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Effects of slurry application on the microstructure of the surface layers of soils from northern Norway*

TORE E. SVEISTRUP[1], VERA MARCELINO[2] AND GEORGES STOOPS[2]
[1]The Norwegian Crop Research Institute, Holt Research Centre, Tromsø, Norway
[2]Laboratory of Mineralogy, Petrology and Micropedology, University of Ghent, Ghent, Belgium

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Thin sections, prepared from undisturbed soil samples, were used to investigate the influence of surface application of fresh and aerated cattle slurry on the microstructure and composition of the topsoil. Virgin and cultivated silty and sandy soils from northern Norway were studied. Both types of slurry were present as a fairly continuous layer on the top of the soil surface, but it was found that neither fresh nor aerated slurry penetrated into the soil. The application of liquid slurry produced an increased compactness of the microstructure of the surface of the virgin silty soil. In the cultivated silty soil and virgin and cultivated sandy soils, the treatment did not affect the fabric of the soil surface. This explains the observed decrease in the infiltration rate after surface application of liquid slurry. In both soils cultivation led to a marked modification of the microstructure: in the silty soils the microstructure of the cultivated soil was less developed and more compact than that of the virgin soil; the cultivated sandy soil had a much lower c/f ratio than the virgin soil.

Keys words: Infiltration rate, slurry application, soil micromorphology.

Tore E. Sveistrup, The Norwegian Crop Reserch Institute, Holt Reserch Centre, P.O. Box 2502, N-9002 Tromsø, Norway

The use of liquid slurry on grassland is a common practice in most parts of northern Norway. The climate is cool and humid and the soils remain wet or moist throughout most of the growing season. The application of slurry, normally done with tankers, leads to reduced water infiltration, and soil compaction due to traffic.

Earlier investigations have been carried out to study the influence of surface application of animal manure and soil compaction on soil physical properties in coastal and northern Norway, but none of them have been followed up by micromorphologial studies of changes in the soil microstructure and composition. Myhr (1987) and Myhr et al. (1990) found a reduction in infiltration rate of the soil due to surface spreading of slurry and soil compaction by machinery on pastures. The reduction in infiltration rate caused by slurry application disappeared within two weeks, but the effect of soil compaction was more persistent.

In other countries little attention has

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been paid to temporary changes in soil physical properties resulting from surface spreading of animal manure. Bottom et al. (1986) found a reduction in infiltration rate on fescue pasture after surface application of dairy manure on soils from Kentucky, USA. There has been a great deal of research into changes in soil physical properties caused by traffic. Investigations by Gaheen & Njøs (1977, 1978), Eriksson (1986) and Hamlett et al. (1988) all showed large decreases in the infiltration rate and hydraulic conductivity of the plough layer in loam and silt soils. Warkentin (1971) found a reduction in size and number of large voids and a reduction of saturated hydraulic conductivity of the soil caused by the spreading of liquid slurry with heavy tankers.

Most micromorphological studies on the effects of organic matter application have been carried out on soils in which the organic material has been ploughed or mixed into the topsoil (e.g. Paglilai et al. 1981; Paglilai et al. 1983a). However, only a few micromorphological studies exist on the influence of surface application of organic matter on the microstructure of soils. Paglilai et al.(1983b) found that in Italian silty clay and sandy loam soils there was an increased porosity after treatment of the soil crust with organic matter from sewage sludge and pig slurry.

The present micromorphological study is part of a broader study on the influence of surface application of liquid manure on soil properties in Norway. A complete description and classification of the soils are presented by Sveistrup (1992). The effects of cattle slurry and cultivation on infiltration rate for the same soils are presented by Haraldsen & Sveistrup (1994). The objectives of this study are: (i) to describe the influence of the slurry on the microfabric of the soils, and (ii) to detect other microfabric differences between the experimental samples which explain differences in infiltration rate among treatments.

MATERIAL AND METHODS

Materials

Soils from two locations in Finnmark county, northern Norway, were selected for the studies. The soils were coarse silty above sandy mixed Dystric Cryochrepts (Soil Survey Staff 1975) from Tana (70°26'N, 28°15'E) and sandy mixed Typic Cryaquents (Soil Survey Staff 1975) from Pasvik (69°28'N, 29°57'E). The sites chosen included virgin soils (uncultivated, never ploughed) and adjacent cultivated soil. The bordering soils were comparable except for the present vegetation and land-use. The macromorphological and physical properties of the soils are presented in Table 1.

The climate at both sites, is characterized as subarctic continental. The mean annual air temperature is -0.3°C at Pasvik (Pasvik meteorological station) and 0.1°C at Tana (Rustefjelbma meteorological station) (Bruun 1967). The growing season (temp. > 6°C) is 124 and 118 days respectively. Monthly mean air temperature and precipitation are given in Fig. 1.

The Tana silty soil was chosen because it often shows restricted plant growth caused by soil compaction during cultivation, and winter damage caused by ponding and ice-cover (Andersen 1960; Lorentzen 1984). The cultivated soil has been ploughed periodically since the 1920s, and the present sward was 7 years old at the time of the experiment. This consisted mostly of weed species with meadow grass (*Poa annua* L.) as dominant species. The meadow had been used

Table 1. Morphological and physical properties of the soils used for the micromorphological study. Data from Sveistrup (1992)

Location	Tana, silty			Pasvik, sandy		
Land use	virgin		cultivated	virgin	cultivated	
Soil depth (cm)	0-7	7-25	0-5	0-14	0-7	7-21
Horizon[1]	Ah	Bw1	Ap1	Cr1	Ap/Bwh	Bhs
Matrix colour[2] (moist)	$10YR^{3}/_{3}$	$2.5Y^{5}/_{4}$	$10YR^{4}/_{2}$	$5Y^{5}/_{1}$	$10YR^{3.5}/_{2}$	$10YR^{4}/_{4}$
Structure[2] (moist)	1-c-pl	1-m-pl	1-m,f-pl	0---sg	1-m,c-pl	0---m
Consistence[2] (moist)	mvfr	mvfr	mfr	ml	mfr	mvfr
(wet)	ws,wp	ws,wps	wss,wps	wso,wpo	wss,wpo	wso,wpo
Roots[3] (size)	1,2,3,4	1,2,3,4	1	3	1,2	1
(abundance)	3,3,3,2	3,3,3,3	2	1	4,4	2
Penetration resistance (kPa)	200-400	400-800	>2900	200	700-1400	1300-1500
Particle size distribution (%)						
coarse fragments(>2mm)	2	1	1	0	4	2
2 -0.6 (mm)	0	0	2	6	7	2
0.6 -0.2 (mm)	6	4	12	25	37	32
0.2 -0.06 (mm)	15	22	38	59	38	60
0.06 -0.02 (mm)	38	42	29	5	8	4
0.02 -0.006 (mm)	23	18	11	2	4	1
0.006-0.002 (mm)	9	7	4	1	3	0
< 0.002 (mm)	9	7	5	2	4	1
Organic carbon (%)	6.3	0.8	2.5	0.5	3.1	1.1
Bulk density (Mg/m3)	-	1.14	1.53	1.47	-	1.44
Total porosity % (v/v)	-	58	43	47	-	47
Air-filled pores %	-	26	6	37	-	25

Abbreviations according to: [1]FAO-UNESCO (1974), [2]Soil Survey Staff (1951), [3]Hodgson (1976)

for cow pasture for the previous 4 years. The virgin soil supported birch forest (*Betula pubescens* L.) with grasses and mosses. A thin mor humus layer covered the soil. This area was grazed to some extent by cows (Sveistrup 1992).

There were no particular agronomic problems with the Pasvik sandy soil. The site was situated on the edge of a peat bog which was drained by open ditches. It had been cultivated for 7 years prior to these investigations. Before cultivation, a shallow peat layer (20-30 cm) covered a layer of outwashed sand of more than 1 m in thickness, which was overlaying sedimentary marine clay. The cultivated and virgin sites were situated on either side of an open ditch. The vegetation at the virgin site was mostly peat moss (*Sphagnum* spp.), with heather (*Ericaceae* spp.)

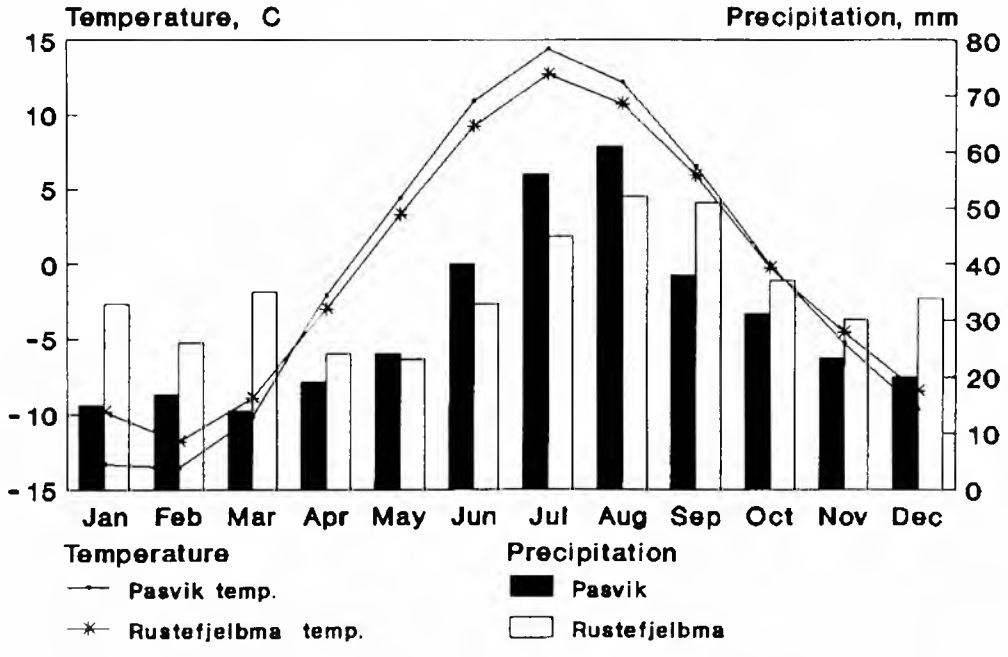

Figure 1. Mean monthly air temperature and precipitation (1931-60) for Pasvik (Pasvik meteorological station) and Tana (Rustefjelbma meteorological station). Data from Bruun (1967) and the Norwegian Meteorological Insitute (1980)

and scattered pine trees (*Pinus sylvestris* L.). The cultivated site had a 5-year-old ley, mainly consisting of smooth meadow grass (*Poa pratensis* L.) and timothy (*Phleum pratense* L.). The ley was harvested once a year for silage (Sveistrup 1992).

The tractors, which have been used in recent years at both sites, weighed approximately 3 Mg (Sveistrup 1992).

Undisturbed soil monoliths, 23.5 cm in diameter and 25 ± 1 cm in height, were collected at each site in rigid plastic cylinders. The distance between the virgin and cultivated soils was appro-ximately 15 m. The vegetation and the humus/peat layer were carefully removed before digging. The soil around the plastic cylinders was carefully removed as the cylinders were pressed down to enclose the monoliths. Monoliths from the cultivated sites consisted of the plough layer and top of the horizon below, and from the virgin sites the upper part of the mineral soil. Twelve monoliths were collected at each site, within a radius of 1.5 m and transported to Holt Research Station. Owing to vibration during transport, the virgin soil from Pasvik subsided and had a higher bulk density than in its natural state.

Methods

For each monolith, water was maintained at 1 cm above its base. The top of each monolith was covered to prevent evaporation so that it would have equilibrated at a matric potential of about -2.4 kPa. Prior to and during the experimental period room temperature was kept at 10 ±

2°C , which reflects the typical temperature from June to August in the region (Fig. 1).

Water infiltration was measured on the soil monoliths before and after application of cattle slurry to the soil surface according to the following scheme: (1) no slurry; (2) fresh cattle slurry, equivalent to 50 Mg/ha; (3) cattle slurry aerated for 4 weeks at 37°C, equivalent to 50 Mg/ha (Haraldsen & Sveistrup 1994). The dry matter contents of the fresh and the aerated slurry were respectively 7.3% and 7%.

Undisturbed soil samples were taken from monoliths used for infiltration measurements by pressing Kubiëna boxes vertically into the soil surface of the monoliths. The sampling was carried out 1 week, 1 month and 3 months after the slurry application (Table 2). The boxes were packed in plastic sheets and stored at 0.5°C before being transported to the Laboratory of Mineralogy, Petrography and Micropedology of the University of Ghent.

To avoid artificial shrinkage and cracking, the soil samples were dried by acetone-water replacement in vapour phase (Fitz Patrick & Gudmundsson 1978). They were then impregnated with an acetone-polyester resin mixture. One thin section (60 x 90 mm) per sample was prepared from a vertical section following the standard procedure in use in the laboratory (Murphy 1986).

The opening of the boxes caused a partial peeling off of the slurry in some of the Pasvik soil samples. The samples were impregnated in the ususal way, but the surface layer was slightly disturbed.

The thin sections were studied with a polarizing microscope. The terminology of the Handbook for Soil Thin Section Description (Bullock et al. 1985) was used for the micromorphological descriptions. Point counting of voids, coarse material (>5µm), fine material (<5µm) and organic

Table 2. Samples selected for the micromorphological study

Location	Slurry treatment	Time of sampling		
		1 week(1w)	1 month(1m)	3 months(3m)
Tana virgin	no slurry, control (c)	Tv-c-1w		
(Tv)	fresh slurry (fs)	Tv-fs-1w		Tv-fs-3m
	aerated slurry (as)	Tv-as-1w		Tv-as-3m
Tana cultivated	no slurry, control (c)	Tc-c-1w		
(Tc)	fresh slurry (fs)	Tc-fs-1w		Tc-fs-3m
	aerated slurry (as)	Tc-as-1w		Tc-as-3m
Pasvik virgin	no slurry, control (c)	Pv-c-1w		
(Pv)	fresh slurry (fs)	Pv-fs-1w	Pv-fs-1m	Pv-fs-3m
	aerated slurry (as)	Pv-as-1w	Pv-as-1m	Pv-as-3m
Pasvik cultivated	no slurry, control (c)	Pc-c-1w		
(Pc)	fresh slurry (fs)	Pc-fs-1w	Pc-fs-1m	Pc-fs-3m
	aerated slurry (as)	Pc-as-1w	Pc-as-1m	Pc-as-3m

residues was performed at a magnification of 125x, using a Leitz point-counting ocular. The quantifications were assessed for the undisturbed samples, counting 600-1000 points along two lines located respectively 5 and 30 mm below the soil surface, as shown in Fig. 2.

RESULTS AND DISCUSSION

The results of point counting can be seen in table 3, expressed as a percentage of the total volume and recalculated as a percentage of solid material. The c/f ratio, calculated from the total volume percentages of coarse material and fine material, is also given.

In the upper 1 cm of the **Tana virgin** (Tv) untreated soil sample (Tv-c-1w) there was a well developed granular microstructure with granules of very coarse sand size (Fig. 3) and, deeper, a platy structure with lens-shaped aggregates of 1000-2000 µm by 300-400 µm (Fig. 4). This platy microstructure is typical of soils subjected to frost action.

The micromorphological characteristics of the Tv soil sample collected one week after the application of fresh slurry were identical to those of the untreated sample (Figs. 3 and 4). However, the other samples of the Tv soil (Tv-fs-3m, Tv-as-1w and Tv-as-3m) had no granular microstructure and a less developed and more compacted platy microstructure (Fig. 5). This was also reflected by the point counting results (Table 3): the surface layers (with granular microstructure) of samples Tv-c-1w and Tv-fs-1w had a considerably higher porosity than the underlying zone (with lens-shaped aggregates). They were also more porous than all the other Tv soil samples (Tv-fs-3m, Tv-as-1w and Tv-as-3m). In these samples no differences between the porosity of surface and subsurface layers were found. Compared with those taken one

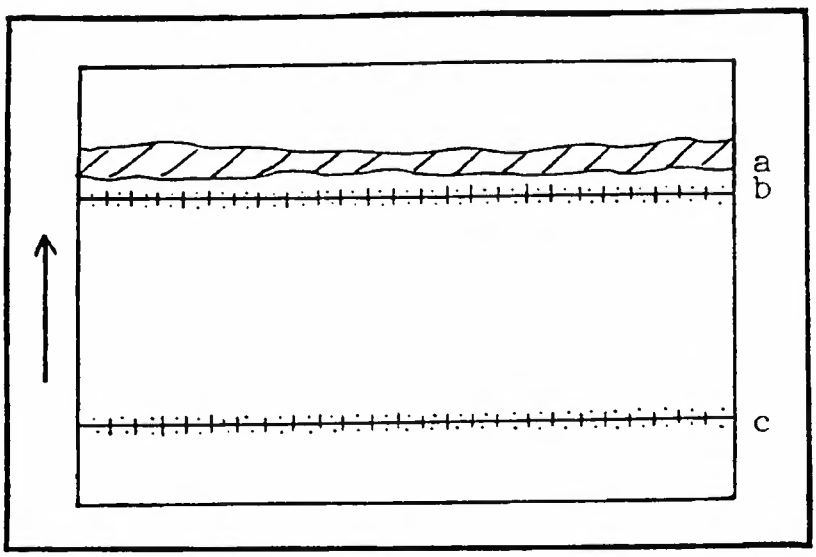

Figure 2. Scheme used in the point counting analysis: (a) slurry layer; (b) distribution of the surface point-counting fields (5 mm depth); (c) distribution of the subsurface point-counting fields (30 mm depth)

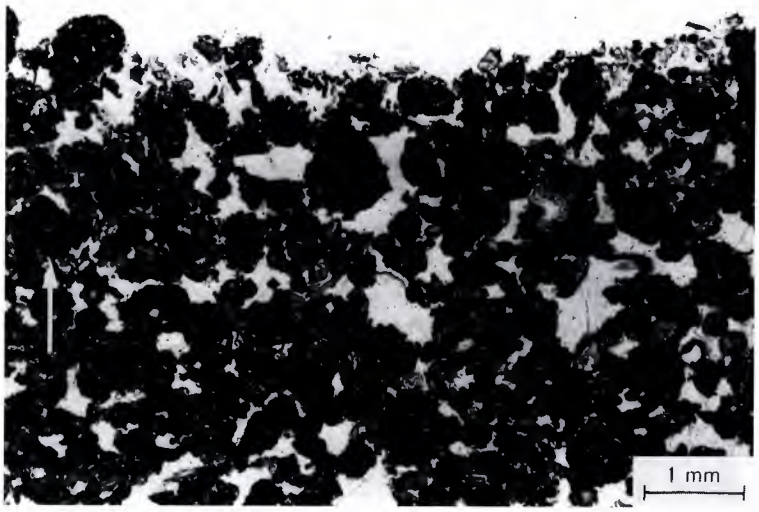

Figure 3. Granular microstructure characteristic of the surface of the Tana virgin soil (Tv). PL

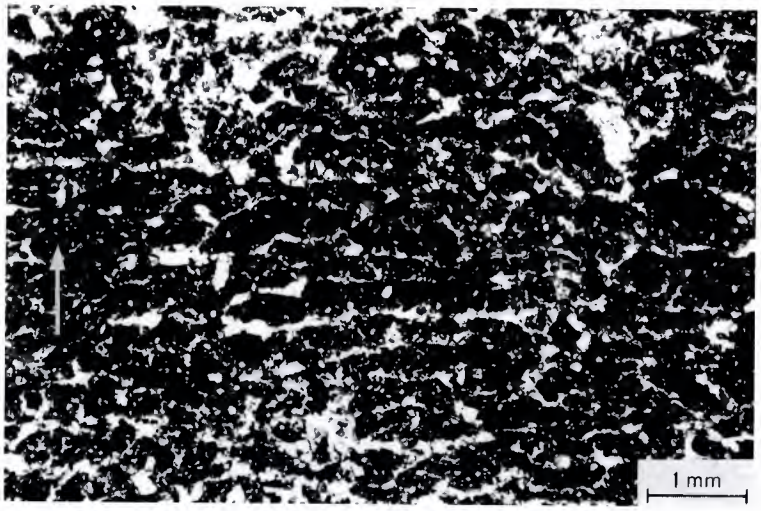

Figure 4. Platy microstructure with lens-shaped aggregates in the Tana virgin soil (Tv), at a depth of approximately 30 mm. PL

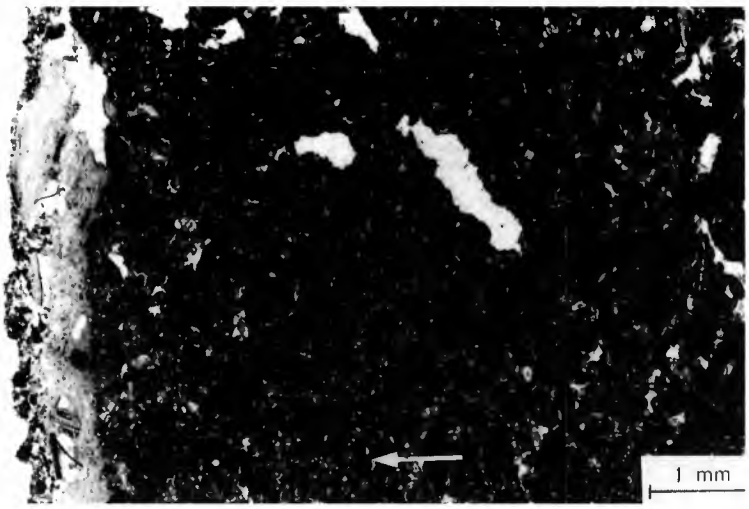

Figure 5. Microstructure of the surface of the Tana virgin soil (Tv) 3 months after the slurry application. PL

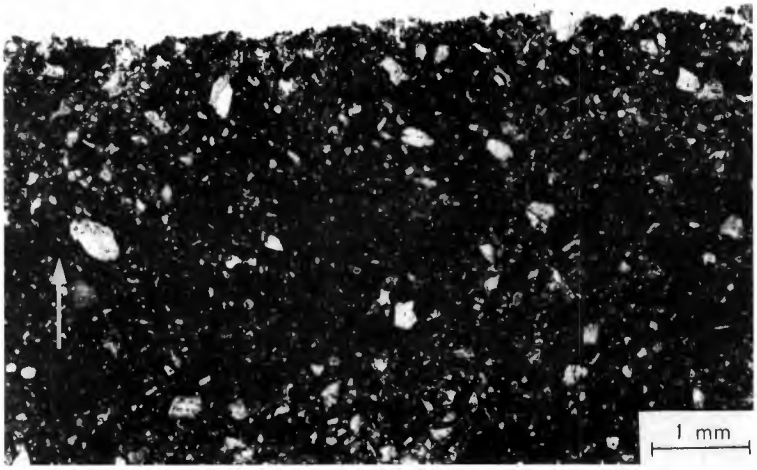

Figure 6. Massive microstructure characteristic of the Tana cultivated (Tc) soil. PL

week after the treatment (Tv-fs-1w, Tv-as-1w), the samples taken three months after the application of slurry (Tv-fs-3m, Tv-as-3m), showed a more marked decrease in porosity.

All the samples from the **Tana cultivated** (Tc) soil had a massive to weakly developed blocky microstructure (Fig. 6). No differences were observed between the micromorphology of the untreated and the treated Tc samples. In view of the similarity of the samples, point-counting analysis was done only for sample Tc-c-1w. This sample, both at the surface and at a depth of 3 cm, was rather homogeneous except for the percentage of pores, which was much lower in the surface layer. This homogeneity was probably a result of cultivation, and the lower percentage of pores in the surface layer a result of traffic by machinery and trampling by cows.

The *Pasvik virgin* (Pv) soil samples were characterized by a single-grain microstructure and a locally intergrain microaggregate structure (Fig. 7). Some samples (Pv-fs-1w, Pv-as-3m), however, had a higher amount of fine material. This cannot be a consequence of the slurry application and reflects heterogeneity of the soil material.

The **Pasvik cultivated** (Pc) soil had an intergrain microaggregate microstructure associated with pellicular and bridged grain (Fig. 8), which did not change after the application of fresh or aerated slurry.

As can be seen from Table 3, the micromorphological differences between the Pv and Pc soils were reflected by the c/f ratio, which was much lower in the Pc than in the Pv sample.

In both the fresh and the aerated slurry layer two phases could be distinguished: (i) raw, undecomposed and fragmented straw on the top, and (ii) isotropic, pale yellowish-brown colloidal material di-

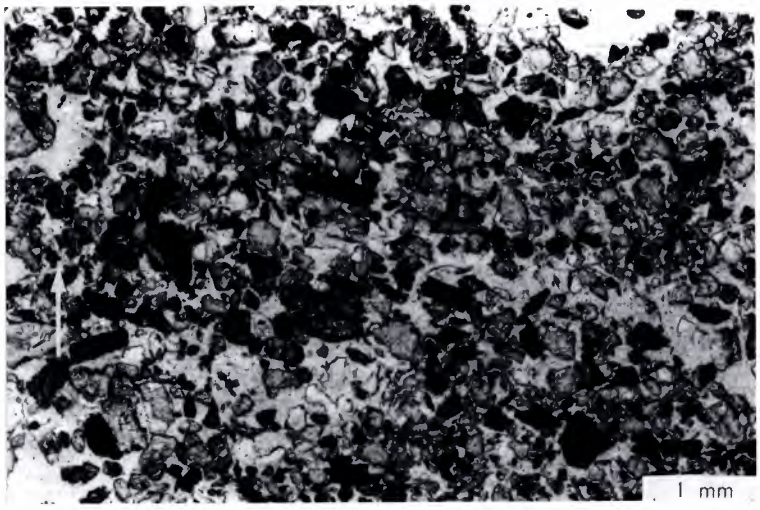

Figure 7. Single-grain microstructure characteristic of the Pasvik virgin soil (Pv). PL

Figure 8. Intergrain microaggregate, pellicular and bridged-grain microstructure characteristic of the Pasvik cultivated soil (Pc). PL

Table 3. Results of point counting

	% of total volume				% of solid material			c/f ratio
Sample	**F**	**C**	**O**	**P**	**F**	**C**	**O**	
Tv-c-1w[1]	43	32	4	21	54	41	5	0.8
Tv-c-1w[2]	45	42	1	12	51	48	1	0.9
Tv-fs-1w[1]	39	40	2	19	48	50	2	1
Tv-fs-1w[2]	44	46	0	10	49	51	0	1
Tv-fs-3m[1]	43	52	2	3	44	54	2	1.2
Tv-fs-3m[2]	39	57	0	4	40	60	0	1.5
Tv-as-1w[1]	38	53	0	9	41	59	0	1.4
Tv-as-1w[2]	38	54	0	8	41	59	0	1.4
Tv-as-3m[1]	37	55	3	5	39	58	3	1.5
Tv-as-3m[2]	40	56	0	4	42	58	0	1.4
Tc-c-1w[1]	43	49	3	5	45	52	3	1.2
Tc-c-1w[2]	39	49	2	10	43	54	2	1.3
Pv-c-1w[1]	7	67	0	26	10	90	0	9.0
Pv-c-1w[2]	5	63	0	32	7	93	0	12.6
Pc-c-1w[1]	25	49	2	25	33	65	2	2.0
Pc-c-1w[2]	24	57	2	17	29	69	2	2.3

F-fine material (<5µm);C-coarse material (<5µm); O- organic residues; P-pores [1]surface of mineral soil [2]subsurface (at a depth of 30 mm)

rectly overlying the mineral soil. This colloidal material did not seem to penetrate into the soil (Figs. 9 and 10), but it was always present as a more or less continuous layer on the top of the mineral soil surface. It had sharp limits in the samples collected one week after the slurry application (Fig. 9) and diffuse limits in the samples collected 3 months after the treatment (Fig. 10). This can explain the findings of Haraldsen & Sveistrup (1994), who observed that the decrease in infiltration rate produced by the application of slurry persisted for 3 months.

Figure 9. Aspect of fresh slurry layer in the Pasvik virgin soil, one week after application. PL

Figure 10. Aspect of fresh slurry layer in the Pasvik virgin soil, 3 months after application. PL

CONCLUSIONS

In both the Tana and Pasvik soils, cultivation led to changes in the microstructure of their surface. The granular and platy microstructure of the surface of the virgin Tana soil was replaced by a very compact massive microstructure in the Tana cultivated soil. In the Pasvik soils the micromorphological differences were related to the fine material content: the surface of the cultivated Pasvik soil was much richer in fine material than that of virgin Pasvik.

The application of liquid slurry produced an increased compaction of the surface of the *Tana virgin* soil. In the other studied soils the treatment did not seem to affect the fabric of the soil surface.

Neither fresh nor aerated slurry penetrated into the soil. In both treatments the slurry was present as a rather continuous layer on the top of the soil surface. This caused a decrease in the in filtration rate of these soils.

As revealed by the micromorphological study, the *Pasvik virgin* soil samples were fairly heterogeneous. This should be taken into account when interpreting the results of other analyses.

The micromorphological study has yielded information which is important for the interpretation of the results of other methods and techniques used in the research project.

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Light source and irradiance level in production of non-pinched plants of *Euphorbia pulcherrima* Willd

OLAV ARNE BÆVRE
The Norwegian Crop Research Institute, Kvithamar Research Centre, Stjørdal, Norway

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Non-pinched plants of poinsettia cultivars were grown at two locations in Norway and three experiments comprising two light sources with different lighting programmes were established. Potting took place between 21 August and 30 September and the experiments were completed before Christmas. The increased growth and the development of breaks during the vegetative phase were dependent on an increase in light in the generative phase and this requirement became greater when the supplementary light level was increased earlier. An interrupted lighting programme resulted in smaller top bracts than those developed under natural daylight conditions only. In comparison with continuously lit plants, interrupted lighting reduced the number and value of the flowering shoots and the economic result of those plants to a level similar to that reached with naturally lit plants. Light from high-pressure sodium lamps increased the growth in comparison with fluorescent lamps, and this effect was strengthened under reduced natural light conditions. There was a marked difference between cultivars in their response to supplementary lighting, especially when grown with a long vegetative phase. This response seemed to correspond with the ability to produce breaks. A moderately high supplementary level in the vegetative phase followed by good light conditions in the generative phase is recommended. The negative effect of a high light level in the vegetative phase on plant quality was reduced when the vegetative period was short.

Key words: *Euphorbia pulcherrima*, flowering, lighting, poinsettia.

Olav Arne Bævre, Planteforsk Kvithamar Research Centre, N-7500 Stjørdal, Norway.

Poinsettia (*Euphorbia pulcherrima* Willd.) is economically the most important Christmas plant in Norway today. Potting of rooted cuttings takes place in August and September and the plants reach marketable stage close to Christmas. The amount of natural daylight decreases rapidly in the late autumn at these latitudes, and daylight for plant growth and development is very scarce in November and December. Poor light conditions in an important production season have led to an increased use of artificial light. In the 1970s, artificial light was used in the later stages of the poinsettia culture period to improve plant quality through increased bract size and bract colour. Since then, however, artificial light has been used from the potting stage up until the marketable stage.

From an economic point of view, flowering laterals are important because non-pinched plants with flowering lateral shoots fetch a higher sales price than

plants without lateral shoots. Kristoffersen (1969); Hagen (1980) and Hagen & Moe (1981) have shown the positive relationship between high irradiation and the induction and growth of lateral bud breaks.

With self-branching poinsettias, like most Annette Hegg cultivars, there is normally no lack of lateral buds when the plants are grown vegetatively in August. A more intensive culture programme, including delayed potting, a shorter vegetative growth period under reduced and partly very low natural radiation and the use of supplemental lighting, is a new approach with respect to lateral bud growth and plant quality. Effects of the irradiance on plant morphology and development were important aspects of this investigation.

MATERIAL AND METHODS

This investigation comprised three experiments, two of which (Exps. 1 and 2) were located at Kvithamar Research Centre (63.5°25'N) and the third (Exp. 3) at Holt Research Centre/The University of Tromsø (69.5°39'N).

Plants of the cvs. Annette Hegg Lady, Annette Hegg Vinterstar and Annette Hegg Topstar were used in Exps. 1 and 2, and Annette Hegg Vinterstar in Exp. 3. The plants were obtained from the Thormod Hegg Company as rooted cuttings and grown as non-pinched plants with one cutting per pot. The potting dates were 21 August, 17 September and 30 September for Exps. 1, 2 and 3, respectively.

The artificial light sources in Exps. 1 and 2 were high-pressure sodium lamps (SON/T) and fluorescent lamps (TL33). High-pressure metal halide lamps (HPI/T) were used in Exp. 3. The plants were grown under continuous light (artificial light in addition to natural daylight) until short day (SD, 10 h) treatment was started (14 September for Exp. 1, 29 September for Exp. 2 and 7 October for Exp. 3). The plants were submitted to a SD inductive treatment using black plastic sheeting until natural daylength was shorter than 10 h. Natural daylight (ND) was supplemented with artificial light (10 h per day) from the start of the SD period to the end of the experiments.

The period from potting to the final registration for each experiment was split into two or three periods with different lighting procedures. Experiment 1 consisted of three periods; vegetative growth (PI) lasting from 21 August to 13 September, generative induction and growth (PII) lasting from 14 September to 12 November and the developmental period (PIII) lasting from 13 November to the end of the experiment (1st, 4th or 8th December cultivar dependent). Experiment 2 was split into two periods; vegetative growth (PI) lasting from 17 September to 30 September and generative induction and development (PIV) lasting from 1 October to 27 November. The corresponding data for Exp. 3 were 30 September to 7 October (PI) and 8 October to 20 December (PIV).

The following lighting procedures were used in the different periods of each experiment:

Experiment 1 (Exp. 1)

Period I (PI)	Period II (PII)	Period III (PIII)
1. Natural daylight (ND)	4. Natural daylight (ND)	6. Natural day light (ND)
2. ND + 17Wm^{-2}P AR	5. ND + 17Wm^{-2}PAR	7. ND + 7Wm^{-2}PAR
3. ND + 34Wm^{-2}PAR		

Light levels in the different periods were combined in seven treatments. The treatments were: 1-4-6, 2-4-6, 2-5-6, 2-5-7, 3-4-6, 3-5-6, 3-5-7. Accumulated natural daylight was 181 MJ/m^2 in PI, 207 MJ/m^2 in PII and 10 MJ/m^2 (until 1 December), 11 MJ/m^2 (until 4 December), 12 MJ/m^2 (until 8 December) in PIII.

Experiment 2 (Exp. 2)

Period I (PI)	Period IV (PIV)
1. Natural daylight (ND)	4. Natural daylight (ND)
2. ND + 17 Wm^{-2}PAR	5. ND + 7 Wm^{-2}PAR
3. ND + 34 Wm^{-2}PAR	

Only treatments with artificial light were used factorially (1-4, 2-5, 3-5). The accumulated global radiation was 183 MJ/m^2 from potting to the end of the experiment.

Experiment 3 (Exp. 3)

17 Wm^{-2} (PAR) from potting to the SD inductive phase (PI, 8 days). After that (PIV) 7.5 or 15 Wm^{-2} (PAR).

The irradiance level was measured with a lux meter at the top of the plants and converted into Wm^{-2}PAR using conversion factors (2.9 for TL33, 2.3 for SON/T and 2.8 for HPI/T).

