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

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Barley-fodder rape silage

III. Feeding experiments with dairy cows

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Barley-fodder rape silage harvested at the yellow ripeness stage of barley, grass silage and a combination of both silages were compared for intake and production response in three experiments. A total of 66 dairy cows in mid lactation were used in the experiments. Both silages were well preserved. The mean organic matter digestibility rates for the barley-fodder rape and grass silage were 64.4 and 72.0%, respectively. Net energy concentrations in the two silages averaged 0.682 and 0.774 feed units (kg dry matter)$^{-1}$, respectively. For cows fed barley-rape, grass, or a mixture of both silages, dry matter (DM) intakes were 9.4, 9.4 and 9.6 kg d^{-1} while net energy intakes were 6.4, 7.3 and 7.1 feed units d^{-1}, respectively. In two of the three experiments the yield of fat-corrected milk was significantly ($P<0.05$) lower for cows fed only barley-fodder rape silage in comparison with the other groups, on average 18.9, 19.4, and 19.5 kg d^{-1}. It is concluded that barley-fodder rape silage can be used successfully as the sole forage component in rations for dairy cows.

Key words: Whole barley, fodder rape, silage, dairy cows, feed intake, milk yield

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The feeding value of silage made from mixtures of whole barley and fodder rape is discussed by Nordang (1990a, b). These papers include details of ensiling experiments with different harvesting stages carried out at the Norwegian State Agricultural Research Stations of Tjøtta, Vågønes, Holt, Flaten and Svanhovd (Nordang 1990a) and bull fattening trials using silages from similar harvesting stages at Vågønes Research Station (Nordang 1990b).

To complete the evaluation, experiments were conducted with dairy cows offered either silage made from the barley-rape mixture (harvested at yellow ripening stage of the barley), grass silage or a combination of both. The main objective of the experiments was to compare the feed intake, nutritive value and milk production of the two silage types. It was also of interest to find out whether a mixed silage diet would enhance feed intake.

These experiments form part of the experimental series «The use of barley-fodder rape silage for cattle and sheep in Northern Norway» and this is the final paper in a series of three (Nordang 1990a, b). The sheep feeding experiments will be published elsewhere.

MATERIALS AND METHODS

A. Plan of experiments

Three feeding experiments with a total of 66 dairy cows, all Norwegian Red Cattle, were carried out during the winters of 1982-85. The experiments were conducted at Bodin Elementary Agricultural School situated near the Vågønes Research Station in Bodø.

A randomized block design with three experimental groups was used. The cows were assigned to blocks of three according to lactation number, milk yield in the preliminary period, days in lactation and liveweight. Three blocks in each experiment contained only heifers. The experiments followed the Danish type of design for continuous group feeding trials with a preliminary period of 4 weeks, an experimental period of 8 (Experiments I and II) or 10 weeks (Experiment III), followed by a post-treatment period of 4 weeks (Presthegge 1959).

In both the preliminary and post-treatment periods the cows were fed the same type of grass silage, *ad libitum*. In the experimental period the diets for the different treatment groups were:

1. Grass silage fed *ad libitum* + concentrates according to the Norwegian standards above 7.5 feed units for fattening (FU).
2. Grass silage and barley-fodder rape silage fed *ad libitum* + concentrates according to the Norwegian standards above 7.5 FU.
3. Barley-fodder rape silage fed *ad libitum* + concentrates according to the Norwegian standards above 7.5 FU.

Further information about the experiments is given in Table 1.

B. Feeds

The mixed sward of barley and fodder rape was established by sowing 100 kg ha^{-1} barley seed (*Hordeum vulgare* cv. Bode) and 10 kg ha^{-1} fodder rapeseed (*Brassica napus var. oleifera* cv. Kentan) in the same field. Nitrogen was applied at the rate of 120 kg N ha^{-1}. The climatic conditions for Vågønes Research Station have already been presented (Nordang 1990a). During the three summers temperature was lower and precipitation higher than normal.

The whole barley and fodder rape mixture was harvested when the yellow ripeness stage of the barley had been reached. The grass came from the first cut from fields dominated by timothy (*Phleum pratense* cv. Bodin), two weeks after heading of timothy. Heading was defined as being at 2 to 10 visible heads m^{-2}.

Samples of about 2 kg herbage were collected from the fields before harvesting for estimation of the botanical composition by sorting. Weighed average composition according to crops harvested from each of the fields is presented in Table 2. The group «other grasses» included mainly *Poa pratensis*, *P. annua* and *Alopecurus geniculatus*. Table 2 also gives harvesting dates and crop dry matter (DM) yields estimated by harvesting

Table 1. Information about the experiments

Experiment		Total no. in experiment		Age in years, Group			Days from calving, Group			Length of experimental periods (weeks)
		Cows	Heifers	1	2	3	1	2	3	
I	1982-83	12	9	5.6	4.1	4.0	86	87	94	8
II	1983-84	15	9	4.5	4.4	4.4	73	68	69	8
III	1984-85	12	9	5.0	7.0	5.1	93	71	69	10

two areas, each about 10 m^2, within each field.

The crops were harvested using a flail-type forage harvester and samples were taken from each wagon load. Formic acid (85%) was applied at a rate of approximately 3 l ton^{-1} of crops directly into the harvester. The crops were ensiled in tower silos and a two-layer plastic sheet was used to cover them before 500 kg m^{-2} pressure was applied.

In addition to silage the cows were fed two concentrate mixtures, «A» (12.5% digestible crude protein (DCP)) and «C» (32% DCP). Concentrate «C» contained 25% fish meal, while the main protein sources in concentrate «A» were rapeseed meal and soya bean meal.

C. Feeding and management

The energy requirement for maintenance was estimated on the basis of liveweight, using the Norwegian standard of 4.0 FU for a 500 kg cow. The protein requirement for maintenance was set at 75 g DCP FU^{-1} (Saue 1977). The requirement for milk production was set at 0.4 FU and 60 g DCP (kg 4% fat corrected milk (FCM))$^{-1}$, with lactating heifers being assigned an extra 0.5 kg concentrate «A» for growth.

The initial level of concentrate in the experimental period for the three cows within any block was based on average liveweight in the preliminary period, and milk production for that particular block in the last week of the preliminary period. This amount was reduced by 0.25 kg every second week in order to match the standard rate of decline in milk yield (5 to 7% $month^{-1}$) during mid-lactation (Mo 1975, Bergheim 1979b).

In an attempt to meet the protein requirement, animals with a yield of over 22.5 kg FCM day^{-1} were given from 0.50 to 1.50 kg day^{-1} concentrate «C». In addition to silage and concentrate, 100 g mineral supplement (Norwegian Standard Mixture) day^{-1} was given.

Individually weighed feed rations were given twice a day, at approximately 110% of voluntary intake. Cows given both silages (group 2) were fed grass silage in the morning and barley-fodder rape silage in the afternoon. Residues were recorded once a day, except those for group 2, which were recorded twice a day. In all experiments the same milking, feeding and management procedures were used. With some minor modifications, the following routine was practised:

	Morning	Afternoon
Weighing of feed refusals		14:30 h
Concentrate feeding	06:15 h	14:45 h
Milking	06:30 h	16:00 h
Silage feeding	07:45 h	15:30 h

Milk yields were recorded four days a week, from Monday morning to Thursday afternoon. Cows were weighed at various intervals on two consecutive

Table 2. Botanical composition (% of DM), dates of harvest and crop yield

Crop	Experiment I		Experiment II		Experiment III	
	Grass	Barley-rape	Grass	Barley-rape	Grass	Barley-rape
Hordeum vulgare		46		56		76
Brassica napus		46		30		23
Phleum pratense	73		87		88	
Other grasses	24		8		11	
Weeds	3	8	5	14	1	1
Harvesting dates	12-13.7.	13.9.	4-6.7.	2.9.	25-26.6.	11-12.9.
DM yield, ton (ha) ^{1}	6.2	8.4	5.7	6.6	3.9	9.2

days before silage feeding in the morning.

D. Sampling and analyses

DM determinations were recorded weekly, while samples from silages and silage refusals were taken for chemical analysis every second week. The concentrate mixtures were sampled every week, from which composite samples were produced and analysed at the end of the experiment. The chemical analyses of feeds and refusals were carried out according to procedures described by Nordang (1990a).

During recording of milk yield from Monday afternoon to Wednesday morning two samples of milk were taken from each animal. These were analysed for milk fat, protein and lactose concentration at the Northern Norway Dairy Laboratory in Harstad using a Foss Electric FMP Combi. The mean of the two samples was used in the computations.

Twice during the experimental periods samples of rumen fluid were obtained by stomach tube. Sampling started at 10.00 h. After determination of pH, a 10 ml sample was preserved with 0.25 ml formic acid and analysed for volatile fatty acids and ammonia using gas chromatography in the Department of Animal Science at the Agricultural University of Norway, Ås.

E. Estimation of the nutritive value of the roughage

Samples of the two types of silage were evaluated in an *in vivo* digestibility experiment using two wethers fed at maintenance level. The estimates of FU, metabolizable energy (ME) and DCP of the silage were based on the chemical analysis from every second week of the experiments and the corresponding coefficients obtained in digestibility trials. A fuller description of methods used in the estimation of energy in silage is presented by Nordang (1990a).

Estimation of the net energy concentration in the silage DM for the two silage types was based on the yield of the cows, the silage DM intake and the estimated FU intake of concentrate as described by Saue et al. (1978). The net energy requirement for maintenance was set at 3.78 FU (100 kg metabolic weight) $^{-1}$, and the requirement for milk production at 0.4 FU (kg FCM)$^{-1}$.

F. Statistical analysis of the data

In the calculation of the results of the experiments the first two weeks of the experimental period and the first week of the post-treatment period were excluded.

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

$$Y_{ij} = \mu + a_i + bX_{ij} + e_{ij}$$

where

Y_{ij} = the parameter analysed
μ = general mean
a_i = the effect of the i-th treatment
b = the effect of the covariate X_{ij}
e_{ij} = random error

Means of the values obtained during the preliminary and post-treatment periods were used as the covariates for each parameter as described by Presthegge (1959). When covariates were used, the least square means (LS means) are given. Differences between LS means were analysed using multiple t-tests; those with different superscripts indicate a significant difference ($P < 0.05$).

The yield responses in animals from the experimental feeds were also calculated as performance in the experimental period minus average performance in the preliminary and extra control period. The data obtained were analysed as a randomized block design.

RESULTS

A. Chemical composition and characteristics of the feed

The chemical compositions of the silages are presented in Table 3. No substantial differences in DM content were observed between the two types of silage. The content of crude protein was generally low, with lower levels in the barley-rape silage than in the grass silage in two of the three experiments. The crude fibre content averaged 32.2 in barley-rape silage, and 36.1 in grass silage.

The silage was generally of good quality, with low concentrations of butyric acid and a pH of 4.0 or lower (Table 4). With the exception of Experiment I, ammonia-N was below 8% of total-N, a level associated with very good silage (Breirem & Homb 1970). In Experiment I, the content of lactic acid was high in both silages, while in Experiments II and III the content of lactic acid was lowest in the barley-rape silage.

The digestibility of organic matter (OM) was lower in barley-rape silage than in grass silage (Table 5). This was possibly

Table 3. Chemical composition of the silages in each experiment

	Experiment I		Experiment II		Experiment III	
	Grass	Barley-rape	Grass	Barley-rape	Grass	Barley-rape
DM %	20.9	21.8	23.0	22.7	24.3	24.6
% of DM:						
Crude protein	11.9	10.3	8.9	9.3	11.8	9.6
Corr. crude protein	10.6	9.2	8.4	8.7	11.1	9.0
True protein	6.2	5.4	6.4	6.1	6.8	5.6
Ether extract	4.8	3.5	3.5	2.1	4.3	2.1
N-free extract	41.7	45.9	46.8	47.9	43.7	54.1
Crude fibre	37.8	32.1	35.6	35.3	35.0	29.3
Ash	5.1	9.3	5.7	6.1	5.8	5.6
Sugar	1.9	2.1	2.6	3.0	2.9	5.3
Ca	0.34	1.27	0.27	0.61	0.33	0.44
P	0.22	0.32	0.19	0.35	0.23	0.25
Mg	0.08	0.12	0.08	0.10	0.10	0.07
K	1.42	1.91	1.29	1.66	1.88	1.55
NO_3-N	0.01	0.05	0.04	0.04	0.03	0.02
True protein in % of crude protein	52.2	52.3	71.8	65.6	57.3	58.1

Table 4. Content of ammonia (NH_3-N), pH and organic acids of the silages

	Experiment I		Experiment II		Experiment III	
	Grass	Barley-rape	Grass	Barley-rape	Grass	Barley-rape
NH_3-N in % of total N	10.7	10.4	7.7	7.4	4.8	6.1
pH	4.0	4.0	3.7	4.0	3.6	3.9
In silage, %:						
Formic acid	0.14	0.09	0.26	0.26	0.22	0.23
Acetic acid	0.61	0.52	0.48	0.31	0.36	0.53
Propionic acid	0.04	0.01	0.07	0.02	0.00	0.01
Butyric acid	0.01	0.01	0.00	0.03	0.00	0.06
Valeric acid	0.01	0.01	0.00	0.00	0.00	0.00
Lactic acid	2.37	3.06	1.22	0.91	1.43	0.63

Table 5. Digestion coefficients of the silages

	Experiment I		Experiment II		Experiment III	
	Grass	Barley-rape	Grass	Barley-rape	Grass	Barley-rape
Dry matter	71.7	66.0	67.1	60.1	72.1	62.1
Organic matter	73.8	68.6	68.4	61.0	73.8	63.5
Crude protein	63.5	56.9	52.7	52.2	67.8	55.6
Ether extract	73.3	70.0	70.5	71.9	75.9	68.4
N-free extract	68.7	72.7	67.0	63.4	73.4	68.8
Crude fibre	82.5	66.0	73.7	59.3	75.9	55.7
Ash	31.0	40.7	45.8	46.5	45.0	39.1

due to the barley-rape silage having a substantially lower crude fibre digestibility than the grass silage. Differences between silages in digestibility of nitrogen free extract (NFE) were less significant.

Because of the lower OM digestibility, the calculated energy value was lower in barley-rape silage than in grass silage (Table 6). Calculation of the FU concentration using the «value number 80» resulted in higher FU values than with the fibre deduction method. The mean FU concentration (value number 80) were 0.682 and 0.774 (kg DM)$^{-1}$ for barley-rape and grass silage, respectively. The DCP concentration was generally low, 49 g (kg DM)$^{-1}$ in barley-rape and 62 g (kg DM)$^{-1}$ in grass silage.

Chemical composition, energy and protein contents of concentrate mixtures «A» and «C» are given in Table 7.

B. Animal health and weight changes during the experiments

Apart from a rather high incidence of clinical mastitis, the general health of the cows was good. During the experimental period 7, 4 and 4 cows were treated for mastitis in Experiments I, II and III, respectively. No correlation between treatment and occurrence of mastitis was observed.

Liveweights during the experiments are presented in Table 8. Liveweight gain for the cows during the experimental period averaged 43, 58 and 116 g day^{-1} for Experiments I, II and III, respectively.

C. Feed consumption

Daily intakes of silage DM and FU are given in Table 9. When computing silage FU intake in the preliminary and post-treatment periods, an energy value of 0.74 FU (kg DM)$^{-1}$ was used.

Table 6. Feed units for fattening (FU), digestible crude protein (DCP) and metabolizable energy (MJ ME) (kg DM)$^{-1}$

	Experiment I		Experiment II		Experiment III	
	Grass	Barley-rape	Grass	Barley-rape	Grass	Barley-rape
FU calculated using:						
Value number 80	0.798	0.709	0.735	0.653	0.790	0.683
Fibre deduction	0.759	0.684	0.696	0.595	0.767	0.670
ME, MJ	11.1	10.1	10.0	8.9	11.4	9.3
DCP, g	67	53	44	45	75	50

Table 7. Chemical composition of concentrates

	Experiment I		Experiment II		Experiment III	
	Mix. A	Mix. C	Mix. A	Mix. C	Mix. A	Mix. C
DM, %	86.7	88.4	86.9	88.3	86.8	89.5
% of DM:						
Crude protein	18.4	41.4	21.1	42.0	18.3	37.5
Ether extract	5.2	7.4	6.0	7.5	5.8	8.5
N-free extract	63.8	33.7	57.2	33.8	62.6	35.9
Crude fibre	7.3	6.2	7.8	5.7	7.8	8.0
Ash	5.3	11.2	7.9	11.0	5.5	10.1
Ca[1)]	0.7	1.6	0.7	1.6	0.7	1.6
P[1)]	0.6	1.2	0.6	1.2	0.6	1.2
Na[1)]	0.3	0.8	0.3	0.8	0.3	0.8
Per kg DM						
FU[1)]	1.08	1.10	1.08	1.10	1.08	1.09
DCP[1)], g	144	362	144	362	144	358

[1)] Given by the producer

Table 8. Liveweights during the experiments

Group	Experiment I			Experiment II			Experiment III		
	1	2	3	1	2	3	1	2	3
Liveweight, kg									
Start, preliminary period	491	473	464	544	516	540	489	513	499
End, preliminary period	498	483	472	527	505	520	500	522	517
After 2 weeks in expt. period	515	489	492	547	510	532	504	526	523
End, experimental period	497	485	479	535	511	516	506	527	530
End, post-treatment period	510	493	491	538	510	505	503	532	516
Changes in liveweights in experimental period, g day^{-1}	-18	+29	+118	+139	+107	-73	+96	+67	+186

Generally, the cows had a high silage DM intake in the experimental periods, although intakes varied between experiments. In Experiment I the silage DM intake in the preliminary period was higher in group 3 than in the other groups (this parameter was not used by blocking the animals). In Experiment III the groups also had variable feed intakes during the preliminary period. Group 2 cows, which were offered both silages, consumed 48%, 47% and 39% of silage DM from barley-rape silage, in Experiments I, II and III, respectively.

The daily amount of concentrate «C» fed in the experimental period averaged at 0.55, 0.65 and 0.71 kg in Experiments I, II and III, respectively. In Table 10 daily intake of silage DM and silage FU are presented as LS means, where the means of observations in the preliminary period and in the extra control period are used as covariates in the calculations.

No difference in intake of silage DM was observed in any of the experiments. As a result of the lower FU concentration in barley-fodder rape silage, intake of FU (LS means) was lower in group 3 than in the other groups, although the difference was significant only in Experiment III.

D. Milk production

The mean daily yield of milk and FCM cow^{-1} and the chemical composition of

Table 9. Daily intake of silage DM, silage DM (100 kg liveweight)$^{-1}$, silage FU (estimated using value number 80), concentrate FU and total FU in the periods of the experiments

Period	Preliminary			Experimental			Post-treatment		
Group	1	2	3	1	2	3	1	2	3
Experiment I									
Silage DM kg	10.44	10.41	11.81	9.17	9.49	10.39	9.63	9.31	9.93
Silage DM kg(100 kg l.w.)$^{-1}$	2.11	2.18	2.52	1.81	1.95	2.15	1.91	1.90	2.05
Silage FU	7.73	7.70	8.74	7.32	7.18	7.37	7.13	6.89	7.35
Concentrate FU	5.03	4.77	5.13	3.99	4.05	3.98	3.38	3.39	3.36
Total FU intake	12.76	12.48	13.87	11.31	11.22	11.35	10.51	10.28	10.71
Experiment II									
Silage DM kg	7.94	8.26	8.00	9.05	9.37	8.91	8.23	8.81	8.45
Silage DM kg(100 kg l.w.)$^{-1}$	1.48	1.62	1.51	1.65	1.84	1.71	1.53	1.72	1.65
Silage FU	5.88	6.11	5.92	6.65	6.53	5.81	6.09	6.52	6.26
Concentrate FU	8.52	8.05	8.01	6.13	6.14	6.14	5.59	5.62	5.55
Total FU intake	14.40	14.16	13.93	12.78	12.67	11.95	11.69	12.15	11.81
Experiment III									
Silage DM kg	8.36	7.97	7.29	9.84	10.01	9.08	8.91	9.60	8.96
Silage DM kg(100 kg l.w.)$^{-1}$	1.69	1.54	1.44	1.94	1.90	1.73	1.76	1.81	1.71
Silage FU	6.19	5.90	5.40	7.78	7.50	6.20	6.60	7.11	6.63
Concentrate FU	8.44	8.66	8.53	6.72	6.73	6.75	5.96	6.05	5.91
Total FU intake	14.63	14.56	13.93	14.50	14.23	12.95	12.56	13.16	12.54

Table 10. Daily intake of silage DM and silage FU (LS means)

Group	1	2	3
Experiment I			
Silage DM	9.40	9.92	9.73
Silage FU	7.49	7.48	6.89
Experiment II			
Silage DM	9.18	9.20	8.94
Silage FU	6.76	6.39	5.84
Experiment III			
Silage DM	9.71	9.70	9.52
Silage FU	7.68[b]	7.27[b]	6.54[a]

the milk for the different groups in the experiments are given in Tables 11, 12 and 13.

In Experiment I the cows in group 1, which were fed grass silage, yielded significantly less than the other groups, but because there was a slightly higher milk fat concentration, the difference in FCM yield was not significant. In Experiment II, cows in group 3 produced significantly less milk and FCM than cows in group 1, while the cows in group 2 were somewhere in between in yield. In Experiment III, the cattle offered both silages, gave the highest yield of milk and FCM, whereas group 3 cows (barley-rape silage) produced the lowest yield. In Table 14 the yield parameters and milk composition are presented as corrected (least square) means.

In Experiment I the milk yield was significantly lower in group 1 compared with the other two groups. Because of a slightly higher milk fat concentration in group 1, the difference in FCM was not significant. In Experiment II the milk fat content and FCM were lower in group 3 than in the other groups, whereas the difference in milk yield was not significant. In Experiment III milk yield, fat content and FCM were lower in group 3 than in the other two groups.

Differences in milk protein and lactose concentrations were not significant in any of the experiments. No differences in milk flavour were detected in milk from Experiments I and II tested by a tasting

Table 11. Mean daily yield and composition of the milk, Experiment I

Group		Preliminary period	Experimental period	Post-treatment period	Performance[1)]	Difference II - I	Difference III - I
1	Milk, kg	21.55	17.85	16.89	-1.37[a]		
	FCM, kg	20.33	16.92	16.62	-1.55		
	Milk fat, %	3.67	3.65	3.88	-0.12		
	» protein, %	3.15	3.11	3.20	-0.07		
	Lactose, %	5.12	4.98	4.94	-0.05		
2	Milk, kg	21.18	18.63	16.76	-0.34[b]	1.03	
	FCM, kg	20.45	17.41	16.26	-0.94	0.61	
	Milk fat, %	3.82	3.57	3.81	-0.25	-0.13	
	» protein, %	3.18	3.11	3.16	-0.07	0.00	
	Lactose, %	5.04	4.94	4.97	-0.06	-0.01	
3	Milk, kg	20.98	18.39	16.53	-0.36[b]	1.01	
	FCM, kg	20.41	17.21	16.02	-1.00	0.55	
	Milk fat, %	3.82	3.58	3.82	-0.23	-0.11	
	» protein, %	3.18	3.16	3.23	-0.04	0.03	
	Lactose, %	5.03	4.97	4.95	-0.02	0.03	

1) Calculated as the difference between observations in the experimental period and the means of preliminary and post-treatment periods.

Table 12. Mean daily yield and composition of the milk, Experiment II

Group		Preliminary period	Experimental period	Post-treatment period	Performance[1)]	Difference II - I	Difference III - I
1	Milk, kg	25.39	20.05	18.29	-1.79[b]		
	FCM, kg	24.97	19.41	18.01	-2.08[b]		
	Milk fat, %	3.86	3.77	3.90	-0.11[ab]		
	» protein, %	3.14	3.10	3.18	-0.06		
	Lactose, %	5.00	4.80	4.77	-0.09		
2	Milk, kg	25.74	19.95	19.14	-2.48[ab]	-0.69	
	FCM, kg	24.60	19.21	18.46	-2.32[ab]	-0.24	
	Milk fat, %	3.70	3.73	3.75	-0.01[b]	0.10	
	» protein, %	3.18	3.10	3.12	-0.05	0.01	
	Lactose, %	5.01	4.78	4.76	-0.10	-0.01	
3	Milk, kg	25.85	20.18	19.92	-2.70[a]	-0.91	
	FCM, kg	24.78	18.64	18.77	-3.14[a]	-1.06	
	Milk fat, %	3.74	3.48	3.62	-0.20[a]	-0.09	
	» protein, %	3.11	3.01	3.09	-0.09	-0.03	
	Lactose, %	5.13	4.91	4.91	-0.11	-0.02	

1) Calculated as the difference between observations in the experimental period and the means of preliminary and post-treatment periods.

Table 13. Mean daily yield and composition of the milk, Experiment III

Group		Preliminary period	Experimental period	Post-treatment period	Performance[1)]	Difference II - I / III - I
1	Milk, kg	25.29	22.94	19.63	0.48[b]	
	FCM, kg	24.19	22.16	19.90	0.11[b]	
	Milk fat, %	3.71	3.80	4.13	-0.12	
	» protein, %	3.16	3.30	3.35	0.04	
	Lactose, %	4.90	4.97	5.08	-0.02	
2	Milk, kg	25.27	23.24	19.68	0.77[b]	0.29
	FCM, kg	24.20	21.81	19.29	0.11[b]	0.00
	Milk fat, %	3.70	3.59	3.88	-0.20	-0.08
	» protein, %	3.16	3.18	3.27	-0.03	-0.07
	Lactose, %	4.84	4.93	5.04	-0.01	0.01
3	Milk, kg	25.17	21.84	19.10	-0.30[a]	-0.78
	FCM, kg	24.47	20.69	19.20	-1.14[a]	-1.25
	Milk fat, %	3.80	3.67	4.08	-0.27	-0.15
	» protein, %	3.09	3.10	3.25	-0.07	-0.11
	Lactose, %	4.90	4.89	4.97	-0.05	-0.03

[1)] Calculated as the difference between observations in the experimental period and the means of preliminary and post-treatment periods.

Table 14. Daily milk yield and milk composition (LS-means)

Group	1	2	3
Experiment I			
Milk, kg	17.60[a]	18.65[b]	18.63[b]
FCM, kg	16.77	17.41	17.37
Milk fat, %	3.67	3.56	3.57
Milk protein, %	3.11	3.11	3.15
Lactose, %	4.96	4.95	4.98
Experiment II			
Milk, kg	20.46	19.92	19.82
FCM, kg	19.48[b]	19.25[b]	18.53[a]
Milk fat, %	3.68[b]	3.76[b]	3.54[a]
Milk protein, %	3.08	3.09	3.05
Lactose, %	4.83	4.82	4.84
Experiment III			
Milk, kg	22.85[b]	23.13[b]	22.04[a]
FCM, kg	21.99[b]	21.96[b]	20.72[a]
Milk fat, %	3.78[b]	3.66[ab]	3.63[a]
Milk protein, %	3.25	3.19	3.15
Lactose, %	4.95	4.94	4.90

panel at the Northern Norway Dairy Laboratory in Harstad.

E. Rumen fluid composition

The proportions of volatile fatty acids in the rumen fluid presented in Table 15 indicate the average of two samplings during the experimental period. In Experiment I the proportion of acetic acid in group 3 was lower, while the contents of propionic and butyric acid were higher than in the other groups. In Experiment II the molar concentration of acetic acid was significantly lower in group 2 than in group 1, while the proportions of propionic and butyric acid were higher. In Experiment III the molar concentration of acetic acid was lowest for the cows in group 2, while group 3 cows had the lowest propionic acid concentration.

In all the experiments proportions of valeric and isovaleric acid were higher in group 3 than in group 1. The ratio $(C_2 + C_4)/C_3$ differed between the groups, consistent with the acids which give rise to this parameter.

