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

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Monitoring programme for forest damage

An overview of the Norwegian programme

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1. The Norwegian «Monitoring Programme for Forest Damage» (Overvåkingsprogram for skogskader - OPS) started in 1985 in response to the demands for annually updated information on forest damage which could be attributable to air pollution. The programme is mainly financed by the Ministry of Agriculture in cooperation with the Ministry of the Environment.
2. The programme is in accordance with the recommendations given by FAO and ECE and includes the following main parts:
   - Measurement of air pollutants in forests
   - Nationwide survey of forest growth and vigour
   - Observations on permanent plots

   Responsible for the three main parts are, respectively:
   - the Norwegian Institute for Air Research (NILU)
   - the Norwegian Institute for Land Inventory (NIJOS)
   - the Norwegian Forest Research Institute (NISK)
3. The programme supplies annual data on crown density and crown colour to the Programme Task Force centre in Hamburg. These data are based on the nationwide representative survey.
4. An extensive permanent plot programme is carried out on 19 plots distributed throughout the country. This programme includes air and precipitation measurements, and tree, vegetation and soil description and analyses.
5. The OPS programme also includes an extension service to investigate reported forest damage.

Key words: Air pollution, Forest damage, Monitoring programme, Forest survey, Vigour criteria.

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In Norway, research on the possible effects of long-range transported air pollutants ("acid precipitation") has been carried out since 1972, mainly within the SNSF project «Acid precipitation - effects on forest and fish» which was completed in 1980. One main conclusion was that although detrimental effects could be identified on freshwater and fish, no such effects on forest growth or vitality could be detected. However, in a number of soil irrigation experiments leaching of cations with simulated acid precipita-

tion was demonstrated. On this background long-term effects on forest soils and tree growth could not be excluded (Overrein & al. 1980).

As a continuation of the SNSF project, the State Pollution Control Authority (SFT) established monitoring programmes for air and precipitation, freshwater and fish, including a small programme for forest soils (SFT 1991).

Alarming reports of "new forest damage" in central Europe in the early 1980s led the Norwegian Ministry of Environment to initiate a programme for monitoring various types of damage in Norway as well. A draft programme was prepared by NISK in 1984, and funding was made available from the Ministry of Agriculture and the Ministry of Environment in 1985.

The principal objective of the draft programme was to develop methods for monitoring forest growth and vigour, and forest soils, but in so doing, the programme would also serve as a monitoring programme, applying the best available methods.

There is extensive international cooperation on methodology and exchange of results in this field (see e.g. Aamlid & al. 1990). According to the guidelines drawn up by ECE (Draft edition from 1986 of PCC 1989) it is recommended that each of the European countries carries out:

- Measurement of air pollutants in forests
- A nationwide survey of forest growth and vigour
- Observations on permanent plots
- Economic analysis of growth losses

The first three topics above are included in the Norwegian programme. Responsible for the topics are, respectively:

- the Norwegian Institute for Air Research (NILU)
- the Norwegian Institute for Land Inventory (NIJOS)
- the Norwegian Forest Research Institute (NISK)

An overview of the programme is given in Fig. 1.

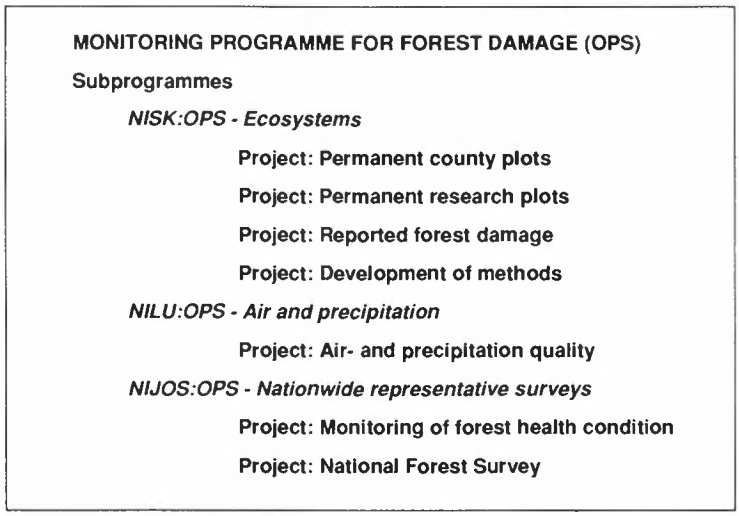


Fig. 1. Monitoring programme for forest damage. Outline of the Norwegian programme

NATIONWIDE REPRESENTATIVE SURVEYS

Completed surveys

In Norway, as in Sweden and Finland, it was considered convenient to link the nationwide survey of "new forest damage" to the existing forest survey system.

Surveys of Norway's forest resources, with regard to species composition, volume and growth (increment), have been carried out five times since 1919 (cf. Table 1). Various additional variables have been included from time to time, e.g. butt and stem rot, "vigour" based on leader length, and soil analyses.

Table 1. Surveys of Norway's forests. ("Landskogtakseringer")

1919-32:	The whole country (below the conifer timber line)
1937-56:	The «forest counties» (excluding western Norway and the two northernmost counties), by county
1957-64:	Most of the «forest counties», and also parts of Hordaland and Møre og Romsdal counties
1964-76:	The "forest counties"» every year. Sogn og Fjordane and the northern part of Nordland counties
1980-86:	The whole country except Finnmark and Sogn og Fjordane counties

A comparison of the five surveys indicates that there has been a continuing increase in standing volume and increment of all species (spruce, pine and deciduous trees), as well as in the number of large trees (DBH > 30 cm) as compared to smaller ones (NIJOS 1990).

"Crown density" was for the first time included in the survey in 1984. The areas covered by the surveys of 1984-85 are shown in Fig. 2. Although important forest areas in southeastern Norway could not be covered by crown density surveys, the remaining areas covered a wide gradient in air pollution loads.

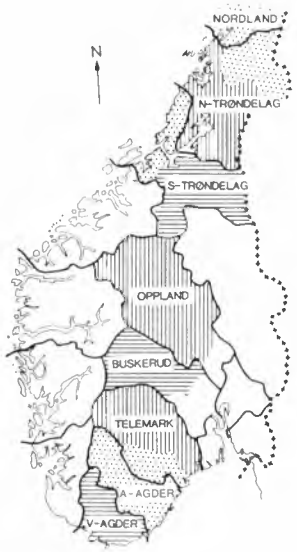
The 1980-86 survey used a systematic cluster design. Twelve sample plots were placed along the sides of a square the side length of which was 750 or 1050 m, depending on region. The distance between the clusters was 4.8 km in the north-south direction, and 6.4 km in the east-west direction.

A number of variables relevant to vigour were observed on the sample trees. These include leader length, annual ring width, width of the sound sapwood in trees with stem rot, and crown density.

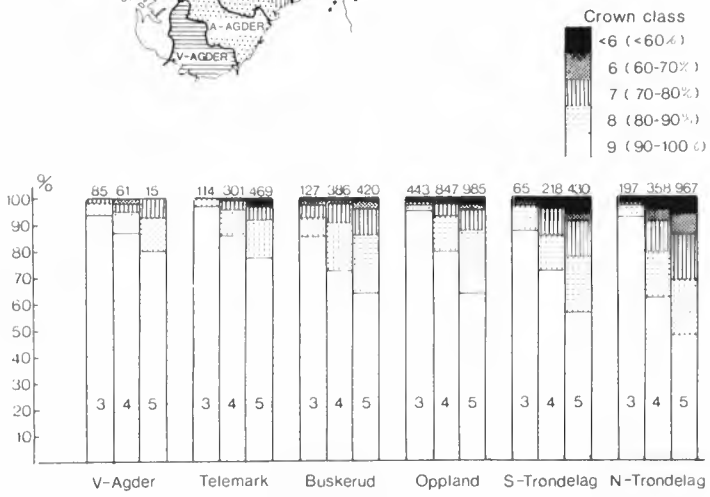
Crown density was assessed according to ten classes, 0-9. A tree crown in class 9 has 90-100% of the density of a normal crown, class 8 has 80-89% of normal density, and so on. A normal crown is a crown without abnormal amounts of needle loss or dead twigs and branches within the part of the crown considered. In spruce the upper half of the crown is considered, in pine the upper two-thirds.

Some 10.000 trees were classified during this survey.The main results were:

- Crown density was lower in the counties of Trøndelag and Nordland than in the counties south of Dovrefjell (Fig. 2).
- Crown density of spruce decreased with tree (and stand) age.
- Crown density of older spruce decreased with altitude.



Areas covered by the 1984-inventory (hatched) and the 1985-inventory (dotted).



Crown density distribution of Norway spruce trees in different counties and cutting classes. Cutting class 3 = young forests, 4 = middle age forests, and 5 = mature forests. Crown class 9 = trees with full density crowns. Unpublished data from the 1984 National Forest Inventory.

Fig. 2. Areas covered by the 1984-85 surveys, and county average crown density of spruce and pine. From Horntvedt & Tveite (1985)

- Crown density of spruce increased with site productivity.
- Width of the last five annual rings at breast height decreased parallel to the crown density reduction.

New surveys

As indicated in Fig. 1, NIJOS is responsible for two nationwide, representative surveys. One is the National Forest Survey ("Landskogtakseringen"), which is a continuation of the series listed in Table 1. This is mainly a forest resources survey, but it includes crown density among the registered variables, and will thus provide information on the forest health condition as well. Its design is a mixture of temporary and permanent sample plots. However, it takes seven years to complete one survey, i.e. the same plot is revised only every seventh year. For this reason, this survey does not provide the nee-

ded information on the annual development of the forest health condition. This survey corresponds to Level 1 in the ECE system.
To meet the need for annually updated information, the second forest survey is established (Rørå et al. 1988, Rørå & Kvamme 1989). This survey is called "Monitoring of forest health condition", and corresponds to level 2 in the ECE system. It includes the following main parts:

- Monitoring of forest
- Monitoring of soil

The design of the "Monitoring of forest health condition" survey is a 9 x 9 km network of permanent plots. Each plot is 250 m^2 in area. Only plots which contain at least 20% by area of spruce or pine trees are established.

It is important that the position of the plots is exactly defined, but kept unknown to the forest owner. The point is that the presence of a monitoring plot must not be allowed to influence the owner's decisions as to cutting or other forest operations.

Monitoring of forest (yearly)
A general description of each plot includes:

- Position and topography
- Tree species composition
- Origin of stand
- Age and cutting class
- Soil depth
- Vegetation type
- Site class

On each tree except suppressed ones, the following variables are registered:

- Type of injury
- Diameter at breast height
- Position within the stand (edge or inside)
- Differing vegetation type
- Social status
- Crown density of the upper half crown of spruce, and the upper two-thirds of pine on a continuous scale 1-100%. 0% = dead trees.
- Defoliation type (top, subtop, etc...)
- External influences, e.g. competition from neighbour trees
- Crown colour
- Secondary shoots

On some of the trees height and leader length are also measured.

Each registration team includes two persons. A total of 16 teams participated in the 1988 survey, 11 of which at the same time carried out the National Forest Survey. Training of the field personnel is considered important, especially for the crown density estimation. All teams go through a one week's field course at the start of the season.

Monitoring of soil (every five years)
This programme uses the same sample plot network as the monitoring of the forest programme. A systematic procedure is adopted to select a location within the plot for soil profile description and classification, as well as for soil sampling.

The soil profile is described and classified according to "The Canadian System of Soil Classification" and "Soil Taxonomy" (USA). The classification is based on both the description in the field and the laboratory analyses.

The description in the field includes:

- Soil layers and their extension
- Texture
- Colour
- Structure
- Root distribution
- Humus type, decomposition, etc.

The field description of soil is carried out by specially trained personnel.

Soil chemical analysis includes, for all layers:

- pH (H_2O)
- Exchangeable cations (Ca, Mg, K, Na, H) in NH_4NO_3-extract
- Al, Fe, Zn, S, and P in NH_4NO_3-extract.

Additional analyses for the LFH, O, Ah and B layers are:

- Org. C
- Kjeldahl N
- AL-soluble P.

Additional analyses for the B layer are:

- Pyrophosphate and dithionite soluble Fe and Al.

PERMANENT COUNTY PLOTS

The civil forest administration on county and municipality levels wanted to participate in the monitoring of forest condition. In response to this, some 800 plots have been established. In each municipality or district four plots are laid out, one in each of the cutting classes III (younger production forest), IV (older production forest), V (mature forest), and one in the over-mature (declining) forest.

Each plot contains at least 50 trees, excluding suppressed ones. They are numbered, and common stand characteristics are measured at the time of establishment. The plots are revised annually in September by a forest officer, and the following variables observed:

- Crown density
- Crown colour (four classes)
- Number of cones (three classes)
- Top breakage, with diameter of the break point
- Diameter at breast height

It should be stressed that these county plots are not «representative» in an objective manner, but in the forest officer's judgement they are typical for the forest in his district. The large number of trees (43.000) serves as a good reference for possible changes in forest health condition.

The results of annual revisions of the county plots are forwarded to NISK for calculation and reporting (see e.g. Dahl 1989, Solberg 1990). The staff of the OPS also carry out checks and run training courses to reduce the variation between observers (Aamlid 1990).

PERMANENT RESEARCH PLOTS

General description

Permanent plots have been established at 19 locations, the main objective beeing to test and develop methods for forest condition monitoring. They are distributed throughout the country, and thus serve as permanent monitoring plots, supplementary to the nationwide network. They are referred to as research plots in this description. This is to separate them from permanent plots in the nationwide system, and to indicate that the programme carried out is more comprehensive than that of the nationwide, representative network. These plots correspond to level 3 in the ECE system.

The location of the research plots is indicated in Fig. 3. There is at least one plot in each county and this gives a fair regional distribution, with a somewhat higher density in the south.

Fig. 3. The permanent research plots

Most of the plots are located far away from local sources of air pollution. One exception is the Pasvik plot, which comprises the two subplots, Svanvik and Mellesmo. These plots are significantly influenced by emissions of SO_2 and heavy metals from industry in the Soviet Union, Nikel.

As a rule, the plots are placed in a mature spruce forest of blueberry type (*Eu-piceetum-myrtilletosum*). The plot should be placed well within the stand, so that edge effects are avoided.

Each plot is photographed from fixed positions in order to document vegetation and tree stand characteristics.

A local observer is engaged for each plot to collect and forward the required samples to NILU and NISK.

Trees and vegetation

All trees greater than 2.5 cm in diameter at breast height (DBH) are numbered, and their location mapped. Site class is determined from measurement of age and height on the ten largest trees adjacent to the plot.

The following measurements and observations are made when the plot is established:

Every tree	- DBH at a fixed point - crown width - social class, by Scotte's system - branching type, by Sylvén's classes
Every second tree	- total height - height to crown border

The field and bottom layer vegetation is described by plant lists, by frequency analysis, and by traditional vegetation analysis.

A traditional vegetation analysis is carried out on 5-6 subplots 16 m^2 in size and subjectively scattered around the plot. The cover of each species of plants, mosses and lichens is estimated.

Frequency analyses are carried out on 10 subplots, 1 m^2 in area, distributed along the plot borders. The subplot corners are marked with plugs. A 1 x 1 m frame divided into 25 squares is placed on the subplot, and the number of squares in which each species occurs is counted. In addition, 40 subplots, 1 m^2 in area, are distributed in a square surrounding the plot (5 m from the plot border), but these are not further divided. In these plots species coverage is estimated.

Air and precipitation measurements

For several years now NILU has measured pollutants in the air and precipitation on a regional scale in Norway. Most of the network is financed by SFT (see e.g. SFT 1991). As many of the research plots as possible established by NISK were located in the neighbourhood of existing NILU stations, e.g. Birkenes, Treungen (OPS name: Fyresdal), Gulsvik (OPS name: Langtjern), Vikedal (OPS name: Nedstrand), Osen, Tustervatn, Kårvatn.

To supplement the network a number of air and precipitation stations have been established close to the research plots. It is the aim of this programme that air and precipitation chemistry can be evaluated on every research plot, either from measurements on the plot or from interpolation between surrounding stations.

The station network is shown in Fig 4.

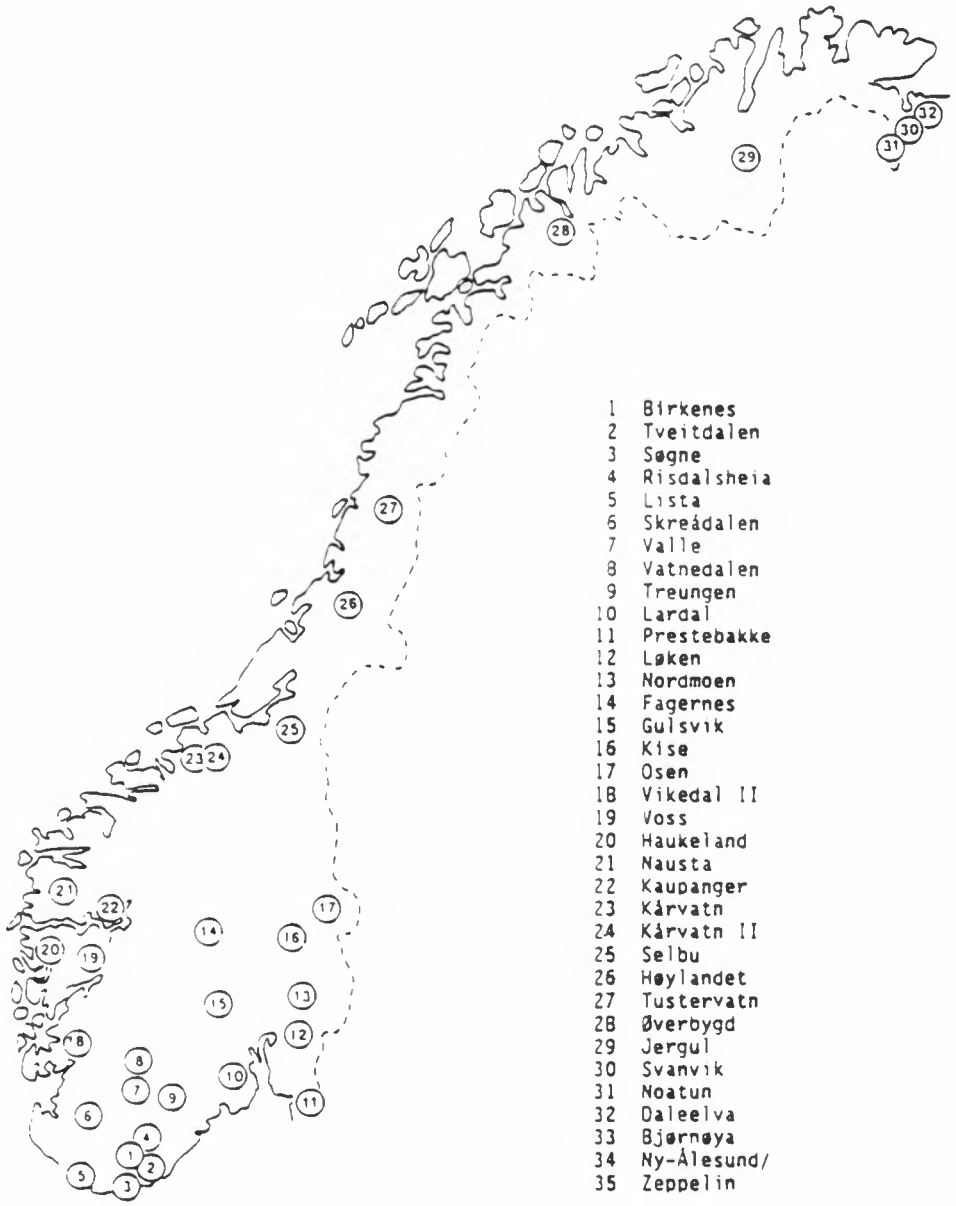


Fig. 4. Norwegian stations for background (rural) air quality measurements. From SFT (1991)

The complete measurement programme includes:

- Precipitation: pH, SO_4, NO_3, Cl, Na, NH_4, Ca, K, Mg and conductivity on weekly samples.
- Air: SO_2. SO_4 (particulate), NO_2, (NO_3 + HNO_3) and (NH_4 + NH_3) three times weekly. Ozone continuously.

A reduced programme is run on some stations. This excludes NO_2, (NO_3 + HNO_3), (NH_4 + NO_3) and O_3 from the complete programme. Analytical methods are described in SFT (1991).

Throughfall

Throughfall is measured on all research plots. The main objective is to assess the potential of throughfall chemistry in evaluating the air pollution situation.

The throughfall collector is shown in Fig. 5.

Fig. 5. The throughfall and the litterfall collectors

Throughfall is collected at ten randomly distributed, fixed points on each plot. This implies that the points are at various distances from the trees. Open field precipitation for reference is measured at one fixed position.

During the frost- and snow-free part of the year, precipitation and throughfall are measured weekly. The amount of water in each throughfall collector is measured, then all the water is mixed, and a sample is taken for chemical analysis.

The funnel and collector bottle are rinsed with distilled water even if there was no precipitation the previous week.

During wintertime the collectors are slightly modified and the sampling period is two weeks.

The throughfall and precipitation samples are analysed for pH, conductivity and all major dissolved elements, including Fe, Al and Pb. Analytical methods are described by Ogner et al. (1991).

Litterfall

Ten litterfall collectors, each 0.16 m^2 in area, are placed at fixed random positions on each plot. They consist of a bag made of nylon fabric, mounted on a metal ring placed on a tripod (see Fig. 5).

The collector bags are exchanged monthly. The litter is removed from the bags and sent to NISK, where it is sorted into main fractions and weighed before chemical analysis. During wintertime another type of litterfall collector is used (Fig. 5). This is left to snow down on the ground, and the sample is collected after snow-melt.

Tree vigour criteria

A set of vigour criteria is assessed annually, preferably in August-October, on all trees except suppressed ones. The criteria are listed in Table 2. They include crown density in percent, and crown colour (yellowing) in four classes.

Table 2. Tree vigour criteria

Crown density:	1% classes, upper crown half (spruce), upper 2/3 (pine), related to a normal dense crown of that region
Discoloration (yellowing):	None, slight, moderate, strong
Top form:	Pointed, rounded, flattened
Leader:	Length
Cones:	Amounts: None or small, intermediate, large amounts. Current and older separately
Top break:	Diameter at the break
Bark wounds:	None, small (< 10 cm), large (> 10 cm)
Root swell:	Normal, slightly, strongly increased
Resin flow:	None, slight, strong

Five trees representative of the plot are climbed by means of portable ladders and free climbing to obtain sample branches for various analyses. Two branches are cut from the seventh whorl from the top, and two from the mass centre of the upper half of the crown.

On each sample branch the criteria listed in Table 3 are assessed in the field. In the laboratory, subsamples of the branches are taken for chemical needle analysis, investigation of needle fungi and insects.

Table 3. Measurements on sample branches

Field:
Basal diameter
Total length
Length of the green part
Total weight
Needle retention (years with >50% of remaining needles)
Years with abnormal needle loss
Length of the last five annual shoots, separately
Number of adventitious shoots
Epiphytic lichen cover, by species
Laboratory:
Needle weight, current, previous and older separately
Element content of needles
Needle fungi
Defoliating insects

The branches from the seventh whorl are separated into current year's, previous year's, and older shoots. The three parts are dried, needles and shoot axes are separated, and the needles are weighed.

These measurements are taken when the plot is established, and some of them will be repeated every five years.

Defoliating insects

Monitoring of the insect fauna is intended to estimate relative levels (between years) of the main groups of needle-eating insects (defoliators). Likewise, sucking insects and mites, which contribute to symptoms like discoloration and necrotic spots and to needle loss.

Material for the insect monitoring comprises the 20 sample branches from each plot.

The 20 sample branches are investigated in the laboratory for the occurrence of insects and mites. The numbers of animals, and of symptomatic units, are recorded.

Needle fungi

A number of needle-inhabiting fungi can cause discoloration and other symptoms, and eventually premature death of the needles.

Except for a few well-known and common species, the fungal flora of spruce needles is not well known. Standard methods for isolation and identification can be very laborious. A limited approach is therefore used in this programme.

The material comprises of green needles from the sample branches, and dead needles from litterfall.

Fungi growing inside the living, green needles are isolated from 10 spruce needles from every second annual shoot in the two sample branches from the seventh whorl (Fig. 6).

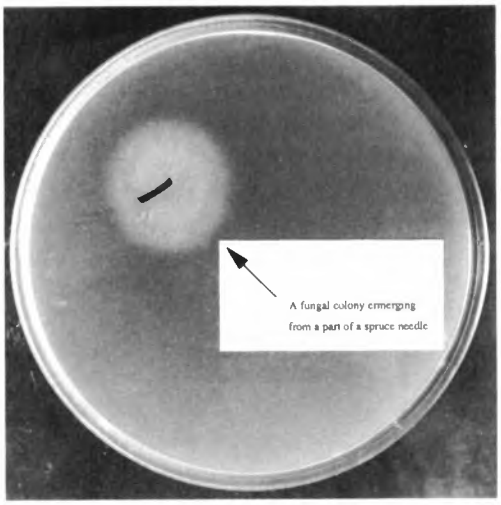


Fig. 6. Fungal colonies emerging from spruce needles incubated on malt agar. The needles are surface sterilized with hypochlorite, their tip and base removed, and the mid-section cut transversely

Spruce needles from the monthly collected litterfall are investigated with respect to fruiting bodies of fungi. One hundred brown needles from each of two litterfall traps are examined.

Element content of needles

Chemical needle analysis is the most common method of evaluating the nutrient status of a tree. The element content can fluctuate somewhat during the year, especially when the new shoots are developing. It is recommended that samples for nutrient analyses are taken in the growth dormancy period(Tamm 1964).

In this programme, the following procedure is used. Separate needle samples of the last five annual shoots are taken from the two branches from the seventh whorl of each of the five sample trees (see under Tree vigour criteria). The needles are dried at 60°C before storage. The analytical procedures are described by Ogner et al. (1991).

Epiphytic lichens

Lichen cover on the lower stem of 5-10 trees is assessed at three levels, 1.2, 1.4, and 1.6 m above the ground. A measuring tape is placed around the stem, and the part of the circumference occupied by each species is recorded by a "hit-point" method.

Lichens inhabiting the branches (cf. Table 3) are recorded by assessment of species cover along the main axis of the sample branches.

Soil profile description and classification

Adjacent to the plot a ditch, 1 x 1 m in area, is dug to a depth of 10 cm into the C-layer. A complete soil profile description is made, following the guidelines of Sveistrup (1984). The soil profile is classified according to the Canadian system (Agriculture Canada Expert Committee on Soil Survey 1987).

Soil samples for pF measurements and chemical analyses are taken from each layer. These chemical analyses are mainly to aid the soil classification.

Soil chemical analyses

Soil sampling for chemical analysis follow the same guidelines as is used in the programme "Monitoring of air pollutants in air and precipitation" (SFT 1991).

Four representative soil samples from each of the main layers are obtained at each plot. Each sample includes 30 subsamples distributed over the plot and obtained by separate stabs with a soil sampler. The thickness of each layer is measured and a subsample is taken, avoiding transitional zones. If there is no definite layer, subsamples are taken from fixed depths.

If the composite sample is large enough it is split into two parts. One is for analyses of ammonium and nitrate, this sample is sealed in a plastic bag and deep frozen as soon as possible. The other part is for other analyses.

Soil sampling for chemical analyses is carried out at the establishment of the plot, and is repeated every five years.

Soil chemical analyses are carried out by the NISK chemical laboratory (Ogner et al. 1991). The samples are dried and the fine soil fraction (< 2 mm) are separated by sieving. A complete texture analysis is done on mineral soil samples.

Chemical analyses of the fine soil fraction include:

- pH (H_2O & $CaCl_2$)
- exchangeable cations (Ca, Mg, K, Na, H, Mn, Fe, Al) extracted in 1M ammonium nitrate. On this basis cation exchange capacity (CEC) and exchangeable acidity is calculated
- org. C, Kjeldahl N, NO_3 and NH_4, SO_4, PO_4
- citrate-dithionite and pyrophosphate extractable Fe and Al, for the classification of podsol profiles.

The relation between water content and water potential (pF-curves) is determined on volume-defined samples, together with raw volume weight, volume and density of the solid material, and pore volume.

Soil water

Samples of soil water are obtained by tension lysimeters of the "PRENART" type (Prenart equipment APS, DK-2000 Fredriksberg). These are made of a mixture of teflon and glass, with an inert plastic tube connected to the collection bottle and the vacuum pump (Fig. 7).

The lysimeters are inserted into the soil through a pipe. A slurry of quartz powder and water is poured into the hole before inserting the lysimeter to improve contact with the soil.

The lysimeters are installed at the depths:

- just beneath the humus layer (ca. 5 cm)
- in the upper part of the B-layer (ca. 15 cm)
- in the lower part of the B-layer (ca. 40 cm)

Water samples are analysed for pH, conductivity, Ca, Mg, K, Na, Al, Fe, NO_3, NH_4, SO_4 and alkalinity.

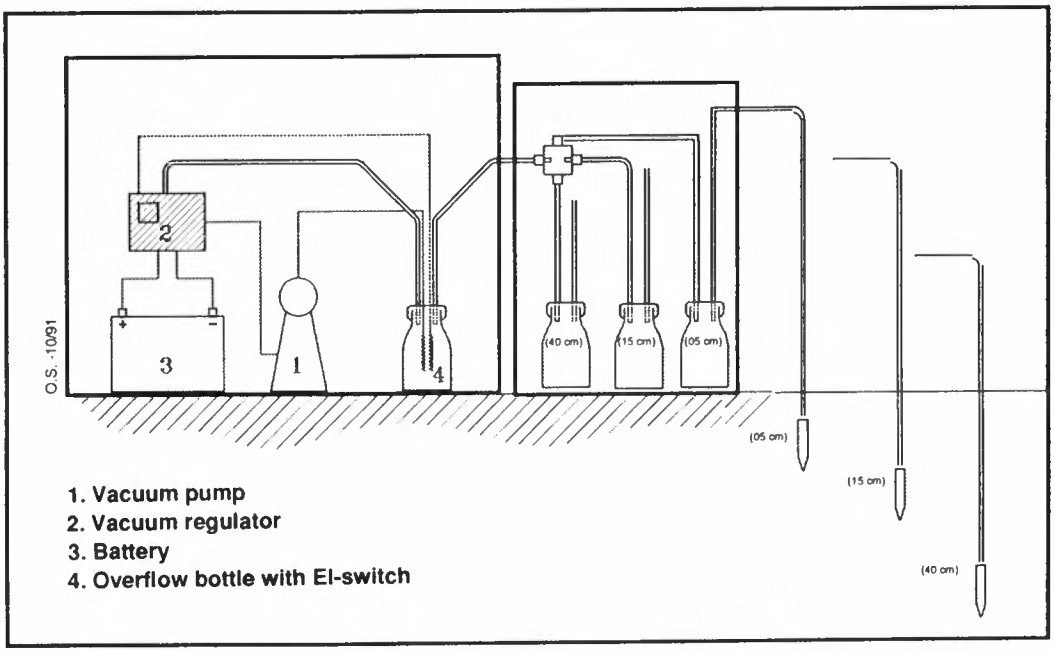


Fig. 7. Soil water lysimeters installed in the field

Root analysis

Root samples are obtained according to PCC (1989). One sample is taken from the crown periphery of each of eight dominating and codominating trees. If possible a humus sampler (diameter 6.5 cm) is used. The samples are stored deep frozen until analyses.

