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PROCEEDINGS, NJF-SEMINAR NO 247

AGROHYDROLOGY AND NUTRIENT BALANCES

OCTOBER 18-20, 1994, UPPSALA, SWEDEN

Editor: Ragnar Persson

Seminar organized by
Scandinavian Association of Agricultural Scientists (NJF.)
Section VIII, Agricultural Water Management and
Section XI, Natural Resources and Environment.

Institutionen för markvetenskap
Avdelningen för lantbrukets hydroteknik

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Preface

Scandinavian Association of Agricultural Scientists (NJF.) Section VIII, Agricultural Water Management in cooperation with NJF. Section XI, Natural Resources and Environment arranged in 18-20 October 1994 a seminar on the subject Agrohydrology and Nutrient Balances.

The seminar themes focused on water flow processes and how to manage nutrient transport in the soil profile, in the field and in the landscape. In the first theme, *"evapotranspiration and transport processes in soil"*, there were seven papers presented. Three of the papers discussed evaporation during different seasons and from different crops and the rest concerned flow processes in the soil profile as it was governed by soil structure. The second theme, *"water management in the field - natural variations, water and nutrient management"*, was a forum for discussions about processes of nitrogen leaching, effects of irrigation and drainage and how precipitation and runoff affects erosion. Ten papers were presented in this session. The third theme concerned *"water balances in the watershed - natural variations, water and nutrient management.* In this session were seven papers presented. Discussions focused on different techniques to reduce nitrogen and phosphorous losses by using buffer zones and constructed wetlands. In a poster session were twelwe posters presented.

The seminar was attended by 57 participants from all Nordic and Baltic countries; 8 from Denmark, 5 from Estonia, 11 from Finland, 1 from Iceland, 1 from Latvia, 2 from Lithuania, 10 from Norway and 19 from Sweden.

On the behalf of the organizers, I would like to thank all participants and speakers that contributed to the seminar with excellent presentations and active discussions.

Ragnar Persson
Seminar secretary

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Sessions and titles of papers presented:

Alphabetical list of authors with page references

Participation list

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Evaporation and discharge from cropped and bare soil during winter.

Question:
Which are the differences between cropped and bare soils during winter in evaporation and discharge?

Background:
- Generally evaporation from a surface is determined by the amount of available energy and the efficiency by which vapour is transported away. Cropped and bare soils may have different albedo and different roughness, which influence the amount of available energy for evaporation and the transport of water vapour.

- Evaporation from different systems is also governed by other specific properties of the systems. Evaporation from bare soil is governed by the availability of water at the soil surface which is mainly regulated by soil hydraulic properties. Evaporation from cropped soil is regulated by factors influencing water uptake by roots, transpiration of water through stomata and evaporation of intercepted water.

Aim of the study:
- To investigate to what extent measured discharge from cropped and bare tile-drained field plots could reveal differences in evaporation from cropped and bare soil during winter.

- To interpret any identified differences using a physically based simulation model.

Conclusions:
- Total annual discharge showed a large degree of inconsistent variation between field plots within the same year and treatment, whereas the discharge dynamics showed more consistent differences between treatments.

- Both measurements and simulations showed that evaporation was higher from cropped soil than from bare soil during early autumn when potential evaporation was relatively high.

- By contrast, during periods with lower temperatures and frequent precipitation, evaporation from bare soil was as high or, for limited periods, exceeded that form cropped soil.

- According to the simulations the annual discharge from the system with cropped soil during winter was 30-40 mm less than that with bare soil. This constituted about 10-15% of the annual discharge.

