiment with a protective spray programme, difenoconazol, kresoxim-methyl, tolylfluanid, and dithianon showed excellent activity.

If new infections were predicted within 7 or 10 days after an application, fungicides were not applied. The protective activity of bitertanol or penconazol was probably too short to inhibit such new infections if these fungicides were not mixed with protectants. One example of this took place at Ås in 1990 (Tables 4 and 7), when the bitertanol treatment applied on June 4 probably had little effect on the infection period that occurred on June 7. Another was at Sauherad in 1993 (Tables 4 and 12), when the penconazol treatment applied on May 18 probably had little effect on the predicted infection on May 21. The effect of different DMI fungicides varies greatly (Szkolnik 1985, Palm 1987, Wilcox *et al.* 1991). In Ontario, Canada, Warner (1990) tested several DMI fungicides used alone or in a mixture with protective fungicides in a

Table 12. Control of apple scab (*Venturia inaequalis*) on cultivar 'Vista Bella' with fungicides applied after infection at Sauherad 1993. Product and g active ingredient are presented in Table 1. Dates of application (day/month): 26/4, 4/5, 18/5, 26/5, 3/6, 16/6, 25/6

Fungicide	g or ml product per 100 L	24 June Leaf lesions per shoot	24 June % fruits with scab	25 August Leaf lesions per shoot	25 August % fruits with scab
Untreated		11.55	25.93	11.05	85.47
Bitertanol + tolylfluanid	50 g 75 g	0.79	0.37	0.93	0.30
Bitertanol + tolylfluanid	12.5-50 g 75 g	1.55	0.00	1.24	1.13
Difenoconazol	30 ml	0.18	0.00	0.02	0.00
Penconazol	25 ml	4.00	4.07	5.69	9.10
Penconazol + tolylfluanid	25 ml 75 g	2.53	0.00	3.99	1.17
Penconazol + tolylfluanid	12.5-25 ml 75 g	3.59	0.00	3.59	1.60
F-test with untreated		***	***	***	***
LSD 5%		3.20	8.39	3.90	7.57
F-test without untreated		**	n.s.	**	*
LSD 5%		1.88	(5.30)	2.61	5.40

Table 13. Control of apple scab (*Venturia inaequalis*) on cultivar 'Vista Bella' with fungicides applied after infection at Sauherad 1993. Product and g active ingredient are presented in Table 1. Dates of application (day/month): 26/4, 4/5, 18/5, 26/5, 3/6, 16/6, 25/6

Fungicide	g or ml product per 100 L	24 June Leaf lesions per shoot	24 June % fruits with scab	25 August Leaf lesions per shoot	25 August % fruits with scab
Untreated		6.30	24.43	6.09	57.23
Bitertanol + tolylfluanid	50 g 75 g	0.73	0.00	0.66	1.17
Kresoxim-methyl	20 g	0.14	0.37	0.07	0.00
F-test with untreated		***	***	***	**
LSD 5%		1.22	5.17	2.02	32.71
F-test without untreated		n.s.	n.s.	n.s.	n.s.
LSD 5%		(2.00)	(1.58)	(2.05)	(5.02)

Table 14. Control of apple scab (*Venturia inaequalis*) on cultivar 'Vista Bella with fungicides applied in a 7-14 day spray schedule at Sauherad 1993. Product and g active ingredient are presented in Table 1. Dates of application (day/month): 23/4, 30/4, 12/5, 19/5, 26/5, 3/6, 11/6, 25/6

Fungicide	g or ml product per 100 L	24 June Leaf lesions per shoot	24 June % fruits with scab	25 August Leaf lesions per shoot	25 August % fruits with scab
Untreated[1]		6.30	24.43	6.09	57.23
Difenoconazol	30 ml	0.00	0.00	0.02	0.00
Dithianon	50 ml	0.32	0.00	0.51	0.47
Kresoxim-methyl	20 g	0.66	0.00	0.59	0.00
Sulphur	150 g	2.80	2.93	3.78	6.97
Tolylfluanid	75 g	0.53	0.00	0.71	0.00
F-test with untreated		***	***	***	***
LSD 5%		1.16	2.90	1.27	18.13
F-test without untreated		**	***	***	*
LSD 5%		1.31	0.53	1.07	4.83

[1]Identical with untreated in Table 13

Ontario, Canada, Warner (1990) tested several DMI fungicides used alone or in a mixture with protective fungicides in a regular preventive spray schedule. Bitertanol mixed with captan, or penconazol mixed with mancozeb provided good control, while the effect of bitertanol or penconazol used alone was poor. In Switzerland, Siegfried *et al.* (1993) had excellent results with difenoconazol mixed with a protectant fungicide, even in years when scab control was difficult. Both penconazol and bitertanol in mixes with protectants, showed a reduced effect in difficult scab years compared to difenoconazol. In an earlier investigation from Switzerland (Bosshard *et al.* 1985), it was reported that penconazol and bitertanol provided very good scab control, despite high infection pressure. A shift towards more resistant *V. inaequalis* strains might explain this difference (Siegfried *et al.* 1993).

In our experiments, fungicides were applied up to 3-4 days after an infection was predicted. Schwabe (1980) reported that dodine was highly effective as a curative fungicide, but for a shorter time after the start of an infection period than the DMI fungicides. This explains some of the slightly reduced effect of dodine compared to the best treatments in our experiments.

By varying the doses of bitertanol and penconazol with time of application, we managed to save significant amounts of chemicals, but in some of the experiments the scab control was reduced. We used very susceptible cultivars and, with the exception of at Sauherad in 1990, there was a high inoculum pressure in the orchards. Lowering the fungicide doses should probably only be done with less susceptible cultivars, at low inoculum

levels, and in areas with few infection periods per season. It is claimed that the frequency of a *V. inaequalis* population tolerant to a DMI fungicide is inversely proportional to the concentration of that material (Köller & Scheinpflug 1987, Köller *et al.* 1991, Smith *et al.* 1991, Köller 1994). Low doses of DMI fungicides could thus increase the population of fungicide resistant *V. inaequalis* strains.

There have been reports from several countries of *V. inaequalis* strains less sensitive to fungicides and loss of disease control because of excessive use of both dodine (Szkolnik & Gilpatrick 1969, 1973, Ross & Newbery 1977, Schwabe 1977, McKay & MacNeill 1979, Cesari *et al.* 1985, Sholberg *et al.* 1989) and DMI fungicides (Stanis & Jones 1985, Thind *et al.* 1986, Fiaccadori *et al.* 1987, Enisz 1988, Hildebrand *et al.* 1988, Hermann *et al.* 1989). It will therefore be important to prevent buildup of *V. inaequalis* strains resistant to curative fungicides in Norwegian orchards.

Köller & Scheinpflug (1987) and Köller (1994) pointed out that it is important to alternate between curative fungicides with different mechanisms of action, e.g. between dodine and DMI fungicides. Since dodine is with-drawn from the Norwegian market, the strobilurines might be a future alternative. The excellent effect of kresoxim-methyl found in our studies concours with that found by Creemers (1994) in Belgium. He found that in both a 7-14-day and a 10-14-day protective spray schedule, the effect of kresoxim-methyl was compara-ble to or even better than the best standard scheme in which difenoconazol was mixed with captan. Furthermore, in a 4- or 6-day postinfection spray programme, kresoxim-methyl F had the same effect as difenoconazol mixed with captan (Creemers 1994).

At Sauherad 1990 (Tables 4 and 6), there were two occasions towards the end of the primary inoculum season when infections were predicted, but no fungicides were applied. Scab control was not lost, possibly because the inoculum level was relatively low. On the contrary, on one occasion at Sauherad 1992 (Table 11), in mid-May, an infection period should probably have been predicted, but the leaf wetness sensors became dry too early compared to the apple foliage. No fungicides were applied, and this might explain the high scab attack in the treated plots that year.

In reports from other countries, postinfection spray programmes have reduced the numbers of fungicide applications significantly when compared to protective spray programmes (Penrose *et al.* 1985, Norin 1989, Lykke Nielsen & Schadegg 1990, Siegfried *et al.* 1990). The number of applications in a postinfection programme will vary with the frequency of infection periods. In our experiments, the mean number of fungicide applications was low. We obtained good scab control by applying no more than 3-4 fungicide sprays in some years, even though there were numerous infection periods at the end of June and in July, after the season for ascospore release was over.

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Nutrient and water balances in lysimeter experiments
I. Barley yields, water use and water balances

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The relationship between barley yield and water balances was investigated in weighing lysimeters with 4 soils, 2 water regimes and 4 nutrient treatments. Irrigation, 100 mm per season, increased barley yield at all fertilizer levels in the dry years 1993 and, in particular 1992, but only at the highest rate of fertilizer application (16 g N/m^2) in 1990 and 1991. The evapotranspiration (May-October) increased and drainage losses decreased by respectively 10 and 8 mm per 100 g/m^2 increase in grain + straw yield. Evapotranspiration of added water increased from 10% at the lowest fertilizer rate (3 g N/m^2) in 1990 to 95% at the highest fertilizer rate in 1992. Increased drainage was responsible for the rest. The increased drainage after irrigation in May-July was delayed to rainy periods in October. There were fairly small differences in evapotranspiration, drainage and effect of irrigation between soils.

Key words: Drainage, evapotranspiration, fertilizers, monoliths, soils, yields.

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Different methods are used for measuring the loss of water and nutrients from agricultural land. In lysimeters precise comparisons can be made between selected treatments, and significant effects can readily be demonstrated. However, a more open question might be to what extent the results from lysimeters will apply to more general field conditions.

A weakness of ordinary lysimeter experiments under Nordic weather conditions is that measurements of surface runoff are not readily included. In districts where the winter precipitation falls on frozen ground and mostly as snow, a considerable part of the yearly runoff will be as surface water. In field lysimeter plots on sloping land at Ås Uhlen (1989) found, as an average for 8 years, 160 mm surface runoff and 230 mm drainage water of a precipitation of 790 mm per year. The proportion of surface runoff of the total runoff varies from site to site and between years (Lundekvam 1993).

The results presented in this paper are from weighing type lysimeters, and include filled cylinders as well as undisturbed soil columns (monoliths).