Ammonia concentration was lower in group 3 than in group 1 in two of the experiments. In Experiments II and III

Table 15. Molar proportion of volatile fatty acids, ammonia-N and pH in rumen fluid

Group	Experiment I			Experiment II			Experiment III		
	1	2	3	1	2	3	1	2	3
Molar percentage:									
Acetic acid	67.4^{b}	66.9^{b}	63.7^{a}	64.1^{b}	61.6^{a}	63.1^{ab}	65.3^{b}	63.0^{a}	66.1^{b}
Propionic acid	19.5^{a}	19.4^{a}	20.7^{b}	18.5^{a}	19.9^{b}	19.6^{ab}	18.3^{b}	19.2^{b}	17.0^{a}
Butyric acid	10.6^{a}	11.2^{a}	12.6^{b}	13.7^{a}	14.6^{b}	13.1^{a}	13.0	14.1	13.1
Isobutyric acid	0.7	0.7	0.7	0.9^{a}	1.0^{ab}	1.1^{b}	0.8	0.8	0.8
Valeric acid	0.8^{a}	0.9^{a}	1.2^{b}	1.3^{a}	1.5^{b}	1.6^{b}	1.4^{a}	1.6^{b}	1.6^{b}
Isovaleric acid	1.0^{ab}	0.9^{a}	1.1^{b}	1.2^{a}	1.5^{b}	1.4^{b}	1.2^{a}	1.3^{a}	1.5^{b}
Ammonia, mmol(L)$^{-1}$	18.8^{b}	12.9^{a}	8.7^{a}	2.6^{a}	4.7^{b}	2.6^{a}	6.5^{b}	8.7^{b}	2.9^{a}
pH	6.60^{a}	6.92^{b}	6.86^{b}	6.70	6.78	6.80	6.91^{a}	6.95^{a}	7.19^{b}
$(C_2+C_4)/C_3$	4.04^{b}	4.07^{b}	3.72^{a}	4.28^{b}	3.90^{a}	3.95^{a}	4.33^{a}	4.10^{a}	4.72^{b}

the ammonia concentration generally was low. In all groups the pH in rumen fluid was quite high, and generally higher for cows in group 3 compared with group 1 cows.

F. Feed utilization

The intakes of FU and DCP (kg FCM)$^{-1}$ and FU concentration of the silage based on the yield of the cows are presented in Table 16. Energy and protein used for milk production was estimated as the difference between total intake and maintenance requirement.

Substantial changes in liveweight were observed following change of silage feeding (Table 8), going from the preliminary to the experimental period, as observed in other experiments (Andersen et al. 1976). Because of this, no corrections for liveweight changes were made.

The energy used for milk production ranged from 0.415 to 0.463 FU (kg FCM)$^{-1}$, which concurs with results obtained by Mo (1975), Bergheim (1979b) and Hole (1985b). The protein supply was generally lower than 60 g DCP (kg FCM)$^{-1}$, but no major differences between the groups were observed.

Whereas in Experiment I the difference in FU concentration between silages estimated from production corresponded well with the digestibility trials, in Experiments II and III there was a lower level of difference between the two silages.

DISCUSSION

A. Characteristics of the silage

In other experiments with silage made from barley-fodder rape mixtures har-

Table 16. Daily intakes of net energy (FU) and digestible crude protein (DCP)(kg FCM)$^{-1}$, and calculated FU (kg DM)$^{-1}$ based on results of the experiments

	Experiment I			Experiment II			Experiment III		
	1	2	3	1	2	3	1	2	3
Above maintenance:									
FU (kg FCM)$^{-1}$	0.418	0.408	0.420	0.430	0.438	0.410	0.463	0.452	0.415
DCP (kg FCM)$^{-1}$	52.7	51.4	52.5	52.6	54.8	55.2	65.8	62.5	56.3
Calculated:									
FU (kg DM)$^{-1}$	0.766	0.740	0.675	0.670	0.618	0.631	0.648	0.635	0.649

vested at yellow ripeness, the OM digestibility varied extensively between years and sites (Nordang 1990a, b). In the experiments reported here, OM digestibility varied less, and was similar to the majority of the silages in the ensiling and bull feeding experiments. The highest digestibility was found in Experiment I, when fodder rape made up about half of the silage DM.

OM digestibility and energy concentrations in the barley-fodder rape silage were in agreement with the results obtained by Sjödahl & Martinsson (1987) and Pestalozzi (unpubl.), and were slightly higher than the results obtained by Lunnan (1983).

The chemical composition and digestibility of the grass silage corresponded well with results from similar experiments in Northern Norway (Bergheim 1979a, b, Hole 1985a, b), although the digestibility of crude fibre was slightly higher than that observed at corresponding harvesting stages in Southern Norway (Homb 1952, Presthegge 1959, Gudmundsson 1979).

The main contrast between the two silages was the lower energy concentration in barley-rape silage. This was partly due to the lower digestibility coefficients, especially those of crude fibre, although it should be noted that the crude fibre content of barley-rape silage was lower than that of grass silage.

In Experiment II and III some problems with aerobic deterioration occurred in the barley-fodder rape silage. The temperature in the silage occasionally rose to about 30°C. In a later experimental series with barley-fodder rape silage, where double the quantity was removed from the silo each day, no temperature rise was detected (Nordang, unpubl.).

B. Feed intake

Factors influencing the voluntary intake of silage DM are, among others, the OM digestibility of the silage, DM concentration, fermentation characteristics (Brenøe 1972, Hermansen 1980) and crude fibre content (Kristensen 1983).

In the present experiments no difference in DM intake between silages was registered, despite the higher OM digestibility of the grass silage. This may have been due to the lower crude fibre content in barley-fodder rape silage. Kristensen's (1983) system for estimating feed intake by dairy cows, based on the content of crude fibre in the forage, has separate equations for grass silage and whole barley silage, the two silage types having similar gut fill values.

Silage DM intakes, averaged over all the experiments, were 9.35 kg, 9.62 kg and 9.46 kg for groups 1, 2 and 3, respectively. These figures are similar to the results of Hole (1985b), Bergheim (1979b) and Bævre (1977).

It is widely recommended that the intake of brassica species by the animals be restricted if adverse effects from the toxic agents glucosinolates and S-methylcysteine (SMCO) are to be avoided (McDonald et al. 1984). In the experiments reported here, no effects on animal health or milk flavour were registered; in Experiments II and III this may have been the case since fodder rape made up a limited part of the total ration. In Experiment I, although the daily consumption of fodder rape DM was 4.78 kg, about one-third of the total DM intake, no adverse effect was observed. Grongnet (1982), who offered 6.2 kg DM fresh fodder rape to dairy cows, did not record any clinical symptoms either, although some blood parameters were altered. Care must therefore be taken when fodder rape content in the crop mixture is high. On the other hand, ensiling experiments have shown that both glucosinolates and SMCO are reduced during the ensiling process (Fales et al. 1987).

As a consequence of the variation between groups in the preliminary period in Experiments I and III, the silage DM intakes differed between the groups in the experimental period, but when cal-

culated as LS means, correcting for differences in the preliminary and extra control periods, no substantial differences were observed.

In Experiments I and II the variation within groups in DM intake was high, with the result that the differences in silage FU intake between group 3 and the other groups were not significant. The cows fed both types of silage (group 2) did not consume significantly larger amounts of silage DM than the other cows. They did, however, have a higher intake of FU and showed a higher milk production than the cows fed only barley-fodder rape silage. Therefore, a combination of grass silage and barley-fodder rape silage may reduce any adverse effect of low energy concentration in barley-fodder rape silage. However, since silage from barley-fodder rape is more prone to aerobic deterioration than grass silage there is an argument for using barley-fodder rape silage as the sole forage. With a high rape content in the crop mixture, the risk of heating problems during unloading is less, and a mixed silage diet may reduce possible health risks associated with high rape content.

C. Animal production and feed utilization

In Experiment I the cows in group 1 displayed a slightly higher intake of silage FU (LS means) than group 3, although not a higher yield of FCM (LS means). On the other hand, calculations showed that the feed utilization in groups 1 and 3 was similar. This apparent inconsistency may be due to the considerable difference in silage intake between the two groups in the preliminary period. This difference influenced the LS means for silage intake but not the calculation of feed utilization, which was based on observed values.

In Experiment II the yield of FCM was lower in group 3 than in the other two groups. The feed utilization was slightly better in group 3, so the production response seems to be a consequence of the lower FU intake, although the difference is lower than was expected from the intake of FU. However, the different patterns of weight gain between the groups in the experimental period may explain some of this deviation.

In Experiment III the yield of FCM was lower for cows fed barley-fodder rape silage than those fed grass silage. The difference in production, however, was lower than expected from differences in FU intake. While the cows in group 3 yielded approximately the amount of FCM expected from the total FU intake, those in the other groups yielded less than was expected. This was expressed through higher values for FU above maintenance (kg FCM)$^{-1}$.

One possible reason for the lower feed utilization for groups 1 and 2 in Experiment II and III could be that the level of feeding was too high in relation to potential yield in these groups. However, the liveweight gains were relatively small in these groups, but could have been more influenced by rumen fill than by energy retention by the animals.

Milk fat content may be depressed by a rumen fermentation pattern characterized by a low ratio of acetic and butyric acid over propionic acid (viz. $(C_2+C_4)/C_3$) (Beever & Oldham 1986). Starch digested post-ruminally and absorbed as glucose could have a similar effect (Ørskov 1975). The lower milk fat concentration in the cows fed barley-fodder rape silage than those fed grass silage may be due to these two factors.

Generally, the production experiments confirmed the trend found in the digestibility trials, i.e. that the barley-fodder rape silage had a lower energy value than the grass silage. However, the obtained differences between silages were lower than those estimated from digestibility experiments with sheep fed at maintenance level.

In deciding the extent to which barley-fodder rape mixture should be grown, the crop yield must also be considered. The yield of FU ha^{-1} was

calculated from DM yield and FU values were estimated either from digestibility trials (D) or from the production experiments (P). The FU yields were always higher in barley-fodder rape than in grass:

	Experiment I		Experiment II		Experiment III	
	Grass	B.-f.r.	Grass	B.-f.r.	Grass	B.-f.r.
D	5000	6000	4200	4300	3100	6300
P	4800	5700	3800	4200	2500	6000

It must be noted that the grass yield is taken from the first cut, and that the second cut at Vågønes is normally about half the yield of the first cut (Larsen pers. comm.). On the other hand, effluent losses will be higher from grass silage than from barley-fodder rape silage, where effluent production is often near zero (Nordang 1990a).

This shows that barley-fodder rape mixture is a high-yielding crop which can be well preserved as silage, and the silage is eaten well by the cattle. The production results demonstrate that barley-fodder rape silage may successfully be fed as the sole forage component in rations for dairy cows in mid-lactation.

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Effects of different environments and selection for persistency in laying hens

I. Effects of two different rearing systems on growth rate, feed conversion, mortality and age at sexual maturity in chickens

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The effects of two different rearing systems for laying hens (battery cages and floor pens) were studied. Body weight at different ages, growth rate, feed conversion, mortality rate and sexual maturity were compared for chicks reared in cages and in floor pens in two generations (1986 and 1987). In both 1986 and 1987 the chicks reared in cages grew faster and were considerably heavier than those reared on floor. The average body weights of chicks at 1, 6, 11 and 18 weeks of age in the 1986 rearing period were 70.8, 545.1, 1136.0 and 1642.6 g, respectively, for cage-reared chicks, and 72.1, 515.5, 1011.3 and 1451 g, respectively, for chicks reared in floor pens. The average body weight gain from 1 to 18 weeks was 13.2 g/day for chicks in cages and 11.6 g/day for those on the floor. In the 1987 rearing period, the body weights at 1, 7 and 16 weeks of age were 73.4, 660.3 and 1582.0 g for chicks in cages, and 75.0, 613.5 and 1377.6 g, respectively, for those on the floor. The average body weight gain from 1 to 16 weeks was 13.5 g/day for chicks in cages and 12.4 g/day for those on the floor. The mortality rates in the different rearing systems were not significantly different with the exception of the 11-18 week period in 1986, when the mortality rate for chicks in cages was significantly higher than the rate for those on the floor. Age at sexual maturity of the chicks reared in cages averaged 143 days, which was 10 days earlier than those in floor pens. Comparison of feed consumption and feed conversion showed that chicks reared in cages consumed more feed than those on floor and had a slightly higher feed conversion. The heritability for body weight at 1, 6, 7, 11 and 18 weeks of age averaged 0.37, 0.44, 0.43, 0.46 and 0.47, respectively. The heritability estimates for age at sexual maturity estimated from sire, dam and sire plus dam components of variance were 0.38, 0.36 and 0.37, respectively. Body weight at different ages was highly correlated, genetically and phenotypically, except at one week of age.

Key words: Body weight, chickens, feed conversion, genetic parameter, mortality, rearing system, sexual maturity.

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In a number of investigations an attempt has been made to determine the effects of different management systems on behaviour of laying hens, either by means of preference testing or by a comparison of behaviour in different environments. It has proved extremely difficult to interpret such studies conclusively (Duncan 1981). Monitoring physiological parameters associated with reaction to a stressor is another approach to the study of welfare in different housing environments. Mashaly et al. (1984) have shown that the level of corticosterone is different for laying hens kept under different management conditions. Egg production has been reported by some to be superior for hens in floor pens than for hens in cages (Froning & Funk 1958, Carlson & Stangeland 1960, Timmons et al. 1961), while others claim that egg production for caged hens is superior compared to that of floor-penned hens (Bailey et al. 1959, Miller & Quisenberry 1959, Rose & Sell 1969). It is generally agreed, however, that cage management has more economic profitability compared with floor operations (Henry 1968, Wildey 1982).

It is commonly believed that it is better to rear the birds under the same management system as will be employed in the future production period since the experience and environment met in early life may have profound and lasting effects on late life periods. The purpose of this study is to compare the effects of cage vs. floor rearing systems on the growth rate, feed conversion and mortality of chicks.

MATERIALS AND METHODS

A base population was established in 1986 through mixing the progeny from two lines of a Norwegian White Leghorn layer breed from two breeding stations. The hatching eggs were taken from the two stations and hatched at the University Chicken Farm. The present analysis is based on data collected in the rearing periods of 1986 and 1987. Only female chickens were included in the analysis.

The chicks were pedigreed, sexed, vaccinated against Marek's disease and individually wing-banded when one day old. The female chicks were randomly assigned to two rearing environments: battery cages and floor pens.

The battery cages were in three tiers, each cage measuring 0.9m x 0.5m = 0.45m^2. Around 40 birds were put into each of the top cages from one day old to six weeks of age. Afterwards, the birds were distributed throughout all three tiers. The floor rearing was carried out in several rearing rooms in the same house. Each room, in which about 400 birds were kept, was 30 m^2 in size.

The same feed, temperature and lighting system were used for the two groups which were reared for 18 weeks before being moved to the laying house.

The lighting system used was a "sudden down" programme with 24-hour lighting for the first day only and 9-hour lighting from the second day to 16 weeks of age. Water was available from nipple drinkers in the cages and from drinking buckets in the floor pens. A standard commercial mash diet was given ad. libitum. The compositions of the diets and calculated contents of nutrients are listed in Table 1.

The chickens were weighed at 1, 6, 11 and 18 weeks of age in 1986, and at 1, 7 and 16 weeks of age in 1987. The mortality rate for both years was calculated and age at sexual maturity recorded individually in 1987.

The SAS GLM (general linear model) procedure was used for carrying out a multivariate analysis of variance (SAS Institute Inc. 1987). The *F* test was carried out according to the different approximations of *F* values to test the effect of the two different rearing systems. Chi-square testing was used for testing the difference in mortality between the two groups. The genetic parameters were estimated using Harvey's LSMLMW program (Harvey 1987). The following sta-

Table 1. Composition and calculated contents of the diets used in the rearing period (percent)

Ingredients	0-8 weeks	8-18 weeks
Herring meal	5.41	2.50
Soybean meal (extr.)	10.51	3.00
Barley	20.00	19.13
Wheat	15.00	5.40
Oat	27.00	45.00
Wheat middlings	10.07	10.00
Fat	3.00	3.00
Grass meal	-----	2.00
Meat and bone meal	4.00	4.00
Methionine	0.02	-----
Shell meal	-----	2.17
Maize gluten	2.32	3.06
Calcium phosphate	2.03	-----
Salt	0.10	0.45
Std. micromin.	0.10	0.10
Mg oxide	0.04	0.04
Choline chloride	0.20	0.05
Vitamin concentrate	0.20	0.10
Calculated contents:		
Crude protein	19.76	15.41
Dig. CP	16.30	12.30
Fat	6.46	6.87
ME Kcal/kg	2800	2700
Lysin	1.00	0.66
Methionine + cystine	0.72	0.59
Linoleic acids	1.24	1.50
Ca	1.20	1.30
P	0.71	0.66
Na	0.15	0.25

tistical model was used for all the traits in the analysis:

$$Y_{ijkl} = \mu + s_i + d_{ij} + H_k + e_{ijkl}$$

where:

Y_{ijkl} is the observation of the $_l$th progeny of the $_j$th dam within the $_i$th sire in the $_k$th rearing system.
μ is the common mean.
s_i is the random effect of the $_i$th sire.
d_{ij} is the random effect of the $_j$th dam mated with $_i$th sire.
H_k is the fixed effect of the $_k$th rearing system.
e_{ijkl} is the residual error.

RESULTS AND DISCUSSION

1. Growth rate

Table 2 and Fig. 1 and 2 show the body weight and growth rate of chickens reared under the two different rearing systems in 1986 and 1987. Average body

[1] $\bar{X}$ = population mean in actual units
SD = standard deviation in actual units
CV = coefficient of variation in percent

Table 2. Population parameters estimated in the 1986 and 1987 rearing periods[1]

Trait	Chickens in cages			Chickens on floor		
	$\bar{X}$	SD	CV	$\bar{X}$	SD	CV
In 1986:						
Body weight, g						
at 1 week of age	70.8	7.3	10.3	72.1	6.2	8.5
» 6 weeks » »	546.2	46.5	8.5	515.6	39.5	7.7
» 11 » » »	1143.0	83.7	7.3	1011.5	65.9	6.5
» 18 » » »	1639.2	131.1	8.0	1447.9	107.2	7.4
Growth rate, g/day	13.2	1.1	8.3	11.6	0.9	7.8
In 1987:						
Body weight, g						
at 1 week of age	73.4	8.1	11.0	75.0	6.1	8.1
» 7 weeks » »	660.3	57.8	8.8	613.5	52.5	8.6
» 16 » » »	1581.8	105.6	6.8	1377.4	88.1	6.4
Growth rate, g/day	14.4	1.0	6.9	12.4	1.1	8.9
Sexual maturity, days	143.0	6.9	4.8	153.3	7.3	4.8

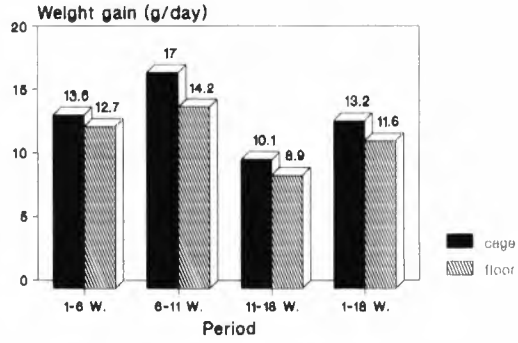

Fig. 1. Body weight gain at different ages in the 1986 rearing period

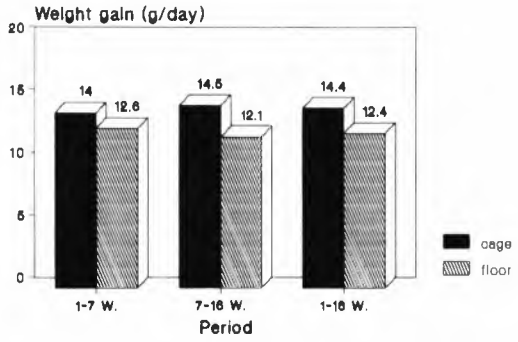

Fig. 2. Body weight gain at different ages in the 1987 rearing period

weights at 1 week of age were nearly the same for the two groups of chickens. At 6, 11 and 18 weeks of age, the chickens reared in the battery cages were heavier than those reared on floor, the difference between the two groups being statistically significant. The average growth rate varied in different periods and the same growth pattern can be seen in both environments (Fig. 1). In 1986 the most rapid growth period of chickens occurred at 7 to 11 weeks - 17.0 g per day in cages and 14.2 g on floor. The chickens in cages grew much faster than those in floor pens. From 11 to 18 weeks the growth rate decreased greatly in both groups because of outbreak of Marek's disease in October 1986.

The results in 1987 was very similar to those in 1986 (Table 2). In both years the chicks reared in cages grew faster and were heavier than those reared in floor pens at the same age. Since the lighting system, temperature and diets were the same, it is obvious that the difference in growth rate between the two groups of chickens could not have been caused by these factors. The chickens in cages had a relatively small "activity area" compared with those reared on the floor and the feeders and drinkers were very close to them, so it was easy to find food and water when needed. On the floor the chickens were more active. They moved around searching for food and water, playing or fighting with each other, all of which are energy consuming activities.

2. Feed consumption and feed conversion efficiency

Although no individual records of feed consumption were made, it is interesting to compare feed consumption for these two groups of chickens on the basis of group means. Table 3 shows the average body weight gain, feed consumption and feed conversion in 1986 and 1987. In general, chickens in cages consumed slightly more food than those reared on the floor. From 1 to 7 weeks of age, the difference in feed consumption and feed conversion between the two groups was not great, but in the 7-16 week period in 1987 the chickens in cages consumed nearly 12% more than the group on the floor (72.0 g vs. 63.3 g). The feed conversion efficiency of the chickens in cages was slightly better than those on the floor. 4.0 g of feed was used to produce 1 g of weight gain in cages in 1987, while the corresponding figure on the floor was 4.2 g. It can also be seen that feed conversion efficiency decreased accordingly (Table 3). From an economic point of view, the cage rearing system seems to be better than the floor system.

3. Mortality

Although mortality rates in the two different rearing systems generally did not differ very much, the figures tended to favour the floor system (Table 4). The

Table 3. Weight gain, food consumption and food conversion in the 1986 and 1987 rearing periods

Rearing system	Period (weeks)	Weight gain (g/day)	Food consumption (g/day)	Food conversion (feed,g/gain,g)
In 1986:				
Cages	1-6	13.6	34.7	2.6
	6-11	17.0	69.4	4.1
Floor	1-6	12.7	31.2	2.5
	6-11	14.2	64.4	4.6
In 1987:				
Cages	1-7	14.0	35.7	2.6
	7-16	14.6	72.5	4.9
	1-16	14.4	57.3	4.0
Floor	1-7	12.8	34.4	2.7
	7-16	12.1	63.3	5.2
	1-16	12.4	51 .8	4.2

Table 4. Mortality rate for chickens reared in different rearing systems in 1986 and 1987

	Cages		Floor	
Period	No. of birds	Mortality %	No. of birds	Mortality %
In 1986:				
1-6 weeks	1014	1.0	1122	0.5
7-11 »	1004	2.3	1116	2.2
12-18 »	981	11.3	1091	8.6
1-18 »	1014	14.1	1122	11.1
In 1987:				
1-7 weeks	1436	0.8	1796	0.6
8-16 »	1425	2.1	1785	1.3
1-16 »	1436	2.9	1796	2.0

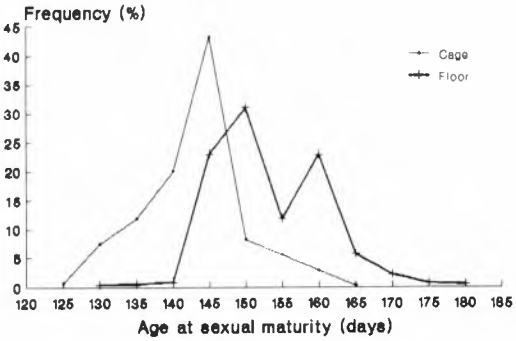

Fig. 3. Distribution of age at sexual maturity of chickens

greatest and most significant difference in mortality between the two groups of chickens in the 12-18 week period in 1986 came after an outbreak of Marek's disease (11.3% vs 8.6%).

4. Age at sexual maturity

Age at sexual maturity is expressed as the number of days from hatching to the first day of laying. On average, the chickens in the cages laid their first egg 10 days earlier than those in the floor pens. Fig. 3 shows the distribution of age at sexual maturity grouped by rearing system. There was little variation in sexual maturity except in some extreme cases. In the cages 90% of the chickens started to lay eggs before 150 days of age, but at this age only 57% of the chickens on the floor had laid their first eggs.

5. Genetic and phenotypic parameter estimates

Heritabilities and genetic and phenotypic correlations were estimated for each group of chickens and for the total population. The heritability estimates are listed in Tables 5 and 6, and the genetic and

Table 5. Heritability estimates for body weight and weight gain in 1986

Traits	h^2_{s+d}	s.e.	h^2_s	s.e.	h^2_d	s.e.
Overall population:						
Body weight at 1 week	0.39	0.06	0.27	0.09	0.50	0.11
» » » 6 weeks	0.44	0.06	0.54	0.13	0.31	0.11
» » » 11 »	0.45	0.06	0.62	0.15	0.24	0.11
» » » 18 »	0.40	0.06	0.34	0.10	0.46	0.11
Weight gain from 1-18 weeks	0.40	0.06	0.34	0.10	0.45	0.11
Chickens in cages:						
Body weight at 1 week	0.33	0.10	0.32	0.16	0.34	0.23
» » » 6 weeks	0.40	0.10	0.59	0.22	0.17	0.24
» » » 11 »	0.36	0.10	0.62	0.22	NC [1]	
» » » 18 »	0.50	0.10	0.40	0.18	0.59	0.22
Weight gain from 1-18 weeks	0.51	0.10	0.40	0.18	0.61	0.22
Chickens on floor:						
Body weight at 1 week	0.45	0.10	0.32	0.15	0.57	0.21
» » » 6 weeks	0.51	0.09	0.58	0.20	0.43	0.22
» » » 11 »	0.56	0.09	0.65	0.22	0.46	0.21
» » » 18 »	0.47	0.09	0.35	0.16	0.57	0.21
Weight gain from 1-18 weeks	0.45	0.09	0.36	0.16	0.53	0.21

[1] NC = not calculated because of negative variance component

Table 6. Heritability estimates for body weight, weight gain and sexual maturity in the 1987 rearing period

Traits	h^2_{s+d}	s.e.	h^2_s	s.e.	h^2_d	s.e.
Overall population:						
Body weight at 1 week	0.34	0.05	0.22	0.06	0.44	0.09
» » » 7 weeks	0.43	0.05	0.47	0.10	0.40	0.09
» » » 16 »	0.48	0.05	0.50	0.11	0.46	0.09
Weight gain from 1-16 weeks	0.47	0.05	0.50	0.11	0.45	0.09
Age at sexual maturity	0.37	0.05	0.38	0.09	0.36	0.09
Chickens in cages:						
Body weight at 1 week	0.29	0.06	0.15	0.08	0.42	0.12
» » » 7 weeks	0.46	0.07	0.53	0.13	0.38	0.12
» » » 16 »	0.52	0.07	0.56	0.13	0.47	0.12
Weight gain from 1-16 weeks	0.52	0.07	0.56	0.13	0.47	0.12
Age at sexual maturity	0.40	0.07	0.64	0.14	NC[1]	
Chicken on floor:						
Body weight at 1 week	0.42	0.07	0.36	0.12	0.47	0.14
» » » 7 weeks	0.39	0.07	0.61	0.16	0.47	0.14
» » » 16 »	0.40	0.07	0.55	0.15	0.22	0.14
Weight gain from 1-16 weeks	0.39	0.07	0.55	0.15	0.20	0.14
Age at sexual maturity	0.32	0.07	0.20	0.11	0.42	0.15

[1] NC = not calculated because of negative variance component

phenotypic correlations in Tables 7 and 8. The heritability estimates usually reported for body weight from 6-12 weeks of age are around 0.40 (Siegle 1962). From the present analyses, the average estimates of h^2 for body weight at one week of

Table 7. Genetic correlations (below diagonal) and phenotypic correlations (above diagonal) between different traits estimated in 1986 (from sire components of variance)

Traits	1	2	3	4	5
Overall population:					
1 Body weight at 1 week		0.44	0.31	0.23	0.18
2 » » » 6 weeks	0.34		0.80	0.49	0.47
3 » » » 11 »	0.28	0.89		0.68	0.68
4 » » » 18 »	0.38	0.65	0.86		0.99
5 weight gain from 1-18 weeks	0.34	0.65	0.86	0.99	
In cages:					
1 Body weight at 1 week		0.38	0.31	0.26	0.21
2 » » » 6 weeks	0.10		0.79	0.49	0.48
3 » » » 11 »	0.28	0.90		0.70	0.69
4 » » » 18 »	0.41	0.60	0.86		0.99
5 Weight gain from 1-18 weeks	0.37	0.61	0.86	0.99	
On floor:					
1 Body weight at 1 week		0.45	0.25	0.13	0.07
2 » » » 6 weeks	0.44		0.79	0.45	0.43
3 » » » 11 »	0.06	0.85		0.65	0.64
4 » » » 18 »	-0.17	0.52	0.83		0.99
5 Weight gain from 1-18 weeks	-0.23	0.49	0.81	0.99	

Table 8. Genetic correlations (below diagonal) and phenotypic correlations (above diagonal) among traits estimated from the 1987 rearing period (from sire components of variance)

Traits	1	2	3	4
Overall population:				
1 Body weight at 1 week		0.47	0.32	0.26
2 » » » 7 weeks	0.55		0.68	0.66
3 » » » 16 »	0.45	0.78		0.99
4 Weight gain from 1-16 weeks	0.42	0.77	0.99	
In cages:				
1 Body weight at 1 week		0.46	0.32	0.26
2 » » » 7 weeks	0.54		0.70	0.69
3 » » » 16 »	0.53	0.84		0.99
4 Weight gain from 1-16 weeks	0.49	0.84	0.99	
On floor:				
1 Body weight at 1 week		0.47	0.32	0.25
2 » » » 7 weeks	0.57		0.67	0.65
3 » » » 16 »	0.40	0.76		0.99
4 Weight gain from 1-16 weeks	0.35	0.75	0.99	

age were 0.35 in 1986 and 0.39 in 1987. The heritability estimates for body weight at 6 and 7 weeks of age were not very different, the former averaging 0.44 and the latter 0.43. The corresponding figures for body weight at 11, 16 and 18 weeks of age were 0.46, 0.47, and 0.46. For weight gain, the heritability estimates averaged 0.46. The heritability of sexual maturity shows a moderate value of $h^2 = 0.38$, which is in agreement with those usually reported (Kinney et al.