The plants were grown in 12-cm diameter plastic pots with limed and fertilized peat moss (Floralux) as the potting medium. The nutrient solution contained (in ppm): 103 N, 24 P, 120 K, 20 Mg, 70 Ca, 26 S, 1.3 Fe, 0.41 Mn, 0.19 Cu, 0.09 Zn, 0.16 B and 0.017 Mo, made from Superba 7-4-21 and calcium nitrate. Subirrigation was used.

Chlormequat (Cycocel) was applied to the plants as a spray in concentrations of 1600 mgl^{-1} a.c. In Exp. 1 spraying was carried out seven times in the period from 2 September to 9 October. In addition, a solution of 2 mgl^{-1} ancymidol (Reducymol) amounting to 50 ml per pot was supplied as a soil drench on 30 September. Experiment 2 was sprayed twice, on 28 September and 9 October, and Exp. 3 was sprayed seven times in the period from 14 October to 25 November.

The temperature was maintained at 21°C, day and night, in Period I. Later on, the temperature was gradually decreased to 20°C, 19°C and 18°C in the final period. A CO_2 concentration of approximately 600 μl l^{-1} was established by enrichment of the greenhouse atmosphere with pure liquid CO_2.

Experiments 1 and 2 were carried out in three replicates with 12 plants per plot, while Exp. 3 consisted of five replicates with 20 plants per plot. The plants were placed close together to begin with and then gradually spaced until they finally reached a density of 25 plants per netto square metre. Experiment 1 came to an end on 1 December, 4 December and 8 December, for 'AH Lady', 'AH Vinterstar' and 'AH Topstar', respectively, while Exp. 2 terminated on 27 November and Exp. 3 on 20 December. Final registrations were made on these dates. Plants grown under ND had not reached full maturity by the final registration. Registration of the marketable stage was carried out when the plants had developed three open cyathia.

The plant height was measured from the pot rim to the top of the plant. The bract diameter ("the star diameter") was measured in two directions, at right angles. The average of these two diameters, called the bract diameter, may be used as a factor for the bract area. The number of completely open cyathia was used as a measurement of developmental stage. Lateral breaks longer than 2 cm were registered as lateral breaks. Lateral shoots with bract diameter greater than 7 cm on the main stem were designated as lateral flowering shoots, and these were num-

bered from the bottom of the plant (1st, 2nd, 3rd). Plants classified as being of the highest quality had at least three lateral flowering shoots. The average bract diameter and the average shoot height of the flowering shoots were based on the three flowering shoots of highest quality, and for this reason plants with fewer than three flowering shoots may have an average bract diameter of less than 7 cm. The bracts and the height of these three lateral flowering shoots have a great influence on the plant value (when they are shorter than the main stem), because having three lateral shoots is normally the critical level for achieving the highest plant price. They are therefore added together as a response parameter of light. Each plant was classified and the Norwegian Growers' Association price list (a gross price in NOK which includes taxes, loss and trade costs) was used when estimating the potential income per plant of different treatments.

Top bract diameter	without flowering shoot	with flowering shoot	with good flowering shoot
10 cm	12 NOK	15 NOK	20 NOK
15 cm	15 NOK	18 NOK	25 NOK
20 cm	20 NOK	22 NOK	28 NOK
25 cm	24 NOK	28 NOK	34 NOK

The observations were subjected to a two-way analysis of variance. The relationship between any variables was determined by simple correlation analysis: $p<0.001$***, $p<0.01$** and $p<0.05$* indicating a 0.1%, 1% and 5% level of significance, respectively. The Ryan-Einot-Gabriel-Welsch multiple range test (REGWQ) was used for general linear model procedures.

RESULTS

Cultivars

It was found that a delayed potting date and a shorter vegetative period resulted in the final plant height being shorter in Exp. 2 than in Exp. 1 (Table 1). The number of breaks and the number and the size of breaks growing into flowering shoots were reduced when the potting date was delayed and the solar radiation was reduced. On the other hand, the uppermost bract was greater with delayed potting. 'AH Topstar' initiated most breaks, but a relatively small proportion of these breaks grew into flowering shoots. This reaction was most pronounced when this cultivar developed a great many breaks. For most parameters, there were greater differences between cultivars in the long culture period (Exp. 1) than in the short culture period (Exp. 2). With 'AH Topstar' it was possible to achieve an increase in the number of flowering shoots, bract diameter and height of flowering shoots, top bract diameter and the potential income in relation to 'AH Vinterstar' with a delayed potting date (Exp. 2). The correlation coefficients between top bract diameter and the potential income for 'AH Lady' and 'AH Vinterstar' ($r=0.76$ and 0.82 for 'AH Lady', and $r=0.83$ and 0.81 for 'AH Vinterstar', Exps. 1, and 2, respectively) were higher than those for 'AH Topstar' ($r=0.61$ and 0.59 for Exps. 1 and 2, respectively), all significant at $p<0.001$.

Artificial light sources

There were no significant interactions between light source and cultivar in any of the experiments. The effects of artificial light sources on the number of developed cyathia, number of breaks or flowering shoots and the top bract diameter were

Table 1. Plant height, bract diameter, lateral branching and the estimated potential income per plant of poinsettia cultivars grown in an early potted culture (Exp. 1) or a late potted culture (Exp. 2). Cultivars in Exp. 1 were registered on different days. Breaks >2 cm and flowering shoots with bract diameter >7 cm are recorded. The bract diameter and the height in centimeters of the three flowering shoots of highest quality per plant are summed up. Values within the columns (within each experiment) followed by different letters are significantly different at the 5% level according to the REGWQ multiple range test

Cultivar	Plant height	Top bract diameter	Number (per plant) of		Sum of flowering shoots		Potential income, NOK
			breaks	flowering shoots	bract diameter	height	
Experiment 1							
AH Lady	22.2c	21.0a	4.2c	2.3b	37.9b	33.9c	25.6a
AH Vinterstar	24.9b	19.6b	5.7b	3.5a	46.9a	44.5b	25.3a
AH Topstar	27.3a	18.5c	7.0a	2.4b	41.4b	51.2a	23.0b
Significance	***	***	***	***	**	***	***
Experiment 2							
AH Lady	13.6b	26.1	0.9b	0.4	8.1b	4.7b	23.3
AH Vinterstar	16.9a	25.7	1.1ab	0.5	9.9ab	7.0ab	23.1
AH Topstar	16.8a	26.2	1.5a	0.6	13.5a	9.9a	23.2
Significance	***	n.s.	*	n.s.	*	**	n.s.

not significant (date not shown). The high-pressure sodium lamps increased plant growth (plant height and lateral shoot growth) compared to fluorescent lamps (Table 2). This effect of an artificial light source was most pronounced under reduced ND conditions (Exp. 2). Flowering shoot growth and the bract diameter

Table 2. Effects of high-pressure sodium lamps (SON/T) and fluorescent lamps (TL33) used in two experiments (see Table 1) on height, bract diameter and height of the three flowering shoots of highest quality of three poinsettia cultivars grown with different lighting schemes. The flowering shoots are numbered from the bottom of the plant

Light source	Plant height, cm	Flowering shoots								Potential income, NOK
		bract diameter, cm				height, cm				
		1st	2nd	3rd	sum 1-3	1st	2nd	3rd	sum 1-3	
Experiment 1										
SON/T	27.3	15.7	15.7	14.4	45.8	19.3	18.0	16.3	63.6	24.3
TL33	25.1	15.5	15.3	13.6	44.4	16.4	15.9	13.7	46.0	25.1
Significance	***	n.s.	n.s.	n.s.	n.s.	**	**	*	**	n.s.
Experiment 2										
SON/T	18.1	9.3	5.0	2.0	16.2	7.4	3.9	1.8	13.0	23.9
TL33	14.7	6.7	3.6	0.9	11.2	3.8	1.9	0.5	6.2	24.7
Significance	***	**	n.s.	n.s.	**	***	***	*	***	n.s.

of the flowering shoots were increased by high-pressure sodium lamps compared with fluorescent lamps, especially under poor ND conditions (Exp. 2). Although non-significant effect, there was, however, a tendency towards a higher potential income when using fluorescent lamps compared with high-pressure sodium lamps.

Lighting programme

Experiment 1

Supplementary lighting during different growth periods had a marked effect on plant growth and development (Table 3). Use of supplementary light had both a positive and a negative effect on the plants compared with ND only. The development of economically valuable plant parts (i.e. lateral shoots and bracts) depended on the irradiance level and lighting scheme in different growth periods. The height and the bract diameter of the single flowering shoots (1st, 2nd and 3rd) were always significantly shorter or smaller when grown under ND conditions compared with ND supplemented with artifical light (date not shown). This effect is expressed when the three flowering shoots are summed up.

High irradiance light levels in the vegetative period were shown to require a satisfactory irradiance light level later on. A high radiation level at the beginning of the culture period followed by poor light conditions was shown to be an unsatisfactory lighting scheme (Table 4). Use of 34 Wm^{-2} compared with 17 Wm^{-2}

Table 3. Effects of different irradiance levels using high-pressure sodium lamps and fluorescent lamps on three poinsettia cultivars (Exp. 1). Plant height, top bract diameter, the sum height and the sum bract diameter of three flowering shoots are measured in cm. For an explanation, see Table 1

Lighting period/ irradiance level	Plant height	Top bract diameter	Number of cyathia per plant	Number (per plant) of breaks	Number (per plant) of flowering shoots	Sum height of flowering shoots	Sum bract diameter of flowering shoots	Potential income, NOK
Light before SD (PI)								
ND	26.2	18.1b	1.6c	3.1b	0.8b	33.1c	26.4b	20.1c
ND + 17Wm^{-2}	26.2	20.3a	3.2a	6.8a	3.1a	48.0b	46.9a	25.8a
ND + 34Wm^{-2}	26.2	18.6b	2.6b	7.1a	2.8a	51.7a	43.5a	23.7b
Significance	n.s.	***	***	***	***	***	***	***
Light under SD (PII)								
ND	27.5	17.4	1.5	4.5	0.8	40.6	29.0	19.8
ND + 17Wm^{-2}	25.8	19.8	3.0	6.9	3.1	49.1	46.1	25.3
Significance	***	***	***	***	***	***	***	***
Light under SD (PIII)								
ND	27.0	16.9	1.5	5.7	1.2	44.5	32.4	20.4
ND + 7Wm^{-2}	25.5	21.1	3.6	6.7	3.6	48.9	49.4	26.8
Significance	***	***	***	***	***	**	***	***

Table 4. Effects of different irradiance levels in different periods on plant height (cm), lateral branching, bracts diameter (cm), developing cyathia and the estimated potential income per plant of three poinsettia cultivars grown under two light sources (Exp. 1). ND=natural daylight. For an explanation, see Table 1

Irradiance		Irradiance from 13 November to the end of the experiment																	
Before SD treatment	14 Sept. - 12 Nov.	Plant height		Cyathia per plant		Breaks per plant		Flowering shoots per plant		Top bract diameter		Sum height of flowering shoots		Sum bract diam. of flowering shoots		Potential income NOK	
ND	ND+7 Wm^{-2}	ND	ND+7 Wm^{-2}	ND	ND+7 Wm^{-2}	ND	ND+7 Wm^{-2}	ND	ND+7 Wm^{-2}	ND	ND+7 Wm^{-2}	ND	ND+7 Wm^{-2}	ND	ND+7 Wm^{-2}	ND	ND+7 Wm^{-2}
ND	ND	26.2b		1.6b		3.1d		0.8cd		18.1bc		33.1d		26.4d		20.1c	
ND+17Wm^{-2}	ND	31.1a		1.2b		7.4ab		0.5d		15.2e		61.4a		37.2bc		18.9c	
ND+17Wm^{-2}	ND+17Wm^{-2}	26.6b	25.4b	2.0b	3.9a	7.2ab	6.6bc	2.2b	3.7a	17.5cd	21.9a	47.1c	46.5c	41.6b	50.0a	22.9b	27.8a
ND+34Wm^{-2}	ND	30.3a		1.4b		7.9a		1.5c		15.8de		56.7ab		33.9c		19.2c	
ND+34Wm^{-2}	ND+17Wm^{-2}	26.1b	25.7b	1.2b	3.3a	7.4ab	6.8bc	1.4c	3.6a	15.5e	20.3ab	51.6bc	51.0bc	33.4c	48.9a	19.7c	26.0a

supplementary lighting in the vegetative period gave no significant differences in plant development or the potential income when the supplementary light in the generative phase was the same. The highest irradiance level in the vegetative period reduced plant quality when the plants were transferred to ND conditions later.

A comparison of different lighting programmes under poor ND conditions revealed some interesting results. Effects induced by an interrupted lighting programme were negative compared to the final result when ND was used without interruption. Lighting investment was lost when the lighting programme was interrupted. Exclusively poor ND conditions in the short final phase after previous treatment with supplementary lighting had significant effects on economically important parameters (i.e. top bract diameter). These effects were clear in comparison with both supplementary lit plants and plants grown without interruption with ND only.

The effect of the lighting programme depended on the cultivar (Table 5). An increased supplementary light level before the SD period had a favourable effect on the development of breaks and this effect was especially marked for 'AH Lady'. The use of supplementary light on 'AH Lady' was of greater importance for the growth and development of flowering shoots than for the other cultivars. Plants of 'AH Lady' grown under ND conditions produced the largest top bracts, which differed from the other cultivars. The large top bracts of 'AH Lady' under ND conditions did not compensate for the lack of flowering shoots when estimating the potential income. There was no significant interaction between cultivar and irradiance level before the SD inductive phase or in the generative phase on plant

Table 5. Effects of different lighting programmes in the vegetative growth period on the development of breaks and flowering shoots per plant, the total height and total bract diameter of three flowering shoots and top bract diameter in cm (Exp. 1). Natural daylight (ND) supplied with artificial light in Wm^{-2}

Lighting programme/ parameter observed	Cultivar			Significant interaction
	AH Lady	AH Vinterstar	AH Topstar	
Breaks				
ND	1.1	2.6	5.1	
ND + 17 Wm^{-2}	4.7	5.2	6.9	***
ND + 34 Wm^{-2}	5.1	6.9	7.7	
Flowering shoots				
ND	0.5	0.9	0.8	
ND + 17 Wm^{-2}	2.6	3.5	3.1	**
ND + 34 Wm^{-2}	2.7	4.2	2.4	
Height of flowering shoots				
ND	9.1	32.7	39.6	
ND + 17 Wm^{-2}	38.3	45.2	51.4	**
ND + 34 Wm^{-2}	40.0	47.8	56.4	
Bract diameter of flowering shoots				
ND	12.6	26.9	30.0	
ND + 17 Wm^{-2}	44.1	49.9	47.2	*
ND + 34 Wm^{-2}	42.6	51.7	41.2	
Top bract diameter				
ND	22.5	15.7	17.5	
ND + 17 Wm^{-2}	21.5	20.8	19.9	*
ND + 34 Wm^{-2}	20.0	20.1	17.8	

height, the number of flowering shoots per plant or the potential income.

Experiment 2

Supplementary irradiation increased plant height and the branching of the plants (Table 6). Compared with ND only throughout the culture period, supplementary lighting was significant for promoting lateral shoots and building up lateral breaks to flowering shoots. With uninterrupted ND conditions only, as few as one in ten plants produced one flowering shoot with a bract diameter of at least 7 cm. Under these light conditions, no single plant had more than one flowering shoot. With supplementary lighting it was possible to develop up to three flowering shoots on some plants. Increasing the irradiance level before the SD treatment resulted in an increase in the lateral shoot development and the growth of these shoots.

Supplementary lighting in the vegeta-

Table 6. Effects of the irradiance levels during periods of vegetative and generative growth on the development of lateral branching, growth and the estimated potential income per plant of poinsettia (three cultivars). Plots with lighting before short day (SD) induction received 7 Wm^{-2} in the SD period and those with lighting in the SD period an average of 17 and 34 Wm^{-2} before SD induction. ND=only natural daylight in both the vegetative and the generative growth phase. For an explanation, see Table 1

Irradiance level	Plant height cm	Top bract diameter, cm	Number of cyathia	Number per plant		Flowering shoot height, cm				Potential income, NOK
				Breaks	flowering shoots	1st	2nd	3rd	sum 1-3	
Before SD induction										
ND	15.0b	20.2c	0.5c	0.3c	0.1c	1.4b	0.0c	0.0b	1.5c	18.6c
ND + 17Wm^{-2}	16.0a	26.0b	2.2b	1.1b	0.5b	4.7a	2.1b	0.7a	7.4b	21.6b
ND + 34Wm^{-2}	16.7a	28.9a	4.3a	1.9a	0.8a	6.3a	3.6a	1.5a	11.4a	26.9a
Significance	*	***	***	***	***	***	***	**	***	***
From SD induction										
ND	15.0	20.2	0.5	0.3	0.1	1.4	0.0	0.0	1.5	18.6
ND + 7Wm^{-2}	16.3	27.5	3.3	1.5	0.7	5.5	2.9	1.1	9.5	24.3
Significance	*	***	***	***	***	***	***	*	***	***

tive or in the generative phase of the plants promoted plant development and had a highly significant effect on the growth of bracts and the potential income. There was also a significant effect on most parameters of increasing the supplementary light level from 17 to 34 Wm^{-2} in the two weeks of vegetative growth. No significant interaction on any parameter was observed between cultivar and irradiance level before the SD induction and between cultivar and lighting programme in the generative phase.

Experiment 3

The plants reached the marketable stage round about Christmas (final registration on 20 December), Table 7. When the natural light level is very low (the sun sinks beneath the horizon from 27 No-

Table 7. Effects of supplementary lighting (high-pressure metal halide lamps) on plant growth and development, branching and bract growth of poinsettia cv. AH Vinterstar at Tromsø (Exp. 3)

Irradiance level in the generative phase	Number per plant			Plant height, cm	Top bract diameter, cm	Sum of the two best flowering shoots, cm	
	cyathia	breaks	flowering shoots			height	diameter
7.5 Wm^{-2}	1.6	0.8	0.1	12.3	21.1	0.6	1.3
15.0 Wm^{-2}	1.7	2.0	0.6	13.9	23.6	3.4	7.3
Significance	n.s.	**	**	*	*	***	***

vember), increasing the artificial light level had a marked effect on plant growth and development. The number of flowering shoots was highest under the highest irradiance level, giving a greater total bract area per plant.

DISCUSSION

It is evident that supplementary lighting has an influence on poinsettia growth and development and therefore the economic outcome. When recommending a lighting programme for poinsettia, both the cost and the effect of artificial light must be taken into consideration.

A high irradiance level in the vegetative phase produced a high number of lateral breaks. This corresponds well with the findings of Kristoffersen (1969); Hagen (1980) and Hagen & Moe (1981). The present investigation further demonstrated that supplementary lighting is necessary if breaks are to develop into flowering shoots during the dark months late in the autumn. The effect of supplementary lighting on lateral branching indicated a correlation between plant growth and spacing (Hagen 1980).

Lighting throughout the whole culture period enhanced development, as was also found by Walla & Kristoffersen (1974); Fjeld (1982); Mortensen (1985) and Moe et al. (1992), but a reduction in supplementary light in the last phase was found to delay development as reported by Tayama (1978). Terminating the use of supplementary light at the beginning of the generative phase or later, increased the elongation. The result was taller plants and longer flowering shoots together with a reduction in the number of flowering shoots, overall bract diameter and the potential income. The increased plant height caused by lighting as found by Miller & Kiplinger (1961); Tayama (1978) and Mortensen (1985) was also observed in these experiments when the plants were subjected to poor light. An increased top bract diameter when using supplementary light compared to natural daylight (Walla & Kristoffersen 1974; Tayama 1978; Fjeld 1982; Mortensen 1985) was only found when the plants were artificially lit up until the final registration.

As expected (Grimstad 1981), light from high-pressure sodium lamps increased the plant height and the length of flowering shoots compared to fluorescent lamps. For other parameters, such as bract diameter, the light source was of secondary importance.

An unregulated use of supplementary light on non-pinched poinsettias may have a negative effect on the final result. A good lighting programme must have a balanced between irradiance level in the vegetative growth phase and in the generative phase. It can be concluded from these experiments that a culture programme which begins with high irradiance levels must be followed up with good light conditions later to give a satisfactory plant development. The marked decrease in the natural light conditions in the autumn, which has to be compensated for by artificial light, strengthens the light energy requirement later on. In any event, an increase in irradiance level throughout the whole culture period resulted in an increase in the total costs, and therefore a better quality product is necessary to compensate for these costs.

Growers have to take into consideration the increasing area that is required from potting to the marketable stage. When there is a given number of lamps available, supplementary light in the vegetative phase has to be limited in

anticipation of an adequate irradiance level later. Economizing on light energy must take place at the beginning of a culture programme, not at any time in the generative growth phase. In general, we have to balance the use of supplementary light in the vegetative phase against the use of artificial light in the generative phase when growing poinsettia plants. Achieving this balance in a period with a marked decrease in natural light condititions is more challenging than during other seasons.

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Promoting the development and quality of *Euphorbia pulcherrima* Willd through programmed supplementary lighting

OLAV ARNE BÆVRE
The Norwegian Crop Research Institute, Kvithamar Research Centre, Stjørdal, Norway.

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Two experiments were carried out to demonstrate that non-pinched poinsettia plants responded to irradiance level in both the vegetative and the generative phase and that even a very short vegetative period induced light-dependent differences in breaks and flowering shoots. It was found that increased irradiance levels in the vegetative phase had a poor or negative effect on the top bract size. The responses observed in the vegetative period as a result of increased irradiance level were not economically profitable. Increased irradiance level in the generative phase accelerated plant development, breaks and the development of flowering shoots. The quality of the flowering shoots, top bract size and the estimated potential income were also enhanced. Reducing natural light by shading in the vegetative phase did not exert any negative effect on bract size or the potential income. Plants exposed to reduced light conditions in the vegetative period increased their quality compared with naturally lit plants when exposed to natural light in the generative phase. Cultivar and potting date influenced the recommended irradiance level in the generative growth phase.

Key words: *Euphorbia pulcherrima*, flowering, irradiance level, poinsettia

Olav Arne Bævre, The Norwegian Crop Research Institut, Kvithamar Research Centre, N-7500 Stjørdal, Norway

Pinched and non-pinched plants of poinsettia differ in growth and development. In pinched plants there is no apical dominance and a number of lateral bud breaks may develop into flowering shoots. On the other hand, lateral bud breaks and flowering shoots on non-pinched plants are more or less dominated by the top shoot. The self-branching ability of the cultivar is of great importance for development. The balance between the development of flowering shoots and the top shoot exerts an influence on the morphology of the saleable plant. The development of bract and flowering shoots differs between cultivars (Sørensen 1994) and is also influenced by growth conditions (Hagen & Moe 1981; Sørensen 1994; Bævre 1995). The irradiance level and the time that supplemental lighting is applied have an influence on plant development and the economic outcome. Unfortunately, negative effects of supplementary lighting of poinsettia have been found (Bævre 1995) and further research into plant responses to light conditions is required.

Investment in lighting, running expenses and plant price have a bearing on the grower's income and have to be taken into consideration when developing culture programmes. A lighting programme that produces plants of good quality at not too high a cost is very im-

portant if the growers are to achieve profitable results. The object of this study was to investigate the relevance of using different light levels throughout the production period when starting the culture at different dates in the autumn.

MATERIAL AND METHODS

This investigation, which comprised two experiments (Exp. 1 and Exp. 2), was carried out in a double-layer acrylic greenhouse in the first year (Exp. 1) and in a glassed greenhouse in the second year (Exp. 2), at Kvithamar Research Centre (63.5°25'N). The cultivars Annette Hegg Lady, Annette Hegg Vinterstar, Annette Hegg Topstar and Annette Hegg Starlight were obtained as rooted cuttings from the Thormod Hegg Company. Plants delivered at different dates were at the same stage of development. 'AH Lady', 'AH Vinterstar' and 'AH Topstar' were used in the first year and 'AH Vinterstar' and 'AH Starlight' in the second year. Potting took place on 8 September, 21 September and 5 October in Exp. 1 and 10 September and 18 September in Exp. 2. The experiments were carried out with two replicates with seven plants per plot. The global radiation levels from potting to the final registration (5 December) in Exp. 1 were 217, 136 and 84 MJ/m^2 for the potting dates 8 September, 21 September and 5 October, respectively. The corresponding global radiation levels in Exp. 2 for the first and the second potting dates were 231 and 158 MJ/m^2, respectively. Climatic conditions (i.e. temperature, CO_2), fertilizing, peat and plant spacing were the same as those by Bævre (1995), as were the light measurements. The supplementary lighting was provided by high-pressure metal halide lamps (HPI/T) in Exp. 1 and high-pressure sodium lamps (SON/T) in Exp. 2.

Chlormequat (Cycocel) was applied to all plants three to seven times as a spray at a concentration of 1600 mgl^{-1} a.c. When potting was delayed, the number of applications was reduced. In addition, ancymidol (2 mgl^{-1}) was applied once as a soil drench, 50 ml per pot, before the last or the second last application of chlormequat.

Experiment 1

Different lighting programmes were used before and after the start of short day (SD) treatment. A 16-day vegetative period lasted from potting until SD treatment. With the exception of the plants grown under natural daylight (ND) only, the plants received artificial lighting for 24 h a day from the second day after potting until the start of SD treatments, i.e. a total of 14 days. Artificial lighting (ND supplied with artificial light) per day was supplied for 10 h from the start of the SD treatment until the end of the experiment:

Lighting before SD treatment	Lighting from start of SD treatment
ND	ND
ND + 17 Wm^{-2}PAR	ND + 7 Wm^{-2}PAR
ND + 34 Wm^{-2}PAR	ND + 14 Wm^{-2}PAR

The experiment was factorially designed with all nine combinations and the final registration took place on 5 December.

Experiment 2

The plants received ND for the first two days after potting. For the remainder of the vegetative period they were subjected to different irradiance levels. This period lasted from 17 September to 28 September for plants potted on 10 September and from 23 September to 28 September for plants potted on 18 September. ND was

reduced by 25% by shading with a thin cotton cloth (measured at noon). Artificially lit plants were supplied with supplementary light for 24 h a day until commencement of SD treatments. The plants received 10 h supplementary light per day from the start of the SD treatments (28 September).

Lighting before SD treatment	Lighting from start of SD treatment
ND reduced 25%	
ND	ND
ND + 4.5 Wm^{-2}PAR	ND + 4.5 Wm^{-2}PAR
ND + 9.0 Wm^{-2}PAR	ND + 9.0 Wm^{-2}PAR
ND + 13.5 Wm^{-2}PAR	ND + 13.5 Wm^{-2}PAR

Experiment 2 was factorially designed with the same or an increased irradiance level in the SD period compared to the period before SD treatments, making a total of 14 lighting combinations (see Table 5). The final registrations took place on 17 December.

The total number of lateral breaks and breaks longer than 0.5 cm were recorded. Other registrations were in accordance with Bævre (1995). The potential income in NOK was estimated on basis of the Norwegian Growers' Association price list (which is a gross price including taxes, losses and trade costs).

Top bract diameter	Without flowering shoots		With good flowering shoots
	Exp. 1	Exp. 2	
15 cm	17 NOK	18 NOK	27 NOK
20 cm	22 NOK	23 NOK	30 NOK
25 cm	26 NOK	28 NOK	36 NOK

The observations were subjected to a two-way analysis of variance using the Ryan-Einot-Gabriel-Welsch (REGWQ) multiple-range test. The relationship between any variables was determined by simple correlation analysis. $p<0.001$***, $p<0.01$** and $p<0.05$* indicating a 0.1%, 1% and 5% level of significance, respectively.

RESULTS

Cultivar and time of potting

The cultivars were significantly different for most parameters recorded (Table 1). 'AH Lady' was significantly shorter than the other cultivars (16.7 cm compared with 18.1 cm and 19.2 cm for 'AH Vinterstar' and 'AH Topstar', respectively), had the largest top bract and displayed a very poor development of breaks and flowering shoots. However, the large top bract of this cultivar compensated for the lack of flowering shoots when estimating the potential income.

In the second experiment no significant difference in plant height was found between 'AH Lady' and the other two cultivars (16.1 cm and 16.3 cm for 'AH Vinterstar' and 'AH Starlight', respectively), but 'AH Starlight' attained the largest top bracts and the best lateral branching and therefore the highest potential income (Table 1).

A delayed potting date resulted in a reduction in the number of open cyathia at the time of registration (Table 2). The delayed cyathia development was less than the delay in potting dates. Delayed potting reduced the value of economically important parameters, which was reflected in the estimated potential income.

In Exp. 2 significant differences ($p<0.001$) in plant development were found between the two potting dates (10 September versus 18 September). With the latest potting date, the plant height was reduced from 16.7 cm to 15.7 cm, the

Table 1. Development of cyathia, breaks (>0.5 cm) and flowering shoots (with bracts >7 cm diameter), bract diameter, height of flowering shoots (cm) and an estimated potential income per plant of poinsettia cultivars grown as non-pinched plants. Values within the columns followed by different letters are significantly different at the 5% level according to REGWQ multiple range test

Cultivar	Cyathia per plant		Number (per plant) of		Top bract	Sum of flowering shoots		Potential income,
			breaks shoots	flowering	diameter	bract diameter	height	NOK
Experiment 1	27 Nov	5 Dec						
AH Lady	0.5c	1.1c	0.2c	0.0c	17.8a	0.5c	0.8c	16.4a
AH Vinterstar	0.9b	2.0b	0.5b	0.1b	15.8c	2.2b	2.9b	13.4b
AH Topstar	1.2a	2.2a	1.1a	0.2a	17.2b	3.3a	4.8a	16.2a
Significance	***	***	***	***	***	***	***	***
Experiment 2	7 Dec	17 Dec						
AH Vinterstar	0.2	1.3	1.4	0.3	20.2	1.4	3.2	21.6
AH Starlight	0.1	0.9	3.1	0.7	21.3	3.2	7.9	24.0
Significance	***	**	***	***	***	***	***	***

Table 2. Effect of potting date on the development, growth and an estimated potential income per plant of three poinsettia cultivars (Exp. 1). All measurements in centimeters. For explanation, see Table 1

Potting date	Cyathia per plant	Number (per plant) of		Top bract diameter	Sum of flowering shoots		Potential income, NOK
		breaks	flowering shoots		bract diameter	height	
8 September	4.2a	0.8a	0.3a	21.2a	3.7a	5.6a	21.1a
21 September	1.3b	0.5b	0.1b	17.9b	2.5b	3.2b	16.0b
5 October	0.1c	0.5c	0.0b	12.0c	0.1c	0.0c	9.2c
Significance	***	***	***	***	***	***	***

number of breaks from 3.1 to 1.5, flowering shoots from 2.4 to 1.1, but there was an increase in the top bract diameter from 20.2 cm to 21.4 cm. No significant differences were observed for any other parameters.

The development of breaks and flowering shoots was poor for all cultivars in Exp. 1. 'AH Topstar' had the greatest number of breaks followed by 'AH Vinterstar' and 'AH Lady'. A delayed potting date reduced the number of breaks and the number of flowering shoots per plant.

None of the cultivars attained economically viable flowering shoots when the plants were potted on 5 October. On average, fewer and shorter flowering shoots were also obtained for the two previous potting dates in Exp. 1 and for both potting dates in Exp. 2 (date not shown). The influx of light had a marked effect on the growth of flowering shoots and the development of bracts on these shoots in both experiments. Few, but high quality flowering shoots were established on all cultivars in both experiments when the plants were supplied with a high level of artificial light. The positive effect of increased irradiation level was especially marked in 'AH Starlight', 'AH Topstar' and 'AH Vinterstar'.

There was a significant ($p<0.001$) interaction between cultivar and potting date for the potential income in Exp. 1. The average potential incomes for 'AH Lady', 'AH Vinterstar' and 'AH Topstar' were NOK 20.8, NOK 20.4 and NOK 22.1, respectively, when the plants were potted on 8 September. The latest potting date resulted in an average plant value of NOK 11.9 for 'AH Lady' compared with NOK 7.2 and 9.0 for 'AH Vinterstar' and 'AH Topstar', respectively. No corresponding significant interaction was found in Exp. 2.

Lighting programmes

Experiment 1

Use of supplementary lighting before the SD phase increased the plant height, delayed the development of cyathia and reduced the top bract diameter, but increased the development of lateral breaks and flowering shoots (Table 3). An increased irradiance level in the vegetative growth phase promoted the development of breaks into flowering shoots of economic importance, which compensates for smaller top bracts when estimat-

Table 3. Effects of irradiance level before the short day inductive phase (SD) and in the SD phase on poinsettia plant growth, the development of bracts and the estimated potential income per plant (Exp. 1). All measurements in centimeters. For explanation, see Table 1

Irradiance level		Plant height	Number of cyathia	Number per plant of		Top bract diameter	Sum of flowering shoots		Potential income, NOK
Before SD induction	From start of SD induction			breaks	flowering shoots		bract diam.	height	
ND		14.8c	2.2a	0.1c	0.0c	17.6a	0.4c	0.6c	14.8b
ND+17Wm^{-2}		19.3b	1.5b	0.8b	0.2b	16.4b	2.6b	3.6b	15.5a
ND+34Wm^{-2}		20.8a	1.5b	1.0a	0.2a	16.3b	3.4a	4.9a	15.4a
Significance		***	***	***	***	***	***	***	*
	ND	14.4c	0.0c	0.0c	0.0c	7.3b	0.0b	0.0b	1.5c
	ND+ 7Wm^{-2}	18.4b	2.2b	0.7b	0.2a	19.8a	2.6a	4.0a	20.0a
	ND+14Wm^{-2}	19.9a	2.5a	0.8a	0.1b	20.0a	2.6a	3.5a	19.0b
	Significance	***	***	***	***	***	***	***	***

ing the potential income. Supplementary lighting in the generative phase had a marked effect on plant development and the potential economic outcome. Nothing was gained by increasing the supplementary light from 7 to 14 Wm^{-2} in the generative phase.

The interaction between cultivar, irradiance level before SD treatment and irradiance level in the generative phase was not significant. There was a highly significant ($p<0.001$) interaction between irradiance level before the SD inductive phase and the irradiance level in the generative phase on the development of cyathia, top bract diameter and plant price (Table 4). Supplementary lighting in the generative phase accelerated the development of cyathia and this effect was most pronounced for plants grown under ND conditions in the vegetative period. The top bract diameter and the potential income decreased dramatically when artificial lighting in the vegetative growth period was followed by a generative period with ND only compared with a generative period with supplementary light. Supplementary lighting in the generative phase gave the best results when the plants were exposed to ND conditions before the induction to generative growth. Artificial lighting in the generative phase was necessary for a satisfactory plant quality if the plants were exposed to artificial light in the vegetative period. There was no significant interaction between irradiance level before the SD inductive period and during the generative period on the other parameters observed.