Referens: *Lewan E. 1993. Evaporation and Discharge from arable land with cropped or bare soils during winter. Measurements and Simulations. Agricultural and Forest Meterorology 64:131-159.*

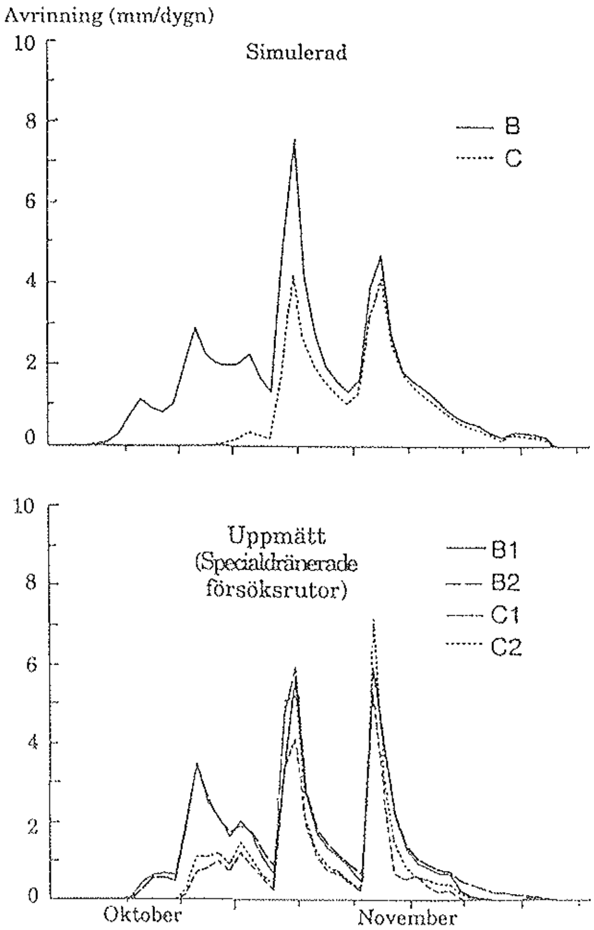

Figure 1. Daily discharge from bare soil (B) and cropped soil (C).

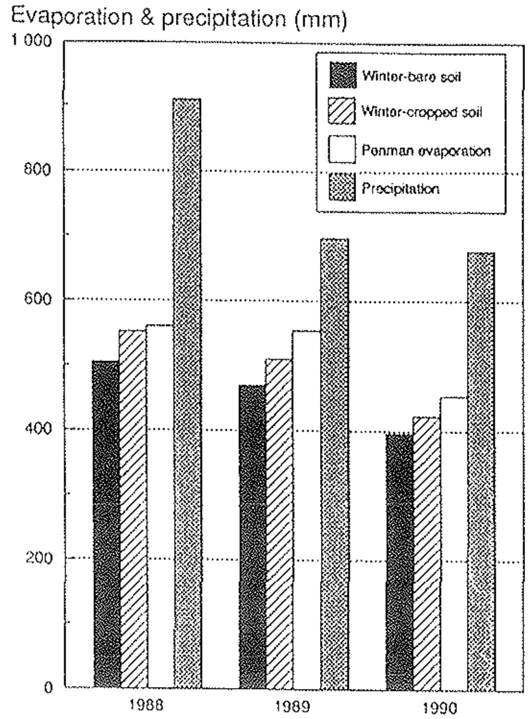

Figure 2. Annual precipitation, potential evaporation (Penman) and simulated evaporation from arable land with bare soil and cropped soil during winter.

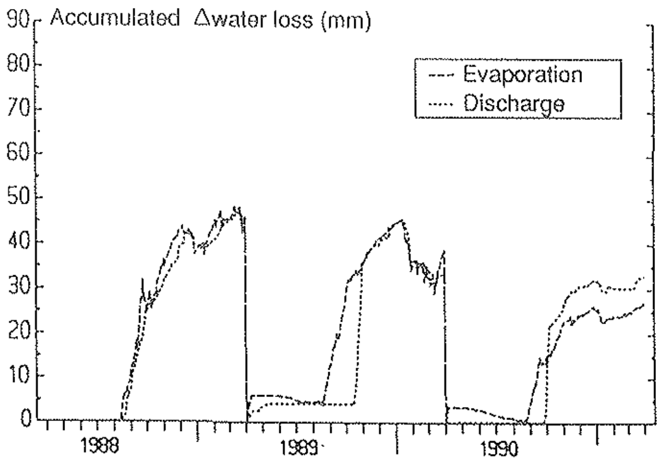

Figure 3. Accumulated daily difference in discharge (arable land with bare soil during winter - arable land with cropped soil during winter) and evaporation (arable land with cropped soil during winter - arable land with bare soil during winter).