1969, Kolstad 1972). When comparing the estimates for different years, they were found to be similar.

In general, the genetic correlations between body weight at different ages in the present analysis were found to be higher than the corresponding phenotypic correlations (Tables 7 and 8). The tables also show that the estimates computed from chickens in cages do not differ much from those computed from chickens on the floor.

As discussed earlier, the chickens in cages grew faster than those in the floor pens and the phenotypic variation of the former group was bigger. It may be assumed that the genetic basis of these two groups of chickens reared under different systems was the same. According to the definition of heritability, which is the proportion of additive genetic variance of the phenotypic variance, $h^2 = V_A/V_p$, the heritability estimated for chickens in cages is expected to be lower than that for chickens in the floor pens. The present analysis shows that for most traits the heritability estimates of the chickens in cages were actually lower than those of chickens on the floor.

SUMMARY

In both 1986 and 1987 the chicks reared in cages grew faster and were considerably heavier than those reared in floor pens. The average body weight gain from 1 to 18 weeks in the 1986 rearing period was 13.2 g/day for chicks in cages and 11.6 g/day for those on the floor. In the 1987 rearing period the average body weight gain from 1 to 16 weeks was 13.5 g/day for chicks in cages and 12.4 g/day for those in floor pens. Chicks reared in cages consumed more feed than those on the floor and had slightly higher feed conversion efficiency. Mortality rates in the different rearing systems were not significantly different with the exception of the 11-18 week period in 1986, when the mortality rate for the chicks in cages was significantly higher than that for chicks in floor pens. Age at sexual maturity of chicks reared in cages averaged 143 days, which was 10 days earlier than those on the floor.

The heritability estimates for body weight at different ages were from moderate to high, mostly at about 0.40. The heritability estimate for age at sexual maturity estimated from sire, dam and sire plus dam components of variance were around 0.40. With the exception of body weight at one week of age, body weight at different ages was highly correlated, genetically and phenotypically.

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Effects of different environments and selection for persistency in laying hens

II. Egg production performance in laying hens in two different environments (Cages vs floor)

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Mou, L.J. & J. Katle 1990. Effects of different environments and selection for persistency in laying hens. II. Egg production performance in laying hens in two different environments (Cages vs floor). Norwegian Journal of Agricultural Sciences 4: 205-216. ISSN 0801-5341.

A comparative study was carried out to test the effects of the individual cage system and the floor system on the production performance of White Leghorn layers. The whole egg production period (up to 88 weeks) was divided into early part-record (up to 42 weeks), annual record (up to 70 weeks), the first residual record (42-70 weeks) and the second residual record (70-88 weeks). It was found that the hens housed in the individual cage system did not differ significantly from those in floor pens in most of the traits under consideration. Owing to the earlier sexual maturity, however, the caged hens laid more eggs in the early part of the egg production period but fewer eggs in the residual periods than the penned hens. There was no significant difference between the two systems in specific gravity and albumen height, but a higher incidence of blood spots was observed in eggs of floor-penned hens than in eggs of caged hens. The mortality rate in the cages was significantly lower than that in the floor pens. In general, the penned hens had better plumage than the caged hens, particularly on the neck, breast and wings, and they had lower incidence of foot problems than the caged birds. It is concluded from this study that the cage system is not superior to the floor pen system in most of the aspects considered with the exception of low mortality. The egg production in the second residual period was low in both systems (50% or less on a survivor basis) and showed considerable variation, indicating that egg production could be increased by improving production persistency.

Key words: Chickens, egg production, part-record, persistency, residual record.

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Abbreviations used in this work: AH = albumen height, BS = blood spots, BW = body weight, EM = egg mass, EN = egg number, EW = egg weight, PE = percent egg production, R1 = first residual period, R2 = second residual period, SG = specific gravity, SM = age at sexual maturity.

The battery cage system is the most commonly used system in commercial egg production today. In recent years, there has been increasing concern about animal welfare. Research work has been carried out regarding the effects of different production environments on the performance, behaviour and physiology of the birds. Attempts have been made to find alternatives to battery cages or to modify existing cage systems. Wegner (1981) summarized the research results from projects carried out in West Germany and concluded that none of the three systems studied could be regarded as optimal from an economic, bird welfare or hygienic point of view.

Many comparisons of the performance of hens under different production systems have been carried out in past years. Lowry et al. (1956), Bailey et al. (1959), Miller & Quisenberry (1959), Rose & Sell (1969) and Koelkebeck & Cain (1984a) reported that egg production of caged hens was higher than that of floor-penned hens. However, the egg production of floor-penned hens has been found to be superior to that of caged hens in other reports (Froning & Funk 1958, Carlson & Stangeland 1960, Timmons et al. 1961, Mench et al. 1985). Grotts (1956), Bailey et al. (1959) and Froning & Funk (1958) found that the egg weight of hens in cages was significantly higher than that of floor-penned hens. Better viability was generally reported for caged hens than for floor-penned hens (Lowry et al. 1956, Wegner 1978, Koelkebeck & Cain 1984b). Cage housing showed economic and hygienic advantages, whereas housing on litter produced behavioural advantages but economic and hygienic disadvantages. There is little doubt that the clear economic superiority of laying cages makes it hard to discard this system at the moment.

Laying hens are usually kept for a one-year production cycle of up to about 70 weeks of age. How would it affect production if the birds are kept for a longer period? Is it possible to increase egg production by improving production persistency in the extended period?

The first objective of this study is to test whether there are differences in effect between cage and floor management on (1) body weight (BW), (2) egg production traits including egg number (EN), egg weight (EW), percent egg production (PE) and egg mass (EM), (3) egg quality, (4) viability and (5) plumage and foot problems. The second objective is to investigate the production performance in different life time-periods up to 88 weeks of age.

MATERIALS AND METHODS

The data used in the present study were from the second generation of an unselected base population. The genetic material was discussed by Kolstad & Mou (1990). A total of 2448 pullets were housed at 16 weeks of age, 1344 in individual cages and 1104 in floor pens. The pullets reared in the cages were put in individual cages while those reared on floor were put in floor pens.

One laying house was used for this experiment, half of which was equipped with individual cages and half with floor pens. The cages were in three tiers and the area of each cage was 1056 cm^2 (44 cm x 24 cm). The floor pens, in which 12 pullets were housed, were 3 m^2 in size. The average space for the penned pullet was 2500 cm^2, which was more than twice as much place as the caged pullet had. About two-thirds of the pen floor was covered with wood shavings and a wire platform took up one-third. Auto-trap nests were used in the pens for recording eggs. Temperature and ventilation were auto-controlled.

The lighting programme used was 9 hours per day from 16 to 20 weeks of age. This was increased by half an hour per week until the lighting reached 16 hours daily and was then kept stable for the rest of the production period.

Water was supplied by nipple drin-

Table 1. Composition and calculated content of the diets used in the production period (percent)

Ingredients	16-20 weeks	20-88 weeks
Herring meal	2.50	3.07
Soybean meal (extr.)	3.00	2.50
Barley	19.13	11.90
Wheat	5.40	15.00
Oat	45.00	40.00
Wheat middlings	10.00	4.35
Fat	3.00	4.00
Grass meal	2.00	2.00
Meat and bone meal	4.00	4.00
Methionine	-----	0.03
Shell meal	2.17	8.29
Maize gluten	3.06	4.00
Calcium phosphate	-----	0.34
Salt	0.45	0.23
Std. micromin.	0.10	0.10
Mg oxide	0.04	0.04
Choline chloride	0.05	0.05
Vitamin concentrate	0.10	0.10
Calculated content:		
Crude protein	15.41	15.40
Dig CP	12.30	12.60
Fat	6.87	7.45
ME Kcal/kg	2700	2700
Lysin	0.66	0.67
Methionine + cystine	0.59	0.59
Linoleic acids	1.50	1.38
Ca	1.30	3.50
P	0.66	0.65
Na	0.25	0.17

kers. All the birds received the same standard commercial mash diets given by feed trough *ad libitum*. Composition and calculated contents of the diets are presented in Table 1.

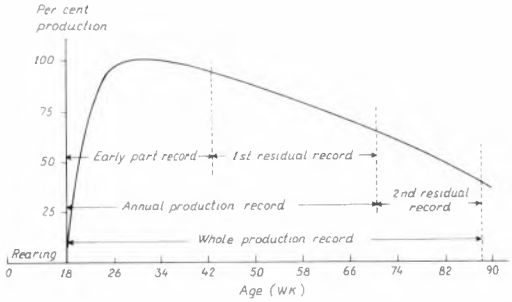

Fig. 1. Division of the total production period into part-periods

The total egg production period in the two housing systems was divided into several part-periods, as shown in Fig. 1. The *early part-record* covered the record from the first egg to 42 weeks of age, *annual record* from the first egg to 70 weeks of age, *whole production record* from the first egg to 88 weeks of age, *first residual record* (R1) from 43 to 70 weeks of age and *second residual record* (R2) from 71 to 88 weeks of age.

The performances were evaluated and included BW, SM, EN, PE, EW and EM. The measurements of egg quality traits included SG, AH and BS. In the formulae and the tables presented later, abbreviations are used with subscripts denoting age in weeks or the residual periods.

The hens were weighed in grams at 16, 28, 42, 54, 70 and 88 weeks of age using an electronic balance. SM was recorded individually as the age at first egg in days. EN were obtained by trap-nesting hens in the floor pens and recording eggs of the caged hens 4 days a week from 18 to 88 weeks of age. All data, however, are presented on a calculated 7-day basis record. Floor eggs were added to the average in floor pens and the standard deviation was adjusted using the method described by Sørensen et al. (1980).

PE was calculated as follows:

$$PE_W\,(\%) = \frac{EN_W}{(W \times 7 - SM)} \times 100 \quad (W = 42, 70 \text{ or } 80 \text{ weeks})$$

The individual PE in the residual periods were calculated using the following formulae:

$$PE_{R1}\,(\%) = (EN_{70}\text{-}EN_{42})/[(70\text{-}42)\times 7] \times 100$$
$$PE_{R2}\,(\%) = (EN_{88}\text{-}EN_{70})/[(88\text{-}70)\times 7] \times 100$$

EW was taken once a week and EM was calculated by using the number of eggs multiplied by the average EW over a 4-week period.

The egg quality traits - SG, AH and BS - were determined at 88 weeks of age.

SG was determined by weighing eggs both in air and in water and then calculated using the following formula:

$$SG = \frac{\text{EW in air}}{\text{EW in air - EW in water}}$$

All was measured as the height of thick albumen. The incidence of BS was determined as the percentage of eggs with BS of all eggs sampled.

Evaluated health conditions included mortality, plumage condition and foot problems. Mortality was expressed as the percentage of birds which died in each part-period. The plumage condition was evaluated at 88 weeks of age using the procedure described by Tauson (1984). Birds were given a score from 1 to 4 points on five individual parts of the body (neck, breast, wings, back and tail), where 4 indicated very good plumage with no or a few worn or otherwise deformed feathers and 1 very poor plumage or 50% or more naked area. Foot problems such as inflammation, lesion or fissures were recorded as a catalogue variable.

Harvey's "Mixed Model Least-squares and Maximum Likelihood Computer Program" (Harvey 1987) was used to perform a mixed model analysis of variance for continuous variables. The differences in incidence of BS, mortality and incidence of foot problems between the two groups were tested using a Chi-square test. The following statistical model was assumed for all continuous variables in the data analysis:

$$Y_{ijkl} = \mu + s_i + d_{ij} + H_k + e_{ijkl}$$

Where Y_{ijkl} is the performance of the l*th* progeny in the k*th* production environment of the j*th* dam mated with the i*th* sire, μ is the common mean, s_i is the random effect of the i*th* sire, d_{ij} is the random effect of the j*th* dam within the i*th* sire, H_k is the fixed effect of the k*th* housing system and e_{ijkl} is the residual error.

The following ANOVA table was used for hypothesis testing.

Source	Sum of squares	E(MS)
Sire	$R(\mu, s, H)-R(\mu, H)$	$\sigma^2_e + k_2\sigma^2_{d:s} + k_3\sigma^2_s$
Dam:sire	$R(\mu, s, d, H)-R(\mu, s, H)$	$\sigma^2_e + k_1\sigma^2_{d:s}$
Housing	$\hat{B}'Z'^{1}\hat{B}'$ (adj. for sd effects)	$\sigma^2_e + Q(H)$
Residual	$y'y - R(\mu, s, d, H)$	σ^2_e

The hypothesis tests are exact for the housing effect and effect of dam within sire under the null hypothesis, but only an approximate test can be made for sire effect.

RESULTS AND DISCUSSION

When the performance of birds housed in different systems were compared, it was found that the effects of sire and dam within sire had a significant influence on almost all the traits. Thus, the effect of the different housing systems was tested after adjusting for the effects of sire and dam within sire. Table 8 gives the results of the analysis of variance.

Body weight (BW)

BW at different ages in the different housing systems is listed in Table 2. From 16 to 28 weeks of age, the BW increased in both housing systems. However, the pullets in the floor pens grew somewhat faster than the birds in the other group, partly, perhaps, to compensate for the slower growth in the rearing period. After 28 weeks of age, the BW did not change significantly either in floor penned or in caged birds.

It can be seen from Table 2 that the caged hens were significantly heavier than the penned hens at 16 weeks of age ($p<0.01$). Thereafter, the difference decreased. The fact that the difference in BW between these two groups of hens decreased from 16 weeks to 42 weeks of age and remained around 60 g from 42 to 88 weeks of age indicated that: (a) the rearing systems had mainly influenced the earlier BW (b) the hens in the floor pens grew faster than the caged hens in the pe-

Table 2. BW at different ages

Trait	Cages $\bar{X}_1$	SD	Floor pens $\bar{X}_2$	SD	Difference $\bar{X}_1-\bar{X}_2$
BW_{16}, g	1583	129	1381	121	202**
BW_{28}, »	2055	190	1965	162	91
BW_{42}, »	2100	201	2054	189	46
BW_{54}, »	2116	233	2061	223	55
BW_{70}, »	2099	224	2040	237	59
BW_{88}, »	2137	254	2069	232	68

** $p < 0.01$

riod from 16 to 42 weeks. The layer's BW is important for two reasons. First, it is closely related to EW, the heavier chickens generally producing larger eggs. Secondly, smaller birds have a lower maintenance requirement and, therefore, better feed conversion if all other factors are equal (Arthur 1986). If lighter birds were able to lay the same amount of EM as the heavier birds, the former would be preferred from an economic point of view. However, the birds with a BW below a certain threshold (e.g. about 1700 g at 500 days) do not usually perform well (Arthur 1986).

Sexual maturity (SM)

SM is affected by many factors such as lighting programme, nutrition and BW. On average the pullets housed in individual cages laid their first egg 10 days earlier than those in floor pens, which was highly significant ($p<0.01$). This result is in agreement with some reported results (e.g. Foster 1981, Fairfull et al. 1983). The variation in SM was not very great (Table 3) although a few pullets started to lay their first eggs at as late as 190 days of age. The difference in SM between the two groups is possibly due to the fact that the birds reared in cages grew faster in the rearing period and

Table 3. Comparison of SM of hens in the two housing systems (days)

Housing system	$\bar{X}$	SD	C.V%	Min.	Max.
Cages	143.2	6.9	4.81	123	193
Floor pens	153.2	7.3	4.77	129	198

reached the minimum BW for SM earlier than the other group.

Egg number (EN)

Average EN calculated on a survivor basis is given in Table 4. Owing to the earlier SM, the early part-period EN (EN_{42}) of the hens in cages was higher than those in floor pens, although there were no significant differences in EN between these two groups at 70 and 88 weeks of age. When the EN in the first (EN_{R1}) and second residual period (EN_{R2}) were considered, the penned hens displayed their superiority to the caged hens, although the differences were not big enough to reach the significant level ($p>0.05$). The variation in EN of survivors in the same

Table 4. Comparison of EN of hens in the two housing systems

Trait	Cages			Floor pens			Difference
	$\bar{X}_1$	SD	C.V.%	$\bar{X}_2$	SD	C.V.%	$\bar{X}_1$-$\bar{X}_2$
EN_{42}	116.9	12.8	11.0	113.4	12.2	11.1	3.5
EN_{70}	241.8	35.0	14.5	247.3	26.6	11.0	-5.5
EN_{88}	299.5	51.7	17.3	313.9	36.0	12.7	-14.4
EN_{R1}	124.9	26.6	21.3	133.9	18.6	14.2	-9.0
EN_{R2}	57.7	21.9	38.0	66.7	16.0	24.6	-9.0

group was not large in the early part-period - C.V. was about 10%. In the residual periods, however, a greater variation in EN was found. In particular, the coefficient of variation in EN_{R2} was almost four times that in EN_{42} in the cages (Table 4). It is worth noting that the larger variation in EN was observed in the cage system in most periods. As will be mentioned later, mortality in floor pens was considerably higher than that in cages.

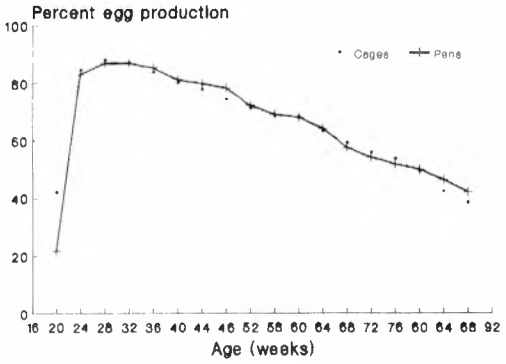

Fig. 2. Hen-day PE in 4-week periods

Percent egg production (PE)

PE in the two housing systems is demonstrated in Fig. 2. The shape of the production curves was almost the same for both caged hens and penned hens. The production peak appeared at about 23 weeks of age and lasted up to 45 weeks of age, then production steadily decreased in both housing systems. The production decreased to 70%, 60%, and 40% at 56, 68 and 88 weeks of age, respectively. In the second residual period, the PE was 50% or less.

The average PE of survivors for different production periods is presented in Table 5. Although average EN_{42} in cages was higher than in pens, the corresponding PE_{42} was lower in cages than in pens. It was found that the averages for PE_{70}, PE_{88}, PE_{R1} and PE_{R2} in pens were higher than those in cages, and that a greater variation in PE occured in cages. In fact, the PE at an early age is not dependent on SM and was found to be more highly correlated genetically with the total annual EN or EM than was EN at an

Table 5. Comparison of survivor PE of hens in the two housing systems

Trait	Cages			Floor pens		
	$\bar{X}_1$	SD	C.V.%	$\bar{X}_2$	SD	C.V.%
PE_{42}, %	77.51	7.96	10.36	81.14	6.84	8.43
PE_{70}, »	69.71	10.07	15.34	73.77	6.75	9.15
PE_{88}, »	63.34	10.93	17.26	68.09	7.07	10.38
PE_{R1}, »	63.71	13.58	21.32	68.32	9.48	13.87
PE_{R2}, »	45.76	17.42	38.07	52.91	12.68	23.97

early age (Bohren 1970, Flock 1977, 1980, Foster 1981, Mou 1991). It is not surprising that several researchers suggested the use of early PE as a selection criterion to improve annual egg production instead of using early EN (Bohren 1970, Bohren et al. 1970, Flock 1977, Gowe & Fairfull 1984). In particular, when SM is relatively early, selection on the basis of early PE can avoid the sharp decrease in SM. For this population, in which SM was relatively early but production persistency was relatively poor, the egg production can be best improved by improving production persistency.

It can be seen from Fig. 2 and Table 5 that egg production greatly decreased in the extended period (70 to 88 weeks) in both housing systems. This was probably related to one biological process, i.e. moulting. Under natural conditions, moulting usually happens after one production cycle but the time for moulting may vary from bird to bird and may last for a long time. Some of the birds were observed to moult during the second residual period. Artificial moulting can be introduced to synchronize moulting in order to increase the production in the extended period.

Egg weight (EW)

Eggs were weighed weekly and average EW was computed for each 4-week period. Fig. 3 shows the changes in EW with age. It can be seen that the average EW increased consistently with age in both cages and floor pens.

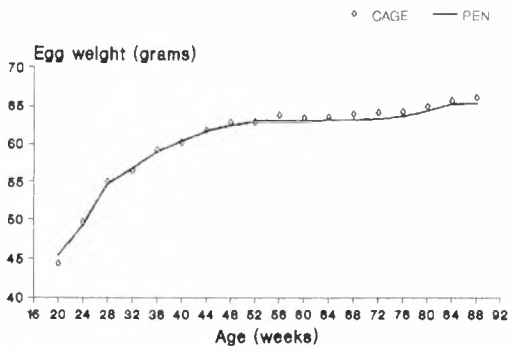

Fig. 3. Changes in EW with age

In general, the penned hens laid slightly heavier eggs in most of the earlier periods, while the caged hens did so in the later periods, although the difference between the two groups was not significant. It appears that cage housing and floor-pen housing did not have a very different effect on EW.

The average EW for the different production periods are given in Table 6. The coefficient of variation ranged from 5.4 to 6.9% for the caged hens and from 4.0 to 4.8% for the penned hens. The average EW was about 55, 63 and 65 g in the early part record, R1 and R2 records, respectively. The difference in EW between the early part-record and the residual record was meaningful because the EM of 5 eggs in the extended period (R2) was almost equal to that of 6 eggs in the early part-record. Extending the production period to 88 weeks of age would be worth while if production persistency could be improved.

Table 6. Comparison of average EW of hens in the two housing systems

	Cages			Floor pens		
Trait	$\bar{X}_1$	SD	C.V.%	$\bar{X}_2$	SD	C.V.%
EW_{42}, g	54.7	3.0	5.5	55.5	2.6	4.7
EW_{70}, »	59.4	3.2	5.4	59.4	2.8	4.7
EW_{88}, »	60.5	3.4	5.6	60.5	2.9	4.8
EW_{R1}, »	63.1	3.5	5.5	62.7	2.5	4.0
EW_{R2}, »	64.9	4.5	6.9	64.2	2.9	4.5

Table 7. Comparison of survivor EM in the two housing systems

Trait	Cages		Floor pens		Difference
	$\bar{X}_1$	SD	$\bar{X}_2$	SD	$\bar{X}_1$-$\bar{X}_2$
EM_{42}, g	6508.0	715.2	6395.7	658.7	112.3
EM_{70}, »	14559.7	1828.8	14833.0	1478.1	-273.3
EM_{88}, »	18358.6	3250.2	19102.1	2108.6	-743.5
EM_{R1}, »	8024.3	1421.9	8423.5	1096.6	-399.2
EM_{R2}, »	3825.9	1321.0	4291.6	1026.5	-465.7

Egg mass (EM)

Accumulative EM in the early record (EM_{42}), annual record (EM_{70}), whole record (EM_{88}), first residual record (EM_{R1}) and second residual record (EM_{R2}) is presented in Table 7, calculated on a survivor basis.

In the early part of the production period, the caged hens laid 112.3 g more eggs than the penned hens. In the first and second residual periods, however, the caged hens laid 399.2 and 465.7 g fewer eggs, respectively, than the penned hens. Although the differences between diffe-

Table 8. The combined least-squares analysis of variance for all continuous variables

Trait	Mean squares by source			
	Housing (H) (DF = 1)	Sire (s) (DF = 123)	Dam:sire (d:s) (DF = 586)	Error (e) (DF = 1238)
BW_{42}	0.01	0.13 **	0.04 **	0.03
BW_{70}	0.05	0.16 **	0.05 **	0.04
BW_{88}	0.05	0.16 **	0.06 **	0.05
SM	2455.5 **	137.0 **	47.1 **	35.9
EN_{42}	831.8 **	256.8 **	139.7 **	99.5
EN_{70}	1427.5	1420.6 **	902.8 **	629.1
EN_{88}	2473.6	2927.5 **	1850.2 **	1400.9
EN_{R1}	88.2	770.6 **	506.8 **	373.0
EN_{R2}	358.6	632.9 **	339.4	310.8
PE_{42}	66.6	95.0 **	54.3 **	40.9
PE_{70}	0.1	120.9 **	72.5 **	51.5
PE_{88}	10.6	135.5 **	81.3 **	62.5
PE_{R1}	20.8	201.0 **	132.2 **	97.3
PE_{R2}	225.8	398.6 **	213.8	310.8
EW_{42}	12.5	22.6 **	7.1 **	5.9
EW_{70}	6.7	25.6 **	7.0 **	5.8
EW_{88}	3.4	27.1 **	7.7 **	6.4
EW_{R1}	0.1	32.7 **	9.5 **	7.9
EW_{R2}	5.6	40.3 **	14.8 **	12.6
EM_{42}	1.71 *	0.83 **	0.44 **	0.36
EM_{70}	3.50	5.20 **	3.24 **	2.37
EM_{88}	6.33	11.19 **	6.99 **	5.43
EM_{R1}	0.32	2.94 **	1.93 **	1.42
EM_{R2}	1.28	2.69 **	1.47	1.34

rent housing systems during the different production periods seemed to be substantial, none of the differences were significant ($p > 0.05$). This was probably due to the greater influence from sire and dam within sire effects (see Table 8). As discussed previously, EM in the residual periods was low even though EW was high. The correlation of EM with EN or PE has been found to be higher than EM with EW (Renganathan et al. 1979, Jain & Roberts 1980, Mou 1991). It can be concluded that EM was mainly influenced by EN and can be increased by improving the production persistency.

Table 9. Egg quality of hens in the two housing systems

Trait	Cages		Floor pens	
	$\bar{X}_1$	SD	$\bar{X}_2$	SD
Specific gravity	1.0756	.0096	1.0749	.0107
Albumen height, mm	5.0	1.0	5.3	1.5
Blood spots, %	3.0		4.7	

Egg quality

Table 9 gives the comparison of egg quality for the two housing environments. As expected, no significant differences were found for the SG and AH. A somewhat higher incidence of BS was observed in the eggs from the penned hens compared with those from the caged hens. This is probably due to sampling error.

Health condition

Mortality, plumage condition and incidence of foot problems were considered in evaluating different housing environments in the present study. The mortality rate during the whole production period (18-88 weeks) was about 8% in the cages and 20% in the floor pens (Table 10). Mortality rate in the late period was higher than in the earlier periods in both cages and floor pens. There was a higher mortality rate in pens than in cages in all periods, which is in agreement with Koelkebeck & Cain (1984b). Generally, the changes in the disease outbreaks among the floor hens are considered to be higher than in the cage system (North 1981). As group size increases, the social interaction (peck order) of hens in pens may also act as a stress factor affecting both behaviour and health. Cannibalism is usually a problem for group-keeping. These factors might be related to the higher mortality in pens.