Material and methods

Seventy-two weighing cylinders, 110 cm deep and 80 cm in diameter, were placed outdoors above an underground cellar (Uhlen et al. 1992). Four soils from agricultural areas in Norway were used:

A. Loam/sandy loam, morainic soil: 14% clay at a depth of 0-20 cm and less than 10% in the deeper layers. 34-40% silt.

B. Silt loam: 20% clay and 55% silt in the upper layers, increasing to 23% clay and 67% silt at 50-100 cm depth.

L. Loamy sand: Only 3-4% clay and a decreasing silt (26-4%) and increasing sand (70-94%) content in the deeper layers.

Ø. Clay loam: 32% clay and 44% silt at 0-20 cm depth, and 50% clay at 50-100 cm.

Organic matter content was 5-7% at a depth of 0-20 cm for all four soils. Physical available water (pF 2-4,2) at 0-100cm was 140 mm for the sandy soil (L) and 180-200 for the A, B and Ø soils. Fig. 1 shows the soil moisture characteristics curves of the four soils.

For soils B and Ø, 8 cylinders were filled layer by layer and 8 were left as undisturbed monoliths. For soils A and L 16 cylinders were filled and only 2, respectively 4, were taken out as undisturbed monoliths.

The following water regimes were compared:

I No irrigations and the cylinders were protected from winter precipitation from 1 January to 31 March in 1990, 1991 and 1992.

II No protection in the winter months and

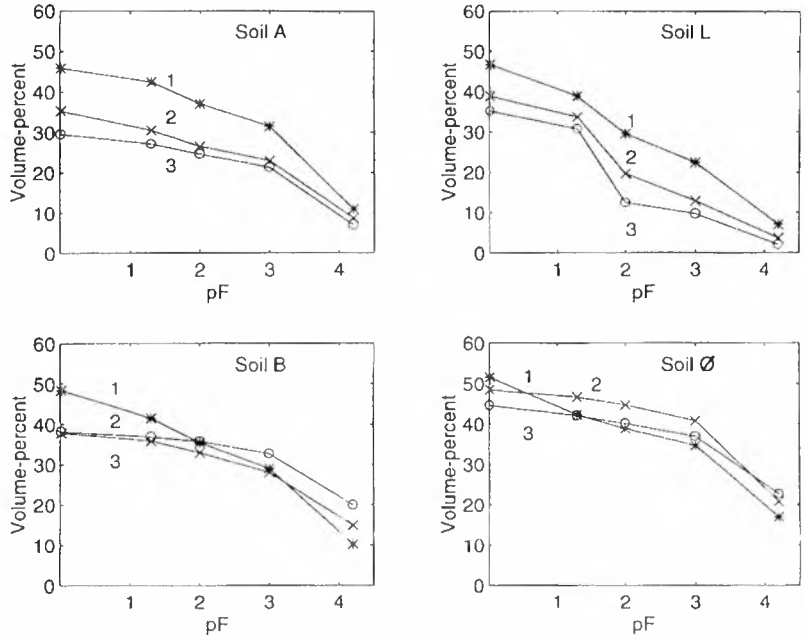

Fig. 1 Soil moisture characteristic curves for four soils used in lysimeter experiments (1 = 0-20 cm, 2 = 20-40 cm,3 = 40-100 cm)

irrigation, gently applied from a garden can in doses of 20 mm in May to July. (100, 80, 120 and 100 mm in 1990, 1991, 1992 and 1993 respectively).

In 1993 and 1994 regimes I and II were given the same winter treatments, protected in 1993 and unprotected in 1994.

Fertilizer treatments:

a. 3 g N per m^2 and year in ammonium nitrate. Phosphorus and potassium fertilizer not added.
b. 9.5 g N per m^2 and year in NPK 18-3-15.
c. 16 g N per m^2 and year in NPK 18-3-15
d. 3 g N in ammonium nitrate and 4 kg per m^2 of cow manure applied in autumn 1989 and 1992 and in spring 1991 and 1992.

The drainage was collected in 30 l polyethylene cans. No day to day registrations were performed. The water balances were followed by weighing of each lysimeter cylinder at 10-20 day intervals from 1 May to October-November. The evapotranspiration in millimetres, calculated from changes in weight, precipitation + irrigation and leaching, was restricted to this period, and for most of the comparisons made the drainage in millimetres was calculated from May to December. For nutrient leaching losses, however, the subsequent winter months had to be included, too.

Precipitation in millimetres and mean air temperature are presented in Table 1 for the actual experimental years (1 May to 30 April) together with the 1961-90 normals at Ås. May was dry in all four years, while June and the first half of July were dry in 1992 and 1993.

In all four years two rows of barley, Pernilla, were sown at the beginning of May and harvested in the first or second week of August. Perennial ryegrass was seeded in with barley in one of two replicates of soils A and L in 1991 and 1992. The harvested yields of the ryegrass were mixed into the soil in late autumn. Barley was also sown in small areas around the lysimeter cylinders (30 cm apart).

Owing to the higher dry bulk density of the soil below the plough layer the total weight of soil per cylinder was almost 100 kg higher for monoliths than for filled cylinders for the clay soils. Nevertheless, open slits caused by shrinkage, appeared along the cylinder walls in the clay soil monoliths. These slits were filled with polyurethane foam at the start of the experiment in 1989. After heavy rain,

Table 1.Climatic conditions in the experimental years (1 May - 30 April.)

	Precipitation, mm				Air temperature, °C			
	May-June	July-Aug.	Sept.-Dec.	Jan.-April	May-June	July-Aug.	Sept-Dec.	Jan-April
1990/91	106	151	306	198	13.2	15.8	3.3	-0.5
1991/92	101	96	377	173	10.8	16.6	5.1	1.5
1992/93	46	242	323	116	15.0	15.0	3.4	1.3
1993/94	82	178	365	247	13.0	13.7	2.3	-1.9
Normals 1961-90	128	164	322	171	12.5	15.5	3.5	-1.4

however, the water infiltration in some of the monoliths of soil Ø became too slow for satisfactory drainage, especially in autumn and winter.

In calculating evapotranspiration and drainage losses some of the monoliths had to be abandoned because of leakages in the bottom of the fiberglass cylinders in the last two years. The statistical analyses are therefore based on mean values of 1 or 2 replicates using the interaction soil x water x fertilizer (Table 2) or soil x water x fertilizer x year (Tables 4 and 5) as error terms. The results from one year to the next may not be strictly independent, and the above 3-factor interaction should be used as an error term if larger than the 4-factor interaction.

Results and discussions

Barley grain yields

Barley grain yields in grams of dry matter per m^2(= kg per decare) are presented in Table 2 summarized over years as well as over soil type. The monolith replicate was included in the factorial arrangement for soils B and Ø.

The results in Table 2 reveal considerable effects of water, fertilizer and also significant interaction between fertilizer x water regimes. It can be added that also the year x water interaction effect was highly significant, also tested against year x water x fertilizer. The yields were different for the four soils, but the effects of fertilizer and irrigation, differed less between soils.

In 1992 the weather was extremely dry and warm until the middle of July, and in 1993 too, there was little rain before the middle of July. The yield response to irrigation, was therefore large, especially in 1992. The reduction in yields for irrigation at low levels of nutrient application in 1990 and 1991 might be an after effect of the different water regimes in winter

Table 2.Barley grain yields in g DM/m^2 at different water regimes. (I-II) and nutrient (a-d) treatments

	I				II			
Treatments	a	b	c	d	a	b	c	d
Soil A 1990-1993	376	545	663	537	389	583	726	544
Soil L " "	272	439	540	457	270	510	687	482
Soil B " "	400	542	606	584	432	648	796	655
Soil Ø " "	347	465	568	569	393	608	757	589
1990 4 soils	470	599	696	633	403	627	781	571
1991 "	349	579	731	637	323	555	778	601
1992 "	266	345	398	386	379	576	664	572
1993 "	309	466	552	493	378	591	743	525
Mean	349	498	594	537	371	587	742	568
Effect of NPK		+149	+245			+216	+371	
Effect of water					+22	+89	+148	+31

F-values:	I-II 208***	a-d 610***	I-II x a-d 26***
LSD, g/m^2:	" 30	" 43	" a-d 61
CV=3.8%			

during these two years. The weight of the cylinders showed, however, that the water content was only a few millimetres higher in regime II than in I on 1 May. In the experimental setup, the water regime in winter was confounded by irrigation in summer. In the last two years the experimental plan was altered, as already noted.

The yields were somewhat less for the sandy soil L than for the other soils. This was particularly marked at the lowest fertilizer rate. Mineralization of nitrogen from the soil reserves has apparently been rather small in soil L and large in soil A, as confirmed by the leaching figures presented in the subsequent paper (Uhlen et al. 1996).

The farm manure (slurry) treatments represents heavy applications of N and other nutrients. The amount of ammonium nitrogen in 4 kg slurry was 6-7 g/m^2/year and that in total-N13 g. Based on NH_4-N, treatment d should be compared with treatment b, whereas based on total-N and P and K additions, the slurry treatment in treatment d equalized the amount added in mineral fertilizer in treatment c.The yield responses in d were, on average, 39 g barley grain pr m^2 higher than those for treatment b without irrigation, but 21 g less with irrigation.

The farm manure was applied in late autumn in 1989 and 1992, and in spring in 1991 and 1992. Spring applications gave higher responses than autumn applications, especially in combination with irrigation. The reason for this will be discussed in the subsequent paper.

The yields in the monolith cylinders in relation to those in filled cylinders are presented in Table 3 for the whole 4 year period and separately for the dry year 1992. It should be added that the topsoil from each soil type was thoroughly mixed and apportioned to the monoliths as well as to the filled cylinders. The conditions causing reduced yields in monoliths are therefore not due to differences in the top soil. The denser subsurface soil probably hampered root development and water uptake from the deeper soil layers. As

Table 3.Barley yields in monolith cylinders in percent of yields in filled cylinders at the same nutrient and water treatment

	I				II					
Treatments	a	b	c	d	a	b	c	d	F	LSD
Means of 4 years:										
A		94				99				
L	79	65			100	91				
B	77	73	81	85	82	91	87	88		
Ø	77	65	71	82	84	89	92	77		
Mean		77				89			14.6++[1]	9
1992 yields:										
A		91				95				
L	57	31			87	87				
B	66	65	63	75	82	84	81	82		
Ø	58	41	48	74	80	82	79	61		
Mean		61					82		13.9++	17

[1] F-values for mean differences between water regimes I and II.

shown, the yield depression in the monoliths compared to the filled cylinders was significantly larger without than with irrigation, and also larger in the extremely dry year 1992 than for the four year period.