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EVAPORATION FROM BARE SOIL

Background

In a humid environment evaporation from bare soil accounts for a major part of the total evapotranspiration, especially in spring and fall when the crop cover is scarce. Quantification of the evaporation from bare soil and the water content in the very upper soil layers are important in relation to a number of aspects: soil biological processes, farm management and modelling of the atmosphere. Numerous studies of evaporation have been conducted in controlled environments during several decades. These studies have documented significant effects of soil types, soil tillage and potential evaporation level, e.g., for a sandy loam Olesen (1970) found up to 68 % reduction in accumulated evaporation in differently tilled soil compared to untilled soil. Simple models have often been applied in these studies to describe the measured evaporation. Comprehensive field studies and modelling of evaporation have been conducted during the last two decades, especially in arid environments, and recently, also in humid areas (Berge, 1986; Plauborg, 1994c). The results and conclusions presented in this abstract are extracted from Plauborg (1994a,b and c).

Results and conclusions

Evaporation from a bare loamy sand was measured with micro-lysimeters and showed in two periods an almost linear relationship with time in the falling rate stage of evaporation. Several simple models were tested, but only one of the models could be calibrated to describe the measured evaporation. Preliminary results show a quite good agreement between measured evaporation and evaporation calculated from a comprehensive, physically based model.

Perspectives

The mechanisms controlling the evaporation at the soil surface are interrelated in a complex system which is still not well understood. The influence of soil aggregation and aggregate stability, affected by soil tillage, seem to be just one of several challenges to be included in future modelling of evaporation from bare soil.

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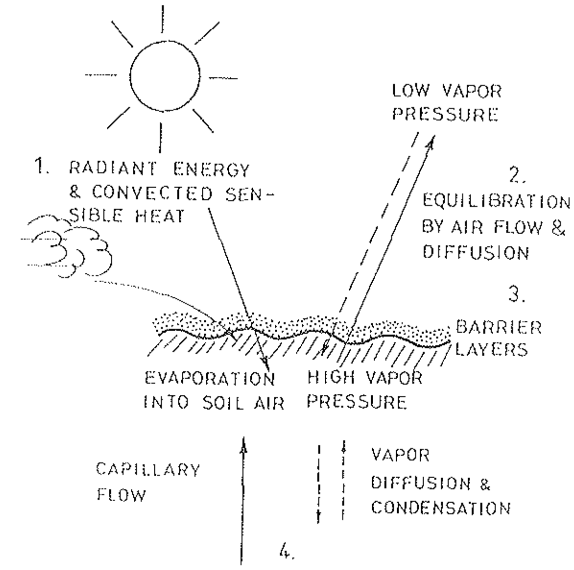


Figure 1. The process of soil water evaporation (from Heinonen, 1985).