In general, the plumage condition on back and tail was good in both the caged hens and penned hens and there was no significant difference in plumage scores in these two parts of the body between the two groups. However, for the neck,

Table 10. Mortality rate of hens in the two housing systems (%)

Period	Cages	Floor pens	Difference
18-42 weeks	1.75	4.62	2.87 **
43-70 »	3.24	6.93	3.69 **
71-88 »	4.00	9.90	5.69 **
Whole period	8.03	20.18	12.15 **

** $p < 0.01$

Table 11. Plumage condition of hens in the two housing systems

	Plumage score[1]				
	Cages		Floor pens		Difference
Part of body	$\bar{X}_1$	SD	$\bar{X}_2$	SD	$\bar{X}_1-\bar{X}_2$
Neck	1.5	0.9	2.3	1.2	-0.8***
Breast	1.9	1.0	2.2	1.0	-0.3***
Wing	1.6	1.0	2.6	1.0	-1.0***
Back	3.3	0.8	3.3	0.9	0
Tail	3.2	1.0	3.1	1.1	0.1
Total score	11.4	3.3	13.5	3.9	2.1***

*** $p<0.001$
1) Max. score = 4, min. score = 1 and max. total score = 20.

breast, wings and total plumage scores, the penned hens had higher scores, i.e. their plumage condition was much better than that of the other group (see Table 11).

The hens in cages had relatively less space to move around in and the plumage was certainly damaged physically to some extent by the wire wall and floor. Feather pecking and cannibalism were also observed between the birds in neighbouring cages. Hens in the floor pens did not suffer from such physical damage because of having more space and a better litter floor, but feather pecking and cannibalism probably still affected the plumage condition of penned hens. Poor plumage was found mostly on the neck, breast and wings in caged hens, the parts of the body which were in contact with the wire walls and wire floor. It can be deduced from this study that the physical damage to the plumage of caged hens is more serious than feather pecking and cannibalism in penned hens under the experimental condition.

No direct relation between production traits and plumage condition was found in this study. It is commonly believed that birds with the worst plumage condition will consume more feed to maintain the normal body temperature, thus a better plumage condition is advantageous from an economical point of view.

The incidence of foot problems in the caged hens was 14.4%, while in the floor pens the corresponding figure was 8.8%. The higher incidence of foot problems for the caged hens might be related to the limited space and the resulting restriction of activities.

SUMMARY

Because of public concern of animal welfare, there is a trend for egg producers to change the present intensive battery cage system back to the less intensive floor system. Selections must be carried out under the same environment conditions as those employed in commercial production. The performance in egg production of laying hens under two different environments (cage vs. floor pen) was compared by viewing a number of traits and health conditions. A summary of the findings of this study is as follows:

(1) The production performance on the survivor basis of hens under two different environments did not differ greatly. The hens in cages had a slightly higher early part-record than those in floor pens owing to earlier SM. Whole production and residual records of EN, PE and EM for the two groups were not significantly different, although the figures seemed to favour the floor pen system.

EW showed a consistent increase with age of hens in both groups. There was no significant difference in EW for the hens in the different housing systems. Average EW in the early part-record was about 9 g lighter than that in the second residual period. There appeared to be no pronounced difference in egg quality traits between the two groups.

(2) The hens in cages had a lower mortality rate but worse plumage than those in floor pens. Floor pens do provide a better environment for hens as certain natural behaviour such as taking dust baths, nesting and wing flapping are not restricted as they certainly are in cages.

(3) Production decreased steadily after the production peak in both housing systems. There were considerable variations in the residual records which may be used in the selection for improving production persistency. EW in the residual periods was much heavier than that in the early part-periods. It can be concluded that extending the production period to 88 weeks of age will have economic advantages providing that the production persistency can be improved and moulting can be synchronized and finished within a short time.

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Effects of temperature and irradiance level on plant quality at marketing stage and the subsequent keeping quality of Christmas begonia (*Begonia* x *cheimantha* Everett)

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The effects of temperature and irradiance level on the quality of Christmas begonia at marketing stage were studied in an experiment in which plants were grown at 15, 18 or 21°C. At each temperature level the plants were exposed to natural daylight conditions (NL) (varying from 2.3 to 5.0 mol $m^{-2}day^{-1}$ PAR) or NL plus supplementary irradiation with either 40 or 80 µmol m^{-2} s^{-1} photosynthetic active radiation provided by means of fluorescent light for 18 h per day. The keeping quality was determined by holding the plants for four weeks in a room where the temperature was kept at 20°C and where the plants received fluorescent light of 13.5 µmol m^{-2} s^{-1} at plant level for 12 h per day. Relative air humidity fluctuated between 47 and 68 %, except for a period of approximately 4 h after watering, when it rose to 80–90 %. Both plant quality at marketing stage and keeping quality improved when plants were given supplementary irradiation of 80 µmol m^{-2} s^{-1}. Increased irradiance level resulted in an increase in number of flowers and flower buds both at the marketing stage and after the interior holding phase. Increased temperature caused an increase in the height of the flower stem and an increase in the abscission of flower buds.

Key words: *Begonia* x *cheimantha*, Christmas begonia, irradiation, keeping quality, temperature.

Abbreviations: DT = day temperature, NL = natural light conditions, NT = night temperature, PAR = photosynthetic active radiation, RH = relative air humidity, SD = short day, VPD = water vapour pressure deficit

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Begonia x cheimantha Everett, commonly known as Christmas begonia or Lorraine begonia, is a herbaceous SD plant. The photoperiodic requirement for flower initiation is modified by temperature (Heide 1962, Rünger 1968). The Christmas begonia has for a long time been of great commercial importance in the Scandinavian countries, especially for Christmas flowering (Sandved 1969). It has now largely been replaced by poinsettia and pot azalea. The rea-

son for this is that Christmas begonia requires a long growing period, and has a rather poor keeping quality. Recently, a short growing program of 12–13 weeks from SD has been suggested, which should make the production of Christmas begonia more profitable (Valsø 1987).

The quality problems in Christmas begonia are primarily excessive elongation of the flower stems, the formation of cup-shaped flowers, and a high rate of flower and flower bud abscission (Sandved et al. 1975, Moe & Smith-Eriksen 1986, Fjeld 1986, Heide & Rünger 1985).

Sandved (1969, 1971) has shown that the plant quality of Christmas begonia at marketing stage is to a great extent determined by the growing conditions. There is also reason to believe that the keeping quality of pot plants in general is affected by the growing conditions (Fjeld 1986), as is the case with cut flowers, e.g. cut carnations (Heide & Øydvin 1969) and roses (Moe 1975).

The present experiment was carried out in order to investigate to what extent irradiation and temperature during the last part of the growing period affect the quality of Christmas begonia at marketing stage, and to what extent the growing conditions affect the subsequent keeping quality when the plants are subjected to interior climatic conditions.

MATERIALS AND METHODS

Leaf-propagated young plants of *Begonia* x *cheimantha* Everett cv Nova were planted in 110 mm pots in fertilized peat at the end of July or at the start of September and grown in a greenhouse under NL and at a NT of 22°C (± 0.5°C) and a DT of 24°C (± 1.0°C). The plants were given 14 days of SD treatment by covering the plants with a black plastic curtain for 14 h per day. They were given a soft pinch one week before SD treatment. From the end of the SD treatment untill the experimental period started, NT and DT were kept at 18°C (± 0.5°C). The plants were watered as needed and fertilized twice a week with a complete nutrient solution. They were sprayed with pyrethrines against aphids.

When the first flowers opened the plants were moved to three temperature controlled glasshouse compartments. A 3 x 3 factorial experiment was carried out. The compartments were kept at 15, 18 or 21°C (± 0.5°C). At each temperature level three irradiance levels were established: NL, NL plus supplementary irradiation corresponding to 40 (± 5) and 80 (± 10) µmol m^{-2} s^{-1} PAR supplied by cool white fluorescent lamps (Philips TL/33). Supplementary irradiation was given for 18 h per day. The irradiance level was measured by means of a Lambda LI-185B instrument with a quantum (400-700nm) sensor.

The relative air humidity was kept between 40 and 60 %. Water vapour pressure deficits were 0.78 kP at 15°C, 1.12 kP at 18°C, and 1.04 kP at 21°C. For a period of 2-4 hours after watering the RH rose to 80–90 %.

Each treatment comprised seven plants. The experiment was replicated in time. The first replicate was given SD from 15 September. The plants were moved to the temperature controlled glasshouse compartments on 10 November, and tested for keeping quality from 24 November. The second replicate was given SD from 29 September. The plants were moved to the controlled glasshouse compartments on 7 January, and tested for keeping quality from 27 January. These plants were kept at a low temperature (14.5°C) for two weeks during Christmas.

The average natural radiation during the experimental period corresponded to 5.01 and 2.34 mol m^{-2} day^{-1}PAR for the first and the second replicate, respectively. The radiation level inside the greenhouse was 67 % of outside radiation and corresponded to an irradiance level of 52 and 24 µmol m^{-2} s^{-1}PAR for a period of 18 h per day for the two replicates respectively.

When the plants had reached marketing stage (10–15 open flowers per plant) they were moved to the interior holding room and were for the following 4 weeks given the following conditions: An irradiance of 13.5 (± 1.5) µmol m^{-2} s^{-1} PAR (1000 lux) at plant level provided by warm

white fluorescent lamps (Thorn) for 12 h per day, a temperature of 20°C (± 0.5°C) and a RH varying from 47 to 68 % (VPD from 1.10 to 1.59 kP) during the night and most of the day, except for a period of approximately 4 h after watering, when RH reached a maximum level of 80 to 90 %. Air velocity was measured by means of a Wallac thermo anemometer (type GGA 23S) as 0.1 m s^{-1} (± 0.04) at plant level.

At marketing stage and at the end of the interior holding period, the heights of the plants from soil level to the top of the inflorescence (flower stem height) and from soil level to the level of the upper leaves (leaf height) together with plant diameter were measured. In addition, numbers of flowers and flower buds were recorded. During the interior holding period the numbers of abscised flowers and flower buds were recorded three times a week.

The numbers of flowers and flower buds after four weeks in a simulated interior climate were divided by the numbers of flowers and flower buds at the marketing stage and multiplied by 100, to give the percentage increase in flowers and flower buds.

The numbers of flowers and flower buds abscised during the interior holding period were divided by the number of flowers and flower buds at the marketing stage and multiplied by 100, to give the persentage abscised flowers.

The results were subjected to an analysis of variance and the least significant difference (LSD) and the Duncans Multiple Range Test at the 5 % level were determined.

RESULTS

Plant quality at marketing stage – There was no significant effect of irradiance level on leaf height at marketing stage. But when no supplementary irradiation was given (NL), flower stem height was slightly less compared with stem height at higher irradiance levels. Plants which received supplementary irradiation had more flowers at marketing stage than plants grown at NL (Table 1 and 2).

Increased temperature caused an increase in flower stem height during the growing period, but influenced leaf height only to a small extent (Table 1 and 2). Temperature thus primarily affected stem elongation above the upper leaves. Numbers of flowers and flower buds increased significantly with increasing temperature (Table 1 and 2), but at 21°C the decorative value of the plants was reduced because of a large increase in flower stem height.

Interactions between irradiation and temperature were found for flower stem height and number of buds (Table 1). At a temperature of

Table 1. The effects of irradiation and temperature during the final stage of the growing period on the quality of *Begonia* x *cheimantha* at marketing stage and on interior keeping quality.

Observations	Irradiance level (I)	Temperature (T)	Interaction (I x T)
1. Market quality			
Leaf height	ns	**	ns
Flower stem height	*	***	*
No. of flowers	**	***	ns
No. of buds	ns	***	**
2. Keeping quality			
% abscised buds and flowers	*	***	***
% increase in buds and flowers	*	***	ns
% flower stem elongation	ns	**	ns

Table 2. Main effects of irradiation and temperature during the final stage of the growing period on leaf height (in cm), flower stem height (in cm), number of flowers and number of flower buds per plant of *Begonia* x *cheimantha* at marketing stage. NL = natural light conditions. 40 and 80 indicate supplementary irradiation in µmol m^{-2} s^{-1} PAR. Data are averages of three temperature levels and three irradiance levels, respectively. * Mean separation by Duncan's Multiple Range Test, 5 % level.

	Leaf height	Flower stem height	No. of flowers	No. of flower buds
Irradiance level				
NL	11.5a*	19.6b	36.6b	50.3a
NL + 40	11.2a	21.2a	45.1a	55.2a
NL + 80	11.5a	21.1a	48.4a	61.4a
Temperature				
15°C	11.0b	18.6c	32.1c	37.2c
18°C	11.9a	20.6b	41.7b	59.0b
21°C	11.4ab	22.6a	56.3a	70.1a

15°C the highest irradiance (NL+80 µmol m^{-2} s^{-1}) resulted in flower stems 1 cm longer than those obtained with NL only, while at 21°C the elongation was almost twice as great. At a temperature of 15°C a high irradiance level resulted in an increase in number of flower buds of less than 10 %. At 21°C the increase was almost 50 % (data not shown).

Keeping quality – The irradiance level had a significant main effect on the persentage increase in flowers and flower buds, and on numbers of flowers and flower buds after four weeks in interior climate (Table 3). Both the persentage increase in flowers and flower buds and the numbers of flowers and flower buds increased with increasing irradiance levels.

Table 3. Effects of irradiation and temperature during the final stage of the growing period on persentage increase in flowers and flower buds during a four week interior holding period, and on the number of flowers and flower buds at the end of the interior holding period of *Begonia* x *cheimantha*. NL= natural daylight conditions. 40 and 80 indicate supplementary irradiation in µmol m^{-2} s^{-1} PAR. Data are averages over three temperature levels and three irradiance levels, respectively. * Mean separation by Duncan's Multiple Range Test, 5 % level.

	% increase in flowers and buds	No. of flowers and flower buds
Irradiance level		
NL	121b*	105b
NL + 40	138ab	138ab
NL + 80	151a	166a
Temperature		
15°C	235a	163a
18°C	101b	102b
21°C	75c	95b

The percentage increase in flowers and flower buds decreased drastically with increased temperature and plants grown at 15°C showed a greater capacity to develop new flowers and flower buds during the interior holding period (Table 3). Plants grown at 15°C also had approximately 70 % more flowers at the end of the interior holding period compared with plants grown at 21°C (Table 3). The decorative value was consequently best in plants grown at a low temperature.

High irradiance level resulted in a higher percentage of abscised flowers and flower buds compared with NL (Table 4). Fully developed flowers contributed with approximately two-thirds of the abscission that occurred (data not shown). The increase in abscission rate caused by higher irradiance levels, however, did not affect the decorative value of the plants. Hence, the decorative value of plants grown at the highest irradiance level was superior to that of plants grown at low irradiance level. This was due to the greater numbers of flowers and buds on plants grown at high irradiance level (see Table 3).

Plants grown at 21°C abscised 20 % more flowers and flower buds than plants grown at 15°C (Table 4). Increasing irradiance level increased the effect of temperature on abscission rate. At low temperature, increased irradiance level resulted in an increased abscission rate from 18.9 to 22.8 %. At high temperature the increase in abscission rate was three to four times greater (Table 4).

Table 4. Effects of irradiation and temperature during the final stage of the growing period on persentage abscised flowers and flower buds of *Begonia* x *cheimantha* during 4 weeks in interior climate. NL= natural daylight conditions. 40 and 80 indicate supplementary irradiation in µmol $m^{-2}s^{-1}$

Irradiance level	Temperature °C 15	18	21	Mean
NL	18.9	34.4	32.2	28.5c
NL + 40	22.0	27.2	45.7	31.7b
NL + 80	22.8	32.9	46.5	34.1a
Mean	21.2c	31.5b	41.5a	

The percentage of flower stem elongation in interior climate was higher for plants grown at low temperature than for plants grown at high temperature (Table 5). However, after four weeks in an interior climate, 15°C still resulted in the most compact plants. The flower stem height was 20.8 cm compared with 24.0 cm in plants grown at 21°C.

Table 5. Effects of temperature during the final stage of the growing period on flower stem height and persentage flower stem elongation of *Begonia* x *cheimantha* after four weeks in simulated interior climate. Data are averages over three irradiance levels. * Mean separation by Duncan's Multiple Range Test, 5 % level.

Temperature	Flower stem height (cm)	% flower stem elongation
15°C	20.8b*	12.3a
18°C	23.5a	15.5a
21°C	24.0a	6.2b

DISCUSSION

Plant quality at marketing stage – Christmas begonia is a flowering pot plant with relatively low light requirements. Supplementary irradiation has not been used for the traditional Christmas crops. The light level in Norway is seldom above 6500 lux on the average from October to February. The daily radiation is less than 1.29 MJ m^{-2} day^{-1}(400–700 nm) in a greenhouse which transmits 60 % of the natural radiation.

In the present experiment supplementary irradiation increased the number of flowers per plant at marketing stage (Table 2). Other experiments have given similar results (Bævre 1985, Valsø 1987). Although the light requirement of Christmas begonia is low, supplementary irradiation enhanced the plant quality.

Temperature seems to have a significant influence on the quality of Christmas begonia. Sandved (1971) found that the quality of the cv Storblomstret Astrid was reduced when the temperature was above 15°C during the final stage of development under the low natural light conditions in November. Excessive elongation of the flower stem occurred when the temperature was raised to 18°C for three weeks or to 21°C for one week or more. Sandved (1969) regards an excessive elongation of the flower stem above the leaves of more than 1.5 cm as a quality reduction in Christmas begonia. In the present experiment this reduction in quality was obtained when the temperature was raised to 21°C (Table 2).

Temperature had a great influence on the numbers of flowers and flower buds (Table 3). Sandved (1968) has reported that flower development was most rapid at high temperature. However, the decorative value was reduced as a result of excessive flower stem height (Table 3). Sandved (1968) also reported that forcing flower development by raising the temperature reduced plant quality.

The interaction which was found between irradiation and temperature with respect to excessive flower stem height (Table 1), indicates that a short growing program based on supplementary irradiation and high temperature (Valsø 1987) may result in poor plant quality. A growing program which accelerates development and growth may result in excessive flower stem height, as was the case in the present experiment. New cultivars, on the other hand, seem to be more suited to short growing programs because of a more compact growth (Fjeld 1988). Use of growth retardants may also be of importance in a short growing program as stated by Valsø (1988).

Keeping quality – Favourable light conditions are beneficial to the keeping quality of carnations (Heide & Øydvin 1969) and chrysanthemum (Kofranek et al. 1972). This may be due to a high carbohydrate content in the shoot at harvest. It has thus been shown that a treatment of cut flowers in a solution with a high sugar content stimulates flower bud opening and keeping quality (Halevy 1976, Nichols 1975). A pot plant such as Christmas begonia seems to respond in a similar way to cut flowers with respect to the effect of the growing conditions on the keeping quality. A high irradiance level during the growing period caused both an increased number of flowers and flower buds at the end of the interior holding period and a high persentage increase in new flowers and flower buds (Table 3). This is probably due to higher reserves of carbohydrates in the plant.

Only a few experiments seem to have been carried out concerning the relationship between the carbohydrate content of flowering pot plants and their keeping quality. Heins & Hanan (1984) demonstrated that a low irradiance level (50 foot candles) in the simulated interior climate resulted in a reduction in fresh and dry weight in cineraria, hydrangea, kalanchoe, gloxinia and cyclamen. They found that the fresh weight / dry weight ratio increased, indicating a steady depletion in carbohydrates in the plants, followed by an early senescence of flowers. The present experiment with Christmas begonia also indicates that a reduced rate of flower development at low irradiance level may be related to carbohydrate depletion and low carbohydrate content during the interior holding period.

It is widely accepted that ethylene plays a

major role in the abscission process (Abeles 1973, Reid 1985). The increased abscission in Christmas begonia as a result of high growing temperature might possibly be an effect of increased ethylene production, increased ethylene sensitivity in the plant (Reid 1985), a low carbohydrate level dueto increased respiration, or a combination of these factors.

The results obtained in this study clearly show that the growing period is of great importance for the keeping quality and decorative value of Christmas begonia. As long as the plant develops new buds and flowers, the decorative value is maintained. Further investigations on the keeping quality of flowering pot plants should include the role of the carbohydrate status with the aim of revealing if the influence of the growing period upon the keeping quality might be mediated through the carbohydrate content of the plant.

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Effects of light on flowering and fruiting in the tomato

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The effects of reduced light conditions were investigated in a spring experiment with three tomato cultivars. Reduced incoming light resulted in significant reductions in the number of flowers, percentage of fruit-set and yield. The initial reduction in light had a greater effect than the subsequent light reductions. The reduction in yield was primarily caused by a decrease in the number of fruits. The percentage of hollow fruits classified by external appearance was not affected by light reduction, but the volume of the hollows in each fruit increased with light reduction. High correlation coefficients were found between fruit weight and the seed content. Regarding this relationship, no significant difference between light levels was found. The importance of seeds in the development of tomato fruit is discussed.

Key words: Fruit development, hollowness, light level, seeds, tomato.

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The poor light in the early spring is a limiting growth factor for the glasshouse production of tomatoes in the north. Under such conditions, growers have problems with fruit-set and hollowness in particular. On the other hand, in summer the light conditions can be very good on sunny days.

Verkerk (1955), Saito et al. (1963) and Takahashi et al. (1974) found a reduction in number of flowers with light reduction. Lewis (1953) and Rodriguez & Lambeth (1975) found that high irradiation had a positive effect on flower production.

Marr & Hillyer (1968) observed no effect on the percentage of mishapen fruits as a result of shading tomato plants in the glasshouse. Shading after flowering was more critical in causing the development of hollow loculi than shading before flowering (Kaname et al. 1968). Winsor (1966), Winsor & Adams (1975) and Adams & Winsor (1977) demonstrated a seasonal trend in the proportion of boxy tomatoes. The percentage of boxy fruits decreased from early spring to summer.

Experiments conducted by Saito et al. (1963) and Cooper et al. (1964) showed fewer fruits and lower fruit weight when light was reduced. In the commercial production of tomatoes, many reports confirm that poor light conditions cause reduction in yield. An investigation was carried out to obtain more knowledge about the importance of low light conditions in tomato production. The experiment focused on effects relating to yield, fruit quality and the significance of seeds in fruit development.

MATERIALS AND METHODS

The cultivars Jet (Enkhuizen) 422/73 (Lindgren frøhandel) and Exhibition (Asmer Seeds Limited) were selected for this investigation because of their responses as observed in a preliminary experiment. The seeds were sown on 9 January and the plants were raised in 20 000 mWm^{-2} (PAR) supplementary irradiance using fluorescent lamps (Philips TL 33) for 16 h per day until transplanting.

After planting on 23 February, the tomatoes were grown in a glasshouse until August. Plant density was three plants per square metre. The soil, with a pH of 6.3, was fertilized with macro and micro nutrients before planting. A nutrient solution with macro elements (200 ppm N, 250 ppm K, 141 ppm Ca and 25 ppm Mg) was supplied through a drip irrigation system. During the first two weeks after transplanting the night temperature was at 20°C ± 1°C. Thereafter the temperature was 17°C ± 1°C at night and 20°C ± 1°C during the day. Shading material of one and two layers thin white cotton cloth was installed between the glass and the plants so that the amount of natural light coming in was reduced by 30 and 60 %, respectively. The light conditions under the shading material varied by ± 5 % of the fixed light levels, depending on the daylight and the sun's meridian. It was found that the cotton cloth delayed the temperature peak somewhat in sunny weather, but had only a small effect on the maximum temperature. The experiment was designed with a plot size of six plants replicated twice.

The normal global radiation (J per day) at the experimental locality is 268 in February, 661 in March, 1260 in April, 1695 in May, 1795 in June, 1574 in July and 1281 in August. During the experimental period, the light conditions were better than normal in February (8.4 %), March (33.0 %) and in May (11.5 %), and somewhat lower in April (10.6 %).

Completely red fruits from the first eight trusses were harvested. Fruit-set was defined as fruits ≥ 30 gran, the lowest weight for saleable fruits. Fruits from two plants in each replicate of the cultivars 'Jet' and 'Exhibition' were used for a comprehensive examination of the fruit quality. From the harvest of these two cultivars, 1855 ('Jet' 933 fruits, 'Exhibition' 922 fruits) of the fruits had two, three or four locules and weighed more than 4 g. These fruits were examined for hollowness and seed content. For 'Jet' and 'Exhibition' respectively, 15 and 18 % of the fruits had a fruit weight of less than 30 g. A further examination of the fruits showed that the apportionment of locules in fruits from the cultivar 'Jet' was 62.0 % with two locules, 37.2 % with three locules and 0.8 % with four locules. The corresponding apportionment of locules for the cultivar 'Exhibition' was 23.2, 65.2 and 11.6 %.

After harvesting, each fruit was classified according to the Norwegian Standard rules of tomato classification (1 = highest quality, 2 = medium quality, 3 = poor quality, not for ordinary sale) and by type of fruit (1 = even fruits with no rills or malformation, 2 = fruits with roughness, rills or boxy appearance) and weighed. The fruits were then cut in half along the radian. If the fruits showed hollow locules, the space was filled in with liquid wax. After some minutes at room temperature, the surplus wax was cut away and the wax in the hollow was removed. Calculation of the volume of the hollow was based on wax density (0.928 gcm^{-3}) and fruit density estimated to 1.

The pulp was placed in a petri dish, filled with 2.5 % sulphur acid and left for two or three days. Then the seeds were washed clean with pure water in a strainer. After drying, the seeds were cleaned of any remaining pulp, then classified, counted and weighed. The seeds were classified subjectively as 'normal seeds' and 'empty seeds'. For statistical significance, one asterisk is used for $P < 0.05$ and two asterisks for $P < 0.01$. The letters n.s. indicaten no significant effect.

RESULTS

Flowers

Reducing the natural light conditions significantly decreased the number of developing

flowers ($P < 0.05$) from 10.0 and 9.8 flowers per truss under natural light conditions and 30 % light reduction, respectively, to 7.2 flowers per truss at 60 % light reduction. The reduction in number of flowers was most obvious for 'Jet' and 'Exhibition', 31.1 and 36.9 %, respectively, when the natural light was reduced by 60 %. '422/73' differed from the other cultivars, and had the greatest number of flowers at 30 % light reduction. No significant interaction was found between the number of flowers per truss and the truss number.

Fruit-set

The fruit-set under natural light conditions was low (59.4 %), and decreased significantly ($P < 0.01$) to 34.3 and 30.8 % when the natural light was reduced by 30 and 60 %, respectively. '422/73' differed significantly ($P < 0.01$) from the other varieties when light effects on fruit-set were concerned. For this cultivar the fruit-set was reduced from 51.6 % under natural light conditions to 37.6 % at 60 % light reduction.