REPORTED FOREST DAMAGE (EXTENSION SERVICE)

For many years the reporting of forest damage has been one of the responsibilities of local civil forest officers. Important damage and the assumed agents are reported to the Ministry of Agriculture and published by the Director General of Forestry (Skogdirektørens Årsmelding)

Whenever a specialist's help is needed to identify the causal agent, this has been provided by NISK.

As a part of the present monitoring programme the investigation of reported damage has been given more resources. One person is engaged full time in following-up any reported damage, especially in cases where there is no identifiable parasitic cause. An example is given in Fig. 8. The activity is in part funded by the Norwegian Forest Owner Association.

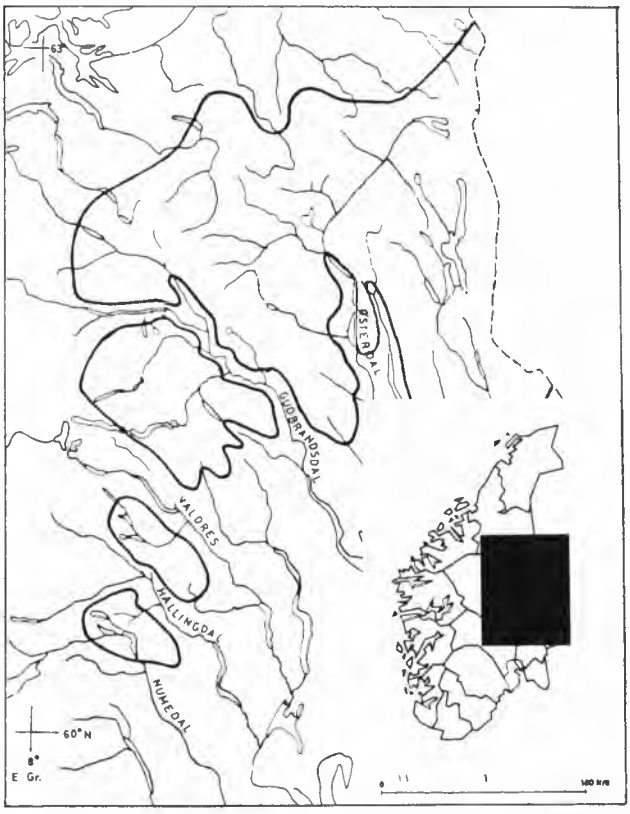


Fig. 8. Distribution of the symptom "Straw coloured leaders in young pine trees" in 1988. From OPS (1989)

LITERATURE

Aamlid, D. 1990. Skogfunksjonærene vurderer riktig! Norsk Skogbruk 36(9):36-37.

Aamlid, D., K. Venn, & A.O. Stuanes, 1990. Forest decline in Norway: monitoring results, international links and hypotheses. Norw. J. Agr. Sci. Supplement No. 4 1990. 27 pp.

Agriculture Canada Expert Committee on Soil survey. 1987. The Canadian system of soil classification. 2nd ed. Agric. Can. Publ. 1646. 164 pp.

Dahl, L.K. 1989. Fylkesvise lokale overvåkingsflater. Vitalitetsregisteringer 1989. Overvåkingsprogram for skogskader, Ås 1989. 22 pp.

Horntvedt, R. & B. Tveite, 1985. Overvåking av skogskader. Årbok-85. Norsk institutt for skogforskning. Ås. ISBN 82-7169-353-0 pp:38-44.

Norsk Institutt for Jord- og Skogkartlegging 1990. Skogressursene i Norge. Hovedresultater fra Landskogtaksering 1919-1989. NIJOS, Ås 1990. 18 pp.

Ogner, G., A. Haugen, M. Opem, G. Remedios, G. Sjøtveit, & B.Sørlie, 1991. The chemical analysis program of The Norwegian Forest Research Institute, 1991. NISK, Ås 1991. 21 pp.

Overrein, L.N., H.M. Seip, & A. Tollan 1980. Acid precipitation - effects on forest and fish. Final report of the SNSF-project 1972-1980. SNSF-project FR 19/80.

OPS (Overvåkingsprogram for skogskader) 1989. Overvåkingsprogam for skogskader. Årsrapport 1988. Ås. 52 pp.

PCC (Programme Co-ordinating Centres with the assistance of the United Nations Environment Programme (UNEP) and the Secretariat of the United Nations economic Commision for Europe (UN-ECE) 1989. Manual on methodologies and criteria for harmonized sampling, assessment, monitoring and analysis of the effect of air pollution on forests. Global Environment Monitoring System. 90 pp.

Rørå, A., H. Kvamme, J.Y.Larsson, Å. Nyborg & T. Økland 1988. Rapport 1988. Program: "Overvåking av skogens sunnhetstilstand". NIJOS, Ås 1988. 23 pp.

Rørå, A. & H. Kvamme 1989. Rapport 1989. Program: "Overvåking av skogens sunnhetstilstand". NIJOS, Ås 1989. 23 pp.

SFT (Statens forurensningstilsyn) 1991. Overvåkning av langtransportert forurenset luft og nedbør. Årsrapport 1989.Statens forurensningstilsyn, rapport 437/91. Oslo. 306 pp.

Solberg, S. 1990. Overvåkingsprogram for skogskader. Fylkesvise lokale overvåkingsflater. Vitalitetsregistreringer 1990. Norsk institutt for skogforskning. Ås. 20 pp.

Sveistrup, T.E. 1984. Retningslinjer for beskrivelse av jordprofil. Jord og Myr 8(2): 30-77.

Tamm, C.O. 1964. Determination of nutrient requirements of stands. International Review of Forest Research 1: 115-170.

Influence of paclobutrazol on germination and elongation of seedlings in cauliflower and sprouting broccoli

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The seeds of seven cultivars of cauliflower and four cultivars of sprouting broccoli were soaked in paclobutrazol (Bonzi) and the influence on germination and elongation of seedlings was investigated. The retardant was rapidly absorbed by the seeds, but different rates of absorption were not regarded as the likely reason for the various levels of tolerance to seed treatment. Seed lots with reduced viability had a low tolerance level to the retardant. Seed treatment consistently reduced the length of the hypocotyl, while the effect on length of leaf petiole and blade was temporary at low concentrations, especially at low light intensity.

Key words: *Brassicas*, cauliflower, elongation of seedlings, germination, growth retardant, paclobutrazol, seed-soaking, sprouting broccoli.

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Extreme elongation of seedlings in cole crops during the raising period causes problems in vegetable production. Some cultivars of Brussels sprouts are especially prone to elongation. Even in cauliflower and sprouting broccoli, compact transplants are difficult to produce. In earlier experiments with Brussels sprouts and swedes soaking the seed in paclobutrazol (Bonzi) was found to reduce elongation of the seedlings, particularly the hypocotyl (Balvoll 1988a). Preliminary experiments with cauliflower and broccoli, however, indicate that the seeds of some cultivars can be damaged by the treatment.

Paclobutrazol, a growth retardant produced by ICA, is a chemical which inhibits the synthesis of gibberellins in plants. There are several advantages in treating seeds with paclobutrazol: The cost is low, the retarding effect disappears before transplanting; there are no after-effects in the greenhouse and no residuale risk to the products.

MATHERIALS AND METHODS

The growth retardant used was Bonzi (4 g paclobutrazol per litre). Seeds of cultivars of cauliflower and sprouting broccoli were soaked in different concentrations and kept at 18-20 °C during the treatment period. After soaking, the seeds were immediately surface dried on filter paper. In Experiment 5, Bonzi was diluted in water, and 100 ml of the solution was mixed into one litre of vermiculite. After sowing 20 seeds in each pot, the seeds were covered with a layer of 5 mm of the treated vermiculite.

The following cultivars of sprouting broccoli were used: 'Gem', 'Shogum', 'Samurain' and 'Corvet'. The rest of the cultivars were cauliflower.

Experiment 1: The seeds were sown on filter paper in Petri dishes, water was added and they were then placed in a greenhouse at 18-20 °C. During the germination period, 11 November-6 December, the natural light intensity was very low.

Experiments 2 and 3: Cauliflower 'Opaal' and 'Floriade' were sown in plastic pots, 12 cm in diameter, 20 seeds in each pot. The peat in the pots was limed and fertilized in the normal way for growing vegetables. The plants were grown in a greenhouse at 15-18°C in natural light supplemented by sodium vapour high-intensity lamps in the period 18 January-25 February (Experiment 2) and 4 March-20 April (Experiment 3).

Experiments 4 and 5: Seeds of cauliflower and broccoli were sown in peat in plastic pots as in Experiment 3 and placed in a growth chamber at approximately 18 °C for 18 h/day and at 14 °C for 6 h/night. The plants were provided with light from cool-white fluorescent 400W lamps, giving approximately 4000 lux.

RESULTS

The results presented in Tables 1 and 4 indicate that seed treatment with paclobutrazol reduced germination, but the cultivars reacted differently: 'Floriade', 'White Rock, 'Linda', 'Samurain' and 'Corvet' tolerated the seed treatment with paclobutarzol fairley well, while 'Opaal' had a very low tolerance level. For some cultivars the results were not consistent in the two experiments, especially for 'Fortuna', 'Cervina', 'Gem' and 'Shogum'. Some of the difference may have been due to different seed lots.

In Experiment 1 'Florida' germinated quite well even after 24 h at 10 ml Bonzi per litre, while 'Opaal' lost most of its vigour at only 0.1 ml/l.

Seed treatment with paclobutrazol delayed germination (Table 3).

Table 2 illustrates that even one hour after the start of seed soaking, much of the retardant must have been taken up by the seeds and could not be washed off with water. The two cultivars 'Floriade' and 'Opaal' reacted similarly to the rinsing treatment.

Paclobutrazol in vermiculite had a strong and long-lasting retarding effect. But the percentage of germinated seed was surprisingly little affected, even for 'Opaal' (Table 4).

The hypocotyl length was consistently reduced by seed treatment with 0.1 ml Bonzi per litre (Tables 2 and 4), but this concentration could not prevent some elongation at

Table 1. Percentage germinated seeds of cauliflower and calabrese after 24 h treatment with paclobutrazol (Bonzi) (Experiment 1)

Cultivar	Bonzi, ml per litre water			
	0.0	0.1	1.0	10.0
Opaal NZ	93	28	10	3
Floriade NIZ	96	96	93	97
Fortuna RZ	85	42	32	24
White Rock SG	96	86	69	43
Linda ENZA	95	93	82	42
Cervina RS	17	3	2	0
Gem ASG	97	95	90	72
Shogum SAK	97	74	67	50
Samurain SAK	95	86	37	55
Corvet RS	92	88	29	51

Table 2. Percentage germinated seed of cauliflower after soaking in Bonzi for 1 or 24 h, with or without rinsing just after end of treatment (Experiment 2)

Treatment	ml Bonzi per litre water			
	0	0.1	1.0	5.0
'Floriade'				
- 1 h,not rinsed	100	92	92	90
- 1 h,rinsed	-	100	95	96
- 24 h, not rinsed	98	89	88	62
- 24 h, rinsed	-	96	89	67
'Opaal'				
- 1 h, not rinsed	95	53	6	0
- 1 h, rinsed	-	91	16	0
- 24 h, not rinsed	81	7	0	0
- 24 h, rinsed	-	4	0	0

Table 3. Percentage germination of 'Floriade' after soaking in Bonzi for one hour (Experiment 2)

Treatment	Days from start of germination					
	1	2	3	5	7	12
0.0 ml Bonzi/l	30	100	100	100	100	100
0.1 » »	5	60	75	90	92	92
1.0 » »	0	42	70	92	92	92
5.0 » »	0	0	8	41	65	90

Table 4. Percentage germination and length of the hypocotyl after covering the sown seed with 5 mm of Bonzi-treated vermiculite (Experiment 5)

Cultivar	% germination				Hypocotyl, cm			
	ml Bonzi/l water				ml Bonzi/l water			
	0.0	0.1	0.5	1.0	0.0	0.1	0.5	1.0
Opaal	85	80	75	55	3.8	0.5	0.4	0.3
Floriade	100	100	100	100	4.3	1.0	0.6	0.5

low light intensity. With few exceptions, soaking in 10 ml Bonzi per litre for 24 h decreased the length of the hypocotyl to less than 10 mm.

Seed treatment with paclobutrazol reduced the length of internodes, petioles and blades (Figs. 1 and 2). In Experiment 2 the effect of 0.1 ml Bonzi per liter disappeared already at the elongation of the first leaf (Fig. 1). In Experiment 3 the retarding effect lasted longer, especially at high concentrations (Fig. 2).

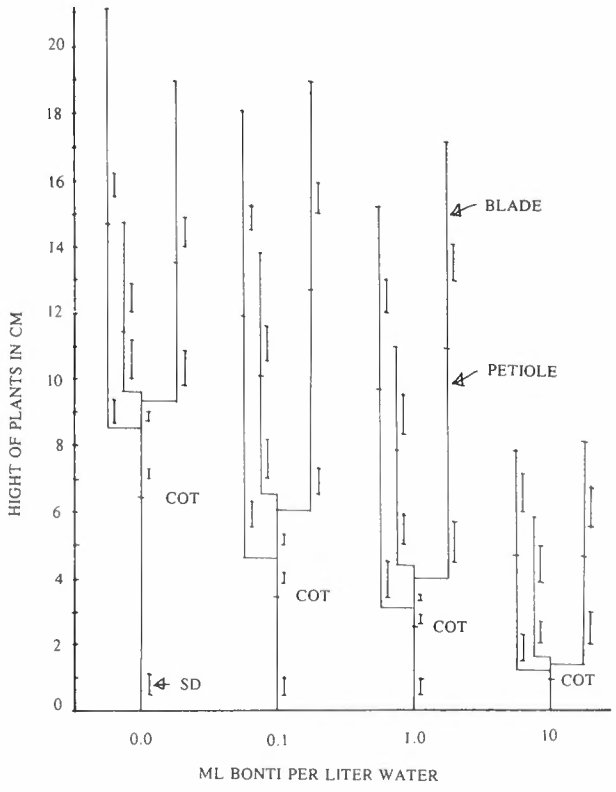

Fig. 1. The height of plants on 25 February for 'Floriade' sown on 18 January. Seed treated for 24 h (Experiment 2)

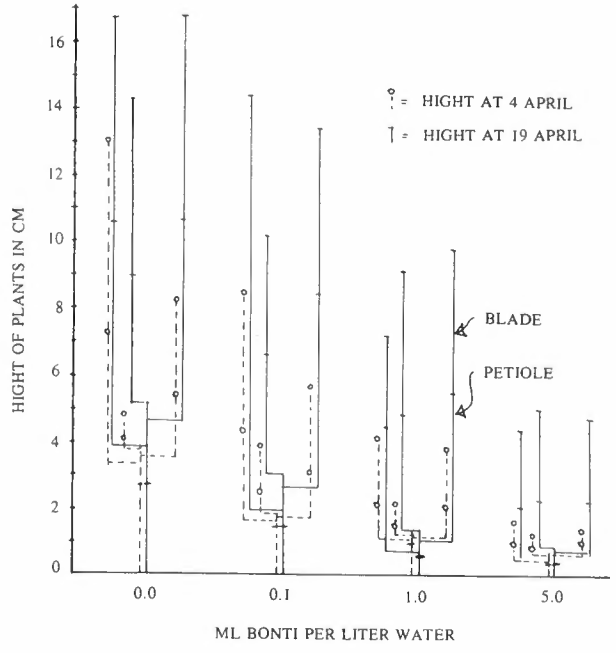

Fig. 2. The height of 'Floriade' on 4 April and 19 April. Seed treated for 24 h and sown on 4 March (Experiment 3)

DISCUSSION

The application of paclobutrazol to the seed clearly reduced the percentage of germinated seed and delayed germination. The effects may be due to a reduction in gibberellins produced in the germinating seed. The treatment with paclobutrazol may even have a more general toxic effect on the seed.

The elongation promoted by endogenous GAs may be necessary to obtain normal germination. But the gibberellins also promote formation of hydrolase that leads to the release and translocation of nutrients.

Rood et al. (1989), working with genotypes of *Brassica rapa*, found that a dwarf mutant (*ros*) was gibberellin-deficient. The *ros* genotype germinated more slowly than the normal genotypes and in some cases *ros* completely failed to germinate under control conditions. Imbibition of seeds of the dwarf *ros* genotype in GA_3 resulted in faster germination. Another mutant *do*, low in GAs, sometimes failed to germinate or germinated slowly (Zanewich et al. 1990). Accordingly, we assume that in our experiments a reduced content of GAs in the germinating seeds is the specific reason for the slow germination and reduced viability after soaking the seed in paclobutrazol.

Different species of *Brassica* may tolerate seed treatment with paclobutrazol differently. In two experiments some cultivars of cabbage, cauliflower, Brussels sprouts and swedes displayed fairly good toleration to 1.0 ml Bonzi per litre for 24 h, while others were severely damaged (Anon. 1989). Sleiman et al. (1987), working with winter rape (*Brassica napus*), found that seed treatment with paclobutrazol (= pp 333) did not affect the germination, but they observed shorter hypocotyl, darker cotyledons and increased branching of the roots. The last observation cannot be confirmed by our observations of seedlings in Petri dishes or in peat.

Our experiments demonstrate large differences between cultivars in tolerating seed-soaking in paclobutrazol. Some of the results indicate a relationship between tendency to elongate and tolerance to seed treatment ('Floriade' and 'Samurain' vs. 'Opaal' and 'Gem' in Tables 4 and 5), but the results are not consistent: the cultivar 'White Rock' although often giving compact transplants with short hypcotyl, tolerates seed treatment with paclobutrazol fairly well.

Table 5. Percentage germination after soaking the seed in different concentrations of Bonzi (Experiment 4)

Cultivar	ml Bonzi per litre water in 24 h			
	0.0	0.1	1.0	10.0
Opaal NZ	80	40	10	5
Floriade NIZ	100	100	100	75
Fortuna RZ	80	20	15	5
Montano SG	85	70	10	0
White Rock SG	95	90	85	40
Linda ENZA	95	93	82	42
Cervina RS	90	65	55	10
Gem ASG	80	50	15	0
Shogum SAK	75	50	30	0
Samurain SAK	100	95	75	25
Corvet RS	85	85	80	80

Some of the damage to the seed caused by paclobutrazol might have been increased by the low viability of the seed. For some of the cultivars different lots of seed were used in different experiments, and the results indicate that lots with a low germination percentage in the control plants had a lower toleration to the treatment with paclobutrazol than lots with more viable seed (Tables 1 and 5). Results with experiments in Brussels sprouts (Berge 1991) and other *Brassicas* (Anon. 1989) support the idea that seeds with low viablity have a low tolerance level to soaking in paclobutrazol.

The retarding effect of seed treatment with 0.1 ml Bonzi per litre water for 24 h disappeared shortly after the cessation of elongation of the hypocotyl, 10-14 days after germination. In Experiment 2 the petiole and blade of the first and second leaves after the cotyledon elongated even more on plants seed-treated with 0.1 ml Bonzi per litre compared with the control plant (Fig. 1). Soaking in 1 ml Bonzi per litre for 24 h inhibited elongation until the plants developed the second true leaf. But Berge (1991) found that for plants of Brussels sprouts continually grown at low light intensity, 1 ml Bonzi per litre retarded the elongation of the first leaf, but later the leaf elongated to the length of the first leaf in the control plants. The difference in response in Experiment 2 vs. Experiment 3 (Figs. 1 and 2) provides the evidence showing that the effect of paclobutrazol in the seeds disappears faster in plants grown under conditions that promote elongation compared with those grown at high light intensity. This assumption is consistent with results from earlier experiments with calabrese and Brussels sprouts (Balvoll 1988b, Berge 1991).

Table 6. Length of hypocotyl in cm after soaking the seed in different concentrations of Bonzi (Experiment 5)

Cultivar	ml Bonzi per l water in 24 hours			
	0.0	0.1	1.0	10.0
Opaal NZ	3.2	2.7	2.4	0.6
Floriade NIZ	4.0	2.7	2.3	1.1
Fortuna RZ	4.1	3.2	2.6	1.0
Montano SG	3.7	2.5	1.8	-
White Rock SG	2.5	2.1	1.4	0.5
Linda ENZA	3.9	2.7	1.4	0.2
Cervina RS	3.1	2.6	2.1	0.3
Gem ASG	2.9	3.2	1.5	0.5
Shogum SAK	3.8	3.8	2.4	0.8
Samurain SAK	4.2	4.7	3.0	1.3
Corvet RS	4.6	4.7	3.6	2.0

Soaking the seed in paclobutrazol delayed germination (Table 3), but the same treatments did not influence the rate of development of leaves (Figs. 1 and 2). Earlier investigations by Balvoll (1988a,b) also provide evidence that although seed treatment with paclobutrazol can delay germination of Brussels sprouts, swede and calabrese, the plants develop the first leaf just as early as do control plants. Later they develop leaves at the same rate.

The results of Experiment 2 (Table 2) indicate that the difference in response between 'Floriade' and 'Opaal' for seed treatment with paclobutrazol is not due to

different rates of absorption of the retardant. 'Opaal' germinated fairly well after seed cover with paclobutrazol-enriched vermiculite (Table 4). We therefore assume that the reduction in viablilty by seed treatments is mostly due to lack of nutrients caused by inhibited formation of hydrolase.

REFERENCES

Anon. 1989. Bonzi-bløyting av frø av ulike kålvekster. Gartnerinærings fagsenter og forsøksring i Vestfold. Melding nr 20: 55-56.

Balvoll, G. 1988a. Strekningsvekst hos småplanter i Brassica. NJF-seminar no 141, Ås, Norway, 20-22 June 1988: 104-106.

Balvoll, G. 1988b. Strekningsvekst i korsblomstra kulturer. Gartnerinæringens fagsenter og forsøksring i Vestfold. Melding nr 19: 59-62.

Berge, M. 1991. Virkningen av lys, temperatur og paklobutrazol på strekningsveksten hos unge rosenkålplanter - *Brassica oleracea* L. *gemmifera* DC. Hovedoppgave NLH, Inst. for hagebruk, 92 pp.

Rood, S.B., D. Pearce, P.H. Williams & R.P. Pharis 1989. A gibberellin deficient *Brassica* mutant -*rosette*. Plant Physiology 89: 482-487.

Sleiman, A.I, B. Boelcke & M. Seiffert 1987. Untersuchungen zum keimungsverhalten von Winterraps (*Brassica napus* L.) unter dem Einfluss von Wachstumsregulatoren. Wiss. Zeitschrift des Wilhelm-Pieck-Universität Rostock. Naturwiss. Reihe 36(6): 105-107.

Zanewich, K.P., S.B. Rood & P.H. Williams 1990. Growth and development of *Brassica* genotypes differing in endogenous gibberellin content. I. Leaf and reproductive development. Physiol. Plant. 79: 673-678.

Maximizing the yield of greenhouse roses with respect to artificial lighting

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The yield and quality of five different greenhouse rose cultivars (Cardinal, Frisco, Jaguar, Kiss and Madelone) grown under four different levels of supplementary light (130, 190, 250 and 370 photosynthetic photon flux density, PPFD) were studied from September until June in a greenhouse under normal and high nutrient solution concentrations. The highest light level contributed to a photosynthetic active radiation which exceeded the natural radiation during summer. Generally the yield increased as the PPFD level increased from 130 to 250 or 370 µmolm $^{-2}$s $^{-1}$, and this was the case during the whole period. The response to PPFD varied between the cultivars, and as an average the yield increased 18, 41 and 53% at 190, 250 and 370 µmolm $^{-2}$s $^{-1}$ PPFD, respectively, compared to 130 µmolm $^{-2}$s $^{-1}$. The positive effect of high-levels supplementary lighting persisted even in the period of high natural light conditions of May-June. Raising the nutrient concentration in the root substrate from normal to high increased the yield by 9% as a mean. The percentage class 1 shoots of the total (class 1 and class 2) was increased by increasing the PPFD from 130 to 190-250 µmolm $^{-2}$s $^{-1}$ particularely in mid-winter. The percentage of long-stem roses (> 40 cm) was significantly increased by PPFD up to 370 µmolm $^{-2}$s $^{-1}$ particularely during mid-winter. The dry weight per shoot or weight per cm stem increased as the PPFD increased up to 370 µmolm $^{-2}$s $^{-1}$.

Key words: Artificial lighting, roses, yield.

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Cut roses is an important greenhouse crop in many countries. Low natural radiation during winter reduce the rose yield and quality in North-European countries, and therefore an interest in high-intensity artificial lighting has arisen. Studies so far have shown a linear increase of the yield with increasing levels of supplementary light, however, the optimal light level has yet to be established (Bredmose, 1990; Zieslin and Mor, 1990; Mortensen et al., 1992). Supplementary light levels corresponding to up to more than the natural photosynthetic radiation in a greenhouse in summer were therefore included in an experiment lasting 10 months. In addition, two nutrient solution levels were included in order to study how sensitive the rose plants are to the nutrient concentration.

MATERIALS AND METHODS

Six-month-old rose plants of cvs. Cardinal and Jaguar, and 1.5-year-old plants of cvs. Frisco, Kiss and Madelone, all on *Rosa indica* 'Inermis' rootstock, were used in the experiment. The plants were planted in a substrate of composted spruce bark mixed with 25% clay soil in 25 l containers, two plants per container. On 27 August the plants were cut back and placed in an double acrylic greenhouse under four different levels of supplementary light (130, 190, 250 and 370 $\mu molm^{-2}s^{-1}$) by means of high pressure sodium vapor lamps (Philips SON/T) applied 20 h day^{-1} (02.00 - 22.00 h). The photon flux density (PPFD) was measured 1.0 m above the containers (1.7 m below the lamps) by means of a Lambda LI-185B instrument with quantum sensor (400-700 nm). Figure 1 shows the daily photon flux (mol m^{-2} day^{-1}) with daylight only (data from the Department of Agricultural Engineering, Ås, 1990-1991) and with the different levels of supplementary light during the experimental period. The natural radiation inside the greenhouse was reduced by 50% compared to the outside level (Sebesta and Reiersen, 1981).

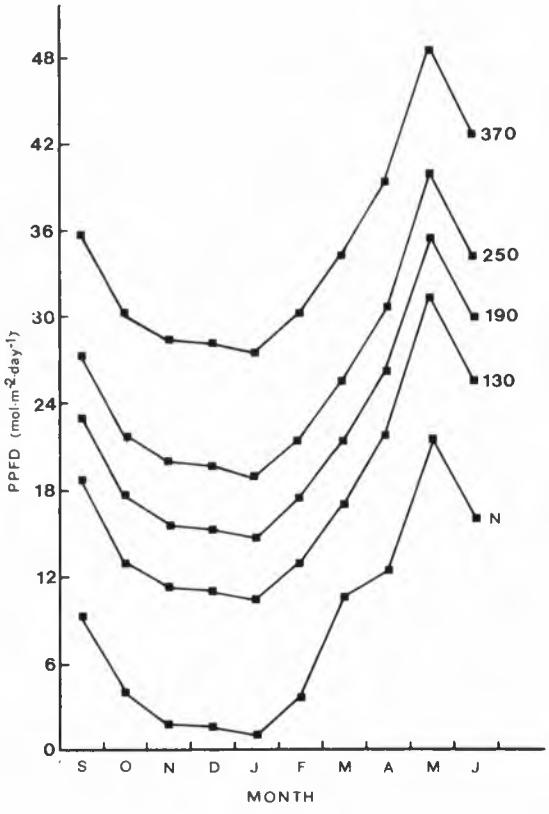

Figure 1. The photosynthetic photon flux density per day (PPFD) as means for each month with daylight only (N), and with different levels of supplementary PPFD levels in $\mu molm^{-2}s^{-1}$

Two nutrient concentrations were maintained in the containers, a normal (2.0-3.0 mS cm^{-1}) and a high (4.0-6.0 mS cm^{-1}). The plants were watered with a complete nutrient solution which consisted of (mll^{-1}): N, 155; P, 36; K, 174; Ca, 114; Mg, 29; S, 22; Fe, 4.0; Mn, 0.9; B, 0.23; Zn, 0.18; Cu,0.12; Mo, 0.03 - which gave a conductivity of 1.7-1.8 mS cm^{-1}. The conductivity level was varied throughout the experiment in order to keep the nutrient concentration on the desired levels. Twelve plants (six containers) of each cultivar and nutrient concentration, spaced at 8 plants m^{-2} brutto, were included at each light level.

The day temperature set-point was 20.0°C, the ventilation set point 23.0°C, and night temperature was 16.0°C (during the 4-hour dark period). Figure 2a shows the mean, maximum and minemum day temperature from November until June. A fan (7000 m^3 h^{-1}) which mixed the greenhouse air reduced the temperature gradient from 2.0 to 0.5°C from the lowest to the highest light level. The relative air humidity was kept below 90% by means of ventilation. The air humidity generally varied between 80 and 90% until April, and thereafter the humidity decreased due to high solar radiation and ventilation (Fig. 2b). The CO_2 concentration was kept at 800 µl l^{-1} in the light period when the greenhouse was closed, and it was gradually decreased as the vents opened. From April on the CO_2 control was rather poor due to much ventilation (Fig. 2c).