In 1991 and 1992 perennial ryegrass was seeded in together with barley in one of the replicates in soils A and L. The yield figures in Table 2 are averages for the two replicates with and without ryegrass. The ryegrass catch crop reduced nitrate leaching considerably, but the yield of barley was reduced by about 7% in 1991 and 12% in 1992. The residual effects in the following year (1993) were positive in eight comparisons and negative in eight comparisons between individual cylinders.

Evapotranspiration and water losses by leaching

The weighing of the lysimeter cylinders in the four years from 1990 to 1993 were carried out from about 1 May and until October/November. Although the measurement period was not exactly the same during the four years, the evaporation in October-November was only about 0.5 mm pr day and also very little affected by the different treatments. For calculation of wateruse efficiency, the evapotranspiration in millimetres was further restricted to the period from sowing in May to harvesting in early August.

The amounts of drainage water referred in Table 5 are from the period 1 May to about 20 December. Since the drainage is delayed in relation to rainfall and evapotranspiration, the figures in Tables 4 and 5 can be compared. Winter runoff (January to April) was not included in these comparisons. The winter leaching was also subjected to variations due to uneven snow depth.

There was no drainage water in May or June, and only small amounts in July and August.

The results in Tables 4 and 5 are given separately for each soil type, and also

Table 4. Evapotranspiration in millimetres May-Oct./Nov. at different water regimes and nutrient treatments

	I				II			
Treatments	a	b	c	d	a	b	c	d
Soil A 4 years	305	335	338	330	345	383	407	383
Soil L 4 "	291	324	331	325	344	397	414	389
Soil B 4 "	308	324	353	343	368	393	433	398
Soil Ø 4 "	305	322	349	331	344	372	407	381
1990 4 soils	319	343	352	349	329	387	402	369
1991 4 "	288	324	348	327	326	357	391	368
1992 4 "	312	327	341	334	411	426	455	433
1993 4 "	290	311	330	318	335	375	414	383
Mean	302	326	343	332	350	386	415	388
Effect of NPK		+24	+41			+36	+65	
Effect of water					+48	+60	+72	+56
F-values:	I-II	1260^{+++},	a-d	171^{+++},	I-II x a-d	9.7^{++}		
LSD		8		12		16		

CV = 2.7%

Table 5.Drainage in millimetres in May-Dec. at different water regimes and nutrient treatments

Treatments	I				II			
	a	b	c	d	a	b	c	d
Soil A 4 years	215	184	166	192	263	221	207	223
Soil L 4 "	207	175	171	182	239	202	186	205
Soil B 4 "	196	191	166	161	232	213	178	205
Soil Ø 4 "	216	200	173	190	266	253	206	237
1990 4 soils	84	67	51	66	143	109	91	121
1991 4 "	222	192	166	194	273	244	200	231
1992 4 "	291	277	266	262	302	285	271	278
1993 4 "	236	215	193	201	283	253	215	242
Mean	208	188	169	181	250	223	194	218
Effect of NPK		-20	-39			-27	-56	
Effect of water					+42	+35	+25	+37
F-values:	I-II 457,		a-d 145,		I-II x a-d 4.7*			
LSD		8		12			17	
CV = 4.5%								

separately for the four years of the experimental periods.

The evapotranspiration as well as drainage results (mm) revealed many highly significant effects. In addition to the F-values presented in the tables, the interaction between water regimes x year and fertilizer x year was also significant. The interaction between soils and treatments was, relatively small. As already noted, the water regime treatments were changed after two years and, furthermore, the water requirement was much more pronounced in the last two years. The fate of the added water was therefore different during the four years.

As an average for all four soils in 1990 only 10 mm of the added 100 mm water was used in evapotranspiration at the lowest rate of fertilizer application, and increasing to 50 mm at the highest fertilizer level. The corresponding wateruse efficiencies in 1992 were respectively 99 and 114 mm of 120 mm added. In Danish field investigations 63% of the added water was used in evapotranspiration (Simmelgaard 1985) and the rest in runoff. The increases in water use for fertilizer rates were larger in the first two years in accordance with the yield responses to fertilizer, as seen by comparing Tables 2 and 4.

The drainage figures in Table 5 show an opposite trend from the evapotranspiration figures in Table 4, decreasing with higher fertilizer rates. Much less of the added water was lost by leaching in the dry year 1992 than in the other years. A straight line positive relationship existed between yield and total water use, and a likewise negative relationship between yield and drainage loss in millimetres. Per 100 g/m^2 increase in yield of grain + straw, evapotranspiration increased by 10 mm and drainage decreased by 8 mm.

In Table 6 we find the relationships between yields and evapotranspiration and likewise between yields and drainage. It should be noted that evapotranspiration figures in this table are restricted to the growth period (approximately 1 May to 10 August) and are 50-55 mm less than the figures given in Table 4. Drainage in millimetres, on the other hand, includes all autumn drainage as in Table 4. Owing to the close relationship between yield, water use and drainage, in Table 6 evapotranspiration and drainage are calculated for a standard yield, 1000 g/m^2, grain + straw.

The differences in the evapotranspiration intercepts at zero yield between soils L and Ø were +22 ± 12 mm and + 27 ± 19 mm for water regimes I and II respectively. The drainage values in millimetres display the opposite trend. The error in the intercept values (not shown in the table) and the values at 1000 g/m^2 yields are large compared with the LSD values given in Tables 4 and 5. Nevertheless, some differences between soils seem to exist, most likely as a result of differences in evaporation from the soil surfaces. In the clay soil (Ø) the capillary rise of water is slow, leaving the surface periodically dried out. The sandy topsoil (L) had a dark colour, which could result in elevated soil temperature and evaporation, especially following irrigation.

In Table 7 water use efficiencies are given for the individual years for the evapotranspiration period 1 May to 10 August, and also after subtracting the calculated interceptions found in the regression analyses.

Yields of grain + straw per mm evapotranspiration increased markedly with increasing yields caused by fertilizer applications. This is apparently due to the fact that evaporation from soil makes up a larger part of the evapotranspiration. Furthermore, water use efficiency was decreased by irrigation in 1990 and 1991 and increased in 1992 and 1993. Bennetzen (1978) also reported higher water use per yield units without irrigation than with irrigation in dry years.

Transpiration from plants (T) and evaporation from soil (E) are not easily

Table 6.Relationships (y = a + bx) between yield g DM/m^2 (grain + straw) evapotranspiration and drainage (mm)

Water regime	I				II			
	Evapotr.		Drainage		Evapotr.		Drainage	
	b[1)]	mm at 1000 g/m^2	b	mm at 1000 g/m^2	b	mm at 1000 g/m^2	b	mm at 1000 g/m^2
Soil A	0.075	284	-0.093	182	0.115	326	-0.086	229
L	0.088	284	-0.070	170	0.083	334	-0.063	206
B	0.105	279	-0.068	178	0.099	327	-0.072	221
Ø	0.101	274	-0.088	193	0.090	314	-0.087	253
Means of 4 soils:	0.092±0.008		-0.080±0.014		0.097±0.008		-0.077±0.017	
R^2	0.89		0.83		0.95		0.88	

b = Regression coefficients.

Table 7. Water-use efficiency for different treatments and years. Grain + straw yields in g DM/m^2. Means of 4 soils.

	I				II			
Treatments	a	b	c	d	a	b	c	d
	Per mm evapotransp. May 1 - Aug. 10.							
1990	3.3	4.1	4.5	4.2	2.7	3.5	4.3	3.4
1991	2.8	3.8	4.4	4.1	2.4	3.6	4.4	3.8
1992	1.9	2.4	2.7	2.5	2.0	2.7	3.1	2.8
1993	2.2	3.2	3.7	3.1	2.4	3.3	3.8	3.1
Per mm evapotransp. corrected for intercept. Means a-d.								
1990	12.0				10.0			
1991	10.0				12.0			
1992	10.0				11.0			
1993	12.0				10.0			

The interception values calculated from regression analyses for treatment I 1990-1993 were respectively: 196, 171, 193 and 196 mm and for treatment II 1990-1993: 212, 215, 276 and 217 mm.

measured separately. Relative transpiration, T/ET, is thought to be influenced by the leaf area index (LA), also due to canopy shading of the soil (Davis 1994). Ritchie & Burnett (1971) found that the plant canopy influenced evaporation when the leaf area index was below 2.7.

In the lysimeter experiment evapotranspiration increased in all four years linearly with yields as shown in Fig. 2. This indicates that plant shading did not differ much between the fertilizer treatments in this case. Nevertheless, the evapotranspiration minus the interception term might not always be equal to plant transpiration. The intercept values were also subject to a relatively large error rate in the regression analysis. Evaporation measured in a cylinder without plants of soil B, however, gave a 4 year average (172 mm) close to the calculated interception for this soil. The calculated values in the lower part of Table 7 will be identical for the four fertilizer treatments, and only the average values for a-d are given. The transpiration calculated in this way will only be 20-40% of the evapotranspiration in May-August. The T/ET ratio was less in 1992 than in 1990 and 1991. Transpiration in mm per g/m^2 grain + straw was, contrary to millimetre evapotranspiration, probably not influenced by yield differences in this experiment.

The fate of the applied water is revealed in Fig. 3, as percentages of the added water evaporated or drained off.