Yield

Reducing the natural daylight by shading resulted in a significant ($P < 0.01$) reduction in yield (Figure 1). In addition to reducing the number of flowers and the fruit-set as supposition for reduction in yield, the reduced incoming light re-

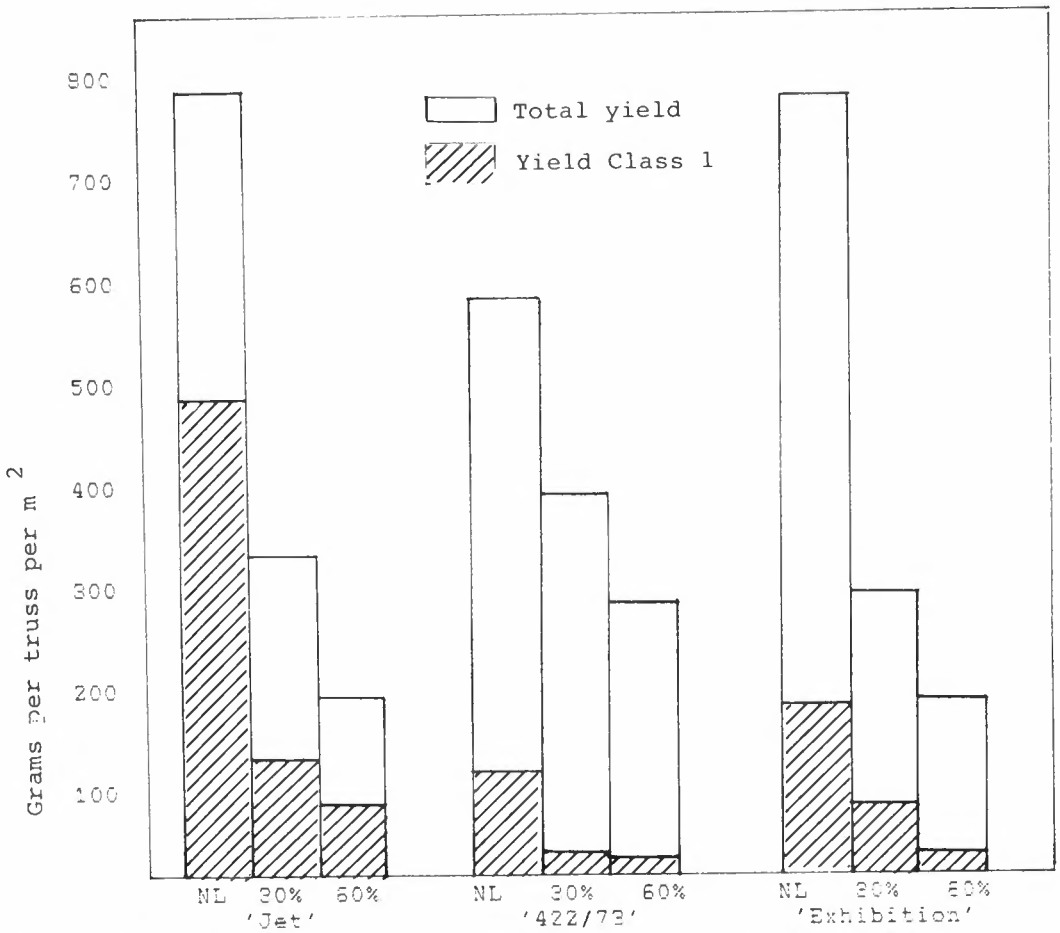

Figure 1. Yield of three tomato cultivars grown in a glasshouse at three different light levels: natural day light (NL), 30 % light reduction (30 %) and 60 % light reduction (60 %)

sulted in a significant ($P < 0.01$) lower fruit weight for 'Jet' and '422/73'. The total yield was positively correlated with the number of flowers ($r = 0.50$) and with the relative fruit-set ($r = 0.87$). These effects were most obvious for cultivars with few flowers.

Fruit quality

Classification of the fruits at harvest, before grouping them in the different categories according to weight and actual occurrence of hollowness, showed that a reduction in the natural light condition had a significantly negative effect in most cases (Table 1).

The results show that the light level was a major factor influencing tomato quality regardless of hollowness.

Table 1. Classification of tomatoes grown under natural light conditions according to the Norwegian Standard (Class 1 = 1, Class 2 = 2, Class 3 = 3) and to fruit type (smooth fruits = 1, rough fruits = 2). Significant negative effects on the classification caused by reduced light conditions (30 and 60 % light reduction) are marked with asterisks

		Standard classification		Fruit type classification	
Cultivar	Fruit quality	All fruits	Fruits ≥ 30 g	All fruits	Fruits ≥ 30 g
'Jet'	Fruits with no hollowness	1.15**	1.09*	1.21*	1.18*
	Hollow fruits	2.21*	2.12 ns	1.86*	1.84*
'Exhibition'	Fruits with no hollowness	1.34**	1.13 ns	1.09*	1.30*
	Hollow fruits	2.53**	2.49*	1.96*	1.94*

Hollowness

The subjective classification of the fruits as hollow or not, showed no significant difference in the occurence of hollowness in relation to light level. Between varieties, there was a highly significant difference ($P < 0.01$) in the relative number of hollow fruits. For the cultivar 'Jet', 44 % of the fruits were classified as hollow, while the other cultivars had about 80 % hollow fruits. Between the two cultivars 'Jet' and 'Exhibition' there was a great difference in the occurrence of hollowness in the fruits. The fruits of the cultivar 'Jet' significantly ($P < 0.01$) increased in relative hollowness from 1.84 % under natural light condition to 2.95 and 3.26 % respectively at 30 and 60 % light reduction, when all the harvested fruits were used. The corresponding values for the cultivar 'Exhibition' were 5.99, 5.52 and 7.28 % ($P < 0.05$) of the fruit volume. The effects of light levels were emphasized with the same level of significance when the calculation was delimited to only hollow fruits. The relative hollowness for the cultivar 'Jet' was now 4.45 and 4.55 % and for the cultivar 'Exhibition' 7.77 and 8.16 % for all hollow fruits or hollow fruits ≥ 30 g, respectively. Fruits with a rough appearance were significantly ($P < 0.01$) more hollow than smooth fruits. The hollowness for the cultivar 'Jet' was 0.33 and 3.95 % for smooth and rough fruits, respectively. The corresponding values for the cultivar 'Exhibition' were 0.50 and 7.20 %. The number of locules in the tomatoes had no significant effect on the relative hollowness.

Seeds

Reducing light levels caused a significant decrease in seed weight (Table 2), the greatest effect occurring at a 30 % reduction.

Classification of the fruits into different categories according to hollowness and fruit weight showed a significant reduction in seed weight with reduced light conditions (Table 3).

Table 2. Dry seed weight (mg per seed) for different categories of seeds from tomato plants grown under different light conditions

Cultivar	Type of seeds	Natural light	Reduction of natural light (%) 30	60	Significance
'Jet'	Normal seeds	3.65	3.26	3.20	**
	Empty seeds	0.54	0.32	0.28	**
	All seeds	3.60	3.23	3.15	**
'Exhibition'	Normal seeds	3.27	2.65	2.89	**
	Empty seeds	0.57	0.38	0.34	**
	All seeds	3.20	2.61	2.85	**

Table 3. Dry seed weight (mg per seed) for tomatoes grown in natural light conditions.Significant reducing effects of light reduction on seed weight are marked with asterisks

Fruit quality	'Jet'						'Exhibition'					
	Normal seeds		Empty seeds		All seeds		Normal seeds		Empty seeds		All seeds	
	All fruits	Fruits ≥30 g	All fruits	Fruits ≥ 30 g	All fruits	Fruits ≥ 30 g	All fruits	Fruits ≥ 30 g	All fruits	Fruits ≥ 30 g	All fruits	Fruits ≥ 30g
Fruits with no hollowness	3.69*	3.84*	0.48*	0.52*	3.67*	3.81*	3.41*	4.16**	0.37**	0.47**	3.37**	4.10**
Hollow fruits	3.31*	3.64**	0.44*	0.53 ns	3.25*	3.57**	2.96**	3.40*	0.52*	0.64*	2.90**	3.32*

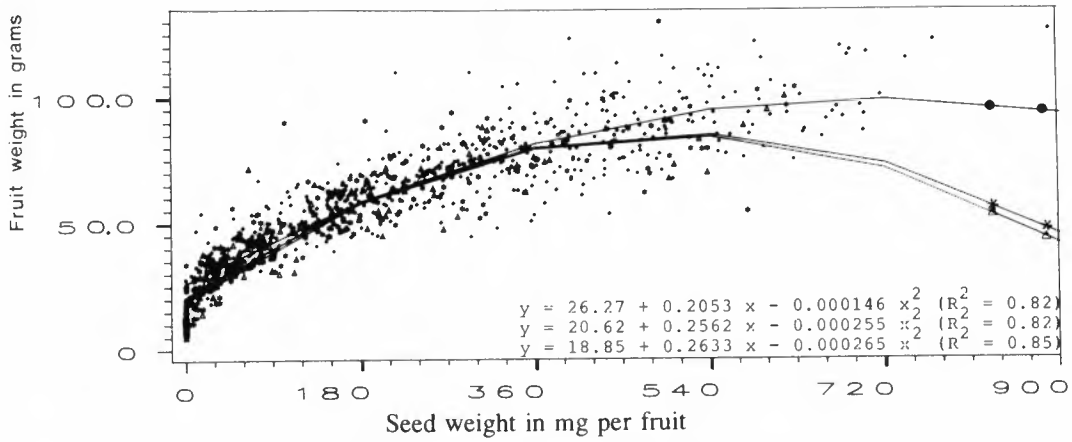

Figure 2. The regression between seed weight per fruit and the fruit weight for the tomato cultivar 'Jet' grown under different light levels, . . natural light conditions, * * 30% light reduction, △ △ 60 % light reduction

The table shows that the average seed weight was highest in non-hollow fruits and in fruits of saleable size ⩾30 g.

Relationship between seed content and fruit weight

The regression for different light levels showed a highly significant seed-induced effect on the fruit weight. Using number of seeds or weight of seeds per fruit the calculation showed the highest R^2 when using the latter variable as the basis for calculating the fruit weight (Figure 2 and 3). The effects of the two seed variables on fruit weight did not vary significantly with light levels.

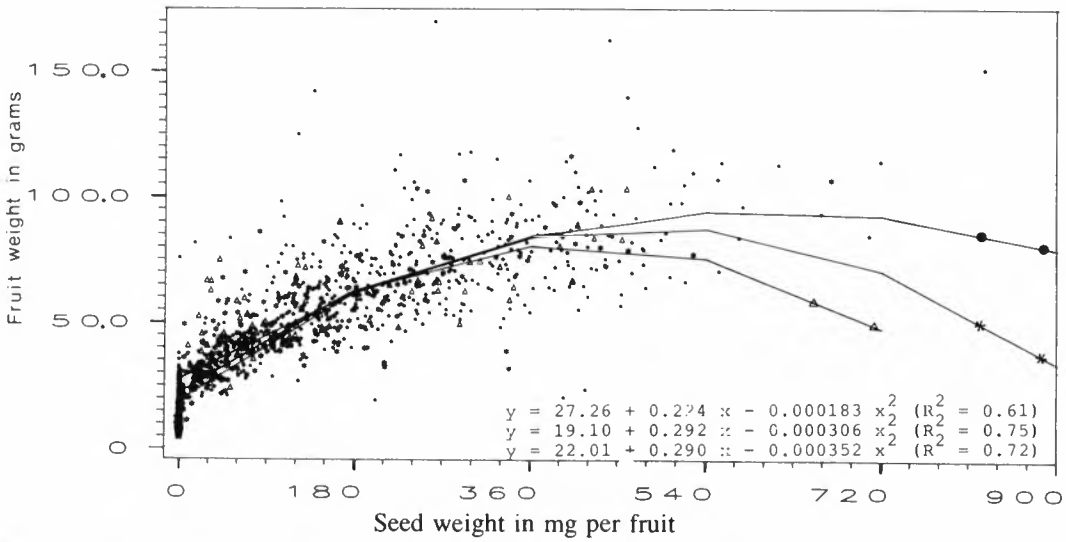

Figure 3. The regression between seed weight per fruit and the fruit weight for the tomato cultivar 'Exhibition' grown under different light levels, . . natural light condition, * * 30 % light reduction, △ △ 60 % light reduction

DISCUSSION

Poor light conditions affect yield and quality of tomatoes in different ways. The low number of flowers per truss, and the fact that there was no interaction between light level and the truss number in this experiment, may be due to abortion at an early stage of flower development. This indicates that there could have been an insufficient carbohydrate production (Calvert 1973), an effect which would increase with reduced light conditions. Mapelli & Lombardi (1982) suggested that low cytokinin levels in the tomato plants reduced flower formation and flower number. The decrease in the number of flowers may be associated with the metabolism of carbohydrates and hormones. The carbohydrate level (Verkerk 1955, Saito et al. 1963) has been suggested as a factor controlling fruit-set. The obvious relationship between fruit-set and light conditions may be an indirect effect of the carbohydrate metabolism and the growth regulator metabolism.

In agreement with Cooper et al. (1964), the reduction in yield caused by shading was primarily due to the light effect on the number of fruits produced and secondarily to an effect on fruit size. This was most pronounced for the cultivar 'Exhibition', which displayed only a decrease in the number of fruits, not in fruit weight. This emphasizes the significance of developing fruits with seeds in the source-sink

relationship. It is likely that the developing fruits with seeds have a regulatory function in the hormonal balance, too.

Effects of light on misshapen and hollow fruits observed by Marr & Hillyer (1968) and Kretchman & Bauerle (1971) have been confirmed in this experiment, too. Provided that the objective occurrence of hollowness is in accordance with the subjective classification, there is some possibility of combining the occurrence of hollowness and the volume of the hollows in a relationship with light conditions. It is likely that poor light conditions increase the hollows. The higher seed weight in normal fruits compared with hollow fruits indicates an effect of seed development in the occurrence of hollowness.

As concluded in many reports (Dempsey & Boynton 1965, Imanishi & Hiura 1977, Varga & Bruinsma 1976, Sawhney & Debbs 1978, Rylski 1979), this experiment showed a clear relationship between the seeds and fruit weight. In this case a higher regression coefficient was found when the calculation was based on seed weight rather than on number of seeds. This observation may indicate that seeds of different weight, do not have identical effects on tomato fruit growth. Such results do not discriminate between the effect of seeds as a sink (Varga & Bruinsma 1976) or seeds as a source for synthesizing auxin for fruit growth (Mapelli et al. 1978). It is likely that perished embryos like seeds, have taken place in the fruit growth.

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Effects of boron on fruit and seed development in the tomato

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Growing the tomato cultivar 'Jet' in peat with different level of boron, reduced mean fruit weight and increased the proportion of fruits weighting between 5 and 30 g. Increased boron fertilization improved fruit shape and reduced hollowness, especially in fruits with a saleable weight. The effect of boron on seed development was most marked for small fruits. Different levels of boron fertilization made no significant difference to the relationship between seed weight per fruit and fruit weight.

Key words: Boron, fruit development, seeds, tomato.

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Fertilization and availability of boron is of great interest when growing plants with a generative product. Messing (1957) found that under conditions of severe boron deficiency tomato fruits frequently failed to set and develop. Adams & Winsor (1974) found an increase in yield of tomato and an improved fruit shape when boron fertilization was increased. Tomato plants with severe boron deficiency were found to depress the yield by 50 % (Adams 1978).

Brown (1979) found a connection between boron deficiency and the generative phase of tomato plants, particularly the role it plays in the germination of pollen tubes. Inadequate supply of boron caused a disturbance in pollen germination and fruit formation was impaired. Gärtel (1974), working with vine, has shown parthenocarpic fruit development in boron deficient plants. Analysis of the stigma showed a boron content of 50–60 ppm in the dry matter when the plants were well supplied with boron, and 8 to 20 ppm in the stigma of boron deficient plants with impaired fertilization.

Many investigations concerning boron fertilization are based on a wide study range from deficiency to toxicity. This investigation was undertaken in the course of a normal cultivation programme with a narrow and rather adequate range of boron fertilization, the effects beeing studied on this basis.

MATERIAL AND METHODS

The cultivar 'Jet' (Enkhuizen) was grown in a light sphagnum peat medium ('Floralux Standard veksttorv') limed to a pH of 5.5 with a mixture of one part of dolomite to two parts of limestone. Peat volume per plants was 20 l. The peat was fertilized with a mixed fertilizer

(0.02 % B as borax) and with Fritted Trace Elements (FTE) no. 36, totalling 1.4 g boron. In addition to the base fertilization, the peat was supplied with 0, 0.8 and 3.2 g boron from borax ($Na_2B_4O_7$. $10H_2O$) per m^3 peat. This fertilization gives three levels of boron in the peat, 1.4, 2.2 and 4.6 g per m^3, 1.0 g of boron in the peat coming from FTE the rest from borax.

The nutrient solution supplied throughout the cultivation period contained 200 ppm nitrogen, 250 ppm potassium, 25 ppm magnesium and 140 ppm calcium, supplied by means of drip watering.

After sowing on 9 January, the plants were raised in supplementary artificial light (20 000mWm^{-2} (PAR) for 16h per day using fluorescent lamps, Philips TL 33) until transplanting on 23 February. In the transplanting period a temperature of 17°C ± 1°C was used in the dark phase and 20°C ± 1°C in the light phase. After transplanting, the night temperature was at 20°C ± 1°C for the first two weeks, thereafter the day and night temperatures were at 20°C ± 1°C and 17°C ± 1°C, respectively.

The experiment included two replicates with six plants per plot. The plants were stopped over eight trusses.

After harvesting the completely red fruits, each fruit was classified according to the Norwegian Standard rules for tomato classification (1 = highest quality, 2 = medium quality, 3 = poor quality, not for ordinary sale) and classified by type of fruit (1 = smooth fruits without rills or disorders, 2 = fruits with roughness, rills or boxy appearance) and weighed. Then the fruits were cut in half along the radian. If they showed hollow locules, the hollow was filled in with liquid wax. After some minutes at room temperature, the surplus wax was cut away and the wax in the hollows was removed.

Calculation of the volume of the hollows was based on the wax density (0.928 gcm^{-3}) and fruit density estimated to 1 (relative hollows). The pulp was placed in a petri dish, filled with 2.5 % sulphur acid for two or three days. The seeds were then washed clean with pure water in a strainer. After drying, the seeds were cleaned of any remaining pulp, then classified, counted and weighed. The seeds were classified subjectively as 'normal seed' or 'empty seed'.

All fruits from the first eight trusses greater than 5 g were harvested. The largest fruit weight was 135.4 g. The fifth leaf from the top of the plants was analysed for boron content (MacLean et al. 1968), when the plants flowered on the fourth, sixth and eighth trusses.

This investigation was based on an examination of 863 fruits. Of these fruits 737 had a weight of at least 30 g. For statistical significance, one asterisk is used for $P < 0.05$, two for $P < 0.01$ and three for $P < 0.001$. The letters n.s. indicate no significant effect.

RESULTS

Boron content in the leaves

The boron content of the leaves increased significantly ($P < 0.001$) with increased boron fertilization. Mean values of boron in the leaves were 32.7 ppm, 37.3 ppm and 41.1 ppm for low, medium and high levels of boron fertilization, respectively. There was no significant difference in boron content between sampling times.

Fruit quality

There was a marked effect of boron fertilization on some fruit quality parameters when the fruits were grouped in different categories (Table 1).

The significant reduction in the mean weight of fruit for all fruits with increased boron fertilization was an effect of a significantly ($P < 0.001$) increased number of fruits with increased boron fertilization weighing between 5 g and 30 g. At the lowest level of boron fertilization, 2.6 % of the fruits had a weight of between 5 g and 20 g. The corresponding figures for the medium and the highest boron fertilization levels were 7.5 and 21.3 %, respectively. For fruits between 20 and 30 g, the number increased from 2.9 % at the lowest level to 4.6 and 6.3% for the medium and highest boron fertilization levels. The increased fruit quality characterized

Table 1. Effects of boron fertilization on tomato fruit weight, grading quality and hollowness

Parameter of quality	Fertilization in g of B per m³ peat						Significance	
	1.4		2.2		4.6			
	All fruits	Fruits ⩾ 30 g	All fruits	Fruits ⩾ 30 g	All fruits	Fruits ⩾ 30 g	All fruits	Fruits ⩾ 30 g
Mean fruit weight, g	64.6	67.1	61.9	68.2	54.5	69.0	***	n.s
Grading quality, 1-3	1.6	1.6	1.5	1.4	1.4	1.2	*	***
Fruit type, 1 or 2	1.5	1.5	1.4	1.4	1.4	1.2	*	***
Hollowness in per cent of fruit volume	2.41	2.19	1.09	0.87	0.73	0.45	***	***

by grading classification or by fruit type was most evident for fruits ⩾ 30 g.

The number of locules did not vary significantly with boron fertilization, and on the average was 2.4 for all fruits and fruits ⩾ 30 g.

Seeds

For saleable fruits, small but insignificant effects of boron fertilization on seed development were observed (Table 2). When small fruits were added to the saleable fruit categories, it was found that increased boron fertilization had the effect of markedly reducing seed number and seed size. For both fruit sizes, different levels of boron fertilization had no significant effect on fruit weight per seed or fruit weight per mg seed.

Table 2. Effect of boron fertilization on the number of seeds per fruit and the mean dry seed weight in mg for different categories of seeds

Categories of seeds	Fertilization in g of B per m³ peat						Significance	
	1.4		2.2		4.6			
	All fruits	Fruits ⩾ 30 g	All fruits	Fruits ⩾ 30 g	All fruits	Fruits ⩾ 30 g	All fruits	Fruits ⩾ 30 g
Number of seeds per fruit	76.4	80.6	65.8	74.6	55.8	76.6	***	n.s.
Number of normal seeds per fruit	75.1	79.3	64.4	73.0	54.8	75.3	**	n.s.
Number of Hemply seeds per fruit	1.3	1.4	1.3	1.5	1.0	1.3	n.s.	n.s.
Mean weight of all seeds, mg	3.44	3.51	3.30	3.54	2.89	3.63	***	n.s.
Mean weight of normal seeds, mg	3.48	3.54	3.35	3.60	2.92	3.68	***	*
Mean weight of empty seeds, mg	0.38	0.14	0.31	0.12	0.29	0.12	***	n.s.

Effects of seeds on hollowness and fruit weight
A negative significant ($P < 0.01$) correlation was found between the relative hollowness of the fruit and the weight of the seeds. Calculations based on all fruits harvested gave correlation coefficients of $r = -0.51$, $r = -0.37$ and $r = -0.36$ with low, medium and high boron fertilization, respectively. The coefficients of correlation varied in the same way for saleable fruits, too. The slight difference in the coefficients of correlation between all fruits or exclusively large fruits was insignificant.

The coefficient of correlation between the relative hollows and fruit weight was significant ($P < 0.01$) and varied from $r = -0.31$ to $r = -0.39$ regardless of fruit category. Different levels of boron fertilization had no significant influence on the coefficients of correlation.

The significant ($P < 0.01$) coefficient of correlation between seed weight and fruit weight varied between $r = 0.84$ and $r = 0.86$ when all fruits were used as material for the calculation and correspondingly between $r = 0.78$ and $r = 0.82$ when the calculation was based on fruits $\geq$ 30 g. Figure 1 shows the regression between seed and fruit weight for different boron fertilizations.

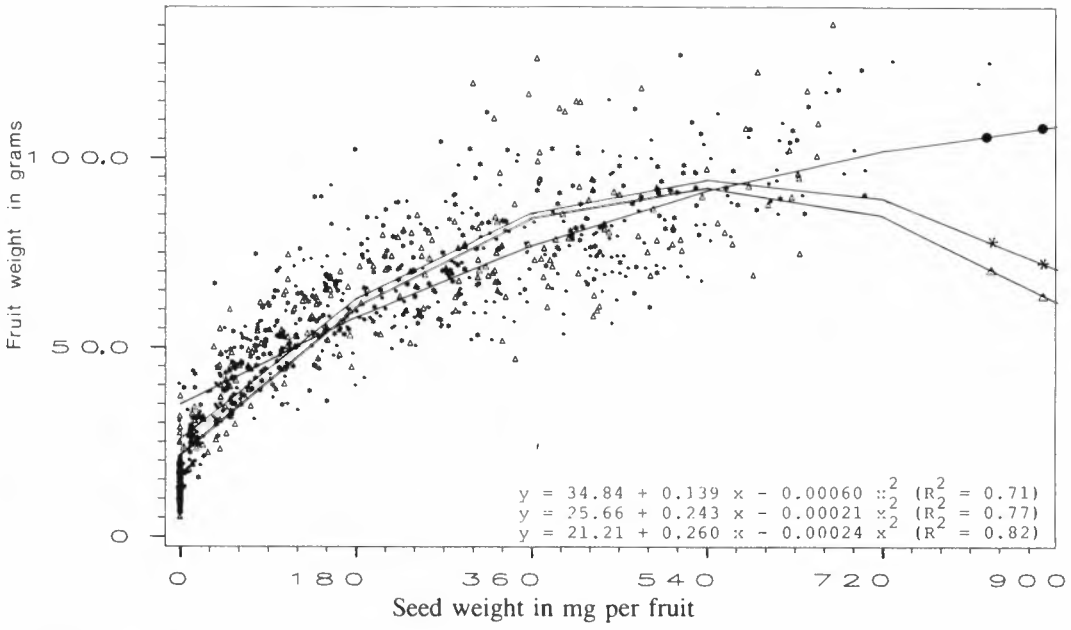

Figure 1. The relationship between seed weight per fruit and the fruit weight induced by boron fertilization, 1.4 g B per m^3 peat, . ., 2.2 g B per m^3 peat, * *, 4.6 g B per m^3 peat, △ △

DISCUSSION

Boron fertilization in accordance with the experimental procedure, produced an adequate boron content in the plants (MacLean et al. 1968, Smilde & Roorda van Eysinga 1968, Adams & Winsor 1974, Alt & Rosen 1987), and no symptoms of deficiency or toxicity were registered.

The effects of boron fertilization on fruit development in this investigation confirm the results of Messing (1957) and Adams & Winsor (1974), dispite a relatively narrow and adequate range of leaf boron content.

The most obvious effect of boron in this investigation was found in small fruits and in the seeds of small fruits. The relative increase in small fruits as a result of high boron levels, may have been an effect of boron in the pollination process (Messing 1957, Gärtel 1974). The decreased fruit weight and the increased precentage of small fruits with increased boron fertilization have also been found by Messing (1957) and Francois (1984). It is possible that a high level of boron contributed to a better pollination, there by reducing parthenocarpic fruit development to the benefit of small seeded fruits. There may be other factors limiting to the further growth of these fruits.

This investigation confirms Messing's (1957) and Adams & Winsor's (1974) description of fruit shape and open locules (Maynard et al. 1959). It is very interesting to note that the boron fertilization affected fruit quality in fruits of a saleable size. In this category of fruit, it is likely that the effect of boron in the pollination process may have been beneficial. The lack of fruitfulness or malformations may be connected with seed quality. It may also be influenced by metabolic substances such as growth regulators and other organic compounds which are necessary for normal fruit development. Boron may play a part in this process.

Some attention must be focused on the upward transport and the translocation of boron in plants, and the rate by which transpiration influences the upward transport (Michael et al. 1969). Translocation of boron to the xylem and the possibility of accumulation in the leaf tips and margins (Jones 1970) may provide adequate boron content in the leaves, as found in this experiment. At the same time, boron content would have to be high in organs such as the anthers, stigma and ovary (Sywortkin 1958, Oerteli & Ricardson 1970).

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Cadmium and Fluoride Uptake by Oats and Rape from Phosphate Fertilizers in two Different Soils

Cadmium and fluoride uptake by plants from P. Fertilizers

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The effects of rates and sources of phosphate fertilizers on the uptake of cadmium (Cd) and fluoride (F) by oats (*Avena sativa* L.) and rape (*Brassica napus* L.) grown in loam and peat soils were investigated in a greenhouse experiment. NPK fertilizers containing low (2.6 mg kg^{-1}) and high (40 mg kg^{-1}) Cd and single superphosphate (SSP) containing 15 mg Cd kg^{-1} at rates ranging from 30 to 180 mg P kg^{-1} soil were used as P fertilizers. While grain and straw yields of both oats and rape were generally unaffected by P fertilization, the P concentration in grain and straw tended to increase with increased rates of P fertilization.

At higher rates of high Cd NPK and SSP, the concentration of Cd in the grain and straw of oats and rape was generally increased, and more so in the peat soil than in the loam soil. In the peat soil, Cd in the grain increased from 0.08 mg kg^{-1} in the control to 0.21 mg kg^{-1} at the highest rate of SSP in the first year. The corresponding values in the loam soil were 0.29 to 0.34 mg kg^{-1}. Cadmium concentration in straw showed a similar trend but it was generally higher than in the grain and the differences were more marked in rape than in oats. The results for the second year from the same pots treated in the previous year were similar to those for the first year, except that the Cd concentration generally decreased in the second year. Application of SSP resulted in a higher uptake of Cd compared with the NPK fertilizers.

P fertilizers had little effect on the F concentration in oats and rape; F concentration, however, was much higher in oats in the first year than in the second year. It was also higher in oats than in rape. With minor exceptions, F concentrations were generally low and were within the normal range for most plants.

The Cd concentration in oats and rape was only slightly changed by P fertilization at the normal level of P application and constituted no danger of contaminating food products. However, use of high rates of acid producing P fertilizers such as SSP, especially in soils rich in organic matter, may lead to an increased uptake of Cd. Fluoride uptake from P fertilizers was very low and was little affected by the rates and sources of P fertilizers.