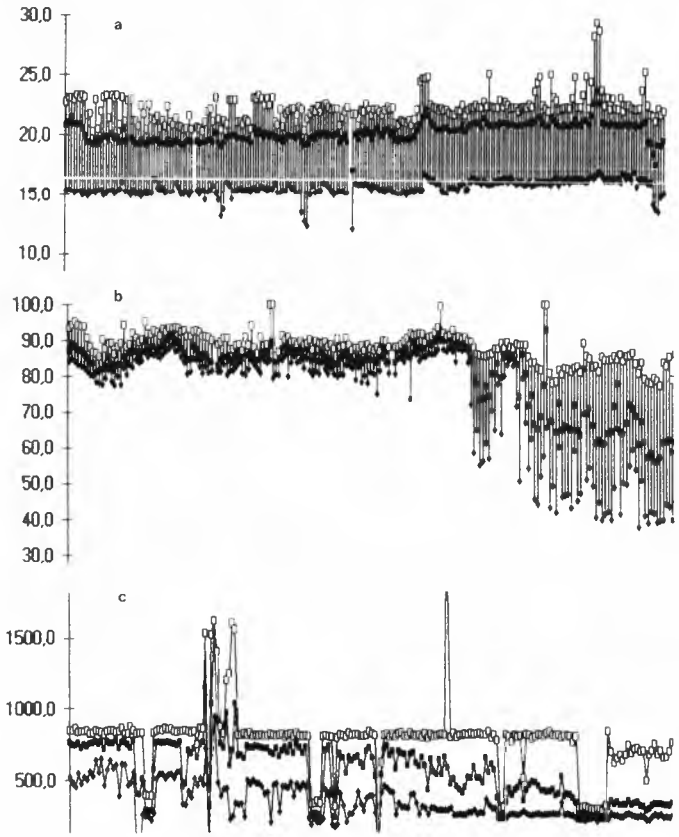

Figure 2. The greenhouse climate during the experiment. a. Mean, maximum and mimimum temperatures. b. Mean, maximum and minimum % relative humidity. c. Mean, maximum and minimum CO_2 concentration

Although the temperature gradient in the greenhouse compartment was low it was impossible to avoid that the lamps caused a temperature gradient in the leaves from top to bottom of the plants. The highest leaf temperature was measured in the leaves which were very close to the lamps (60 cm). In sunny weather with 1000 $\mu molm^{-2}s^{-1}$ natural light plus 700 $\mu molm^{-2}s^{-1}$ from the lamps, giving a total of 1700 $\mu molm^{-2}s^{-1}$, the leaf and flower temperature could reach about 40°C when the air temperature was about 23°C. With about 200 $\mu molm^{-2}s^{-1}$ from the natural radiation, i.e. a total of about 900 $\mu molm^{-2}s^{-1}$, the leaf and flower temperature was about 30°C (air temperature 23°C). At same time the air and leaf temperature was about 22°C at a distance of 1.7 m from the lamp (1.0 m above the pots) in between the shaded leaf mass. At the same PPFD level the temperature of the red flowers of cvs. Cardinal and Jaguar was about 2°C higher than the temperature of the yellow flowers of cv. Frisco.

The rose stems were harvested three times a week above the first 5-leaflet leaf. When the plants grew too high they were cut below the last pinching point. They were divided into class 1 which included stems longer than 20 cm and of good quality, while class 2 shoots were shorter than 20 cm and/or with weak or bent stems. The stems were put in different length classes, 20-30 cm, 30-40 cm, 40-50 cm and >50 cm. In November, January and March 10 rose shoots from each of the treatments were analysed with respect to dry weights of the different shoot components.

RESULTS

Number of rose shoots throughout the 10 months experimental period as a mean for all cultivar increased by 18, 41 and 53% when the PPFD level increased from 130 to 190, 250 and 370 $\mu molm^{-2}s^{-1}$ respectively (Table 1). The effect of raising the PPFD level was similar in winter and summer (Table 1). The cultivars Frisco, Cardinal and Madelone responded more to the increased PPFD level (66-75%) than the two other cultivars (24-29%). The yield as a mean for all cultivars and PPFD levels per 12 plants was 799 at normal and 870 (8.9% increase) at high EC. The yield was higher at high compared to normal EC in all cultivars except in Jaguar where high EC slightly decreased the yield, and in Madelone where no effect was found.

Table 1. The effect of supplementary PPFD level on number of harvested shoots (class 1 and class 2 shoots) per 12 plants of different cultivars. Means of two EC levels are given

	September-June PPFD ($\mu molm^{-2}s^{-1}$)				December-February PPFD ($\mu mol\ mol^{-1}$)				April-June PPFD ($\mu mol\ mol^{-1}$)			
Cultivar	130	190	250	370	130	190	250	370	130	190	250	370
Cardinal	452	541	739	789	107	145	218	223	182	208	270	307
Frisco	940	1180	1502	1582	231	351	423	465	344	453	571	646
Jaguar	700	689	799	866	173	193	228	240	345	263	315	383
Kiss	697	746	752	900	209	232	262	255	253	260	200	344
Madelone	531	623	793	884	122	152	226	252	205	236	316	352
Mean	664	756	917	1004	168	215	271	287	266	284	334	406

Table 2. Percentage class I shoots of the total as affected by cultivar, PPFD and time period. Means of two EC levels are given

	October-November PPFD (µmolm $^{-2}$s $^{-1}$)				January-February PPFD (µmolm $^{-2}$s $^{-1}$)				April-May PPFD (µmolm $^{-2}$s $^{-1}$)			
	130	190	250	370	130	190	250	370	130	190	250	370
Cardinal	86.8	93.7	90.4	91.8	86.6	91.4	88.9	87.6	86.3	85.7	90.5	83.7
Frisco	69.4	71.9	89.0	89.0	79.1	84.3	83.1	83.7	82.0	79.9	82.5	79.5
Jaguar	86.6	89.0	89.0	93.5	86.5	84.4	90.0	82.6	84.3	88.1	90.5	88.6
Kiss	89.0	89.0	91.3	90.0	74.4	85.0	86.2	86.4	86.6	87.7	81.9	89.6
Madelone	89.9	88.1	90.4	88.1	75.5	84.1	85.1	82.4	88.4	90.8	88.8	85.7
Mean	84.3	86.3	90.0	90.5	76.8	85.8	86.7	84.5	85.5	86.4	86.8	85.4
(± SD)	±7.6	±7.5	±0.9	±1.9	±6.0	±2.8	±2.5	±2.1	±2.2	±3.7	±3.8	±3.6

The percentage of class I roses of the total significantly increased as the PPFD level was increased from 130 to 190 µmolm^{-2}s^{-1} in January-February while only small effects were found during the autumn and spring/summer (Table 2). In mid-winter PPFD levels up to 370 µmolm^{-2}s^{-1} increased the percentage of long shoots while relatively small effects were observed during October-November and April-May (Table 3). No effect of EC level was found on shoot quality (data not presented).

Table 3. Percentage rose shoots > 40 cm or > 50 cm as affected by cultivar, PPFD and time period. Means of two EC levels are given

		October-November (µmolm^{-2}s^{-1})				January-February (µmolm $^{-2}$s $^{-1}$)				April-May (µmolm $^{-2}$s $^{-1}$)			
		130	190	250	370	130	190	250	370	130	190	250	370
Cardinal	>40	73.1	72.5	73.0	75.3	82.6	93.4	96.3	97.7	89.8	97.1	93.9	91.2
	>50	27.8	28.0	22.4	31.1	20.5	53.0	51.9	65.3	33.2	54.4	39.2	45.9
Frisco	>40	29.4	32.8	31.7	34.1	56.1	59.7	76.0	74.8	68.4	97.2	72.7	66.7
	>50	3.4	2.3	1.8	5.1	4.1	10.0	17.8	28.8	5.3	13.2	9.7	13.7
Jaguar	>40	29.1	29.9	21.2	38.8	21.9	45.4	50.8	66.2	43.7	48.3	41.3	57.7
	>50	2.7	4.0	2.9	6.2	0.0	14.6	1.2	9.7	2.5	4.4	0.0	1.3
Kiss	>40	59.7	70.9	67.0	75.0	56.4	67.3	76.0	84.3	63.1	67.4	70.3	66.9
	>50	14.6	24.3	20.1	25.4	3.2	16.2	15.6	30.7	4.1	8.7	9.5	9.8
Madelone	>40	78.8	81.6	77.3	76.0	100.0	99.1	99.7	99.7	99.0	97.3	99.2	83.5
	>50	27.1	54.7	43.4	47.7	88.3	94.3	94.2	89.9	90.1	85.8	89.0	88.4
Mean >40		54.0	57.5	54.0	59.8	63.4	73.0	79.8	84.5	72.8	75.5	75.5	73.2
Mean >50		15.1	22.7	18.1	23.7	23.2	37.6	36.1	44.9	27.0	33.3	29.5	31.8

No leaf or flower injury was observed which could be related to high PPFD or temperature levels close to the lamps. From mid-December some plants were attacked by *Verticillum*, and particularely plants from the cv. Frisco at 370 µmolm^{-2}s^{-1} PPFD at

high EC become severely injured. The results from this treatment were therefore excluded and the values from normal EC level are used in the tables.

Shoot dry weight increased 43% as a mean for all cultivars when the PPFD level increased from 130 to 370 $\mu molm^{-2}s^{-1}$ (Table 4). The stem weight per cm and dry weight per leaf increased 34 and 49% respectively, when the PPFD level increased from 130 to 370 $\mu molm^{-2}s^{-1}$. The leaf:stem dry weight ratio was only slightly affected by PPFD whereas the flower dry weight of total shoot weight decreased as the PPFD level increased. Although the values varied between the cultivars the effects were similar in all cultivars (data not presented).

Table 4. The effect of PPFD on rose shoots. Means of five cultivars and two EC levels are given. Each value represents 300 shoots. Values followed by different letters are significant different according to Duncan's multiple range test at $P < 0.05$ level

PPFD	Shoot wht. (g)	Shoot length (cm)	Stem dry wht. ($mg\ cm^{-1}$)	Leaf dry wht. (g leaf)	Dry wht. ratio Leaves: stem	Dry wht. ratio Flower: shoot
130	4.01d	45.8c	27.4d	0.204d	1.53c	0.292a
190	4.90c	47.1b	32.3c	0.262c	1.66a	0.258b
250	5.27b	47.8b	35.2b	0.279b	1.59b	0.253b
370	5.75a	49.0a	36.8a	0.304a	1.63ab	0.242c

DISCUSSION

The most spectacular findings in the present experiment was the positive effect of supplementary PPFD levels up to 370 $\mu molm^{-2}s^{-1}$ on rose yield even in the months of April-June. However, the relative effect of raising the light level was somewhat larger in winter as should be expected because of lower solar radiation in this period. For the whole 10-month period altogether the effect of increasing the PPFD from 130 to 250 $\mu molm^{-2}s^{-1}$ was much larger than a further increase to 370 $\mu molm^{-2}s^{-1}$. Earlier investigations which included a lower range of supplementary PPFD levels have shown about a linear increase in the yield with increasing light level (Zieslin and Mor, 1990; Mortensen et al., 1991). The present experiment indicate, however, that raising the PPFD level above about 250 $\mu molm^{-2}s^{-1}$ has less effect than raising it at lower light levels. Although variations beetween cultivars exist it seems that up to about 250 $\mu molm^{-2}s^{-1}$ supplementary lighting could be recommended to cut roses from a biological point of view. However, the economical optimal would of course depend on the energy cost. Furthermore, the climate at the location of the greenhouse should also influence the PPFD level which should be chosen. It is important that a high ventilation rate is avoided because this will reduce the CO_2 concentration control in the greenhouse. In a cold climate more light can therefore be installed than in a warmer climate before ventilation takes place at for instant 23°C. The importance of keeping the CO_2 concentration on 600-800 $\mu l\ l^{-1}$ in order to obtain a high yield and longer shoots is well documented (Mortensen, 1987).

At same time as a high yield is desired it is also important that the shoot quality is not negatively affected by the extreme light conditions in the greenhouse. However this was not the case, indeed the shoot length was significantly enhanced in the winter season. The shoot quality as partly described by the shoot length, has previously been reported both to be decreased (Carpenter and Anderson, 1972; Hendriks and Ludolph, 1987) and increased (Armitage and Tsujita, 1979) by supplementary light. In a previous experiment we found that the PPFD level had little effect on the shoot length even in mid-winter in the same greenhouse as the present experiment was carried out (Mortensen et al., 1991). The reason why this experiment turned out to show a positive effect of increased PPFD could be explained by smaller difference in air temperature between the different PPFD levels since a fan was used to move the air and reduce the temperature gradient. In experiment with lighting to roses the temperature under the different light treatments is a crucial point with respect to the number of shoots produced as well as to the length of the stem. This is so because the number of shoots increases and the shoot length decreases as the temperature increases (Moe, 1972; DeVries et al., 1982). Of course higher temperature were measured as the light level increased also in the present experiment, but nevertheless in spite of this increase the light stimulated the shoot length as much or even more than the temperature reduced it. Analysis of 1200 rose shoots clearly showed that PPFD levels up to 370 $\mu molm^{-2}s^{-1}$ increased the stem length as well as the weight per cm stem. This of cource improves another aspect of quality, the stem stiffness, as also previously shown at increasing, but lower PPFD levels (Hendriks and Ludolph, 1987; Mortensen et al., 1992).

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REFERENCES

Armitage, A.M. & M.J. Tsujita, 1979. Supplementary lighting and nitrogen nutrition effects on yield and quality of Forever Yours rose. Canadian Journal of Plant Science 59: 343-350.

Bredmose, N. 1990. Vækstlys til snitroser. Gartner Tidende 33: 883-884.

DeVries, D.P., L. Smeets & L.A.M. Dubois, 1982. Interaction of temperature and light on growth and development of hybrid tea-rose seedlings, with reference to breeding for low-energy requirements. Scientia Horticulturae 17: 377-382.

Hendriks, L. & D.Ludolph, 1987. Assimilations belichtung von rosen. Deutscher Gartenbau 49: 64-67.

Moe, R. 1972. Effects of daylength, light intensity, and temperature on growth and flowering in roses. Journal of American Society of Horticultural Science 97: 796-800.

Mortensen, L.M. 1987. Review: CO_2 enrichment in greenhouses. Crop responses. Scientia Horticulturae 33: 1-25.

Mortensen, L.M., H.R. Gislerød & H.Mikkelsen, 1992. Effects of high levels of supplementary lighting on yield of cut roses. (submitted).

Sebesta, Z. & D. Reiersen, 1981. A comparison on single glass and double acrylic sheeting with respect to heat loss and effects on plant environment. Acta Horticulturae 115: 409-416.

Zieslin, N. & Y. Mor, 1990. Light on rose. A review. Scientia Horticulturae 43: 1-14.

Supplementation of dairy cows at pasture and during the initial housed period

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The type of energy supplement offered to dairy cows during the pasture season significantly influenced virtually all parameters examined. In comparison with cattle given Italian ryegrass (IRG) or fodder turnips, concentrate-supplemented cattle produced a greater quantity of milk as well as milk with the highest protein and lactose content, but lowest fat content. They also consumed a significantly greater quantity of silage and had a faster rate of liveweight gain. The considerable quantities of water ingested when IRG or fodder turnips were consumed appeared to have a negative effect on both pasture and silage intake. The results suggest that no economic benefit would accrue from using either IRG or fodder turnips in place of concentrate. The current method used to allocate supplementary feed is inaccurate and resulted in periods when the cattle were not being provided with adequate energy.

Key words : Dairy cows, fodder turnips, pasture, ryegrass, supplementation.

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Since the introduction of milk production quotas it has become increasingly obvious that to maintain profitability farmers have to reduce variable costs. This can be most easily achieved by reducing the quantity of concentrate feed offered and increasing that of feedstuffs such as high quality roughages or root crops. Such feeds would be of greatest benefit if used to maintain production at the end of the grazing season, when the milk price is increased to encourage continuity of supply. The research reported here examined whether the use of supplementary feeds could offset the drop in production normally observed at the end of the grazing season and during the changeover to housing.

MATERIALS AND METHODS

This production trial, conducted in 1988, consisted of a treatment phase plus introductory and post-treatment periods. During the introductory period (weeks 23-29) weekly yields and estimated pasture quality were used to calculate concentrate allocation. One of two commercial concentrates was then offered to cover yield in excess of that which the pasture was estimated to support, at the standard rate of 0.4 kg concentrate per kg

4% fat-corrected milk (FCM). The results obtained during this period have been reported earlier (Mould 1989). Twenty-four NRF spring-calving cattle (12 cows and 12 heifers) were used for this trial. On a rotational basis the cattle grazed 6.1 ha of permanent pasture consisting mainly of perennial ryegrass (*Lolium perenne*), timothy (*Phleum pratense*), cocksfoot (*Dactylis glomerata*) and meadow grass (*Poa annua*) with some white clover (*Trifolium repens*). The cattle were housed overnight from week 37 and fully from week 40. In the treatment phase (weeks 30-42) they received one of three energy supplements: Italian ryegrass (*Lolium multiflorum*), fodder turnips (*Brassica napus*) or a commercial concentrate (156 g crude protein kg^{-1}), initially at a rate of 2.0 fattening feed units (ffu) daily. This was increased to 3.0 ffu when the cattle were housed overnight and offered silage. Additional concentrate was offered to meet requirements above what was calculated as being supplied by the various dietary components. Two swards of the Italian ryegrass (IRG) «Meritra» were established (28 March and 12 April) to ensure a regular supply of high quality material. The grass was cut daily using a flail harvester. Two sowing dates (11 May and 23 June) were also used to ensure continuity of supply of fodder turnips (var. «Civasto»). Plants were harvested daily by hand and offered to the cattle whole, with the first sowing used until week 34, thereafter the second sowing was used. At the end of the introductory period the cattle were blocked in eight groups of three, taking into account initial concentrate feed, FCM yield during the last three weeks of the introductory phase, parity, liveweight and days since calving. One supplement was then randomly allocated to each animal within a block. During post-treatment phase (weeks 44-49) the cattle were offered grass silage *ad libitum* plus concentrate to meet requirements.

Records

Milk yields were estimated on three consecutive days per week and an a.m./p.m. sample taken for composition and quality assessment. Intakes of concentrate, supplemental feeds and silage were measured on an individual basis and representative samples of pasture, IRG, turnips and silage were taken on a daily basis for dry matter (DM) analysis and chemical analyses. The total quantity and area of fodder turnips harvested daily was recorded. Estimates were also made of leaf:root ratio and plant density. Eighteen-month old Dala rams were used to estimate the digestibility coefficients of six feeds: two IRG samples (obtained in weeks 30 and 40 offered as the sole dietary component) and four turnip samples (two harvesting dates per sowing) offered in a 50:50 combination (DM basis) with chopped hay. Chopped hay was then offered alone and the coefficients determined by difference. Apart from the concentrate feeds, where the manufacturer's values were used, estimates of feed energy values are based on chemical analyses and *in vivo* digestibility coefficients. The net energy was calculated after Kellner (1905) using correction factors of 0.75 and 0.80 (for fodder turnips and silage, respectively) or a reduction of 1.0 NKF (g crude fibre)$^{-1}$ (IRG) (Breirem & Homb 1970). The cattle were weighed and condition scored at regular intervals throughout the trial. Any injuries and signs of adverse health were noted, as were reproduction details such as number of services and pregnancy diagnoses.

Data Handling and Analysis

Following allocation to treatment, the groups were subjected to an analysis of variance to ensure homogeneity. The results were analysed using SAS GLM procedures (SAS

1987) to generate LSM and significances of difference. Covariates, obtained in the preliminary periods, were used in all analyses except those for liveweight. It should be noted that calculated values (FCM, and fat, protein and lactose yields) are generated independently and so may not necessarily be equal to the sum of their separately determined mean values. In order to reduce the quantity of data only mean values over the entire period are presented, while trends in FCM yield over the trial period are given as two-week rolling averages (Figure 1).

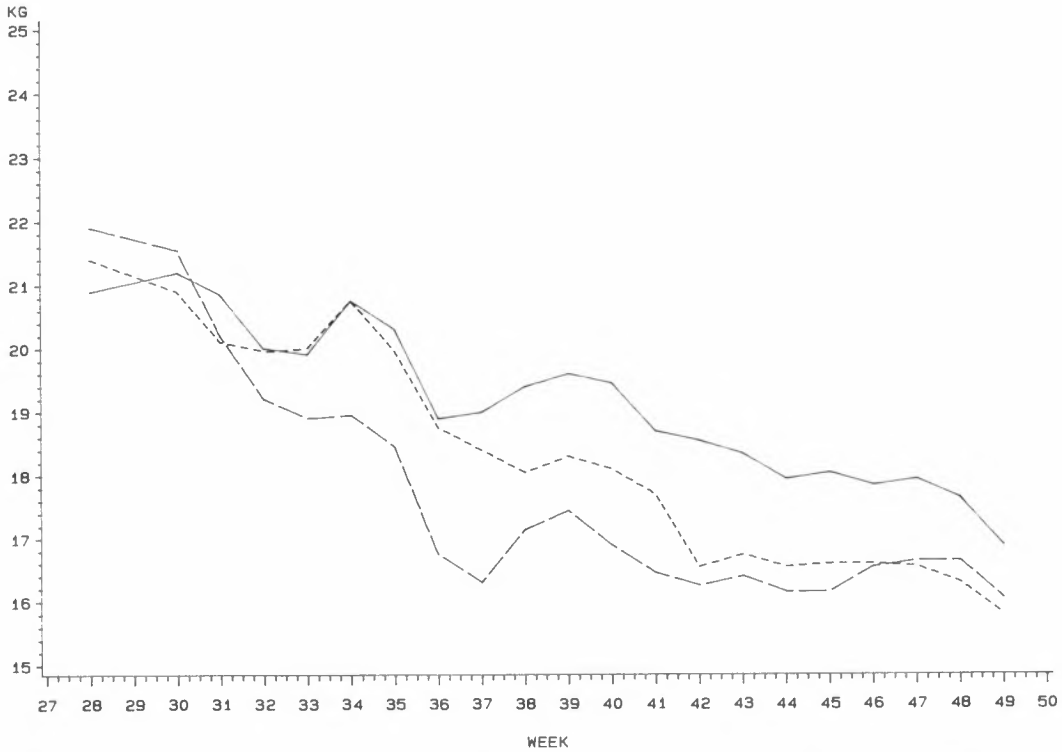

Figure 1. Two-week rolling average fat-corrected milk yields (kg). (Concentrate ————, fodder turnips - - - - and ryegrass — — —)

RESULTS

Milk production

A very low incidence of health problems was noted and no effect of any treatment on reproduction or health, including mastitis, could be identified, but all data from one animal (chronic ketosis, IRG group) was excluded. Overall, cattle supplemented with concentrate produced significantly ($P > 0.05$) more milk than either of the other two groups, equivalent to a mean increase of 2.7 and 2.1 kg d^{-1}, with the IRG, turnip and concentrate groups producing 18.5, 19.1 and 21.2 kg d^{-1}, respectively. FCM yield was of the same order as that of milk yield (concentrate > turnip > IRG) with the concentrate group producing significantly more FCM than the IRG cattle (Table 1). Milk from cattle offered either IRG or turnip had a similar, and significantly higher, fat content

than milk from those offered concentrate. Because of the higher fat content and higher fat content plus greater yields of the fodder turnip- and concentrate-supplemented groups, respectively, these tended to produce greater daily fat yields than the IRG cattle. No significant effect of treatment on protein content was recorded, but, as a result of higher milk yields, the concentrate group produced significantly ($P > 0.05$) more protein than the other two groups. No significant effect on lactose content was found, although the concentrate cattle produced a significantly higher yield compared to the others.

Table 1. Daily milk production

	Weeks	Supplement[1]		
		IRG	T	C
Milk yield (kg)	30-42	18.48a	19.08a	21.16b
	44-49	15.92a	15.80a	17.66b
FCM yield (kg)	30-42	17.82a	18.80ab	19.62b
	44-49	16.26a	16.31a	17.58a
Fat content (g kg^{-1})	30-42	38.5a	39.4a	35.5b
	44-49	42.3a	42.3a	39.4a
Fat yield (kg)	30-42	0.694a	0.743a	0.747a
	44-49	0.657a	0.664a	0.703a
Protein content (g kg^{-1})	30-42	32.7a	32.6a	33.4a
	44-49	33.4a	33.3a	33.9a
Protein yield (kg)	30-42	0.599a	0.621a	0.706b
	44-49	0.530a	0.526a	0.599b
Lactose content (g kg^{-1})	30-42	50.3a	50.4a	51.0a
	44-49	48.8a	48.7a	49.5a
Lactose yield (kg)	30-42	0.928a	0.961a	1.078b
	44-49	0.776a	0.772a	0.874b

[1] IRG - Italian ryegrass, T - turnips, C - concentrate
Means in rows with similar letters are not significantly different ($P > 0.05$)

Feed intake

Significant differences ($P > 0.05$) were found between supplement groups in both DM and energy intakes (Table 2). Poor intakes of fodder turnips were recorded, especially for weeks 30-36 when less than 50% of the desired level was consumed. Silage intake varied with treatment, with the concentrate group consuming significantly ($P > 0.05$) more than the other two groups. The total measured intakes of IRG and fodder turnip groups were similar, but significantly less than those of the concentrate-supplemented cattle. Measured crude protein (CP) intakes varied with treatment and were highest with the IRG group (Table 3).

Liveweight

Liveweight of all cattle declined during weeks 30-36, with the IRG group losing weight faster than either the fodder turnip or concentrate-supplemented cattle (-0.465, -0.207 and -0.106 kg d^{-1} respectively). This liveweight was regained when silage was included in the diet (Table 4). Overall, no change in the liveweight of cattle supplemented with either IRG or fodder turnips was observed, while the concentrate group gained 0.358 kg

Table 2. Daily intakes

Weeks	Feed[1]	DMI (kg) IRG[2]	T	C	Energy Intake (ffu) IRG	T	C
30-36	Conc.	2.68a	2.78a	2.74a	2.86a	2.97a	2.93a
	Suppl.	2.10a	1.02b	1.75c	2.04a	0.83b	1.87a
	Total	4.78a	3.80a	4.49a	4.91a	3.80a	4.80a
37-39	Conc.	2.80a	3.45a	3.40a	2.99a	3.68a	3.67a
	Suppl.	3.62a	3.47a	2.63b	3.28a	2.98b	2.81c
	Sil.	3.16a	2.58b	3.28a	2.21a	1.80b	2.30b
	Total	9.57a	9.50a	9.35a	8.48a	8.46a	8.78a
40-42	Conc.	2.62a	3.22a	3.48a	2.84a	3.43a	3.72a
	Suppl.	3.79a	3.06b	2.63c	3.28a	2.69b	2.81b
	Sil.	7.16a	7.26a	9.22b	5.02a	5.08a	6.45b
	Total	13.62a	13.54a	15.33b	11.14a	11.21a	12.98b
37-42	Conc.	2.73a	3.33a	3.46a	2.92a	3.56a	3.70a
	Suppl.	3.71a	3.27b	2.63c	3.28a	2.84b	2.81b
	Sil.	5.16a	4.92a	6.25b	3.61a	3.44a	4.38b
	Total	11.60a	11.52a	12.34a	9.81a	9.84a	10.88a
30-42	Conc.	2.70a	3.03a	3.07a	2.89a	3.24a	3.28a
	Suppl.	2.84a	2.06b	2.15b	2.61a	1.75b	2.30c
	Total	5.54a	5.09a	5.23a	5.50a	5.00a	5.59a

[1] Conc. - concentrate, Suppl. - supplement, Sil. - silage
[2] IRG - Italian ryegrass, T - turnips, C - concentrate
Means in rows with similar letters are not significantly different ($P > 0.05$)

Table 3. Crude protein intakes

Weeks	Intake g day[1] IRG	T	C
30-36	811	599	700
37-39	1518	1430	1360
40-42	2033	1927	2133
30-42	952	807	814

[1] IRG - Italian ryegrass, T - turnips, C - concentrate
Means in rows with similar letters are not significantly different ($P > 0.05$)

Table 4. Liveweight and average daily gain (ADG)

	Weeks	Supplement[1] IRG	T	C
Liveweight (kg)	29	502.3a	501.0a	477.8a
	49	531.2a	546.6a	549.1a
DG (kg d^{-1})	30-36	-0.465a	-0.207a	-0.106a
	37-42	0.542a	0.354a	0.899b
	30-42	0.000a	0.052a	0.358b
	44-49	0.367a	0.627a	0.406a

[1] IRG - Italian ryegrass, T - turnips, C - concentrate
Means in rows with similar letters are not significantly different ($P > 0.05$)

d^{-1} ($P > 0.05$). Condition score was closely related to changes in bodyweight and, although no significant differences between treatment were observed, the cattle offered IRG showed the greatest change over the experimental period.

Post-treatment effects

No significant post-treatment (weeks 44-49) differences were found in any of the milk production parameters of the cattle previously supplemented with either IRG or tur-

nips. The concentrate group, however, had significantly ($P > 0.05$) higher milk and milk protein and lactose yields (Table 1) than both these groups. This group also tended to have higher FCM and milk fat yields, but a lower milk fat content than the other cattle. Silage intakes were similar between groups, approximately 7.2 kg DM d^{-1}, while concentrate intake varied with milk yield. There was no significant difference in final liveweight.

Feed quality

Pasture and ryegrass quality, as assessed by *in vitro* analysis (Fig. 2), showed seasonal trends but remained high throughout. The DM content of the fodder turnips was found to increase as the leaf:root ratio decreased and both DM and energy yield m^{-2} increased with plant age. Despite the fact that the two IRG samples were obtained 10 weeks apart, *in vivo* digestibility coefficients were found to be only slightly lower in the later sample (Table 5). The DM values were similar to the *in vitro* DM values unlike those for fodder turnips, which varied widely. This effect may be due to the high and variable ash content associated with soil contamination of the roots used in the *in vivo* studies (139 to 214 g g DM^{-1}). OM digestibility coefficients were higher than those for IRG and better correlated to *in vitro* DM values.