As seen, also from Tables 4 and 5, the increases in evapotranspiration and the additional leachings after irrigation add up to about the same quantities as applied millimetres at water. This was not always the case in the individual years. In 1990 about 20 mm of the 100 mm of added water remained in the soil in November in spite of rainfall and leaching events earlier in autumn. In 1992, on the other hand, the high yield at the highest fertilizer application, also combined with irrigation, left the soil more dried out after the growing season, and this water deficit was not fully compensated for two months after harvest despite a high rainfall, 300 mm in Aug.-Sept., and substantial drainage from all the lysimeter

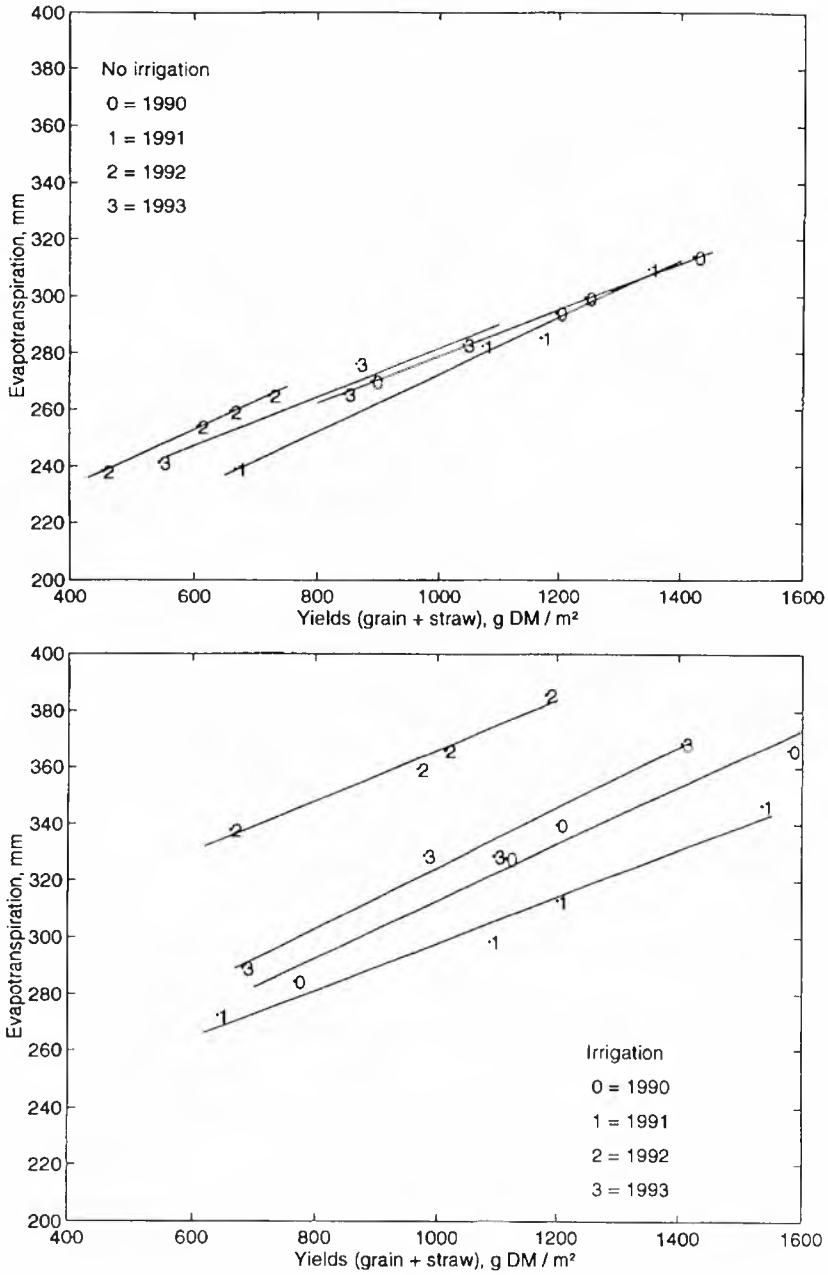

Fig. 2 Evapotranspiration in millimtres 1 May - 10 August in relation to yields of grain + straw in g DM/m²

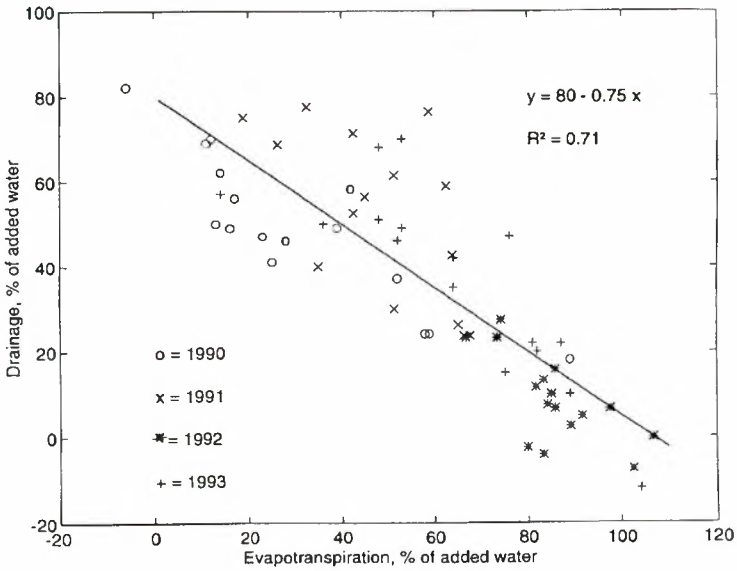

Fig. 3. Additional evapotranspiration and drainage after irrigation. Averages for four soils

cylinders in this period. This time lag or hysteresis effect in drainage is explained by the fact that water movement can take place in larger pores also when the small pores are not fully saturated (Thomas & Phillips 1979).

Another aspect of the fate of the added water is demonstrated in Fig. 4 as summation curves for the two years 1991 and 1993. The curves are from the lowest fertilizer treatment, with the highest drainage losses. Water was added (4-5 x 20 mm) from May to July. The increased runoff caused by this irrigation, however, was delayed and occurred in connection with the autumn rain, largely in October of both years. No clear differences existed between the soil types. The extra leaching did not appear any earlier in the sandy soil than in the other soil. Shrinking and cracking in the clay soil did not cause an immediate leakage following irrigation.

Evapotranspiration figures for individual periods of the growing season are produced by intermittent weighing of the lysimeter cylinders. These results are presented in Fig. 5 for 1992 together with pan evaporation. Results from 1990 and 1991 have been reported earlier (Uhlen et al. 1992). In 1992 an evaporation pan with an 0.4 m^2 surface area was placed close to and on the same level as the barley stand in the cylinders. The walls of a PVC water container were covered with white expanded polystyrene plates. Nevertheless, the evaporation in millimetres per day was larger from this pan than from a pan placed nearby under standard field conditions.

It should also be added that in this lysimeter setup barley was sown in small areas around each cylinder. The growth of barley lagged somewhat behind that of the barley in the lysimeter cylinders.

In all years the evapotranspiration levels in millimetres per day were grater than the pan evaporation in part of the growing season, with large areas of green

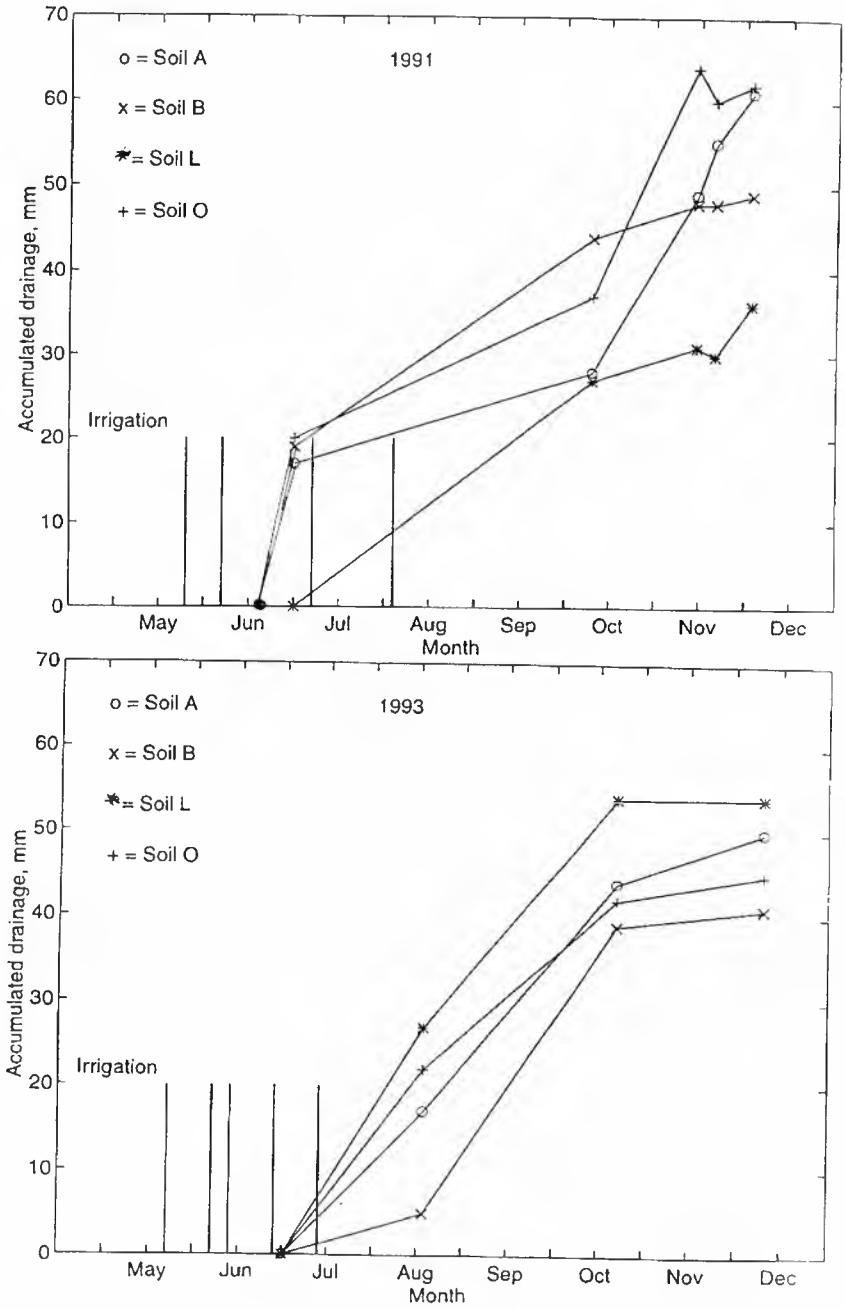

Fig. 4. Additional drainage after irrigation at the lowest fertilizer rate, treatments IIa-Ia. Summation curves for 1991 and 1993. Soils A, B, L and Ø