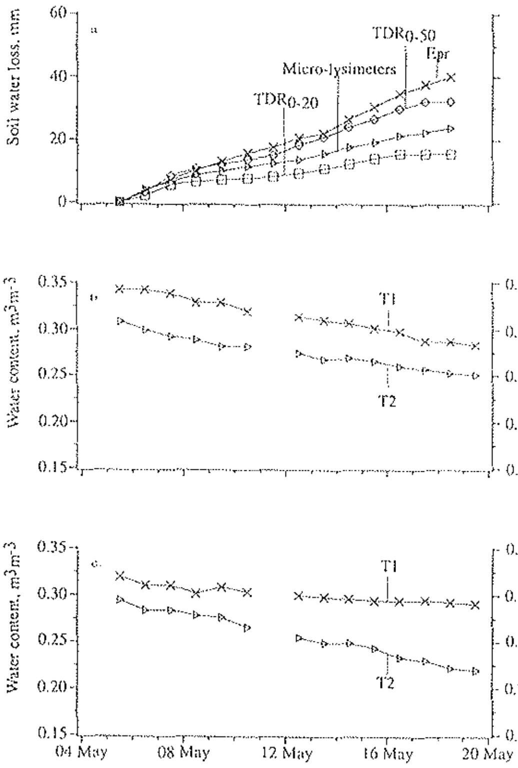
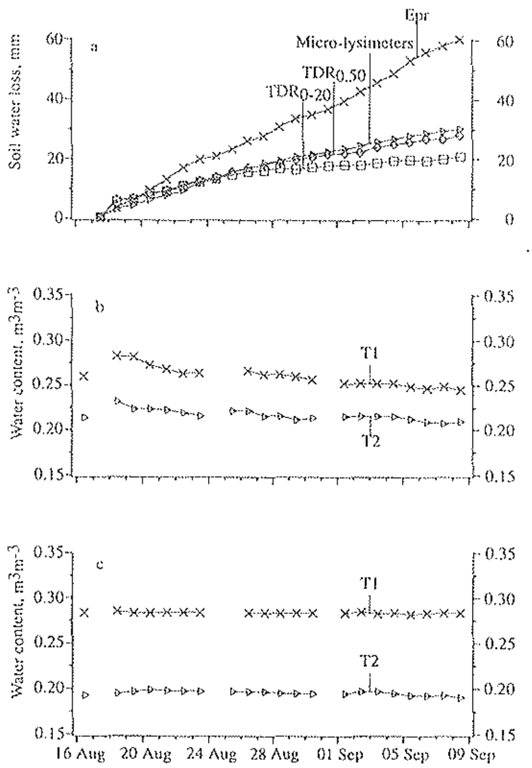


Figure 2 a. Estimates of accumulated soil water loss.
b. Soil water content at 20 cm depth measured with TDR.
c. Soil water content at 50 cm depth measured with TDR (Plauborg, 1994a).



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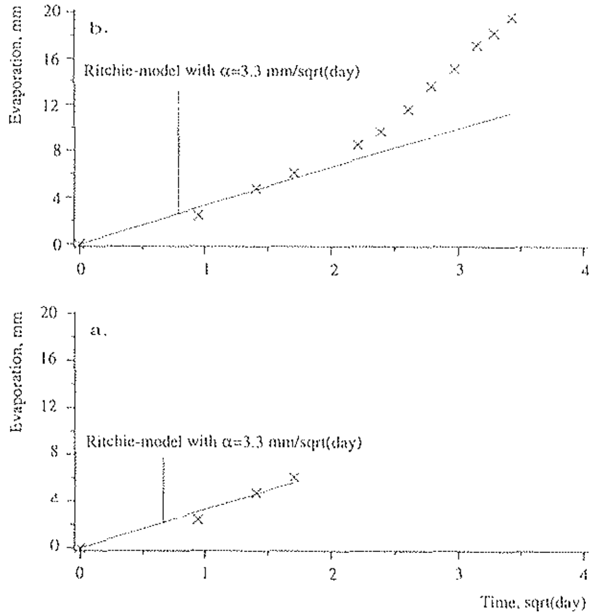

Figure 4. Accumulated evaporation in the falling rate stage of evaporation.
a. α determined by regression, 3 days data.
b. 12 days data.
(Plauborg, 1994b)

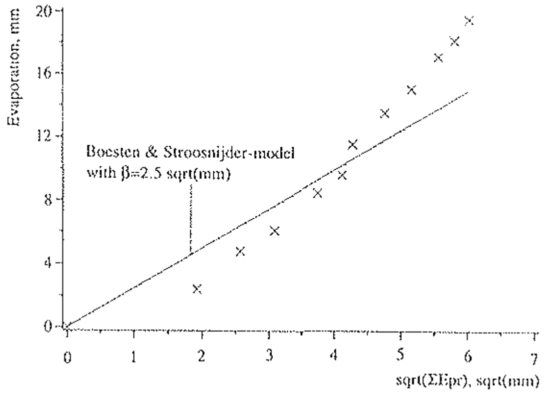

Figure 5 Accumulated evaporation in the falling rate stage of evaporation (Plauborg, 1994b).