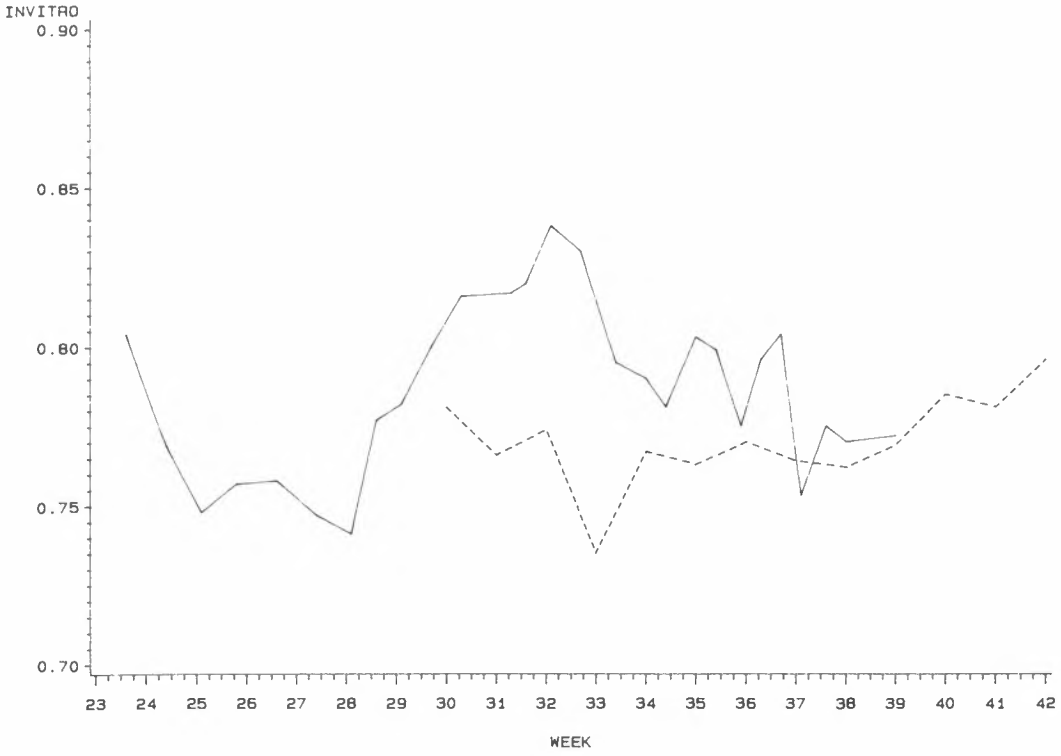

Figure 2. Dry matter *in vitro* digestibility coefficients. (Pasture ———— and ryegrass - - - -)

Table 5 : *In vivo* digestibility coefficients (g g DM $^{-1}$)

Feed	Week[1]		*In vivo*[2]					*In vitro*[3]
	S	H	DM	OM	CF	ADF	CP[4]	
IRG	13	30	0.790	0.812	0.894	0.864	0.763	0.781
	15	40	0.757	0.788	0.879	0.853	0.686	0.785
Turnips	19	30	0.815	0.890	0.852	0.842	0.913	0.823
	19	35	0.766	0.864	0.817	0.833	0.863	0.833
	25	35	0.734	0.840	0.794	0.807	0.950	0.822
	25	40	0.840	0.891	0.837	0.848	0.887	0.836

[1] S - sowing, H - harvest
[2] DM - dry matter, OM - organic matter, CF - crude fibre, ADF - acid detergent fibre, CP - crude protein
[3] *In vitro* digestibility
[4] Apparent digestibility

DISCUSSION

The type of energy supplement offered significantly influenced not only most of the milk production parameters examined, but also intake and liveweight. In addition, the main effects of treatment were, to some extent, confounded by the method of concentrate allocation. Those cattle producing the highest level of milk were offered the most additional concentrate which, in turn, will have helped maintain yields especially in the later stages of the trial. During weeks 37 to 39 an additional 0.7 kg concentrate day^{-1} was offered to the concentrate- and turnip-supplemented cattle compared to the IRG cattle, while over the housed period (weeks 37-42) the concentrate group received 0.9 kg d^{-1} more than the IRG group. Assuming that 0.4 kg concentrate provides sufficient dietary energy for 1.0 kg milk, these differences account for at least part of the variation in milk production observed between treatments. Despite the diversity of the supplements offered, measured energy intakes did not vary greatly except during the initial pasture period when a low intake of fodder turnips was observed. Protein intake was, however, markedly influenced by the type of supplement offered with the cattle offered fodder turnips consuming over 200 g less supplemental protein daily than the IRG group (Table 3). However when the contribution of the protein obtained by grazing is included and consideration is taken regarding the intakes of the different groups to match their energy requirements little variation is obtained, with all groups consuming about 150-160 g CP ffu^{-1}. This level is equivalent to a CP concentration in the diet of 120 g kg DM^{-1}, which is slightly higher than the minimum recommended CP content (ARC 1984) of 115 g for similar cattle, production levels and diet. However, when examined in terms of rumen- and non-rumen degradable protein (RDP and UDP, respectively), requirement calculations using both ARC (1984) and Madsen (1985) indicate that, while rumen microbial nitrogen requirements have been met, the diets may be marginal in UDP. Treatment effects on milk composition were as expected, with fat content varying inversely with the level of readily fermentable carbohydrate offered and protein content tending to increase with the total dietary energy (Broster et al. 1979, Sutton & Morant 1989). It would appear, however, that factors other than energy and protein content of the supplement have indirectly influenced milk production. For ins-

tance, during weeks 30-36 the IRG cattle had the highest measured intakes of energy and protein but the lowest milk yields and greatest liveweight loss. IRG and fodder turnips can both be considered as low energy density supplements despite the fact that their energy contents, expressed in terms of DM, are relatively high (ca. 0.75 ffu kg^{-1}). Not only does the DM occupy a large volume, but the considerable quantities of water that have also to be ingested (approximately 8.0 and 11.0 kg water ffu^{-1} for IRG and turnips in this experiment, respectively) will have a marked depressive effect on the intake of other dietary components, because of a rumen fill effect. The cattle offered these feeds consumed significantly less silage than the concentrate supplemented cattle. It follows that this effect also occurred when the cattle were at pasture, where the higher level of milk production and liveweight gain of the concentrate group probably resulted from a greater total energy intake (the smaller rumen volume occupied by the supplement allowed a greater intake of grazed herbage). Compared with the IRG group, the lower supplement consumption and, therefore, lower water intake of the turnip group may have allowed sufficient pasture to be consumed to maintain milk production during this period. The greater intake of water, approximately 32 kg d^{-1}, when the quantity of turnips consumed increased during the housed period restricted silage intake (Table 2). This resulted in the FCM yield of the turnip group decreasing to virtually the same level as that of the IRG group by the end of the supplementation period (Figure 1). While the use of supplemental concentrate reduced the depression in FCM yield when grass availability declined (after week 34), none of the three treatments totally alleviated this effect (Figure 1). The rapid decline in yield after week 34 was probably brought about by the allocation method used overestimating pasture availability, resulting in the cattle receiving insufficient supplementary energy. It was not until week 37, when silage was offered and supplement levels increased, that yields recovered. An increase in the level of supplementary feed given, rather than an increase in the quantity of additional concentrates, would seem to be the most obvious way to avoid this depression. But increased intakes of such supplements may not be possible (low intake of fodder turnips) or desirable (if the supplement consumed restricts intake of the basal dietary component). Therefore, not only do the nutritive value of supplemental feeds need to be considered but so also do the extent to which these affect basal roughage intake. Where supplementation has a marked effect on basal roughage intake, the effect on milk production will be directly correlated with the quality of that feed. In addition, the system of providing supplementary feed based on an estimated roughage intake to meet production requirements needs revision. While it was probably adequate with daily yields of up to 20 kg, with today's higher yielding cows this will easily lead to excessively high levels of concentrate (+ 60% of total dietary energy) being offered, thus reducing roughage utilization, increasing the possibility of acidosis and metabolic diseases such as ketosis and initiating the «low milk fat» syndrome. An economic assessment of the various supplements was conducted based on mean FCM yields and feed intakes. When full production costs for the fresh feeds were included little if any economic benefit accrued from using either IRG or fodder turnips in place of concentrate. Further trial work is in progress to identify more suitable supplements and also to investigate an alternative method of allocating supplemental feed so that periods of under-feeding, resulting from the incorrect assessment of pasture quality and availability, are avoided.

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REFERENCES

Agricultural Research Council 1984. The Nutrient Requirements of Livestock. Supplement No. 1. Commonwealth Agricultural Bureaux, Farnham Royal, England.

Breirem, K. & T. Homb 1970. Fôrmidler og Fôrkonservering. Forlag Buskap og Avdrått A/S, Gjøvik. 459 pp.

Broster, W.H., J.D. Sutton & J.A. Bines 1979. In Haresign & D. Lewis (eds.), Recent Advances in Animal Nutrition - 1978, Butterworths, London. P. 99.

Kellner O. 1905. Ernährung der Landwirtschaftlichen Nutztiere. Paul Parey, Berlin.

Madsen J. 1985. The basis for the proposed Nordic protein evaluation system for ruminants. Acta Agriculturae Scandinavica, Supplement 25: 9-20.

Mould 1989. Mjølkeforsøk 1989. Bondevennen Nr. 19/20: 12-13.

SAS 1987. SAS Institute Inc. SAS/STAT and SAS/GRAPH Guide for Personal Computers, Version 6 Edition. Cary, NC. SAS Institute Inc., 1987.

Spörndly, E. 1989. Effects of diet on milk composition and yield of dairy cows with special emphasis on milk protein content. Swedish Journal of Agricultural Research 19: 99-106.

Sutton, J.D. & S.V. Morant 1989. A review of the potential of nutrition to modify milk fat and protein. Livestock Production Science 23(3-4): 219-237.

Morphological and physical properties of virgin and cultivated silty and sandy soils from Finnmark, Northern Norway

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The study was conducted to investigate the soil morphological and physical properties of paired virgin and cultivated silty and sandy soils from northern Norway. The two soils studied were coarse silty above sandy mixed Dystric Cryochrepts and sandy mixed Typic Cryaquents, respectively. Both soils normally remain frozen for 7 to 9 months of the year. The silty soil was seriously compacted through cultivation, the sandy soil less so. Both cultivated soils had higher penetration resistance down to a depth of 40 cm, fewer air-filled pores, a lower water infiltration rate, and massive structure below ploughing depth. In addition, the cultivated silty soil had higher bulk density and lower total porosity than in the virgin state. Roots grew between platy structure aggregates down to a depth of 40 cm in the virgin silty soil, but few deeper than 2 cm in the compacted cultivated silty soil. No restriction in root growth due to cultivation was found in the sandy soil.

Key words: Root development, soil classification, soil description, soil morphology, water infiltration.

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Cultivation has a profound impact on soil properties, and many studies have been carried out to investigate the effects of different cultivation and tillage systems on soil physical properties in cultivated soils (e.g. Wiklert 1962, Børresen 1987, Ehlers & Teiwes 1987, Paglilai 1987, Packer & Hamilton 1987, Shipitalo & Protz 1987, Edwards et al. 1990).

Only a few papers, however, have dealt with the changes in soil morphology and soil physical properties due to the cultivation of virgin soils. When comparing virgin and cultivated silt loam and clay soils, Bouma & Hole (1971) found that a century of cultivation had led to reductions in hydraulic conductivity and increases in bulk density in the upper part of the solum below the Ap horizon. Modification of the plough layer by cultivation had also reduced the hydraulic conductivity of the topsoil. They described corresponding changes in soil morphology. Domzal et al. (1980) reported that a change from forest to agricultural land-use led to a decrease in total porosity and macropores, and to an increase in the bulk density of the arable layer. Thompson et al.

(1990), comparing morphological features in forest soil with those of soils under permanent grass and annual cultivation, found that the B horizon of the cultivated soil had a somewhat lower macroporosity. Froehlich et al. (1985) found that the soil bulk density was significantly higher in skid trails than in undisturbed areas. There was still a significant difference 23 years after logging. Martel & Deschenes (1976), comparing the water-stable aggregates in cultivated and non-cultivated soils, found a decrease of 84% as a result of cultivation.

In the Norwegian project "Animal manure and soil factors" (1986-90), some of the soil problems related to the use of cattle slurry and soil compaction have been studied. A special study was conducted to investigate the effects of cultivation and surface spreading of animal manure on water infiltration (Haraldsen & Sveistrup 1990), air exchange (Haraldsen 1990), and micromorphology (Stoops & Marcelino 1989). This paper discusses the classification, the morphological, physical and chemical characteristics, and the infiltration properties of the soils.

MATERIAL AND METHODS

Material

Soils from two locations in Finnmark county, northern Norway, were selected for the studies, Tana (70°26' N, 28°15' E), with silty topsoil above sandy subsoil, and Pasvik (69°28' N, 29°57' E), with sandy soil in both horizons. At both sites virgin soil bordered cultivated soil. The bordering soils were considered to be comparable except for the present vegetation and land-use. The distance between the virgin and cultivated soils was approximately 15 m. Field headlands were avoided.

The climate could be characterized as subarctic continental at both sites (Figs. 1 and 2), particulary so at Pasvik, where annual precipitation is 375 mm, with a higher proportion in summer than in winter (Skogfoss, 14 km south-west of the study site) (Det norske meteorologiske institutt 1980). The mean annual air temperature is -0.3°C (Pasvik meteorological station, situated 43 km south-west of the study site), and the vegetation period (temperature $\geq$ 6°C) is 124 days. At Tana, the annual precipitation is 423 mm, with a more even distribution throughout the year than at Pasvik (Rustefjelbma meteorological station, situated 4 km south of the study site). The mean annual air temperature at Tana is 0.1°C, the vegetation period 118 days.

Both soils have a cryic soil temperature regime (Soil Survey Staff 1975). Also at Pasvik, the insulation from the snow cover during winter gives a mean annual soil temperature above zero, despite its lower air temperature, resulting in a cryic instead of a pergelic soil temperature regime. In the area of the Pasvik study site, discontinuous permafrost was described by Løddesøl & Lømsland (1937, 1939). After drainage, which took place in the 1930s, the frozen mounds gradually disappeared and were not observed in the study area when the present investigations took place.

The soils at both study sites are normally frozen for 7 to 9 months of the year to a depth greater than normal ploughing depth. Frost is commonly found in the soil until after midsummer.

The Tana location was chosen because of previous observations of restricted plant growth caused by soil compaction resulting from cultivation, and winter damage caused by ponding and ice-choking (Andersen 1960, Lorentzen 1984). The soil has develo-

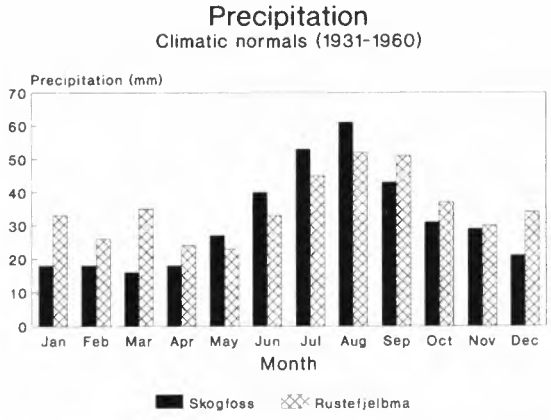

Fig. 1. Precipitation at Skogfoss and Rustefjelbma meteorological stations

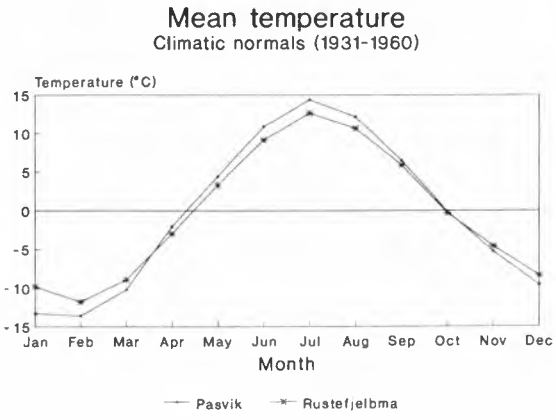

Fig. 2. Temperature at Pasvik and Rustefjelbma meteorological stations

ped on alluvium of the Tana floodplain in the lower part of the Tana valley, about 5 m above sea level. The landscape is flat to slightly undulating. The study sites were situated upland on an almost flat area, 10 - 15 m from a shallow depression. The soils were imperfectly drained (Canada Dep. Agr. 1974). The virgin soil supported birchforest with grasses and mosses. This is considered to have been the vegetation also at the cultivated site before cultivation started in the 1920s. A thin mor humus layer covered the soil. The cultivated site was a meadow of seven years' sward age, and the vegetation consisted mostly of weed species with meadow grass (*Poa annua*) as the predominant plant species. The meadow had been used for cow pasture for the previous four years, and the forest was also grazed by cows to some extend.

The soils of the Pasvik location were without any particular agronomic problems. The studied site was situated on the edge of a peat bog which was initially drained by open ditches in the 1930s (Løddesøl & Lømsland 1937). The landscape was almost flat, 1 to 2% slope, and situated about 35 m above sea level. At the study site a shallow peat

layer (20 to 30 cm) covered a layer of outwashed sand more than 1 m thick, over sedimentary marine clays. The groundwater was at the surface of the soil in parts of the year until systematic drainage of the area took place seven years prior to the investigations. The groundwater level was then lowered to about 1 m below the soil surface. The cultivated and virgin sites were situated on each side of an open drainage ditch. The vegetation at the virgin site, which was also the vegetation of the whole area before cultivation, was mostly peat moss (*Sphagnum* spp.), with heather (*Ericaceae* spp.) and scattered pine trees (*Pinus sylvestris*). The cultivated land had a five-year-old meadow, mainly consisting of smooth meadow-grass (*Poa pratensis*) and timothy (*Phleum pratense*). The meadow was harvested once a year for silage.

The weight of the tractors used in agriculture was ± 3 Mg at both Tana and Pasvik.

Methods

The soils were classified according to Soil Taxonomy (Soil Survey Staff 1975). Soil descriptions were carried out in profile pits at the virgin and cultivated sites at both locations according to FAO (1977) except for the root descriptions, which follow Hodgson (1976). Counts of roots were carried out in horizontal sections of each soil horizon. The penetration resistance was measured with a pocket penetrometer (Eijkelkamp WF 24950), which had a flat point with an area of 30 mm^2. Resistances up to 2900 kPa could be recorded. The penetrometer was pressed ± 6 mm into the soil before recording the value. Ten individual readings were made at each 5 cm depth or closer in horizontal cuts in each profile. Soil samples were collected for standard chemical and physical soil analyses.

For particle size analysis, a pipette method was used (Elonen 1971). The soil textural names are given according to the Soil Survey Staff (1951). Water retention measurements were carried out in accordance with standard methods using ceramic plates and pressure membranes. The analysis of exchangeable cations was performed according to Ogner et al. (1975, 1977). The KCl extraction was carried out in the same way as the NH_4OAc-extraction. Organic carbon was determined by means of a Leco IR 212 Carbon System.

Undisturbed soil monoliths were collected at each profile site in rigid plastic cylinders. The vegetation on the sites was removed before digging. The plastic cylinders were pressed down consecutively on the soil monoliths as the excavation proceeded. A layer of grease was applied to the inside of the cylinder wall before sampling to ensure firm contact between cylinder wall and soil. The cylinders were designed to be used as lysimeters. The inner diameter was 23.5 cm and the soil monoliths had a height of 25 ± 1 cm. Twelve monoliths were collected at each site, within a radius of 1.5 m of the profiles described, and transported to Holt Research Station. Because of vibration during transportation the virgin soil from Pasvik had subsided and this caused a somewhat higher bulk density than was the case in the natural state.

Infiltration measurements

The monoliths were placed on fibre mats on top of perforated wooden plates in the laboratory. The water level was kept to 1 cm above the bottom of the cylinders. Before the infiltration measurements, water was added to the surface of the soil, which was kept at about -2.5 kPa water potential, and plastic covers placed on the top of the cylin-

ders prevented evaporation. When necessary, additional grease was applied to ensure firm contact and to prevent leakage between the soil and the cylinder wall. The temperature in the room was kept constant at 10 ± 2°C before and during the infiltration period.

Immediately before the infiltration measurements, the soil was flooded for one hour to stabilize the infiltration rate. The temperature of the water was 10 ± 1°C and the recording period was 2 hours, with measurements taken every 30 minutes. The measurements of the water level were made at a fixed level with a micrometer screw and the precision was one-tenth of a millimetre. The water head was kept at 20 ± 10 mm above the soil during the recording periods. The infiltration rates presented are the means of the infiltration rate of the last three measurements after the infiltration rate was stabilized.

RESULTS

Classification

The silty Tana soils were both classified as coarse silty above sandy mixed Dystric Cryochrepts, the sandy Pasvik soils as sandy mixed Typic Cryaquents. The classification of the Pasvik soils was carried out in accordance with morphological features which dated back to the physical environment before the lowering of the groundwater level seven years earlier. With the present soil physical conditions, and disregarding soil colour, both profiles would be classified as mixed Typic Cryopsamments.

Abbreviated macromorphological descriptions and physical and chemical data for each soil are given in Tables 1, 2, and 3, respectively.

Morphology

An organic layer overlaid the mineral soil at the virgin site at both Tana and Pasvik. At Pasvik, a few centimetres of the sphagnum peat still remained at the cultivated site also. At the time of the soil descriptions (1 and 3 July 1987), patches of frozen soil were found in all the soil profiles except at the cultivated site at Tana. In the virgin Tana soil, isolated lenses of frozen soil were found from a depth of 7 cm down to approximately 40 cm. At the Pasvik virgin site, the lower 10 cm of the organic soil layer was frozen in most of the investigated soil. The cultivated soil had a discontinuous frozen layer of 5 cm thickness at a depth of 70 cm.

The mineral soil at both locations was of sedimentary origin. At Tana a silty cover of approximately 40 cm overlaied the sandy sediments. The texture of the Pasvik soil was sandy throughout in both profiles. At both sites the virgin topsoil had a somewhat finer texture than the cultivated topsoil.

All soils had a shallow and weak soil development. In the virgin Pasvik sandy soil no soil development was observed below the peat layer, except for a few roots down to a depth of 14 cm. The other three soils had a colour alteration in the upper part of the profiles. The same three soils had a weak platy structure development. In both cultivated soils the development was limited to the plough layer, and below the plough layer the soils were massive down to a depth of approximately 40 cm. In the virgin Tana silty soil the platy structure was found in all the silty layers down to a depth of 43 cm.

Table 1. Macropedology of pedons by horizons

Depth (cm)	Horizon[1]	Matrix colour[2] (moist)	Texture[2]	Structure[2]: grade-size-shape	Consistence[2] Moist	Wet	Roots[3]: size-abundance	Boundary[2]
Tana, silty virgin								
3-0	O	10YR 3/1					1-3,2-3,3-3,4-2	aw
0-7	Ah	10YR 3/3	sil	1-c-pl	mvfr	ws,wp	1-3,2-3,3-3,4-2	aw
7-25	Bw1	2.5Y 5/4	sil	1-m-pl	mvfr	ws,wps	1-3,2-3,3-3,4-3	as
25-34	2Bw2	10YR 5/4	lfs	1-m,c-pl	mvfr	wso,wpo	1-2,2-3,3-2,4-2	as
34-43	2Bw3	2.5Y 4/2	lfs	1-c-pl	mvfr	wso,wpo	2-1,3-1	as
43-69	3C1	2.5Y 5/2	s	0---sg	mvfr	wso,wpo		as
69-	3C2	2.5Y 6/2	s	0---sg	ml	wso,wpo		
Tana, silty cultivated								
0-5	Ap1	10YR 4/2	vfsl	1-m,f-pl/ 0---m	mfr	wss,wps	1-2 (0-2cm) 1-1 (2-5cm)	as
5-23	Ap2	10YR 4/2	vfsl	1-m-pl/0---m	mfr	wss,wp	1-1	as
23-36	Bwg	2.5Y 4/3	vfsl	0---m	mfr	wss,wpo		as
36-46	2C1	2.5Y 5/2	s	0---sg	ml	wso,wpo		as
46-49	3C2	5Y 4/2	vfsl	0---sg	ml	wso,wpo		
Pasvik, sandy virgin								
20-15	H1	7.5YR 3/4					2-1,3-1	as
15-5	H2	5YR 2.5/2					2-1,3-1	as
5-0	H3	10YR 2.5/1					2-1,3-1	as
0-14	Cr1	5Y 5/1	fs	0---sg	ml	wso,wpo	3-1	as
14-36	2Cr2	5Y 4/1	cos	0---sg	ml	wso,wpo		as
36-	3Cr3	5Y 5/1	fs	0---sg	ml	wso,wpo		
Pasvik, sandy cultivated								
9-0	Op	5YR 2.5/1		2-f-sbk, gr	mvfr	ws,wpo	1-4,2-4	aw
0-7	Ap/Bwh	10YR 3.5/2	ls	1-m,c-pl	mfr	wss,wpo	1-2	cw
7-21	Bhs	10YR 3/4	s	0---m	mvfr	wso,wpo	1-2	aw
21-44	Crw	2.5Y4.5/2	s	0---m	mvfr	wso,wpo		aw
44-	2C	5Y 5/1	cos	0---sg	ml	wso,wpo		

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

Roots

Good root development was found in the virgin Tana silty soil down to a depth of 34 cm, whereas in the cultivated soil few roots reached a depth of more than 2 cm. The cultivated Pasvik sandy soil had a rooting depth greater than the ploughing depth. In both cultivated soils the roots had a random orientation. In the virgin silty soil the roots below a depth of 7 cm were predominantly horizontally oriented between the platy structural aggregates. Only exceptionally did roots penetrate the structural aggregates.

Physical properties

The cultivated soils were more dense down to a depth of approximately 40 cm than those in the virgin state. This was more pronounced in the silty than in the sandy soil.

Table 2. Physical properties of pedons by horizons

Depth (cm)	Horizon	Particle size distribution* (%) csa	msa	fsa	csi	msi	fsi	cl	cf	Bulk density (Mg/m^3)	Total porosity (%)	Air-filled pores % (v/v) At sampling	<0.1 bar	Available water % (v/v) (0.1-1bar)	(0.1-15 bar)	Penetration resistance (kPa)
Tana, silty virgin																
0-7	Ah	-	6	15	38	23	9	9	2							200-400
7-25	Bw1	-	4	22	42	18	7	7	1	1.14	58	29	26	10	27	400-800
25-34	2Bw2	-	9	65	19	4	-	3	1	1.34	52	29	34	12	15	600
34-43	2Bw3	-	1	79	17	1	-	2	-	1.34	52	26	26	17	23	800-900
43-69	3C1	-	54	43	2	-	-	1	-	1.46	48	42	43	2	4	400-900
69-	3C2	-	59	39	1	-	-	1	-	1.42	49	40	43	2	3	
Tana, silty cultivated																
0-5	Ap1	2	12	38	29	11	4	5	1	1.53	43	10	6	7	26	>2900
5-23	Ap2	1	11	36	29	13	4	6	1	1.44	46	11	7	6	30	2100->2900
23-36	Bwg	-	7	58	24	5	2	3	1	1.49	47	20	18	4	24	500-1800
36-46	2C1															1000
46-49	3C2	-	3	52	37	5	1	2	1	1.55	46	37	39	3	5	
49-	4C3	3	75	22	-	-	-	-	1	1.52	46	43	41	2	3	
Pasvik, sandy virgin																
20-15	H1															
15-5	H2									0.18	88	14	22	17		
5-0	H3															
0-14	Cr1	6	25	59	5	2	1	2	-	1.47	47	30	37	6	8	200
14-36	2Cr2	36	37	23	2	-	1	-	17	1.53	46	39	41	2	3	200
36-	3Cr3	-	23	73	3	-	-	1	-	1.54	45	9	37	5	6	300
Pasvik, sandy cultivated																
9-0	Op									0.47	75	11	8	4	56	
0-7	Ap/Bwh	7	37	38	8	4	3	4	4							700-1400
7-21	Bhs	2	32	60	4	1	-	1	2	1.44	47	26	25	8	17	1300-1500
21-44	Crw	1	35	60	3	-	-	1	1	1.50	46	29	35	6	9	1100-1400
44-	2C	24	52	21	2	-	1	-	25	1.60	43	32	39	3	3	

* csa = coarse sand (2-0.6 mm); msa = medium sand (0.6-0.2 mm); fsa = fine sand (0.2-0.06 mm); csi = coarse silt (0.06-0.02 mm); msi = medium silt (0.02-0.006 mm); fsi = fine silt (0.006-0.002 mm); cl = clay (< 0.002 mm); cf = coarse fragments (> 2 mm)

Table 3. Chemical properties of pedons by horizons

Depth (cm)	Horizon	pH (H_2O) 1:2.5	Exch. acidity me/100 g	Exch. ions 1M NH_4OAc pH 7, me/100 g dry matter Na	K	Ca	Mg	CEC sum[1] cations me/100 g	BS sum[1] cations (%)	Exch. acidity (1M KCl) me/100 g	CEC sum[2] cations me/100 g	BS sum[2] cations (%)	Organic carbon (%)
Tana, silty virgin													
3- 0	O	4.4	98.22	0.75	1.24	12.53	0.92	113.6	14	3.84	19.2	80	37.8
0- 7	Ah	4.0	34.20	0.17	0.11	0.43	0.12	35.0	2	6.85	7.7	11	6.3
7-25	Bw1	4.8	13.44	0.13	0.02	0.32	0.11	14.0	4	2.04	2.6	22	0.8
25-34	2Bw2	5.1	9.38	0.11	0.02	0.53	0.11	10.2	8	0.92	1.7	45	0.4
34-43	2Bw3	5.2	8.92	0.09	0.03	0.49	0.09	9.6	7	0.72	1.4	49	0.2
43-69	3C1	5.4	5.77	0.05	0.01	0.15	0.14	6.1	6	0.31	0.7	53	0.1
69-	3C2	5.5	6.69	0.06	0.01	0.17	0.14	7.1	5	0.29	0.7	57	0.1
Tana, silty cultivated													
0- 5	Ap1	5.0	14.61	0.12	0.29	1.74	0.40	17.2	15	0.84	3.4	75	2.5
5-23	Ap2	5.5	12.91	0.11	0.10	2.88	0.57	16.6	22	0.32	4.0	92	2.0
23-36	Bwg	5.5	8.95	0.09	0.04	1.45	0.36	10.9	18	0.28	2.2	87	0.4
36-46	2C1												
46-49	3C2	5.2	9.63	0.08	0.08	0.90	0.26	11.0	12	0.53	1.9	72	0.3
49-	4C3	5.6	5.86	0.04	0.04	0.12	0.06	6.1	4	0.10	0.4	72	0.1
Pasvik, sandy virgin													
21-15	H1												
15- 5	H2	6.3	35.75	0.45	0.05	52.31	0.89	89.5	60	0.19	53.9	100	45.6
5- 0	H3	6.0	45.27	0.44	0.06	66.70	1.22	113.7	60	0.19	68.6	100	43.9
0-14	Cr1	6.5	5.18	0.06	0.01	1.21	0.02	6.4	20	0.04	1.4	97	0.5
14-36	2Cr2	6.5	4.86	0.04	0.01	0.44	0.01	5.4	9	0.04	0.5	93	0.3
36-	3Cr3	6.7	4.66	0.05	0.01	0.32	0.01	5.1	8	0.07	0.5	85	0.2
Pasvik, sandy cultivated													
9- 0	Op	5.6	31.80	0.31	0.92	20.35	1.13	53.9	42	0.19	22.7	99	20.5
0- 7	Ap/Bwh	5.2	10.01	0.07	0.06	1.66	0.06	11.9	16	0.26	2.1	88	3.1
7 -21	Bhs	5.0	8.35	0.04	0.01	0.38	0.01	8.8	5	0.56	1.0	44	1.1
21-44	Crw	4.7	6.81	0.05	0.01	0.16	0.00	7.0	3	0.56	0.8	29	0.5
44-	2C	6.2	5.17	0.05	0.01	0.30	0.01	5.5	7	0.06	0.4	86	0.2

1) Sum cations = Sum of exch. acidity and exch. ions (1M NH_4OAc, pH 7)
2) Sum cations = Sum of exch. acidity (1M KCl) and exch. ions (1M NH_4OAc, pH 7)

Penetration resistance in the plough layer of the cultivated silty soil was 4 to 7 times higher than that in the virgin soil at the same depth, while in the cultivated sandy soil the penetration resistance was about half that of the cultivated silty soil.