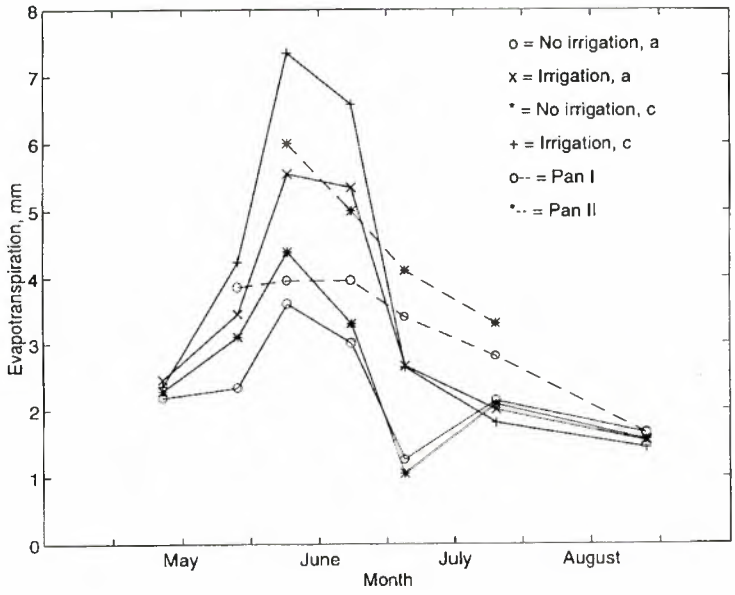

Fig. 5. Evapotranspiration in millimeters per day May-September 1992 at different fertilizer (a,c) and irrigation treatments (0,120 mm). Pan I. Placed in nearby field. Pan II. Placed on lysimeter roof

leaves. This effect may have been brought about by an active transfer of energy from the surroundings. Dry air will pass between the plants and affect a large area of leaves. Owing to such a clothes line effect (Ritchie & Johnson 1990), it is found that evapotranspiration will increase with increased leaf area indexes only up to a certain level.

Higher evapotranspiration from areas with plants than from evaporation pans and calculated values of potential evaporation were also found by Myhr (1988) and by Roth & Gunther (1987).

The large water use in 1992 can be explained by a high air temperature (Table 1). It should also be noted that a drop in daily evapotranspiration for treatments without irrigation in the period 28 June to 16 July 1992 is apparently caused by shortage of available water.

Final discussion

In this lysimeter experiment water use and drainage were largely determined by the crop yields of barley. Monolith cylinders gave lower yields than filled cylinders, but the monoliths were not functioning well. Roughly 60% of the additional water applied was evapotranspirated, varying, however, from 10 to 90% in the individual years, treatments and soils.

Utilization of the 100 mm added water increased with increased fertilizer rates from 53 to 73%. The rest was lost through leaching in late autumn. Even after considerable surplus precipitation in autumn, differences in soil water content brought about by irrigation, or by vigorous plant growth, were not fully eliminated. Such effects of hysteresis could be the result of preferential flow of water through the 1-m-deep cylinders. The downward trans-

port of solutes in lysimeter cells may be somewhat different from the much longer transport distance through the soil in a pipedrained agricultural soil. In experiments with small units, also a more elevated evapotranspiration than that found under larger field condition is likely. Nevertheless, lysimeter experiments can give valuable information about water balances and transport mechanisms.

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Nutrient and water balances in lysimeter experiments
II. Nitrogen and mineral leaching and balances

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Nitrogen and mineral leaching and balances were investigated in a 4-year lysimeter study including 4 soils, 2 water regimes and 4 nutrient treatments. High yields of barley gave small leaching losses. Increased levels of N at the rates 3, 9.5 and 16 g/m²/year in NPK fertilizer did not increase average N leaching and actually reduced it in a loam soil with high N mineralization. Irrigation and farm manure applications gave small increases in the amount of N leached. The differences in soil organic N between the additional 16 and 3 g N/m² corresponded well with the calculated N-balances after four years. Cl was leached out more rapidly in sand than in clay soil, P was not leached out. The cation content of the drainage varied among the four soils and was governed by the exchangable cation composition in the deeper layer of the clay soil. Excess leached cations over anions (minus bicarbonate) in drainage varied among soils, water regimes and nutrient treatments.

Key words: Anion/cation leaching, farm manure, fertilizer rates, irrigation, N utilization.

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In publication I (Uhlen et al. 1996), barley yields, water use and water balances are reported from a weighing lysimeter experiment at Ås, Norway 1990-93/1994. A factorial plan was used including 4 soils, 2 water regimes and 3 rates of mineral fertilizer (a, b, c) and one of farm manure (d). The nutrient applications in g/m²/year are recorded in Tables 3, 4 and 6. Of the four soils A and L were loam and loamy sand respectively and soils B and Ø were clay.

Furthermore, a comparison of monoliths and cylinders filled with soil are included, and for two soils (A and L) in two years ryegrass is also used as catch crop in a mixture with spring barley. A more detailed description of materials and methods and characteristics of the soils can be found in paper I.

Samples of leaching water were analysed for NO_3-N, NH_4-N, total-P, Cl, SO_4-S, K, Na, Ca and Mg. In samples of barley grain and straw dry matter, Kjeldahl-N and with some exceptions the same mineral elements as those for leaching water samples were determined. The content of NH_4-N in water was found to be less than 0.05-0.1 mg per litre. Total-N content in samples from the first two years was not consistently higher than that of NO_3-N + NH_4-N. Therefore, only the

results of NO_3-N were used in the tables and nitrogen balance calculation. Furthermore, only composite drainage samples for the two periods May-December and January-April were analysed in the first two years, 1990/1991 and 1991/1992. In the last two years 1992/1993 and 1993/1994, the composite drainage samples representing the whole drainage year (1 May to 30 April) were analysed. As mentioned in paper I (Uhlen et al. 1996), in this experiment no drainage water occurred in May-June and only small amounts in July-August. The main runoff period was October to December.

The drainage water was collected in 30-l polyethylene cans in the cool cellar. Before reforwarding to the chemical laboratorium, samples were conserved by adding 7 ml HCl per litre. Another set of samples for Cl determination was conserved by adding 5 ml H_2SO_4 per litre. The chemical analyses were carried out in accordance with Norwegian standard methods.

Results

Nitrate and chloride concentration in drainage water

The amounts of nitrogen added in complex NPK fertilizers in treatments a, b and c were 3, 9.5 and 16 g/m^2 respectively. Roughly 53% of the fertilizer nitrogen was applied as ammonium and 47% as nitrate nitrogen. The Cl added in the same treatments were 0, 5.6 and 10 g/m^2 per year respectively.

The concentrations of NO_3-N and Cl in the runoff water in the period May to December 1991 and likewise for the winter runoff January-April 1992 are reported in Table 1. The results demonstrate the differences in NO_3-N and Cl leaching and the differences between the soils. Increased N applications in spring did not increase NO_3-N in drainage, except for soil L. The concentrations of NO_3-N in the period Jan.-April for the clay soils B and Ø were even higher than in the former period May-Dec. The Cl concentrations, on the other hand, are considerably increased by adding Cl in fertilizer and most of the chloride is leached out in the autumn. Leaching behaviour is influenced by soil type. Both NO_3-N and especially Cl are leached out most rapidly in the sandy soil L. The amount of drainage water in May-Dec. 1991 was 150-250 mm and in Jan.-April 1992 150-200 mm, the quantity being larger in water regime II than in I. Similar results were available for 1990-91, but the precipitation and drainage volume were rather small in the autumn period of 1990.

Transport mechanism measured by Cl leaching

The leaching behaviour of chloride ions revealed some striking differences between the sandy soil L and the other soil types related to differences in soil water content. The total volumetric water content (Vm) in 0-100 cm at field capacity (pF2) was 17% for soil L, and 28, 35 and 41% respectively for soils A, B and Ø, increasing with increasing clay content. Owing to lack of intermittent registration of the chemical composition of the drainage water, only tentative calculations could be made. In Table 2 some results of Cl losses by leaching are given for the four soils in 1990/1991 and also for soil L in 1991/1992. For sandy soil L the total of increased Cl leached and increased plant uptake was about equal to the added Cl, also in the first experimental year. For the other soils large residuals of Cl were carried over to the 1991/1992 season. The amount of drainage in 1990 was small, and for wa-

Table 1.Concentrations of NO_3-N and Cl in drainage water, 1991-92

Treatments[1)]	I				II			
	a	b	c	d	a	b	c	d
NO_3-N mg/l								
1/5-31/12 1991								
Soil A	12	11	10	11	13	12	13	13
" L	8.0	8.9	10	8.1	3.0	5.1	6.1	5.8
" B	7.9	8.3	8.5	8.7	6.6	6.9	6.4	9.4
" Ø	4.4	4.6	6.2	5.0	7.9	6.1	6.0	8.8
1/1-30/4 1992								
Soil A	13	11	12	11	11	10	9	9
" L	5.0	4.8	4.7	4.3	3.5	4.8	4.3	5.4
" B	9.7	8.9	9.3	9.5	8.6	8.1	7.3	8.6
" Ø	8.1	7.2	8.4	8.1	13	8.1	7.9	10.2
Cl mg /l								
1/5-31/12 1991								
Soil A	3	18	27	12	4	13	31	14
" L	4	18	40	15	4	16	31	14
" B	4	16	38	16	4	14	29	12
" Ø	4	16	30	10	5	12	29	13
1/1-30/4 1992								
Soil A	3	7	17	6	3	5	8	6
" L	3	4	4	3	4	5	5	4
" B	4	7	16	8	4	6	11	6
" Ø	4	9	16	6	4	6	16	6

[1)] See Tables 3 and 5 for additions of respectively N and Cl in a-d, and publication I for soil descriptions and water treatments.

ter regime I the total water runoff for the whole year from 1 May 1990 to 30 April 1991 was also small. The cylinders in I were protected against most of the winter precipitation that year.

The Cl fraction leached from the added Cl, corrected for Cl removals in crops, was largest for soil L and smallest for the heavy clay soil Ø (Table 2), in accordance with the differences in Vm. The same relationships between the four soils were found for the fraction (f) calculated from Burnss equation (Burns 1975), although this equation underestimated the Cl leaching losses by a factor of two or more. Moreover, in field lysimeters the real losses of NO_3-N were about twice the fraction calculated after Burns (Uhlen 1978). Addiscott & Cox (1976) reported similar results and suggested that the most inaccessible water should be left out of the calculation.