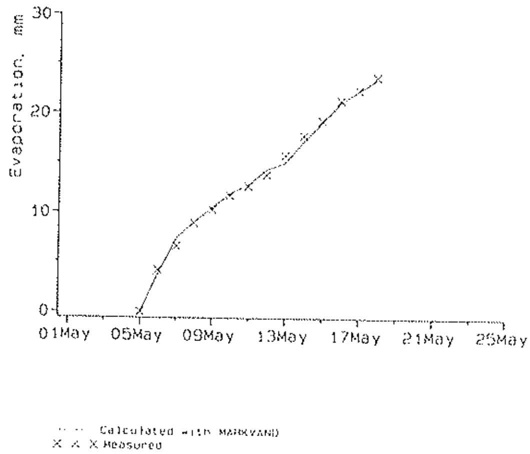

Figure 6. Accumulated evaporation. Data from 6-18 May used for calibration (from Plauborg, 1994b)

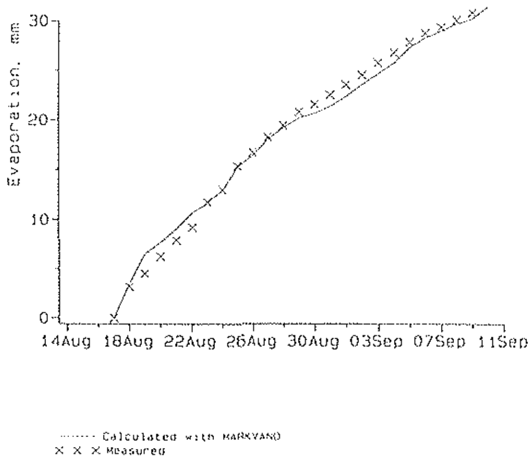

Figure 7. Accumulated evaporation. Data from 18 August to 9 September used for validation (from Plauborg, 1994b)

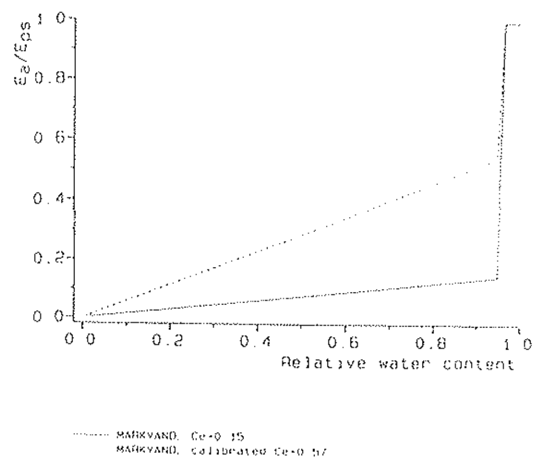

Figure 8. Evaporation function in MARKVAND, standard and calibrated (from Plauborg, 1994b)

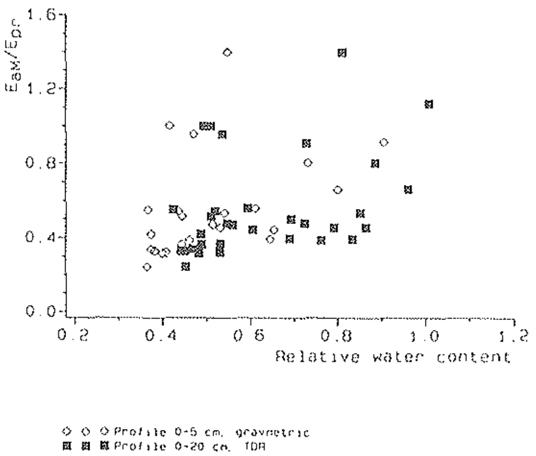

Figure 9. Relativ evaporation plottet against relativ available soil water content (from Plauborg, 1994b)