The bulk density in the plough layer of the cultivated silty soil was about 25% higher than that of the virgin soil; the total porosity was 12% higher. No such differences were found in the sandy soil. The top layers of both cultivated soils had lower values of air-filled pores (after water extraction at 0.1 bar suction) than in the virgin soils. This was most pronounced in the silty soil where the virgin soil had more than four times as many coarse pores as the cultivated soils.

The physically available water in the root zone was only 5 mm in the cultivated silty soil (Table 4), when the root zone is defined as the soil layers with common or more roots. The amount of roots is classified according to Hodgson (1976). The easy available fraction (0.1 - 1 bar) for the same soil was 1 mm. In the cultivated sandy and virgin silty soils, where the root zone reached deeper than normal ploughing depth, more water was available in the root zone than in the layer from 0 to 20 cm.

Table 4. Physically available water in virgin and cultivated silty soil from Tana and sandy soil from Pasvik

Soil	Depth of root zone (cm)[1]	Physically available water (mm) In the root zone[2] 0.1-1 bar	0.1-15 bars	From 0-20 cm 0.1-1 bar	0.1-15 bars
Silty virgin	0-34	36	81	20	54
Silty cultivated	0- 2	1	5	13	58
Sandy virgin	no vegetation	not calculated		10	13
Sandy cultivated	9- 0 0-21	20	86	16	34

[1] The root zone is defined where common or more roots were observed
[2] Measured from the top of the mineral soil

Chemical properties

A slight gypsum crusting was observed at the soil surface in dry summers in the area of the sandy soil. On drainage, the groundwater level was lowered the most at the cultivated site, and gypsum crusting was only observed afterwards in the virgin soil. This was reflected in the pH and in the base saturation of the topsoil, which were both highest in the virgin soil. In the silty soil, which was not influenced by groundwater, the topsoil at the cultivated site had higher pH and base saturation values due to liming compared with that at the virgin site.

Infiltration rate

Very low infiltration rates were found for the cultivated silty soil compared with those for the virgin soil, 1.0 versus 22.9 mm per hour (Table 5). The infiltration rate of the sandy soil was much higher than that of the silty soil. Here, too, there was a clear difference between cultivated and virgin soil, 16.6 and 106.2 mm per hour respectively.

The sandy soil showed little variation between replicates in infiltration rate. The coefficients of variation for virgin and cultivated soil were 15% and 33% respectively. In the less permeable silty soil, the variation between replicates was higher, with coefficients of variation of 51% and 160% for virgin and cultivated soil respectively (Table 5).

Table 5. Mean values of infiltration rate and coefficients of variation (CV%) on virgin and cultivated silty soil from Tana and sandy soil from Pasvik (12 replicates in each case)

Soil	Infiltration rate mm/hour	CV%
Silty virgin	22.9	51
Silty cultivated	1.0	160
Sandy virgin	106.2	15
Sandy cultivated	16.6	33

DISCUSSION

Cultivation had a significant impact on the morphology and physical properties of the soils investigated in this study, the effects appearing to be more pronounced in the silty soil than in the sandy soil.

The formation of a platy structure in the silty soil was probably due to frost action, with the formation of ice in a laminar structure (Key et al. 1985). In a cultivated silt loam they found that the formation of discrete ice lenses caused a considerable drop in the bulk density of the soil as a whole. It was assumed that the soil between the ice lenses retained its pre-freezing bulk density. This was considered to be the reason for the rapid reconsolidation of the soil upon thawing. As the water drained away, the aggregates settled to a position similar to the one they had occupied prior to freezing, and left planes of weakness where the ice lenses had been located. These findings correspond to our own in the cultivated silty soil. Here the platy aggregates were separated by planes of weakness which only became visible on handling the soil blocks. In the wall of the profile cut, different structure aggregates were not visible. The root development, which was very poor and shallow in this soil, was random and not located to the planes of weakness. The planes of weakness from the annual freezing-thawing cycles had not caused any loosening of the soil to have promoted root penetration.

In the virgin silty soil, annual cycles of freezing and thawing have taken place for centuries without any visible soil alteration. Here, planes of weakness are assumed to have developed further into more stable planar voids which have given a platy structure throughout the silty layers. This structure has remained stable under the present soil management. Roots have been able to grow along the voids throughout the silty layers and have thus also helped to stabilize the voids and the soil structure. Hardly

any roots penetrated the aggregates, but most were located in the planar voids between the aggregates. This indicates unfavourable growing conditions within the aggregates, as was also the case in the cultivated silty soil, where hardly any macropores were observed. No visible biological activity was observed within the aggregates. In the cultivated soil, the aggregates, which have remained stable under the present soil management, have proved to be very unstable when disturbed, and are therefore sensitive to compaction by cultivation.

The physical properties of the cultivated silty soil indicate unfavourable conditions for root growth. A minimum of 10% coarse pores is often quoted in the literature as the limiting value for the growth of agricultural crops (e.g. Kohnke 1979). In the upper part of the plough layer the volume of coarse pores was only 6 to 7%. The penetration resistance was also higher than that thought to limit root penetration in soil without coarse pores (Eriksson 1982). Evidence of compaction was found down to a depth of about 40 cm in both soils through morphological studies and the physical analyses.

The effects of compaction by cultivation on soil morphology and physical soil factors were less pronounced in the sandy soil than in the silty soil. A weak platy structure was developed in parts of the plough layer of the sandy soil, but the number of air- filled pores and the penetration resistance did not suggest any restriction to root development. Sveistrup & Østgård (1985) also found lower bulk density and higher porosity in sandy than in silty agricultural soils in the region, with better root development and higher grass yields in the sandy soil.

The infiltration and percolation capacity of a soil is largely dependent upon its structure and texture. As guiding values for steady-state infiltration capacities on bare soil, Kohnke (1979) quotes 8 mm per hour for silt loam and 25 mm for loamy sand. The infiltration rate of the virgin silty soil studied here was considerably higher than the quoted value, but the infiltration rate of the cultivated silty soil was much lower. This difference corresponds well with the difference in structure development and the number of coarse pores in the two soils as indicated in Tables 1 and 2. The high infiltration rate and the deep root development also suggested that many of the coarse pores of the virgin soil were continuous. The cultivated sandy soil had an infiltration rate of the magnitude indicated for loamy sand, while the virgin sandy soil here had a much higher infiltration rate.

CONCLUSION

Cultivation of the silty soil has led to soil compaction, which has produced very unfavourable conditions for root development and plant growth. In this soil the plants may very quickly suffer from drought stress in dry periods as a result of shallow rooting depth. Stress caused by prolonged water saturation and surface pounding after rainfall due to low infiltration capacity, may also occur. The agricultural plants will probably die under such conditions and be replaced by weeds with a superficial rooting system. In the sandy soil, cultivation was also shown to have changed the physical and morphological soil features, but no restriction in root development or water infiltration was observed.

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REFERENCES

Andersen, I.L. 1960. Overvintringsundersøkelser i eng i Nord-Norge. I. Forskning og forsøk i landbruket 11: 635-660.

Bouma, J. & F.D. Hole 1971. Soil structure and hydraulic conductivity of adjacent virgin and cultivated pedons at two sites: A typic argiudoll (silt loam) and a typic eutrochrept (clay). Soil Sci. Soc. Amer. Proc. 35: 316-319.

Bruun, I. 1967. Climatological Summaries for Norway. Standard Normals 1931-60 of the Air Temperature in Norway. Det Norske Meteorologiske Institutt, Oslo.

Børresen, T. 1987. Tre jordarbeidingssystemer for korn kombinert med ulik pakking og halmdekking, virkning på avling, jordtemperatur og fysiske egenskaper på leirjord i Ås og Tune, 1983-1984. Norsk landbruksforsking, Supplement No. 3 1987. 175 s.

Canada Department of Agriculture 1974. The system of soil classification for Canada. Publication 1455. 255 pp.

Det norske meteorologiske institutt 1980. Nedbørsnormaler. Oslo.

Domzal, A., A. Slowinska-Jurkiewicz, R. Turski & M. Palikot 1980. The influence of agricultural cultivation on density and water retention of soils formed from loesses. Polish Journal of Soil Science 13: 91-98.

Edwards, W.M., M.J. Shipitalo, L.B. Owens & L.D. Norton 1990. Effects of *Lumbricus terrestris* L. burrows on hydrology of continuous no-till corn fields. Geoderma 46: 73-84.

Ehlers, W. & K. Teiwes 1987. Der Einfluss der Bodenbearbeitung auf Poreneaumgliederung, ungesattigte Wasserleitung und Gasdiffusion. I. Porenraumgliederung und Wasserleitung. Mitteilungen der Deutschen Bodenkundlichen Gesellschaft 53: 381-386.

Elonen, P. 1971. Particle-size analysis of soil. Acta Agralia Fennica 122. 122 pp.

Eriksson, J. 1982. Markpackning och rotmiljö. Packningsbenägenheten hos svenska åkerjordar. Förändringar i markens funktion orsakade av packning. Sveriges lantbruksuniversitet, Institutionen för markvetenskap. Rapport 126. 138 s.

FAO 1977. Guidelines for Soil Profile Description. Second ed. FAO, Rome. 66 pp.

Froehlich, H.A., D.W.R. Miles & R.W. Robbins 1985. Soil bulk density recovery on compacted skid trails in central Idaho. Soil Sci. Soc. Am. J. 49: 1015- 1017.

Haraldsen, T.K. 1990. Effects of cattle slurry and cultivation on air exchange in a sandy soil and a silty soil from Finnmark, northern Norway. In: Haraldsen, T.K., Effects of Soil Compaction and Cattle Slurry on Air Exchange and Water Infiltration in Soils from Northern Norway: 21-46. Agricultural University of Norway. Doctor Scientiarum Theses 1990: 15.

Haraldsen, T.K. & T.E. Sveistrup 1990. Effects of cattle slurry and cultivation on water infiltration in a sandy soil and a silty soil from Finnmark, northern Norway. A study of different statistical methods for infiltration experiments. In: Haraldsen, T.K., Effects of Soil Compaction and Cattle Slurry on Air Exchange and Water Infiltration in Soils from Northern Norway: 47-73. Agricultural University of Norway. Doctor Scientiarum Theses 1990: 15.

Hodgson, J.M. (ed.) 1976. Soil Survey Field Handbook. Describing and Sampling Soil Profiles. Soil Survey Technical Monograph 5. 99 pp.

Key, B.D., C.D. Grant & P.H. Groenevelt 1985. Significance of ground freezing on soil bulk density under zero tillage. Soil Sci. Soc. Am. J. 49: 973-978.

Kohnke, H. 1979. Soil Physics. T M H Edition. TATA McGraw-Hill Publishing Company Ltd., New Delhi. 224 pp.

Lorentzen, I. 1984. Jorda på Finnmark landbruksskole. En vurdering av problemer med overflatevann og overvintringsskader. Hovedoppgave ved Norges landbrukshøgskole 1984. 84 s.

Løddesøl, Aa. & D. Lømsland 1937. Myrundersøkelser i Sør-Varanger. Meddelelser fra Det Norske Myrselskap. 35: 77-99.

Løddesøl, Aa. & D. Lømsland 1939. Orienterende teleundersøkelser på myr i Sør-Varanger. Meddelelser fra Det Norske Myrselskap. 37: 97-108, 151-186.

Martel, Y.A. & J.M. Deschenes 1976. Les effets de la mise en culture et de la prairie prolongée sur le carbone, l'azote et la structure de quelques sols du Québec. Can. J. Soil Sci. 56: 373-383.

Ogner, G., A. Haugen, M. Opem & B. Sørlie 1975. Kjemisk analyse program ved Norsk institutt for skogforskning. Meddr. Norsk inst. skogforsk. 32: 207- 232.

Ogner, G., A. Haugen, M. Opem & B. Sørlie 1977. Kjemisk analyse program ved Norsk institutt for skogforsking. Supplement I. Meddr. Norsk inst. skogforsk. 33: 87-101.

Packer, I. & G.J. Hamilton 1987. Changes in soil physical properties due to tillage over seven years. In: K.J. Coughlan & P.N. Truong (eds.). Conference and Workshop Series - Queensland Department of Primary Industries 1987 (No. qc87006): 65-68. Proceedings National Workshop, Toowooba, Queensland.

Pagliai, M. 1987. Effects of different management practices on soil structure and surface crusting. In: N. Fedoroff, L.M. Bresson & M.A. Courty (eds.), Soil Micromorphology. Versailles, France: Association Française pour l'Etude du Sol. Pp. 415-421.

Shipitalo, M.J. & R. Protz 1987. Comparison of morphology and porosity of a soil under conventional and zero tillage. Can. J. Soil Sci. 67: 445-456.

Soil Survey Staff 1951. Soil Survey Manual. USDA Agriculture Handbook 18. 503 pp.

Soil Survey Staff 1975. Soil taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys. USDA Agriculture Handbook 436. 754 pp.

Stoops, G. & V. Marcelino 1989. Micromorphological study of Surface Samples of Soils after Different Treatments with Slurry. Laboratory of Mineralogy, Petrography and Micropedology, State University Ghent, Belgium (unpublished). 17pp.

Sveistrup, T.E. & O. Østgård 1985. Engundersøkelser i Troms og Finnmark. Sluttrapport nr. 598, Norges landbruksvitenskaplige forskningsråd. 10 s.

Thompson, M.L., N. Fedoroff & B. Fournier 1990. Morphological features related to agriculture and faunal activity in three loess-derived soils in France. Geoderma 46: 329-349.

Wiklert, P. 1962. Ett jämförande markfysikaliskt studium av tre matjordsprofiler. Grundförbättring 15: 15-49.

Simulation of surface runoff and pipe drainage (SOIL-model) from a field lysimeter on cultivated soil at Ås, Norway, 1973-81

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Estimates from simulations of surface runoff and pipe drainage using the Swedish SOIL-model were compared with results from a field lysimeter study on arable land in Ås, Norway. The plot size was 20 m x 3.75 m with a 4.5% slope. The soil was a clay loam with a content of organic matter in the topsoil of 3% C. The simulation model provided a good estimate of the runoff components averaged over the 8-year period. For shorter periods, months or days, the models partitioning between surface runoff and pipe drainage showed greater deviation from the measurement, especially during the snowmelt period. Simulations with different parameter settings gave some indication of the importance of reliable and independent estimates of the hydraulic conductivity, the fate of the water on the surface during the snowmelt period and the snowmelt function. However, although still we lack information about these conditions, the model appears to be a useful tool in evaluating the different runoff components for Norwegian conditions.

Key words: Field lysimeter, model simulation (SOIL), pipe drainage, surface runoff.

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Field measurements of surface runoff and pipe drainage are both time and labour consuming, and can only be performed at a few, it is hoped, representative sites. Therefore a generalization of site-specific measurements is necessary in order to make practical use of the results, with modelling as one of the possible tools in this process. A simulation model represents a simplification of nature. A crucial question is the degree of simplification in relation to the purpose when using the model. A too detailed model may demand too much information and may therefore be limited to only a few sites where detailed investigations have been carried out. On the other hand, a too simple model may be limited in its use since the input data would be more site-specific and therefore difficult to estimate with independent methods.

For Norwegian climatic conditions with snow and usually frost in the soil during the winter period, these aspects have to be included in models of surface runoff and pipe drainage from agricultural land. A promising model, which includes both a snow- and a soil frost-function, is the Swedish SOIL-model (Jansson & Halldin 1980, Jansson 1990a). The model has provided acceptable estimates of surface runoff and pipe drainage from agricultural land in Sweden (Jansson & Gustafson 1987), and should therefore also be of relevance for Norwegian conditions. In this article we have compared the results from model simulation with measurements from a field lysimeter study at Ås, Norway. The measurements include the monthly figures for surface runoff and pipe drainage during an 8-year period, 1973-81 (Uhlen 1989).

MATERIALS AND METHODS

Site description

A detailed field description is given by Uhlen (1978) and only information relevant to the present context will be repeated here. The field lysimeter was constructed in 1973 on cultivated land at Ås, Norway, with a 4.5% slope. The soil in this area is clay loam (FAO 1977), with a content of organic matter in the topsoil of 3% C.

During construction of the field lysimeter the topsoil and subsoil were pushed aside, which of course disturbed the natural soil profile. To reduce the variability between plots, 12 in all, the topsoil from the whole area was thoroughly mixed before it was replaced. The treatments comprised different cropping systems and different fertilizer rates. Only the results from three plots with spring grain, four years with barley, three years with oats and one year with spring wheat, are used here. The plots were ploughed in the autumn each year, and the N-fertilizer rates were 0, 100 and 200 kg/ha.

From each of the plots, 20 m x 3.75 m, surface and drainage runoffs were collected and measured. The surface runoffs were caught in 3.75 m long gutters made from 160 mm polyvinyl chloride tubes. The gutters were connected to the plot surface by 35 mm plastic strips. In order to catch the percolating water, double 0.06 mm polyethylene sheets were placed at 90 cm depths and on the side walls of each plot. Two 50 mm drain tubes, length 20 m, were placed on the polyethylene sheets, covered with glass-wool strips and a layer of sand.

Model description

A detailed description of the SOIL-model is given by Jansson & Halldin (1980) and of the revised version by Jansson (1990a). The water and heat model is based on two coupled differential equations describing one-dimensional heat and water transport in a soil profile. The model uses standard daily meteorological input data: air temperature, relative humidity, precipitation, global radiation, duration of sunshine or cloudiness and wind speed. Snow dynamics, frost, evapotranspiration, ground water flow, plant water uptake and drainage flow are calculated. In the model the potential evapotranspiration is estimated according to the Penman-Monteith equation (Monteith 1965), and the actual evapotranspiration is calculated as a function of the soil water content and soil temperature (Jansson 1990a). The model predicts soil climate variables (soil temperature, water content, etc) with a daily resolution at any level in the soil profile.

Soil properties are defined by the water retention curve and the hydraulic conductivity as a function of water content or tension. The water retention function is estimated by a modified version of the Brooks & Corey (1964) equation. The unsaturated hydraulic conductivity is estimated from the retention function and the hydraulic conductivity according to Mualem (1976). Separate account is taken of the influence of macropores in the wet range close to saturation. The thermal conductivity of the soil was estimated by using Kersten's (1949) equations.

Adaption of the model to the site

Although the SOIL-model is a simplification of the natural system, it requires extensive input data and model coefficients which are often not available. In our case the only measured parameters were the water retention curve and the saturated hydraulic conductivity for the soil. With the exception of the sowing date and the harvesting date, the other plant characteristics are estimated. Instead of adjusting the different parameters in order to obtain agreement between the measured and simulated data, we have estimated the different parameters from information found in the literature and from previous experience using the model summarized in the SOIL user's manual (Jansson 1990b).

Input variables / parameter settings

The daily meteorological observations are from the main meteorological station at Ås, situated about 1 km from the experimental site.

The water retention curve for the soil layers 0-20, 20-50, 50-80 and 80-130 cm are shown in Figure 1. The plastic sheet at the bottom of the field lysimeter was simulated with a sand layer at 80-130 cm. The following layers were used in the model simulation: 0-10, 10-20, 20-50, 50-80, 80-130 and 130-990 cm. The water retention curve used for the deepest layer was set the same as that for the layer at 50-80 cm. Median values of saturated hydraulic conductivity measured on undisturbed soil cores from the different depts are given in Table 1. The hydraulic conductivity at 4% volume of air in the soil, saturated hydraulic conductivity excluding macropores (Jansson1990a), was estimated to 1/100 of the median saturated hydraulic conductivity. This almost corresponds to the minimum values of the saturated hydraulic conductivity including macropores for each layer.

Since detailed plant parameters were not registered, we have used the average yearly date for sowing and harvesting over the 8-year period. The leaf area index is estimated from data presented by Hansen (1985). Root distribution is estimated after Marti (1984); 70% of the roots in the upper 20 cm of the soil. Mean values of root growth are estimated from tensiometer measurements on nearby plots with spring grain from the same 8-year period. The root growth was about 1 cm/day from the sowing date, and this corresponds fairly well with data given by Aslyng & Hansen (1982). The maximum root depth was estimated to be 80 cm.

In order to reduce the influence of different water storage in the soil profile as much as possible, the period from 1 November to 31 October is used instead of the calendar year. From the model simulation the change in water content between years on 1 November was in most cases within 10 mm.

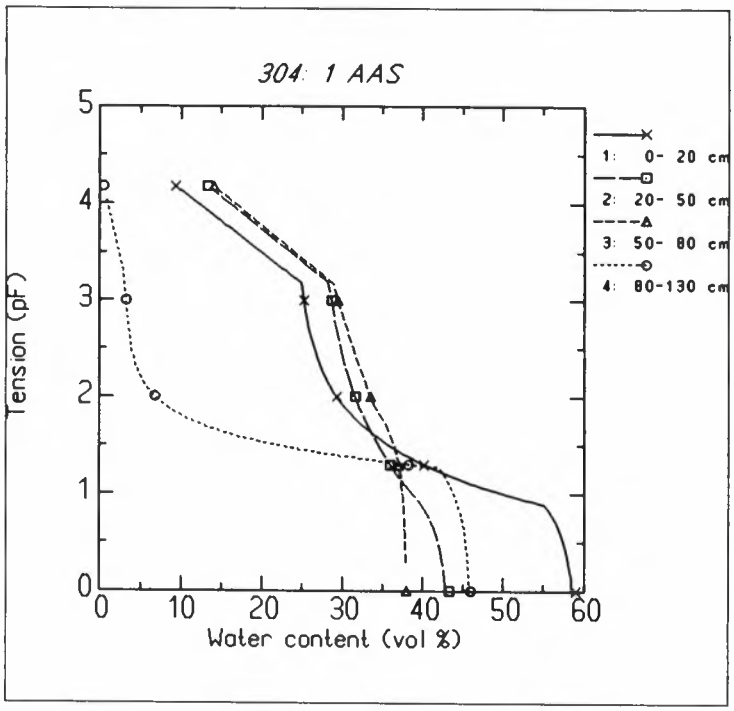


Figure 1. Soil water characteristic curves for the soil profile at the field lysimeter, Ås. Soil layer 80-130 cm simulated as a sand layer

Table 1. Saturated hydraulic conductivity measured on undisturbed soil cores from different depths in the field lysimeter

Depth cm	Number of rep.	Saturated hydraulic conductivity, cm/h Median	Min - Max
5	11	18.0	0.02 - 63
20	8	6.6	0.2 - 123
30	13	5.9	0.1 - 31
40	12	6.5	0.02 - 153
60	5	3.0	0.4 - 20
Simulated sand layer	3	150	0.015 (estimated min)

Boundary conditions

For the heat equation the surface temperature is set equal to the measured air temperature during the snow-free periods as the upper boundary conditions. For periods with snow cover, the soil surface temperature in the model is estimated from the presumption of steady state heat flow between soil and the homogeneous snowpack (Jansson 1990a). For the lower boundary conditions we have assumed the heat flux at the bottom of the soil profile as being close to zero by using the depth of the soil profile equal to 9.9 m.

For the water equation the upper boundary conditions are calculated from precipitation and simulated snowmelt. The lower boundary conditions are set as water flow

that corresponds to drainage pipes, which are represented as a sink term in the one-dimensional solution of the partial differential equation for water flow. This is simulated by placing the drainage pipes, 0.9 m apart, in a coarse sandy layer with a ground water table at the bottom of the pipes at the start of simulation. The reason for the inclusion of a coarse sandy layer is in order to simulate the plastic sheet, because a dense layer with low porosity and hydraulic conductivity lead to unstable results in the model simulation. Another reason was that a sandy layer would also reduce the effect of capillary rise from the ground water table. The hydraulic gradient for the water flow to the drainage pipes is calculated from the height of ground water above the pipes and divided by 1.9 m.

Initial conditions
The simulation period began on 18 October 1973, at which date we used tensiometer and soil temperature measurements from a nearby experimental site as input.

RESULTS

Climate
Daily mean values of air temperature, monthly totals for precipitation and measured snow depth from the meteorological station at Ås for the period from 1 November 1973 to 1 November 1981 are given in Figure 2 (Fysisk Institutt 1973-1981). The lowest daily mean air temperature in the period was -20°C, and the highest daily precipitation was 55.6 mm. The normal annual air temperature and precipitation are 5.5°C and 785 mm respectively. The average values for the years 1973-81 were 6.2°C (4.2-7.1°C) and 786 mm (537-931 mm), where minimum and maximum values are given in parenthesis.

Total runoff
The yearly figures for simulated and measured total runoff, which include both surface runoff and pipe drainage, are given in Figure 3a. On average for the 8-year period the measured total runoff was 386 mm of which 41% was surface runoff (Uhlen 1989). With exception of the year 1976/77 the estimated runoff was within 15% of the measured values, which indicated that differences between the measured precipitation and the simulated evapotranspiration were reasonable. For the whole period the model slightly underestimated the total runoff by about 10%. One likely explanation was that neither the precipitation as rainfall nor snowfall was corrected for wind, ie the aerodynamic error in precipitation measurements. Following the SOIL user's manual (Jansson 1990b) the standard corrections used in Sweden are +7% for rainfall and +14% for snowfall. The results of simulation with these corrections to precipitation are given in Table 2 - simulation 2. During the winter 1976/77 the measured total runoff was higher than the precipitation, indicating that snow drift could be the explanation for the deviation.

Pipe drainage and surface runoff
The yearly totals of simulated and measured pipe drainage and surface runoff are given in Figures 3b and c. The variations in the measured values are mostly within 15%. The results clearly show that the partitioning of the total runoff in pipe drainage and surface

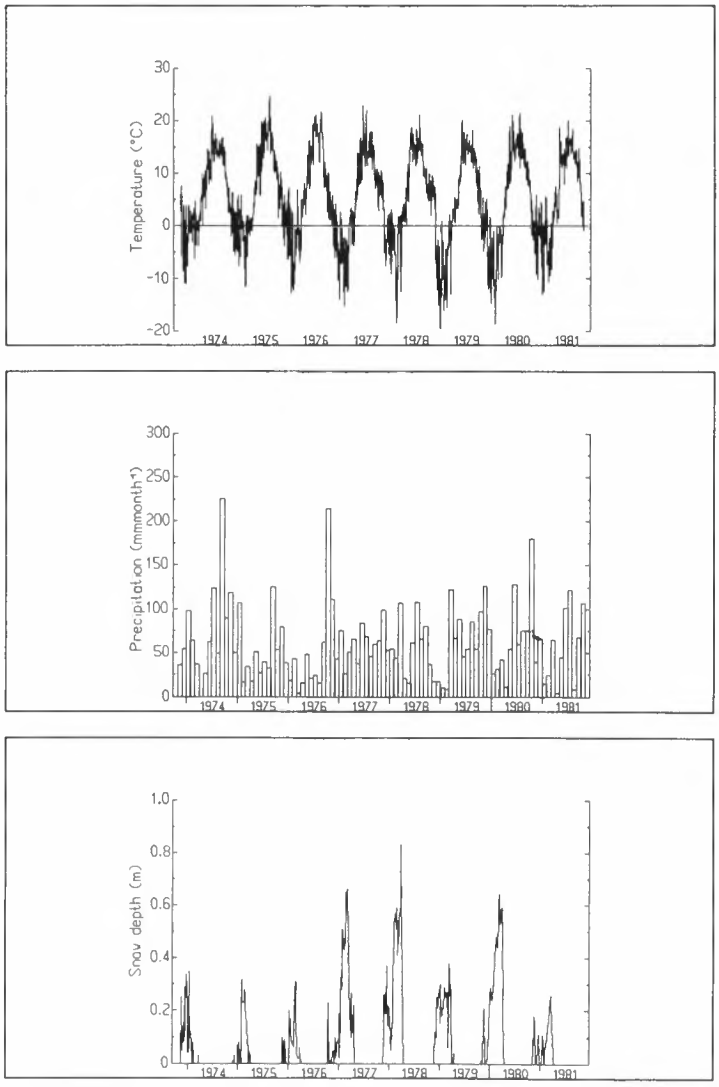


Figure 2. Daily means of air temperature, monthly figures for precipitation and measured snow depth at the meteorological station, Ås

runoff was more difficult to simulate with the model than the total runoff. It is interesting to note that with the average values for the 8-year period the model gives a reasonable estimate of both the surface runoff and the pipe drainage. This indicates that the differences between measured and simulated values over years are not systematic, but rather of a more random nature.