Key words: Cadmium, fluoride, oats, peat/bog soils, plant uptake, phosphate fertilizers, rape.

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In recent years increased attention has been focused on the uptake of non-essential chemical elements by plants in order to safeguard against their possible entry into the human food chain. The possibility of introducing potentially toxic elements into the food chain by the addition of phosphatic fertilizers to the soil has been suggested by Bowen (1966) and Lisk (1972). In particular Cd may be singled out as one of the more dangerous contaminants because of the possibility of its transfer from the soil to the human food chain, and its association with various diseases.

The commercial fertilizers together with atmospheric deposition are major sources for Cd input to cultivated soils (Andersson 1977; Hanson and Tjell 1978). Andersson and Hahlin (1981) found significant positive correlations between the Cd content of barley grain and added amounts of P and different fractions of soil Cd. Dam Kofoed and Søndegård-Klausen (1983), on the other hand, found no significant increase in the Cd content of barley and wheat grain at normal application of fertilizer, except that Cd content increased at a higher rate. Similarly, Shroeder and Balasa (1963) showed that high application rates of triple superphosphate containing 7 mg Cd kg^{-1} resulted in a slight increase in Cd concentration in several vegetable species. Mortvedt and Giordano (1977) reported greater Cd uptake by maize from commercial diammonium phosphate (DAP) containing 30 and 50 mg Cd kg^{-1} than from reagent grade DAP (1 mg Cd kg^{-1}).

Fluoride is seldom taken up in large quantities by plants; its uptake is dependent on soil type, soil reaction, amounts and types of fertilizers applied, and plant species grown. Hurd-Karrer (1950) and MacIntire et al. (1951) have demonstrated that the addition of large quantities of soluble F-containing materials to unlimed acid soils will result in increased uptake by the plants and possible injury. For example, in one of the frame experiments with different plant species grown in the soil at pH 5.0, the application of 50 mg F kg^{-1} soil applied through NaF and HF resulted in an injuriously high F content in the plants (Hurd-Karrer 1950). Braen and Weinstein (1985) reported that as F levels in the soils increased as a result of contamination from air pollution, the F in the foliage of both orchard grass and maple increased, the concentrations, however, were within those levels considered as background ones.

Cadmium and possibly also F may well be transferred from the soil to the human food chain and the use of P fertilizers containing these elements may be one of their avenues of entry to it. Therefore, the uptake of Cd and F by oats and rape grown in loam and peat soils as affected by sources and rates of P fertilizers was investigated.

MATERIALS AND METHODS

Greenhouse pot experiments using loam and peat soils, collected from Ås, southeastern Norway, were conducted. Some of the chemical properties of these soils are presented in Table 1. The NPK fertilizers containing low and high Cd, single superphosphate (SSP), and the reagent grade Ca $(H_2PO_4)_2$ were used as P sources. The chemical composition of the fertilizers used is given in Table 2. The rates of P were 30, 60, and 90 mg P kg^{-1} soil for the NPK and the reagent grade $Ca(H_2PO_4)_2$ and 60, 120, and 180 mg P kg^{-1} soil for the SSP. The rates in SSP were raised in order to investigate whether increased P could result in increased uptake of Cd and F by plants. Two levels of Cd and F applied through $CdCl_2$ and NaF, respectively, were included in the experiment in order to study the Cd and F uptake by plants from their mineral salts. The treatment combinations along with the sources and rates of P, Cd, and F are presented in Table 3.

The loam and peat soils were limed at the rates of 7.5 and 15.0 g $CaCO_3$/pot, respectively in order to bring the pH of the soils to above 5.5. The rates of N and K applied were 219 and 163 mg kg^{-1} soil through NPK in treatments 4 to 9 and through NH_4NO_3 and K_2SO_4 in treatments 1 to 3 and 10 to 12. Treatments 4, 5, 7, and 8 received extra amounts of NH_4NO_3 and K_2SO_4 so that the rates of N and K in all the treatments

Table 1. Some chemical characteristics of the soils used

Soils	pH (1:2.5 water)	CEC	Exch.cations me/100 g Ca^{++}	Mg^{++}	K^+	Na^+	H^+	mg/kg P-Al	K-Al
Loam	5.2	16.8	4.50	0.45	0.32	0.07	11.5	100	120
Peat	3.6	37.8	6.48	4.56	0.32	0.48	26.0	–	–

Table 2. Concentrations of major nutrients and Cd and F in fertilizers used

Fertilizer source	% N	P	K	Ca	Mg	F	Cd mg/kg
Low Cd NPK fert.	15.8	6.5	12.0	3.4	1.2	1.6	2.6
High Cd «	15.9	6.7	11.8	3.4	0.8	1.5	40.0
S. Superphosphate.....	–	9.4	0.2	19.5	0.2	0.15	15.0

Table 3. Sources and rates of P, Cd and F applied

Treatment No.	Fertilizer source P	Cd	F	Fertilizer rate – mg/kg – P	Cd	F
1	$Ca(H_2PO_4)_2 \cdot H_2O$	$CdCl_2 \cdot 5/2\ H_2O$	NaF	30	0	0
2	»	»	»	30	1.25	5
3	»	»	»	30	12.5	50
4	Low Cd NPK 16-7-12			30	1.2×10^{-3}	7.3
5	»	»		60	2.4×10^{-3}	14.6
6	»	»		90	3.6×10^{-3}	21.8
7	High Cd NPK 16-7-12			30	17.9×10^{-3}	6.8
8	»	»		60	35.8×10^{-3}	13.6
9	»	»		90	53.7×10^{-3}	20.4
10	Single superphosphate			60	9.6×10^{-3}	3.3
11	»	»		120	19.2×10^{-3}	6.6
12	»	»		180	28.8×10^{-3}	10.0

could be uniform. A mixture of micronutrients containing 6.4, 8.1, 14.9, 0.28, and 0.27 mg kg^{-1} soil of Cu, Mn, F, B, and Mo, respectively, was applied to all pots. A basal dose of 10 mg Mg kg^{-1} soil through $MgSO_4.7H_2O$ was applied to compensate for Mg and S in the respective treatments. Lime and all fertilizers were thoroughly mixed with 5-L each of the loam and the peat soils. The soil was then filled into 6-L plastic pots. A u-shaped perforated rubber tube was installed in the pots for watering during the growing season.

The treatments were replicated three times. Twenty seeds of oats (*Avena sativa* L.) and 30 seeds of rape (*Brassica napus* L.) were sown, after germination these were thinned to 14 and 8

plants, respectively. The moisture content in the pots was maintained at near field capacity by regular irrigation with deionized water.

Crops were harvested at maturity and threshed to separate grain and straw. The dry weights of grain and straw were recorded. Samples of grain and straw were ground and stored for chemical analysis.

Cation exchange capacity in the soil was determined by the method of Schollenberger and Simon (1945) and P and K by the method of Egner et al. (1960). Plant samples, grain and straw, were dry ashed at 450°C and the ash dissolved in 5 ml concentrated HCl and diluted to 100 ml by distilled water. Cadmium in the digested sample was determined by atomic absorption spectrophotometry using a graphite oven. Fluoride in the plant samples was determined with a F selective electrode (Eyde 1982). Phosphorus was determined calorimetrically as a phosphovandomolybdate complex. All results were reported on an oven dry basis (105°C).

RESULTS

Oats (first year)

There was no consistent response to applied P in the loam soil, and neither grain nor straw yields at the same level of applied P from different sources differed significantly (Table 4). However, both grain and straw yields at 120 and 180 mg P kg^{-1} soil applied through SSP were significantly higher than those at 30 and 60 mg P kg^{-1}soil applied through NPK or Ca $(H_2PO_4)2$. Application of Cd and F, through their salts or their fertilizers, did not affect the yields except that the straw yield at the highest rate of Cd and F (Treatment 3) tended to be lower than that of the control. Some stunting and tip burning of plants in pots with this treatment were observed five weeks after germination and these anomalies may be responsible for slightly lower dry matter yield.

The concentration of P in grain and straw was generally not affected by increased rates of

Table 4. Yield and concentrations of P, Cd, and F in oats grown in a loam soil as affected by rates and sources of P fertilizer varying in Cd concentrations (first year)

Treatment No.	Grain				Straw			
	Yield g/pot	P %	Cd – mg/kg –	F	Yield g/pot	P %	Cd – mg/kg –	F
1*	45.4^{d+}	0.29	0.29	20.2	87.5^{cd}	0.04	0.41	13.2
2	50.1^{cb}	0.28	3.13	17.2	91.5^{cd}	0.02	3.67	13.6
3	46.8^{d}	0.32	20.00	15.0	85.0^{e}	0.03	47.10	10.8
4	48.2^{cd}	0.30	0.40	15.0	88.0^{ed}	0.03	0.80	9.6
5	48.0^{cd}	0.33	0.30	14.0	89.6^{ecd}	0.04	0.43	6.4
6	52.9^{ab}	0.30	0.30	13.8	95.0^{cb}	0.03	0.35	9.2
7	50.3^{cb}	0.31	0.29	12.4	90.9^{cd}	0.03	0.45	8.4
8	50.1^{cb}	0.30	0.29	8.0	91.5^{cd}	0.03	0.45	7.6
9	52.0^{ab}	0.30	0.32	12.8	93.8^{cb}	0.03	0.45	9.2
10	51.8^{ab}	0.30	0.28	10.8	94.5^{cb}	0.03	0.47	8.0
11	53.7^{a}	0.35	0.33	7.6	98.6^{ab}	0.03	0.44	8.8
12	54.8^{a}	0.37	0.34	8.4	101.0^{a}	0.04	0.42	9.6

* Treatment details in Table 3.

\+ Means with the same letter in the same column are not significantly different at P = 0.05.

NPK but it tended to increase with increased P rates through SSP. It was also higher in the SSP treated pots than in those treated with other P sources. Although, the Cd concentration in grain and straw increased manyfold with increased rates of $CdCl_2$ application, it was generally not affected by the Cd contained in NPK fertilizers. As with P concentration, Cd in the grain increased slowly but steadily with increased rates of SSP. Quite unexpectedly, the Cd concentration in straw at the lowest rate of low Cd NPK was much higher than in all other treatments. As this treatment followed immediately after the highest Cd application through $CdCl_2$, the possibility of contamination during the various operations of the experiment cannot be ruled out. Cd concentration in straw was generally higher than in the grain.

The application of F through its sodium salt or through NPK and SSP showed no consistent effect on the F concentration in the grain and straw of oats.

Oat yields in the peat soil at 60 to 120 mg P kg^{-1} levels were significantly higher than oat yield at the 30 mg P kg^{-1} level of $Ca(H_2PO_4)_2$ (Table 5). In contrast to the loam soil, P concentration in grain and straw generally increased with increased P rates and more so in straw than in grain. The concentration of P in the straw at higher P rates of SSP (120 and 180 mg P kg^{-1} soil) was many times higher than that in all other treatments. This may be the cause of tip burning and necrosis on the upper half of oat leaves, observed five to six weeks after germination. The effect of $CdCl_2$ application was similar to that observed in the loam soil but the Cd concentration in grain and straw increased consistently with increased rates of P applied through the high Cd NPK and SSP. Unlike the loam soil, the F concentration in straw increased with increased rates of F applied either through NaF or through the high Cd NPK and SSP, but no such effect was observed in the grain.

Table 5. Yield and concentrations of P, Cd, and F in oats grown in a peat soil as affected by rates and sources of P fertilizer varying in Cd concentrations (first year)

Tratment	Grain				Straw			
	Yield g/pot	P %	Cd – mg/kg –	F	Yield g/pot	P %	Cd – mg/kg –	F
1*	50.0^{de}	0.23	0.08	17.2	106.0^{e}	0.03	0.25	7.2
2	51.9^{de}	0.23	3.93	17.6	107.0^{e}	0.03	10.40	10.4
3	48.9^{e}	0.26	14.00	21.2	97.4^{f}	0.03	56.10	44.4
4	53.0^{cd}	0.17	0.16	14.0	109.0^{ed}	0.02	0.54	10.8
5	59.5^{a}	0.30	0.11	16.8	118.0^{ab}	0.50	0.23	10.4
6	58.6^{ab}	0.34	0.09	17.2	115.0^{abcd}	0.18	0.17	11.6
7	52.8^{cd}	0.17	0.09	11.8	111.7^{bcde}	0.02	0.23	9.6
8	58.4^{ab}	0.27	0.13	13.2	119.3^{a}	0.04	0.25	13.6
9	56.8^{ab}	0.34	0.18	10.0	113.7^{abcd}	0.14	0.30	15.6
10	59.7^{a}	0.32	0.14	13.6	118.3^{a}	0.07	0.26	15.8
11	59.6^{a}	0.38	0.18	12.6	116.7^{abc}	0.33	0.36	18.2
12	55.5^{bc}	0.42	0.21	13.2	111.0^{cde}	0.63	0.40	21.0

* Treatment details in Table 3.

+ Means with the same letter in the same column are not significantly different. at P = 0.05.

Oats (second year)

There was again little effect of the residual P at various rates on the yield in the loam soil (Table 6). However, the concentrations of P and Cd, especially in the grain, increased consistently with increased rates of P. The trends in the concentration of F were almost identical to those observed in the first year, except that the concentration was reduced manyfold in the second year (Table 6).

Table 6. Yield and concentrations of P, Cd, and F in oats grown in a loam soil as affected by rates and sources of P fertilizer varying in Cd concentrations (second year)

Treatment	Grain				Straw			
	Yield g/pot	P %	Cd – mg/kg –	F	Yield g/pot	P %	Cd – mg/kg –	F
1*	32.9[a+]	0.30	0.18	2.6	60.8[a]	0.05	0.35	0.5
2	34.5[a]	0.31	1.51	1.6	63.3[a]	0.05	2.96	0.5
3	33.6[a]	0.33	7.8	1.0	60.8[a]	0.05	12.80	4.4
4	35.5[a]	0.31	0.19	1.0	64.9[a]	0.04	0.68	2.8
5	33.2[a]	0.33	0.15	0.5	61.0[a]	0.04	0.32	0.5
6	35.0[a]	0.37	0.16	3.2	64.7[a]	0.07	0.31	0.5
7	33.1[a]	0.32	0.16	0.5	61.6[a]	0.04	0.31	0.5
8	33.2[a]	0.35	0.18	2.0	61.6[a]	0.06	0.37	0.5
9	34.3[a]	0.36	0.24	1.0	63.9[a]	0.06	0.12	1.0
10	33.3[a]	0.35	0.22	1.0	62.1[a]	0.05	0.15	0.5
11	34.2[a]	0.37	0.26	1.2	63.2[a]	0.08	0.15	2.0
12	34.5[a]	0.39	0.28	0.5	63.6[a]	0.13	0.15	0.5

* Treatment details in Table 3.

\+ Means with the same letter in the same column are not significantly different at P = 0.05.

The effects of rates and sources of P on the yield and concentration of P, Cd, and F in oats grown in the peat soil were generally the same as those observed in the first year in this soil. However, the yield and concentrations of Cd and F were lower in the second year, especially the F concentration, which was reduced manyfold (Table 7).

Rape (first year)

As with oats, there was no consistent effect of rates and sources of P on the yield and the P and F concentrations in the loam soil. But the Cd concentration, especially in the grain of the high Cd NPK and SSP treatments and in the straw of the SSP treatment, increased with increased rates of P application. The effect of $CdCl_2$ on Cd concentration was somewhat similar in both crops but the F concentration in rape (Table 8) was many times lower than that in oats (Table 4).

The yields decreased significantly when rape was grown in the peat soil but the effects of P rates were similar in the two soils. The yields at the highest rates of Cd (Treatment 3) and in the SSP-treated pots were significantly lower than all other treatments (Table 9). Some leaf chlorosis, stunted growth, and poor flowering in these treatments were observed during growth and appeared to be responsible for yield reduction. Like the loam soil, the P concentration generally increased with increased P application but was little affected by P sources. Although the Cd concentration in straw tended to increase with increased rates of high Cd NPK and SSP, the effect was not marked in the grain. With the

Table 7. Yield and concentrations of P, Cd and F in oats grown in a peat soil as affected by rates and sources of P fertilizer varying in Cd concentrations (second year)

Treatment	Grain				Straw			
	Yield g/pot	P %	Cd – mg/kg –	F	Yield g/pot	P %	Cd – mg/kg –	F
1*	26.4^{f+}	0.21	0.09	1.6	56.1^{d}	0.04	0.16	0.5
2	26.1^{f}	0.21	2.43	0.5	55.6^{d}	0.05	9.70	0.5
3	27.3^{ef}	0.22	9.80	0.5	54.1^{d}	0.06	12.00	9.2
4	28.8^{cde}	0.21	0.14	0.5	60.1^{c}	0.04	0.20	1.6
5	31.4^{ab}	0.28	0.09	0.5	64.1^{a}	0.06	0.17	0.5
6	32.3^{a}	0.32	0.09	0.5	64.4^{a}	0.12	0.16	0.5
7	28.2^{de}	0.22	0.10	0.5	59.4^{c}	0.04	0.25	0.5
8	32.2^{a}	0.29	0.14	0.5	63.5^{a}	0.08	0.31	0.5
9	32.8^{a}	0.34	0.17	1.0	64.2^{a}	0.16	0.38	0.5
10	29.5^{cd}	0.27	0.08	0.5	60.8^{bc}	0.06	0.19	0.5
11	31.7^{ab}	0.33	0.10	2.6	62.5^{ab}	0.13	0.21	2.8
12	30.3^{bc}	0.40	0.12	2.4	60.8^{bc}	0.46	0.28	3.2

* Treatment details in Table 3.

\+ Means with the same letter in the same column are not significantly different at P = 0.05.

Table 8. Yield and concentrations of P, Cd, and F in rape grown in a loam soil as affected by rates and sources of P fertilizer varying in Cd concentrations (first year)

Treatment	Grain				Straw			
	Yield g/pot	P %	Cd – mg/kg –	F	Yield g/pot	P %	Cd – mg/kg –	F
1*	23.9^{c}	0.66	0.20	1.2	80.3^{c}	0.03	0.68	1.4
2	24.2^{c}	0.69	1.70	0.5	80.3^{c}	0.03	5.70	1.0
3	26.1^{abc}	0.66	7.80	0.5	82.9^{bc}	0.04	38.00	1.2
4	25.4^{bc}	0.64	0.20	0.5	81.9^{c}	0.07	0.71	0.5
5	26.0^{abc}	0.72	0.20	0.5	88.7^{ab}	0.11	0.58	0.5
6	25.4^{bc}	0.80	0.17	0.5	86.6^{abc}	0.09	0.50	0.5
7	24.5^{c}	0.73	0.18	0.5	81.8^{c}	0.04	0.58	0.5
8	28.7^{a}	0.81	0.20	0.5	91.8^{a}	0.05	0.59	0.5
9	28.0^{ab}	0.71	0.28	0.5	92.2^{a}	0.06	0.55	1.0
10	25.7^{bc}	0.73	0.21	0.5	84.0^{bc}	0.04	0.57	0.5
11	26.1^{abc}	0.80	0.24	0.5	86.6^{abc}	0.08	0.79	0.5
12	26.7^{abc}	0.78	0.28	0.5	86.7^{abc}	0.12	0.82	0.5

* Treatment details in Table 3.

\+ Means with the same letter in the same column are not significantly different at P = 0.05.

Table 9. Yield and concentrations of P, Cd and F in rape grown in a peat soil as affected by rates and sources of P fertilizer varying in Cd concentrations

Treatment	First year								Second year			
	Grain				Straw				Straw			
	Yield g/pot	P %	Cd – mg/kg –	F	Yield g/pot	P %	Cd – mg/kg –	F	Yield g/pot	P %	Cd – mg/kg –	F
1*	15.4^{ab+}	0.41	0.08	0.5	65.0^{a}	0.02	0.17	0.5	24.0^{bcd}	0.31	0.35	0.5
2	18.4^{a}	0.40	3.10	0.5	68.4^{a}	0.02	15.00	0.5	26.2^{bcd}	0.25	9.00	0.5
3	8.7^{c}	0.53	58.00	0.5	43.3^{cd}	0.11	98.00	31.0	33.1^{a}	0.18	95.00	34.0
4	2.1^{de}	0.64	0.58	0.0	48.5^{bc}	0.08	1.70	0.5	20.6^{cde}	0.39	1.70	0.5
5	5.1^{cd}	0.94	0.23	0.0	65.0^{a}	0.18	0.35	0.5	19.0^{de}	0.39	0.68	4.0
6	8.4^{c}	0.88	0.14	0.2	68.0^{a}	0.23	0.23	1.6	28.7^{ab}	0.41	0.25	0.5
7	3.7^{de}	0.50	0.20	0.0	54.0^{b}	0.07	0.66	0.5	16.0^{e}	0.37	0.48	0.5
8	12.6^{b}	0.82	- ++	0.5	64.5^{a}	0.11	0.68	0.5	25.8^{bcd}	0.40	0.53	4.0
9	13.8^{b}	0.82	0.06	0.5	67.7^{a}	0.16	0.70	0.5	23.1^{bdd}	0.48	0.67	7.0
10	1.8^{de}	0.89	0.13	0.0	40.0^{d}	0.27	0.43	0.5	22.7^{bcde}	0.39	0.34	2.0
11	0.8^{e}	0.94	0.13	0.0	48.9^{bc}	0.36	0.51	0.5	19.3^{cde}	0.61	0.51	9.0
12	1.0^{c}	0.90	0.17	0.0	50.0^{bc}	0.39	0.68	3.2	21.4^{cde}	0.66	0.58	9.0

*Treatment details in Table 2.
+ Means with the same letter in the same column are not significantly different at P = 0.05.
++ Sample was contaminated.

Table 10. Yield and concentrations of P, Cd and F in rape grown in a loam soil as affected by rates and sources of P fertilizer varying in cd concentrations (second year)

Treatment	Grain				Straw			
	Yield g/pot	P %	Cd – mg/kg –	F	Yield g/pot	P %	Cd – mg/kg –	F
1*	9.2^{ab+}	0.76	0.13	++	37.1^{ab}	0.09	0.35	0.5
2	8.9^{ab}	0.78	1.10	1.2	40.5^{a}	0.07	4.4	0.5
3	8.1^{ab}	0.83	5.00	0.5	37.9^{ab}	0.10	22.6	1.0
4	9.1^{ab}	0.82	0.26	0.5	38.4^{ab}	0.09	0.46	0.5
5	9.2^{ab}	0.83	0.16	0.5	37.4^{ab}	0.09	0.41	0.5
6	6.7^{ab}	0.82	0.14	0.5	31.7^{ab}	0.11	0.21	0.5
7	9.9^{a}	0.83	0.17	0.5	38.8^{ab}	0.08	0.20	0.5
8	5.1^{b}	0.81	0.19	0.5	24.0^{b}	0.13	0.23	0.5
9	10.0^{a}	0.83	0.15	0.5	39.6^{ab}	0.10	0.29	0.5
10	8.5^{ab}	0.82	0.16	0.5	38.7^{ab}	0.11	0.27	1.0
11	9.8^{ab}	0.83	0.21	0.5	38.5^{ab}	0.14	0.71	1.0
12	6.2^{ab}	0.85	0.21	0.5	28.3^{ab}	0.21	0.74	2.0

*Treatment details in Table 3
+ Means with the same letter in the same column are not significantly different at P = 0.05.
++ Sample was contaminated.

exception of the highest rate of NaF, there was no effect of the applied F, either through NaF or through P fertilizers on the F content of rape.

Rape (second year)

Although the yield in the loam soil decreased to less than half of that obtained in the first year, there was no response to previously applied P. The trends in the concentrations of P, Cd, and F were very much similar to those obtained in the first year. Cadmium concentration was slightly lower in the second year (Table 10).

In the peat soil, flowering and seed formation was very poor due to a soil-borne disease and there was almost no grain yield. Only the straw yield and the concentrations of P, Cd, and F are presented in Table 9. The effect of rates and sources of P on the concentrations was very much the same as was observed in the first year apart from the concentrations being higher in the second year probably as a result of lower yield and no translocation to the grain.

DISCUSSION

The results show that the Cd concentration in the grain and straw of both oats and rape grown either in loam or in peat soils tended to increase with increasing rates of high Cd NPK and SSP and the increase was more marked in the peat soil than in the loam. For example, Cd in oat grain in the peat soil increased from 0.08 to 0.21 mg kg^{-1} when 180 mg P kg^{-1} soil was applied. The corresponding values in the loam soil were 0.29 to 0.34 mg kg^{-1}. Similarly, there was little change in the Cd concentration of straw in the loam soil, but in the peat soil it increased from 0.25 to 0.40 mg kg^{-1}. Although the increase was small in most cases, it was consistent and suggests that the P fertilization, especially at high rates, may lead to an increased uptake of Cd by crops. The results corroborate those from some earlier investigations (Sorteberg 1974; Bærug and Martinsen 1977; Andersson and Hahlin 1981; Mortvedt et al. 1981; Dam Kofoed and Søndergård-Klausen 1983) which showed that application of Cd in fertilizers sometimes, but not always, increases Cd in crops.

Cadmium concentration in the grain and straw of oats and rape grown especially in the loam soil was many times higher than that reported from field experiments by others in oats (Bærug and Singh 1987), barley (Andersson and Hahlin 1981), and wheat (Mortvedt et al. 1981). The loam soil was collected from a long term fertilized field and hence Cd accumulated in the soil may have contributed to higher concentrations in the crops. It is also observed that the plants grown in pots often contain higher levels of nutrients than those grown in the open fields. Although the trends in the Cd concentration in both crops in the second year were similar to those in the first year, the concentrations generally decreased in the second year, as was also found by Mortvedt et al. (1981).

Grain generally contained lower Cd than straw in both crops but the differences were more marked in rape. On average, the Cd content of grain was 30 % that of straw. The corresponding value for oats was 67 % in the loam and 47 % in the peat soil. The results indicate that a higher percentage of Cd taken by oats was translocated to the grain while in rape it was retained in the vegetative parts.

Although the Cd applied through SSP was about half of that applied through high Cd NPK fertilizer, its concentration in both crops was consistently higher in the SSP-treated pots. This suggests that factors other than the applied Cd have influenced the Cd uptake by plants. The SSP applied contained 12.2 % S and is known to have a slight acidifying action. It is well documented that the solubility and availability of Cd increases as pH decreases. The acidifying effect of SSP may have caused the higher Cd concentrations in both crops in this study. Similar results were obtained by Poletschny and Kick (1981) when they found that greater amounts of Cd were taken up by plants when fertilized with super- and hyperphosphate compared with Thomas phosphate.

The two crops investigated showed a similar trend in Cd uptake except that rape contained higher levels of Cd in the vegetative parts than

oats. The differences in the Cd content of the grain and straw of both crops caused by increased P application through different P fertilizers were more marked in the peat soil than in the loam, probably attributable to more acidity development caused by the decomposition of organic matter in the former soil under greenhouse conditions.

The slight change in F content of oats and rape caused by the application of P fertilizers supports the observations by others that soil is not an important source of F uptake for most plants (Brewer 1966; Sidhu 1976; Braen and Weinstein 1985). With the exception in oats in the first year and rape in the NaF-treated pots, F concentrations were generally low and were within the range considered to be normal (2 to 20 mg kg^{-1}) for most plant foliage growing in non-polluted areas (Brewer 1966). Lower concentrations in oats in the second year may have resulted from increased F fixation by the soils over a longer period. As pointed out by Hurd-Karrer (1950) since the amount of F taken up from the soil by plants is usually unrelated to the F content of the soil, it is difficult to assign any specific reason to the variations in the F content of oats and rape observed in this study.

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Cadmium levels in soils and crops after long-term use of commercial fertilizers

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In order to determine whether the long-term use of commercial fertilizers has resulted in an accumulation of Cd in soils and crops, samples of soils and plants were collected from newly cleared (new) and old cultivated (old) lands located in southeastern Norway, Rogaland/Agder, and Trøndelag (referred to as N. Trøndelag in the subsequent text). These were analysed for Cd and P. Corresponding samples of soils and plants were taken from the new and old soils of 57 farms in southeastern Norway, 18 farms in Rogaland/Agder and 20 farms in N. Trøndelag. The crop species in the old and new lands on each farm were the same, but they differed among farms, regions and counties. The soil samples were also analysed for pH and organic C.