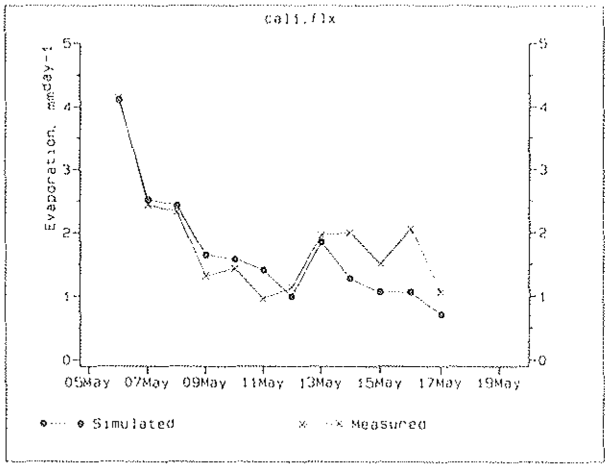

Figure 10 Calibration of the phusically based model SWEAT (Plauborg, 1994C).

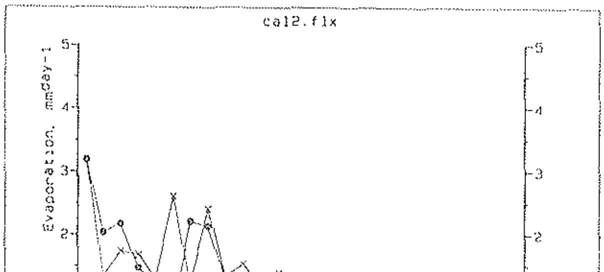

Figure 11. Validation with the physically based model SWEAT (Plauborg, 1994c).

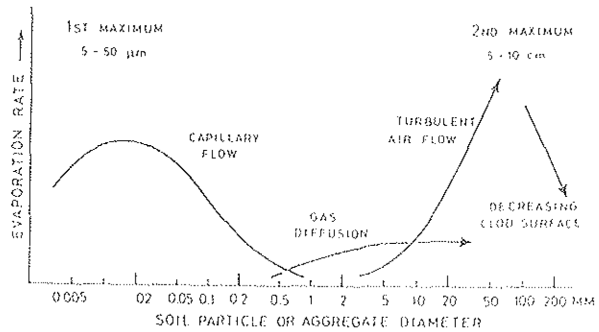

Figure 12. A scematic presentation of relative evaporation losses and water transport processes in relation to aggregate size (from Heinonen, 1995).

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EVAPOTRANSPIRATION FROM AGRICULTURAL CROPS

In 1955 measurement of agroclimate were initiated at The Climate and Water Balance Station, Højbakkegård, Tåstrup. Besides parameters as temperature, humidity, wind speed and precipitation, normally observed at meteorological stations, the measurements includes radiation balance components, evaporation from free water surface and potential evapotranspiration from short grass.

Actual evapotranspiration E_a plays an important role in the water and energy balance of the earth surface. E_a from different fields crops have been measured in the growing season (April-October), mainly in the period 1969 to 1980. In order to evaluate the climatical effect on E_a the Daisy model was used to simulate E_a for a 30 year normal period.

Daisy is a mathematical model for simulation of crop production, and soil water and nitrogen dynamics in crop production at various agricultural management practices and strategies, (Hansen *et al.* 1990, 1991). The hydrological processes considered include snow accumulation and melting, interception of precipitation by the crop canopy, evaporation from crop and soil surfaces, infiltration, water uptake by plant roots, transpiration and vertical movement of water in the soil profile. E_a is based on a climatical determed potential evapotranspiration, the availability of water, and crop production and canopy development from emergency to harvest, described in terms of temperature sum and solar radiation.

E_a was simulated for four crops: Grass, Winter Wheat, Spring Barley and Beet, and two soils: Sand and Loam, for the period 1964–1993. The soils are defined by one set of retention and hydraulic conductivity curves for the soil profile. Maximum root zone capacity and root depth for Sand was 130 mm (pF 1.7–4.2) and 60 cm, and for Loam 185 mm (pF 2.0–4.2) and 90 cm.