For five out of the eight years the estimated pipe drainage was within 15% of the measured values. The relative difference between measured and simulated surface runoff was higher, and only for two years the difference was within 15%. But as seen from Figure 3 the magnitude of the differences is about the same for the surface runoff and pipe drainage, see for instance 1978, 1979 and 1981. For the year 1978, the simulated surface runoff was higher than measured, and for the other two years there was an opposite trend.

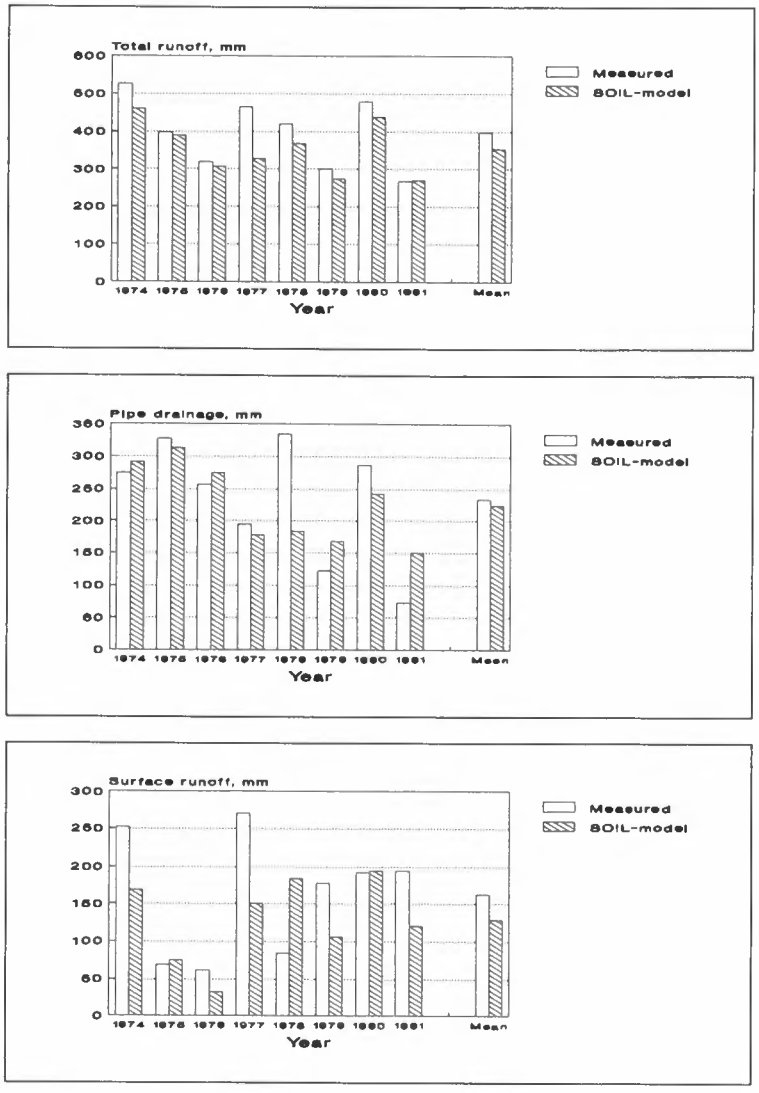


Figure 3. Yearly totals for measured and simulated total runoff, pipe drainage and surface runoff. The year gives the values for the period 1 November to 31 October (ie 1974 = 1 November 1973 to 31 October 1974)

The monthly measured and simulated pipe drainage and surface runoff for the 8-year period is given in Figure 4. With monthly output data from the model the time trend fits fairly well with the measured values, but the magnitude of the different runoff components indicated greater variations. The average monthly differences between simulated and measured values for the 8-year period and the spread of the data are shown in Figure 5. Only the results from months with measured or simulated surface runoff exceeding 1 mm are shown in the figure. The results indicated that there is a tendency toward the model overestimating the surface runoff and underestimating the pipe drainage in November and December. Further, there is an underestimation of pipe drainage in May, probably because of a delay in drainage, which stems from the underestimation of the surface runoff in April. Jansson & Gustafson (1987) also found that

the simulated pipe discharge was delayed in comparison with the measurements, especially during the spring period.

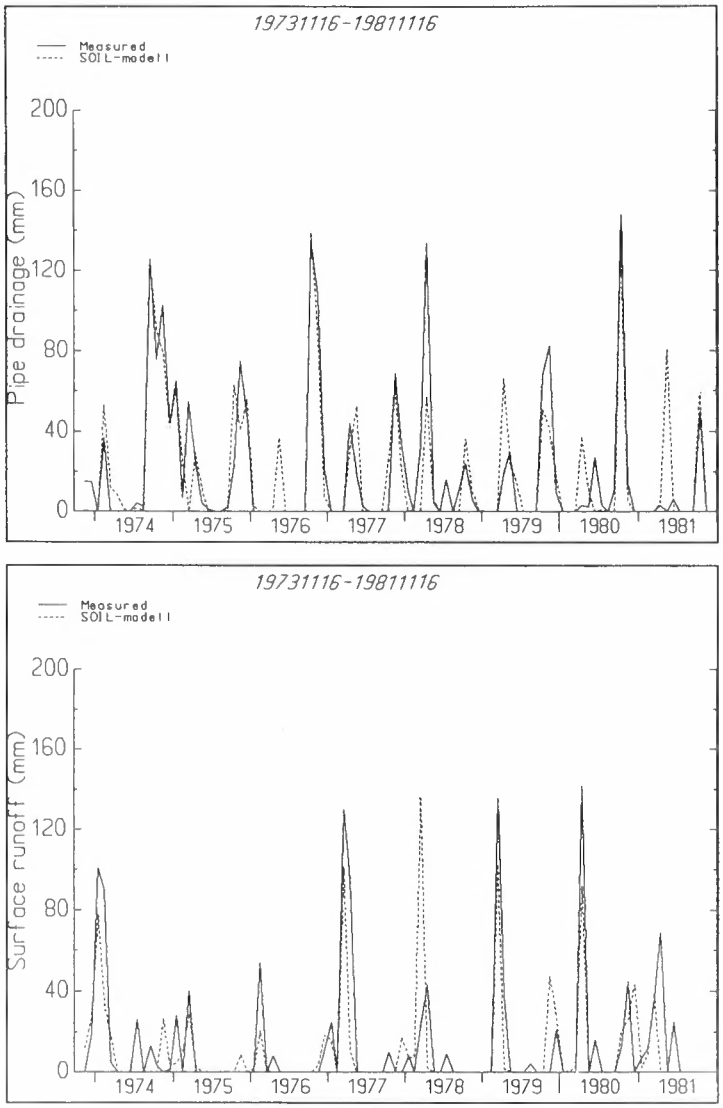
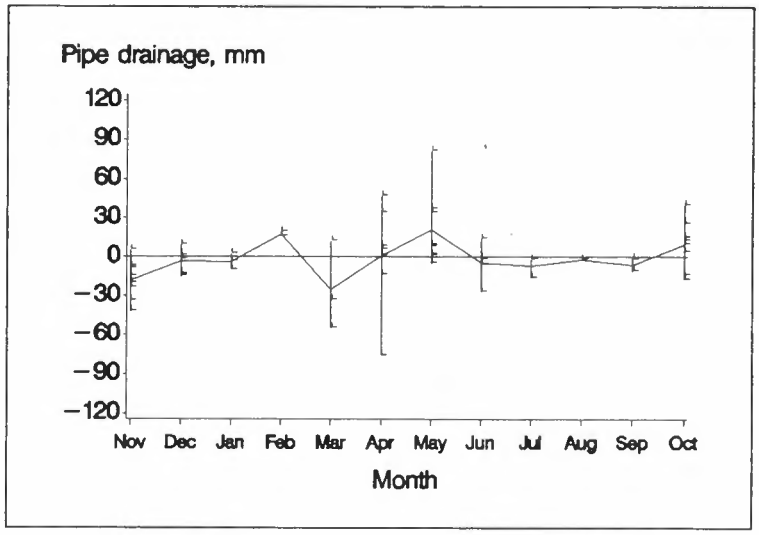


Figure 4. Monthly values of measured and simulated pipe drainage and surface runoff, 1 November 1973 - 1 November 1981

During the main growing season, May-August, the model clearly underestimates the surface runoff. In this period surface runoff is measured at five months for the years 1974-81, totalling 80 mm. Using the daily precipitation figures as input data, one should not expect to simulate surface runoff during the growing season. Hourly precipitation values might have improved the results. When using the simulated drainage data in connection with leaching studies, one should be aware of this feature.



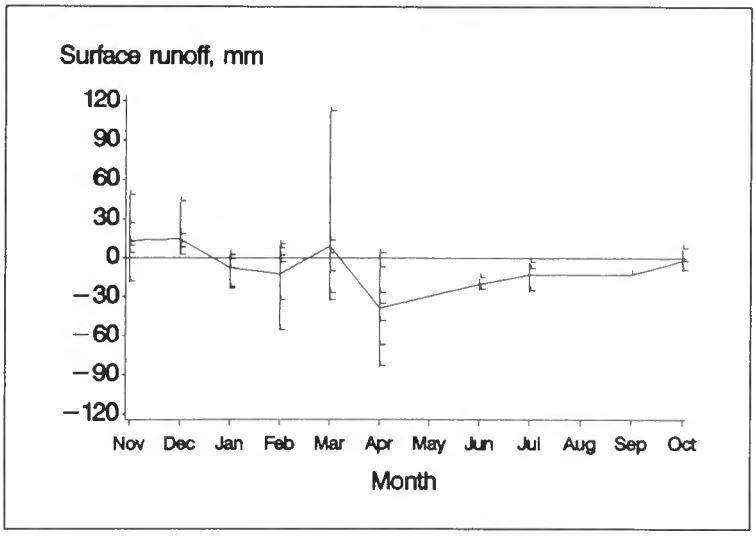


Figure 5. Monthly differences between simulated and measured pipe drainage and surface runoff, 1973-81. Only months with measured or simulated values above 1 mm are shown. Negative values show underestimation by the model

DISCUSSION

A general sensitivity analysis of the model has not been carried out. Although it has been stated by Jansson & Halldin (1980) that it is not meaningful to discuss generally the sensitivity of the model to variations in parameter values, some information about the sensitivity of the most important parameters would clearly increase the quantitative understanding of many soil physical processes. This is often one of the difficulties in using models. Since we had to estimate many of the parameters in the model, we made some simulations with different settings of parameters we assumed were important in estimating the runoff components.

Effect of hydraulic conductivity and surface water storage capacity on the simulation results

The model uses two different parameters for saturated hydraulic conductivity, one including macropores, ksat, and one excluding macropores, kmat (Jansson 1990a). Since measurements of the latter type of conductivity were not available, and in order to evaluate the influence of this conductivity, we therefore increased it by a factor of 10 in a new run of the model (Table 2 - simulation 3).

Table 2. Measured (mm) and simulated runoff (%) with different parameter settings. Period 1 November 1973 - 1 November 1981

Runoff component	Measured (mm)	Percent of measured					
		1[1]	2	3	4	5	6
Pipe drainage	1867	98	108	123	112	100	96
Surface runoff	1308	79	94	50	64	73	83
Total runoff	3175	90	102	92	92	89	91

[1] = number of simulation
Simulation 1: Main simulation: Kmat = 1/100 of Ksat, SURDEL = 1.0, PSLIM = -2°C, SMRIS = 1.5E-7 kg/j

Changes with respect to simulation 1:
Simulation 2: Precipitation corrected for aerodynamic error (rainfall +7% and snowfall +14%)
Simulation 3: Kmat = 1/10 of Ksat
Simulation 4: SURDEL = 0.1
Simulation 5: PSLIM = 0°C
Simulation 6: PSLIM = 0°C and SMRIS = 0

SURDEL: first order rate coefficient for calculation of surface runoff from the surface pool
PSLIM: snow temperature threshold
SMRIS: global radiation coefficient in snowmelt function

Another factor that could be important is the fate of the surface pool of water especially in connection with snowmelt. In the model this is described as a first-order rate process, and the rate coefficient (SURDEL) has to be estimated. In the main model simulation we set this parameter to 1.0, which means that most of the water in the surface pool escapes as surface runoff. This was also the experience from observations in the field lysimeters. But to evaluate the influence of this parameter it was decreased by a factor of 10 in a new simulation for the whole period (Table 2 - simulation 4).

The results of the two different settings are shown as the totals for the 8-year period together with measured values and the results from the main run of the model, Table 2. Both the increase in kmat and the decrease in the first-order rate coefficients led to an increased part of the runoff as pipe drainage, 23% and 12% respectively. The surface runoff decreased by the same magnitude, so the change in the total runoff was small compared with the main simulation. This clearly shows the importance of reliable estimation of the unsaturated hydraulic conductivity for the partitioning between surface runoff and pipe drainage.

The snow conditions

The SOIL-model estimates the amount of the precipitation as snow as a function of the daily mean air temperature. If the prescribed settings are used then precipitation is treated as rainfall when the air temperature exceeds +2°C, and as snow when the air temperature is below -2°C. For further information see Jansson (1990a). The snowmelt function in the model includes three parts: air temperature, global radiation and the soil heat flux. The simulation of snow depth and the snowmelt function from the prescribed values, showed a clear tendency to lower snow depth and earlier snowmelt than the measurements from the meteorological station at Ås. An example for the months January-April 1978 is given in Figure 6. There was an indication that the threshold limit for snowfall (PSLIM) equal to -2°C for daily means of air temperature may be too low, especially during the spring period. To evaluate the influence of this parameter on the snow conditions the threshold limit was set to 0°C (Figure 6 - simulation B, Table 2 -

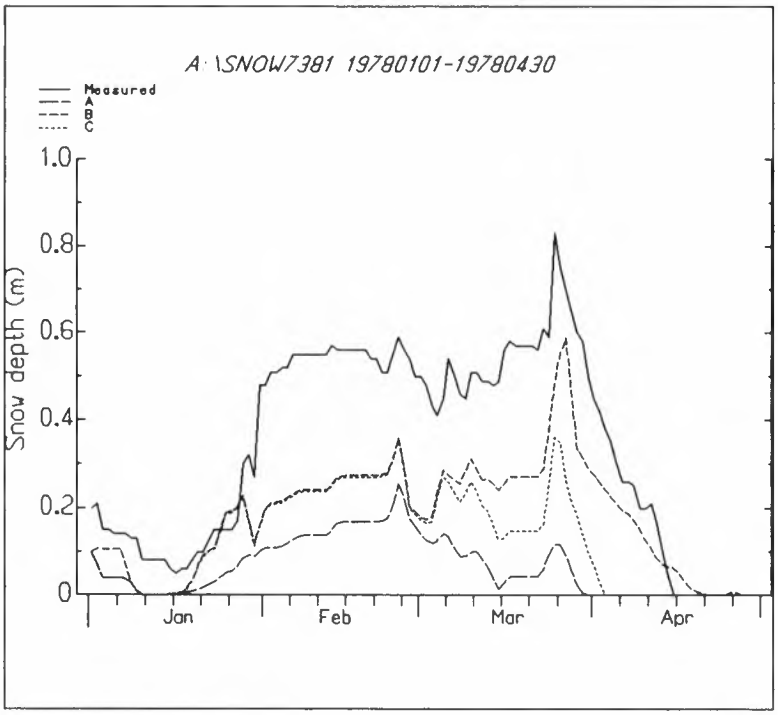


Figure 6. Measured and simulated snow depth with different parameter settings. A: Prescribed values from the Soil-model user's manual. B: Snow limit for precipitation = 0°C, and global radiation part of the snowmelt function set equal to zero (as simulation 6 in Table 2). C: Snow limit for precipitation = 0°C. Otherwise as A (as simulation 5 in Table 2)

simulation 5). With the same setting of the temperature, the global radiation component (SMRIS) of the snowmelt function was set to zero (Figure 6 - simulation C, Table 2 - simulation 6). Then the temperature coefficient in the snowmelt function will be the traditonal day-degree coefficient commonly used in snowmelt modelling (Jansson 1990b). One should be aware that some of the differences in estimated and measured snow depth could be due to factors such as snow drift, etc. Although the changed parameter settings clearly influenced the snow depth and time of snowmelt, they had only a minor influence on the runoff components (Table 2). The difficulties in estimating the

snowmelt rate were also found by Thunholm (1990). He showed that the variations between measured and simulated soil temperature reached maximum in May, and this was partly a result of difficulties in predicting the snowmelt rate. Results from the field lysimeters in spring 1978 also clearly showed that the frost in the surface layer influenced the amount of surface runoff. In the spring of 1978 runoff from four plots was measured, two of the plots had a surface runoff of about 35 mm, while the other two plots had a runoff of 135 mm. The total runoff from the four plots was almost the same, within 15 mm. The measured differences in surface runoff were found within a distance of about 10 m thus indicating that these processes will also be difficult to describe with a model.

Spatial variation

A deterministic model such as the SOIL-model presumes that a system or process operates such that the occurrence of a given set of events leads to an uniquely definable outcome (Addiscott & Wagenet 1985). Every real system must be considered subject to uncertainties of some kind, but these are ignored in the formulation of a deterministic model. Such a model can therefore only simulate the system's response to a single set of assumed conditions, and whether its predictions are of practical use must therefore depend on the nature and the extent of the variability within the system. Knowledge of the spatial variation of the different parameters and of the boundary conditions is of the highest interest if we are to use the model for non-homogeneous sites.

It is well known that flow parameters, such as the saturated hydraulic conductivity, often have a coefficient of variation of 100% or more (Warrick & Nielsen 1980). A sensitivity analysis (Table 2 - simulation 3) demonstrated that a tenfold increase in the unsaturated conductivity increased the pipe drainage by 25% and decreased the surface runoff by 63%. This clearly shows the importance of a reliable estimate of the hydraulic conductivity (kmat). Other important parameters would be the snow conditions and other factors affecting the soil temperature. So information about the spatial variations of different model parameters will be of importance in the evaluation of the model output. A validation of the model would require not only an independent technique for estimating an area mean value but also a distribution function for the spatial variability.

CONCLUSIONS

The results of the model simulation were compared with measured runoff from small plots, and therefore conclusions with respect to the usefulnes for larger areas (watersheds) could not be directly drawn from this material. The model gave a good estimate of the runoff components averaged over the 8-year period, 1973-81. The yearly minimum and maximum values were also predicted within acceptable limits. But for shorter periods, months or days, the models partitioning between surface runoff and pipe drainage, showed greater deviation from the measurement. This occurs especially during the main growing season and during the snowmelt period. For the growing season the main reason was thought to be the low temporal resolution of input used. Hourly values of precipitation might have improved the results but would also have slowed down the simulation. The different simulations indicated the importance of reliable and independent estimates of the hydraulic conductivity, the fate of the water on the surface du-

ring the snowmelt period and the snowmelt function. However, despite the lack of information about these conditions, the model seems to be useful in evaluating the different runoff components for Norwegian conditions. Before a more solid conclusion can be drawn the model will have to undergo further evaluation. Preferably this type of evaluation would represent experimental studies where as many properties as possible are measured by independent methods. Different soil types and plot sizes/areas are also of interest.

REFERENCES

Addiscott, T.M. & R.J. Wagenet 1985. Concepts of solute leaching in soils: A review of modelling approaches. Journal of Soil Science 36: 411-424.

Aslyng, H.C. & S. Hansen 1982. Water balance and crop production simulation. Report from Hydrotechnical Laboratory, the Royal Veterinary and Agricultural University. 200 pp.

Brooks, R.H. & A.T. Corey 1964. Hydraulic properties of porous media. Hydrology Paper No. 3, Colorado State University, Fort Collins, Colorado, 27 pp.

FAO 1977. Guidelines for soil profile description (second edition). Food and Agriculture Organization of the United Nations, Rome, 66 pp.

Hansen, V. 1985. Barley transpiration and soil water status. Acta Agric Scand 35: 99-111.

Jansson, P.E. 1990a. SOIL water and heat model. Technical description. Department of Soil Sciences, Uppsala, Sweden. 41 pp. .

Jansson, P.E. 1990b. SOIL model. User's manual. Department of Soil Sciences, Uppsala, Sweden. 30 pp.

Jansson, P.E. & A. Gustafson 1987. Simulation of surface runoff and pipe discharge from an agricultural soil in northern Sweden. Nordic Hydrology 18: 151-166.

Jansson, P.E. & S. Halldin 1980. Soil water and heat model. Technical description. Technical Report 26 1980. Swedish Coniferous Forest Project. Dept. of Ecology and Environmental Research. Swedish University of Agricultural Sciences, Uppsala, Sweden. 81 pp.

Kersten, M.S. 1949. Thermal properties of soils. University of Minnesota, Inst. of Technology Engineering, Exp. Station, Bull. No. 28, Minneapolis, 226 pp.

Marti, M. 1984. Kontinuierlicher getreidebau ohne pflug im südosten Norwegens - Wirkung auf ertrag, physikalische und chemische bodenparameter. Dr. scient abhandlung.

Department of Soil Fertility and Management, Agricultural University of Norway, Ås. 155 pp.

Monteith, J.L. 1965. Evaporation and environment. In: Fogg, G.E. (ed.). The State and Movement of Water in Living Organisms, 19th Symp. Soc. Exp. Biol., 205-234.

Mualem, Y. 1976. A new model for predicting the hydraulic conductivity of unsaturated porous media. Water Resour. Res. 12: 513- 522.

Thunholm, B. 1990. Temperature and freezing in agricultural soils as related to soil properties and boundary conditions. Ph. D. thesis. Swedish University of Agricultural Sciences, Department of Soil Sciences. Reports and Dissertations: 7, 26 pp.

Uhlen, G. 1978. Nutrient leaching and surface runoff in field lysimeters on a cultivated soil. Runoff measurements, water composition and nutrient balances. Meld. Norg. Landbr. Høgsk. 57 (27): 1-26.

Uhlen, G. 1989. Nutrient leaching and surface runoff in field lysimeters on a cultivated soil. Nutrient balances 1974-81. Norwegian Journal of Agricultural Sciencies 3: 33-46.

Warrick, A.W. & Nielsen, D.R. 1980. Spatial variability of soil physical properties in the field. In: Hillel, D. Applications of soil physics. Academic Press. 319-355.

A study of extraction methods for assessing soil zinc availability: II. Estimation of the relationship between soil zinc quantity and intensity

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Wu, X. & I. Aasen 1992. A study of extraction methods for assessing soil zinc availability: II. Estimation of the relationship between soil zinc quantity and intensity. Norwegian Journal of Agricultural Sciences 6: 73-84. ISSN 0801-5341.

The functional relationship between soil zinc quantity (Q), soil zinc intensity (I), soil pH, soil titratable alkalinity (TA) and soil exchangeable base cation concentration (BC) was studied using non-calcareous soil samples collected from 109 barley fields in southeastern Norway. The basic Q-I relationship was found to be non-linear and can be better described by either the Freundlich isotherm or the Langmuir isotherm. The inclusion of soil pH, TA and BC greatly improved the correlation between soil zinc Q and I. The present results support the argument that the soil zinc quantity-intensity relationship is subject to the interactions between the soil alkalinity quantity factor, TA, the soil alkalinity intensity factor, pH, and the soil alkalinity buffering capacity factor, BC.

Key words: Buffering capacity, intensity, quantity, non-calcareous soils, zinc.

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The uptake of a nutrient depends not only on its intensity (I) (solution concentration or activity) but also on its quantity (Q) (the labile pool) in the soil. Earlier studies on the Q-I relationship were mainly concentrated on macronutrients such as potassium (Addiscott 1970; Beckett 1964; LeRoux & Sumner 1968), nitrogen (Pasricha 1976; Pasricha & Singh 1977), phosphorus (Barrow 1967; Salmon 1966) and magnesium (Alston 1972). More recently, researchers started to pay attention to soil micronutrients including soil zinc (Maskina et al. 1980; Mengel 1982; Prabhakaran Nair et al. 1984).

For a nutrient in a given soil or soils with similar properties, soil zinc quantity (Q) and soil zinc intensity (I) are directly correlated with each other and the buffering capacity (B), generally defined as dQ/dI, can thus be easily determined at a given Q and I. For soils with significant variation in their properties, however, the Q-I relationship will be subject to this variation and B will then become a function of the related soil properties. Pasricha et al. (1987) showed in their study that the slopes of Q-I curves varied with soil type with a general tendency to increase with increasing soil pH. In various studies several soil factors, e.g., soil exchangeable base cation concentration (BC), soil

organic matter and soil texture, were found to affect soil zinc adsorption, selective distribution, self-diffusity, solubility and extractability (Anderson & Christensen 1988; Clarke & Graham 1968; McBride & Blasiak 1979; Havlin & Soltanpour 1984; Gupta et al. 1987; Metha et al. 1984; Rattan & Deb 1981; Shukla et al. 1980). All these soil variables are expected to play certain roles, either directly or indirectly, in determining the Q-I relation of zinc in the soil.

Normally, it is more practical to use one extraction method to predict the nutrient availability than to use two or more methods. On the other hand, a good extraction method should be applicable for at least a population of soil samples. Thus to estimate the Q-I relationship for a group of soils with a relatively large number of sample sizes and great variation in soil properties may be of value for at least the area represented by the soil samples.

MATERIALS AND METHODS

The collection, preparation and determination of 109 soil samples from barley fields in southeastern Norway has been described by Wu et al. (1991). A brief description of the relevant analyses is given below:

0.5 M $Mg(NO_3)_2$ (Solbraa & Selmer-Olsen 1981) was used to extract the water soluble plus readily exchangeable zinc from the soil. The zinc concentration determined by this method is denoted as ZnM and regarded I.

For the determination of Q, three methods, DTPA-$CaCl_2$-TEA (Lindsay & Norvell 1978), Ammonium acetate-EDTA (AA-EDTA) (Levesque & Mathur 1988) and HCl (Ellis et al. 1964), were used and compared. The respective quantity factors are denoted as ZnD for DTPA, ZnA for AA-EDTA and ZnH for HCl. The analysis of soil extractable zinc was carried out using atomic absorption spectrophotometry.

A 1:2 soil-water volume ratio was used for determining soil pH on a pH meter. Soil titratable alkalinity (TA) was obtained using a procedure given by Nelson et al. (1959). The soil cation exchange capacity (CEC) was determined using the ammonium acetate (pH 7.0) method. All soil characteristics are given on a dry matter volume basis.

The linear scatter plotting was made using the HG (Harvard Graphics) program and the multiple regression analyses were carried out using the stepwise procedure from the SAS (Statistical Analysis System) program on an IBM computer. It is known that the sample coefficient of determination, R^2, always has a positive bias as an estimator of the population parameter, ρ^2, and that this bias can be quite severe when ρ is large or moderate. Helland (1987) proposed an approximate confidence interval for ρ^2 and found that the adjusted R^2 is always inside the two-sided confidence interval. Thus, in addition to the scatter plotting, the adjusted R^2 is used to indicate the fraction of the variation explained by the regression equations.

RESULTS

The following three regression models have been tested for describing the soil zinc quantity-intensity relationship:

linear model	$Q = a_0 + a_1 I$	(1)
reciprocal model	$1/Q = b_0 + b_1/I$	(2)
logarithmic model	$\log Q = c_0 + c_1 \log I$	(3)

Equations 2 and 3 are analogous to, respectively, the Langmuir isotherm and the Freundlich isotherm, both of which have been frequently used for describing soil metal adsorption under equilibrium conditions (Kuo & Mikkelsen 1979; Kurdi & Doner 1983; Shukla & Mittal 1979; Shuman 1975, 1988; Zasoski & Burau 1988). The results of regression analyses (Table 1) indicate that the Q-I relationship can be better described by the reciprocal model and the logarithmic model.

Extractant		DTPA	AA-EDTA	HCl
$Mg(NO_3)_2$	Linear model	0.63	0.58	0.62
	Reciprocal model	0.72	0.69	0.64
	Logarithmic model	0.79	0.74	0.68

Table 1. Coefficient (r) of correlation between soil zinc quantity and intensity factors (n = 109)

Inclusion of either soil pH, TA or BC significantly improves the soil zinc Q-I correlation (Table 2). The magnitude of the correlation coefficent for different regression models (Table 2) follows the order: D > C > B > A.