The effects of the irradiance level before the SD inductive phase and in the SD phase depended on potting dates. The interaction between the potting date and the irradiance level before the SD induction or the irradiance level after that point was highly significant ($p<0.001$) for both the total height and total diameter of flowering shoots (data not shown). Plants potted on 5 October had only a few flowering shoots regardless of lighting procedure. Supplementary light of more than 17 Wm^{-2} before the SD induction did not have any positive effect on the development of flowering shoots when the potting date was 8 September. Supplementary lighting in the generative phase increased the height and the bract diameter of the flowering shoots of plants potted on 8 or 21 September, but no positive effect was found when the artificial light level exceeded 7 Wm^{-2} in the SD period. When potting took place on 21 September, increased irradiance levels before the SD period increased the total height and the total bract diameter of flowering shoots. (Fig. 1)

Table 4. Cyathia, top bract development and the estimated potential income per plant as affected by irradiance level (supplementary light level in Wm^{-2}) before short day (SD) treatment and irradiance level in the SD period (Exp. 1). ND=Natural daylight. For explanation, see Table 1

Irradiance before SD treatment	Number of cyathia			Top bract diameter, cm			Potential income, NOK		
	Irradiance level in the short day period								
	ND	ND+7	ND+14	ND	ND+7	ND+14	ND	ND+7	ND+14
ND	0.0d	3.4a	3.5a	9.8c	21.7a	22.3a	2.3d	21.6a	22.1a
ND+17	0.0d	1.5c	2.0b	3.8d	19.1b	18.8b	0.4d	19.6b	17.4c
ND+34	0.0d	1.6c	2.0b	3.8d	18.6b	19.0b	0.2d	18.8b	17.7c

Potting date	Cultivar
8 Sept.	
21. Sept.	AH Lady
5. Oct.	
8 Sept.	
21. Sept.	AH Vinterstar
5. Oct.	
8 Sept.	
21. Sept.	AH Topstar
5. Oct.	

34	34	17	17	ND	ND	ND	Vegetative period
14	7	14	17	14	7	ND	Generative period

Supplemental irradiance in Wm^{-2} PAR

Figure 1. Effects of potting date and supplemental lighting on poinsettia plant development. ND=Natural light conditions only

A significant ($p<0.001$) interaction between potting date and lighting programme was observed for top bract development and potential income (Fig. 2). Restricted use of supplementary light before SD induction in late-potted cultures seemed to be of great importance.

The potential income was highly correlated ($r=0.87$, $p<0.001$) with the top bract diameter. The correlation coefficients varied between cultivars from $r=0.84$ for 'AH Vinterstar', $r=0.88$ for 'AH Topstar' to $r=0.92$ for 'AH Lady'. The relationship between potential income and

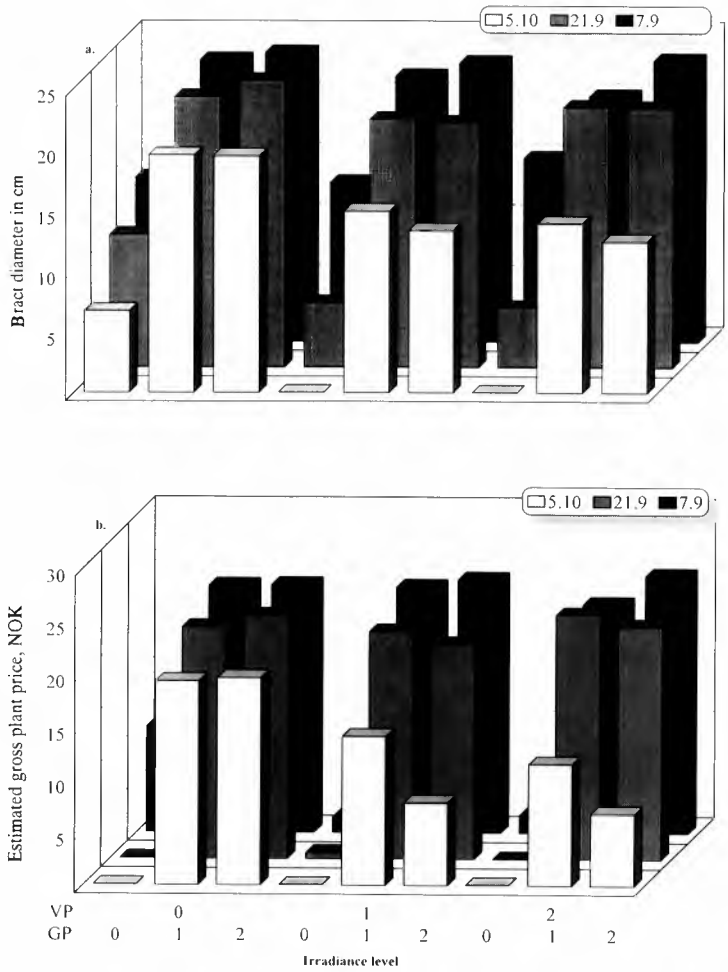

Figure 2. The effects of irradiance level before SD induction and in the generative phase with different potting dates (8 September, 21 September and 5 October) on (a) the development of top bract, and (b) estimated potential income per plant (Exp. 2). Irradiance in the vegetative period (VP): 0= Natural daylight, 1= natural daylight + 17Wm^{-2}, 2= Natural daylight + 34Wm^{-2}. Irradiance in the generative period (GP): 0= Natural daylight. 1= Natural daylight + 7Wm-2, 2= Natural daylight + 14Wm^{-2}

the total diameter of flowering shoot bracts was r=0.38 ($p<0.001$) for all cultivars, but this varied from r=0.22 for 'AH Lady' to r=0.46 for the other two cultivars.

There was a poor relationship between top bract diameter and number of flowering shoots, total height or total diameter of flowering shoots. The correlation coefficients varied between r=0.11 and r=0.29 ($p<0.001$) for different relationships and cultivars.

Experiment 2

The irradiance level in the generative phase was most important for the development of cyathia but the lighting programme before SD induction was of minor importance (Table 5). Increased use of supplementary light in the generative period promoted the development of cyathia. The 13.5 Wm^{-2} treatment enhanced the development by little more than one week relative to the 4.5 Wm^{-2} treatment.

There was a significant interaction between cultivar and irradiance level ($p<0.05$) and potting date and irradiance level ($p<0.001$) for top bract diameter. 'AH Starlight' had a more marked course than 'AH Vinterstar' and the effect of high irradiance level increased with delayed potting. Corresponding results were also observed for the potential income. There was a close relationship between the development of breaks and the artificial irradiance level in the generative phase (Table 6). Increased artificial lighting increased the number of breaks in both categories. There also tended to be a positive effect of increased irradiance level in the vegetative phase on the development of breaks, but this tendency only became significant when the breaks grew to flowering shoots. The coefficient of correlation between breaks >0.5 cm and number of flowering shoots was r=0.42 ($p<0.001$). Low light conditions during the first part of the culture reduced the relative number of breaks that would later become flowering shoots. This effect was most pronounced when the irradiance level in the generative phase was high. Increased artificial lighting in the generative phase continued to have a positive effect on the development of flowering shoots.

Taking into consideration the final results for breaks and flowering shoots, in most cases there was a significant effect of irradiance level before the SD inductive phase on both the height and the bract

Table 5. Number of open cyathia per poinsettia plant (two cultivars) as affected by irradiance level (supplementary irradiance level in Wm^{-2}) before short day (SD) treatment and lighting programme in the SD period. ND=Natural daylight. ND-25%=Natural daylight reduced 25% (Exp. 2). For explanation, see Table 1

Irradiance before SD treatment	Per 7 December Irradiance level in the SD period				Per 17 December Irradiance level in the SD period			
	ND	ND+4.5	ND+9.0	ND+13.5	ND	ND+4.5	ND+9.0	ND+13.5
ND - 25%	0.00c	0.00c	0.04c	0.12bc	0.00e	0.15de	0.83cd	2.35a
ND	0.00c	0.00c	0.12bc	0.26ab	0.00e	0.15de	1.44bc	1.70ab
ND+ 4.5		0.00c	0.02c	0.26ab		0.12de	0.80cd	2.07ab
ND+ 9.0			0.04c	0.40a			1.43bc	2.28a
ND+13.5				0.32a				2.42a

Table 6. Development of breaks and lateral flowering shoots per poinsettia plant (two cultivars) as affected by lighting programme (supplementary irradiance level in Wm^{-2}) before short day (SD) treatment and lighting programme in the SD period. ND=Natural daylight. ND - 25%=Natural daylight reduced 25% (Exp. 2). For explanation, see Table 1

Irradiance before SD treatment	Total number of breaks				Number of breaks > 0.5 cm				Number of flowering shoots			
	Irradiance level in the SD period				Irradiance level in the SD period				Irradiance level in the SD period			
	ND	ND +4.5	ND +9.0	ND +13.5	ND	ND +4.5	ND +9.0	ND +13.5	ND	ND +4.5	ND +9.0	ND +13.5
ND - 25%	0.08c	0.57c	2.31b	3.90a	0.04d	0.24d	1.50c	3.00ab	0.04c	0.06c	0.23c	0.18c
ND	0.10c	0.42c	2.08b	4.12a	0.10d	0.33d	1.48c	3.32a	0.04c	0.19c	0.42bc	0.26c
ND+ 4.5		0.98c	2.78b	4.02a		0.55d	2.14bc	3.02ab		0.35c	0.80ab	0.89a
ND+ 9.0			2.88b	4.30a			2.16bc	3.72a			1.00a	1.10a
ND+13.5				4.14a				3.26a				1.16a

diameter of the flowering shoots (Table 7). A high irradiance level in the generative phase failed to promote flowering shoot development when the initial culture was carried out under poor light conditions. The highest artificial irradiance level in the generative phase showed a positive effect on both the height and the bract diameter of flowering shoots when a high irradiance level had been used before SD induction.

Poor light conditions throughout the whole culture resulted in small top bracts and a low potential income (Table 8). Increased irradiance before the SD inductive phase tended to have a negative effect on the size of the top bracts, whereas increased irradiance in the generative phase had the opposite effect. The economic result showed only small variations with the supplementary lighting programme used in the generative period, particularly when the artificial irradiance was at least 9.0 Wm^{-2}. The potential income was almost independent of the lighting procedure before the SD inductive phase.

The potential income showed a close relationship with the top bract diameter ($r=0.71$, $p<0.001$). There were no significant coefficients of correlation between top bract diameter and different parameters for breaks and flowering shoots for any cultivar. The number of flowering shoots, the total height and the total bract diameter of flowering shoots showed low coefficients with the potential income ($r=0.29$, $r=0.27$, $r=0.31$, ($p<0.001$), respectively).

Table 7. Total height (cm) and total bract diameter (cm) of the three best flowering shoots of poinsettia as affected by irradiance level (supplementary irradiance level in Wm^{-2}) before short day (SD) treatment and lighting programme in the SD period. ND=Natural daylight. ND - 25%=Natural daylight reduced 25% (Exp. 2). For explanation, see Table 1

Irradiance before SD treatment	Total height of flowering shoots Irradiance level in the SD period				Total bract diameter of flowering shoots Irradiance level in the SD period			
	ND	ND+4.5	ND+9.0	ND+13.5	ND	ND+4.5	ND+9.0	ND+13.5
ND - 25%	0.2d	0.2d	1.3d	0.8d	0.5c	0.7c	2.9c	2.4c
ND	0.3d	0.9d	2.6bcd	0.9d	0.5c	2.1c	5.4bc	2.8c
ND+ 4.5		1.7cd	4.2ab	3.9abc		3.9c	9.5ab	10.6a
ND+ 9.0			4.5ab	5.5a			10.8a	13.0a
ND+13.5				6.0a				13.4a

Table 8. Top bract diameter and the estimated potential income per plant of poinsettia as affected by lighting programmes (supplementary irradiance level in Wm^{-2}) before short day (SD) treatment and irradiance level in the SD period. ND=Natural daylight. ND - 25%=Natural daylight reduced 25% (Exp. 2). For explanation, see Table 1

Irradiance before SD treatment	Top bract diameter, cm Irradiance level in the SD period				Potential income, NOK Irradiance level in the SD period			
	ND	ND+4.5	ND+9.0	ND+13.5	ND	ND+4.5	ND+9.0	ND+13.5
ND - 25%	16.4d	20.8cb	21.5abc	22.8a	16.1c	22.1b	24.5a	25.1a
ND	14.9e	20.7cb	22.0ab	22.9a	13.2d	23.1ab	24.8a	24.9a
ND+ 4.5		20.2c	21.2bc	22.1ab		22.7ab	24.1ab	24.8a
ND+ 9.0			21.1bc	22.0ab			24.7a	24.8a
ND+13.5				22.1ab				25.0a

DISCUSSION

This investigation confirmes the effects of light on poinsettia plants found by Bævre (1995). The branching capacity, development of bracts and economic value of the flowering poinsettia plant are all closely correlated with irradiance levels in the vegetative and generative growth phases. The irradiance levels in the different growth periods have an influence on one another and it is necessary to balance the light if a standard quality is to be achieved in a short culture period.

An increase in irradiance level enhanced cyathia development, which concurs with the findings of Fjeld (1982); Mortensen (1985); Moe et al. (1992) and Bævre (1995). This effect of irradiance level was most pronounced in the generative phase, wheras the irradiance level in the vegetative phase was of minor importance. The short vegetative period used in a late-potted culture has to be taken into consideration when interpreting the

results. In the generative phase of these experiments plant development was enhanced at the highest supplementary light level (13.5 and 14.0 Wm^{-2}) compared with at lower light levels, irrespective of light conditions before the SD inductive phase.

Light level had an influence on break development (Hagen & Moe 1981; Mortensen 1985; Bævre 1995). There was a tendency towards an increased number of breaks with increased irradiance level in the vegetative phase, but this effect was of secondary importance compared with the irradiance level in the generative phase. However, the short vegetative period which is necessary in an intensive culture programme, followed by an intensive light generative period may explain these responses. A longer vegetative period based on an ordinary culture programme may induce more breaks and then a higher requirement for light in the generative period. The induced effects of irradiance level in the vegetative phase were dependent on the irradiance level in the generative phase for growth potential to be realized. Lighting in the vegetative phase delayed plant development, but an increased irradiance level increased the number and the quality of flowering shoots. An increased influx of light in the generative phase had a positive reaction with light level in the vegetative phase. A relatively high irradiance level in the generative phase was necessary in order to utilize the growth potential induced.

There may be a slight relationship between top bract diameter and the development and growth of flowering shoots. Only a poor flowering shoot development was recorded in this investigation. The unanswered question is whether there is a relationship when the plants produce a great many flowering shoots. Unpublished data from earlier investigations indicate that there is a reduction in top bract diameter when many flowering shoots are produced. Cultivars that readily induce breaks and that are grown under a vegetative period which stimulates the development of breaks strengthen these effects.

Flowering shoots were of minor importance for the estimated potential income in these experiments compared to the top bract diameter. The quality of the flowering shoots and the subjective judgement have an influence on the plant value.

As found by Christensen (1972), late potting enhanced development relative to early potting. Reduced growth and poor break and flower shoot development under poor light conditions may have an influence on these responses.

This investigation demonstrates that the response of plants to increased light conditions does not always produce a better economic outcome. Indiscriminate use of supplementary light may result in reduced profits, especially if the lighting costs are included. Poor light conditions in the vegetative growth phase do not preclude a satisfactory economic result and using a high level of supplementary light in the generative phase can compensate for a poor start.

It is important to emphasize the use of the lighting equipment in these experiments. In the vegetative growth phase disposable lamps should be used for the growth area in the final period of the culture. The lighting programme should be adapted to the needs of groups of cultivars or single cultivars.

Growers must take the plant price list into consideration when planning a culture of non-pinched plants. The cultivar, the lighting programme and the importance of top bract versus flowering shoots all have to be considered in order

to achieve the desired economic result.

Plant quality is stimulated by light conditions in both the vegetative and the generative phase of development. It is of utmost importance to balance the irradiance level before short day induction and also later in the culture period. In order to balance a limited access to supplementary light in the generative phase, the natural light conditions in the vegetative phase can be reduced. The use of supplementary light in the vegetative phase should not be overdone. A light level of about 9 Wm^{-2} seems to be sufficient in the generative phase, irrespective of the light level in the vegetative phase.

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Resistance to raspberry root rot (*Phytophthora fragariae* var. *rubi*) in red raspberry cultivars

NINA HEIBERG
The Norwegian Crop Research Institute, Ullensvang Research Centre, Division Njøs, Hermansverk, Norway

Heiberg, N. 1995. Resistance to raspberry root rot (*Phytophthora fragariae* var. *rubi*) in red raspberry cultivars. Norwegian Journal of Agricultural Sciences 9: 41-47. ISSN 0801-5341.

Six raspberry cultivars, grown in Norway, were screened for resistance to root rot caused by *Phytophthora fragariae* var. *rubi* in pot experiments in a growth room. The plants were inoculated with zoospores from a single isolate. The local Norwegian cultivar 'Asker' was resistant to the pathogen, and might be a new source of resistance. 'Chilliwack', a Canadian cultivar, showed moderate resistance, while 'Malling Admiral', 'Malling Orion', 'Balder' and 'Veten' were all susceptible.

Key words: Phytophthora fragariae var. rubi, pot experiment, Rubus ideaus, soilborne pathogen.

Nina Heiberg, The Norwegian Crop Research Institute, Ullensvang Research Centre, Division Njøs, N-5840, Norway.

Root rot of red raspberry (*Rubus ideaus*) can be caused by a number of different *Phytophthora* species, but the most common and serious form is caused by one particular species which has now been named *Phytophthora fragariae* var. *rubi* (Wilcox et al. 1993).

The disease was first reported from North America (Converse & Schwartze 1968) and about 20 years later in several countries in Europe (Seemüller et al. 1986; Duncan et al. 1987; Nourrisseau & Baudry 1987). In Scandinavia the disease has been identified in Norway (Heiberg et al. 1989), Denmark (Thinggaard 1990) and recently in Sweden in 1994 (Olsson, pers. comm.).

Control of root rot is difficult, and there is therefore increasing interest in resistant cultivars. Resistance has been reported in several *Rubus* species and species hybrids (Bristow et al. 1988; Knight 1991; Duncan & Kennedy 1991) but, unfortunately, few raspberry cultivars are resistant to the disease. The North American cultivars 'Latham' and 'Newburgh' have high levels of resistance, and a number of cultivars and selections with these cultivars in their ancestry have shown a high or moderate degree of resistance to the disease (Barritt et al. 1979). Only two European cultivars, 'Winkler Sämling' and 'Autumn Bliss', have been reported to have a high level of resistance to root rot (Scherer & Riedel 1990; Kennedy & Duncan 1991; Kennedy & Duncan 1993). None of the valuable, commercial summer fruiting cultivars grown in Europe are resistant to the disease.

Breeding for resistance is well established in some North American programmes (Barritt et al. 1979; Bristow et al. 1988). In Europe, raspberry breeding

programmes in Britain (Knight 1991; Duncan & Kennedy 1991), and Norway (Nestby & Heiberg 1995) have included resistance to root rot caused by *P. fragariae* var. *rubi*.

Screening raspberry genotypes for root rot resistance in field experiments is time consuming, but Kennedy & Duncan (1991) developed methods for greenhouse tests which have proved to be a reliable way of screening (Kennedy & Duncan 1993; Laun 1993).

The aim of this work was to test the resistance level of raspberry cultivars grown in Norway to raspberry root rot.

MATERIAL AND METHODS

Origin of cultivars

The cultivar 'Malling Orion' is of complex parentage, and includes 'Preussen', 'Burnetholm', 'Baumforth A', 'Pyne's Royal' and 'Lloyd George' in its ancestry. 'Malling Admiral' derived from a cross between 'Burnetholm', 'Preussen', 'Norfolk Giant' and 'Malling Promise' (Keep et al. 1972). 'Veten' is the main commercial cultivar in Norway. Its parents were thought to be 'Asker' and 'Lloyd George' (Hjeltnes 1963), but it is more likely that 'Veten' is an offspring of 'Preussen' x 'Lloyd George' (Øydvin 1970). The origin of 'Asker' is unknown but this cultivar has been grown in Norway for more than 100 years, having been imported as 'Surpasse Falstof' from Holland during the 1880s. Subsequently, it was grown in Norway under various names; such as 'Falstof', 'Paragon' and 'Baumforth Seedling' (Gran 1911; Gran 1917). Gran (1911) noted that 'Asker' was very similar to 'Baumforth Seedling', but not to the other clones sold as 'Paragon' and 'Falstof' in Norway. Heggli (1959) wrote that 'Asker' was synonymous with 'Winklers Sämling', which is the other European cultivar resistant to raspberry root rot. 'Balder', a Norwegian cultivar, originated in 1975 from a cross between 'Norna' and 'Malling Jewel' (Redalen 1990). 'Norna' itself resulted from a cross between 'Preussen' and 'Lloyd George'. 'Chilliwack' is a Canadian cultivar, not grown commercially in Norway but of interest because of its resistance to root rot (Heiberg 1995). 'Chilliwack' originated from a three-way cross between ('Sumner' x 'Carneval') x 'Skeena' (Daubeny 1987).

Production of plants

The experimental plants were produced from root cuttings. Roots from plants of all cultivars, with the exception of 'Chilliwack', were obtained from the Norwegian Stock material at Gartnerhallen Sauherad. Roots of 'Chilliwack' were obtained from a cultivar trial at the Ullensvang Research Centre, Division Njøs. No root rot was observed in this field. All roots were stored in polythene bags in a ventilated storage room from October until the start of the experiment.

The roots, diameter 3-10 mm, were cut into pieces 3-5 cm in length and layered 2 cm deep in a fertilized commercial peat substrate (Hasselfors P-jord). The experiment was replicated twice; in the first experiment the forcing of plants started in January and in the second the forcing started in April. In the first experiment the plants were forced in a growth room continuously illuminated with white fluorescent tubes, ranging from 52 to 70 watt m-2. The temperature varied between 21 and 24°C. In the second experiment, forcing started in a heated plastic house with a temperature variation from 18 to 25°C. In both experiments plants of about 3 cm height were removed after three weeks and transplanted into 8-cm pots containing fresh peat substrate. After

transplanting, the plants were placed in the growth room for 12 (experiment 1) or 14 days (experiment 2) before inoculation. Each cultivar was represented by seven plants per experiment, of which two were control plants. Each experiment included seven containers with six pots, one of each cultivar. The containers were watertight with a net on the top in which the pots were suspended in holes to avoid contamination during the experiments.

Inoculation

The day before inoculation the temperature was lowered to 15°C. Of the seven containers in each experiment, five were inoculated leaving two as uninoculated controls. The mean plant height was 5 cm at the time of inoculation. All plants were inoculated with zoospores of the designated isolate of *P. fragariae* var. *rubi*: 2/4 Ullensvang Research Centre Division Njøs collection/R 189 (Wilcox et al. 1993). Kennedy & Duncan (1993) assigned the isolate used in the present experiment to race 1. The isolate was tested for pathogenicity prior to the investigation by inoculating six plants of 'Veten' using the same method as that described for the experiments. All six plants developed the characteristic symptoms of root rot and died within 4 weeks after inoculation.

Zoospore suspensions were produced as described by Nestby & Heiberg (1995). Zoospore concentration was estimated using a haemocytometer and adjusted to approximately 1000 spores ml-1 by adding distilled water. Each plant was inoculated by pouring 50 ml of the zoospore suspension over the surface of the pot; distilled water only was applied to the control plants. After inoculation all plants were irrigated every day, excluding Saturdays and Sundays, until water drained through the pots.

Assessment

Plant height and disease symptoms on the leaves were measured once a week. The disease symptoms on the leaves were based on yellowing and wilting using a scale from 0-9; 9 indicated symptom-free, green leaves; 5 indicated 50% yellow or wilted leaves; 0 indicated all leaves yellow or wilted.

Assessment of individual plants was conducted 6 weeks after inoculation. Root systems were carefully washed free of compost, and the fresh weight of above-ground parts, fresh weight of roots, length of above-ground lesions of stem and percentage of brown and rotten roots were recorded. From each plant, a minimum of three brown, rotten roots were examined by microscope for oospores.

The data were analysed, using the GLM-procedure in the PC-SAS system (SAS Institute Inc., Cary, NC, USA) to test the significance of the difference between inoculated and uninoculated control plants within the six cultivars for each character. No significant differences were found between the two experiments and the data were therefore combined.

RESULTS

There were no significant differences between the uninoculated control plants of the six cultivars, and the means of all controls are presented in Table 1. The size of the oospores observed in the roots varied from 27 to 38 μm. They were found only in brown, rotten roots with an particularly soft texture. Even root systems with a high percentage of brown, rotten roots contained only a few soft roots. On the other hand, all the soft roots which were examined contained oospores.

Table 1. Percentage of plants with oospores, percentage of root rot, root weight, leaf symptoms (0-9), stem lesions and height increase in six red raspberry cultivars 39 days after inoculation with zoospores of P. fragariae var. rubi. Significant levels of difference between inoculated and uninoculated (controls) plants within cultivars are n.s.=P>0.05, *=P<0.05, **=P≤0.01, ***=P≤0.001

	Percent with oospores	Percent root rot	Root weight (g)	Yellow and wilted leaves	Stem lesions	Height increase[1]
'Malling Admiral'	90 ***	73.0 **	5.3 **	5.1 *	0.6 n.s.	33.9 ***
'Asker'	0 n.s	4.4 n.s	15.4 n.s	8.9 n.s.	0 n.s.	88.0 n.s.
'Balder'	90 ***	78.0 **	4.8 **	1.8 ***	3.3 *	34.8 ***
'Chilliwack'	90 **	56.0 n.s	4.3 ***	6.4 n.s.	0 n.s	44.9 **
'Malling Orion'	90 ***	77.3 ***	6.0 **	1.6 ***	3.0 *	30.7 ***
'Veten'	90 ***	94.0 ***	3.7 ***	0.5 ***	12.7 **	38.7 **
Mean of controls	0	6.0	14.9	9.0	0	100

[1] As percentage increase of control plants

Inoculated plants of 'Asker' showed no symptoms of root rot and were not significantly different from the control plants for any of the characters (Table 1). Inoculated plants of all the other cultivars showed various symptoms of root rot, and differed significantly from control plants for at least three characters. They all had a significantly lower root weight and significantly smaller height increase than their controls, while oospores were detected in 90% of the inoculated plants. The percentage of root rot was significantly higher in inoculated plants than in the controls for 'Malling Admiral', 'Balder', 'Malling Orion' and 'Veten'. It was also found that inoculated plants of these cultivars had significantly more yellow and wilted leaves than uninoculated control plants.

All ten inoculated plants of 'Veten' developed stem lesions which were larger than those in the other cultivars. Inoculated plants of 'Balder' and 'Malling Orion' also differed significantly from their controls for stem lesions. 'Malling Orion' developed stem lesions on six and 'Balder' on eight of the plants. In 'Malling Admiral' only one plant developed stem lesions, but neither 'Asker' nor 'Chilliwack' developed any stem lesions.

Inoculated plants of 'Chilliwack' displayed fewer symptoms of root rot than the other cultivars, with the exception of 'Asker'. In addition to the absence of stem lesions, neither the level of leaf symptoms, nor the percentage of brown and rotten roots differed significantly from the controls. However, as in the other susceptible cultivars, oospores were found in nine of the ten inoculated plants and the root weight of inoculated plants was significantly lower than that of control plants.

Inoculated plants of 'Malling Admiral' differed significantly from control plants for all characters except stem lesions.

DISCUSSION

The technique used in the present experiment is a rapid and sensitive method for testing genotypes for resistance to raspberry root rot. The plants inoculated with zoospore suspensions of *P. fragariae* var. *rubi* produced typical symptoms of root rot, and their severity reflected the relative resistance of the genotypes in previous pot and field tests (Scherer & Riedel 1990; Kennedy & Duncan 1991; Laun 1993; Heiberg 1995).

The size of the oospores observed in the present test was within the range of variation for oospores of *P. fragariae* var. *rubi* (Wilcox et al. 1993). Oospores were not found in all plants with a high percentage of rotten roots, but that might be due to the softness of the rotten roots in which the oospores were exclusively observed. These roots were small, very soft and easily broken. Some might therefore have been lost during the washing process, even though this was done very carefully. Why oospores were restricted to these soft roots in the present experiment is not known, as Duncan et al. (1987) observed oospores in both the roots and the stem lesions of diseased plants two weeks after inoculation with zoospores.

Daubeny (1987) reported that 'Chilliwack' had moderate resistance to root rot, and this was subsequently confirmed in a field experiment (Heiberg 1995). According to Kennedy & Duncan (1991) the absence of stem lesions is a simple way of distinguishing resistant cultivars from less resistant cultivars. No stem lesions were observed on 'Chilliwack' in the present test, but, on the other hand, as in the more susceptible cultivars, root weight was significantly reduced and oospores were detected in 90% of the inoculated plants. This indicates that the level of resistance is perhaps lower than the above-ground symptoms suggest.

'Malling Admiral' has shown some resistance in field experiments (Scherer & Riedel 1990). Barritt et al. (1981) grouped 'Malling Admiral' among the extremely susceptible cultivars, but it was significantly less affected than 'Malling Orion'. In the present investigation only one plant of 'Malling Admiral' formed stem lesions, but the root system seemed to be as affected as the most susceptible cultivars. 'Veten' is highly susceptible both to root rot caused by *P. fragariae* var. *rubi* (Scherer & Riedel 1990; Heiberg 1995), and to root rot caused by *P. citricola* (Profic-Alwasiak & Danek 1993). The cultivars 'Balder' and 'Asker' have not been included in any previous screening tests, but Nestby & Heiberg (1995) found that 'Asker' produced offspring with a high degree of resistance. No symptoms of raspberry root rot have been reported in Norway where 'Asker' has been grown.

The present results indicate that 'Asker' is resistant to the isolate (race 1) used in this test. In spring 1993, when the present trial was carried out, there was no evidence of different races of the fungus and only one race of the pathogen, that isolated from diseased raspberry plants in Norway, was included. Kennedy & Duncan (1991) found no differences between several isolates of P. fragariae var. rubi. Later, however, they observed a significant isolate/genotype interaction, suggesting the existence of three different races (Kennedy & Duncan 1993). Race 1 severely attacked the greatest number of genotypes. The only two cultivars which had a high degree of resistance to race 1 were 'Latham' and 'Autumn Bliss'. These

two cultivars also exhibited a high degree of resistance to the other two races (Kennedy & Duncan 1993).

'Asker' might be a new source of resistance to raspberry root rot, but further investigations will be required to establish whether 'Asker' is also resistant to the other races and whether the cultivar is synonymous with 'Winklers Sämling'.

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Soil pH increase and ENV of granulated chalk and dolomite, depending on a two weeks' daily rain shower on surface prior to soil incorporation

KARL-JAN ERSTAD
The Norwegian State Agricultural Research Stations, Særheim Research Station, Division Fureneset, Fure, Norway

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Pot experiments using a barren soil were carried out in a study on dissolution of granulates of chalk and dolomite liming materials, according to the soil incubation method. A two weeks' daily rain shower (0.22 mm) prior to soil incorporation had no apparent effect on increases in pH levels, microbial processes possibly having counteracted the effect of the rain showers. The commercially available granulated dolomite contained a large proportion of fine granulates (66.3%<2.0 mm), whereas the chalk contained 88.8% granulates of 2.0-5.0 mm. On a chemical basis (kg CaO equivalents) the separate granulate fractions of chalk were superior from the 6th week of incubation, and from the 12th week this was also the case with the coarser commercially available chalk product compared with the finer dolomite product. On the basis of product mass there were no significant differences. Compared with crushed and wet sieved material of the same origin as the granulated chalk, the latter achieved a maximum efficiency of 92% during a 24-week incubation period, whereas the granulated dolomite achieved only 80%. Calculated ENV figures were expected to increase in the course of 5 years in the field.

Key words: Key words: Chalk, dolomite, fineness, granulation, liming materials, precipitation, reactivity, rock carbonates, soil incubation

Karl-Jan Erstad, Særheim Research Station, Division Fureneset, Fureneset, N-6995 Hellevik i Fjaler, Norway.

Abbreviations: ENV: Effective Neutralizing Value = Neutralizing Value * Dissolution in soil during a defined period (normally 1 and 5 years in field).

The dissolution of liming materials in soil has been intensively studied and tested, concerning commercially available products for agriculture and their primary particle size classes. However, little has been done to quantify the reduction in liming efficiency as a result of granulation of the liming materials, which is a fairly new process.

In spite of rapid disintegration in water, there has been some concern about an uneven soil acidity neutralization when granulated products were applied in the fields.

Neutralization of acid soils consists of two processes, chemical dissolution of the liming material and its diffusion into the soil phase. There are numerous publications dealing with the effect of particle sizes of ungranulated materials upon reactivity. In mathematical terms Bondorff (1974) proved that the physical

characteristics of a liming material were decisive for dissolution, and that different materials could be compared by fractionwise experiments. Concerning slow penetration into the soil deTurk (1938) demonstrated that the maximum diffusion distance from a polished slab of limestone in an acid clay soil was 0.6 and 1.7 cm after 259 and 528 days respectively (70°F).

Barber (1967) presented an extensive review indicating the importance of fine grinding. Concerning dolomite, Gamble & Kenworthy (1961) pointed out that the initial reaction of this material is slow, followed by a good lasting effect in the long run (2-5 years). Jensen (1939) described the effects on soil and yield in field experiments with different qualities of Danish chalks and particle sizes of coral liming material.

Sauerbeck & Rietz (1985) have developed a quick laboratory method using a strong acid (HCl at pH2) to describe dissolution of different products, and which can also be implemented for different qualities of chalks and dolomites. The granulated chalk in this experiment was tested by the Sauerbeck/Rietz method, and is declared to be 'highly reactive' ($R \geq 80\%$) in accordance with German fertilizer law. However, the method does not yield proper information about performance in soil.

Spotwise effects of granulated liming materials in soil have been found by Bussières (1980). He concluded that compaction or granulation of finely ground particles reduced the velocity of their reaction, and that very fine grinding of liming materials was not justified when it was incompletely mixed into soil.

This investigation was conducted in order to study the effect of granulation on the efficiency of chalk material, to compare granulated products of chalk and dolomite, and to determine whether or not precipitation on the surface prior to soil incorporation would increase the efficiency of these liming materials. It has been suggested that exposing granulates on soil surface to rain could counteract the reduced dissolution velocity from these particles.

MATERIALS AND METHODS

This experiment was carried out at Fureneset in 1994. The granulated liming materials used were Cretaceous chalk from Vereinigte Kreidewerke, Lägerdorf in Germany, mixed with Zechsteiner dolomite, and finely crystalline Ordovician dolomite from Franzefoss Bruk, Ballangen in Norway. The dolomite was granulated by means of a sulphite cellulose byproduct as a binding agent, whilst the chalk was granulated merely by aggregating wet material by rolling.

The average values of NV (neutralizing value according to Norsk Standard 1987) and Mg as declared by the companies, and confirmed by the Norwegian National Agriculture Inspection Service, are presented in Table 1A. Table 1B presents the particle size distribution of the liming materials as delivered, tested at Fureneset by dry sieving.

A loamy soil from Strømmen in Askvoll, Sunnfjord, was selected as a reference soil in the incubation method.This mineral soil was analysed mechanically by the pipette method, after oxidation of the organic material with H_2O_2, according to Elonen (1971). The results are presented in Table 2, together with its soil class name, in accordance with the classification of the Soil Survey of England and Wales (Hodgson 1974).