Meteorological input are daily values of solar radiation, air temperature, precipitation P and potential evapotranspiration EP, calculated according to the Penman equation with radiation data for short grass. Annual mean of P is 603 mm, ranging from 415 to 742 mm. For EP it is 578 mm, ranging from 486 to 649 mm. From april to august monthly mean of potential net precipitation (P-EP) is negative.

Mean annual E_a simulated for the four crops were of the same size, a result too found in actual field measurement. For Sand E_a varied from 358 mm (Barley) to 372 mm (Grass), for Loam from 441 mm (Beet) to 468 mm (Wheat). Lowest E_a found in 1976 was 245 mm (Sand) and 345 mm (Loam). Highest E_a was approx. 420 mm and 500 mm for the two soils. The standard deviation of E_a was highest for crops on Sand soil. For Sand E_a from Barley and Beet was allays lower than Grass, up to 40 mm. For Loam only Wheat E_a was higher than Grass, up to 50 mm.

Mean monthly E_a from Beet reached for both soils maximum in July and were higher than E_a from the other crops in the rest of its growing season. In generally E_a for all crops and both soils followed the development of leaf area index. Daily E_a in years with low P and normally high EP showed in the growing season a strong dependency of the availability of soil water in the root zone.

References.

Hansen, S., H.E. Jensen, N.E. Nielsen and H. Svendsen, 1990: Daisy. A Soil Plant System Model. Danish Simulation Model for Transformation and Transport of Energy and Matter in The Soil Plant Atmosphere System. NPO-Research Report N0. A 10. The National Agency of Environmental Protection. Copenhagen, Denmark.

Hansen., H.E. Jensen, N.E. Nielsen and H. Svendsen, 1991: Simulation of nitrogen dynamics and biomass production in winter wheat using the Danish simulation model Daisy. Fert. Res. 27:245-259.

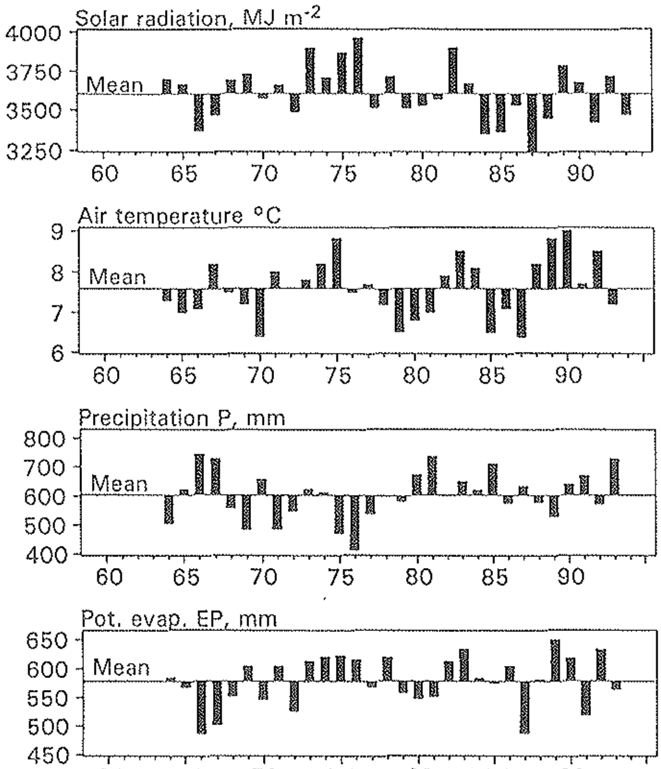

Fig. 1. Annual values of solar radiation, air temperature, precipitation and potential evapotranspiration 1964-93.