The results show that the total Cd was higher in the old soils than in the new soils in all the regions. The differences between old and new soils were significant in two of the three regions. Rogaland/Agder had the highest content of Cd in mineral soils, but the smallest difference between old and new soils. N. Trøndelag, on the other hand, had the lowest Cd in mineral soils, but the largest difference between old and new soils. In all the regions, considerable variations in the Cd content of soils from both the old and the new fields were observed. P-AL was generally much higher in the old than in the new soils. With some exceptions the pH values were also higher in the old than in the new soils, but there were only slight differences in Rogaland/Agder.

The cadmium content of plants was generally lower in the old cultivated fields than in the newly cultivated fields in all the regions, but the differences were found to be significant only in southeastern Norway and N. Trøndelag. On average, the Cd content in plants was highest in Rogaland/Agder and lowest in N. Trøndelag. Ryegrass from Rogaland/Agder contained nearly ten times more Cd than timothy from N. Trøndelag. Some negative correlations between plant Cd and soil pH and negative correlations between soil Cd and plant Cd were observed, but the correlations were not consistent in all the soils and in all the regions.

It can be concluded from these results that although the long-term use of fertilizers increased the Cd levels in the soil, it did not necessarily result in a higher uptake of Cd in the plants. On the contrary, the results show that Cd in the plants was as high, or even significantly higher, in samples from the newly cultivated fields as compared with those from the fields fertilized over many decades. Factors such as soil parameters and atmospheric input of Cd, which may have influenced the results, are briefly discussed.

Key words: Cadmium, grain crops, grass, phosphate fertilizers, potato, regions.

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The occurrence of Cd as a component of sedimentary and eruptive rock phosphates used for the manufacture of commercial fertilizers has been recognized for many years (Swaine 1962, Simonsen 1975, Andersson 1977, Jung et al. 1979).

Cadmium accumulation in soils as a result of fertilization has been reported in several investigations. Mulla et al. (1980) found that the concentration of Cd in surface soils was highly correlated with the concentration of total P. The concentration of Cd in surface soil treated with brodcast P for 36 years averaged 1 mg Cd kg^{-1} as compared with to 0.07 mg kg^{-1} in the control. Dam Kofoed & Söndergård Klausen (1983) found a yearly increase of 0.25 % in Cd in soils fertilized over a period of 80 years. Andersson (1984) reported an annual increase in Cd in Swedish soils of 0.3–0.4 % based on an input of 1.9 g Cd ha^{-1} $year^{-1}$ from fertilizers and other sources, and a corresponding loss of 0.9 g Cd ha^{-1} $year^{-1}$.

Earlier investigations have shown that the use of commercial fertilizers containing Cd often, but not always, increased the Cd content in crops. Sorteberg (1974), Mulla et al. (1980), Andersson & Hahlin (1981) and Singh (1990) found increased contents of Cd in the crops after application of Cd to the soil in fertilizers or pure salts. Kjellstrøm et al. (1975) and Vigerust & Selmer-Olsen (1985) reported increased Cd in some crops, but not in others. Bærug & Martinsen (1977), Jung et al. (1979) and Smilde & Van Luit (1983) all found only slight or no influence of sludge or fertilizers on the Cd content of crops.

Commercial fertilizers containing Cd have been used in Norway for more than 100 years. In the first 60 years the amounts were small, but since 1950 the rates have increased rapidly until a maximum was reached in 1980. Rock phosphates used for manufacturing the commercial fertilizers in Norway have mostly been Kola apatite and other rock phosphates which are very low in Cd (Kaarstad & Steen 1980). It is possible, however, that other rock phosphates with a higher content of Cd may be used in the future when the present reserves of low Cd rock phosphate are exhausted.

In order to test whether the long-term use of commercial fertilizers has influenced the content of Cd in soils and crops, investigations were carried out in southeastern Norway (Østfold, Vestfold, Akershus, Hedmark and Oppland counties) in 1983, and in central Norway (N. Trøndelag county) and southwestern Norway (Rogaland/Agder counties) in 1986.

MATERIALS AND METHODS

Soil and plant samples were collected from different farms in the three regions. Locations of the sampling sites are shown in Fig. 1. The collection of soil and plant samples was carried out in pairs from old cultivated (> 30 years) and newly cultivated (< 4 years) fields located near each other in order to avoid wide soil variation. In Rogaland/Agder counties, the newly cultivated soil was cleared in the year of sampling. The levels of fertilization in the sampled fields were those commonly used in the respective districts.

Sampling in the counties of southeastern Norway was carried out during the 1983 cropping season, and in those of southwestern and central Norway in the 1986 cropping season. The number of farms sampled, crops and main soil groups are presented in Table 1. All the sites were sampled from 0 to 20 cm depths. In Rogaland/Agder, samples were also collected from 30 cm depths.

Plant samples of oats and potatoes were collected at maturity, whereas those of grass and a few additional samples of oats were sampled at the heading growth stage. All plant samples except potato tubers were dried at 70°C and ground before analysis. The soil samples were dried at 100°C, crushed and passed through a 2 mm sieve. Cadmium in the soils was extracted by conc. HNO_3 according to the method of Øien & Gjerdingen (1977). Cadmium in the extract was determined by atomic absorption spectrophotometry using a graphite oven.

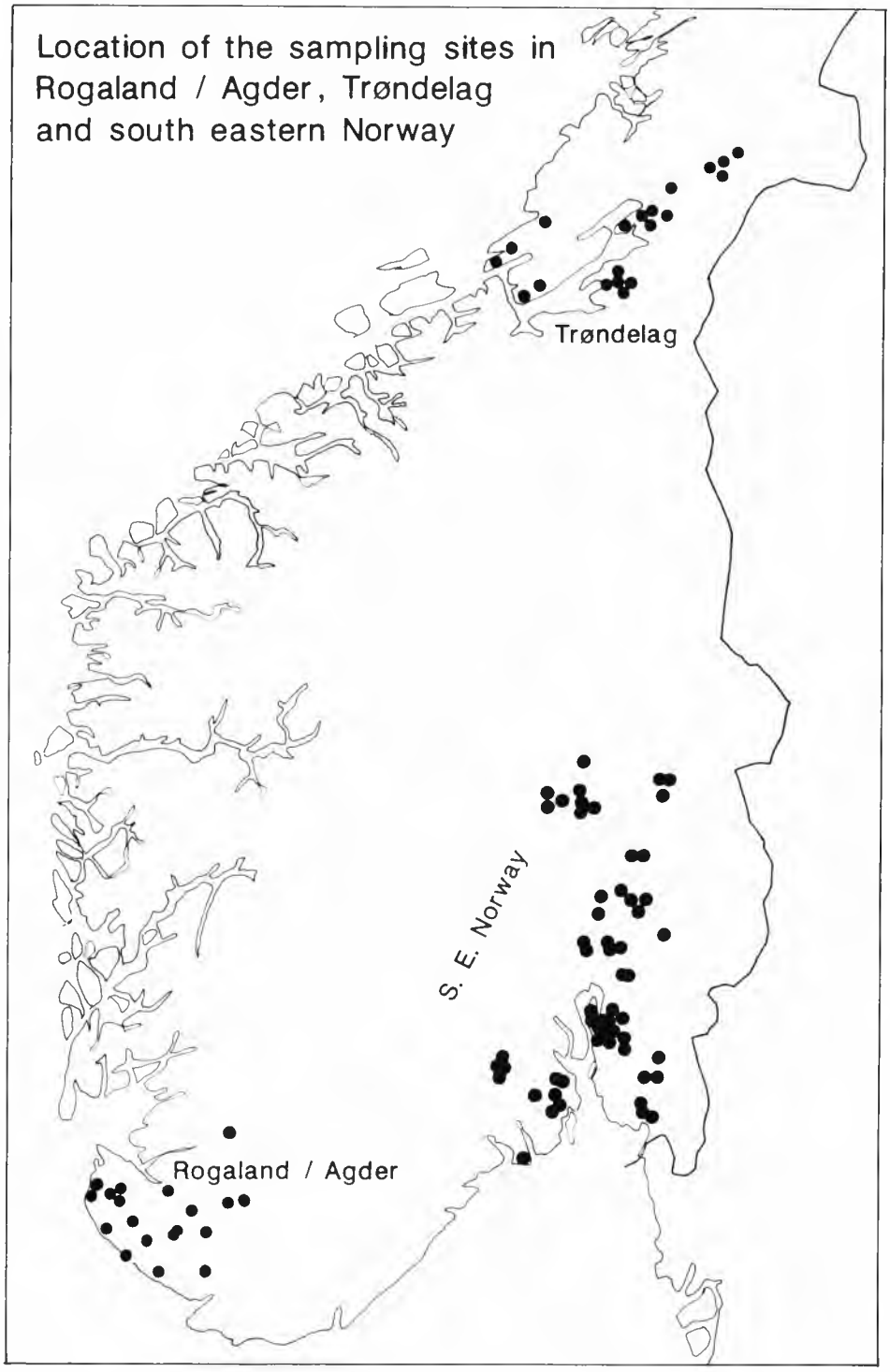
Location of the sampling sites in
Rogaland / Agder, Trøndelag
and south eastern Norway
Trøndelag
S. E. Norway
Rogaland / Agder

Table 1. Number of farms, crops and soils sampled in different regions

Regions	No. of farms	Crops sampled	No. of soils	
			Mineral	Peat
Southeast. Norway	57	Oats, grass[1]) potatoes	57	–
Southwest Norway	18	Grass[2])	14	4
Central Norway	20	Grass[3])	7	13

[1]) *Phleum pratense, Festuca pratensis, Dactylis glomerate (one sampling).*
[2]) *Lolium multiflorum* (two samplings).
[3]) *Phleum pratense* (one sampling).

Table 2. Cadmium concentration (mg kg^{-1}) in soils collected from old and newly cultivated fields

Region/ county	Soil	Old soil			New soil			No. of fields
		Range	Mean	SD	Range	Mean	SD	
Southeastern Norway								
Akershus	M	0.025–0.120	0.061	0.030	0.009–0.078	0.046	0.024	27
Hedmark.....	»	0.017–0.061	0.036	0.015	0.017–0.043	0.031	0.010	5
Oppland	»	0.023–0.110	0.058	0.022	0.023–0.067	0.046	0.017	8
Vestfold	»	0.034–0.089	0.050	0.018	0.030–0.130	0.052	0.028	11
Østfold.....	»	0.028–0.130	0.058	0.022	0.010–0.078	0.033	0.010	6
All.....	»	0.017–0.130	0.057a)	0.03	0.009–0.130	0.044b)	0.057	57
Rogaland/ Agder								
	M	0.020–0.180	0.072a)	0.041	0.030–0.080	0.052a)	0.041	14
	P	0.180–0.210	0.190a)	0.025	0.200–0.250	0.225b)	0.025	4
	All	0.020–0.210	0.098a)		0.030–0.250	0.092a)		18
	M*	0.010–0.160	0.040a)		0.010–0.080	0.031a)		14
	P*	0.050–0.160	0.130a)		0.040–0.170	0.115a)		4
	All*	0.010–0.160	0.060a)		0.010–0.170	0.050a)		18
N. Trøndelag								
	M	0.0–0.100	0.044a)		0.00–0.070	0.013a)		7
	P	0.080–0.380	0.205a)		0.030–0.210	0.092b)		13
	All	0.00–0.380	0.148a)		0.00–0.210	0.064b)		20

M = Mineral
P = Peat
Means with the same letter in the same row are not significant at P = 0.05.
* = Samples from 30 cm soil depth.
SD = Standard deviation.

Available P in the soils was determined by the ammonium lactate (AL) method (Egner et al. 1960), and organic C by combustion in an EC-12 LECO-carbon analyser. The plant samples were dry-ashed at 450°C, treated with conc. HNO3, and thereafter dissolved in dilute HCl. Cadmium in the digested solution was determined by atomic absorption spectrophotometry using a graphite oven: P was determined colorimetrically by the vanado-ammonium molybdate method.

RESULTS

Cadmium in soils

The soils from the old fields were higher in Cd than those from the newly cultivated fields. The difference between old and new fields was significant in southeastern Norway and in N. Trøndelag, but not in Rogaland/Agder. In a few peat soils in Rogaland/Agder, the Cd content was found to be higher in the new fields than in old fields (Table 2).

The mineral soils from N. Trøndelag contained the lowest amounts of Cd and those from Rogaland/Agder the highest. The variation in soil Cd was large within all subgroups of old as well as new fields.

The differences in soil Cd between the counties in south-eastern Norway were generally small, except for a significantly lower content of Cd in Hedmark. In Rogaland/Agder, the highest content of Cd in the topsoil layer (0–20 cm) was found in the district of Flekkefjord and the lowest in Jæren (Table 3). The content of Cd in the soil was substantially lower at a depth of 30 cm than in the topsoil (0–20 cm).

Table 3. Cd in soils in different districts of Rogaland/Agder

District	Cd, mg kg^{-1}				No. of farm
	New	Old	New	Old	
	0 - 20 cm		30 cm		
Flekkefjord	0.153	0.135	0.057	0.082	6
Dalane	0.073	0.112	0.063	0.075	6
Jæren	0.045	0.042	0.026	0.023	6

Easily soluble P, pH and organic C in soils

The easily soluble P, as measured by the P-AL method, was significantly higher in soils from the old fields compared with those from the newly cultivated fields. This shows that the continuous use of phosphatic fertilizers and farmyard manure over many decades has substantially increased the P levels in the soils. The P levels were generally higher in the soils from Rogaland/Agder and N. Trøndelag than in those from southeastern Norway (Table 4).

The pH of the soils was low in Rogaland/Agder and low to medium in the other regions. The mineral soils in southeastern Norway and Rogaland/Agder and peat soils in N. Trøndelag from the newly cultivated soils had significantly lower pH than those from the old fields. The differences in pH were generally small (Table 5).

In southeastern Norway organic C was significantly higher in the newly cultivated fields than in the old fields, whereas inconsistent differences were found in the other regions (Table 6).

Cadmium content in the plants

In both southeastern Norway and Rogaland/Agder, plants grown in newly cultivated fields contained significantly more Cd than those grown in old fields. The trend was the same for all the crops tested, except potato haulm. In N.

Table 4. P-AL (mg P 100 g^{-1}) in soils from long-term (old) and newly cultivated (new) fields

Region/ county	Soil	No. of samples	Old		New	
			Mean	SD	Mean	SD
Southeastern Norway						
Akershus	Mineral	42	10.7	5.6	5.0	3.2
Hedmark	»	5	8.1	0.7	3.9	1.9
Oppland	»	8	6.6	2.1	3.2	2.3
Vestfold	»	11	7.6	4.4	3.8	1.7
Østfold	»	6	12.1	10.5	5.6	5.7
All	»	72	9.6a)	5.7	4.6b)	3.2
Rogaland/Agder						
	Mineral	14	15,8a)	13.2	5.6b)	7.6
	»	*14	8.9a)	7.4	3.0b)	6.0
	Peat/Bog	4	9.5a)	7.3	12.1a)	7.2
	»	* 4	4.8a)	5.5	1.7a)	0.5
N.Trøndelag						
	Mineral	7	14.3a)	6.9	5.8b)	4.7
	Peat/Bog	13	15.7a)	7.2	9.7b)	5.9

SD: Standard deviation.
Means with the same letter in the same row are not significantly different at P = 0.05.
* Samples collected from 30 cm soil depth.

Table 5. The pH (H2O) in soils from long-term and newly cultivated fields

District/ county	Soil	No. of samples	Old		New	
			Mean	SD	Mean	SD
Southeastern Norway						
Akershus	Mineral	42	6.0	0.4	5.5	0.7
Hedmark	»	5	6.0	0.4	5.3	0.3
Oppland	»	8	5.7	0.4	5.3	0.5
Vestfold	»	11	5.8	0.6	5.6	0.7
Østfold	»	6	6.1	0.6	5.7	0.7
All	»	72	5.9a)		5.5b)	
Rogaland/Agder						
	Mineral	14	5.6a)	1.0	5.5 a)	0.8
	»	*14	5.6a)	1.0	5.2b)	0.8
	Peat/Bog	4	4.5a)	0.4	4.8a)	0.4
	»	* 4	4.3a)	0.5	4.1a)	0.6
N.Trøndelag						
	Mineral	7	6.0a)	0.3	6.3a)	0.7
	Peat/Bog	13	5.8a)	0.5	5.4b)	0.6

Legends: See Table 4.

Table 6. Organic carbon (%) in soils from long-term and newly cultivated fields

Region/ county	Soil	No. of samples	Old		New	
			Mean	SD	Mean	SD
Southeastern Norway						
Akershus	Mineral	42	2.6	0.6	4.7	2.9
Hedmark	»	5	2.4	1.5	6.2	6.1
Oppland	»	8	3.2	1.1	2.3	0.6
Vestfold	»	11	2.7	0.6	5.2	3.1
Østfold	»	6	4.5	3.8	6.3	4.8
All	»	72	2.8a)	1.5	4.9b)	3.6
Rogaland/Agder						
	Mineral	14	8.9a)	10.1	5.5a)	2.4
	»	*14	7.6a)	12.6	4.1a)	2.1
	Peat/Bog	4	43.6a)	12.6	46.8a)	11.6
	»	* 4	36.8a)	22.6	48.9a)	15.6
N. Trøndelag						
	Mineral	7	4.7a)	3.2	5.2a)	5.3
	Peat/Bog	13	31.9a)	14.6	35.5a)	14.2

Legends: See Table 4.

Table 7. Cadmium in plants (mg kg^{-1}) of dry matter from long-term and newly cultivated fields

Region/ county	No of samples for old and new soils	Crop	Old		New	
			Mean	SD	Mean	SD
Southeastern Norway						
«	65	All	0.028a)		0.038b)	
»	11	Grass	0.044	0.017	0.044	0.014
»	41	Grain	0.020	0.018	0.036	0.028
»	41	Straw	0.011	0.016	0.025	0.033
»	12	Oats, heading	0.032	0.035	0.055	0.031
»	11	Potato tubers	0.003		0.008	0.018
»	9	Potato haulm	0.137	0.141	0.119	0.121
Rogaland/ Agder	18	Ryegrass 1st cut	0.064a)		0.097b)	
		» 2nd »	0.045a)		0.072b)	
N.Trøndelag	20	Timothy 1st cut	0.008a)		0.007a)	

Legends: See Table 4.

Trøndelag the differences between plants grown in the old and newly cultivated fields were small and non-significant. Potato haulm had the highest content of Cd and potato tubers the lowest. Grain contained more Cd than straw (Table 7). There was a marked difference in the Cd content of ryegrass in Rogaland/Agder and that of timothy in N. Trøndelag. The differences in the Cd content among crops were largly attributable to species and field variations.

Effects of soil Cd, soil pH and easily soluble P (P-AL) on the Cd contents of plants

In two of the three regions soil pH was negatively correlated to Cd in the plants. However, soil pH was less attributable to the variation in Cd in the newly cultivated fields than in the old fields. The relationship between soil pH and plant Cd was generally better in the mineral soils than in the peat soils (Table 8).

Cadmium in the plants in two of the three regions was positively correlated to total Cd in soils from the old fields, whereas the relationship was weaker in soils from the new fields. The soil P (P-AL) showed no correlation with the plant Cd in any of the regions.

DISCUSSION

An important question relating to the modern, high yielding agriculture systems is how to minimize the supply of Cd to the soil. At the same

Table 8. Regression equations relating plant Cd to soil Cd and soil pH in different regions

Field type	Plant Cd – soil Cd	Plant Cd – soil pH
	Southeastern Norway	
Old	$y = 0.18 + 0.26\ x$	$y = 0.18 - 0.028\ x$
	($r^2 = 0.08$ ns)	($r^2 = 0.08$ **)
New	$y = 0.0064 + 0.132\ x$	$y = 0.064 - 0.006\ x$
	($r^2 = 0.01$ ns)	($r^2 = 0.01$ ns)
	Rogaland/Agder	
Old	$y = 0.028 + 1.29\ x$	$y = 6.34 - 17.38\ x$
	($r^2 = 0.33$*)	($r^2 = 0.30$*)
New	$y = 0.066 + 0.29\ x$	$y = 5.85 - 5.22\ x$
	($r^2 = 0.02$ ns)	($r^2 = 0.06$ ns)
	Rogaland/Agder + Trøndelag	
Old (Min.)	$y = 0.37 + 0.75\ x$	$y = 6.17 - 11.89\ x$
	($r^2 = 0.21$*)	($r^2 = 0.19$*)
Old (Peat)	$y = 0.202 + 0.05\ x$	$y = 5.84 - 14.79\ x$
	($r^2 = 0.001$ ns)	($r^2 = 0.50$**)
New (Min.)	$y = 0.018 + 0.35\ x$	$y = 6.26 - 7.62\ x$
	($r^2 = 0.36$**)	($r^2 = 0.19$*)
New (Peat)	$y = 0.089 + 1.30\ x$	$y = 5.45 - 6.35\ x$
	($r^2 = 0.54$***)	($r^2 = 0.20$ ns)

***, **, * = Significant at
P = 0.001, 0.01, and 0.05 respectively.
ns = Not significant.

time it is also of interest to know what happens to Cd already supplied to the soil through commercial fertilizers or manure.

The results of the investigations reported here show that the application of fertilizers over many decades increased the Cd levels in the upper layers of the soil. The differences between old and newly cultivated soils were calculated to be 33, 15 and 75 g Cd ha^{-1} for southeastern Norway, Rogaland/Agder and N. Trøndelag, respectively. Evidently the average supply has been greater than the average loss of Cd as a results of leaching and removal in the crop. The content of Cd in the old mineral soils from Rogaland/Agder was nearly 25 and 60% higher than in those from southeastern Norway and N. Trøndelag, respectively.

During the period 1945–85, the Cd supply in commercial fertilizers in Norway varied from 0.2 to 1.5 g Cd ha^{-1}, except for two years with higher levels (Kaarstad & Steen 1980). According to Allen & Steinnes (1979) and Steinnes (1980), the contamination of Cd from atmospheric transport can be as high as 3 g Cd ha^{-1} in southwest Norway, decreasing to 1/5–1/10 of this level in the central and northern parts of the country. The differences in the soil and plant Cd between the counties could therefore be attributed partly to the differences in atmospheric input of Cd.

The Cd content of the soils before the phosphatic fertilizers came into use is not known, and so the changes over time cannot easily be calculated. A comparison between the soil Cd levels in the old and newly cleared fields could, however, give an indication of changes over time. Assuming an average addition of 1.0 g Cd ha^{-1} y^{-1}, and crop removal plus leaching losses of 0.2 g ha^{-1} y^{-1}, the net addition of Cd works out to be 0.8 g ha^{-1} y^{-1}. In southeastern Norway the difference between old and newly cultivated fields was 33 g Cd ha^{-1}. This corresponds well with an accumulation in old fields of 0.8 g Cd ha^{-1} y^{-1} over a period of about 40 years. The relationship was less clear in Rogaland/Agder and N. Trøndelag.

While the results strongly indicate that Cd accumulates in the soils after the long-term use of commercial fertilizers and manure, the Cd concentration in almost all the plant species tested in these investigations was higher in the plants grown in the newly cultivated fields than in old fields. A low soil pH is known to increase Cd uptake (Sorteberg 1974, Andersson & Nilsson 1976, Williams & David 1976, Smilde and van Luit 1983, Vigerust & Selmer-Olsen 1985). In our investigations, lower pH in the new fields than in the old fields was observed in southeastern Norway. The same was true of the peat soils in N. Trøndelag, but the differences in pH between old and new fields were relatively small in Rogaland/Agder. Although a general negative correlation was found between Cd in plants and soil pH, the differences in soil pH could only partly explain the results for Cd in the plants. Large variations in other soil properties, for example organic matter, extractable P or the clay content, may have contributed to a poor relationship. It is also known that the Cd extracted by HNO_3 is not a reliable index of plant available Cd in the soil.

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The authors thank Norsk Hydro for financial support in conducting these investigations and Drs Å. Håland and K. Myhr for supplying soils and plant samples from Rogaland/Agder and N. Trøndelag, respectively. The comments on atmospheric deposition of Cd from Dr E. Steinnes are highly appreciated.

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Spiders in Norwegian spring barley fields and the effects of two insecticides

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During May-July 1988 a total of 3873 spiders were caught in pitfall traps in ten Norwegian spring barley fields. Peak activity for most species occurred in June. Linyphiidae, subfamily Erigoninae (73.2 % of the total catch), Linyphiidae, subfamily Linyphiinae (14.5 %) and Lycosidae (11.6 %) were the dominant groups. The linyphiid species *Oedothorax apicatus* (Blackwall), *Erigone atra* (Blackwall), *E. dentipalpis* (Wider) and *Meioneta rurestris* (C.L. Koch) together with four *Pardosa* species comprised a mean of 87.9 % of the catch in each field. Fenvalerate sprayed at the beginning of June reduced spider activity for six weeks. Pirimicarb had much less effect on the spiders, reducing the activity of only *O. apicatus*.

Key words: Aphids, Araneae, fenvalerate, insecticides, pirimicarb, pitfall traps, *Rhopalosiphum padi*, spiders, spring barley.

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Spiders are polyphagous predators which prey on several other arthropod groups. They feed on important pest species like the cereal aphids *Sitobion avenae* Fabr., *Rhopalosiphum padi* L. and *Metopolophium dirhodum* Walker (Vickerman & Sunderland 1975, Nyffeler & Benz 1982). Predation has been estimated as reaching 31 aphids eaten per m^2 in July (Sunderland et al. 1986). It is especially important that, unlike the aphid-specific predators such as coccinellids, spiders and other polyphagous predators are present during the aphid pre-peak period, thus eating and reducing them in their important build-up phase. Cultural practices, for instance pesticide treatments, often have a negative effect on the spiders (Luczak 1979, Basedow 1985, Powell et al. 1985, Krause 1987).

Few investigations have been carried out on spiders in cereals in Scandinavia. Raatikainen & Huhta (1968) and Huhta & Raatikainen (1974) reported on the species composition in oats and winter cereals in Finland in sweep-net samples, Roesgaard & Lindhardt (1979) studied the effects of straw-burning on the spiders, and Toft (1989) investigated the spider fauna in two barley fields in Denmark. The other Scandinavian investigations treat spiders as a group and investigate their importance as aphid predators (Chiverton 1982, Ekbom & Wiktelius 1985, Chiverton 1986, Helenius 1990) and the effects of using different insecticides (Nilsson 1980, Ekbom 1985). The present investigation reports on the species composition of spiders caught in pitfall traps in ten Norwegian spring barley

Table 1. Descriptions of the ten fields

Field number	Location	Barley cultivar	Size (ha)	Number of traps	Trapping period	% stems with aphids 15/6	1/7	Insecticide
1	Ås, Akershus	Bamse	5.0	5	5/5-25/7			None
		Bamse	7.0	7	5/5-25/7			8/6: Fenvalerate
						See figure 7		
2	Ski, Akershus	Bamse	5.5	10	4/5-25/7			None
		Bamse	5.5	10	4/5-25/7			7/6: Pirimicarb
		Bamse	3.4	10	4/5-25/7			7/6: Fenvalerate
3	Ås, Akershus	Ida	2.0	5	29/5- 8/8	100[1])	50	None
		Bamse	3.2	5	13/5- 5/8	100[1])	94	None
4	Vinstra, Oppland	Pernilla	1.7	5	16/5-18/7	?	?	None
5	Hokksund, Buskerud	Pernilla	3.8	5	10/5-11/7	100	10	15/6: Pirimicarb
6	Gvarv, Telemark	Several	1.2	5	20/5-15/7	79	90	None
7	Øyestad, Aust-Agder	Bamse	2.2	5	13/5-11/7	90	44	3/6 & 23/6: Dimethoate
8	Bygland, Aust-Agder	Bamse	1.0	5	30/5-20/7	9	26[2])	6/6: Fenvalerate
9	Melhus, Sør-Trøndelag	Gunilla	1.0	5	27/5-13/7	0	0	None
10	Mære, Nord-Trøndelag	Gunilla	1.6	5	18/5-15/7	0	0	None

[1]) 22/6
[2]) 14/7

fields and the effects of the insecticides pirimicarb and fenvalerate.