Table 1A. Average values of NV and Mg in granulated liming materials tested by the soil incubation method

Granulated liming material	NV	Mg %
Granulated chalk (Vereinigte Kreidewerke, Lägerdorf)	50	1.7
Granulated dolomite (Franzefoss Bruk, Ballangen)	60	12

Table 1B. Particle size distribution of the granulated liming materials as delivered, dry sieved at Fureneset

Particle size class (mm)	Distribution in percentage	
	Granulated chalk Vereinigte Kreidewerke, Lägerdorf	Granulated dolomite Franzefoss Bruk, Ballangen
<0.4	3.0	3.6
0.4-0.6	0.6	8.8
0.6-0.8	0.6	10.8
0.8-1.0	0.8	11.2
1.0-2.0	5.5	31.8
2.0-3.15	32.1	20.6
3.15-5.0	56.7	12.3
>5.0	0.7	0.9

Table 2. Mechanical analysis (Elonen 1971) of the mineral material <2 mm of the soil used in the laboratory incubation experiment. Numbers in parentheses present subdivisions for sand and silt fractions: Sand: (2-0.6 mm - 0.6-0.2 mm - 0.2-0.06 mm). Silt: (0.06-0.02 mm - 0.02-0.006 mm - 0.006-0.002 mm)

Soil	% sand	% silt	% clay	Soil class
Strømmen, Askvoll	11.3 (1.3-2.4-7.6)	73.2 (40.2-23.5-9.5)	15.5	Silty loam

A set of soil characteristics was analysed. The soil density values were obtained following the procedure described by Bondorff (1950). Loss on ignition was measured at 823 K for 12 h, and organic matter found by subtracting the hygroscopic water kept in the clay minerals of the soil, obtained from tables of correction. pH(H_2O) was achieved from the ratio soil:distilled water 1:2.5 v/v.

Exchangeable cations H, Ca, Mg, K and Na were extracted using the NH_4OAc method pH 7.00, as described by Thomas (1982). The acidity was assessed by back titration to pH 7.00, and Ca, Mg, K and Na by atomic absorption spectrometry. The results together with the calculated base saturation are listed in Table 3.

The soil incubation method used with the above mentioned reference soil is a laboratory method intended to resemble reactivity of liming materials under agricultural conditions. Because the experiment was conducted in the laboratory at a constant 293 K, the incubation rate was twice as fast as that in the field. Dried soil and the liming materials to be tested were mixed and water added to a defined field capacity at free drainage (70% for mineral soils). On each sampling date 10 cm^3 soil was collected separately from each pot with a miniauger, mixed and stirred with distilled water 1:2.5 v/v, and pH measured after one night. A detailed description is given in Erstad (1992).

The granulated liming materials were sieved and the following fractions were kept separate: <1.0, 1.0-2.0, 2.0-3.15 and 3.15-5.0 mm. Increments were supplied to the top of the soil, equal to 5000 kg CaO equivalents*ha^{-1} (20 cm plough layer), two weeks before mixing the liming materials into the soil.

The experiment was then subdivided according to rain treatments. Half of the pots were exposed to a daily small (0.22 mm), but intensive rain shower during a two-week period. The water was sprayed on the soil surface and the particles of liming material by a nozzle from a pump. The other half was left dry with no water flow on the liming material surfaces. After the rain treatment all soil samples and related liming materials were gently mixed in a tray. The mixing should not be any more thorough than might be expected from soil tillage processes. The incubation was performed on a barren soil.

The treatments that included liming materials had two replicates, while the treatment without liming was replicated eight times. The pots were covered with a parafilm during the 24-week incubation period, and this was removed 5-7 days before each sampling. Samples were taken out 1, 3, 6, 12 and 24 weeks after liming. The equipment used for pH measurements was a METROHM 654 digital pH meter with separate electrodes.

The net pH effects (DpH) were calculated by subtracting the pH values of the zero treatment from those of the limed treatments. Because of linearity between liming and pH in the range 4.5-6.5(7.0), it was possible to convert the pH increase from a kg CaO equivalents basis to that of liming material mass for commercial and practical use.

The same incubation experiment also included the effect of different wet sieved particle size classes of crude chalk from Lägerdorf. On the basis of these data, relative efficiency figures for the particle sizes of granulate liming materials were

Table 3. Chemical analyses of the soil used in the laboratory incubation experiments

Soil density	Loss on ignition		Organic matter	EXCHANGEABLE CATIONS					Base saturation, %
				Ca^{2+}	Mg^{2+}	K^+	Na^+	H^+	
$kg*dm^{-3}$	%	%	$pH(H_2O)$	$meq*100g^{-1}$					
0.91	12.7	10.7	5.1	1.26	0.54	0.19	0.19	20.0	9.8

assessed, relating their efficiency to pH increase. Finely ground chalk is known to give complete dissolution. The values for the 24 weeks were equivalent to an ENV of one year according to Erstad (1992), when multiplied by the results from NV analyses.

All analyses of variance were effected using the Statistical Analysis System (SAS), Release 6.03 (SAS INSTITUTE 1985, 1987a & 1988). Means of the variables (treatments) were compared with the Ryan-Einot-Gabriel-Welsch Multiple F Test (REGWF) at the 5% level (type I experimentwise error rate). All graphs were produced by the means of the SAS Graph (SAS INSTITUTE 1987b).

RESULTS AND DISCUSSION

Statistical analyses revealed that daily rain showers prior to soil incorporation had no major effects on soil pH during 24 weeks of incubation.

The net pH effects (ΔpH) attributable to the addition of commercially available granulated liming materials and their particle size classes during 24 weeks can be seen in Figs. 1 and 2, which present the results on the basis of kg CaO equivalents and mass products respectively. These figures included all pots, independent of rain exposure prior to mixing of soil and liming materials.

During the first weeks of the investigation the granulated dolomite had an apparent advantage in containing a high proportion of rather small granulates, i.e. in the particle size range 0.4-2.0 mm. In general the soil pH effects were quite uneven in the first weeks of incubation, mainly due to 'spot dissolution' of granulates and lime-saturated soil particles from rain exposed surfaces.

When samples were collected from each pot by an auger, the instrument occasionally hit lime penetrated areas, and randomly very acid zones. These quite disparate results could be observed in the first six weeks, after which the granulated chalk became superior on the basis of kg CaO equivalents, and there was a slight tendency for this effect on the basis of mass of liming materials, too.

Table 4 presents the analyses of variance for the soil ΔpH effects when adding granulated chalk and dolomite on a chemical equivalent basis versus material mass, unconstrained by treatments prior to soil incorporation.

As a commercially available product, the granulated dolomite was superior in the 6th week of incubation, whilst this trend changed in the period up until the 24th week. This development became conceivable when taking into consideration the gradual dissolution and the pH increasing capability of the coarser granulates, to the particular benefit of the chalk. The granulated chalk demonstrated a quite uniform 2.0-5.0 mm size distribution. As time passed, the granulated chalk exhibited a superiority on the basis of kg CaO equivalents. Owing to the 'lime spot effect' in soil there was, however, a substantial variation in pH measurements which only yielded a tendency on the basis of mass of liming materials. By this criterion the products proved practically equal in effect.

Although of no great significance there was a tendency for dissolution of the granulates to be promoted by the rain treatment prior to incorporation, particularly in the coarser granulates, as indicated in Fig. 3. These rapid pH effects were presumably counteracted by soil microbial acidification processes, which rendered higher pH values for the dry-stored samples at the end of the incubation period, as shown in Fig. 4. Acidification

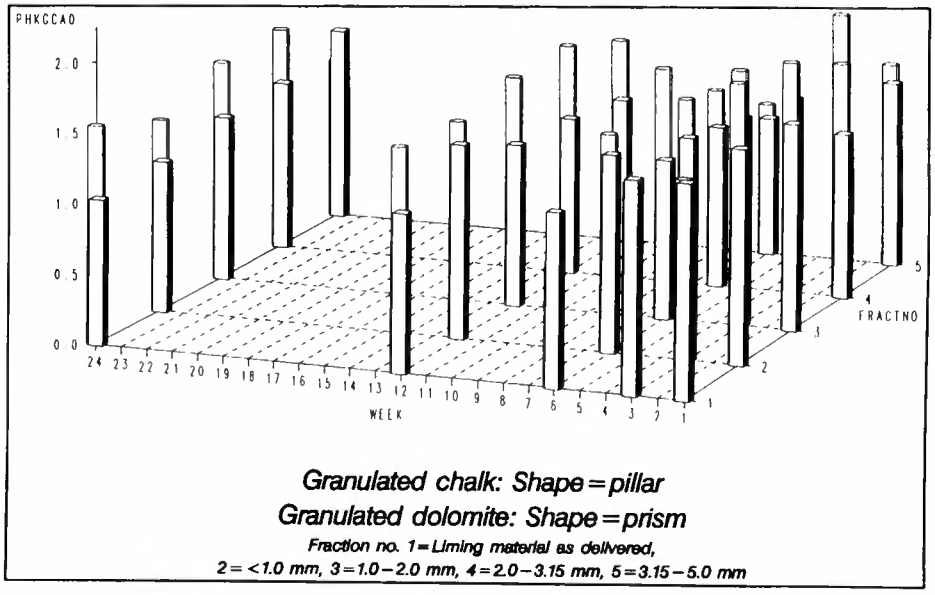

*Figure 1. ΔpH values (pHkgCaO) of commercially available granulated chalk and dolomite and their particle size classes during 24 weeks, presented on the basis of kg CaO equivalents. 5000 kg CaO equiv.*ha^{-1} added to a silty loam from Askvoll, Norway. Dry-stored and rain-shower-exposed samples of liming materials prior to soil incorporation all included*

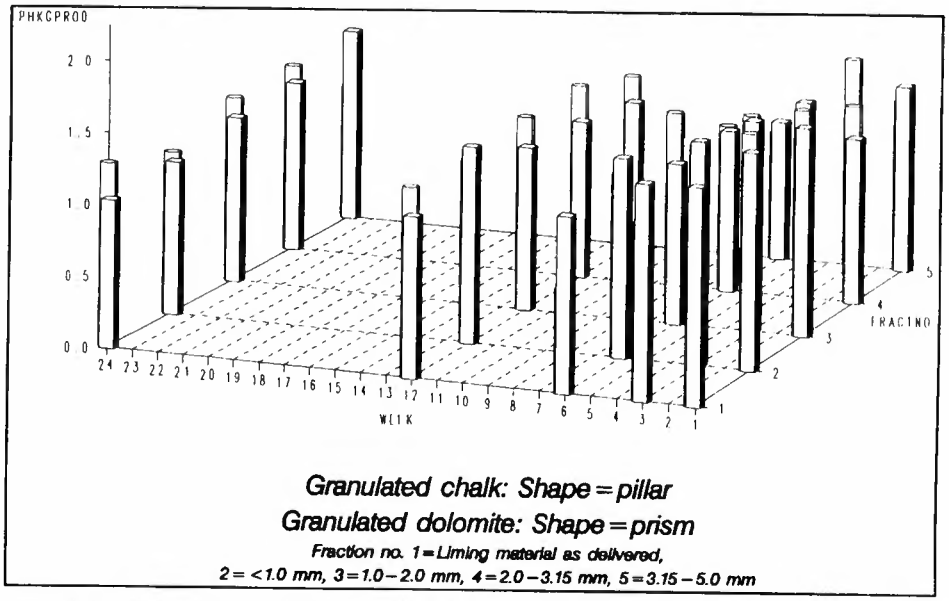

*Figure 2. ΔpH values (pHkgProd) of commercially available granulated chalk and dolomite and their particle size classes during 24 weeks, presented on the basis of mass of liming materials. Ca. 9000 kg liming materials*ha^{-1} added to a silty loam from Askvoll, Norway. Dry-stored and rain-shower-exposed samples of liming materials prior to soil incorporation all included*

Table 4. Analyses of variance of the soil ΔpH effects when adding the two granulated li- ming materials on kg CaO equivalent basis versus material mass, independent of dry sto- ring and daily rain shower treatments prior to soil incorporation. 5000 kg CaO equiv.*ha^{-1} or ca. 9000 kg liming materials*ha^{-1} added to a silty loam from Askvoll, Norway

Source of variation	DF tot.	kg CaO equiv. basis		Mass liming materials basis	
		MS	Model P>F	MS	Model P>F
Overall model	199	4.541	0.001	0.090	0.418
Effects by week					
1 week	39	0.973	0.030	0.007	0.827
3 weeks	39	1.163	0.036	0.038	0.665
6 weeks	39	0.265	0.181	0.037	0.566
12 weeks	39	1.730	0.001	0.233	0.107
24 weeks	39	0.757	0.022	0.011	0.758
Effects by fraction					
<1.0 mm	39	0.701	0.011	0.001	0.914
1.0-2.0 mm	39	2.147	0.001	0.297	0.020
2.0-3.15 mm	39	1.278	0.015	0.092	0.458
3.15-5.0 mm	39	0.887	0.056	0.041	0.642
Products, commercial	39	0.152	0.430	0.120	0.412
Products, effects by week					
1 week	7	0.001	0.966	0.107	0.599
3 weeks	7	0.001	0.949	0.146	0.434
6 weeks	7	0.247	0.074	0.493	0.012
12 weeks	7	0.420	0.260	0.076	0.551
24 weeks	7	0.527	0.011	0.130	0.100

attributable to organic matter decomposition and nitrification was found by Lyngstad (1979). The drop in pH values independent of treatments was due to extraordinary drying of the soil and thereby a decline in pH by chemical oxidation in the 6th week of incubation, mainly affecting the higher pH ranges (pH 6-7), which are quite sensitive to changes because of weak aluminium and carbonate buffering systems. The buffering at clay and humus colloids gives less pH stability in this range, and fluctuations are normally observed following changes in soil water saturation. The effect of rain showers could in this way be greater than that revealed by the pH measurements, as the acidification by microorganisms was a

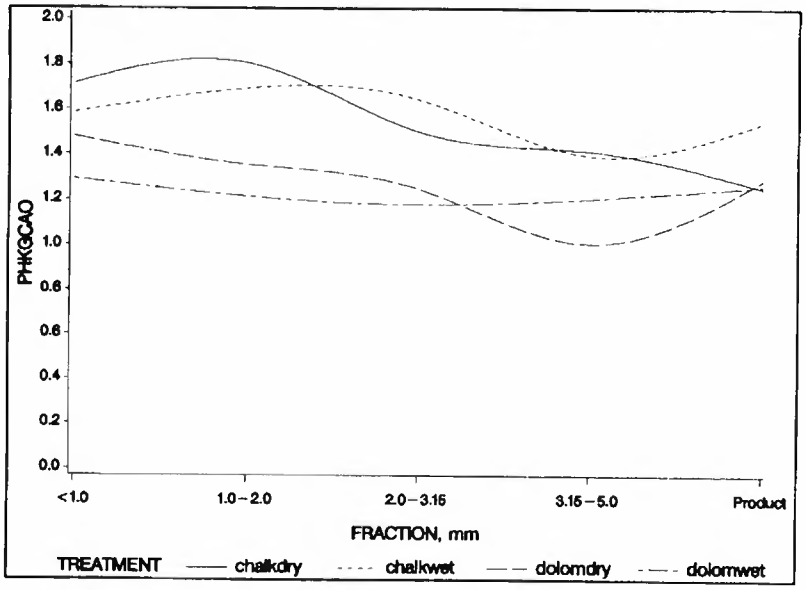

*Figure 3. ΔpH values (pHkgCaO) of particle size classes and commercially available products of granulated chalk and dolomite, presented on basis of kg CaO equivalents.5000 kg CaO equiv.*ha^{-1} added to a silty loam from Askvoll, Norway. Dry-stored and wet-exposed samples of granulated chalk and dolomite and zero treatments separately described. Average values of measurements during 24 weeks*

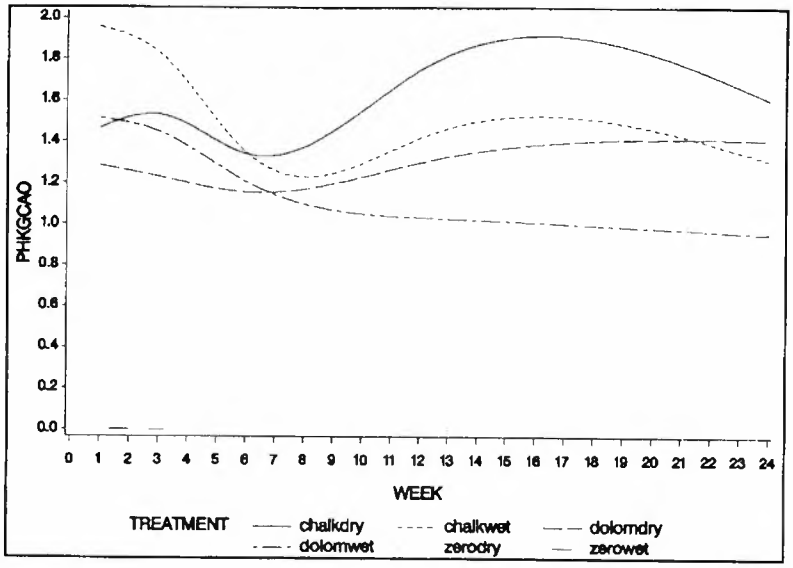

*Figure 4. ΔpH values (pHkgCaO) of granulated chalk and dolomite during 24 weeks, presented on the basis of CaO equivalents. 5000 kg CaO equiv.*ha^{-1} added to a silty loam from Askvoll, Norway. Dry-stored and wet-exposed samples of granulated chalk and dolomite and zero treatments separately described. Average values of commercially available products and their particle size classes tested*

rapid response to efficient liming reliefs.

Considering sulphite cellulose by-product as a granulating agent of the dolomite, it would seem reasonable to assume that coarser granulates of this dolomite product were more hampered by dry incorporation in soil than was the case for the chalk. The sulphite glue might cover the surfaces of the primary particles and thus delay dissolution and diffusion processes in the soil.

Table 5 (divided into 5A-5D) presents the relative dissolution efficiency for the particle sizes of granulated liming materials during a 24-week incubation period. The values for the 24 weeks match the ENV 1-year data for soil incubation when multiplied by NV levels.

The peak pH values tended gradually to move towards slightly coarser particles, due to microbial processes at previous high soil pH levels. The peak values are

Table 5. Relative dissolution efficiency (%) of particle size classes of crude chalk from Lägerdorf, and granulated liming materials of chalk and dolomite during 24 weeks, and ENV 1 year figures for the particle size classes of the granulated materials. Peak values indicated in bold figures

5A. Relative dissolution efficiency (%) of wet sieved crude chalk

Particle size classes, mm	Period of soil reaction (weeks)				
	1	3	6	12	24
<0.063	**100**	**100**	100	100	100
0.063-0.2	92	93	100	100	100
0.2-0.4	84	93	100	100	100
0.4-0.6	73	90	100	100	100
0.6-0.8	47	79	**100**	**100**	100
0.8-1.0	41	77	80	85	**100**
1.0-1.4	32	57	62	93	97
1.4-1.6	23	27	53	67	85
1.6-2.0	17	34	40	75	81
2.0-3.15	10	19	35	54	51
3.15-5.0	7	3	11	17	37
5.0-20	7	9	0	16	10

5B. Relative dissolution efficiency (%) of granulated chalk

Particle size classes, mm	Period of soil reaction (weeks)				
	1	3	6	12	24
<1.0	**91**	**91**	91	91	91
1.0-2.0	88	90	**100**	**83**	90
2.0-3.15	78	73	81	84	**92**
3.15-5.0	68	89	63	75	67

5C. Relative dissolution efficiency (%) of granulated dolomite

Particle size classes, mm	Period of soil reaction (weeks)				
	1	3	6	12	24
<1.0	**70**	**77**	**79**	**70**	**80**
1.0-2.0	68	73	65	59	70
2.0-3.15	54	69	65	57	70
3.15-5.0	62	37	57	70	80'

' uncertain result

5D. ENV 1-year figures for the particle size classes of the granulated materials

Particle size classes, mm	Granulated chalk	Granulated dolomite
<1.0	46	48
1.0-2.0	46	42
2.0-3.15	46	42
3.15-5.0	34	48'

' uncertain result

marked in bold figures. Some variations in the coarser particle size range were natural soil inhomogeneities due to the dissolution pattern of these particles. The results for the crude chalk, however, were found to fit very well with previous experimental data (Erstad 1992).

The data for the coarsest granulate size class is undoubtedly very uncertain, because sampling a soil with such unevenly distributed particles of highly soluble liming materials will always be arbitrary. If undissolved granulates are included by sampling, the pH level would be raised by laboratory measurements far beyond the true soil solution values. Furthermore, according to the deductions of Bussières (1980), the achieved results for the coarsest granulates would be too high. His methods were quite similar to those used in this experiment, but differed in that all soil was turned out and mixed again in each sampling for pH analysis. Granulates were more exposed to crushing than is normal in an arable soil. Nor could the inhomogeneity in soil could be measured in a proper way, either.

In this experiment a larger number of replicates was deemed desirable in order to reduce some of the random errors from time to time, even though the 'spot dissolution effect' could not be avoided.

CONCLUSIONS

The granulation process will not be favourable to any liming material because

it hampers dissolution and diffusion of these alkaline compounds into the soil. The neutralization steps are dependent on short distances to the soil colloids to obtain a homogeneous soil reaction. Obviously the two weeks' daily rain showers promoted the disintegration of the granulates on the soil surface, but the beneficial effects of this strategy were masked by the microbial offsets and the fact that the ensuing mixing of the soil should not be more vigorous than that expected from a thorough tillage on arable land, e.g. by a cultivator or a harrow.

On the basis of chemical content (kg CaO equivalents) the granulated chalk was superior to the dolomite product, at least in the short term, i.e. during the first year in the soil. Implementing the agglomerating capability of the chalk material itself by adding water in the process might be more advantageous than applying foreign materials such as sulphite cellulose byproducts, since this type of substance might inactivate carbonate surfaces. Other producers have used water-expanding clays as bentonite for the granulation process.

Chalk consists of small primary calcite crystals, with high intercrystalline porosity, which yield the most rapid dissolution. Dolomite is, however, a very slow- reacting carbonate mineral, but sustains steady pH levels in soil for a long time.

Consequently, sporadic measurements will continue to be made for another 2 years to check this process and to establish the ENV figures covering 5 years.

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The impact of the nickel industry in Russia on concentrations of heavy metals in agricultural soils and grass in Sør-Varanger, Norway

ÅSGEIR ALMÅS[1], BAL RAM SINGH[1] AND TORE E. SVEISTRUP[2]
[1]Agricultural University of Norway, Department of Soil and Water Science, Ås, Norway
[2]"PLANTEFORSK", Norwegian Crop Research Institute, Holt research centre, Tromsø, Norway

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Soil and grass samples from agricultural fields in Sør-Varanger, northern Norway were collected and analysed for concentrations of Cd, Cu, Cr, Ni, Pb and Zn to determine whether the atmospheric deposition from the Russian metal industry at Nikel has caused contamination of soil and grass with these metals. Heavy metal concentrations in soils were determined after extraction with 7 M HNO_3 and 0.005 M DTPA, grass samples were dry ashed and ash dissolved with aqua regia. The mean concentrations of HNO_3-extractable Cd, Cu, Ni and Zn in the investigated area were 0.8, 44.0, 30.4 and 47.5 mg kg^{-1} soil, respectively, wich indicates an accumulation of these elements. The mean concentrations of Pb and Cr were 9.1 and 20.4 mg kg^{-1} soil, respectively, which are near to the normal levels of these metals in Norwegian soils. The concentration of DTPA-extractable Cd in the soils was also relatively high (up to 0.58 mg kg^{-1}). In grass samples, the concentrations of most of the metals were in the normal range, but the concentration of Cu (19.1 mg Cu kg^{-1} dry matter) exceeded the normal level. Important soil properties which accounted for the variation in the concentrations of Cd, Cu, Cr, Ni, Pb and Zn in the soil were organic carbon, cation exchange capacity, pH and available P. The effect of these properties on metal concentration varied greatly among metals. The results show an accumulation of HNO_3-extractable Cd, Ni, Zn and to some extent also Cu in soils in the Sør-Varanger county that are exposed to winds from Nikel and Zapolyarnyy. Grass uptake of Cd, Cu, Zn and Pb was only significantly correlated with the DTPA-extractable fraction of these metals in the soil. Grass contamination was limited to Cu.

Key words: Grass, heavy metal pollution, metal industry, northern Norway, Russia, soils.

Åsgeir Almås, Agricultural University of Norway, Department of Soil and Water Science, Box 5028, N–1432 Ås, Norway

Previous studies have revelated high concentrations of heavy metals in wildlife, berries, ground and forest vegetation, water, and in the air in the border areas of North Norway, as a result of the Russian metal industry in Nikel and Zapolyarnyy (Norwegian Institute for Air Research (NILU) 1991a and b; Aamlid 1992a and b; Sivertsen et al. 1992; Steinnes & Sjøbakk 1992; Norwegian Pollution Control Authority (SFT) 1993a and b). The contamination is caused by

airborne metals emitted by the metal industry and the wind direction is shown to be a factor in determining the extent of contamination. Nickel, Cu and As are thought to be emitted from the Russian nickel industry, and atmospheric depositions were 2-4 times higher on the Russian side of the border than on the Norwegian side. Concentrations of the metals Pb, Cd and Zn were also detected and found to be at the same level as those found in South- and East Norway, but higher than the concentrations detected in the remaining stations in Norway (NILU 1994). Hence, industrial activity such as that located in Nikel and Zapolyarnyy may be a significant source of heavy metal pollution of soils and grass in Sør-Varanger. The survey conducted by these investigators was concentrated mainly on natural wildlife and vegetation. To our knowledge there have not been any investigations carried out on cultivated soils and crops grown in this area.

Atmospheric deposition in Norway was shown to contribute toward from 20 to 50% of the Cd burden of plants (Singh et al., 1991). Industrial pollution may supply the terrestrial environment with concentrations of some metals that are several times higher than the levels produced by natural weathering processes, and the atmospherically deposited metals are also much more available to plants than metals in the mineral material (Singh & Steinnes 1994). Direct contamination seems to be the most important pathway into the green parts of the plants, though stem and roots absorbe heavy metals from the soil through root uptake (Buchauer 1973). Yearly increases in heavy metals in surface layers of agricultural soils were generally <1%, but this increment may become significant over a long period of time if the air pollution persists (Singh & Steinnes 1994). Use of phosphoric fertilizer could be a minor factor in enhaced Cd concentrations in the soil, but accumulation of Cd in agricultural soil after long term use of phosphate fertilizers has been reported by several investigators (Gunnarsson 1983; Bærug & Singh 1990; He & Singh 1993). Heavy metals in soils are affected by both soil properties and climatic conditions. The low evapotranspiration in northern Norway due to low temperatures has led to the accumulation of organic matter in many places, which in turn resulted in the development of peat soils and raw humus. Soils with a high content of organic C are considered to retain heavy metals efficiently (White & Chaney 1980; Elliot et al. 1986; Christensen 1989).

Metals such as Co, Cu, Fe, Mn and Zn are essential elements in biological systems, and are connected with a number of enzymatic reactions. On the other hand, metals such as Cd, Pb and Hg are toxic elements, and these metals can be hazardious to health, even at low concentrations. The mining industry, such as that sited in Nikel and Zapolyarnyy, and the use of phosphate fertilizers, may be important sources of soil and plant pollution in Sør-Varanger. Therefore it was concidered expedient to examine the possibility of heavy metal contamination of agricultural soils and crops in this part of Norway. The aims of this investigation were: (1) To assess the impact of the nickel industry in Russia on the concentrations of Cd, Cu, Cr, Ni, Pb and Zn in soils and crops in the agricultural areas of Sør-Varanger, and (2) to investigate the relationship between soil properties and the concentrations of these metals in soils and in grass.

MATERIALS AND METHODS

Description of the sampling area

Climate

The sampling area lies in a region with a very cold climate with temperatures (1961-90) varying from -15°C in December to 15°C in July. The annual mean temperature in the area is about -1.0°C and the precipitation ranges from 391 to 440 mm (The Norwegian Meteorology Institute 1993a and b). The prevailing winds are from the northeast, south-southwest and west-southwest. Winds from northerly and easterly directions are infrequent (NILU 1991a and b).

Parent material

The rock material composition in Sør-Varanger is complex, but granites and gneiss are the most common rock types, of though areas with lime rocks, micashales, gabbros, amphiboles and sandstones have also been described (Siedlecka & Nordgulen 1992). The district is dominated by loose masses of shallow moraines, covering most of the landscape. Along the Pasvik river, dense bottom moraine covers most of the landscape with overlaying bogs and cultivated peat soils. Marine clay soils are also an important feature. Some deltas of glacifluvial material are deposited in the valley, while along the Pasvik river there are deposites of fluvial material (Lebesby & Bakkejord 1985).

Among the 27 sampling sites, 9 were of organic soils and 18 were of mineral soils. Among the mineral soils, 9 were sandy loam, 6 were sandy silt loam, 2 were sand soils and 1 was a clay loam.

The background levels of metals in the soil samples are presented in Table 2 and those for grass in Table 4. In the text these levels will bee referred to as normal levels of heavy metals in soils and grass.

Soil and grass sampling

Soil and the corresponding grass samples were collected from different farms located in Sør-Varanger in Finnmark county (Fig. 1). The grass samples were collected during the growing season (summer 1993), whereas the soil samples were collected after the growing season (August 1993).

At each sampling site, two soil samples from 0-2 cm and 2-15 cm depths and one grass sample (about 1 kg) were collected. Samples of both soil and grass were collected (in pairs) from permanent fields (no crop rotation in the past 10 years) and from cultivated fields (crop rotation usually every fifth year). A total of 22 soil samples and 11 grass samples, were collected from each of the field types. In addition soil and grass samples amounting to 12 and 6 respectively were collected at Svanhovd Environment Centre from three different soil types (two sandy soils and one peat soil). The fields for pair sampling were located close to each other to minimize the effect of soil types, topography and climatic conditions. Soil samples were air dried, crushed and passed through a 2-mm sieve and the grass samples were dried at 60-70°C and ground in a stainless steel mill.

Soil analysis

Available phosphorus (P-AL) was determined in accordance with the method by Egnér et al. (1960) and the cation exchange capacity (CEC) with the method by Schollenberger & Simon (1945). Soil pH was measured in a soil to water ratio of 15:35. Organic carbon was determined by LECO-carbon analyser and for the grain size distribution analysis the pipette method of Elonen (1971) was followed. For the total content of Cd, Cr,

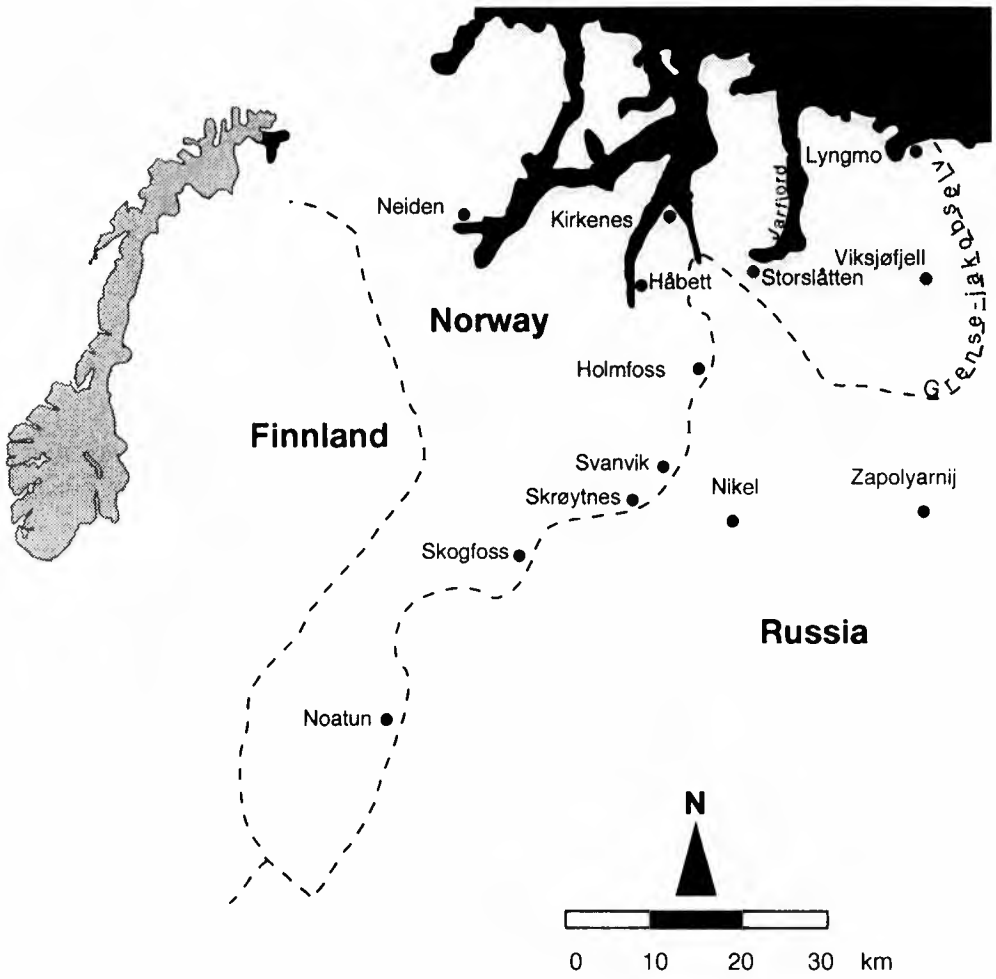

Figure 1. Location of the sampling sites in Sør-Varanger municipality in northeastern Norway

Cu, Ni, Pb and Zn, soil samples were extracted with 7 M HNO_3 (Øien & Gjerdingen 1977) and the extract was analysed for Cr, Cu, Ni and Zn by ICP (Inductively Coupled Plasma) emission spectrometry. Cadmium and Pb concentrations in the-same extract were determined by atomic absorption spectrophotometry (AAS). Soil samples were also analysed after extraction with 0.005 M DTPA (Lindsay & Norvell 1978). The concentrations of Cd and Pb in the DTPA extract, were determined by AAS using a graphite furnace, whereas the concentrations of Cr, Cu, Ni and Zn were determined by AAS.

Grass analysis

The grass samples (3 g) were dry ashed at 580-600°C (Cd and Pb only at 450°C) for 4-6 h. The ash was treated with concentrated HNO_3: HCl in the ratio 1:3. After evaporation, the residue was dissol-

ved in 5 ml concentrated HNO_3, diluted to 50 ml with distilled water, and filtered through blue ribbon filter paper. Copper and Zn concentrations in the digested solution were determined by ICP emission spectrometry, whereas the concentrations of Cd and Pb were determined by graphite furnace AAS.

RESULTS AND DISCUSSION

Soil properties

The mean value of soil pH was 5.6 (Table 1), which is slightly below the generally recommended level (pH= 6-7) in cultivated soils (Krogstad 1992). The high mean content of organic carbon in these soils is caused by a number of samples originating from peat soils. Out of a total of 56 samples, 38 were collected from peat soils. The concentrations of P-AL ranged from high to very high (Krogstad 1992) in these soils, and the mineral soils contained lower levels of P-AL (Table 1) than the peat soils.