In this experiment calculated fraction based on the water content between pF2 and 4.2, (i.e. leaving out the water content below the wilting point) gave acceptable values, especially for soils A and B, but did not satisfactorily reflect the high leaching of Cl in soil L. In this soil, dominated by rather coarse sand in the underground layer, the water transport may be of a fingering type. If 0-20 cm of the topsoil only were included in the calculation, assuming a rapid gravitational water movement in the 20-100 cm sand layers, the calculated fraction of Cl

Table 2.Chloride transportation in different soils. Treatments Ic and IIc 10 g Cl/m²/year

	Drainage in cm(P)	Fractions (f) of Cl residuals leached Measured	Estimated*		
1990/1991:					
Soil A			1	2	3
Ic May-April	8.1	0.25	(0.03)		
IIc " "	24.8	0.47	0.32	0.46	0.74
Soil L					
Ic May-Dec	7.6	0.67	0.11	0.22	0.47
May-April	9.5	0.77	0.17	0.23	0.54
IIc May-Dec	9.4	0.51	0.16	0.23	0.54
May-April	28.9	0.89	0.55	0.60	0.81
Soil B					
Ic May-April	7.6	0.22	(0.01)		
IIc May-April	24.9	0.47	0.25	0.47	0.76
Soil Ø					
Ic May-April	5.9	0.14	(0.00)		
IIc May-April	24.4	0.28	0.19	0.45	0.72
1991/1992					
Soil L					
Ic May-Dec	17.4	0.97	0.38	0.45	0.71
IIc May-Dec	19.3	0.96	0.42	0.49	0.72

* f, estimated acc.to Burns (1975): $\frac{P}{P+0.01\ {}^{V}m}$ h

Alternative parameterizations of leaching equations:
1. Vm at pF2 h = 100 cm 2. Vm pF2 - 4.2 h = 100 cm
3. Vm at pF2 h = 20 cm.

residual leached would be in the same range as the measured Cl losses from soil L. This soil had a relatively high water content in the topsoil due too high content of silt, as well as organic matter. (See Fig. 1 in paper I).

As pointed out, by Thomas & Philips (1979) and Addiscott & Cox (1976) among others, some of the water in the soil will be transported as gravitational water. Preferential flow in larger pores may also occur in situations where the capillary pores are not fully water saturated. It is therefore not surprising that the calculations, which take only capillary water into account, were incomplete. Furthermore, in the fields where the surplus water is taken care of with pipe drains, the water will move a considerable distance through the soil and not only in a vertical direction.

In spite of somewhat defective materials in this investigation it is obvious that it takes only 50-100 mm drainage water to leach out 50% or more of the added Cl left in the sand soil L. The corresponding figures for soils A and B were roughly 200 mm and for soil Ø apparently much higher.

Nitrate leaching and nitrogen balance

The nitrate losses by leaching are presented in Table 3. The figures for soils A and L in 1991 and 1992 represent only

Table 3.Nitrate leaching in g N/m²/year at different water regimes (I-II) and nutrient (a-d) treatments

Treatments	I				II			
	a	b	c	d	a	b	c	d
N added	3	9.5	16	3+13[1)]	3	9.5	16	3+13[1)]
Soil A 4 years	4.00	3.19	3.02	3.64	4.80	3.81	3.49	4.19
L 4 "	1.52	1.53	1.87	1.95	0.94	1.37	2.03	1.78
B 4 "	2.31	2.08	2.24	2.19	2.35	2.51	2.05	2.73
Ø 4 "	1.80	1.68	1.92	2.12	2.41	2.30	1.92	3.03
1990 4 soils	0.74	0.77	0.78	0.97	0.55	0.84	0.83	0.93
1991 4 "	3.17	2.70	2.51	2.83	3.96	3.25	2.98	3.75
1992 4 "	3.24	2.78	3.78	3.74	3.42	3.40	3.43	3.79
1993 4 "	2.49	2.24	2.00	2.36	2.56	2.49	2.24	3.26
Mean	2.41	2.12	2.27	2.48	2.62	2.50	2.37	2.93
Effect of fertilizer		-0.29	-0.14			-0.12	-0.25	
Effect of water					+0.21	+0.38	+0.10	+0.45
F values	I-II 7.7"a-d 2.7 n.s.				I-II x a-d 0.6n.s.			
	LSD 0.25							
Soil A (1991+1992):								
Without ryegrass	5.16	3.97	4.12	4.92	6.78	4.97	4.95	4.62
Undersown "	1.30	1.25	1.72	1.92	1.02	1.06	1.91	1.33
Soil L (1991+1992):								
Without ryegrass	2.23	2.13	2.47	2.06	0.87	1.73	2.63	1.40
Undersown "	0.55	0.37	0.59	0.97	0.38	0.30	0.91	0.49
Mean concentration of NO_3-N, mg/l. (without ryegrass in A and L 1991 and 1992)								
4 soils, 4 years	7.7	7.3	8.4	8.7	6.5	6.8	6.9	8.0

[1)] Total N in farm manure.

the replicate without undersown perennial ryegrass. In ryegrass, leaching losses were drastically reduced as shown in the lower part of Table 3. In addition, the results from soil Ø in 1991-93 represent only one of the two replicates, since the monolith cylinders of this soil did not give reliable results (impermeable in winter and also leakages in some cylinders as noted in report I). No further comparison between filled cylinders and monoliths will be presented. Variance analyses were performed on the mean results of 1 or 2 replicates using the 4 factor interaction, soil x nutrient rates x water regime x year as error term.

The leaching of nitrate differed greatly among the four soils, as can seen from Table 3. In soil A increased rates of N in fertilizer actually decreased the leaching of nitrate in the last three years (not shown in the tables). In 1990 the drainage volume was far below normal. Apparently, as a consequence of the high yield levels and yield responses even the highest rate of fertilizer nitrogen was well utilized and, besides, vigorous plant root systems might have resulted in an increased uptake of mineralized soil nitrogen as well.

In sandy soil L, on the other hand, the

amount of nitrate leached increased somewhat with increasing rates of application. In the clay soils B and Ø the trend in leaching losses was somewhat varyied. The 4-factor interaction therefore also includes real interaction effects in addition to random error variance. Nevertheless, also tested against this variance, the effects of soils, years, soils x years and water regimes were significant at the one percent level.

The nitrogen yield in barley grain + straw, and the calculated N balances for the different treatment combinations are reported in Table 4. The nitrogen yield figures varied much less than the nitrate leaching in g/m^2, and the 4-years means for the nutrient treatments in water regime II were almost identical to those for the same treatments in regime I.

The nitrogen balances, including 1 g N/m^2 in precipitation per year, averaged ÷ 5 g N/m^2/year for the lowest rate of N applied (3 g/m^2/year), and almost zero for the 16 g N/m^2 application rate in both water regimes.

In spring of 1995 soil samples from 0-18 cm depth were taken from fertilizer treatments a and c for total-N and total-C determinations. The results are presented in Table 4. In the fifth year, 1994, spring grain was given the same N treatment as

Table 4.Nitrogen in barley crops and nitrogen balances, g N/m^2/year and total-N in soil/m^2

	I				II			
Treatments	a	b	c	d	a	b	c	d
N added	3	9.5	16	3+13[1)]	3	9.5	16	3+13[1)]
Soil A 4 years	6.9	10.2	15.0	10.1	7.0	10.4	14.3	9.6
L "	4.2	8.3	12.6	8.4	4.2	8.1	13.0	7.8
B "	7.8	11.3	15.5	11.8	7.4	11.3	15.6	11.6
Ø "	7.5	10.9	15.9	11.9	7.5	11.1	15.8	11.2
Means of 4 soils	6.6	10.2	14.8	10.5	6.5	10.2	14.7	10.1
Effect of water					-0.1	0.0	-0.1	-0.5
Effect of fertilizer		+3.6	+8.2			+3.7	+8.2	
Utilization, %		55	63	(34)		57	63	(29)
F-values	I-II	2.4 n.s.	a-d 1700***	I-II x a-d	1.5 n.s.			
LSD				0.3				
Crop N + leaching	9.0	12.3	17.0	13.0	9.1	12.8	17.1	13.0
N balances [2)]	-5.0	-1.8	0	+4.0	-5.1	-2.3	-0.1	+4.0
Total-N in soil 0-18 cm g N/m^2 (1994)								
Soil A 2 rep	606		640		599		625	
L "	444		457		454		468	
B "	413		444		408		435	
Ø 1 "	642		682		650		672	
Means of 4 soils	526		556		528		550	
			+30				+22	
LSD (for 2 rep)	9 g N/m^2							

[1)] In farm manure, total-N

[2)] Included 1 g N/m^2 in yearly precipitation

that received in the previous years. If we assume the same N balance per year also in 1994/1995, the difference between treatments a and c will sum up to -25 g/ m^2. As indicated in Table 4 the differences in topsoil total-N might explain the balance accounts in this investigation. A weak area in the calculation is the topsoil quantity, here set to 200 kg/m^2. Some differences in the N losses exist between the soil types. The negative N-balance in treatment a versus that in treatment c was 50% higher for soil A than for soil L, primarily as a result of the high nitrate leaching in A. The soil analyses gave similar results.

Total-C content of the soil samples is not given here. Within the same soil, however, the C:N ratios were almost constant, but differed among the four soils as follows: A 9.8, L 12.1, B 9.4 and Ø 8.4. The apparently low mineralization rate of the soil nitrogen in soil L could be a consequence of a higher C:N ratio, whereas soil A with the highest nitrate production did not have a lower C:N ratio in the topsoil layer than soil B and Ø.

From the balance calculations and the soil analyses there seems to be little N left for gaseous losses of the applied mineral nitrogen in this lysimeter study. Reliable comparisons of the soil nitrogen at the start and end of the experimental period cannot be made, and we can therefore not exclude gaseous losses of soil nitrogen. The somewhat lower recovery of total-N in soil samples from regime II, with periodically a higher soil water content than regime I, may indicate a slight stimulation of denitrification.