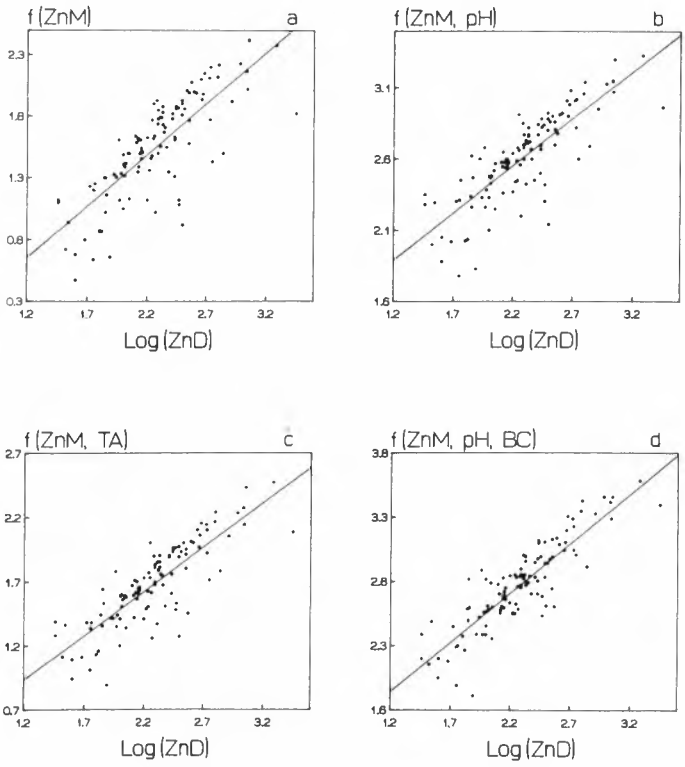

Figure 1. ZnD-ZnM relationship affected by soil pH, titratable alkalinity (TA, m.e. l^{-1}) and exchangeable base cation concentration (BC, m.e. l^{-1}). ZnD: DTPA-extractable soil zinc (mg l^{-1}). ZnM: $Mg(NO_3)_2$-extractable soil zinc (mg l^{-1}). Functions f(ZnM, pH), f(ZnM, TA) and f(ZnM, pH, BC) represent the determined regression equations given in Table 2

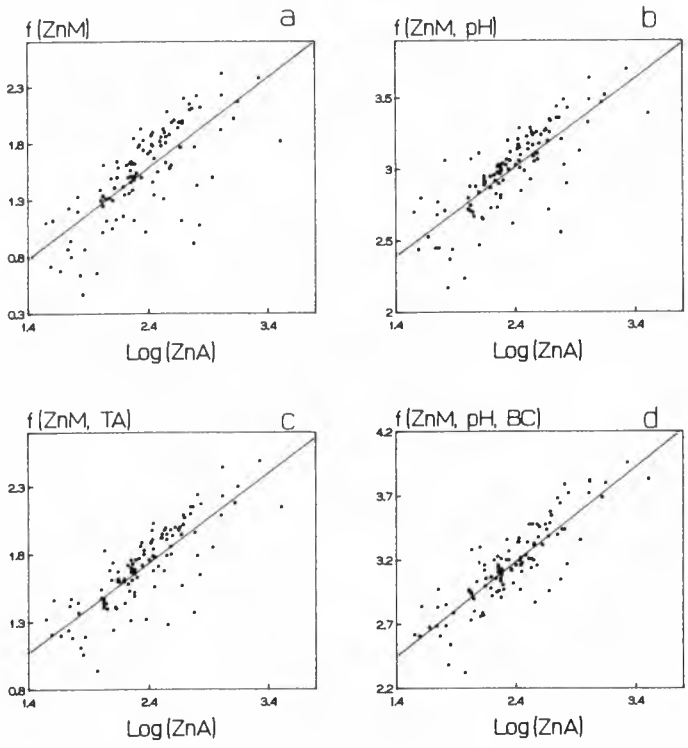

Figure 2. ZnA-ZnM relationship affected by soil pH, titratable alkalinity (TA, m.e. l^{-1}) and exchangeable base cation concentration (BC, m.e. l^{-1}). ZnA: AA-EDTA-extractable soil zinc (mg l^{-1}). ZnM: $Mg(NO_3)_2$-extractable soil zinc (mg l^{-1}). Functions f(ZnM, pH), f(ZnM, TA) and f(ZnM, pH, BC) represent the determined regression equations given in Table 2

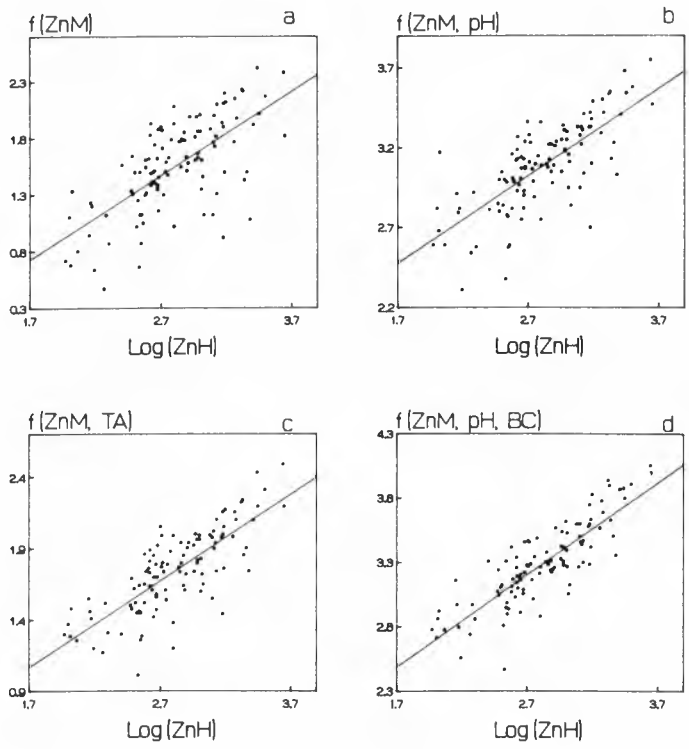

Figure 3. ZnH-ZnM relationship affected by soil pH, titratable alkalinity (TA, m.e. l^{-1}) and exchangeable base cation concentration (BC, m.e. l^{-1}). ZnH: HCl-extractable soil zinc (mg l^{-1}). ZnM: $Mg(NO_3)_2$-extractable soil zinc (mg l^{-1}). Functions f(ZnM, pH), f(ZnM, TA) and f(ZnM, pH, BC) represent the determined regression equations given in Table 2

The effects of soil pH, TA, and BC, are also illustrated in Figs. 1, 2 and 3 for different extraction methods. The results indicate that for the samples used, the inclusion of soil pH is not sufficient in explaining the variations, and the effect of BC has to be taken into consideration for a better estimation.

The effects of CEC, organic carbon content (C%) and clay content (clay%) were also tested in the stepwise factor selection processes. The entry of these three factors into the regression models was not accepted when the exchangeable base cation concentration (BC) was included.

In corresponding regression equations, the highest R value was always obtained when the Q factor was represented by the DTPA-extractable zinc content (ZnD). This is due to the fact that log(ZnD) is more closely related to log(ZnM) than are log(ZnA) and log(ZnH). The inclusion of TA and BC became more critical when the HCl method was used to represent the soil zinc quantity. After taking pH and BC into consideration, the R value was found to be 0.876 for DTPA, 0.858 for AA-EDTA and 0.846 for HCl (Table 2). The differences between these three R values are not significant, suggesting that both HCl and AA-EDTA are also suitable methods for estimating the soil zinc quantity provided that additional soil factors can be properly considered for interpretation of the results.

Table 2. The determined regression equations and correlation coefficients (R) for the soil zinc quantity-intensity-buffering capacity relationship

Regression model		R	R^2adj^b
A) log ZnD[a]	= 0.607 + 0.742 log ZnM	0.787	0.613
B) log ZnD	= -0.331 + 0.866 log ZnM + 0.156 pH	0.812	0.653
C) log ZnD	= 0.596 + 0.883 log ZnM + 0.363 log TA	0.832	0.683
D) log ZnD	= -0.498 + 0.884 log ZnM + 0.039 pH + 0.752 log BC	0.876	0.760
A) log ZnA	= 0.664 + 0.678 log ZnM	0.736	0.540
B) log ZnA	= -0.631 + 0.848 log ZnM + 0.220 pH	0.788	0.614
C) log ZnA	= 0.650 + 0.858 log ZnM + 0.463 log TA	0.813	0.655
D) log ZnA	= -0.780 + 0.866 log ZnM + 0.098 pH + 0.757 log BC	0.858	0.728
A) log ZnH	= 1.081 + 0.614 log ZnM	0.675	0.451
B) log ZnH	= -0.277 + 0.793 log ZnM + 0.226 pH	0.739	0.537
C) log ZnH	= 1.066 + 0.813 log ZnM + 0.512 log TA	0.778	0.601
D) log ZnH	= -0.480 + 0.814 log ZnM + 0.844 pH + 0.913 log BC	0.846	0.708

a: ZnD = DTPA-extractable zinc (mg l^{-1})
ZnA = AA-EDTA-extractable zinc (mg l^{-1})
ZnH = HCl-extractable zinc (mg l^{-1})
ZnM = $Mg(NO_3)_2$-extractable zinc (mg l^{-1})
TA = titratable alkalinity (m.e. 100 ml^{-1})
BC = exchangeable base cation concentration (m.e. 100 ml^{-1})

b: R^2adj = the ajusted R^2

DISCUSSION

The basic Q-I relationship

In general, the soil metal Q-I relationship is non-linear. The adsorption of ions by soil colloids is subject to the availability of adsorption sites and the density of solid surface charges or some other attraction forces, namely, the binding energy. Thus, the adsorption process has a limitation factor, namely, the adsorption potential which is related to the nature of the concerned adsorbent. If using Y to denote the ion adsorption, C to denote the ion concentration in the relevant solution and X to denote the potential factor, under steady state, it can be assumed that Y is related to C and X by,

$$Y = aCX \tag{4}$$

where a is a proportional factor. The potential factor, X, is a variable related to the adsorption maximum, Ym, and the amount of ion adsorbed, Y, at a given time for different adsorbent types. Theoretically, X increases with increasing Ym and decreases with increasing Y with the following boundary conditions:

$$\begin{aligned} &Y = 0, \quad X = Xm; \\ &Y = Ym, \quad X = 0 \end{aligned} \tag{5}$$

Assuming that

$$X = B(Ym - Y) \tag{6}$$

on substitution and rearrangement,

$$\begin{aligned} Y &= aCX = ab(Ym-Y)C \\ &= YmC/(K + C) \end{aligned} \tag{7}$$

Equation 7 is essentially a type of the Langmuir relation. However, if ignoring the boundary conditions given in Equation 5 and assuming that X is inversely related to Y by

$$\begin{aligned} &X = bYm/(Y)n\text{-}1 \\ &n > 1 \end{aligned} \tag{8}$$

then, on substitution, it yields the form of Freundlich isotherm,

$$\begin{aligned} Y &= aCX = aCbYm/(Y)n\text{-}1 \\ &= KC1/n \end{aligned} \tag{9}$$

In Equation 9, Y does not approach an upper limit as C increases because Equation 8 does not satisfy the boundary conditions given by Equation 5. Thus the definition of Ym is obscured in Equation 9. Equations 7 and 9 define two different but very simple relationships between X and Y. This may explain why the Langmuir and the Freundlich isotherms are not always applicable to metal adsorption under different soil conditions.

The effect of soil pH and base cation concentration (BC)

Considering that the transformation of soil zinc from reserve forms in labile solid phase to soluble forms in soil solution is subject to soil alkalinity condtions, the following reaction may be applied for soil zinc,

$$(\text{labile-Zn}) + n(H^+) \rightleftharpoons m(\text{soluble-Zn})^{(n/m)+} + sX \qquad (R\text{-}1)$$

where n, m and s are reaction coefficients and X denotes the available sites for zinc adsorption. Under steady state, the reaction constant is given as

$$K = \frac{(\text{soluble-Zn})^m X^s}{(\text{labile-Zn})(H^+)^n} = \frac{I^m X^s}{Q(H^+)^n} \qquad (10)$$

Thus,

$$Q = K_I I^m 10^{npH} X^s \qquad (11)$$

where $K_I = 1/K$, and $npH = -\log(H^+)^n$. Taking the logarithms of Equation 11 gives

$$\log Q = \log K_I + m\log I + npH + s\log X \qquad (12)$$

If BC, the exchangeable base cation concentration, is used as an estimator of X, Equation 12 becomes

$$\log Q = \log K_I + m\log I + npH + s\log BC \qquad (13)$$

which has exactly the same form as Model D in Table 2.

The positive effect of pH on zinc adsorption may be mainly attributed to two mechanisms: (1) direct involvement of hydrogen ions in cation exchange processes and (2) precipitation. In practice, however, it is difficult to distinguish between adsorption and precipitation.

The second important factor affecting zinc adsorption is the adsorption capacity of the adsorbent, which is actually the adsorption maximum, Ym, defined by Equation 5. Generally, the Ym factor, as a component of X defined by Equation 4 as well as by Reaction 1, remains constant for a given soil but varies with soil types. Thus, when dealing with different soils, the variation in zinc adsorption cannot be simply explained by the pH effect. For a given pH value, it was observed that the adsorption increased with increase in the fineness of the soil texture and the levels of soil organic matter (Shukla & Mittal 1979; Elrashidi & O'Connor 1982; Shuman 1988; Zunino et al. 1979). A logical reason for this is that fine-textured soil and high levels of organic matter have high cation exchange capacity (CEC). Reports concerning the CEC effect, however, are not always consistent. Harter (1983) found it almost impossible to use CEC in explaining zinc retention differences between soils. Although any one soil at a given pH did exhibit some relationship to sorption and CEC in that horizon with the highest CEC usually

had a higher sorption, the relationship could not be quantified. Similar results were also reported by Kurdi & Doner (1983).

As has been discussed by Wu et al. (1991), the inconsistency of the CEC effect could possibly be a result of the counteraction between the exchangeable acidity (EA) and the base cation saturation (BS). Zinc adsorption may not be high in soils with a high CEC, depending on how high the levels of EA or BC are. Generally, for a given CEC, zinc adsorption will decrease with increasing EA, which is equivalent to saying, zinc adsorption will increase with increasing BC. It follows that in soils with different CEC levels, when the EA effect is accounted for by soil pH, zinc adsorption will also be positively related to BC at a higher degree of significance than CEC. This explains why in the stepwise factor selection processes, BC, has a higher priority in entering the equation over CEC, C% and clay%. The results from the present study indicate that BC is a good estimator of the adsorption capacity factor.

The effect of titratable alkalinity (TA)

As opposed to soil pH, which measures the hydrogen activity of soil solution, TA is a quantity factor and it measures not only the intensity but also the buffering capacity of soil alkalinity. The soil titratable alkalinity is obtained by titrating a soil solution with HCl to a certain pH value (pH 5). The substances that react with the added H^+ should mostly be the exchangeable (more appropriately, titratable) bases. Thus, the following reaction can be assumed for the titration process,

$$a(\text{base}) + b\,H^+ \rightleftharpoons c(\text{base cation})^{(b/c)+} + d\,H_2O \qquad \text{(R-2)}$$

Since soil is a buffer system, the above reaction may reach equilibrium with the constant

$$K^* = \frac{(\text{base cation})^c}{(\text{base})^a\,(H^+)^b} \qquad (14)$$

If we compare the definition of TA and BC, respectively, to the terms (base) and (base cation) in Equation 14, it can be seen that TA is approximately proportional to (base) and BC to (base cation). Thus,

$$K^* = \frac{(BC)^c}{(TA)^a(H^+)^b} \qquad (15)$$

Equation 15 has the following logarithmic form,

$$\log(TA) = b_0 + b_1 pH + b_2 \log(BC) \qquad (16)$$

which shows that BC is related to soil alkalinity as a buffering capacity factor. Results in Table 3 and Fig. 4 show that Equation 16 is a proper approximation for the samples used.

Regression model	R	R^2adj*
log TA[a] = -2.8846 + 0.4871 pH	0.8628	0.7420
log TA = -2.9000 + 0.3888 pH + 0.5206 log BC	0.9143	0.8328

*: R^2adj = the adjusted R^2
a: TA and BC given as m.e. 100 ml^{-1} of dry soil

Table 3. Regression coefficients and correlation coefficients (R) for the relationship between soil titratable alkalinity (TA), pH and exchangeable base cation concentration (BC)

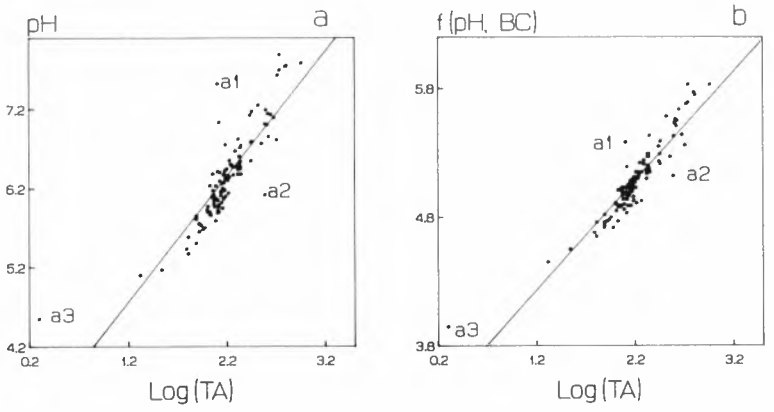

Figure 4. Relationship between soil titratable alkalinity (TA, m.e. l^{-1}), pH and exchangeable base cation concentration (BC, m.e. l^{-1}). Function f(pH, BC) represents the determined regression equation in Table 3. Points a_1, a_2 and a_3 denote three outliers

Three typical outliers marked as a_1, a_2 and a_3 can be seen in Fig. 4. The first outlier, a_1, represents a sandy soil which has a higher pH but a lower BC, thus giving a lower TA. On the other hand, the loamy soil sample, a_2, has a lower pH but a higher BC, thus resulting in a higher TA. The third outlier, a_3, represents a loamy soil with extremely low pH, TA and BC.

From Fig. 4b it can be seen that the three outliers draw much closer to the regression lines when the BC effect is considered. Since TA includes both pH and BC effects, Model C (Table 2) is expected to give a higher R value than Model B and a lower R value than Model D.

REFERENCES

Addiscott, T.M. 1970. The potassium Q/I relationships of soils given different K manuring. J. Agric. Sci. Camb. 74: 131-137.

Alston, A.M. 1972. Availability of manganese in soils. J. Agric. Sci. Camb. 79: 197-204.

Anderson, P.R. & T.H. Christensen 1988. Distribution coefficients of Cd, Co, Ni and Zn in soils. J. Soil Sci. 39: 15-22.

Barrow, N.J. 1967. Relationship between uptake of phosphorus by plants and the phosphorus potential and buffering capacity of the soil - an attempt to test Schofield's hypothesis. Soil Sci. 104: 99-106.

Beckett, P.H.T. 1964. Studies on soil potassium. I. Confirmation of ratio law: Measurement of potassium potential. J. Soil Sci. 15: 1-8.

Clarke, A.L. & E.R. Graham 1968. Zinc diffusion and distribution coefficients in soil as affected by soil texture, zinc concentration and pH. Soil Sci. 105: 409-418.

Ellis, R. Jr., J.F. Davis & D.L. Thurlow 1964. Zincavailability in calcareous Michigan soils as influenced by phosphorus level and temperature. Soil Sci. Soc. Am. Proc. 28: 83-86.

Elrashidi, M.A. & G.A. O'Connor 1982. Influence of solution composition on sorption of zinc by soils. Soil Sci. Soc. Am. J. 46: 1153-1158.

Gupta, R.K., S. Van Den Elshout & I.P. Abrol 1987. Effect of pH on zinc adsorption-precipitation reactions in an alkali soil. Soil Sci. 143: 198-204.

Harter, R.D. 1983. Effect of soil pH on adsorption of lead, copper, zinc and nickel. Soil Sci. Soc. Am. J. 47: 47-51.

Havlin, J.L. & P.N. Soltanpour 1984. Changes in NH_4HCO_3-DTPA- extractable zinc and iron as affected by various soil properties. Soil Sci. 137: 188-193.

Helland, I.S. 1987. On the interpretation and use of R^2 in regression analysis. Biometrics 43: 61-69.

Kuo, S. & D.S. Mikkelsen 1979. Zinc adsorption by two alkaline soils. Soil Sci. 128: 274-279.

Kurdi, F. & H.E. Doner 1983. Zinc and copper sorption and interaction in soils. Soil Sci. Soc. Am. J. 47: 873-876.

LeRoux, J. & M.E. Sumner 1968. Labile potassium in soils: I. Factors affecting the quantity-intensity (Q/I) parameters. Soil Sci. 106: 35-41.

Levesque, M. & S.P. Mathur 1988. Soil tests for copper, iron, manganese and zinc in Histosols: 3. A comparison of eight extractants for measuring active and reserve forms of the elements. Soil Sci. 145: 215-221.

Lindsay, W.L. & W.A. Norvell 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. Soil Sci. Soc. Am. J. 42: 421-428.

Maskina, M.S., N.S. Randhawa & M.K. Sinha 1980. Relation of growth and zinc uptake of rice to quantity, intensity and buffering capacity factors of zinc in soil. Plant and Soil 54: 195-205.

McBride, M.B. & J.J. Blasiak 1979. Zinc and copper solubility as function of pH in an acid soil. Soil Sci. Soc. Am. J. 43: 866-870.

Mehta, S.C., S.R. Poonia & R. Pal 1984. Adsorption and immobilization of zinc in calcium- and sodium-saturated soils from a semiarid region, India. Soil Sci. 137: 108-114.

Mengel, K. 1982. Factors of plant nutrient availability relevant to soil testing. Plant and Soil 64: 129-138.

Nelson, J.L., L.C. Boawn & F.G. Viets Jr. 1959. A method for assessing zinc status of soils using acid-extractable zinc and «titratable alkalinity» values. Soil Sci. 88: 275-283.

Pasricha, N.S. 1976. Exchange equilibria of ammonium in some paddy soils. Soil Sci. 121: 267-271.

Pasricha, N.S. & T. Singh 1977. Ammonium exchange equilibria in the submerged soils and forms of ammonium which are not water-soluble but are available to lowland paddy. Soil Sci. 124: 90-94.

Pasricha, N.S., H.S. Baddesha, M.S. Aulakh & V.K. Nayyar 1987. The zinc quantity-intensity relationships in four different soils as influenced by phosphorus. Soil Sci. 143: 1-4.

Prabhakaran Nair, K.P., N. Ram & P.K. Sharma 1984. Quantitative relationship between zinc transport and plant uptake. Plant and soil 81: 217-220.

Rattan, R.K. & D.L. Deb 1981. Self-diffusion of zinc and iron in soils as affected by pH, $CaCO_3$, moisture, carrier and phosphorus levels. Plant and Soil 63: 377-393.

Salmon, R.C. 1966. Relations between intensity level and quantity of phosphate and its availability. Soil Sci. 101: 450-454.

Shukla, U.C. & S.B. Mittal 1979. Characterization of zinc adsorption in some soils of India. Soil Sci. Soc. Am. J. 43: 905-908.

Shukla, U.C., S.B. Mittal & R.K. Gupta 1980. Zinc adsorption in some soils as affected by exchangeable cations. Soil Sci. 129: 366-370.

Shuman, L.M. 1975. The effect of soil properties on zinc adsorption by soils. Soil Sci. Soc. Am. Proc. 39: 454-458.

Shuman, L.M. 1988. Effect of removal of organic matter and iron- or manganese-oxides on zinc adsorption by soil. Soil Sci. 146: 248-254.

Solbraa, K. & A.R. Selmer-Olsen 1981. Manganese toxicity - in particular when growing plants in bark compost. Acta Agr. Scand. 31: 29-39.

Wu, X, I. Aasen & A.R. Selmer-Olsen 1991. A study of extraction methods for assessing soil zinc availability: I. Soil zinc extractability and soil zinc buffering capacity in relation to soil properties. Norw. J. Agric. Sci. 5: 89-107.

Zasoski, R.J. & R.G. Burau 1988. Sorption and sorptive interaction of cadmium and zinc on hydrous manganese oxide. Soil Sci. Soc. Am. J. 52: 81-87.

Zunino, H., M. Aguilera, M. Caiozzi, P. Peirano, F. Borie & J.P. Martin 1979. Metal-binding organic macromolecules in soil: 3. Competition of Mg(II) and Zn(II) for binding sites in humic and fulvic-type model polymers. Soil Sci. 128: 257-266.

A study of extraction methods for assessing soil zinc availability: III. Zinc concentration in barley plants as a function of soil extractable zinc and soil zinc buffering capacity

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The plant zinc concentration (ZnP) and soil extractable zinc (ZnE) were analysed using samples from 109 barley fields in southeastern Norway. Results show that the ZnP-ZnE relationship is non-linear and can be better described by reciprocal and logarithmic models. The quantity (Q) factors (DTPA-, ammonium acetate-EDTA- and HCl-extractable zinc) were found to be better predictors than the intensity (I) factors ($Mg(NO_3)_2$- and H_2O-extractable zinc). Among the extractants studied, DTPA appeared to be the most suitable for estimating soil zinc availability. Inclusion of buffering capacity factors improved the correlation between ZnP and ZnE. The effect of soil zinc buffering capacity (B) on ZnP was found to be positive at a given soil zinc intensity (I), but negative at a given soil zinc quantity (Q). The effect of soil exchangeable base cation concentration (BC) on ZnP is comparable to that of B with respect to both the nature and the levels of the correlations.

Key words: Barley, exchangeable base cation concentration, extractable zinc, non-calcareous soils, zinc buffering capacity.

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Prediction of zinc deficiency normally involves a soil test and a correlation study (Lindsay 1972; Lindsay & Cox 1985; Sillanpaa & Vlek 1985). A linear model is often applied to determine whether a method is effective or superior to the others for assessing soil zinc availability (Alley et al. 1972; Kennedy & Brown 1981; Haq et al. 1980; Rohman & Cox 1988; Singh & Narwal 1984; Mandal & Mandal 1986). As the soil - plant system is complex and the uptake of zinc is not only dependent on soil conditions but also subject to plant absorption metabolic mechanisms (Chandel & Saxena 1980), the results from linear correlation analyses may fail to reflect the real situation.

Studies on the functional relationship between plant uptake and nutrient levels in its growth media were mostly carried out under controlled conditions (Epstein & Hagen 1952; Homma & Hirata 1984; Bowen 1986; Mullins et al. 1986) and focused on macro-

nutrients (Whitmore & Addiscott 1987; Silberbush & Barber 1983a; Silberbush & Barber 1983b). It is somewhat unclear whether the uptake of a micronutrient like zinc follows the same rules as the macronutrients do, particularly under field conditions.

Various analytical methods have been used for differentiating soil zinc fractions such as with isotope exchange and DTPA extraction to determine the soil zinc labile pool (Lopez & Graham 1970; Lindsay & Norvell 1978) and with neutral salts and the electro-ultrafiltration technique to determine the soil zinc intensity (I) (Prabhakaran Nair 1984; Murthy & Schoen 1987; Levesque & Mathur 1986; Mathur & Levesque 1988). It is of interest to find out whether zinc uptake is better related to its quantity level or intensity level or both, and to study the relevant mechanisms.

MATERIALS AND METHODS

A description of 109 barley plant and soil samples and analytical methods has been given by Wu et al. (1991). The barley samples consist of three varieties, Bamse (69 samples), Pernilla (31 samples) and Ida (9 samples). The plants were harvested at growth stages between 10.0 and 10.1 according to the Feekes scale (Large 1954). Zinc deficiency symptoms were observed in seven samples and it was suspected that an additional sample had developed zinc deficiency symptoms in its later growth period.

The total zinc concentration in both plant and soil samples was determined using the ashing plus acid digestion method. The soil zinc quanity (Q) was determined by DTPA (Lindsay & Norvell 1978), ammonium acetate-EDTA (Levesque & Mathur 1988) and 0.2 N HCl (Ellis et al. 1964), while I was determined using. 0.5 M $Mg(NO_3)_2$ (Solbraa & Selmer-Olsen 1981) and deionized water. The concentration of zinc was measured on an SP9 atomic absorption spectrophotometer and reported on a dry matter basis.

RESULTS AND DISCUSSION

Comparison of the regression models

The following three regression models were tested using the present data:

Linear model	$ZnP = a_0 + a_1(ZnE) + e_a$	(1)
Reciprocal model	$1/ZnP = b_0 + b_1(1/ZnE) + e_b$	(2)
Logarithmic model	$\log ZnP = c_0 + c_1 \log ZnE + e_c$	(3)

where ZnP represents the zinc concentration in barley plants; ZnE represents the soil extractable zinc extracted by DTPA (ZnD), AA-EDTA (ZnA), HCl (ZnH), $Mg(NO_3)_2$ (ZnM) and water (ZnW), respectively; $\underline{a}$, $\underline{b}$ and $\underline{c}$ are constant terms; and $\underline{e}$ denotes the error. The results of the regression analyses are given in Table 1 and the scatter plottings are shown in Figs. 1, 2, 3, 4 and 5 for ZnD, ZnA, ZnH, ZnM and ZnW, respectively.

The reciprocal model is apparently the best of the three tested equations in fitting the present data. This is supported not only by its highest correlation coefficient (r) values for the five extraction methods studied, but also by its most regular and close

Table 1. Coefficient values of the tested regression models

Model		n	r
Linear	ZnP[a] = 20.05 + 1.244 ZnD	109	0.5182
	ZnP = 17.70 + 2.151 ZnD	106[b]	0.6035
	ZnP = 20.05 + 1.045 ZnA	109	0.5002
	ZnP = 17.70 + 1.787 ZnA	106[b]	0.5822
	ZnP = 18.48 + 0.570 ZnH	109	0.5327
	ZnP = 17.54 + 0.654 ZnH	106[b]	0.5493
	ZnP = 17.15 + 12.32 ZnM	109	0.6724
	ZnP = 18.68 + 29.69 ZnW	109	0.4606
Reciprocal	1/ZnP = 0.030 + 0.026/ZnD	109	0.8170
	1/ZnP = 0.026 + 0.030/ZnD	106[b]	0.8135
	1/ZnP = 0.030 + 0.032/ZnA	109	0.7860
	1/ZnP = 0.030 + 0.032/ZnA	106[b]	0.7821
	1/ZnP = 0.031 + 0.079/ZnH	109	0.7714
	1/ZnP = 0.032 + 0.079/ZnH	106[b]	0.7708
	1/ZnP = 0.037 + 0.003/ZnM	109	0.7216
	1/ZnP = 0.037 + 0.0008/ZnW	109	0.6593
Logarithmic	Log ZnP = 1.251 + 0.333 log ZnD	109	0.7613
	Log ZnP = 1.247 + 0.347 log ZnD	106[b]	0.7637
	Log ZnP = 1.224 + 0.330 log ZnA	109	0.7344
	Log ZnP = 1.218 + 0.343 log ZnA	106[b]	0.7376
	Log ZnP = 1.089 + 0.315 log ZnH	109	0.6906
	Log ZnP = 1.084 + 0.317 log ZnH	106[b]	0.6947
	Log ZnP = 1.475 + 0.296 log ZnM	109	0.7141
	Log ZnP = 1.573 + 0.244 log ZnW	109	0.6019

a: ZnP denotes zinc concentration in young barley plants (mg kg^{-1}); ZnD, ZnA, ZnH, ZnM and ZnW denote extractable soil zinc (mg l^{-1}) determined by DTPA, AA-EDTA, HCl, $Mg(NO_3)_2$ and H_2O, respectively

b: Point B, C and D in Figs. 1, 2 and 3 removed, thus n = 106

distribution of scatter points along the regression lines. The logarithmic model appears to be the second best model, while the linear model does not seem to be applicable for describing the ZnP-ZnE relationship. Results also show that the reciprocal and the logarithmic models are much more suitable for the quantity factors, ZnD, ZnA and ZnH than for the intensity factors, ZnM and ZnW

There is one outlier, point A, in Fig. 1b, which represents a sample having a high pH associated with a light texture and a low native zinc concentration in the soil. Another three points are marked as B, C and D in the first plot of Figs. 1, 2 and 3. Points B and C represent two unusual cases which largely determine the trends of the regression lines. The r values obtained on 106 cases in Table 1 show that removal of the three points does not result in essential changes in the correlation levels for the reciprocal and logarithmic models.