Heavy metals in the soils

The concentrations of different heavy metals presented in Table 2 reflect a wide variation among the soils. One soil sample at Lyngmo contained an abnormally high level of Cu which may have been caused by local contamination of the site. The DTPA-extractable Cr was below the detection limit (0.01 mg kg^{-1}) and hence was not determined. The results revealed that the concentrations of the HNO_3-extractable metals in the soil in were higher several places than normal background levels found in soils (Table 2).

Vertical distribution of metals in the soil

Metals supplied through atmospheric deposition are generally accumulated in the topsoil because they are relatively less mobile even at low pH (Elliot et al. 1986; Schmitt & Sticher 1991), and are subject to sorption by organic material present in the upper soil layers. In the present study the concentrations of heavy metals in the top (0-2 cm) and underlying (2-15 cm) soil layers from permanent fields differed significantly ($p<0.05$), suggesting that the atmospheric deposition has caused an accumulation of Cd, Cu, Ni and Zn in the top layer of the soils. This effect was not significant for Pb and Cr (Table 3). No significant differences were observed in the concentrations of heavy metals in the

Table 1. Some important properties of the soil samples (0-2 cm and 2-15 cm depths)

Soil properties	Number of samples	Minimum	Maximum	Mean	Standard deviation
pH	56	4.30	7.20	5.60	0.60
CEC (me/100 g)	56	4.06	101.87	39.96	26.91
Clay (%) [1)]	18	0.40	22.80	9.24	6.10
Organic C (%)	56	1.01	47.15	18.65	15.47
P–Al (mg/100 g)	56	3.80	90.00	33.88	19.98

[1)] Particle size analysis was carried out only in the 2– 15 cm depth of the mineral soils

Table 2. The concentrations (mg kg^{-1}) of HNO_3-extractable and DTPA-extractable Cd, Cu, Cr, Ni, Pb and Zn in the soils (0-2 cm and 2-15 cm depths, n= 56)

Metals/ Extractants	Minimum	Maximum	Mean	Standard deviation	Normal levels [2]
HNO_3-extractable					
Cd	0.32	2.10	0.82	0.40	0.07
Cu	6.20	[1] 553.00	44.00	76.60	15
Cr	5.00	51.25	20.44	11.77	40
Ni	6.25	136.88	30.43	27.37	25
Pb	3.44	25.63	9.06	0.58	14
Zn	7.50	258.75	47.54	50.75	55
DTPA-extractable					
Cd	<0.01	0.58	0.14	0.14	
Cu	0.45	[1] 255.00	9.86	34.54	
Ni	0.50	70.00	7.95	11.50	
Pb	<0.01	8.85	1.12	0.71	
Zn	1.75	88.65	13.93	16.68	

[1] One of the soil samples showed extremely high concentrations of Cu
[2] Kongshaug (1992)

Table 3. Vertical variation of metal concentrations between soil depths (mg kg^{-1}) in soil from permanently cultivated fields (n= 22)

Sampling depth	Cd	Cu	Cr	Ni	Pb	Zn
HNO_3-extractable	**	*	ns	**	ns	**
0-2 cm	1.11	46.20	16.50	45.10	10.92	82.50
2-15 cm	0.75	17.90	22.60	17.60	8.10	37.60

*,** and ns, indicate significant differences at 95%, 99% and not significant respectively

permanent fields and the cultivated fields in rotation. This may indicate that there is no detectable effect of cultivation on metal concentration in the soil.

Variation among sites

The soil samples collected were grouped according to site location and each group consisted of one pair of samples from the two depths. To distinguish between the heavy metal concentration distribution between the sites, the mean concentrations of HNO_3-extractable and DTPA-extractable Cd, Cu, Cr, Ni, Zn and Pb in soil samples from each site were calculated and are precented in Figs. 2 and

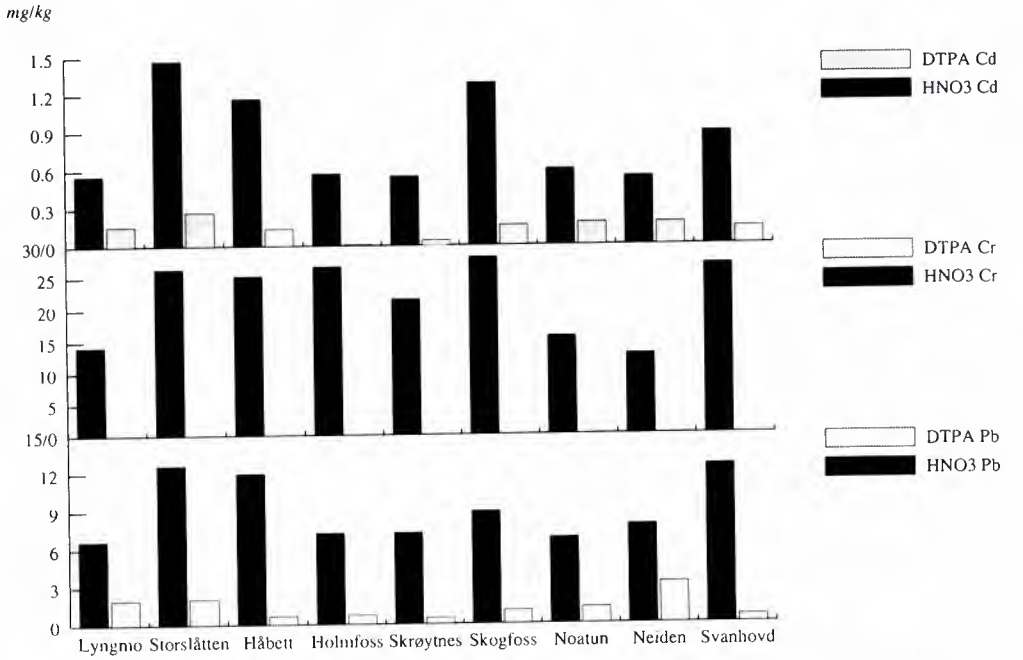

Figure 2. Concentrations of HNO_3- and DTPA-extractabel Cd, Cr an Pb in soil from nine sampling sites in Sør-Varanger, Norway. Each bar represents an average of four samples from each of the samplings sites.

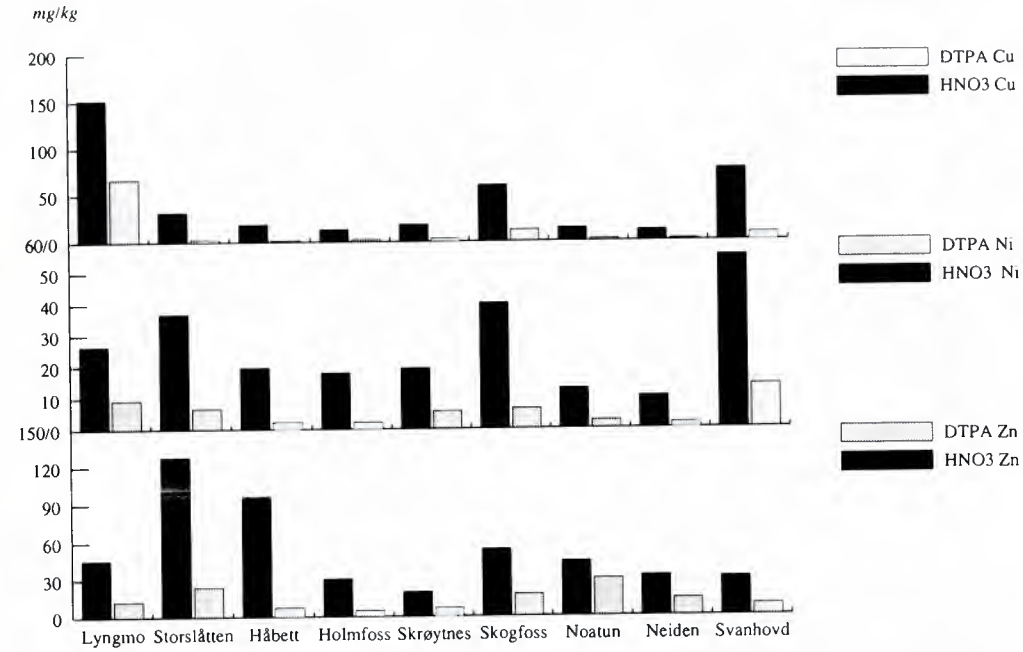

Figure 3. Concentrtrations of HNO_3- and DTPA-extractable Cu, Ni and Zn in soil from nine samøling sites i Sør-Varanger, Norway. Each bar represents an average of four samples from each of the sampling sites.

3. The concentrations of HNO_3- extractable Cd and Zn were significantly higher ($p<0.05$) in the soils at Storslåtten compared with those at the other sites, with the exception of the soils at Håbett, Skogfoss and in the case of Cd, at Svanhovd. The HNO_3-extractable Ni was significantly higher in the soil at Svanhovd compared with that from most of the other sites. This indicates that the highest accumulation of Cd and Zn occurred in the soil at Storslåtten and of Ni at Svanhovd. The concentrations of Cu and Pb showed the same trends as those of Cd, Ni and Zn, but the concentration differences between sites were found not to be significant. The levels of heavy metals in soils from Sør-Varanger reported in this article are lower than those reported in the study by Steinnes & Sjøbakk (1992), in wich the samples were collected from virgin lands that were not affected by agricultural activities, and hence the metals deposited may have remained in the upper few centimetres of the soil. The SFT (1993b) reports concentrations of Cd, Ni and Cu in precipitation at the meteorological station at Svanhovd 10 to 15 times higher than those reported in similar studies at either Noatun, or other locations in Norway. The rate of deposition was higher a few years earlier as the levels of Cu, Ni, Zn in the precipitation were 2-3 times higher in 1989 than in 1992. The soils containing the highest levels of the investigated metals are located in areas where the winds from the industrial cities in Russia are most frequent. NILU (1991a) describes the districts between the border and Viksjøfjell-Jarfjord as being the most highly charged areas of general contamination from Russian industry, whereas the areas close to Kirkenes and Noatun districts show concentrations below the normal level.

The soil samples in this study contained higher concentrations of HNO_3- and DTPA-extractable Cd than normal background levels and concentrations of Cd found in the soils from South Norway and Trøndelag county (Bærug & Singh 1990). Copper concentrations exceeding the background levels were found only in samples from Skogfoss and Svanhovd. Chromium and Pb concentrations were below the background levels in most of the soils. The concentration of HNO_3-extractable Ni in the soil samples exceeded background levels only at Svanhovd. The concentration of Zn in the soil samples from Storslåtten and Håbett contained a higher concentration of HNO_3-extractable Zn than the back-

Tabell 4. Cadmium, Cu, Pb and Zn concentrations (mg kg^{-1}) in grass samples (n=27)

Element	Minimum	Maximum	Mean	Standard deviation	Normal concentrations [1]	
					Minimum	Maximum
Cd	<0.01	0.10	0.03	0.02	0.0	0.93
Cu	8.42	47.70	19.10	11.90	5	13
Pb	0.42	1.00	0.15	0.64	0.07	5.4
Zn	3.68	49.10	11.10	21.30	20	150

[1] Kongshaug (1992)

ground level in soils.

No significant differences in metal concentrations between soil samples from the permanent and cultivated fields were detected, and the correlations between Cd and Zn and the plant available P (P-Al) were low (Table 5). This perhaps suggests that the long term use of phosphoric fertilizer had only a minor effect on metal accumulation in the agricultural soils of Sør-Varanger.

Heavy metals in grass

The concentrations of Ni and Cr in grass were below the detection limits of the method used. The concentrations of Zn, Cu and Pb in grass (Fig. 4) did not show any significant difference among sampling sites ($p>0.05$). Among grass samples collected from permanent fields, the Cd concentrations varied. In determining the Cd concentrations in grass, the cation exchange capacity was pronounced to be more important than the total concentrations in the soils. Cadmium in grass was highest in the samples from Håbett and Noatun (0.09 mg kg^{-1} and 0.10 mg kg^{-1}, respectively), but the soils from these sites had the lowest CEC. The mean concentrations and the ranges of concentration for Zn, Cu, Cd and Pb in grass material are disented in Table 4. The concentration of Cd in grass (with some exceptions) was within the normal range found in grass but it was lower than the Cd concentration in grass, oat and potato samples from South Norway and Trøndelag county (Bærug & Singh 1990). This variation in Cd concentration in grass could primarily be ascribed to a significant decline (up to 5 times) in the Cd deposition from the southwest to northern

Table 5. Relationships between HNO_3- extractable and DTPA-extractable Cd, Cu, Cr, Ni, Pb and Zn and the soil properties. Only significant relationships ($p<0.05$) are listed

Extraction solution	Variables in eqution[1)]	r^2
HNO_3- extractable		
Cd	$Y = - 0.48 + 0.01\ X_3 + 0.19\ X_4$	0.28
Cu	$Y = 14.58 + 1.58\ X_3$	0.10
Cr	$Y = - 45.72 - 1.55\ X_3 + 11.39\ X_4 + 0.78\ X_2$	0.44
Ni	$Y = 27.84 + 3.04\ X_3 - 1.36\ X_4$	0.29
Pb	$Y = 7.90 + 0.08\ X_2 - 0.06\ X_5$	0.23
DTPA– extractable		
Cd	$Y = - 0.09 + 0.19 X_1 + 0.01\ X_5$	0.38
Cu	$Y = - 6.46 + 0.47\ X_1 - 1.09\ X_3 + 0.40\ X_2$	0.96
Ni	$Y = 11.83 + 0.39\ X_1 - 2.80\ X_4$	0.84
Zn	$Y = - 2.26 + 0.13\ X_1 + 0.30\ X_5$	0.29

[1)] X_1 (HNO_3-extractable), X_2 (CEC), X_3 (organic C), X_4 (pH) and X_5 (P–Al)
HNO_3-extractable Zn and DTPA– extractable Pb were not significantly related to any of the soil properties.

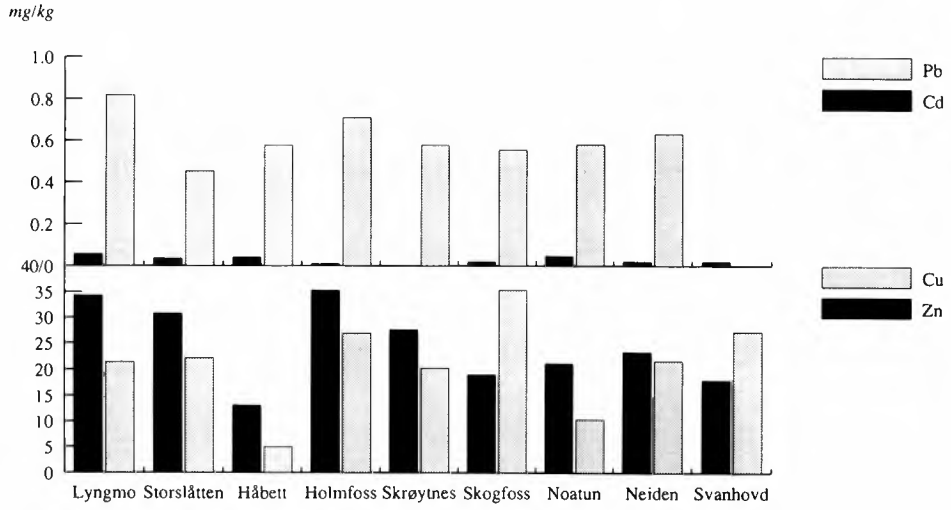

Figure 4. Total concentrations of Cd, Cu, Pb and Zn in plants from nine sampling sites in Sør-Varanger, Norway. Each bar represents an average of two samples from each of the sampling sites.

parts of Norway (Steinnes 1980). The concentration of Pb in grass was somewhat higherthan the normal level. Since the root uptake of Pb is generally insignificant (Singh & Jeng 1993), the detected grass Pb could be ascribed to the atmospheric deposition on grass surfaces. Copper and Zn concentrations in grass were generally within the normal range. There were no significant differences in heavy metal concentrations in grass grown in the different soils at Svanhovd Environmental Centre.

Relationships between heavy metals in soils and grass and the soil properties

The relationships between HNO_3-and DTPA-extractable metals and the soil properties, such as CEC, pH, P-Al, organic C, sand, silt and clay, were assesed by using the stepwise regression analysis. The regression equations along with the coefficient of determination (r^2) values showing significance at $p<0.05$ are presented in Table 5. Similar relationships between metals in grass and soil properties were also studied, but r^2 was not found to be significant and hence the results are not reported.

Cadmium:

Organic C and pH were the main soil properties affecting HNO_3-extractable Cd which explained 20% and 8% of the variations, respectively. The DTPA-extractable Cd showed a significant correlation with HNO_3-extractable Cd and P-AL, and the HNO_3-extractable Cd alone accounted for 29 % of the variation. The correlation value was improved when P-AL was included in the equation.

Copper:

The HNO_3-extractable Cu was mainly influenced by organic C but the correlation was very weak. The r^2 value was improved from 0.10 to 0.41 when an extreme value of Cu in the topsoil at Lyngmo site was excluded from the

calculations. The correlations between the soil properties and the DTPA– extractable Cu were, on the other hand very strong, as the HNO_3-extractable Cu together with organic C and CEC could accounted for as much as 96% of the variations.

Chromium:
Organic C, pH and CEC were the soil properties which showed significant correlation with the HNO_3-extractable Cr and together accounted for 25% of the variations.

Nickel:
Organic C and CEC showed significant correlation with the HNO_3-extractable Ni in the soil and these properties accounted for 28% of the variations. Apart from the HNO_3-extractable Ni, pH was the only soil property which affected the DTPA–extractable Ni significantly.

Lead:
The most important factor affecting the HNO_3-extractable Pb was CEC. Lead is retained very efficiently in the soil (Schmitt & Sticher 1991; Elliot et al. 1986) and hence it is not surprising that the DTPA-extractable Pb did not display significant relationship with any of the soil properties.

Zinc:
None of the soil properties displayed any significant relationship with the HNO_3-extractable Zn. The DTPA-extractable Zn was related to the HNO_3-extractable Zn and P-AL which together were responsible for 29% of the variations.

CONCLUSION

The results suggest that Cd, Ni and Zn and to some extent also Cu are accumulated in the agricultural soils of Sør–Varanger as a result of the atmospheric deposition from the industrial towns of Nikel and Zapolyarnyy in Russia. The accumulation of Cd, Cu, Ni and Zn was more marked in the soils most exposed to winds from these industrial towns. Among the metals, the concentration of HNO_3-extractable Cd (mean value of 0.82 mg kg-1) in the soil samples was much higher than Cd found in agricultural soils at other locations in Norway (Bærug & Singh, 1990). Grass material, on the other hand, did not contain elevated levels of these metals with the exception of Cu, which exceeded the normal level found in plants from other parts of Norway. Among the soil properties, organic C, CEC, pH and P-AL displayed significant correlations with a number of metals, but none of the properties showed any significant relationship with metal concentrations in grass samples.

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Rumex longifolius DC., *Ranunculus repens* L. and *Taraxacum officinale* (Web.) Marss. in grassland

1. A simple model relating dry matter yield to proportion of dicots

ESPEN HAUGLAND
Norwegian Crop Research Institute, Plant Protection, Department of Herbology, Aas, Norway

Haugland, E. 1995. *Rumex longifolius* DC., *Ranunculus repens* L. and *Taraxacum officinale* (Web.) Marss. in grassland. 1. A simple model relating dry matter yield to proportion of dicots. Norwegian Journal of Agricultural Sciences 9: 75-83 ISSN-801-5341.

A study was carried out on the effects of three dicotyledonous species, *Rumex longifolius* DC., *Ranunculus repens* L. and *Taraxacum officinale* (Web.) Marss., on dry matter (DM) yield of grassland. Field trials were established at locations where one of the three species was the predominant dicot. Within each experimental site ten plots were selected along one or two transects, aiming at as large a variation as possible between the plots in the proportion of the predominant dicot. Parallel to these plots, another ten plots were treated with a ready-to-use mixture of dichlorprop and MCPA. The parameters of the present model were estimated from the unsprayed plots, while the model was validated by data from the sprayed plots. The effects on DM yield were not significantly different between the species. In conclusion, the proportion of dicots did not affect total DM yield in the first harvest, while the effect was negative in the second cut. The present model is acceptable for the purpose of predicting yield changes following a herbicide renovation in grassland.

Key words: Dicotyledonous species, grassland, herbicide, *Ranunculus repens, Rumex longifolius, Taraxacum officinale,* yield model, weeds.

Espen Haugland, Norwegian Crop Research Institute, Plant Protection, Department of Herbology, Fellesbygget, N-1432 Aas, Norway.

In addition to grasses, grasslands often include various dicotyledonous species that are usually termed «weeds». But, according to Dietl (1982) a species should not be regarded as a weed unless it has a negative effect on yield, the technological properties of the forage, or the intake, production or health of the animals. This has led to the development of the concept of «threshold values for weeds in grassland». As a key part in the establishment of threshold values in grassland, it is necessary to elucidate the relationship between the proportion of dicots in grassland and herbage yield.

In arable crops, yield or yield loss is often related to weed density (e.g. plants/m^2) by using additive experiments. Sim-

ple models exist relating yield loss to weed density (e.g. Spitters 1983; Cousens 1985; Håkansson 1988). There are clearly several differences between arable crops and grassland. Weeds in annual crops are usually a disadvantage, while in grassland they can, with the exception of extremely toxic species, be eaten by animals and they should therefore be regarded as part of the DM yield. Weeds in an annual crop are mainly competitors, germinating more or less simultaneously with the crop. In grassland, when sown grass species die or lose their production potential, wild grasses or dicots replace them by a substitutive mechanism. The content of dicots in grassland is often measured by proportion of ground cover or biomass, in contrast to weed density in arable crops. It is therefore reasonable to believe that the relationship between yield, or yield loss, and weed density found in annual crops is not applicable in grassland.

As far as is known there are no simple models relating herbage yield to the proportion of dicots in grassland. The aim of the present investigation was therefore to develop a biologically realistic model suitably describing this relationship.

EXPERIMENTAL DATA

Eight meadows were selected in different parts of Norway (Table 1). In each field *Rumex longifolius* DC., *Ranunculus repens* L. or *Taraxacum officinale* (Web.) Marss. was the predominant herb. At each experimental site ten plots of 1 m^2 were selected along one or two transects, aiming at as large a variation as possible between the plots in proportion of the predominant dicot. Parallel to these unsprayed plots, another ten plots were sprayed. The goal was to achieve an equal amount of the species within each of the ten unsprayed/sprayed parallels before herbicide treatment.

The herbicide treatment took place in the first spring of the experimental period, about 3-4 weeks before the first harvest, when the herbs had large rosettes. A ready-to-use mixture of dichlorprop and MCPA was applied at a rate of 3 + 1 kg a.i./ha respectively, in 500 l water.

The experimental sites are described in Tables 1 and 2. Fertilization was carried out by the farmers in the same way as in the rest of the field. Both commercial fertilizer and farmyard manure were used. All fields were harvested twice each year for two or three years, except for experimental sites 2 and 6, where the climatic conditions made only one harvest possible. The first harvest was taken within two weeks after the beginning of heading of timothy (*Phleum pratense* L.) and the second cut six to eight weeks after the first. At each harvest the herbage of each plot was separated into grasses and dicots before drying at 60°C for 48 h before weighing. The experimental work was performed by local experimental groups.

MODEL DERIVATION

The relation between the grass component and the dicot component of total herbage yield can be illustrated by a bivariate diagram as described and discussed by Snaydon & Satorre (1989). It is assumed that grasses and dicots sharing the same niche compete for the same growth resources, with the result that no overyield, compared to the components grown alone, is expected. This is illustrated by the straight lines in a NW-SE direction in Fig. 1 joining the axes of the yields of the two components. The yield level varies between fields, which is illustrated by parallel lines, while the lines radiating

Table 1. Location of the experimental sites, altitude in metres above sea level, age at the start of the experiments and mean yearly nitrogen fertilization (N)

Exp. sites	Predominant dicot	Predominant grass species	Total number of species	Location	Altitude m	Age yrs	N kg/ha
1	*Rumex*	Poa	7	62° 35' N	4	6	210
	longifolis	pratensis	20	6° 16' E			
2	*Rumex*	Phleum	20	69° 56' N	30	4	100
	longifolis	pratense		23° 15' E			
3	*Ramuculus*	Dactylis	21	60° 9' N	65	6	200
	repens	glomerata		5° 45' N			
4	*Ranunculus*	Poa	18	60° 20' N			
	repens	pratensis		5° 42' E	190	>10	160
5	*Ranunculus*	Poa	19	60° 34' N			
	repens	trivialis		5° 4' E	30	>20	220
6	*Ranunculus*	Poa	20	62° 49' N			
	repens	pratensis		11° 22' E	460	7	130
7	*Ranunculus*	Poa	5	68° 44' N			
	repens	pratensis		18° 7' E	160	>10	180
8	*Taraxacum*	Poa	10	61° 18' N			
	officinale	pratensis		5° 28' E	170	5	200

Table 2. Percentage of dicots on the experimental sites, means (x) and standard deviation (SD), average of the two years following herbicide treatment

Exp. site	Predominant dicot	Percent of dicots							
		1st harvest				2nd harvest			
		Unsprayed		Sprayed		Unsprayed		Sprayed	
		x	SD	x	SD	x	SD	x	SD
1	*Rumex longifolius*	36	12	24	11	25	11	20	11
2	*Rumex longifolius*	18	10	1	2	only one harvest			
3	*Ranunculus repens*	43	23	5	8	52	20	12	18
4	*Ranunculus repens*	25	18	2	5	34	25	4	9
5	*Ranunculus repens*	34	13	1	2	25	13	2	3
6	*Ranunculus repens*	29	30	13	25	only one harvest			
7	*Ranunculus repens*	60	24	0	0	67	24	0	0
8	*Taraxacum officinale*	53	18	31	28	65	18	54	29

from the origin indicate various proportions of the dicots.

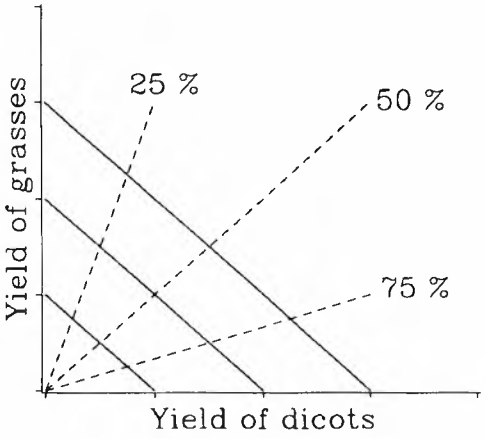

Figure 1. Bivariate diagram where yield of grasses per unit area is plotted against yield of dicots. Parallel lines in the NW-SE direction indicate various yield levels. The lines radiating from the origin indicate various proportions of the dicots

Based on the assumption that there is a straight-line relation between grass yield and dicot yield, this relationship can be expressed as

$$g(x)=g_0+ \beta^*x \qquad (1)$$

where g(x) is grass yield as a function of yield of dicots (x). The intercept g_0 is the grass yield when no dicot is present. Total yield (Y) may be expressed as

$$Y = g_0+ (\beta^*+1)x \qquad (2)$$

From equations 1) and 2) it is apparent that the proportion of dicots (p) in the grassland can be expressed as

$$p= \frac{x}{(g_0+(\beta^*+1)x} \qquad (3)$$

and that the total yield can be reexpressed, in terms of proportion of dicots, as

$$Y_{model} = \frac{g_0}{1-\beta p} \qquad 0 \le p \le 1 \qquad (4)$$

where $\beta=\beta^*+1$. Before renovation DM yield (Y_i) and proportion of dicots (p_i) of site i may be known. The potential yield when dicots are removed (g_{0i}) can be calculated using the expression

$$g_{0i}=Y_i-Y_i p_i \beta \qquad (5)$$

and potential future yields (Y_{model}) if dicots are not fully removed, can be calculated from (4). Figure 2 illustrates that the total yield is unaffected by the proportion of dicots when $\beta=0$. The negative effect of dicots is expressed by $\beta<0$ and a positive contribution to total yield by $\beta>0$.

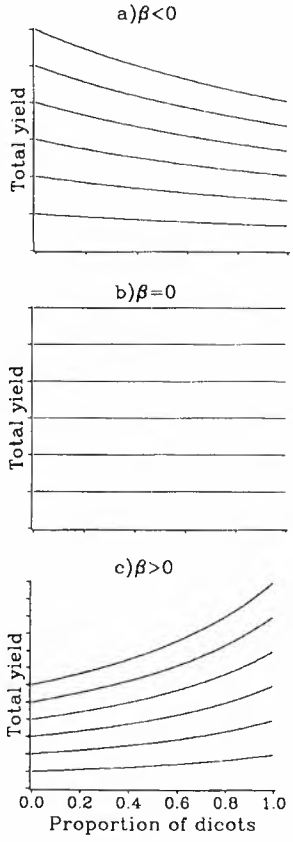

Figure 2. Relationships between total yield and proportion of dicots of the present model at different yield levels when (a) $\beta<0$, (b) $\beta=0$ and (c) $\beta>0$

Parameter estimation

To estimate the slope (ß*) of the relationship between DM yield of grasses and DM yield of dicots (g/m^2), an analysis of covariance was used by introducing DM yield of dicots as a covariate. The statistical model was

$$g_{ijk} = \mu + x_i + s_j + (x*s)_{ij} + Y_k + (s*Y)_{jk} + e_{ijk}$$

where g is DM yield of grasses, μ is an overall mean, x is DM yield of dicots, s is different experimental sites and Y is experimental year. Variation in ß*-values between experimental sites was estimated by the interaction term (x*s). The slopes of the three different groups of predominant dicots were compared by contrasts. When the test did not show a significant difference between the three groups, a joint estimate of the slope was calculated by removing the interaction term (x*s) from the model. Only unsprayed plots were used in these calculations. The first and the second harvests were analysed separately. A generalized linear models procedure was used (SAS Institute Inc. 1988). The results are presented as the ß-value, which is ß*+1.

Model validation

The above model was validated using DM yield data from the sprayed plots. The two years after spraying were used, assuming that the space left vacant after herbicide treatment was occupied by grasses or dicots. The spraying reduced the proportion of dicots, which in turn may have affected DM yields. Expected DM yields on sprayed plots (Y_{model}) were estimated by first calculating g_0 within each parallel of unsprayed/sprayed plots, based on DM yields of the companion unsprayed plot within experimental sites and years. This calculation was based on the assumption that the yield of an unsprayed plot represents the yield of the sprayed plot before herbicide treatment. After calculating g_0, the expected DM yield of sprayed plots (Y_{model}) was calculated from (4). The prediction error (PE) was calculated as an absolute magnitude

$$PE = n_j^{-1} \sum_{i=1}^{n_j} | Y_{modell} - Y_i |$$

where n_j is the number of observations within each experimental site and Y_i is the observed DM yield of sprayed plots. This evaluation was done over a selected range of ß-values, to identify the slope which resulted in the minimum prediction error.

RESULTS AND DISCUSSION

With the present model the assumption is that there is a linear relationship between the DM yield of grasses and dicot DM. This implies that the mixture of such species does not result in overyield compared to the components grown alone. This has been confirmed in several competition studies. The results of Wit & Bergh (1965) fit this pattern quite closely and Snaydon & Satorre (1989), Trenbath (1974) and Wilson (1988) all conclude that this relationship applies to most mixtures, with the exception of those of legumes and non-legumes.

A simple linear relationship between total herbage yield and proportion of dicots may be an alternative to the present model, but there are several arguments against such a relationship. First, it is difficult to give such a model a biologically realistic reasoning. Secondly, a regression between total yield and proportion of dicots would be unsatisfactory from a statistical point of view. The proportion of dicots was measured by sepa-

rating herbage yield into grasses and dicots before drying and weighing, and then calculating the proportion of dicots. Dry matter yield of both grasses and dicots would in this way be present on both sides of the equation. Thirdly, such a model with a fixed ß-value would result in incorrectness at lower yield levels, where it might indicate a yield level of zero under certain circumstances. Figure 2 shows that the effect of dicots on DM yield is, in a way, adjusted by the yield level in the present model.

With the exception of site 5, the analysis of covariance resulted in a ß-value greater than zero at all experimental sites in the first harvest (Table 3), indicating that total DM yield increased as the proportion of dicots increased (as in Fig. 2c). However, all confidence intervals, except for that of site 7, included the value 0 of the slope. Oswald & Haggar (1983) examined the effects of *Rumex obtusifolius* L. on the seasonal yield of two swards of mainly *Lolium perenne* L. and found positive effects on total DM yield of *R. obtusifolius*. Nesheim (1986) reported no yield reduction in meadows dominated by *R. repens*, while *Ranunculus acris* L. was found to reduce yields. In the second harvest all values of ß, except that for site 5, were lower than zero (Table 4), indicating that an increasing proportion of dicots reduced total herbage yield (as in Fig. 2a). Once again, however, all confidence intervals of ß included zero.

Since no significant differences in ß-values between the three groups of predominant dicot species could be detected (Table 5), a joint estimate of all sites and dicot species can be used. These estimates indicate a slope of 0.21 in the first harvest and -0.11 in the second, and validation slopes of 0 and -0.2, respectively (Tables 3 and 4). The confidence intervals of the ß-values were quite wide, indicating that the experimental noise was rather large. This may have overshadowed effects of different species.

The slopes were negative in the second cut, but positive in the first cut. This indicates that the regrowth potential of grasses is greater than that of dicots. Oswald and Haggar (1983) found that there was an increased negative effect of *R. obtusifolius* on DM yield in the Oc-

Table 3. Results of the first harvest. Mean total DM yield of unsprayed plots ($\bar{Y}_0$), ß- values estimated by analysis of covariance and the slope values of validation ($ß_v$), resulting in the minimum prediction error (PE)

Exp. sites	Predominant dicot	$\bar{Y}_0$ g/m²	Analysis of covariance		Validation	
			ß (conf. limits, 95%)	n_{cov}	$ß_v$ (PE)	n_{val}
1	*Rumex longifolius*	684	0.29 (-0.07,0.65)	30	0.2 (79)	20
2	*Rumex longifolius*	367	0.09 (-0.52,0.70)	30	-0.7 (71)	20
3	*Ranunculus repens*	318	0.10 (-0.23,0.44)	30	0 (84)	20
4	*Ranunculus repens*	297	0.25 (-0.13,0.64)	30	0.4 (59)	20
5	*Ranunculus repens*	420	-0.22 (-0.97,0.52)	20	-0.6 (34)	10
6	*Ranunculus repens*	200	0.16 (-0.30,0.61)	19	-0.4 (56)	9
7	*Ranunculus repens*	341	0.37 (0.04,0.69)	20	0.2 (59)	10
8	*Taraxacum officinale*	420	0.15 (-0.30,0.59)	21	0.3 (70)	14
ALL			0.21 (0.06,0.35)	200	0 (74)	123

Table 4. Results of the second harvest. Mean total DM yield of unsprayed plots ($\bar{Y}_0$), ß-values estimated by analysis of covariance and the slope values of validation ($ß_v$), resulting in the minimum prediction error (PE)

Exp. sites	Predominant dicot	$\bar{Y}_0$ g/m²	Analysis of covariance		Validation	
			ß (conf. limits, 95 %)	n_{cov}	$ß_v$ (PE)	n_{val}
1	*Rumex longifolius*	519	-0.01 (-0.41,0.39)	30	-0.9 (67)	19
3	*Ranunculus repens*	213	-0.24 (-0.90,0.41)	22	-0.6 (39)	19
4	*Ranunculus repens*	209	-0.20 (-0.72,0.33)	29	-0.1 (65)	20
5	*Ranunculus repens*	404	0.07 (-0.67,0.81)	20	-0.2 (82)	10
7	*Ranunculus repens*	176	-0.23 (-1.15,0.69)	10	-0.1 (27)	10
8	*Taraxacum officinale*	261	-0.23 (-1.22,0.76)	21	-0.1 (31)	14
ALL			0.11 (-0.35,0.14)	132	-0.2 (57)	92

Table 5. Comparison of ß-values between sites with differing predominant dicot

Predominant dicot	p-values	
	1st harvest	2nd harvest
Rumex longifolius vs. *Ranunculus repens*	n.s[1)]	n.s
Ranunculus repens vs. *Taraxacum officinale*	n.s	n.s
Rumex longifolius vs. *Taraxacum officinale*	n.s	n.s

[1)] not significantly different at the 5 % level

tober cut compared with the July cut. Nesheim (1986) and Lemieux et al. (1987) also reported that the negative effects of dicots on herbage yield increased at the second harvest compared with the first harvest.