Chloride leaching and chloride balance

The chloride losses by leaching made up 47-55% of the chloride added in complex fertilizer (18-3-15) or in potassium chloride (Table 5). Plant uptake constitutes virtually the other half of the added Cl (Table 6). The somewhat higher Cl leaching and also Cl uptake in IIa than in Ia can be explained by the Cl content in the irrigation water.

As for nitrogen, the variability in uptake of Cl was less than the variability in Cl leaching. For uptake as well as for leached Cl no significant effects of soil x Cl treatments were found when tested against the 4-factor interaction variances. However, there are some indications of a higher total recovery of Cl in crops + drainage for the sandy soil L than for the other soils (not shown in the tables). As demonstrated earlier, some of the chloride in the clay soils was left over to the following years.

An almost 100% recovery in plants and drainage of the Cl added was demonstrated also in an 8-year field lysimeter trial at Ås (Uhlen 1989), and also in a 7-year lysimeter study with spring wheat (Uhlen 1994).

The fate of the Cl added in farm manure was almost the same as that in mineral fertilizer. However, in two of the four years FYM was applied applied in autumn, and high leaching losses followed, especially in water regime II (Table 5).

Phosphorus and sulphur

The uptake of phosphorus increased in accordance with the yield increase for nutrient additions. The P additions are presented in Table 7. The correspondent P uptakes, (not given here), were 1.7 g for treatment Ia increasing to 2.9 g P/m^2/ year for treatment IIc. The P balances, additions minus crop removals, had no influence on P leaching, which was almost nil. PO_4-P, as well as total-P in water were determined. Only total-P is reported in Table 7. In many cases <0.01 mg P/l was found for both P fractions. The results varied, however. Traceable

Table 5.Chloride leaching, Cl/m²

	I				II			
Treatments	a	b	c	d	a	b	c	d
Cl added	0	5.6	10.0	4.6	0	5.6	10.0	4.6
1990 4 soils	0.48	1.64	2,57	1.63	0.94	2.18	3.75	1.70
				1.33[1)]				3.48[1)]
1991 4 "	1.25	3.95	8.24	3.35	1.74	4.18	7.77	4.02
1992 4 "	0.99	4.24	7.23	4.41	1.54	4.53	7.24	5.03
1993 4 "	1.41	5.39	8.12	2.67	2.22	6.13	8.49	3.20
Meas of 4 years	1.03	3.81	6.54	3.34	1.61	4.26	6.82	4.35
Effect of water					+0.58	+0.45	+0.28	+1.01
Effect of added Cl		+2.78	+5.51			+2.65	+5.21	
F-values		I-II 24*** a-d 550*** I-II x a-d 0.5 n.s.						
LSD	"	0.21	" 0.30					
Mean concentration mg Cl/l	3.3	13.1	24.4		4.0	11.5	1 9.9	

[1)] Cl in winter leaching in 1990 after FYM applied in late autumn 1989.

Table 6. Chloride in barley crops and Cl-balances, g Cl/m²/year

	I				II			
Treatments	a	b	c	d	a	b	c	d
Cl-added	0	5.6	10.0	4.6	0	5.6	10	4.6
In grain + straw	1.02	3.46	5.16	2.84	1.76	4.21	6.37	3.35
Effect of water					+0.74	+0.75	+1.21	+0.51
Effect of added Cl		+2.44	+4.14			+2.45	+4.61	
F-values	I-II	240***	a-d	1250***		I-II x a-d 8.5***		
LSD	"	0.12	"	0.17		"	0.23	
In crops + leached		+5.22	+9.65	+4.13		+5.10	+9.80	+4.33

concentrations of P in clay soil drainage were apparently associated with soil particles. Readily soluble P (Egnér et al. 1960) was very high in the L topsoil (P-AL 57 mg P/100g) and also high in the deeper layers of soils A, B and Ø (Uhlen et al. 1992).

Sulphur in barley yield was determined in 1990 only, giving values of 1-2 g S/m². Moreover, after including 1 g S/m²/year in precipitation, the S balance will be negative for all soils and treatments. Only small differences in SO_4-S leaching existed among the four soils. The concentration of SO_4-S in mg/l seemed to be a little higher in water regime II than in regime I.

Metal cations in lysimeter drainage

Additions of K, Na, Ca and Mg as well as withdrawals of the same elements in crop yields will not be presented in the tables.

Table 7.Phosphorus (total P) and sulphur (SO_4-S) in lysimeter drainage. Means of 4 years.

	I				II			
Treatments	a	b	c	d	a	b	c	d
P-added g/m²	0	1.4	2.9	2.8	0	1.4	2.9	2.8
S- "	0	1.5	2.5	1.5	0	1.5	2.5	1.5
Total-P leached mg/m²								
Soil A	4	5	3	4	5	4	5	4
L	4	3	3	5	5	4	6	4
B	6	6	4	3	12	8	6	6
Ø	22	13	10	14	20	19	13	17
SO_4-S leached g/m²								
Soil A	2.3	2.3	2.6	1.8	3.1	4.5	3.4	2.7
L	1.9	2.1	2.3	2.0	2.6	3.2	3.6	2.7
B	2.0	2.5	2.0	1.6	3.0	3.4	2.9	2.8
Ø	1.6	2.3	2.0	1.7	2.5	3.1	2.7	2.7
SO_4-S concentrations mg/l 4 soils	6.2	7.9	8.3	6.3	6.9	9.6	9.2	7.4

For the leaching losses, only the averages for treatments a-d are reported (Table 8).

Potassium was added in mineral fertilizer in treatment a, b and c in rates of respectively 0, 7.7 and 14 g/m²/year, and in farm manure in treatment d at the rate of 12 g K/m² as an average for four years.

Potassium in grain + straw, as mean figures for four soils in the four years, varied from 5.4 g K/m² (Ia) to 13.4 g/m² (IIc). A positive K balance of about 2 g K was found for the farm manure treatment; otherwise, the K balance was negative, particularly for treatment a (-6.5 g K/m²/year).

Sodium, calcium and magnesium were applied in small quantities in the fertilizer, Ca from 0.4 to 2.3 g/m² and Mg from 0.1 to 1 g, respectively for treatment a and c. The additions in farm manure, d, were about 4 g Ca and 2 g Mg per m² per year.

Calcium removals in crops (analyses for 1990 and 1991 only) were 1.4 to 2.8 g/m², and for magnesium 0.9 to 1.7 g/m² respectively for treatments Ia and IIc. Sodium analyses for yields in the first year revealed uptake of only 0.2-0.4 g Na/m².

Leaching losses of K, Na, Ca and Mg in g/m²/year are recorded in Table 8. The concentration in drainage (not shown) in most years and soils did increase a little from treatments a to c, but due to the higher volume of drainage water in treatment a than in treatment c (see Table 4 in part I) the amounts of these elements lost by leaching were not consistently larger for c than for a. For soil L such increases were apparent, but the opposite results tend to prevail in soil A.

Owing to the fact that leaching in sum cations is governed by the soluble anions available for downward movement in the soil, the cation concentration is expected to vary much in the same way as that of nitrate and chloride. These two anions are the dominant species together with bicarbonate and sulphate. The content of

Table 8.Potassium, sodium, calcium and magnesium in lysimeter drainage, g/m²/year and mg/l. Mean figures for treatment a-d in four years

	Soil A		Soil L		Soil B		Soil Ø	
Water regime	I	II	I	II	I	II	I	II
K g/m²	0.56	0.75	2.28	2.98	0.46	0.79	0.75	1.05
K mg/l	1.89	1.95	8.3	8.5	1.65	2.20	2.49	2.73
Na g/m²	0.94	1.34	0.92	1.30	2.13	2.63	2.28	2.74
Na mg/l	3.2	3.5	3.3	3.7	7.6	7.3	7.5	7.1
Ca g/m²	17.0	24.9	7.3	9.1	6.1	8.7	5.9	8.4
Ca mg/l	58	64	26	26	22	24	19	22
Mg g/m²	0.92	1.22	0.57	0.72	2.66	3.55	3.29	4.45
Mg mg/l	3.1	3.2	2.1	2.1	9.5	9.8	10.9	11.6

bicarbonate was not measured directly in this experiment.

Differences in additions of cations, for instance of K, seemed to have no effects of cation leaching in this experiment. On the other hand, differences among the soils were found to be very large (see Table 8). A high K content in drainage water was found only for the sandy soil (L) which had a 3-5 times higher K leaching than the other soils. In soil A, concentration of Ca in drainage was 3-4 times that from the other three soils. Mg and Na behaved rather similarly, being 2 and 3 times higher for the clay soils B and Ø than for soils A and L. The explanation for these differences lies in the relationship between the exchangeability or the adsorption energy of the four cations in the soil, and especially the relative amount of exchange cations in the deeper layer of the soil (Table 9). Similar results were demonstrated for another soil type in a field lysimeter (Uhlen 1978).

In Table 9 the cation composition of the leaching water, at 1 m depth, was compared with the cation content in three soil layers. Readily soluble can be looked upon as estimates of exchangeable cations in soil. For the elemements Ca, Mg and Na in the clay soils B and Ø it is obvious that the cation composition of the drainage water was determined mainly by the cation composition of the deeper soil layers. In soils A and L the percentage composition of the cations was almost the same in the topsoil as in the deeper layers.

Exchangeable Na is much more soluble than the other exchangeable cations. If the relationship between Na in soil and that leached were set to unity (= 1), the relationships in soils B and Ø would be: K 8-10, Ca 11-12 and Mg 13-14. Likewise, in soils A and L the figures were about 4 for Ca and Mg, whereas the ratio for K was only 1-2 times higher than that for Na. Similar results demonstrating the firm binding in clay of Ca, Mg and in particular K, with decreasing concentrations, were demonstrated by Wiklander (1974). Potassium in the soil, even if determined as exchangeable, will apparently also be influenced by specific adsorption mechanisms.