When comparing the correlation coefficient (r) values obtained with the linear regression model, the $Mg(NO_3)_2$ extraction appears to be the best method. When the reciprocal model and the logarithmic model are used, however, the analytical results indicate the order of superiority as: DTPA > AA-EDTA > HCl > $Mg(NO_3)_2$ and H_2O. A false impression could have been obtained if the linear regression model only had

been used. The present results suggest the necessity of scatter-plotting as this can give a perceptive picture of how the factors concerned are related, thus providing an opportunity for selecting a better model.

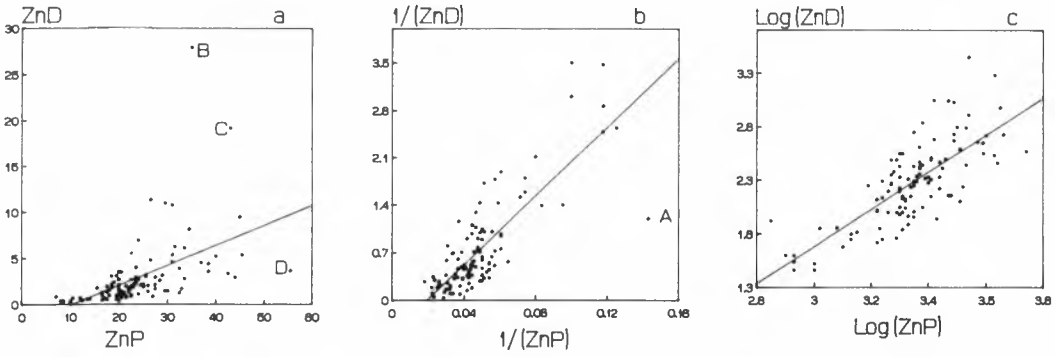

Figure 1. ZnP-ZnD relationship given by different regression models. a: linear model, b: reciprocal model, c: logarithmic model. ZnP: zinc concentration in barley shoots (mg kg^{-1}), ZnD: DTPA-extractable soil zinc (mg l^{-1}). Points A, B, C and D denote outliers

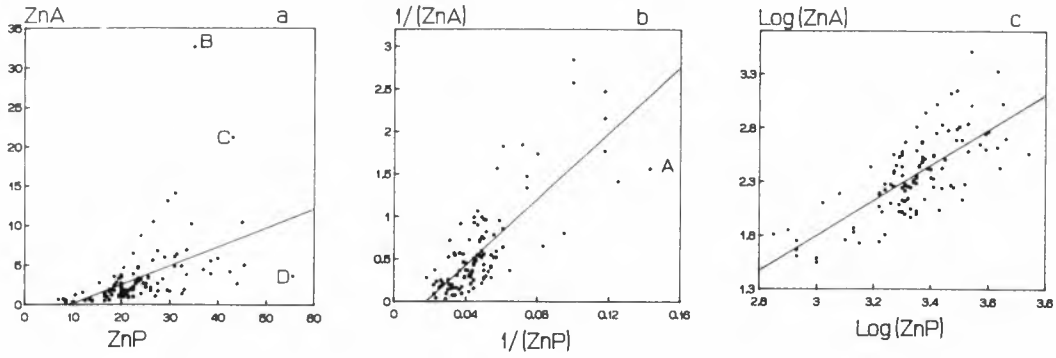

Figure 2. ZnP-ZnA relationship given by different regression models. a: linear model, b: reciprocal model, c: logarithmic model. ZP: zinc concentration in barley shoots (mg kg^{-1}), ZnA: AA-EDTA-extractable soil zinc (mg l^{-1}). Points B, C and D denote outliers

Reciprocal relation and Michaelis-Menten's equation

Rearranging the reciprocal model, Equation 2, and ignoring the error term give

$$ZnP = a(ZnE)/(b + ZnE) \quad (4)$$

where $\underline{a} = 1/a_0$ and $b = a_1/a_0$. Equation 4 resembles exactly the Michaelis-Menten's

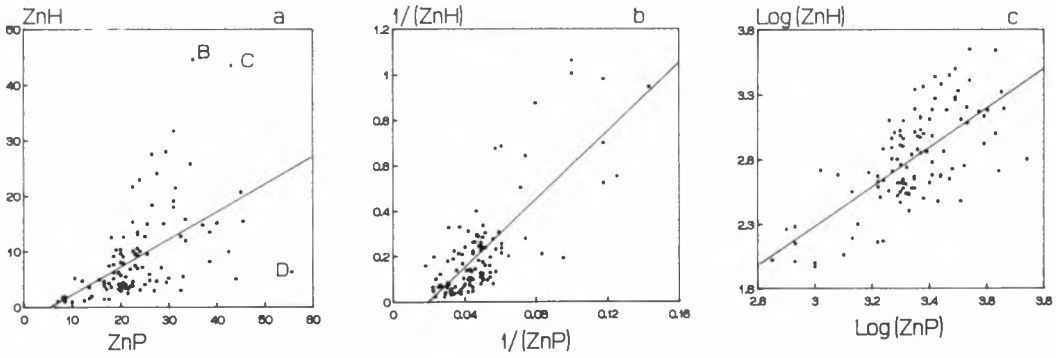

Figure 3. ZnP-ZnH relationship given by different regression models. a: linear model, b: reciprocal model, c: logarithmic model. ZnP: zinc concentration in barley shoots (mg kg^{-1}), ZnH: HCl-extractable soil zinc (mg l^{-1}). Points B, C and D denote outliers

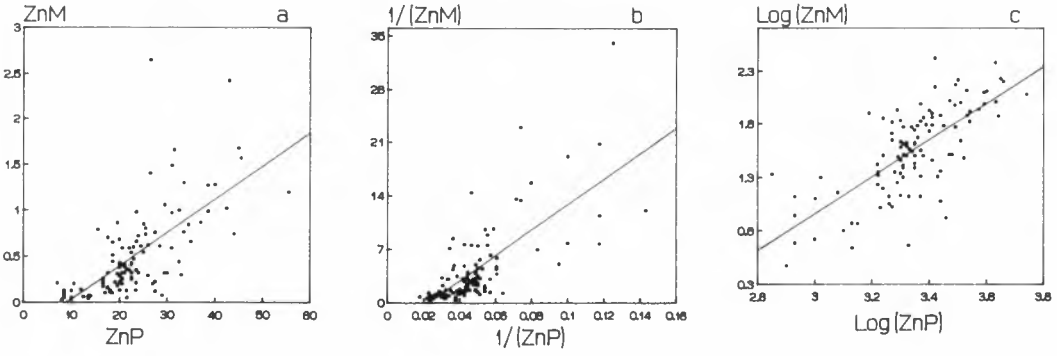

Figure 4. ZnP-ZnM relationship given by different regression models. a: linear model, b: reciprocal model, c: logarithmic model. ZnP: zinc concentration in barley shoots (mg kg^{-1}), ZnM: $Mg(NO_3)_2$ - extractable soil zinc (mg l^{-1})

equation for enzyme catalyzed reaction. The reciprocal of Michaelis-Menten's equation is known as the Lineweaver-Burk equation (Fruton & Simmonds 1958). Epstein & Hagen (1952) applied the carrier theory proposed for active transport of ions passing through plant cell membranes against a chemical potential gradient. Under the assumption that some metabolically produced compound, namely, the carrier, is involved in ion absorption, they expressed the active transport with an equation analogous to Equation 4. Although the carrier theory is still a speculation, the Michaelis-Menten relation has been frequently applied for plant absorption (Cushman 1979, 1984; Khasawneh 1971).

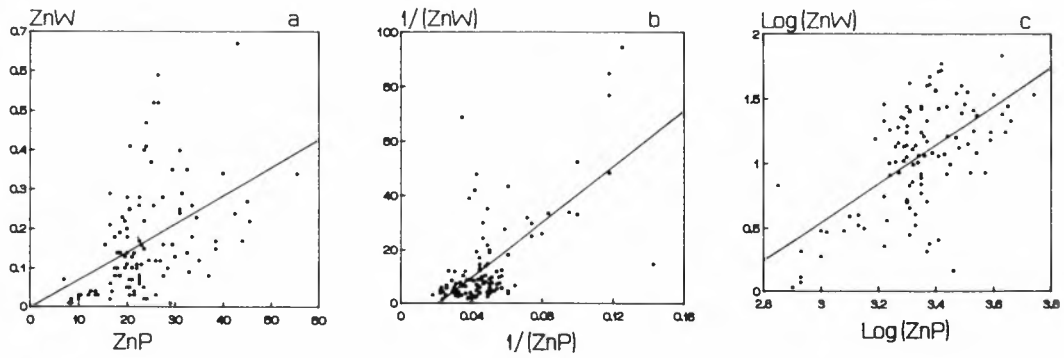

Figure 5. ZnP-ZnW relationship given by different regression models. a: linear model, b: reciprocal model, c: logarithmic model. ZnP: zinc concentration in barley shoots (mg kg^{-1}), ZnW: water-extractable soil zinc (mg l^{-1})

Ion desorption and plant absorption

The following reaction describes the movement of ions in the soil solid-solution-plant root system:

$$\underset{(C_1)}{\text{Solid phase}} \overset{V_1}{\rightleftharpoons} \underset{(C_2)}{\text{soil solution}} \overset{V_2}{\rightarrow} \underset{(C_3)}{\text{Plant root}} \qquad \text{(R-1)}$$

The terms, V_1 and V_2 in R-1 denote respectively the net ion desorption rate and the uptake rate. The term, C_1, represents the available fraction of ions in the soil solid phase; C_2 represents the ion concentration in the soil solution; and C_3 represents the ion concentration inside the root cell membrane.

Since
$$dC_2/dt = V_1 - V_2 \qquad (5)$$

where t denotes the time, keeping C_2 constant demands that

$$dC_2/dt = 0 \qquad (6)$$

Thus under steady-state conditions,

$$V_2 = V_1 \qquad (7)$$

Equation 7 emphasizes the fact that ion uptake by plants is highly dependent on the ion desorption rate, i.e., without the continuous supply of the ions from the solid labile pool, the ions in the soil solution would soon be depleted and the uptake would finally stop. For this reason, the ion uptake is not only determined by the soil nutrient intensity factor, C_2, but also determined by the soil nutrient replenishment factor, C_1. Although Equation 7 only holds under steady-state conditions, the essential relationship

between ion uptake, soil nutrient intensity (I) and soil nutrient labile pool (Q) will also hold in the transient phases.

Effect of soil zinc buffering capacity (B)

In order to take the buffering capacity (B) effect into account, the following regression equations were further tested:

Reciprocal model

$$(R_1) \qquad 1/ZnP = a_{01} + a_{11}/Q + a_{21}/B + e_{a1} \tag{8}$$

$$(R_2) \qquad 1/ZnP = a_{02} + a_{12}/I + a_{22}/B + e_{a2} \tag{9}$$

$$(R_3) \qquad 1/ZnP = a_{03} + a_{13}/Q + a_{23}/I + e_{a3} \tag{10}$$

Logarithmic model

$$(L_1) \qquad \log ZnP = b_{01} + b_{11} \log Q + b_{21} \log B + e_{b1} \tag{11}$$

$$(L_2) \qquad \log ZnP = b_{02} + b_{12} \log I + b_{22} \log B + e_{b2} \tag{12}$$

$$(L_3) \qquad \log ZnP = b_{03} + b_{13} \log Q + b_{23} \log I + e_{b3} \tag{13}$$

where Q represents ZnD, ZnA or ZnH; I represents ZnM; and e denotes error. The soil zinc buffering capacity, B, is given as B_D = ZnD/ZnM, B_A = ZnA/ZnM and B_H = ZnH/ZnM, respectively.

Compared with the figures in Table 1, the R values in Table 2 show that the inclusion of B generally improves the correlation between ZnP and ZnE. The reciprocal model still fits the data better than the logarithmic model as does Equation 2 than Equation 3. However, the differences in the levels of significance between the two models were reduced after B was included. Higher R values were also obtained from the reciprocal model for ZnD, ZnA and ZnH than for ZnM.

Inclusion of B together with either zinc quantity or intensity resulted in no differences in R values for the logarithmic models. This is because Equations 11, 12 and 13 are related by

$$b_{03} = b_{01} = b_{02},$$
$$b_{11} = b_{12},$$
$$b_{13} = -b_{21} = b_{11} - b_{22} > 0$$

and $b_{23} = b_{22} > 0$ (See Table 2).

The improvement in the correlation levels by including B is very pronounced for the AA-EDTA and particularly for the HCl method. By this inclusion, the differences in R values between the three methods, DTPA, AA-EDTA, and HCl, were greatly reduced.

Another phenomenon that can be observed in Table 2 is that ZnP is always positively correlated with B, when B is included along with I; or negatively correlated with B when B is included along with Q; or positively correlated with both Q and I if Q and I

Table 2. Coefficients of multiple regression with inclusion of buffering capacity (B) (n = 109)

Regression model		R	R^2_{adj}*
Reciprocal model			
R_1)[a]	$1/ZnP^{b} = 0.0343 + 0.0267/ZnD - 0.0248/B_D$	0.8230	0.6773
R_2)	$1/ZnP = 0.0170 + 0.0033/ZnM + 0.0358/B_D$	0.7534	0.5676
R_3)	$1/ZnP = 0.0290 + 0.0229/ZnD + 0.00060/ZnM$	0.8236	0.6783
R_1)	$1/ZnP = 0.0357 + 0.0327/ZnA - 0.0358/B_A$	0.7978	0.6364
R_2)	$1/ZnP = 0.0198 + 0.0033/ZnM + 0.0811/B_A$	0.7451	0.5551
R_3)	$1/ZnP = 0.0290 + 0.0261/ZnA + 0.00093/ZnM$	0.8038	0.6461
R_1)	$1/ZnP = 0.0381 + 0.0840/ZnH - 0.1115/B_H$	0.7981	0.6369
R_2)	$1/Znp = 0.0267 + 0.0031/ZnM + 0.1270/B_H$	0.7402	0.5479
R_3)	$1/ZnP = 0.0303 + 0.0629/ZnH + 0.0011/ZnM$	0.7986	0.6348
Logarithmic model			
L_1)	$\log ZnP = 1.3357 + 0.3549 \log ZnD - 0.1252 \log B_D$	0.7848	0.6159
L_2)	$\log ZnP = 1.3357 + 0.3549 \log ZnM + 0.2297 \log B_D$	0.7848	0.6159
L_3)	$\log ZnP = 1.3357 + 0.1252 \log ZnM + 0.2297 \log ZnD$	0.7848	0.6159
L_1)	$\log ZnP = 1.3389 + 0.3620 \log ZnA - 0.1569 \log B_A$	0.7780	0.6052
L_2)	$\log ZnP = 1.3389 + 0.3620 \log ZnM + 0.2051 \log B_A$	0.7780	0.6052
L_3)	$\log ZnP = 1.3389 + 0.1569 \log ZnM + 0.2051 \log ZnA$	0.7780	0.6052
L_1)	$\log ZnP = 1.2864 + 0.3633 \log ZnH - 0.1887 \log B_H$	0.7680	0.5958
L_2)	$\log ZnP = 1.2864 + 0.3633 \log ZnM + 0.1746 \log B_H$	0.7680	0.5958
L_3)	$\log ZnP = 1.2864 + 0.1887 \log ZnM + 0.1746 \log ZnH$	0.7680	0.5958

a: Regression models refer to Equations 8 to 13
b: ZnP denotes zinc concentration in young barley plants (mg kg^{-1}); ZnD, ZnA, ZnH and ZnM denote extractable soil zinc (mg l^{-1}) determined by DTPA, AA-EDTA, HCl and $Mg(NO_3)_2$, respectively
*: R^2_{adj} = the adjusted R^2

are included at the same time. This confirms the basic relation of ZnP to Q, I and B. In general, a higher uptake of zinc by plants requires both a higher level of zinc intensity and a higher level of zinc quantity in the soil. Thus the values of b_{13} and b_{23} defined in Equation 13 were both found to be positive. Since $B = dQ/dI$, for a given I, B is directly related to Q. Thus B has a positive effect on zinc uptake. On the contrary, for a given Q, B is inversely related to I, and it therefore has a negative influence on zinc uptake.

The fact that the quantity factor is better correlated with ZnP than the intensity factor can also be explained by the soil nutrient supply theory. Equation 7 illustrates that the ion uptake rate is equal to the ion desorption rate under steady state conditions. According to the definition of the nutrient labile pool given by Page et al. (1982), Q is the sum of the isotopically exchangeable quantities of the ion in solution (I) plus that adsorbed on the solid surface (Q'), i.e.,

$$Q = I + Q' \qquad (14)$$

As I is equivalent to C_2 and Q' is comparable to C_1 defined in R-1, for a given I, the correlation between ZnP and Q, Cor(ZnP, Q), is equal to the correlation between ZnP and Q',

$$\text{Cor}(\text{ZnP}, Q|I) = \text{Cor}(\text{ZnP}, I+Q'|I) = \text{Cor}(\text{ZnP}, Q'|I).$$

Since at a given C_2, the ion desorption rate will be determined by C_1, the correlation between the uptake rate V_2 and C_1 should be positive, i.e.,

$$\text{Cor}(V_2, C_1|C_2) = \text{Cor}(V_2, Q'|I) > 0.$$

Thus, when I remains constant, ZnP will increase with increasing Q because

$$\text{Cor}(\text{ZnP}, Q|I) = \text{Cor}(V_2, Q'|I) > 0.$$

Effect of exchangeable base cation concentration (BC) and ionic ratios

The effect of BC was tested by changing the reciprocal and the logarithmic models into the following forms:

$$1/\text{ZnP} = a_0 + a_1/Q + a_2\text{BC}/Q + e_a \quad (15)$$

$$\log \text{ZnP} = b_0 + b_1 \log \text{ZnE} + b_2 \log \text{BC} + e_b \quad (16)$$

Table 3 shows that the BC effect is equivalent to the B effect on ZnP with respect to the nature of the correlations. In general, including BC gives higher R values than including B (Tables 2 and 3). The results support the suggestion from Wu et al. (1991) that BC functions as a soil zinc buffering capacity factor because it determines the soil alkalinity buffering capacity.

Table 3. Coefficients of multiple regressions with inclusion of soil base cation concentration (BC) (n = 109)

Regression model[a]	R	R^2_{adj}*
Reciprocal model		
$1/\text{ZnP}^{b}$ = 0.0299 + 0.0130/ZnD + 0.00067(BC/ZnD)	0.8506	0.7236
1/ZnP = 0.0297 + 0.0105/ZnA + 0.0012(BC/ZnA)	0.8399	0.7055
1/ZnP = 0.0319 + 0.0194/ZnH + 0.0033(BC/ZnH)	0.8258	0.6864
Logarithmic model		
log ZnP = 1.5278 + 0.3492 log ZnD - 0.2285 log BC	0.8012	0.6419
log ZnP = 1.5503 + 0.3577 log ZnA - 0.2739 log BC	0.7918	0.6270
log ZnP = 1.4589 + 0.3617 log ZnH - 0.3318 log BC	0.7747	0.6002
log ZnP = 1.3658 + 0.3077 log ZnM + 0.0934 log BC	0.7431	0.5522

a: Regression models refer to Equations 15 and 16

b: ZnP denotes zinc concentration in young barley plants (mg kg^{-1}); ZnD, ZnA, ZnH and ZnM denote extractable soil zinc (mg l^{-1}) determined by DTPA, AA-EDTA, HCl and $Mg(NO_3)_2$, respectively

*: R^2_{adj} = the adjusted R^2

To account for the influence of the presence of ion j on the uptake of ion i, Epstein & Hagen (1952) in their solution culture studies developed the Michaelis-Menten's equation into

$$V_i = \frac{V_m C_i}{K_i + C_i + (K_i/K_j)C_j} \tag{17}$$

Khasawneh (1971) further generalized Equation 17 into Equation 18 for the presence of several other ion species,

$$V_i = \frac{V_m C_i}{K_i + C_i + \Sigma (K_i/K_j)C_j} \tag{18}$$

There should be no doubt that Equations 17 and 18 will work if the influence of other ionic species on the uptake of ion i is negative. This negative effect can be caused either by depression in ionic activity in the growth media or competition between ions in plant uptake.

Studies on ionic activity ratios have been widely carried out for macronutrients (Khasawneh 1971). Pasricha et al. (1987) used the following parameter to represent the soil zinc intensity factor,

$$AR^{ZN} = \frac{(a_{Zn})^{1/2}}{(a_{Ca+Mg})^{1/2}} \tag{19}$$

where a denotes the solution activity. Moore & Patrick (1989) related manganese uptake to a term called the divalent charge fraction, E'-Mn, defined as

$$E'\text{-}Mn = \frac{M_{Mn}}{M_{Ca} + M_{Mg} + M_{Fe} + M_{Mn}} \tag{20}$$

where M is the molinity in soil solution (mmol kg^{-1}). Equations 19 and 20 agree in principle with Equations 17 and 18.

Recalling Equation 16,

$\log ZnP = b_0 + b_1 \log ZnE + b_2 \log BC$

and on transformation,

$ZnP = K(ZnE)^{b1}(BC)^{b2}$.

Since, $b_2 > 0$ if $ZnE = 1$ and $b_2 < 0$ if $ZnE = Q$, the above equation can be written as either

$$ZnP = K_1 I^{n1}(BC)^{n2} \tag{21}$$

or

$$ZnP = (K_2 Q^{m1})/(BC)^{m2} \tag{22}$$

where K_1, K_2, n_1, n_2, m_1 and m_2 are all positive terms. Since BC is the sum of the content of exchangeable Ca, Mg, K and Na, denoting BC as (Ca + Mg + K + Na) gives

$$ZnP = K_1 I^{n1}(Ca + Mg + K + Na)^{n2} \tag{23}$$

and

$$ZnP = \frac{K_2 Q^{m1}}{(Ca + Mg + K + Na)^{m2}} \tag{24}$$

Equation 15 can also be rearranged as

$$1/ZnP = a_0 + a_1/Q + a_2 BC/Q$$

$$= \frac{a_0 Q + a_1 + a_2 BC}{Q}$$

Then

$$ZnP = \frac{(1/a_0)Q}{a_1/a_0 + Q + (a_2/a_0)BC} \tag{25}$$

Equation 23 does not agree with Equations 17, 18, 19 and 20 as it shows that the uptake is positively related to the product of I and (Ca + Mg + K + Na) rather than to the ratio of I to (Ca + Mg + K + Na). Equation 24 has a similar form to that of Equations 19 and 20, and Equation 25 has a form similar to that of Equations 17 and 18. The term representing the soil zinc level in Equations 24 and 25, however, is not I but Q.

The R values obtained using Q factors being higher than those obtained using I factors (Table 3) indicates that Equation 24 is better suited than Equation 23 for the present data. This may be due to the complexity of the BC effect. If, in the uptake process, zinc is in competition with the four base cations, Ca, Mg, K and Na, then the positive effect of BC as a soil zinc buffering capacity component will be in counteraction with this competitive effect when ZnP is related to I. There is one special case where the use of activity ratios to represent ion availability is consistent with the soil nutrient supply mechanism. That is when B = dQ/dI = a constant. As

$$Q = I + Q' \tag{14}$$

$$B = dQ/dI = d(I + Q')/dI = 1 + dQ'/dI \tag{26}$$

which shows that B is mainly determined by dQ'/dI. Solution cultures provide extreme conditions of B = 1, as I = Q and dQ'/dI = 0.

With respect to this contradictory effect of BC, the soil zinc quantity (Q) factor further appears to be a better parameter than the intensity (I) factor, as the effect of BC in Equations 24 and 25 is in accordance with its competitive effect. Equations 24 and 25 should hold in every type of plant growth medium including solution culture, provided that the interactions between ionic species are not synergistic. Since Q and BC are both quantity factors, the term $Q^{m1}/(BC)^{m2}$ may be regarded as a quantity ratio in contrast to a activity ratio. When B remains constant, both quantity ratios and activity ratios

have essentially the same effect on ion uptake. Especially when B = 1, the quantity ratio is equal to the activity ratio.

REFERENCES

Alley, M.M., D.C. Martens, M.G. Schnappinger Jr. & G.W. Hawkins 1972. Field calibration of soil tests for available zinc. Soil Sci. Soc. Am. Proc. 36: 621-624.

Bowen, J.E. 1986. Kinetics of zinc uptake by two rice cultivars. Plant and Soil 94: 99-107.

Chandel, A.S. & M.C. Saxena 1980. Mechanism of uptake and translocation of zinc by pea plants (*Pisum sativum* L). Plant and Soil 56: 343-353.

Cushman, J.H. 1979. An analytical solution to solute transport near root surfaces for low initial concentration: I. Equations development. Soil Sci. Soc. Am. J. 43: 1087-1095.

Cushman, J.H. 1984. Nutrient transport inside and outside the root rhizosphere: Generalized model. Soil Sci. 138: 164-171.

Ellis, R. Jr., J.F. Davis & D.L. Thurlow 1964. Zinc availability in calcareous Michigan soils as influenced by phosphorus level and temperature. Soil Sci. Soc. Am. Proc. 28: 83-86.

Epstein, E. & C.E. Hagen 1952. A kinetic study of the absorption of alkali cations by barley roots. Plant Physiol. 27: 457-474.

Fruton, J.S. & S. Simmonds 1958. General Biochemistry. 2nd Edn. pp. 244-283. New York, John Wiley & Sons, London, Chapman & Hall.

Haq, A.U., T.E. Bates & Y.K. Soon 1980. Comparison of extractants for plant-available zinc, cadmium, nickel, and copper in contaminated soils. Soil Sci. Soc. Am. J. 44: 772-777.

Homma, Y. & H. Hirata 1984. Kinetics of cadmium and zinc absorption by rice seedling roots. Soil Sci. Plant Nutr. 30: 527-532.

Kennedy, A.C. & J.R. Brown 1981. A comparison of three extractants for soil zinc. Soil Sci. Soc. Am. J. 45: 1000-1002.

Khasawneh, F.E. 1971. Solution ion activity and plant growth. Soil Sci. Soc. Am. Proc. 35: 426-436.

Large, E.C. 1954. Growth stages in cereals: Illustration of the Feekes scale. Plant. Path. 3: 128-129.

Levesque, M. & S.P. Mathur 1986. Soil tests for copper, iron, manganese, and zinc in Histosols: 1. The influence of soil properties, iron manganese, and zinc on the level and distribution of copper. Soil Sci. 142: 153-163.

Levesque, M. & S.P. Mathur 1988. Soil tests for copper, iron, manganese, and zinc in Histosols: 3. A comparison of eight extractants for measuring active and reserve form of the elements. Soil Sci. 145: 215-221.

Lindsay, W.L. 1972. Zinc in soils and plant nutrition. Adv. Agron. 24: 147-186.

Lindsay, W.L. & F.R. Cox 1985. Micronutrient soil testing for the tropics. Fertilizer Research 7: 169-200.

Lindsay, W.L. & W.A. Norvell 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. Soil Sci. Soc. Am. J. 42: 421-428.

Lopez, P.L. & E.R. Graham 1970. Isotopic exchange studies of micronutrients in soils. Soil Sci. 110: 24-30.

Mandal, L.N. & B. Mandal 1986. Zinc fractions in soils in relation to zinc nutrition of lowland rice. Soil Sci. 142: 141-148.

Mathur, S.P. & M. Levesque 1988. Soil tests for copper, iron, manganese, and zinc in Histosols: 2. The distribution of soil iron and manganese in sequentially extractable forms. Soil Sci. 145: 102-110.

Moore, P.A. Jr. & W.H. Patrick Jr. 1989. Manganese availability and uptake by rice in acid sulfate soils. Soil Sci. Soc. Am. J. 53:104-109.

Mullins, G.L., L.E. Sommers & S.A. Barber 1986. Modeling the plant uptake of cadmium and zinc from soils treated with sewage sludge. Soil Sci. Soc. Am. J. 50: 1245-1250.

Murthy, A.S.P. & H.G. Schoen 1987. A comparative study of the soil zinc fractions determined by chemical methods and electro-ultrafiltration (EUF) and their relations to zinc nutrition in rice. Plant and Soil 102: 207-210.

Page, A.L., R.H. Miller & D.R. Keeney (Eds.) 1982. Methods of soil analysis. Part 2. Chemical and microbiological properties. 2nd Edn. pp. 323-335. Madison Wisconsin USA.

Pasricha, N.S., H.S. Baddesha, M.S. Aulakh & V.K. Nayyar 1987. The zinc quantity-intensity relationships in four different soils as influenced by phosphorus. Soil Sci. 143: 1-4.

Prabhakaran Nair, K.P. 1984. Zinc buffer power as an important criterion for a dependable assessment of plant uptake. Plant and Soil 81: 209-215.

Rohman, P.C. & F.R. Cox 1988. Evaluation of the modified Olsen extracting reagent for copper, zinc and manganese. Commun. in Soil Sci. Plant Anal. 19: 1859-1870.

Silberbush, M. & S.A. Barber 1983a. Sensitivity analysis of parameters used in simulating potassium uptake with a mechanistic mathematical model. Agron. J. 75: 851-854.

Silberbush, M. & S.A. Barber 1983b. Sensitivity of simulated phosphorus uptake to parameters used by a mechanistic mathematical model. Plant and Soil 74: 93-100.

Sillanpää, M. & P.L.G. Vlek 1985. Micronutrients and the agro-ecology of tropical and Mediterranean regions. Fertilizer Research 7: 151-167.

Singh, B.R. & R.P. Narwal 1984. Plant availability of heavy metals in a sludge-treated soil: II. Metal extractability compared with plant metal uptake. J. Environ. Qual. 13: 344-349.

Solbraa, K. & A.R. Selmer-Olsen 1981. Manganese toxicity - in particular when growing plants in bark compost. Acta Agr. Scand. 31: 29-39.

Whitmore, A.P. & T. M. Addiscott 1987. A function for describing nitrogen uptake, dry matter production and rooting by wheat crops. Plant and Soil 101: 51-60.

Wu, X., I. Aasen & A.R. Selmer-Olsen 1991. A study of extraction methods for assessing soil zinc availability: I. Soil zinc extractability and soil zinc buffering capacity in relation to soil properties. Norw. J. Agric. Sci. 5: 89-107.

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Strømnes, R. 1983. Maskinell markberedning og manuell planting. Landbrukets årbok 1984: 265-278.

Uhlen, G. 1968. Nitrogengjødsling til ettårig raigras. Jord og avling 10(3): 5-8.

Aase, K.F., F. Sundstøl & K. Myhr 1977. Forsøk med strandrøyr og nokre andre grasartar. Forskning og forsøk i landbruket 27: 575-604.

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