Lundekvam & Myhr (1975) reported a yield reduction of 67 kg hay/ha per. 1 % increase in content of dicots visually estimated, which is a much greater reduction than that found by Nesheim (1986) and in the present investigation. However, Lundekvam & Myhr (1975) based their calculations on regression over experimental sites, while the present results are based on variation within experimental sites. The former probably included variation in climatic and edaphic factors among sites, an effect which is probably much smaller in the latter.

There is also a great variation in production potential among grass species (Nesheim 1986) and this may have influenced the estimated ß values. The predominant grass species of site 5 was the highly productive *L. perenne*. This may have caused the negative ß values of -0.22 and -0.6 in the first harvest for the analysis of covariance and validation, respectively. On the other hand, in the second harvest

a contrary result of ß=0.07 was determined by the analysis of covariance, while the validation result was -0.2.

In general, the results of validation were quite close to those of the analysis of covariance, with some exceptions. In the first harvest, a large deviation in ß was obtained at sites 2 and 6 (Table 3), both indicating a decline in total DM yield with an increasing proportion of dicots. The ß-value of validation of site 5 also deviated substantially from the slope of the analysis of covariance, the first indicating a more negative effect of dicots than the latter. In the second cut the slope of validation in site 1 diverged substantially from that of the analysis of covariance (Table 4). The main cause of these deviations is probably the large experimental noise of the present material, illustrated by the confidence intervals of the ß-values. It was also difficult to obtain an exact equal amount of species in the unsprayed/sprayed parallels of the experiments before herbicide treatment, because of the patchy distribution of some of the species, and there was a poor effect of herbicide treatment in experimental sites 1 and 6 (Table 2), which probably influenced the results of validation.

The model relates total DM yield to proportion of dicots. Under certain circumstances some species, both grasses and dicots, will not be eaten by animals (e.g. *Deschampsia cespitosa* (L.) Beauv. or *Urtica dioica* L. in pastures), and in such a situation the present model will not be practicable.

In conclusion, dicots had a greater effect on DM yield in the second harvest than in the first cut. Although there was some variation between experimental sites, it seems reasonable to believe that various proportions of dicots will not have a negative effect on total DM yield of the first cut. In the second harvest, however, increasing amounts of dicots have a negative influence on herbage DM yield. It seems unreasonable to expect a considerable increase in yearly DM yield after herbicide control of dicots unless highly productive species are successfully introduced as a part of the renovation. The present model is acceptable for the purpose of predicting yield changes following a herbicide renovation in grassland.

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Rumex longifolius DC., *Ranunculus repens* L. and *Taraxacum officinale* (Web.) *Marss. in grassland*

2. *Crop nutritive value in relation to proportion of dicots*

ESPEN HAUGLAND
Norwegian Crop Research Institute, Plant Protection, Department of Herbology, Aas, Norway.

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The effects on the crop nutritive value of varying proportions of three dicotyledonous species in grassland were studied. Field trials were established in which *Rumex longifolius* DC., *Ranunculus repens* L. or *Taraxacum officinale* (Web.) Marss. was the predominant dicot. In the first harvest *R. longifolius* had a negative effect on *in vitro* dry matter digestibility (IVDMD), whereas *T. officinale* and *R. repens* had no effect or a positive effect, respectively. The effect of the herbs on crude protein (CP) was mostly positive, with the exception of *T. officinale*, which had a negative effect in the first cut. All species had a positive influence on IVDMD and CP in the second cut. In both the first and the second harvests crude fibre (CF) content was reduced, while the percentage of ash increased with increasing amount of these dicots. It would seem that the effects of these dicots on the given quality parameters can be estimated by a linear function of proportion of dicots. Quality changes following herbicide renovation of grassland can be estimated by such equations.

Key words: Ash, crude fibre, crude protein, herbage quality, herbicide, *in vitro dry* matter digestibility, weeds.

Espen Haugland, Norwegian Crop Research Institute, Plant Protection, Department of Herbology, Fellesbygget, N-1432 Aas, Norway.

In grassland the term «weed» frequently is used specifically to mean dicotyledonous species or herbs, excluding legumes. Fairbairn & Thomas (1959) discussed the use of this term in connection with these species and found that the definition applied well in arable land, but was much less appropriate in the case of grassland. Vengris et al. (1953 concluded that, «Their value as a feed, so far as they are palatable, should not be underestimated».

Studies of the nutritive value of individual dicot species are reported in several articles (e.g. Dietl 1982; Bosworth et al. 1985; Lehmann et al. 1985; Timenes 1986) and it has been found that their nutritive value can be inferior as well as superior to that of the grasses. The investigations usually include analyses of *in vitro* dry matter digestibility (IVDMD), crude protein (CP), fibre fractions and minerals. Another aspect of the quality concept of dicots in grassland is harvesting losses when drying (Höhn 1988) or ensiling. A comprehensive investigation of quality also includes feeding trials, with determination of voluntary intake and digestibility (Dutt et al. 1982; Bergen et al. 1990), and an evaluation of toxic substances (Keeler et al. 1978).

As a key part in the establishment of threshold values for weeds in grassland, it is necessary to elucidate the effects of dicots on herbage yield and quality. Haugland (1995) has discussed the effects on crop yield. The main objective of the present investigation was therefore to evaluate the effects of varying proportions of dicots in grassland on different quality parameters. Because of the great variation between dicot species (Lehmann et al. 1985), the investigation was restricted to three predominant species in Norwegian meadows and pastures, namely *Rumex longifolius* DC., *Ranunculus repens* L. and *Taraxacum officinale* (Web.) Marss.

MATERIALS AND METHODS

Experimental sites and treatments

Seven meadows in different parts of Norway, all with a wide range in proportion of dicots, were used to evaluate the response in quality parameters to increasing proportions of dicots. In each field either *Rumex longifolius*, *Ranunculus repens* or *Taraxacum officinale* was the predominant dicot. The experimental sites, herbicide treatment and measurement procedures are described by Haugland (1995).

IVDMD, CP, crude fibre (CF) and ash content were evaluated by near-infrared reflectance spectroscopy (NIRS), using a broad-based calibration equation specially prepared for the present investigations. The calibration material is described by Almøy & Haugland (1994).

Statistical considerations

The relationship between the individual quality parameters and proportion of dicots was calculated from a linear relationship between the quality parameter and proportion of dicots:

$$q(w) = q_g + \beta w \qquad 0 \leq w \leq \quad (1)$$

where q(w) is the quality parameter as a function of the proportion of dicots (w) on a dry matter basis. q_g represents the quality of the grass component of the herbage, while the slope ß represents the difference between the quality of the dicot component and the quality of the grass component of the herbage. To estimate the slope (ß) of the function (1), an analysis of covariance was used by introducing the proportion of dicots as a covariate. The statistical model was:

$$q_{ijk} = \mu + w_i + s_j + (w*s)_{ij} + Y_k + (s*Y)_{jk} + e_{ijk}$$

where q is the quality parameter (as a percentage of DM), μ is an overall mean, w is proportion of dicots, s is different experimental sites and Y is experimental year. Variation in ß-values between experimental sites was estimated by the interaction (w*s), and the slope values of the different predominant dicots were compared by contrasts. Only unsprayed plots were used in these calculations. The first and the second harvests were analysed separately. A generalized linear models procedure was used (SAS Institute Inc. 1988).

Validating the results

The sprayed plots were used to validate the results of the analysis of covariance. The two years after spraying were used, assuming that the space left vacant after herbicide treatment was occupied by grasses or dicots. The spraying reduced the proportion of dicots, which in turn may have affected herbage quality. When the proportion of dicots after spraying was known, it was possible to predict the change in quality as compared to the unsprayed parallel by

$$\Delta q = \beta (w_i - w_0) \qquad (2)$$

where w_1 and w_0 are proportion of dicots on the sprayed and unsprayed plots, respectively. Expected quality of the sprayed plots (q_{pred}) was then calculated as

$$q_{pred} = q_0 + \Delta q \qquad (3)$$

where q_0 is the measured quality of the unsprayed plot. This calculation is based on the assumption that the quality of an unsprayed plot represents the quality of the companion sprayed plot before herbicide treatment. Prediction error (PE) was calculated as an absolute magnitude

$$PE = n_j^{-1} \Sigma |q_{pred} - q_{ij}|$$

where n_j is the number of observations within each experimental site and q_{ij} is the observed value of the quality parameter of sprayed plots. This evaluation was done over a selected range of ß-values, to identify the slope which resulted in the minimum prediction error.

RESULTS

There was a positive effect of increasing amounts of dicots on IVDMD of the first harvest in fields where *R. repens* was the predominant dicot (Table 1). Fields where *R. longifolius* was the predominant herb showed negative ß-values, but the effect was not significant in site 1. It was found that there was almost no effect of increasing amounts of *T. officinale* on IVDMD. In the second harvest all ß-values of IVDMD were positive, although three sites showed a slope not significantly different from zero.

In general the results of the validation showed much the same tendencies as the analysis of covariance (Table 1). In the first harvest the difference between the ß-values of IVDMD in the two fields dominated by *R. longifolius* was much smaller in the validation than in the analysis of covariance. This was caused by a rather large change in the ß-value of experimental site 2. The ß-values of *T. officinale* and *R. repens* varied less among sites in the validation than in the analysis of covariance. The slope values of validation of the second harvest were very homogeneous.

In both cuts a positive effect of dicots on CP was recorded in all fields, with the exception of sites 4 and 8 in the first harvest, but most of the ß-values were not significantly different from zero (Table 2). The slope values of CP determined by the validation procedure diverged substantially from those of the analysis of covariance in three cases: the slope values of site 3 in the first cut and of site 4 in the second cut, showed opposite signs, while $ß_v$ of site 8 in the second cut was much greater than the ß-value of the analysis of covariance (Table 2).

Increasing amounts of dicots in the field where *T. officinale* was the predominant herb affected CF and ash content in the first harvest only slightly, while in the other species there was a negative and a positive ß-value of CF and ash content, respectively (Tables 3 and 4). In the second cut, increasing amounts of dicots affected CF negatively and ash content positively in all fields. The results of the validation and the analysis of covariance were rather similar for both CF and ash content, with one exception: $ß_v$ of CF content on site 8 in the first harvest was negative, while the analysis of covariance showed no effect of an increasing proportion of dicots.

Table 1. Effects of varying proportions of dicots on *in vitro* dry matter digestibility (IVDMD). Mean value of unsprayed plots ($\bar{q}_0$), ß-values estimated by analysis of covariance and the slope values of validation ($ß_v$) resulting in the minimum prediction error (PE)

Exp. sites	Predominant dicot	$\bar{q}_0$ %	Analysis of covariance ß (conf. limits, 95%)	n_{cov}	Validation $ß_v$ (PE)	n_{val}
1st harvest:						
1	*Rumex longifolius*	73.2	- 1.9 (-9.1,5.4)	30	-1 (1.4)	20
2	*Rumex longifolius*	66.4	-10.6 (-18.3,-2.9)	30	-3 (1.3)	20
3	*Ranunculus repens*	70.0	8.9 (4.7,13.1)	20	7 (2.2)	10
4	*Ranunculus repens*	71.6	13.6 (8.8,18.5)	19	10 (2.2)	9
6	*Ranunculus repens*	70.0	7.2 (3.3,11.0)	19	4 (2.1)	9
7	*Ranunculus repens*	72.2	12.7 (9.1,16.3)	30	9 (3.7)	20
8	*Taraxacum officinale*	70.3	0.3 (-4.4,5.1)	30	5 (1.5)	19
2nd harvest:						
1	*Rumex longifolius*	68.1	3.5 (-3.2,10.2)	30	6 (2.1)	20
3	*Ranunculus repens*	68.3	4.9 (-0.5,10.4)	10	5 (1.8)	10
4	*Ranunculus repens*	77.1	3.6 (-1.0,8.1)	10	5 (2.0)	10
7	*Ranunculus repens*	75.3	7.6 (3.3,12.0)	20	5 (2.0)	20
8	*Taraxacum officinale*	72.5	6.9 (2.9,10.9)	30	5 (2.0)	19

Table 2. Effects of varying proportions of dicots on crude protein (CP) content. Mean value of unsprayed plots ($\bar{q}_0$), ß-values estimated by analysis of covariance and the slope values of validation ($ß_v$) resulting in the minimum prediction error (PE)

Exp. sites	Predominant dicot	$\bar{q}_0$ % of DM	Analysis of covariance ß (conf. limits, 95%)	n_{cov}	Validation $ß_v$ (PE)	n_{val}
1st harvest:						
1	*Rumex longifolius*	16.7	3.6 (-2.0,9.2)	30	2 (1.7)	20
2	*Rumex longifolius*	9.9	5.1 (-0.9,11.0)	30	3 (1.1)	20
3	*Ranunculus repens*	18.0	5.4 (2.2,8.7)	20	-2 (1.7)	10
4	*Ranunculus repens*	15.2	-1.4 (-5.2,2.3)	19	-1 (1.0)	9
6	*Ranunculus repens*	16.4	3.1 (0.1,6.1)	19	5 (1.6)	9
7	*Ranunculus repens*	15.9	3.1 (0.3,5.9)	30	0 (1.0)	20
8	*Taraxacum officinale*	13.8	-4.1 (-7.8,-0.4)	30	0 (1.1)	19
2nd harvest:						
1	*Rumex longifolius*	18.7	11.8 (5.8,17.8)	30	9 (1.6)	20
3	*Ranunculus repens*	19.8	3.5 (-1.4,8.4)	10	2 (1.1)	10
4	*Ranunculus repens*	15.4	2.8 (-1.3,6.9)	10	-2 (1.5)	10
7	*Ranunculus repens*	22.0	0.7 (-3.3,4.6)	20	0 (1.6)	20
8	*Taraxacum officinale*	18.8	1.1 (-2.5,4.7)	30	8 (0.9)	19

Table 3. Effects of varying proportions of dicots on crude fibre (CF) content. Mean value of unsprayed plots ($\bar{q}_0$), ß-values estimated by analysis of covariance and the slope values of validation ($ß_v$) resulting in the minimum prediction error (PE)

Exp sites	Predominant dicot	$\bar{q}_0$ % of DM	Analysis of covariance ß (conf. limits, 95%)	n_{cov}	Validation $ß_v$ (PE)	n_{val}
1st harvest:						
1	*Rumex longifolius*	25.3	-7.9 (-13.2,-2.6)	30	-10 (1.5)	20
2	*Rumex longifolius*	29.7	-10.9 (-16.5,-5.3	30	-8 (0.9)	20
3	*Ranunculus repens*	26.7	-9.4 (-12.5,-6.3)	20	-6 (1.0)	10
4	*Ranunculus repens*	27.0	-8.3 (-11.8,-4.7)	19	-5 (1.1)	9
6	*Ranunculus repens*	26.9	-7.9 (-10.7,-5.1)	19	-10 (1.5)	9
7	*Ranunculus repens*	25.0	-11.0 (-13.6,-8.3)	30	-9 (2.1)	20
8	*Taraxacum officinale*	27.5	0.2 (-3.4,3.7)	30	-5 (1.6)	19
2nd harvest:						
1	*Rumex longifolius*	26.2	-16.1 (-20.2,-12.1)	30	-9 (1.9)	20
3	*Ranunculus repens*	24.4	-6.4 (-9.6,-3.1)	10	-7 (1.2)	10
4	*Ranunculus repens*	22.5	-1.4 (-4.1,1.3)	10	-2 (0.8)	10
7	*Ranunculus repens*	20.9	-9.0 (-11.7,-6.4)	20	-5 (1.7)	20
8	*Taraxacum officinale*	23.7	-8.6 (-11.0,-6.2)	30	-9 (1.1)	19

Table 4. Effects of varying proportions of dicots on ash content. Mean value of unsprayed plots ($\bar{q}_0$), ß-values estimated by analysis of covariance and the slope values of validation ($ß_v$) resulting in the minimum prediction error (PE)

Exp sites	Predominant dicot	$\bar{q}_0$ % of DM	Analysis of covariance ß (conf.limits, 95%)	n_{cov}	Validation $ß_v$ (PE)	n_{val}
1st harvest:						
1	*Rumex longifolius*	7.8	5.1 (2.1,8.1)	30	3 (0.4)	20
2	*Rumex longifolius*	6.3	3.8 (0.6,7.0)	30	3 (0.5)	20
3	*Ranunculus repens*	8.9	6.1 (4.3,7.8)	20	2 (0.5)	10
4	*Ranunculus repens*	8.6	3.4 (1.4,5.4)	19	0 (0.7)	9
6	*Ranunculus repens*	7.9	6.1 (4.5,7.7)	19	6 (1.4)	9
7	*Ranunculus repens*	9.2	3.6 (2.1,5.1)	30	5 (0.9)	20
8	*Taraxacum officinale*	7.6	0.8 (-1.2,2.8)	30	3 (0.7)	19
2nd harvest:						
1	*Rumex longifolius*	9.7	5.0 (2.4,7.5)	30	5 (0.5)	20
3	*Ranunculus repens*	9.6	4.0 (2.0,6.1)	10	3 (0.6)	10
4	*Ranunculus repens*	9.0	5.8 (4.0,7.5)	10	3 (1.2)	10
7	*Ranunculus repens*	10.7	3.5 (1.8,5.2)	20	5 (1.0)	20
8	*Taraxacum officinale*	10.1	3.3 (1.8,4.9)	30	4 (0.5)	19

The ß-values of IVDMD in fields where *R. longifolius* or *T. officinale* was the predominant dicot differed significantly from fields of *R. repens* in the first harvest, wheras there were no significant differences between the three predominant dicots in the second cut (Table 5). In the first harvest the ß-values of CP, CF and ash content in fields dominated by *R. longifolius* or *R. repens* were significantly different from the ß-values in the field dominated by *T. officinale*. In the second cut the ß-values of both CP and CF on the site dominated by *R. longifolius* were significantly steeper than those of the other predominant species, while no significant difference between the predominant species was recorded in ash content.

DISCUSSION

Wheras several investigations show results from quality analysis of individual species of both grasses and dicots, the present investigation studied the effects on the nutritive value of varying proportions of three dicots in grassland. However, the results of analysis of individual species indicate a negative or positive effect on the nutritive value of mixtures of such species. Timenes (1986) found lower IVDMD of *R. longifolius* compared to valuable grass species such as *P. pratense* and *Festuca pratensis* Huds., while IVDMD of *R. repens* was found superior to that of the grass species. Both dicots had a higher content of CP and lower content of CF than the grass species. Bosworth et al. (1985) found *Rumex crispus* L. to have lower IVDMD and higher levels of CP than *Festuca arundinacea* Schreb. Dutt et al. (1982) reported higher IVDMD and CP in *T. officinale* than in a mixture of grasses, primarily *Elytrigia repens* (L.) Nevski., *Bromus inermis* Leyss. and *Dactylis glomerata* L. Meister & Lehmann (1988) also found a superior IVDMD and lower level of CF in *T. officinale* and *R. repens* compared to *D. glomerata* or *Alopecurus pratensis* L. These findings, which are supported by the results found in the pre-

Table 5. Comparison of ß-values of sites with differing predominant dicots

Predominant dicot	p-values of contrasts			
	IVDMD[1]	Crude protein	Crude fibre	Ash
1st harvest:				
Rumex longifolius vs. *Ranunculus repens*	0.0001	n.s.[2]	n.s.	n.s.
Ranunculus repens vs. *Taraxacum officinale*	0.0002	0.002	0.0001	0.0004
Rumex longifolius vs. *Taraxacum officinale*	n.s.	0.003	0.0004	0.02
2nd harvest:				
Rumex longifolius vs. *Ranunculus repens*	n.s	0.005	0.0001	n.s
Ranunculus repens vs. *Taraxacum officinale*	n.s	n.s	0.05	n.s
Rumex longifolius vs. *Taraxacum officinale*	n.s	0.003	0.002	n.s

[1] *In vitro* dry matter digestibility.

[2] Not significantly different at the 5-% level.

sent investigation, indicate a negative ß-value of IVDMD and CF as a function of proportion of dicots in grassland where *R. longifolius* is the predominant dicot, and a positive effect on CP, while increasing proportions of *R. repens* may result in a positive effect on both IVDMD and CP, and a negative effect on CF.

The cited literature indicates a positive effect of increasing proportions of *T. officinale* on both IVDMD and CP, and a negative effect on CF. The analysis of covariance in the present investigations showed, however, no significant effect of *T. officinale* on either IVDMD or CF in the first harvest, while the effect on CP was negative. This is contrary to the findings in Switzerland (Meister & Lehmann 1988) and in the USA (Dutt et al. 1982), and may be due to an early maturation of this species in the first growth in Norwegian meadows as related to cutting time. On the other hand, the results of the validation were more in accordance with those reported in the literature.

As found almost invariably in the present investigation, Nesheim (1986) reported an increased content of ash with increasing proportions of *R. repens* and, in general, with increasing amounts of dicots.

The ß-values of IVDMD varied between the predominant dicots in the first harvest, while in the second harvest an increasing proportion of dicots invariably improved IVDMD. The change from a negative to a positive effect of *R. longifolius* was probably caused by different plant morphology in the two cuts. At the first harvest *R. longifolius* often flowered, and a large proportion of the plant was fibrous stems, while the regrowth of *R. longifolius* consisted mainly of leaves.

The present calculations are based on a linear relationship between quality parameters and proportion of dicots. This presumes that varying amounts of grasses and dicots do not influence the partial quality of either of the two components, which in turn implies that an increasing proportion of a species does not affect its morphological or chemical properties. This may be the case when there is no competition within a species, but such competition may change the morphology of a species and result in changed partial quality of the component. The ß-value of the linear function may also be calculated from results of quality analysis of individual species of both grasses and dicots. The values estimated from results presented by Timenes (1986) and Meister & Lehmann (1988) proved to be rather similar to the results of the present investigation. This supports the assumption of a linear relationship between proportion of dicots and the quality parameters.

There is a great variation in the rate of development between species, and stage of development at harvesting is of importance when evaluating the quality of the species. The rate of change in quality parameters with advance in plant maturity will also influence the ß-values of the function of quality parameters and proportion of different dicots. In the first growth, Timenes (1986) found a greater decline in IVDMD of *R. longifolius* during one week from heading of *P. pratense* than in *P. pratense* and *F. pratensis*. She also found a greater decrease in CP and increase in CF of *R. longifolius* compared to the grass species, whereas in *R. repens* it was found that there were almost no changes in these three quality parameters during the same period. Marten et al. (1987) compared *B. inermis* with, among others, *R. crispus* and *T. officinale* at different sampling dates during the first growth. Almost no decline was recorded in IVDMD of *T. officinale* over 11 days, while the decline was considerably stee-

per in both *B. inermis* and *R. crispus*. There was almost no difference in decline in CP among the species. Meister & Lehmann (1988) reported a lesser decline in IVDMD of *R. repens* and *T. officinale,* and a smaller increase in CF, than in those of *D. glomerata* or *A. pratensis*. These results indicate that the negative effect on IVDMD of *R. longifolius* in a mixture with common grass species will be enhanced by advancing plant maturity in the first growth, while the positive effects of *T. officinale* and *R. repens* on IVDMD and CP will probably increase.

The variation in ß-values among experimental sites may be due to variation in altitude or latitude, cutting times or soil characteristics. Meister & Lehmann (1988) found that species, maturation and crop (first or second cuts) were the predominant factors influencing quality. Elevation and location had a much more limited effect when a species was compared at the same developmental stage. This indicates that the variation in stand maturity at harvest time and botanical composition may be the main cause of the variation in ß-values among experimental sites.

Substances harmful to livestock are reported in both *Ranunculus* and *Rumex* species (Stählin 1971). Although the concentration of glycosides is much lower in *R. repens* than in *Ranunculus acris* L. (Stählin 1971), and also positive effects of *Rumex* species are reported (Waghorn & Jones 1989), the effects of these substances must be considered as an aspect of the nutritive value. Other aspects that should be considered in following investigations are voluntary intake and *in vivo* digestibility of herbage with varying proportions of dicots, and assessment of utilizable yield when ensiling, drying or grazing.

In conclusion, the validation gave almost the same result as the analysis of covariance. This indicates that the effects of the specific dicots on the given quality parameters, can be estimated by a linear function of proportion of dicots, and that quality changes following a herbicide renovation of grassland can be predicted by such an equation. However, if grass species of different quality are introduced as a part of the renovation, the equations may not be reliable.

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Embryo development and embryo rescue within the genus *Ribes*

VIDMANTAS STANYS, TADEUSHAS SHIKSHNIANAS & GRAZHINA STANIENE
Lithuanian Institute of Horticulture, Kaunas, Lithuania

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The in vivo dynamics of embryo development was investigated in four current species with various ripening season and in two interspecific hybrids. Development interdependence in black currant berries, seeds and embryos, the commencement of embryo autonomy character and the optimal period for embryo rescue were determined. The suitabality of White's, Nitch & Nitch and MS media was assessed for culturing rescued embryos, and a composition of phytohormones was optimized in a medium. It was established that when supplemented with kinetin the media were most suitable for growing rescued currant embryos. Interspecific currant hybrids were produced when using rescued embryo culture.

Key words: Embryos, embryo culture, hybrids, Ribes.

Vidmantas Stanys, Lithuanian Institute of Horticulture, Babtai 4335, Kaunas dist., Lithuania.

In currant breeding, donors with useful characters are sought within various Ribes species. (Trajkovski & Anderson (1992). Distant hybridization frequently takes place and a low percentage of hybrid seed-setting is often observed following such interspecific hybridization. Very often hybrid seeds are not of great vitality, and plant output is low. But the fact that hybrid embryos frequently fail due to abortion does not prove their lack of vitality. Such embryos usually can develop, but because of the disharmony between genotypes of different species natural metabolism is broken down. Hybrid plants can be raised by using the culture of isolated embryos. An investigation of these possibilities was started at the beginning of this century (Hannig 1904). Leibach (1925) was the first to grow distant flax hybrids. More recently, culturing of isolated embryos has been widely applied in hybrid development of grain, legumes, fodder and industrial crops (Raghaven & Srivastava 1982). Growth of isolated embryos of sweet cherry (Tukey 1933) and peach (Davidson 1933) was the first development of this kind to be reported in the horticultural plants. The method was especially promising in the development of early varieties of these crops (Zdruykovskaja-Rikhter 1985). Kravstov & Kasyanova (1968) succeded in growing interspecific currant hybrids *in vitro*. Eight hybrid (*R. nigrum x G. reclinata*) plants were raised from 108 undeveloped seeds.

Up until now the natural development of currant berry, seed and embryo has not been quite clear. Seed development

periods critical for embryo survival, when and why hybrid seeds and embryos abort and what the possibilities are for averting this are still unknown.

The aim of our work was to investigate the development dynamics of currant berries,seeds and embryos, formation of embryo autonomy and conditions for culturing isolated embryos of various currant species and interspecific hybrids.

MATERIALS AND METHODS

Plant material

Berries, seeds and embryos of controlled intra- and interspecific crosses were studied. The plants involved were the *Ribes nigrum* varieties Ben Lomond, Titania, Vakariai, Minaj Shmyriov, Lee's Prolific, Dochka, selection No. 65-59-4; the (*R. petraeum x R. multiflorum*) variety Rote Spätlese; the (*R. vulgare x R. rubrum*) variety Jonkheer van Tets; the (*R. multiflorum x R. vulgare*) variety Rondom; the *R. aureum* variety Corona; the *R. americanum* wild forms and R. *x uva-crispa* varieties Kurshu dzintars, Scchedryj, Beloruskij, Captivator and Tschornyj negus.

Culture procedure and conditions

In order to define embryo autonomy, embryos at various stages of development were isolated and under aseptic conditions planted in media defined by White (1943). Murashige & Skoog (1962) and Nitsch & Nitsch (1969) supplemented with 20 g/l sucrose, 6 g/l agar with or without the supplement of 0.2 mg/l kinetin, 0.5 mg/l 6-benzylaminopurine (BAP), 0.5 mg/l 2.4-dichlorophenoxyacetic acid (2.4-D).

Explants were grown in growth chamber at 25 ±2°C, with a relative air humidity of 60%, lighting of 3000 lux over the explant and for a 16 h photoperiod. Each treatment included 18-40 explants.

An investigation was carried out in 1990-93, during which berry, seed and embryo development was observed 20 days after pollination and thereafter every 2-5 days. Berry mass, seed size, embryo size and plant growth were evaluated. Alternative data were determined by the analysis of dispersion method, described by Volf (1966).

RESULTS

Berry, seed and embryo development under natural conditions in the genus ribes

If we use the in vitro method of growing isolated embryos to obtain distant hybrids we first have to know how berries, seeds and embryos develop under natural conditions. The development of black currant berries, seeds and embryos in the cross-combination of Lee's Prolific x Minaj Shmyriov is presented in Fig. 1. Three stages of fruit development can be distinguished. Consecutive increases in berry mass and seed length take place during the first stage. This stage lasts until the beginning of cotyledon differentiation of the embryo 36-38 days after pollination. During this period the seed reaches the maximum size. Rapid growth of the embryo is a characteristic feature of the second stage, which lasts up to approximately 50 days. In a relatively short time the embryo changes from a globular proembryo to a cordate, torpedo-shaped embryo before reaching its maximum size. The embryo remains in the cordate stage for 1-2 days. There is virtually no change in berry mass during the period of intensive embryo growth and at this stage there is an opportunity to isolate and culture black currant embryos

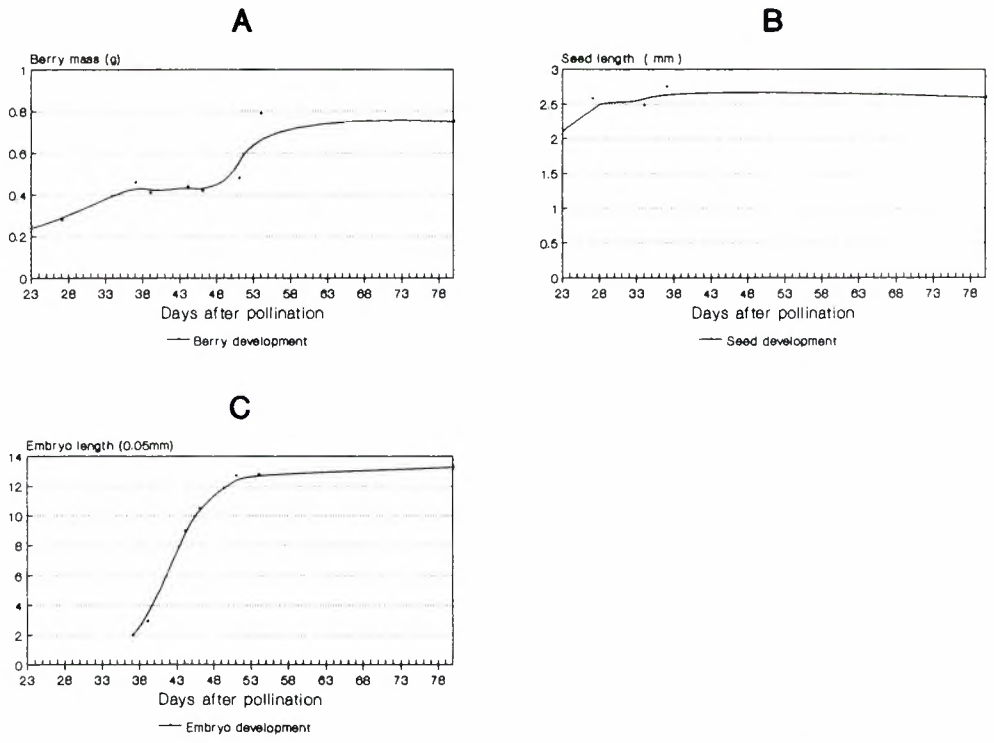

Figure 1. Dynamics of berry, seed and embryo development in black currants (Lee's Prolific x Minaj Shmyriov) Means of 30 observations each date

in vitro. Berry mass and size increase again in the third stage. The given data reflect thedevelopment dynamics of berries, seeds and embryos in the Ribes nigrum species.

When utilizing isolated embryo cultures to obtain distant hybrids it is essential to know the dynamics of embryo development in the different varieties and forms within the genera and species studied. The dynamics of embryo development in R. nigrum, R. x uva-crispa, R. aureum, R. americanum and (R. vulgare x R. multiflorum) is presented in Fig. 2. In the investigated Ribes species the embryos reached the final size during a short period (8-17 days) of rapid growth. The embryo differentiation in black currant varieties of different origin and different ripening season had a very similar pattern (Fig. 2A) which lasted for 12-17 days and was not dependent upon variety ripening season. However, final embryo size was quite different. The period of embryo differentiation in the early maturing genotypes (No. 65-59-4 and Minaj Shmyriov) was 2-5 days longer than that in the later maturing varieties (Titania and Ben Lomond). There seemed to be no significant differences in the time of embryo differentiation, which started on the 31st-34th day after pollination and ended on the 46th-48th day. Embryo size increased 4-9 times during the period, depending on the variety. The embryo differentiation period in black currants did

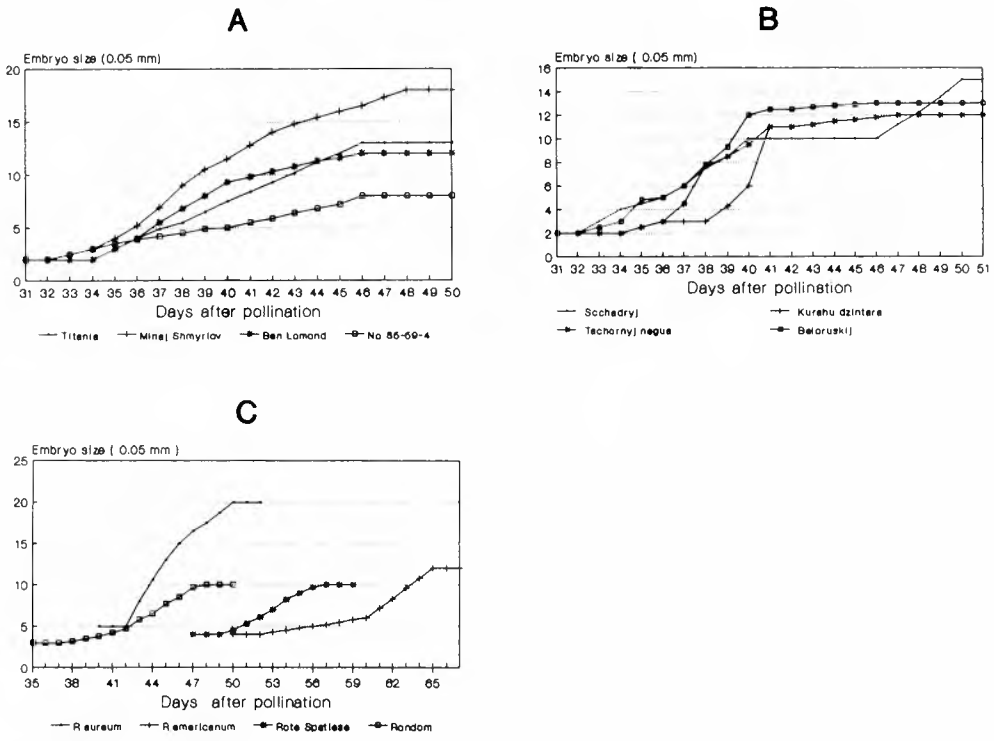

Figure 2. Dynamics of embryo development in Ribes.
A - R. nigrum varieties; B - R. x uva crispa varieties; C - Ribes species and interspecific hybrids

not seem to be influenced by the meteorological conditions of the year, whereas the period from pollination to the beginning of embryo differentiation depended upon the meteorological conditions and varied from 5 to 10 days within the same variety.