MATERIALS AND METHODS

Locations of the ten experimental fields are shown in Figure 1. The trapping was carried out in May – July 1988. Data for each field are given in Table 1. The pitfall traps (diameter 92 mm, depth 38 mm), containing water and some detergent, were emptied once (fields 4–10) or twice (fields 1–3) a week. In fields 1 and 2 the traps were placed more than 25 m apart and not less than 40 m from the field edge. In fields 3–10 the trapping was done for surveying only, and traps were placed 10 m apart (40 m apart in field 3) and not less than 20 m from the field edge. A total of 3873 spiders belonging to 78 species in 10 families were identified.

Only a rough count of aphid populations was made as the main aim of this study was to investigate the effect of insecticides on the spiders. The aphid infestations were measured on

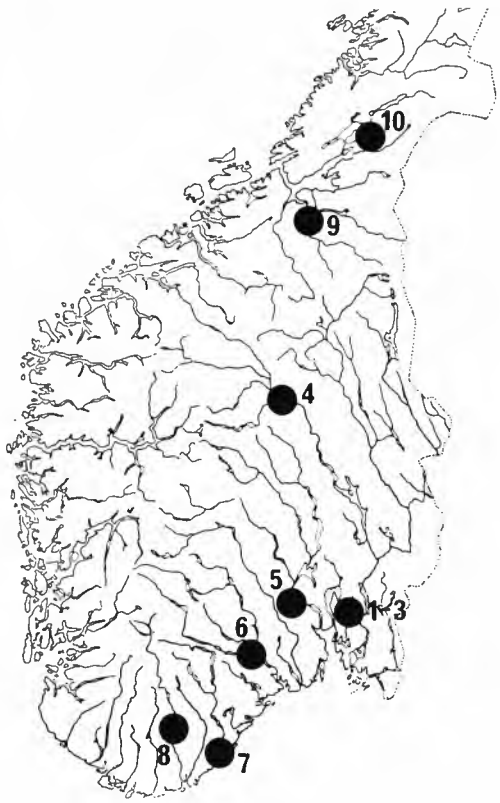

Figure 1. Locations of the ten fields in southern and central Norway.

15 June and 1 July in fields 3 and 5–10; in fields 1–2 they were measured weekly from the end of May to the end of July. On each date five tillers were taken randomly from each of 20 stations along a diagonal line in the field/plot. Each tiller was recorded as being with or without aphids. The aphids from fields 1–3 were all identified as *R. padi*. In the other fields the aphids were not identified to species, but the majority belonged to *R. padi* since this was the only cereal aphid which occurred in large numbers in Norway that year. *R. padi* was present in field 4 (personal observation), but was not counted.

Field 1 was divided into two parts. Five hectares were left untreated and 7.0 hectares were treated with fenvalerate (50 g a.i./ha) on 8 June. Field 2 was divided into three parts. Five and a half (5.5) hectares were left untreated, 3.4 hectares were treated with fenvalerate (50 g a.i./ha), and 5.5 hectares were treated with pirimicarb (100 g a.i./ha) on 7 June.

For statistical analysis of the pitfall-trap catches the Kruskal-Wallis' test and the Wilcoxon paired-comparison test were used. The Wilcoxon two-sample test was used on the aphid counts.

RESULTS

The spider fauna

The total catches of the different species in each field are given (as numbers per 100 trap days) in Table 2, as well as the number of specimens, the number of species found per field and the number of trap days. The Linyphiidae, subfamily Erigoninae, was the dominant group, represented by 29 species and making up 73.2 % of the catch. The second and third dominant groups were Linyphiidae, subfamily Linyphiinae (15 species, 14.5 % of the catch) and Lycosidae (16 species, 11.6 % of the catch). The percentage catch in each field for the eight most dominant species in two or more fields appears in Table 3. *Erigone atra, E. dentipalpis* and *Oedothorax apicatus* were dominant in most fields, and together with *Meioneta rurestris* and four *Pardosa* species they made up 79.4–96.2 % (mean: 87.9 %) of all specimens caught in each field. Figures 2–6 show the temporal distribution of these species from the untreated fields in which they were dominant. Most species had their activity peak in June and low activity in May and July; *M. rurestris* was the exception, with more uniform activity throughout the trapping period. In most species it was mainly males that were caught (Table 3); females were predominant in *O. apicatus* catches, however.

Effects of insecticides

In at least six of the ten fields an outbreak of *R. padi* occurred in June–July (Table 1). The temporal distribution of the percentage of tillers infested with aphids in fields 1 and 2 is shown in Figure 7. The treatments with insecticides had a

Table 2. Mean number of specimens per 100 trap days for spiders caught in spring barley fields in 1988. r < *0.1*

Species/Field number	1	2	3	4	5	6	7	8	9	10
Fam. Gnaphosidae										
Drassodes pubescens(Thorell)				0.3						
Haplodrassus signifer (C.L. Koch)			0.1							
Micaria nivosa (L. Koch)		0.2			0.3					
Zelotes lutetianus (C.L. Koch)		r								
Fam. Clubionidae										
Agroeca proxima (O.P.-Cambridge)			0.1							
Clubiona compta C.L. Koch								0.4		
C. pallidula (Clerck)							0.3			
Phrurolithus festivus (C.L. Koch)		0.1								
Fam. Thomisidae										
Xysticus ulmi (Hahn)			0.2							
Fam. Salticidae										
Bianor aenescens (Simon)			0.1							
Heliophanus flavipes C.L. Koch		0.1	0.1							
Fam. Lycosidae										
Alopecosa pulverulenta (Clerck)	0.1	0.1					0.3			
A. trabalis (Clerck)					1.0					
Pardosa agrestis (Westring)	0.3		0.1							
P. agricola (Thorell)	6.3	0.1		1.3	2.9		1.0			
P. amentata (Clerck)	1.5	r	1.2		0.3	1.1	12.2		6.8	3.1
P. fulvipes (Collett)	1.0	0.5	0.8	1.6	1.0	1.8	0.3	4.3		
P. lugubris (Walckenaer)	0.2	0.1	0.2	1.9		0.4	1.4	0.8		
P. paludicola (Clerck)		0.1	0.5			1.1				
P. palustris (L.)	1.3	0.6	0.6	8.9	0.6	2.9	9.5	9.4	0.4	
P. pullata (Clerck)	0.7	0.5					0.3			0.3
P. riparia (C.L. Koch)		r			1.0			0.4	0.9	
P. sphagnicola (Dahl)			0.1							
P. sp.									0.9	
Pirata piraticus (Clerck)							0.3			
Trochosa ruricola (Degeer)	0.6	0.7	0.2		0.3	0.4	1.0			
T. spinipalpis (F.O.P.-Cambridge)		r								
Xerolycosa nemoralis (Westring)							0.3			
Fam. Agelenidae										
Hahnia pusilla C.L. Koch	0.1	0.1								
Fam. Theridiidae										
Robertus arundineti (O.P.-Cambridge)	0.1									
R. neglectus (O.P.-Cambridge)					0.6					
R. scoticus Jackson			0.1							
Theridion sisyphium (Clerck)			0.1							
Fam. Tetragnathidae										
Pachygnatha degeeri Sundevall	0.3									
P. listeri Sundevall		r								
Fam. Araneidae										
Araniella cucurbitina (Clerck)		r								
Fam. Linyphiidae, subfarm. Erigoninae										
Araeoncus crassiceps (Westring)		0.1								
Asthenargus paganus (Simon)				0.3						

Species/Field number	1	2	3	4	5	6	7	8	9	10
Cnephalocotes obscurus (Blackwall)		0.2								
Dicymbium nigrum (Blackwall)	0.8	0.1	0.2							
D. tibiale (Blackwall)	0.1	r								
Diplocephalus cristatus (Blackwall)			1.0							
D. latifrons (O.P.-Cambridge)	0.1		0.1							
Erigone atra (Blackwall)	11.2	6.0	31.7	23.5	1.9	3.2	0.7	1.6	6.8	13.4
E. dentipalpis (Wider)	9.6	0.8	21.2	19.4	2.3		1.0	2.7		1.7
Erigonella hiemalis (Blackwall)	0.6	0.3	0.2							
Micrargus apertus (O.P.-Cambridge)		r								
Milleriana inerrans (O.P.-Cambridge)								0.8		
Moebelia penicillata (Westring)	0.1									
Oedothorax apicatus (Blackwall)	4.1	52.8	17.5	26.3	7.1	5.4	1.0		0.4	
O. fuscus (Blackwall)		r								
O. retusus (Westring)	0.8	1.4	1.8						0.4	
O. sp.		r								
Pelecopsis parallela (Wider)								0.4		
Pocadicnemis pumila (Blackwall)		r								
Savignya frontata (Blackwall)	1.3	0.3	1.1					0.4		
Silometopus elegans (O.P.-Cambridge)	0.1									
S. reussi (Thorell)	0.1		0.2					1.2		
Tapinocyba pallens (O.P.-Cambridge)	0.1	r	0.1							
Thyreosthenius biovatus (O.P.-Cambridge)			0.2							
Tiso vagans (Blackwall)	0.1		0.1							
Troxochrus nasutus Schenkel	0.1									
Walckenaeria antica (Wider)		r								
W. cucullata (C.L. Koch)								0.4		
W. vigilax (Blackwall)		r	0.4							
Fam. Linyphiidae, Subfam. Linyphiinae										
Allomengea scopigera (Grube)		0.1								
Bathyphantes approximatus (O.P.-Cambridge)		r								
B. gracilis (Blackwall)		r	0.1							
B. nigrinus (Westring)		0.1		0.3						0.3
B. parvulus (Westring)			0.4							
Diplostyla concolor (Wider)	0.3	0.2	1.6							
Leptorhoptrum robustum (Westring)										0.3
Meioneta beata (O.P.-Cambridge)	0.1									
M. rurestris (C.L. Koch)	13.0	11.6	9.6	0.3						
Microlinyphia pusilla (Sundevall)	0.3	0.3	0.5		0.6					
Microneta viaria (Blackwall)				0.3						
Neriene chlathrata (Sundevall)		r								
Porrhomma lativela (Schenkel)	0.4	0.3	0.5							
P. pallidum Jackson		r								
P. pygmaeum (Blackwall)		r	0.1							
P. sp.					0.3					
Number of specimens	547	1935	776	266	63	45	88	58	39	56
Number of species	32	44	36	12	14	8	14	12	6	6
Number of trap days	972	2460	830	315	310	280	295	255	235	290

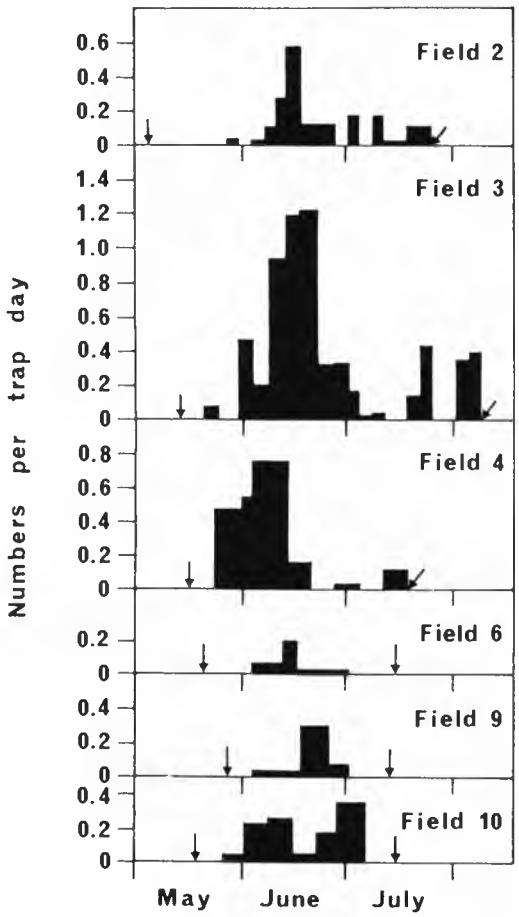

Figure 2. Pitfall-trap catches of *Erigone atra* in fields/plots not treated with insecticide. ↓ = start and end of trapping period.

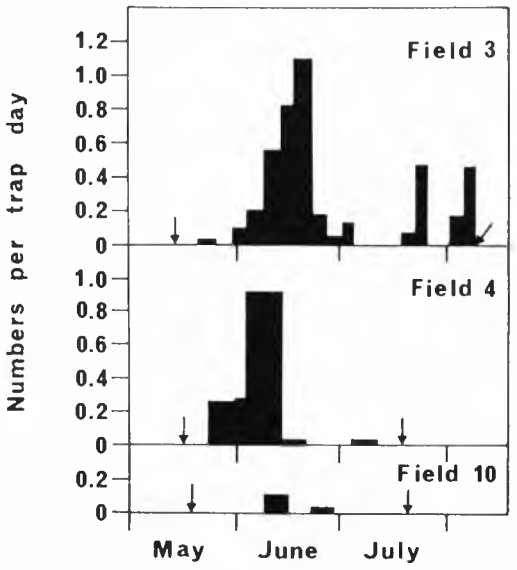

Figure 3. Pitfall-trap catches of *Erigone dentipalpis* in fields/plots not treated with insecticide.
↓ = start and end of trapping period.

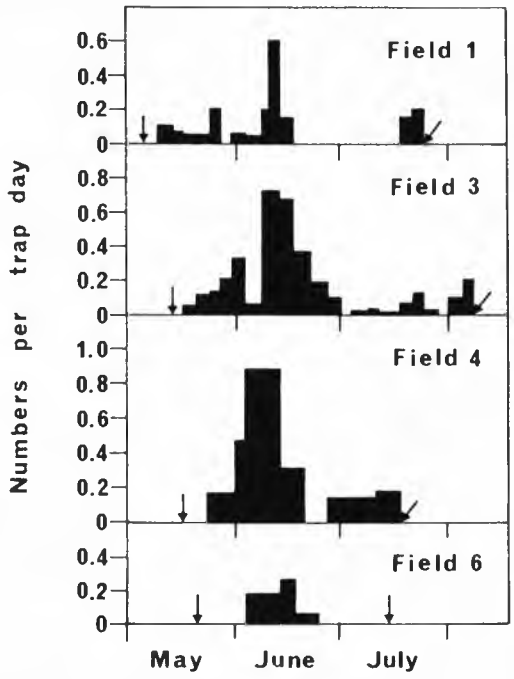

Figure 4. Pitfall-trap catches of *Oedothorax apicatus* in fields/plots not treated with insecticide.
↓ = start and end of trapping period.

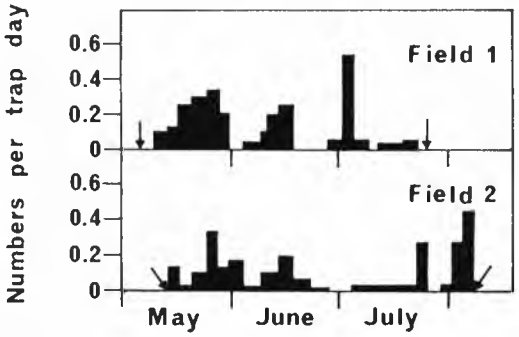

Figure 5. Pitfall-trap catches of *Meioneta rurestris* in fields/plots not treated with insecticide.
↓ = start and end of trapping period.

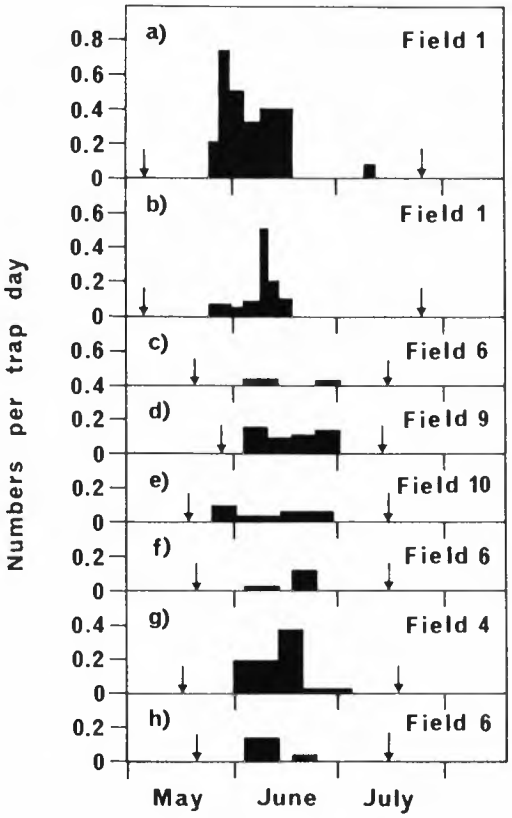

Figure 6. Pitfall-trap catches of *Pardosa* species in fields/plots not treated with insecticide. (a) *P. agricola* (b-e) *P. amentata* (f) *P. fulvipes* (g-h) *P. palustris*. ↓ = start and end of trapping period.

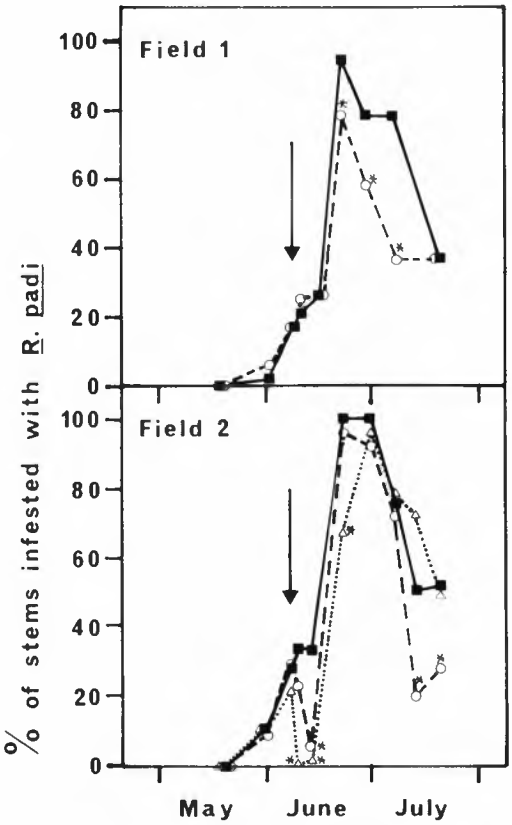

Figure 7. Aphid infestation in fields 1 and 2. * = significantly lower ($P < 0.05$) than untreated. ↓ = time of insecticide application. ■ ■ = untreated ○- - -○ = fenvalerate △.....△ = pirimicarb.

knockdown-effect in field 2 ($P<0.05$), but re-infestation occurred within 2 weeks. In field 1, there was no knockdown effect with fenvalerate. However, fenvalerate had a long-term reducing effect on the aphids in both fields.

The spiders trapped before and after insecticide treatments in fields 1 and 2 are presented in Figures 8 and 9, respectively. With the exception of *O. apicatus* in the plot treated with fenvalerate in field 2, the catches of spiders in all plots in fields 1 and 2 were not significantly different before spraying (Tables 4 and 5). In Tables 4 and 5 a few of the dominant species are treated separately. The remaining species were pooled as too small a number did not allow for separate statistical testing. The spraying with fenvalerate in field 1 reduced the two *Erigone* species for a period of five to six weeks compared with the unsprayed plot (Figure 8). In field 2, fenvalerate had a strong reducing effect on *M. rurestris*. The effect on *O. apicatus*, however, is difficult to measure, as the species' activity in this plot was low before spraying, too (Figure 9). In both fields the use of fenvalerate reduced the catch of all the remaining spider species (treated as a group), compared with the untreated plots. The treatment with pirimicarb reduced only *O. apicatus* (Table 5), while the trapping of the other species seemed to be less affected.

Table 3. Percentage catch and total number of males and females in the dominant species (>5 %) *in two or more fields*

Species/Field number	1	2	3	4	5	6	7	8	9	10	Mean	Total catch	
												Males	Females
1 *Erigone atra*	19.9	7.6	33.9	27.8	9.5	20.0	2.3	6.9	41.0	69.6	23.9	526	13
2 *Oedothorax apicatus*	7.3	67.1	18.7	31.2	34.9	33.3	3.4	–	2.6	8.9	19.9	424	591
3 *Pardosa palustris*	2.4	0.7	0.6	10.5	3.2	17.8	31.8	41.4	2.6	–	11.1	102	11
4 *P. amentata*	2.7	0.1	1.3	–	1.6	6.7	40.9	–	41.0	16.1	11.0	76	14
5 *E. dentipalpis*	17.0	1.0	22.7	22.9	11.1	–	3.4	12.1	–	8.9	9.9	307	13
6 *Meioneta rurestris*	23.0	14.8	10.3	0.4	–	–	–	–	–	–	4.9	225	22
7 *P. fulvipes*	1.8	0.6	0.9	1.9	4.8	11.1	1.1	19.0	–	–	4.1	41	1
8 *P. agricola*	11.2	0.1	–	1.5	14.3	–	3.4	–	–	–	3.1	63	5
All eight species	85.3	92.0	88.4	96.2	79.4	88.9	86.3	79.4	87.2	94.6	87.9		

DISCUSSION

The spider fauna

Pitfall traps catch spiders that are active on the soil surface. The survey was carried out in only one season, but nevertheless should be representative of the dominant spider species active on the ground in Norwegian spring barley growing areas. Linyphiidae (mainly Erigoninae) and Lycosidae were the dominant groups. This is much in accordance with the results from agricultural fields in other European countries (Geiler 1963, Sunderland 1987, Nyffeler & Benz 1988, Toft 1989). Among the linyphiidae a few species are dominant, mainly *E. atra, E. dentipalpis, O. apicatus* and *M. rurestris*. Among the lycosids the *Pardosa* species are dominant. These species are common in European agricultural fields (e.g. Sunderland 1987). Raatikainen & Huhta (1968) and Huhta & Raatikainen (1974) found other species to be dominant in oat fields in Finland, mainly by using a sweepnet to catch spiders present in the vegetation layer.

The fact that most spiders were highly active in June (Figures 2–6 and 8–9) may be partly explained by reproduction (Granström 1973, Toft 1989) and high temperatures. Males were caught in much higher numbers than females (Table 3). The only exception was *O. apicatus,* in which the catch was dominated by females. This was found by Thornhill (1983), too, for *O. apicatus* in sugarbeet fields, leading him to conclude that females of this species might be actively engaged in hunting rather than relying on webs.

The high spider activity in the first half of June is promising, as this is the important buildup phase for the aphid populations (Figure 7). This was also noted by Sunderland et al. (1985), and by Chiverton (1986), who showed a positive correlation between the numbers of polyphagous predators (including spiders) and the peak number of *R. padi.*

Effects of insecticides

The effects of insecticides on the spiders were studied in fairly large plots. Large plots were chosen in order to minimize the effects of spider immigration after spraying. The pitfall-trap

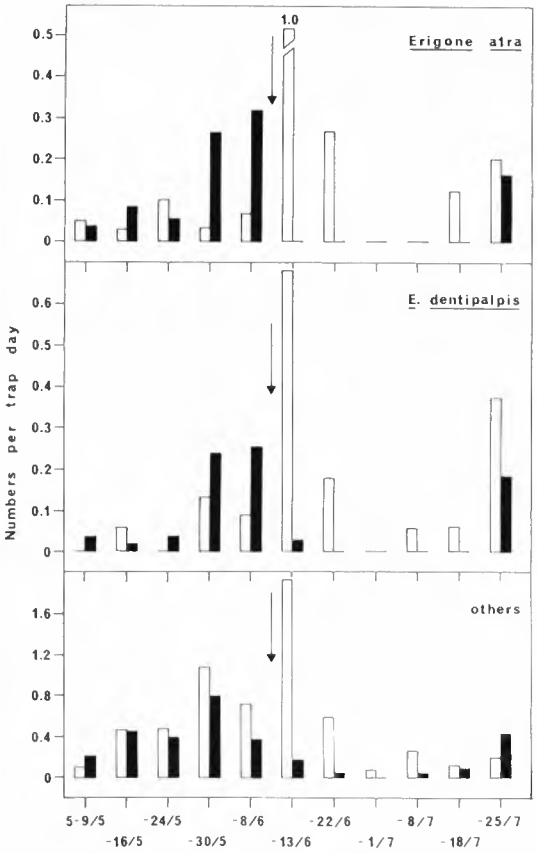

Figure 8. Pitfall trap catches of spiders in field 1 before and after treatment with fenvalerate. ↓ = time of insecticide application. □ = untreated ■ = fenvalerate.

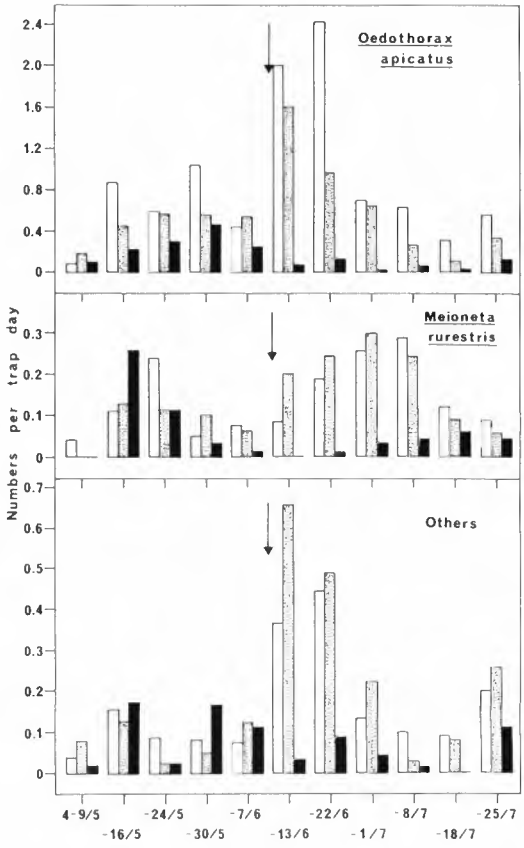

Figure 9. Pitfall-trap catches of spiders in field 2 before and after treatment with insecticides. ↓ = time of insecticide application. □ = untreated ■ = fenvalerate ▨ = pirimicarb.

catches, especially in field 1 (Figure 8), indicate that during the second half of June and the first half of July few spiders entered the treated plots. At the end of July, the numbers of trapped specimens of many species rose again in both insecticide treated and untreated plots, probably because of new immigration.

By using fenvalerate at the beginning of June the spider activity was strongly reduced for five–six weeks (Tables 4 and 5). This negative effect of fenvalerate on specific spider species has previously been indicated for spiders as a group (Nilsson 1980, Ekbom 1985). Pirimicarb, on the other hand, seemed to have much less effect on the spiders (except on *O. apicatus).* This fits in with the results of previous experiments (Nilsson 1980, Powell et al. 1985). The high activity of most species in the plot treated with pirimicarb shortly after spraying (Figure 9) might be explained by some sublethal effect of the insecticide on the spiders (Pullen 1988), or by starving specimens actively searching for food, as was shown by Chiverton (1984) for the carabid *Pterostichus melanarius.*

As spiders are beneficial in the field as pre-

Table 4. Spiders caught per five pitfall traps in field 1 before (5/5 – 8/6) and after (8/6 – 25/7) spraying. * = P <*0.05* ** = *P <0.01*.

	Before spraying		After spraying	
	Number of specimens	Sign.	Number of specimens	Sign.
Erigone atra				
Control	10	–	50	–
Fenvalerate	27.9	NS	5.7	*
E. dentipalpis				
Control	10	–	43	–
Fenvalerate	21.4	NS	6.4	**
Other spiders				
Control	101	–	99	–
Fenvalerate	75.7	NS	27.1	*

Table 5. Spiders caught in ten pitfall traps in field 2 before (4/5 – 7/6) and after (7/6 – 25/7) spraying. ** = P <*0.01* *** = *P <0.001*.

	Before spraying		After spraying	
	Number of specimens	Sign.	Number of specimens	Sign.
Oedothorax apicatus				
Control	222	–	514	–
Pirimicarb	140	NS	299	***
Fenvalerate	89	**	34	***
Meioneta rurestris				
Control	38	–	83	–
Pirimicarb	29	NS	91	NS
Fenvalerate	30	NS	16	***
Other spiders				
Control	31	–	104	–
Pirimicarb	28	NS	131	NS
Fenvalerate	34	NS	23	***

dators of pest insects, the present investigation suggests that pirimicarb is preferable to fenvalerate if aphids are to be controlled chemically.

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