The change in the cation composition of the leaching water upon downward

Table 9.Cation composition of soil and drainage water

Soil layer	Readily soluble [1] cations, mg/100g soil				In drainage water mg/l			
	K	Na	Ca	Mg	K	Na	Ca	Mg
Soil A 0-20 cm	8.7	1.6	255	11				
20-50 "	1.7	1.2	148	5.0				
50-100 "	2.2	1.7	141	5.2	1.9	3.3	61	3.1
Soil L 0-20 "	17	2.7	252	8.6				
20-50 "	4.6	0.8	73	2.5				
50-100 "	2.8	0.9	28	2.2	8.4	3.5	26	2.1
Soil B 0-20 "	16	2.1	64	8.9				
20-50 "	6.4	2.5	85	27				
50-100 "	9.1	4.4	145	73	1.9	7.4	23	9.6
Soil Ø 0-20 "	33	2.2	138	21				
20-50 "	17	3.0	112	53				
50-100 "	19	5.2	150	108	2.6	7.3	20	11.2
Composition percentages[2] of cations:								
	K	Na	Ca	Mg	K	Na	Ca	Mg
Soil A50-100 cm	1	1	92	6	2	4	87	7
" L "	4	2	83	11	12	8	71	9
" B "	2	2	53	44	2	14	50	34
" Ø "	3	1.5	44	52	3	14	43	40

[1] Readily soluble exchangeable after Egner at al. (1960)

[2] Based on equivalent weights of the cations.

transport, as found also in field lysimeters (Uhlen 1978), will have consequences for the nutrient balances in the topsoil layer. Leaching measurement at pipe-drain depth will underestimate losses of K and sometimes Ca from the topsoil layer and overestimate such losses of Mg and Na. For plant growth the losses of cations from layers at 50 cm and deeper may be important only in a very long-time perspective.

Only very small proportions of the exchangeable cations will be solved in the drainage water passing through the soil. Table 10 shows the relationship between adsorbed cation in mg per 100 cm^3 soil (=160-180 g DM) in the 50-100 cm layer in 1989, and the same cations in the water volumes (30-40 %) of the same 100 cm^3. Mean drainage water concentrations are from all treatments and for four years. The total amount of drainage water in the four years was about 1300 mm.

Table 10 demonstrates further the differences in cation mobility in the four soils. K, Ca and Mg behaved almost in the same way in the clay soils, whereas Na was about ten times more mobile. In the sand soil L, the reserves of cations are much less, and relatively higher proportions were leached out. The amount of soluble anions governing the ionic strength and, therefore, the total leaching loss of cations was apparently highest for

soil A (Table 11).

The relative composition of the cations in the same soil layers and in the drainage will calculated on volume units be the same as those given on the 100 g soil in Table 9.

Anion cation relationship

The sum of Ca + Mg + K + Na is much higher than the sum of the measured NO_3-N, Cl and SO_4-S in milligram equivalents of drainage water samples.

The results are presented in Table 11 for treatments Ia, Ic, IIa and IIc. These calculations revealed that excess cation over anion in drainage was reduced by increased rate of NPK-fertilizer, and increased in water regime II with irrigation and higher leaching volumes. Larger differences existed also among the soils.

Bicarbonate ions probably make up the main part of the differences between the measured cations and anions. The bicarbonate content of the soil solution is highly pH-dependent. Soil samples from the 50-100 cm layer in 1989 had pH values of 6.5-7 in the four soils. The bicarbonate content will also be affected by CO_2-production and soil aeration in the lysimeter cylinders. A possible higher production of CO_2 after adding farm manure (d), did not result in a higher calculated cation excess in the drainage water. The results for treatments d and b (not given in Table 11) were both in the same range, between the figures for treatments a and c.

Table 10.Relationship between adsorbed cations (mg/100 cm^3 soil in 50-100 cm layer) and the same cations in the water volumes (mg per 100 cm^3 soil)

	K	Na	Ca	Mg
Soil A	65	29	131	95
Soil L	15	12	48	47
Soil B	194	24	255	308
Soil Ø	266	26	272	350

Effects of farm manure

The results of the farm manure treatment d, are presented in the tables of yield and water balances in part I, and in tables of leaching losses and nutrient balances in

Table 11.Anion-cation relationship of drainage water in milligram equivalents per liter. Means of 4 years.

	Sum anions				Sum cations			
Treatments	Ia	Ic	IIa	IIc	Ia	Ic	IIa	IIc
Soil A	1.40	2.08	1.35	1.82	3.19	3.64	3.80	3.52
Excess cations					+1.79	+1.56	+2.45	+1.70
Soil L	0.85	1.84	0.72	1.78	1.37	2.32	1.47	2.33
Excess cations					+0.52	+0.48	0.75	+0.55
Soil B	1.07	1.76	1.03	1.47	2.06	2.51	2.22	2.49
Excess cations					+0.99	+0.75	+1.19	+1.02
Soil Ø	0.83	1.63	0.94	1.47	2.16	2.56	2.34	2.53
Excess cations					+1.33	+0.93	+1.40	+1.06
Means of 4 soils	1.04	1.83	1.01	1.64	2.20	2.76	2.46	2.72
Excess cations					+1.16	+0.93	+1.45	+1.08

this paper.

As noted in part I, the applications of total-N, P and K in FYM in treatment d were roughly equivalent to the rates in treatment c, and the amount of ammonium-N in FYM + 3 g N/m^2 in ammoniumnitrate corresponded almost to the 9.5 g N/m^2 N level in treatment b. In water regime I the barley dry matter and nitrogen yields were a little higher in treatment d than in b, whereas in water regime II the opposite trend was observated.

The farm manure was applied in autumn 1989 and 1992 and in spring 1991 and 1992. The yield effect and N uptake were a little higher after spring application compared with autumn application. A clear picture of the effects of autumn application on yields and leaching losses can only be seen in the first year (Nov. 1989-April 1991) since the effect of the FYM applied in Nov. 1992 was confounded by the residual effect of FYM applied in the previous three years.

The average leaching losses of nitrate were 0.36 g and 0.43 g N/m^2 more in treatment Id and IId respectively than in Ib and IIb (Table 3). In a paper dealing with the results from the first year of this lysimeter experiment (Uhlen et al. 1992), leaching losses of chloride and nitrate, but not of ammonium, were found in winter drainage as a result of FYM applied in late autumn 1989. Adding this N to the 4-year means in Table 3, the average N leached in treatments Id and IId will be 0.5 and 0.6 g N/m^2 more than that for the comparable treatments Ib and IIb. The additional Cl leaching in winter 1990 has been included in Tables 5 and 6. The added total sulphur in FYM was probably somewhat less available for leaching than the SO_4-S added in mineral fertilizer (Table 7). No special effect of FYM on the leaching of cations was discernible and the figures are not presented.

As already noted, practically no NH_4-N was detected in drainage water in this experiment. The reduced efficiency and utilization of FYM-N in water regime II compared to regime I, as well as the somewhat reduced N effect after autumn than after spring-applied FYM, might be caused by differences in gaseous losses of N, mainly as ammonia.

Discussion

a) Leaching

The total leaching losses of nitrogen was much higher in a loam soil of morainic origin (A) than in a sandy soil (L) with a high C:N ratio of the topsoil. In soil A, too, soil respiration was found to be higher than that for the other soils in May, August and October 1993 (Haugen & Olsen 1993). Furthermore, in soil A, losses actually decreased from 4-4.8 to 3-3.5 g/m^2 by adding increasing rates of fertilizer N. In soil L the 4 years' average NO_3-N leaching increased with increasing fertilizer rates from 1-1.5 to 1.9-2 g/m^2. The two clay soils, displayed an intermediate trend. Also the fact that surplus chloride was fully and more rapidly leached out than NO_3-N, proved that the nitrate leached was largely liberated from the soil and plant residue in the late summer and autumn. The same result was found by Lyngstad (1990), Yläranta et al. (1993) and in British investigations (McDonald et al. 1989; Johnston & Jenkinson 1989). As shown in Table 3, NO_3-N in drainage was drastically reduced when undersown perennial ryegrass took care of the mineralized nitrate after the barley harvest.

The effect of irrigation on N leaching was not clear due also to confounding by the different winter treatments in the first two experimental years. If we leave out

1991, with little need for irrigation, the leaching figure for the other three years will be almost the same in the two water regimes. A large positive yield response to irrigation in 1992, which resulted in a large uptake of N, did not give reduced leaching of nitrate. Prolonged periods of drought might also have hampered the N mineralization that year. In 1993 it was found that there was a tendency to higher soil respiration with than without irrigation (Haugen & Olsen 1993).

The total leaching of cations is governed by the total amount of soluble anion as discussed by Johnson & Cole (1977). In this experiment a small increase in cation concentrations, but not in quantities in g/m^2, followed increased rates of fertilizer application, particularly as a result of Cl leaching. The cation composition in drainage was determined by the relative amount and the exchangeability of the cations in the deeper layer, here mainly 50-100 cm. Apparently, high leaching losses of Mg and Na in the clay soil occurred from this layer. A relatively larger surplus of cation over anion in drainage, assumed to be due to bicarbonate, varied with fertilizer and water application and among the four soils.

b. Nitrogen utilization and balance

Vigorous growth of barley and high response to fertilizer resulted in lower surpluses of nitrogen available for leaching in this experiment. Furthermore, utilization percentages increased from 56% for the 9.5-3 g N/m^2 to 70% for the 16-9.5 g N dose. The same results were found in a lysimeter experiment using ^{15}N (Lyngstad 1990) and by difference calculations (Kjellerup & Dam Kofoed 1983; Uhlen 1994). Johnston & Jenkinson (1989) reported similar results from Rothamsted long-term experiments, and ^{15}N work (Powlsen et al. 1986) showed that a larger proportion of the lower doses of N had been used to produce roots. The relative proportion in microbiomass production may also be affected by increasing N rates. The average proportion of the added N (16-3g/m^2) during 4-5 years recovered as increased total-N in topsoil was 40% in our experiment. The same quantities of N residuals in soils from N fertilizers were found in an 8 year field lysimeter experiment (Uhlen 1989) and in some long-term Norwegian field experiments, where the half-life of residual N from fertilizer was estimated to be 14 years (Uhlen 1991). A more rapid breakdown of newly accumulated N reserves in soil occurred in lysimeter experiments (Lyngstad 1990; Yläranta et al. 1993). It is likely that the decomposition is somewhat slower under Nordic climatic conditions, compared to results from other short and long-term European experiments (McDonald et al. 1989; Johnston & Jenkinson 1989; Dam Kofoed 1980).

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