The course of embryo differentiation in gooseberry varieties is very similar (Fig. 2B). Embryos started to differentiate on the 32nd-34th day after pollination and reached maximum size after 46-50 days. During this period embryos increased 6-7.5 times.

In our investigation we also studied the R. aureum variety Corona. Its short period of embryo differentiation is similar to that of the other representatives in the genus Ribes (Fig. 2C). Differentiation started on the 42nd day after pollination and embryos reached maximum size on the 50th day. A characteristic feature of this variety was that embryos started to differentiate when they were large in diameter. During the period of rapid differentiation they increased four times. In the R. americanum species, where the berries ripen significantly later than in other currant varieties, embryo differentiation started on the 52nd day after pollination, and, as in the other investigated currant species this lasted for a short period – 13 days. Embryos increased three times.

Hybrid varieties by nature, Rondom and Rote Spätlese were chosen for our red

currant investigation. Their embryo development was similar to that of the other currant species studied, except that cotyledon differentiaiton of the late maturing Rote Spätlese variety started on the 49th day after pollination and embryos of the Rondom variety started to differentiate on the 36th day.

There are about 20-50 seeds in a mature black-currant berry. The differentiation of ovules takes place in the course of berry formation. Some of them fail to develop at the beginningbecause they have not been fertilized. Table 1 shows the percentage of seeds with embryos in a berry at different times throughout its lifetime. At the beginning of embryo differentiation one-third of the seeds had no embryos. The percentage of seeds with embryos increased and reached the final level at the time when embryo differentiation was completed. In the investigated samples we found a proportion of seeds without embryos in mature berries ranging from 2 to 12%. After crossing blackcurrant with gooseberry, the percentage of seeds with embryos was 13-45 in mature berries despite the fact that the number of seeds in a berry was significantly smaller than in an intrespecific combination.

The effect of embryo development stage on the growth *in vitro*

When an immature embryo is rescued and placed in the medium, one would expect growing plantlets. However, only the embryos that have achieved a certain autonomy can grow in vitro. In Table 2, data are presented on the growth of isolated embryos in White's medium supplemented with BAP depending on their development stage. Embryo optimal development was found after rescue on the 43rd day from pollination. By that time they had achieved their maximum size and, as can be seem from Table 2, full autonomy. Reduced embryos rarely developed in the global stage. During the first month of cultivation they formed very small undifferentiated plants. They had reduced rootlets and fully developed cotyledons. A significantly greater number of isolated embryos developed after later rescue. The percentage of developing embryos depended directly on their lifetime. After one month of cultivation, plants derived from later embryo rescue grew bigger and a significantly greater number of them were differentiated as compared to early embryo rescue. The percentage of developing rescued embryos began to decrease from days 45 to 83.

Table 1. Percentage of viable seeds in the course of berry development

Days after pollination	Seeds with embryos (%)	
	Ben Lomond x Beloruskaja sladkaja	Titania x Beloruskaja sladkaja
36	75.3	65.4
40	71.2	82.7
46	98.8	94.9
50	97.4	-
74	98.0	94.8

Table 2. *In vitro* growth of rescued black currant embryos depending on their development stage

Days after pollination	Embryo length mm	Planted embryos	Developed [x] embryos no	%	Mean plant length mm-1	Differentiated plants (%)
34	0.10	30	6	20.0 d	10.8 ±2.14[y]	16.6
36	0.32 ± 0.16[z]	29	16	55.2 c	16.6 ± 2.56	50.0
41	0.35 ± 0.16	30	20	66.7 c	19.0 ± 2.47	45.0
43	0.50 ± 0.15	28	28	100.0 a	29.5 ± 2.00	78.6
45	0.46 ± 0.15	26	23	88.5 ab	36.3 ± 3.31	82.6
48	0.47 ± 0.15	28	24	85.7 b	27.8 ± 1.75	83.3
83	0.52 ± 0.15	30	19	63.3 c	-	84.2

[x] Means are significantly different at p 0.01 applying Duncans multiple range test

[z] Mean ± SD for ten replications; [y] Mean ± SE

The effect of medium on the embryo growth *in vitro*

In order to select an optimal growth media for isolated currant embryos we studied White's, Nitch & Nitch and MS media, which differed in salt concentration and ratio of ammonium and nitrate nitrogen. Table 3 presents data on the development of black currant embryos, isolated at various differentiation stages on the above-mentioned media. The most suitable medium for all investigated Ribes species appeared to be White's medium. Plantlets were established for 87.5% of embryos rescued at the end of differentiation and 46.1% of embryos rescued at the beginning of differentiation. No plants were obtained on Nitsch & Nitsch medium, while only young enbryos developed on MS medium. Developing embryos grew rapidly on this medium and during the first subcultivation they were

Table 3. The effect of medium on the development of rescued embryos of black currants (Titania x Beloruskaja sladkaja)

Medium	Embryo size mm	Planted embryos	Developed embryos no.	%	Plant length after 1st subcultivation mm-1
White's	0.23 ± 0.16[x]	26	12	46.1	19.0 ± 2.43[z]
Nitsch & Nitsch	0.23 ± 0.15	26	0	0	-
MS	0.27 ± 0.16	28	8	28.6	56.1 ± 10.70
White's	0.44 ± 0.19	24	21	87.5	24.9 ± 2.64
Nitsch & Nitsch	0.42 ± 0.18	24	0	0	-
MS	0.43 ± 0.18	25	0	0	-

[x] Mean ± SD for ten replications; [z] Mean ± SE

more than double the number of embryos on White's medium. On MS medium all small plants were differentiated. Hence we suggest application of White's medium for growth induction, followed by subcultivation on MS medium.

The achieved data encouraged us to perform optimization of White's medium. Table 4 shows the effects of various phytohormones on the development of rescued black currant embryos. Kinetin was found to be the most effective. Both the embryos from the beginning of cotyledon differentiation and the differentiated embryos developed at high frequency when placed on the medium with kinetin. Small plants were fully differentiated and considerably greater in plant height compared with plants grown on other media. When the medium was supplemented with 2.4-D, most embryos formed calluses from epicotyl, but failed in the next subcultivation. In some cases these calluses formed embryoids on the medium that was supplemented with 2.4-D and kinetin, and we succeded in re-

Table 4. Impact of phytohormones on *in vitro* development of rescued black currant embryos on White's medium

Variety	Phytohormone concentration per litre	Planted embryos	Embryo size mm	Developed[x] embryos no.	%	Plant length after 1st subcultivation mm[1]
Titania x	2.5 mg BAP	20	0.1x0.1	1	5.0 c	18.0
Beloruskaja	1 mg kinetin	20	0.1x0.1	2	10.0 c	58.5
sladkaja	2.5 mg 2.4D	20	0.1x0.1	1	5.0 c	28.0
	2.5 mg 2.4D					
	1 mg kinetin	20	0.1x0.1	1	5.0 c	callus
	2,5 mg BAP	40	0.6x0.2	32	80.0 b	48.9
	1 mg kinetin	20	0.6x0.2	19	95.0 a	99.5
	2.5 mg 2.4D	20	0.6x0.2	17	85.0 ab	22.6
	2.5 mg 2.4D					
	1 mg kinetin	20	0.6x0.2	19	95.0 a	23.4
Ben Lomond	2.5 mg BAP	18	0.1x0.1	3	16.7 c	15.0
x Beloruskaja	1 mg kinetin	20	0.1x0.1	10	50.0 b	114.2
sladkaja	2.5 mg 2.4D	20	0.1x0.1	0	0 e	
-						
	2.5 mg 2.4D					
	1 mg kinetin	20	0.1x0.1	3	15.0 c	12.6
	2.5 mg BAP	40	0.6x0.5	35	87.5 a	54.0
	1 mg kinetin	20	0.6x0.2	19	95.0 a	207.6
	2.5 mg 2.4D	20	0.6x0.2	8	40.0 b	30.6
	2.5 mg 2.4D					
	1 mg kinetin	20	0.6x0.2	17	85.0 a	26.4

[x] Mean separation by Duncan's multiple range test, $p \leq 0.01$

generating plants from them. Even though most epicotylsformed calluses, the upper part of the plant continued to grow, but the roots did not develop.

In vitro development of embryos from distant hybridization

The chosen optimum composition of the medium was applied in cultivation of isolated embryos of interspecific hybrids (Table 5). In vitro embryo development depended on the genotypes. When the black currant variety Ben Lomond was used as the female parent, embryo development reached almost 100%, with the exception of hybrids with the gooseberry variety Kurshu dzintars (61.4%).

DISCUSSION

Growing isolated embryos in the early stages of embryogenesis is a complicated problem in experimental botany, genetics and breeding. So far, establishment of normal plants following *in vitro* isolation of a zygote or embryo in the earliest stages of development has not been reported. In general, an embryo can be successfully rescued relatively late when embryos reach the stage of autonomy (Batygina & Vasilyeva 1987).

Embryo development of plants in the genus *Ribes* occors according to the Caryophyllad type, Saxifraga variation (Chetobar et al. 1987). Cotyledons, a

Table 5. In vitro development of rescued embryos of currant interspecific hybrids

Cross combination	Planted embryos	Developed[x] embryos		Embryo size
		no.	%	mm
Titania x *R. americanum*	51	36	70.5 c	0.78x0.25
Titania x Tschornyj negus	50	46	92.0 a	0.62x0.22
Titania x Kurshu dzintars	50	43	86.0 ab	0.73x0.23
Titania x Jonkheer van Tets	49	28	57.1 d	0.65x0.25
Titania x Rondom	47	28	59.6 cd	0.65x0.25
Titania x Corona	33	19	57.6 d	0.62x0.25
Ben Lomond x *R. americanum*	46	46	100.0 a	0.71x0.24
Ben Lomond x Tschornyj negus	30	30	100.0 a	0.69x0.23
Ben Lomond x Kurshu dzintars	44	27	61.4 a	0.41x0.15
Ben Lomond x Jonkher van Tets	49	48	97.9 a	0.74x0.25
Ben Lomond x Rondom	51	50	98.0 a	0.66x0.24
Ben Lomond x Corona	6	6	100.0 a	0.74x0.25
Minaj Shmyriov x *R. americanum*	26	23	88.5 a	0.84x0.25
Minaj Shmyriov x Tschornyj negus	30	21	70.0 bc	0.86x0.25
Minaj Shmyriov x Kurshu dzintars	10	6	60.0 c	0.58x0.21
Minaj Shmyriov x Jonkher van Tets	47	35	74.5 ab	0.85x0.25
Minaj Shmyriov x Rondom	61	38	62.3 bc	0.90x0.25
Minaj Shmyriov x Corona	18	12	66.7 bc	0.79x0.25

[x] Mean separation by Duncan's multiple range test, $p \leq 0.01$

gemma and a rootlet remain weakly developed after fruit maturation. Embryo differentiation is accomplished during stratification. The analysis of embryo development in the genus Ribes has shown characteristic regularities for all species. They all have a very rapid embryo differentiation and intensive embryo growth.

Depending on specific characters, differences were found in the periods of embryo differentiation, embryo size, start of differantiation and embryo increase during the differentiation. The embryos of black currants increased the most significantly (4-9 times), while the embryos of red and americanum currants increased least (2.5-3 times). The size of the mature embryo differed too. The largest embryos were those of *R. aureum* (1 mm), while the smallest were of red currants (0.5 mm). The gooseberries, were closest to black currants according to the size of mature embryos. The formation of the autonomy character in black currants coincides with the beginning of cotyledon differentiation. Owing to the genetic variance of wide hybrids, the embryo development often differs from the norm that determines embryo survival. It is important to ascertain not only the mature of embryo damage but also the time when it is likely to occur. The differentiation of currant cotyledons takes place over a very short period (about 2 weeks) and the growing of isolated embryos from distant hybrids that escape damage caused by genome incompatibility is possible during this period. So far, it is impossible to eliminate the embryo damage of a distant hybrid during earlier phases of embryo development by the method of growing rescued embryos. According to the reported reaction of *in vitro* growth of isolated embryos, it is possible to divide the period from the beginning of cotyledon differentiation up to seed maturity into two subperiods. The first period marks the beginning of embryo autonomy and the second period covers seed transition into dormancy.

In our test the degree of autonomy of black currant embryos was found to increase duringcotyledon differentiation. At the beginning of differentiation 20% of embryos grew *in vitro*, as compared with 100% when the embryo reached maximum size. The percentage of normally differentiated plants was found to increase parallel with a growing embryo.

The percentage of developing explants decreased when currant embryos were taken from mature berries. We believe this was due to two reasons. First, some of the embryos did not develop due to mechanical damage during rescue. Embryo isolation tends to become more complicated when seed tissue becomes callused. The main reason, however, seems to be changes in embryo quality caused by biochemical processes during fruit ripening and seed transition into dormancy. This corresponds with Lasheen & Blackhurst's (1956) data which showed accumulation of inhibitors in currant seeds. But, obviously, accumulation of inhibitors is seeds does not alone explain this phenomenon.

This investigation demonstrates that berry growth of all the investigated *Ribes* species followes the same regularities, which are characteristic of grape and stone fruit development too (Esau 1977). We suppose that these regularities are characteristic of all species within the *Ribes* genus.

In summary, the results of our investigation suggest that the method of rescued embryo culture can be successfully applied for the development of wide currant hybrids, especially in those cross-

combinations in which traditional hybrids are not available. Embryos have to be extracted during cotyledon differentiation. This period is rather short and lasts for 8-17 days, depending om species or form.

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Sweet cherry nutrition: effects of phosphorus and other major elements on vigour, productivity, fruit size and fruit quality of 'Kristin' sweet cherries grown on a virgin, acid soil

JONAS YSTAAS & ODDMUND FRØYNES
The Norwegian Crop Research Institute, Ullensvang Research Centre, Lofthus, Norway

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'Kristin' sweet cherry responded positively to phosphorus fertilization in a field trial carried out over a period of 13 years on a virgin, acid soil low in plant available P and exchangeable K, Mg and Ca. Application of 20 kg P ha^{-1} per year significantly increased tree size as measured by trunk girth, cumulative yield, yield efficiency and fruit size. The sweet cherry trees had a sufficient supply of P when soil plant available P was above 4 mg P/100 g and leaf P was in the range 0.20-0.30% P. The soil non-exchangeable potassium (180 mg K/100 g) contributed consistently over time to meet the demand for K. Accumulated yield, however, was increased by application of 60 kg K ha^{-1} per year. Fruit quality as measured by soluble solids was negatively affected by phosphorus and potassium fertilization. Liming with ground limestone and dolomitic limestone (2000 - 6000 kg ha^{-1}) at the start of the experiment raised soil pH from 4.4 to 5.5-6.0 thus supplying the trees sufficiently to maintain the leaf Mg and Ca within the optimal range throughout the experimental period.

Key words: *Prunus avium*, fertilizer, P, K, Mg, Ca, yield, fruit quality.

Jonas Ystaas, The Norwegian Crop Research Institute. Ullensvang Research Centre, N-5774 Lofthus, Norway.

The fertilizer requirement of fruit crops is much less than that of farm crops and vegetables (Greenham 1976). Apple tree nutrition has been studied extensively (Boynton & Oberly 1966; Atkinson et al. 1980), whereas sweet cherry nutrition has attracted less attention (Westwood & Wann 1966; Ystaas 1990).

The phosphorus requirement of fruit trees is small (approximately 5 kg ha^{-1}) and fruit trees seem to have a greater ability than other crops to take up phosphorus from the soil (Greenham 1976). A direct response of fruit trees to phosphorus fertilization is not usually observed under orchard conditions (Lilleland et al. 1942; Stiles 1994). The potassium requirement of fruit trees is much higher than the phosphorus requirement and is dependent on the weight of crop carried, because of the relatively high concentration of potassium in the fruit (Greenham 1976). The estimated calcium and magnesium requirement of fruit crops are of the order 25 and 4 kg ha^{-1}, respectively (Green-

ham 1976). In acid soils, application of ground limestone and dolomitic limestone provides for plant available Ca and Mg in addition to regulating soil acidity.

In the present study the nutritional phosphorus, potassium, magnesium and calcium requirement of 'Kristin' sweet cherries is examined over 13 years on a virgin, acid soil low in P and exchangeable K, Mg and Ca.

MATERIALS AMD METHODS

During the years 1981-93 a fertilizer trial with young sweet cherry trees was carried out at The Norwegian Crop Research Institute, Ullensvang Research Centre, western Norway. The experiment was carried out on a loamy sand, high in organic matter (7.2%). The soil was a morainic deposit on a hillside facing west. The land was under deciduous forest with alder (*Alnus incana* L.), birch (*Betula spp.*) and European ash (*Fraxinus excelsior* L.) as the predominant trees before the land was cleared in 1979. The virgin soil was acid (pH 4.4) and had very low levels of plant available P and exchangeable K, Mg and Ca. No fertilizers had ever been applied to the soil prior to the experiment.

One-year-old trees of 'Kristin' on rootstock *Prunus avium* F 12/1 were planted in early spring 1981. The planting distance was 6 x 4 m. Each experimental tree was surrounded by guard trees of the cultivars 'Vista', 'Valeska', 'Bada' and 'Rainier', which also served as pollinators. The trees were trained with a central leader and given the form of free spindle. Tree height was kept at 4 m by annual pruning.

A split-plot experimental design was used. On the small plots three levels of potassium applied as muriate of potash (49% K) at rates of 0, 60 and 120 kg K ha^{-1} were combined with three levels of phosphorus applied as granular superphosphate (8.8% P) at rates 0, 20 and 40 kg P ha^{-1}. On the large plots two levels of calcium and magnesium were applied in the form of ground limestone (50% CaO) and dolomitic limestone (50% CaO - 13% Mg). At level one 1000 kg CaO ha^{-1} in the form of 1000 kg ground limestone ha^{-1} and 1000 kg dolomite ha^{-1} was applied. At level two 3000 kg CaO ha^{-1} in the form of 4000 kg ground limestone ha^{-1} and 2000 kg dolomite ha^{-1} was used. All dolomite and ground limestone treatments were applied to the soil surface at the start of the experiment. The experiment had 4 replications and included 36 one-tree plots. The ground was kept under grass, with 1-m-wide herbicide strips along the tree rows. Nitrogen applied as calcium nitrate (15.5% N, 0.3% B) at a rate of 80 kg N ha^{-1} per year was broadcast evenly over the experimental area in early spring.

Trunk circumference 25 cm above the graft union was recorded annually in the autumn. Total yield, including rain-induced cracked fruits, was recorded every year and fruit weight and fruit quality as measured by the content of soluble solids were determined on random samples of 50 fruits from each tree. Concentration of soluble solids was measured by an Atago digital refracto-meter from free-run fruit juice from 10 mature fruits of the 50-fruit sample.

Soil samples from the 0-20 cm soil layer from each plot were collected annually in October. Every year during the last week of August 25 leaves from the middle of current year shoots of each tree were sampled and dried at 60°C. Exchangeable cations and soil phosphorus were extracted according to the method described by Egnér et al. (1960). Non-exchangeable K was determined according

to Reitemeier et al. (1948). For determination of K, Mg, Ca and P in the leaves, the plant material was digested in a 1:2 mixture of perchloric and nitric acids (Oland & Opland 1956). The determination of cations was achieved by atomic absorption spectrophotometry. Determination of phosphorus in plant material and soil extract was carried out according to methods proposed by Michelsen (1957) and Murphy & Riley (1962), respectively.

Analysis of all data was performed by the SAS statistical package (SAS Institute, Cary, N.C., USA) using the PROC GLM procedure.

RESULTS

Main effects on tree vigour, productivity and fruit quality

Phosphorus

The year before the start of the experiment the growth of a grass sward in the experimental field was seriously affected by acid soil conditions (pH 4.4) and very low phosphorus-supplying power of the soil; plant available P was only 1.1 mg P/100 g soil. Before the experimental trees were planted the field had been ploughed. The differential application of P, K, Mg and Ca fertilizers made the re-established sward and the sweet cherry trees grow normally, without any symptoms of mineral deficiencies.

Tree vigour, cumulative yield, yield efficiency, fruit weight and soluble solids were significantly affected by the phosphorus fertilization (Table 1). No additional effects were obtained by increasing the P application from 20 kg P ha^{-1} to 40 kg P ha^{-1}. Cumulative yield was increased by 74% when 20 kg P ha^{-1} was applied over 13 years. The yield efficiency of the 'Kristin' trees was increased significantly by the P fertilization. The effect on fruit size was small, but fruit quality was affected in a negative way; the content of soluble solids was reduced significantly by phosphorus fertilization.

Potassium

Differential potassium application over 13 years had no effect on tree vigour, while annual application of 60 kg K ha^{-1} increased cumulative yield significantly. K application at a rate of 60 kg ha^{-1} improved yield efficiency, defined as accumulated yield, kg/tree, divided by the trunk cross-sectional area in cm^2, but did not affect fruit size. Fruit quality as measured by the content of soluble solids was negatively affected by the application of 120 kg K ha^{-1}.

Magnesium and calcium

The application of two rates of liming materials (ground limestone and dolomite) did not produce any significant difference in tree vigour, yield or fruit quality.

Effects of major nutrients on soil and trees

As no significant interaction between treatments was found, the effects of differential supply of P, K, Mg and Ca will be dealt with separately.

Phosphorus

Annual application of superphosphate at rates 20 and 40 kg P ha^{-1} to the ground surface significantly increased the plant available P in the soil 0-20 cm layer over the 13 years of the trial (Fig. 1). The higher content of plant available P in the soil brought about by the P fertilization was reflected in the leaf phosphorus content (Fig. 2). Annual application of 20 kg P ha^{-1} significantly increased the leaf P content over the control. A further increase in the rate of P fertilization raised

the leaf P content significantly during the last seven years of the experimental period.

Tree vigour as measured by the trunk girth was significantly affected by the phosphorus supply throughout the experimental period (Fig. 3). The phosphorus application affected yield in a favourable way; a significant increase in cumulative yield at the lower rate of P fertilization compared to the control trees was obtained (Fig. 4).

Potassium

Over a period of 3 years soil application of muriate of potash at 60 and 120 kg K ha^{-1} per year established three different levels of exchangeable K in the top 20 cm soil layer in relation to the amount of potassium supplied (Fig. 5). The established levels were maintained throughout the experimental period as significantly different. The content of non-exchangeable K was very high (Table 2) and was not influenced by different potassium applications. The differential K fertilization was reflected in the K leaf content (Fig. 6); the control trees receiving no potassium had a significantly lower content of leaf K than those that were fertilized. The leaf K content of trees treated with different amounts of potassium fertilizer established significantly different leaf K levels, except for the last five years of the trial period.

Magnesium and calcium

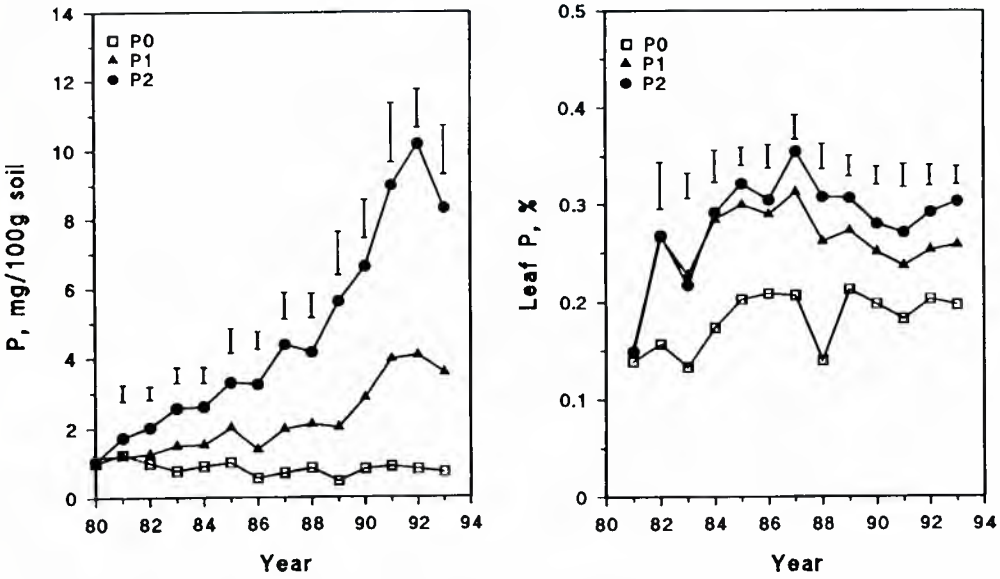
Magnesium was applied to the soil surface at the start of the experiment by application of 1000 kg and 2000 kg dolomite ha^{-1}, respectively. Different soil Mg levels were established within three years and were maintained for the rest of the experimental period (Fig. 7). The leaf Mg content was affected by the different Mg supply (Fig. 8), but did not differ in relation to the amount of magnesium applied.

The orchard soil responded slowly to the ground limestone applied at the start of the trial (Fig. 9). Two levels of soil Ca were established according to the rate of ground limestone and dolomite applied. Leaf Ca was influenced by the low soil Ca level at the start of the trial (Fig. 10). Later, the leaf Ca attained values that did not differ much from year to year or between rates of Ca applied.

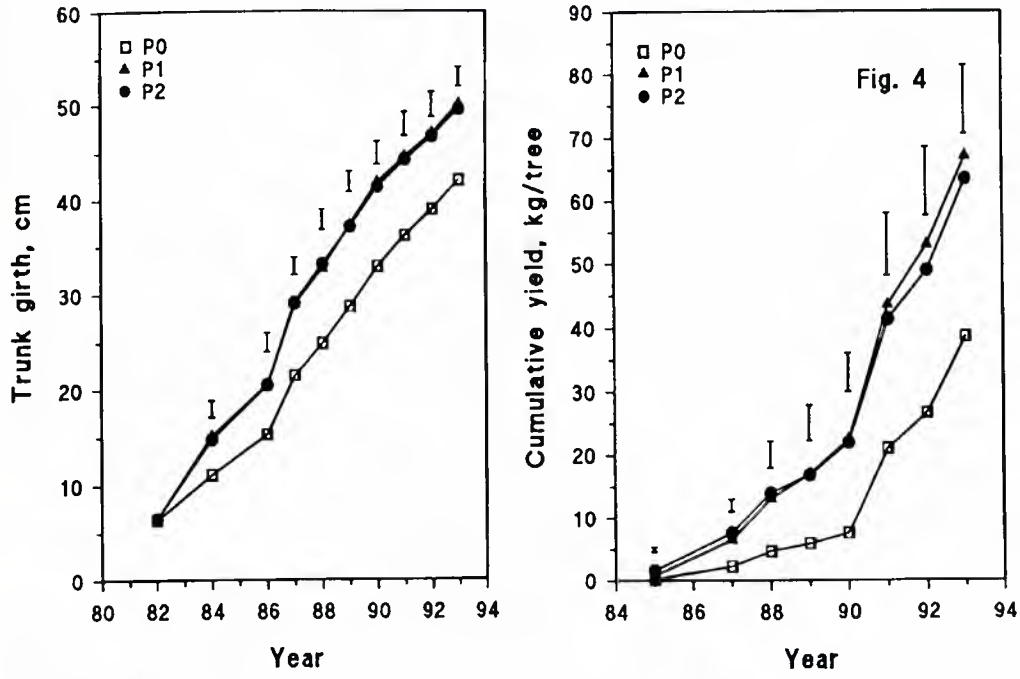
Soil acidity was greatly influenced by lime application (Fig. 11). Depending on the amount of ground limestone and dolomite applied, two different levels of soil acidity were established, changing the soil pH from pH 4.4 at the start to pH 5.3 and pH 5.7 at the end of the trial.

DISCUSSION

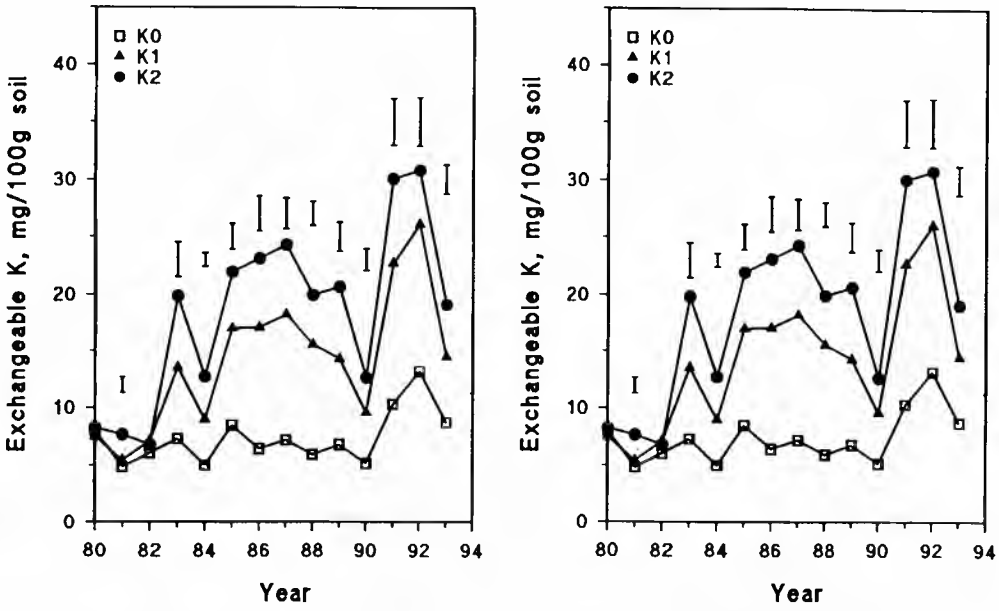
The soil in this experiment can be characterized as phosphorus-deficient, having a plant available P content as low as 1 mg P/100 g soil (Fig. 1). This offered a unique opportunity to study the phosphorus requirement of cropping sweet cherry trees, whereas a direct response of fruit trees to phosphorus fertilization is not usually observed under orchard conditions (Greenham 1976; Stiles 1994). Annual application of 20 kg P ha^{-1} increased the soil plant available P over the years to 4 mg P/100 g soil, which resulted in significantly improved vigour as measured by trunk girth, higher yields and improved fruit size. No additional positive effects were obtained on the performance of the sweet cherry trees by increasing the annual phosphorus application to 40 kg P ha^{-1}. On this background the leaf P data (Fig. 2) indicated that the optimal range of leaf P for sweet



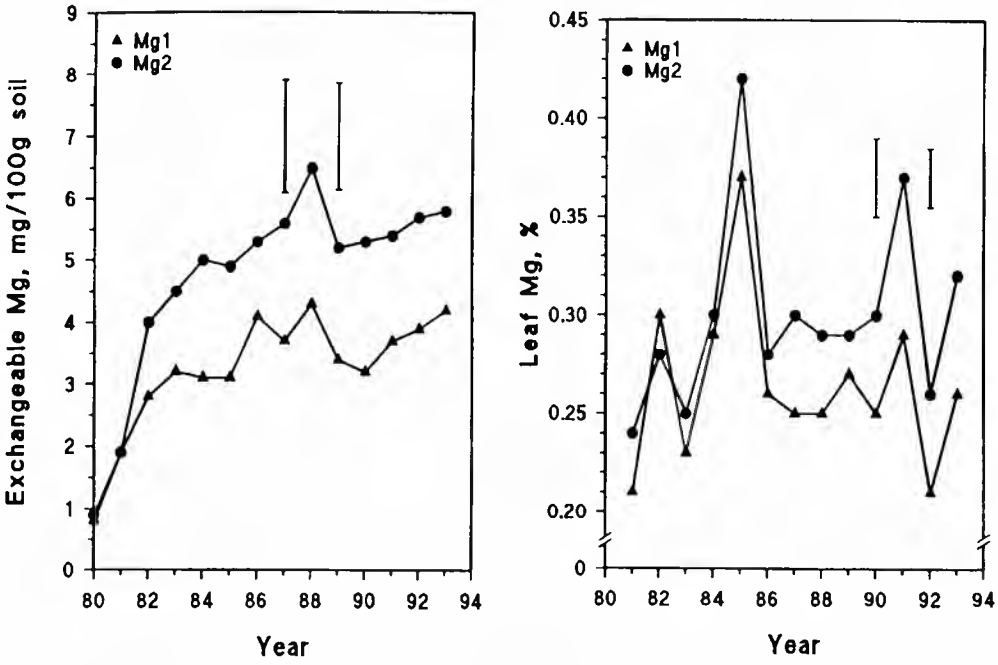
Figs. 1 - 2. Plant available P in the soil and leaf P as affected by phosphorus fertilization over 13 years. P0 = no P; P1 = 20 kg P ha^{-1}; P2 = 40 kg P ha^{-1} per year. Vertical bars represent LSD, P = 0.05



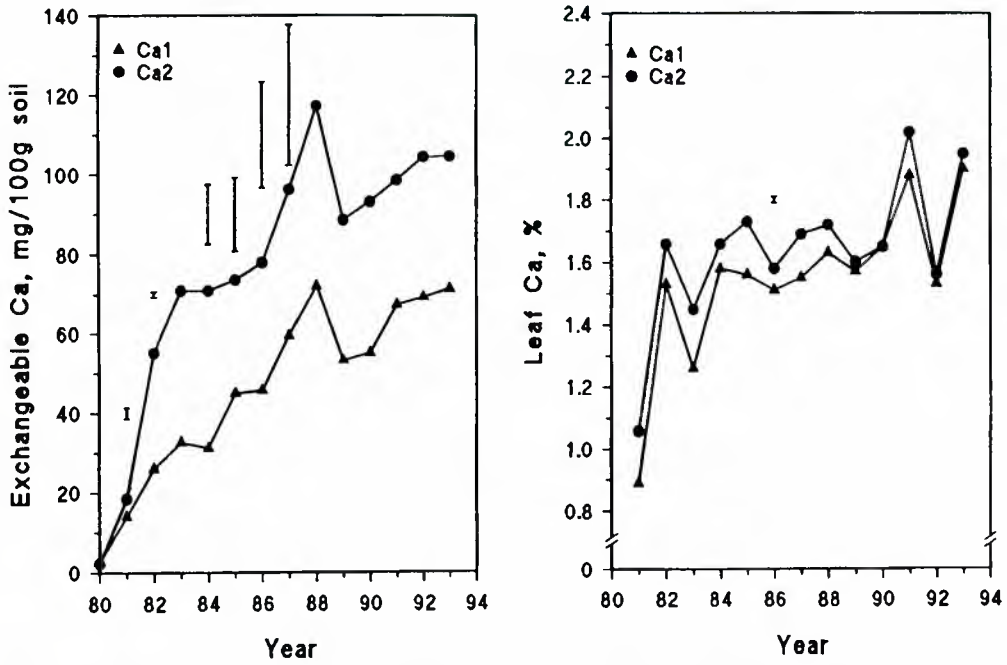
Figs. 3 - 4. Effects of P fertilization on tree size as measured by trunk girth (cm) and cumulative yield (kg/tree) over the years. P0 = no P; P1 = 20 kg P ha^{-1}; P2 = 40 kg P ha^{-1} per year. Vertical bars represent LSD, P = 0.05



Figs. 5 - 6. Effects of K fertilization on soil exchangeable K (mg K/100 g soil) and leaf K (per cent of leaf dry matter) over 13 years. K0 = no K; K1 = 60 kg K ha^{-1}; K2 = 120 kg K ha^{-1} per year. Vertical bars represent LSD, P = 0.05



Figs. 7 - 8. Effects of ground dolomitic limestone on soil exchangeable Mg (mg Mg/100 g soil) and leaf Mg (per cent of leaf dry matter) over 13 years. Mg1 = 1000 kg dolomite ha^{-1}, Mg2 = 2000 kg dolomite ha^{-1} applied at the start of the trial. Vertical bars represent LSD, P = 0.05



Figs. 9 - 10. Effects of ground limestone and dolomite on soil exchangeable Ca (mg/100 g soil) and leaf Ca (per cent of leaf dry matter) over 13 years. Ca1 = 1000 kg ground limestone + 1000 kg dolomitic limestone ha^{-1}, Ca2 = 4000 kg ground limestone + 2000 kg dolomitic limestone ha^{-1} applied at the start of the trial. Vertical bars represent LSD, P = 0.05

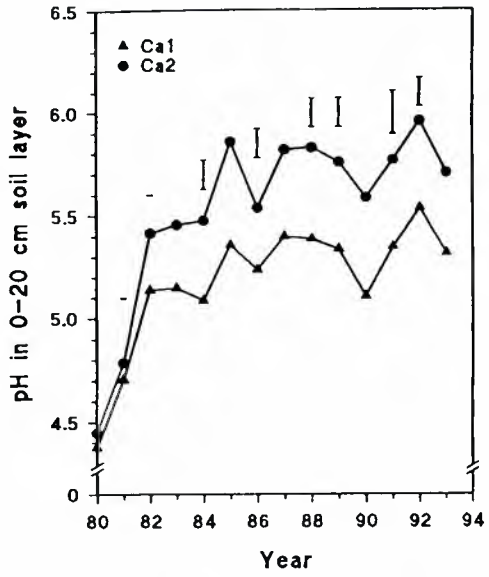


Fig. 11. The effect of liming on soil pH in the 0-20 cm layer over 13 years. Ca1 = 1000 kg ground limestone + 1000 kg dolomitic limestone ha^{-1}, Ca2 = 4000 kg ground limestone + 2000 kg dolomitic limestone ha^{-1} applied at the start of the trial. Vertical bars represent LSD, P = 0.05

cherries should be adjusted to 0.20-0.30% P of leaf dry matter. This is in accordance with the range recom-mended in England (Greenham 1976), but is in contrast to American recommen-dations of 0.13-0.33% P (Stiles & Shaw Reid 1991). In Denmark the range 0.15-0.30% P (Vang-Petersen 1989) is proposed, while in Norway 0.15-0.25% P has been recommended (Ystaas 1981).

The positive effect of P found on tree vigour was in accordance with the results obtained by Neilsen et al. (1990) working with one-year-old *Prunus avium* L. seedlings in pot experiment in a green-house. They found that the establishment and initial growth of perennials, such as cherry, were increased by both P application and liming of acid soils. Moreover, Neilsen (1994), working with young apple trees in British Columbia, Canada, in greenhouse and field experiments using P fertilization to overcome replant disorders, presented data which showed that improved P nutrition could benefit the establishment and early growth of young fruit trees. The optimal range of 1.5-2.0% leaf K (Greenham 1976; Ystaas 1981) for sweet cherries indicated that the trees on the control plots receiving no potassium had a leaf K content just below or within the threshold limit (Fig. 6). The turnover of potassium from non-exchangeable to exchangeable form had apparently taken place at a rate almost sufficient to meet the demand of the sweet cherry trees. Similar results were obtained with apple trees on a sandy soil high in non-exchangeable K (Ystaas & Frøynes 1993). Disregarding the potassium supplying power of the soil, application of 60 kg K ha^{-1} significantly increased cumulative yield. This was in accordance with the positive effects of K fertilization on yield of sour and sweet cherries reported by Sandvad (1962) and Ystaas (1990). The application of 1000 and 2000 kg dolomite ha^{-1} at the start of the experiment gave the sweet cherry trees a sufficient supply of magnesium throughout the experimental period. No symptoms of magnesium deficiency were observed. The leaf Mg content (Fig. 8) was within or above the optimal range for cherry as proposed by Greenham (1976): 0.20-0.25%, Ystaas (1981): 0.20-0.30%, and Vang-Petersen (1989): 0.20-0.40%. The European recommendations for optimal leaf magnesium content, however, are considerably lower than the optimal range of 0.40-0.60% Mg proposed by Stiles & Shaw Reid (1991) for stone fruit under American growing conditions.

Surface application of ground limestone and dolomite at the start of the experiment gradually raised soil pH from 4.4 to 5.5-6.0 depending on the amount of lime applied (Fig. 11), thus creating more favourable soil conditions for the availability of phosphorus (Stiles 1994). Although two different levels of exchangeable Ca in the soil were established, leaf Ca was approximately the same, within the 1.5-2.0% range, which is within the optimal range proposed by Stiles & Shaw Reid (1991): 1.3-2.0% Ca, and Vang-Petersen (1989): 1.6-2.1% Ca.

CONCLUSION

Liming and application of phosphorus to an acid, virgin soil produced positive effects of phosphorus on young sweet cherry trees by significantly increasing vigour, yield, yield efficiency, and fruit size. Even though the soil had a considerable potassium supplying power application of potassium had a positive effect on yield and yield efficiency.

Table 1. Main effects of phosphorus, potassium, calcium and magnesium application to 'Kristin' sweet cherries on tree size as measured by trunk girth of 13-year old trees, cumulative yield, cumulative yield efficiency, fruit weight and soluble solids, average figures

Fertilizer application kg ha^{-1}	*Trunk girth cm*	*Cumulative yield kg/tree kg/cm^2*	*Cumulative yield efficiency*	*Fruit weight g*	*Soluble solids %*
Phosphorus					
0	42.1	38.6	2.88	7.7	18.5
20	50.0	67.0	4.24	8.0	18.0
40	49.5	63.4	4.04	8.0	17.9
LSD, P=0.05	2.1	11.8	0.80	0.2	0.4
Potassium					
0	48.0	47.1	3.05	7.8	18.4
60	47.4	63.1	4.11	7.9	18.1
120	46.2	58.8	4.00	8.0	17.9
LSD, P=0.05	NS	11.8	0.80	NS	0.4
Calcium + magnesium					
2000[1)]	47.2	56.9	3.79	7.9	18.3
6000[2)]	47.2	55.8	3.66	7.9	17.9
LSD, P=0.05	NS	NS	NS	NS	NS

[1)] *Applied as 1000 kg ground limestone and 1000 kg dolomite*
[2)] *Applied as 4000 kg ground limestone and 2000 kg dolomite*

Table 2. The effects of different potassium applications on non-exchangeable K in the 0-20 cm soil layer

Potassium applications kg K ha^{-1}	*K, mg per 100 g soil*		
	Year 1	*Year 13*	*Mean*
0	*175*	*177*	*176*
60	*182*	*184*	*183*
120	*176*	*194*	*185*
LSD, P=0.05	*NS*	*NS*	*NS*

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Feed with divergent fat: carbohydrate ratios for blue foxes (*Alopex lagopus*) and mink (*Mustela vison*) in the growing-furring period

ØYSTEIN AHLSTRØM AND ANDERS SKREDE
Agricultural University of Norway, Department of Animal Science
Aas, Norway

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A study was carried out to investigate the effect of divergent dietary fat:carbohydrate (F:C) ratios on growth, general health status and fur quality in blue fox and mink during the growing-furring period. The F:C ratios, as percentages of metabolizable energy, ranged from 65:5 to 40:30. Lard and soybean oil were used as experimental fat sources and precooked wheat and oats, and extruded corn as carbohydrate sources. In blue foxes (n=20), higher F:C ratios resulted in increased energy intake (ME), higher final body weight and longer skins. Neither health status nor fur quality in blue foxes was affected significantly by the F:C ratio. In mink (n=64) it was found that with the highest F:C ratios there seemed to be an increase in ME consumption per body weight gain. It was also found that very high F:C ratios had a negative effect on fur quality in mink, possibly owing to impaired guard hair growth. We conclude that blue foxes can tolerate higher F:C ratios than mink.

Key words: Blue fox, carbohydrate, energy intake, fat, fur quality, mink.

Øystein Ahlstrøm and Anders Skrede, Agricultural University of Norway, Department of Animal Science, P.O. Box 5025, N-1432 Aas, Norway.

Previous investigations have shown that dietary fat:carbohydrate (F:C) ratios, based on metabolizable energy, can vary without markedly influencing the performance of mink (Høie 1954; Skrede 1983; Riis Olesen 1990) or blue foxes (Rimeslåtten 1976; Hillemann & Lyngs 1988), provided the protein level fulfils the amino acid requirements and the feed ingredients are of satisfactory quality. However, the general increase in energy content and F:C ratio in commercial fur animal feed during the last decade has raised concern that animals exposed to extremely high fat levels could be adversely affected. The literature does not include any studies comparing blue foxes and mink in terms of their ability to achieve normal growth and fur quality when fed high dietary F:C ratios. A major difference in optimum F:C ratio between blue foxes and mink would imply that the feed suppliers should consider producing separate feed mixtures for each of the two species.

The purpose of the present experiment was to study the effects of the dietary F:C ratios on growth, energy consumption, general health status and fur quality of blue foxes and mink.

MATERIAL AND METHODS

Animals and diet composition

The experiment was carried out at the experimental farm of the Department of Animal Science, Agricultural University of Norway. There were six experimental groups each of which comprised 20 blue fox cubs and 64 standard dark mink kits, with 50% males and 50% females per group. The animals were assigned to treatment groups according to genotype, age, body weight and pre-experimental treatment. The experiment started on 13 July for mink and 3 August for foxes, and ended at pelting in late November. One male and one female were kept in each cage, which was equipped with a nestbox for mink and a wooden shelf for foxes. The animals were fed once a day *ad libitum*, and water was provided by an automatic system. Feed consumption was recorded daily on a group basis. The diets were prepared twice weekly and kept in a refrigerator until feeding. Animals that died during the experiment were autopsied at the National Veterinary Institute, Oslo.

The divergent dietary F:C ratios were achieved by replacing precooked wheat/oats (steam-cooking at 2 x atmospheric pressure and 120°C adding 3% water) and extruded corn with lard and soybean oil (Table 1). The protein level was kept constant at 30% of metabolizable energy (ME).

Growth and fur quality

The animals were weighed every four weeks during the experimental period and final body weight was recorded at the start of the pelting season. The fur characte-

Table 1. Feed composition (%)

	Fat:carbohydrate ratio[1]					
	65:5	60:10	55:15	50:20	45:25	40:30
Cod fillet scraps	36.2	33.8	30.1	29.1	27.5	26.9
Fish meal (Norseamink)	8.2	7.7	6.9	6.6	6.3	6.2
Slaughter offal	13.0	12.2	10.9	10.5	10.0	9.8
Blood	7.8	7.3	5.0	3.2	1.6	0.4
Lard	6.4	5.3	4.1	3.5	2.7	2.2
Soybean oil	5.5	4.7	3.7	3.0	2.5	2.0
Precooked wheat/oats [2]	2.1	4.1	5.7	7.3	8.8	10.3
Extruded corn	1.6	3.2	4.4	5.7	6.7	8.0
Vitamin mixture [3]	1.0	1.0	1.0	1.0	1.0	1.0
Hemax [4]	0.2	0.2	0.2	0.2	0.2	0.2
Water	18.0	20.5	28.0	30.0	32.7	33.0

[1] The fat carbohydrate ratio is given as percentage of ME.

[2] Contains 70% wheat and 30% oats.

[3] Contains grass meal (50%), brewer's yeast (35%) and wheat bran (14%) fortified with the following vitamins per 100 g: Vit.A, 30000 I.U.; Vit D_3, 3000 I.U.; DL-α-tocopherol acetate, 300 mg; thiamine, 180 mg; riboflavin, 18 mg; niacinamide, 15 mg; Ca-pantothenate, 15 mg; pyridoxine-HCl, 30 mg; folic acid, 1.5 mg; biotin, 0.15 mg; Vit B_{12}, 0.1 mg.

[4] Product of Peter Møller A/S, Oslo, contains ferric glutamate at 20 mg Fe per g.

ristics were evaluated on dried skins by the staff at the fur farm of the Department of Animal Science. An additional evaluation of general impression was made at the Oslo Fur Auctions. Fur characteristics for blue fox skins were colour, colour purity, cover, texture, density, hair quality and general impression. For mink skins the characteristics were density of guard fur and underfur, length of guard fur and underfur, fur colour, the fur defect metallic, hair quality and general impression. In addition, the fur defects grey underfur and wet belly were recorded in mink. At the Oslo Fur Auctions both mink and fox skins were assigned to the following quality groups: Saga Royal, Saga, Quality I and Quality II regarding general impression.

Analyses

Four samples of feed and three samples of some feed ingredients were taken throughout the experimental period and sent for chemical analysis after some days of storage at -20°C.

Proximate composition in the experimental diets and free fatty acids (FFA), peroxide value, and anisidin value of some feed ingredients were determined at the laboratory of the Norwegian Fur Breeders' Association. Dry matter was determined by drying at 104°C for 4 h after pre-drying at 70°C for 12 h. Ash was determined by heating at 550°C for 12 h. Crude fat was determined by extraction with diethyl ether (Soxhlet), and crude protein as Kjeldahl-N x 6.25 using a macro-method. Carbohydrates were estimated by difference calculation. Free fatty acids and peroxide value were determined by the methods described by Welch (1976) and the A.O.A.C. (1980), respectively. The anisidin value was determined by mixing 0.1 g fat with 9.9 ml hexane. Absorbance at 350 nm (A2) was then measured, whereupon anisidin reagent (0.5 ml) was added to the mixture (2.5 ml) and incubated for 10 min at room temperature. Another absorbance reading at 350 nm (A1), yielded the anisidin value = 100(1.2 * (A1-A2)). Hexane was used as a blank in the assay. The ME content of the diets was calculated on the basis of chemical analyses, digestibility coefficients determined in digestibility experiments with blue foxes and mink fed the respective diets (Ahlstrøm & Skrede 1995), and the following values of ME (kJ/g): protein (N x 6.25), 18.8; fat, 39.8; carbohydrate, 17.6 (Enggaard Hansen et al. 1991).

Statistics

An analysis of variance was applied in the statistical analysis (SAS Institute Inc. 1985) and the effect of diet was tested by the PROC GLM procedure using the model $Y_{ij} = \mu + a_i + \varepsilon_{ij}$ where Y_{ij} = the ijth observation, μ = overall mean, a_i = fixed effect of diet and ε_{ij} = random effect. The LSMEANS/PDIFF (least-squares method) was used for testing of differences between diets.

RESULTS

Feed

As might be expected, the ME content per kg feed increased along with the F:C ratio, mainly owing to enhanced ME levels in the dry matter in the high F:C diets (Table 2). The ME content of the diets was higher for blue fox than for mink because of higher energy digestibilities for blue foxes compared with those for mink. However, the difference in ME content in the feed between the two species had little influence on the F:C ratios, which were close to target values and quite similar for blue fox and mink (Table 2).

Table 2. Average proximate composition and metabolizable energy data for blue fox and mink based on four samples of each diet

	Fat:carbohydrate ratio					
	65:5	60:10	55:15	50:20	45:25	40:30
Dry matter(%)	36.7	37.0	34.4	34.2	34.8	35.7
Ash (%)	3.2	3.0	2.5	2.3	2.3	2.4
Protein (%)	15.7	14.9	13.5	12.6	12.2	12.5
Fat (%)	14.1	12.8	10.6	9.2	8.1	7.0
Carbohydrates (%)	3.5	6.2	7.7	10.0	12.0	13.5
Metabolizable energy (ME) [1]:						
Blue fox, MJ/kg feed:	8.38	8.16	7.28	6.95	6.80	6.57
F:C ratio	64:5	59:10	55:15	50:20	44:27	0:30
Mink, MJ/kg feed	8.05	7.86	6.93	6.48	6.29	6.02
F:C ratio	64:6	60:11	54:16	49:21	44:27	40:31

[1] Calculated on the basis of chemical analyses, digestibility coefficients determined for blue foxes and mink, and the following values of ME (kJ/g): protein (Nx 6.25), 18.8; fat, 39.8; carbohydrate, 17.6.

The contents of lipid oxidation products in the major dietary fat sources were relatively moderate, indicating good fat quality (Table 3).

ME consumption and growth performance

ME intake was lowest in the group receiving the lowest F:C ratio and increased progressively with increasing F:C ratio (Fig. 1). In foxes the palatability of all the diets seemed satisfactory, and the pattern of change in feed intake during the experiment was similar for all dietary groups: Daily feed intake increased until a peak was reached in late October, whereafter it decreased slightly. The difference in ME intake was clearly reflected in the body weight gain (Table 4). On average, body weights at pelting, were about 1.5 kg higher in the blue foxes receiving the diet with the highest F:C ratio compared with those receiving the lowest F:C ratio.

Table 3. Fat quality parameters for major fat sources. Average of three samples with standard deviation in parentheses

	Free fatty acids (%)	Peroxide value (meq O_2/kg fat)	Anisidin value
Slaughter offal	2.4 (0.2)	3.1 (1.9)	1.5 (1.2)
Lard	0.4 (0.1)	2.7 (0.7)	3.8 (3.0)
Soybean oil	0.4 (0.1)	2.9 (0.6)	2.3 (0.7)

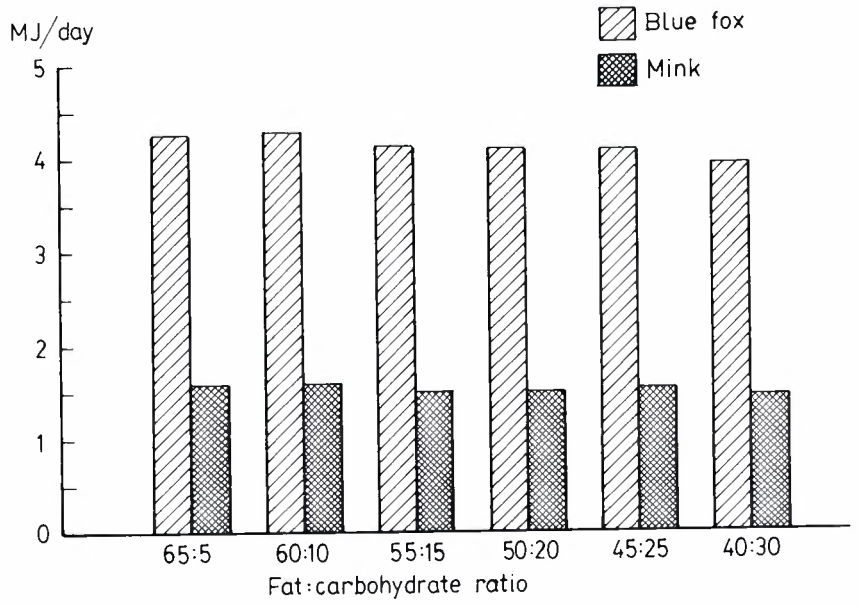

Figure 1. Daily energy (ME) consumption

In mink, voluntary feed intake seemed to be positively related to the F:C ratio. Cases of feed refusal occurred during the first days of the experiment, particularly where the lowest F:C ratio diets were offered. However, after about one week of adaption, the feed intake improved. The course of feed intake during the experiment differed somewhat among the dietary groups (data not shown). Animals receiving the highest F:C ratios (65:5, 60:10) reached a high level of feed intake in August and maintained this level until mid- October, when intake began to decline. Groups receiving the intermediate and low F:C ratios consumed increasing amounts of feed from August until mid-October. Thereafter the feed intake remained stable until early November when it started to decline.

In contrast to the overall picture in blue fox, the daily energy intake in mink did not exert any influence on total body weight gain or final body weights (Table 5).

Mortality

Two of the foxes that had been given intermediate F:C ratios (55:15, 50:20) died early in the experiment (September). The autopsies revealed that in both animals minor wounds had become infected with *Streptococcus canis* which had then spread to vital organs (Table 4).

A total of 17 mink died during the experiment (Table 5). They were about equally distributed across dietary groups, except for six animals in the group given the 65:5 F:C ratio. The deaths were mainly caused by bacterial infections. However, one animal died of heart failure and two died of fatty liver.

Skin size and fur characteristics

The skins from the blue foxes given the highest F:C ratio were significantly longer than those from the other blue fox groups (Table 6), reflecting the high body weights obtained in this group. No significant differences in fur quality parameters were found in blue foxes. Regardless of dietary

Table 4. Effects of divergent fat:carbohydrate ratios on body weight gain (g) and mortality in blue foxes

	Fat:carbohydrate ratio						
	65:5	60:10	55:15	50:20	45:15	40:30	p-values
Males							
3 Aug	2525	2495	2468	2466	2453	2439	*0.99*
4 Sept	4945	4900	4696	4603	4390	4408	*0.17*
2 Oct	7282a	6673ab	6425bc	6207bc	6076bc	5952c	*0.002*
31 Oct	9479a	8397b	8396b	8416b	8020b	7691b	*0.002*
Females							
3 Aug	2446	2380	2555	2392	2453	2430	*0.97*
4 Sept	4519	4351	4465	4406	4317	4211	*0.55*
2 Oct	6361a	6195ab	5917abc	5857bc	5668c	5567c	*0.01*
31 Oct	8174a	7913ab	7388bc	7583abc	7392bc	6938c	*0.009*
Mortality (n)							
(bacterial infection)		**1**	**1**				

Group means with only different letters within row are significantly different ($p<0.05$).

Table 5.Effects of divergent fat:carbohydrate ratios on body weight gain (g) and mortality in mink

	Fat:carbohydrate ratio						
	65:5	60:10	55:15	50:20	45:15	40:30	p-values
Males							
13 July	1162	1144	1133	1115	1110	1088	*0.45*
10 Aug.	1870	1817	1766	1810	1806	1727	*0.11*
7 Sept.	2223	2200	2166	2220	2187	2103	*0.47*
5 Oct.	2468	2466	2353	2427	2455	2326	*0.15*
2 Nov.	2651	2636	2596	2664	2649	2552	*0.60*
Females							
13 July	776	762	781	787	774	747	*0.58*
10 Aug.	1088	1067	1069	1049	1071	1021	*0.32*
7 Sept.	1222	1197	1220	1173	1194	1142	*0.68*
5 Oct.	1290	1314	1295	1236	1330	1250	*0.19*
2 Nov.	1348	1381	1407	1350	1392	1367	*0.80*
Mortality (n)	**6**	**2**	**2**	**4**	**2**	**1**	
Death cause							
Bacterial infections	3	2	2	3	1	1	
Fatty liver	1			1			
Heart failure					1		
No certain cause	2						

Table 6. Effects of divergent fat:carbohydrate ratios on skin characteristics in blue fox. The figures represent 50% males and 50% females.

	Fat:carbohydrate ratio						
	65:5	60:10	55:15	50:20	45:15	40:30	p-values
Number of skins	13	15	13	13	14	16	
Skin length, cm	106.0a	102.3b	103.0ab	103.2ab	101.1b	100.6b	*0.001*
Skin weight, (dry) g	565	553	568	579	582	556	*0.56*
Colour [1]	7.0	6.6	6.9	7.3	6.6	6.8	*0.34*
Colour clarity [2]	5.9	6.3	6.1	6.3	6.4	6.5	*0.17*
Cover [2]	6.0	5.6	5.6	5.8	5.9	6.0	*0.65*
Hair quality [2]	6.0	5.9	6.3	5.9	5.8	6.2	*0.47*
Texture [2]	6.5	6.1	6.2	6.1	6.5	6.1	*0.34*
Density [2]	6.0	5.9	6.2	6.5	6.1	6.0	*0.06*
General impression [3]	3.6	3.6	3.5	3.5	3.5	3.6	*0.30*

Group means with different letters within row only are significantly different ($p<0.05$).

[1] Subjectively graded from 1 (lightest) to 10 (darkest).

[2] Subjectively graded from 1 (poorest) to 10 (best). [3] Graded at Oslo Fur Auctions in these groups: 1, Quality II (poorest); 2, Quality I; 3, Saga; 4, Saga Royal (best).

treatment, the skins obtained high general impression scores, with about 50% of them graded as Saga and 50% as the highest quality, Saga Royal.

Although there was no significant difference in skin length in mink, some of the fur parameters were significantly influenced by the dietary F:C ratio (Tables 7-8). The length of guard fur decreased with increasing F:C ratio, but the underfur length was not affected. The general impression scoring showed that the intermediate and low F:C ratios resulted in slightly improved fur quality compared with higher F:C ratios.

DISCUSSION

The present study demonstrates that all the dietary F:C ratios examined were adequate for achieving normal production in both blue fox and mink. However, the two species seemed to differ in their optimum range of dietary F:C ratio.

It has long been recognized that the long-term regulation of body weight and feed intake in blue foxes and mink, and seasonal fluctuations in these variables, is controlled by photoperiod. These seasonal variations in body fat depots, which probably have evolved in response to seasonal changes in food availability, are still intact in farm raised animals (Enggaard Hansen et al. 1991). Thus, the differences in body weight among animals in the present study, are probably mainly a result of differences in fat deposition. The presumably greater potential for fat deposition in blue foxes, compared with mink, is indicated by the former's relatively higher feed intake and body weight gain during the late stage of the experiment. These species differences could reflect differences in their adaptive response to winter temperature and winter

Table 7. Effects of divergent fat:carbohydrate ratio on skin characteristics in mink males

	Fat:carbohydrate ratio						
	65:5	60:10	55:15	50:20	45:15	40:30	p-values
Number of skins	30	31	31	29	29	30	
Skin length, cm	75.4	74.4	76.2	77.0	76.7	73.8	*0.19*
Skin weight, (dry) g	180.8	185.6	185.4	196.4	189.3	176.7	*0.20*
Density guard fur [1]	5.5	5.5	5.7	5.8	5.5	5.6	*0.90*
Density underfur [1]	5.1	5.3	5.3	5.2	5.3	5.6	*0.76*
Length guard fur, mm	21.4	22.2	22.5	22.9	22.1	23.1	*0.31*
Length underfur, mm	14.4	14.7	14.8	15.0	14.7	14.9	*0.61*
Fur colour [2]	3.1	3.1	3.2	3.4	3.2	3.2	*0.82*
Metallic [3]	1.6	1.6	1.8	1.9	2.0	2.1	*0.61*
General impression [4]	1.6	1.6	1.8	1.9	2.0	2.1	*0.40*
Grey underfur (n)	1	2	3	4	2	4	
Wet belly (n)	6	8	6	6	6	7	

[1] Subjectively graded from 1 (poorest) to 10 (best).

[2] Subjectively graded from 1 (lightest) to 10 (darkest).

[3] Rated from 1 (no) to 4 (severe).

[4] Graded at Oslo Fur Auctions in these groups: 1, Quality II (poorest); 2, Quality I; 3, Saga; 4, Saga Royal (best).

Table 8. Effects of divergent fat:carbohydrate ratios on skin quality in mink females

	Fat:carbohydrate ratio						
	65:5	60:10	55:15	50:20	45:15	40:30	p-values
Number of skins	22	23	24	22	23	22	
Skin length, cm	59.5	60.8	60.8	59.9	59.2	60.2	*0.90*
Skin weight, (dry) g	85.3	90.4	85.9	91.4	91.1	91.6	*0.77*
Density guard fur [1]	6.4	6.1	6.2	6.1	6.7	6.3	*0.14*
Density underfur [1]	6.1	5.8	5.9	6.0	6.0	6.0	*0.96*
Length guard fur, mm	19.8b	20.2b	20.5ab	21.0a	20.3ab	21.1a	*0.05*
Length underfur, mm	14.3	14.3	14.3	14.6	14.4	14.2	*0.81*
Fur colour [2]	3.4	3.0	3.1	3.4	3.0	3.4	*0.38*
Metallic [3]	0.6	0.4	0.3	0.1	0.4	0.3	*0.11*
General impression [4]	1.9b	2.0b	2.2b	2.4ab	2.8a	2.3ab	*0.05*
Grey underfur (n)	5	6	6	6	5	7	

Group means with different letters within row only are significantly different ($p<0.05$).

[1] Subjectively graded from 1 (poorest) to 10 (best).

[2] Subjectively graded from 1 (lightest) to 10 (darkest).

[3] Rated from 1 (no) to 4 (severe).

[4] Graded at Oslo Fur Auctions in these groups: 1, Quality II (poorest); 2, Quality I; 3, Saga; 4, Saga Royal (best).

food shortage under natural conditions. For blue foxes, which live in arctic areas, body fat depots are essential for winter survival (Prestrud & Nilssen 1992), whereas the mink is subjected to a shorter winter period and has a better winter food supply in its natural habitat. Another adaptation to the length of the winter period is reflected in the fact that the time-lapse between mating in the spring and the end of winter fur growth is longer in mink than in blue foxes.

Mink showed almost no weight gain after mid-October in the present study, indicating that the body fat depots were full by that stage of the experiment. According to Ganong (1989), there is some evidence that information concerning the size of body fat depots is relayed to the brain via either neural or hormonal signals and that long-term feed intake is partly controlled in this fashion. Tolkamp & Ketelaars (1992) conluded that long term voluntary feed intake was closely related to feed conversion efficiency and stated that feed consumption was controlled by the basal metabolic requirement and the metabolizability of the feed. In the present study, the energy intake increased with F:C ratio of the feed. This could have been due to the higher energy digestibility and higher net energy available in the high fat diets, as also proposed by Tauson (1988) in studies with mink diets differing in energy content. The relative energy value of fat and carbohydrates for metabolism will vary depending on whether the energy is used for tissue synthesis or maintenance (Nehring & Haenlein 1973). In growing animals fat energy appears be to utilized more effectively than carbohydrate energy for body fat deposition. This difference in efficiency is largely due to the fact that, unlike carbohydrate energy, dietary fat can be directly incorporated into body fat. In the present experiment the improved growth performance in blue fox, but not in mink, fed high F:C ratio diets can not solely be explained by higher ME intake but also suggests that the net energy value of fat for blue foxes is higher than that of carbohydrates when the energy is used for fat deposition. Rimeslåtten (1976) came to the same conclusion based on feeding experiments with blue foxes.

In accordance with the present findings, Skrede (1983) reported reduced body weight gain per unit ME consumed in mink fed diets with high F:C ratios. He suggested that increased feed wastage or an increased energy requirement for maintenance, because of the larger body surface resulting from early fat deposition, could have been the reason for the disparity between energy intake and expected body weights. In the present study increased feed wastage could partly explain the reduced body weight gain per unit ME consumed in mink fed the high F:C ratio diets because those diets had the loosest consistency. Another factor that could have been involved is a glucose shortage associated with the high F:C ratio diets. Glucose has an important function in the fat metabolism (Ganong 1989). For instance, a shortage of glucose will reduce the supply of oxaloacetate necessary for fatty acid oxidation. This situation may cause accumulation of ketone bodies in the blood and thereby energy loss represented by ketone bodies excreted in urine. Péreldik et al. (1984) reported that body weight gain in mink fed a carbohydrate-free diet was slower compared with that of animals fed diets containing 13% or more of the ME from carbohydrates. The retarded growth was observed during the late part of the growing-furring period. Kienzle & Meyer (1989) reported that carbohydrate-free diets caused an increase in plasma ß-

hydroxybutyrate and adverse effects in pregnant and lactating dogs. The frequency of ketosis was not recorded in the present study, but the highest F:C ratio (65:5) resulted in higher mortality and a somewhat reduced growth rate in mink.

The superior production performance of the blue foxes fed the highest F:C ratio (65:5), compared with that of mink, could be a result of differences in energy utilization, i.e. the blue fox could have benefited from the more redundant protein supply. The protein requirement in blue foxes is lower than that in mink (NRC 1982; Enggaard Hansen et al. 1991) and protein can readily be converted to glucose, thereby compensating for low dietary carbohydrate levels (Kienzle & Meyer 1989). The general higher feed conversion efficiency in blue foxes compared with that in mink is due to the lower basal requirement per kilogram of body weight and probably because of less physical activity in blue foxes.

In blue foxes fur quality was not significantly affected over the wide range of dietary F:C ratios tested. This suggests that blue foxes can tolerate high F:C ratios. In silver foxes, and to a lesser degree in blue foxes, high F:C ratios were reported to reduce colour purity (Hillemann & Lyngs 1988). In the present study there was no significant effect of F:C ratio on colour purity in blue foxes ($p<0.15$). However, the average score was highest at the lowest F:C ratio, thus indicating that colour purity tended to improve as F:C ratio decreased.

It is not clear why the fur quality of mink fed the highest F:C ratio was somewhat reduced. Blumenkrantz & Sandø Lund (1989) demonstrated that restricted feeding reduced fur quality in mink, but restricted feeding was not employed in the present study. However, the pattern of change in daily feed intake differed slightly for the high fat and low fat diets, with the feed intake on the high fat diets being relatively lower during the late stages of the experiment, as also reported by Tauson (1988). Low feed intake in late October and early November, which is a critical period for growth of hair bundles with guard hairs (Blomstedt 1989), could have suppressed their growth and thereby reduced hair quality. Shorter guard hairs and a tendency to an increased incidence of the fur defect metallic in mink fed high F:C ratios were also reported earlier by Skrede (1983).

CONCLUSIONS

Provided there is good fat quality, dietary F:C ratios for blue fox and mink during the growth period can vary widely without negatively affecting production performance. Blue foxes grow faster and produce longer skins when the dietary F:C ratio is high, whereas fur quality is only slightly affected by the F:C ratio. In mink, F:C ratios higher than 60:10 tend have a negative effect on health and to reduce fur quality when *ad libitum* feeding is used.

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Norsk Institutt for Skogforskning
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