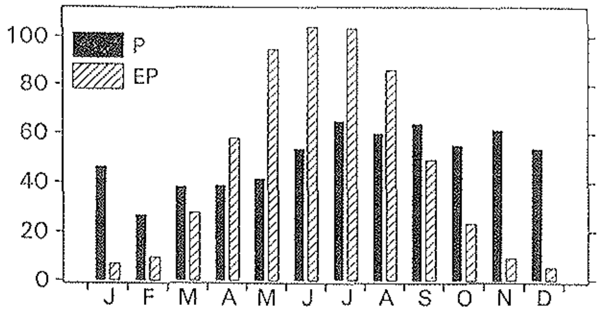

Fig. 2. Mean monthly values of P and EP 1964-1993, mm

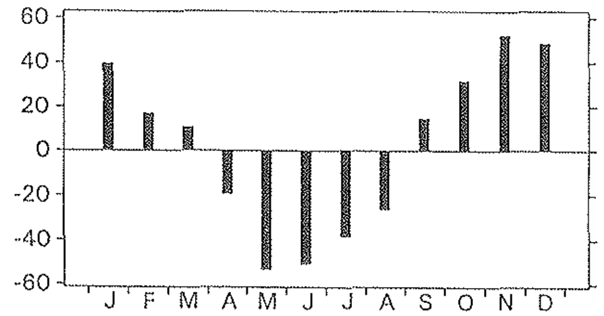

Fig. 3. Mean monthly values of P - EP 1964-1993, mm.

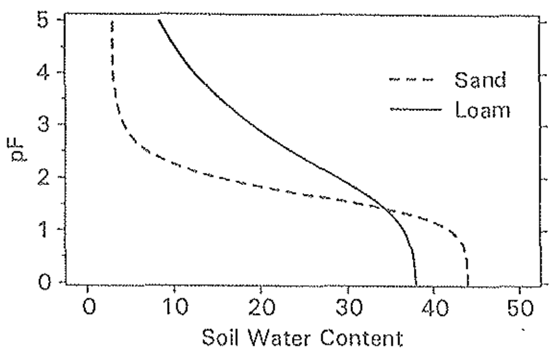

Fig. 4. pF values for Sand and Loam soil.

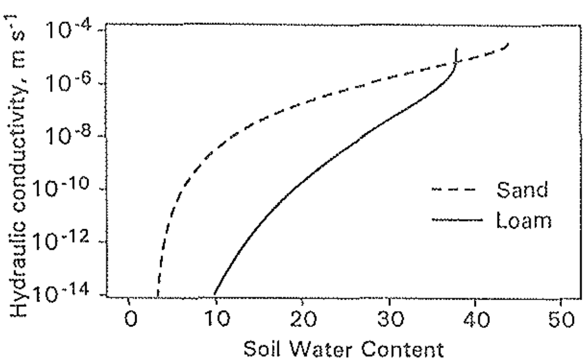

Fig. 5. Hydraulic conductivity for Sand and Loam soil.

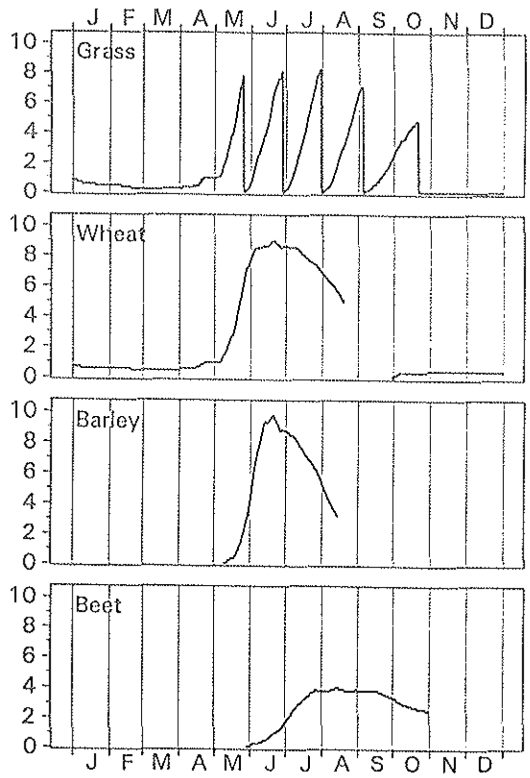

Fig. 6. Crop Area Index for four crops on Loam soil in 1985, a year with high actual evapotranspiration.

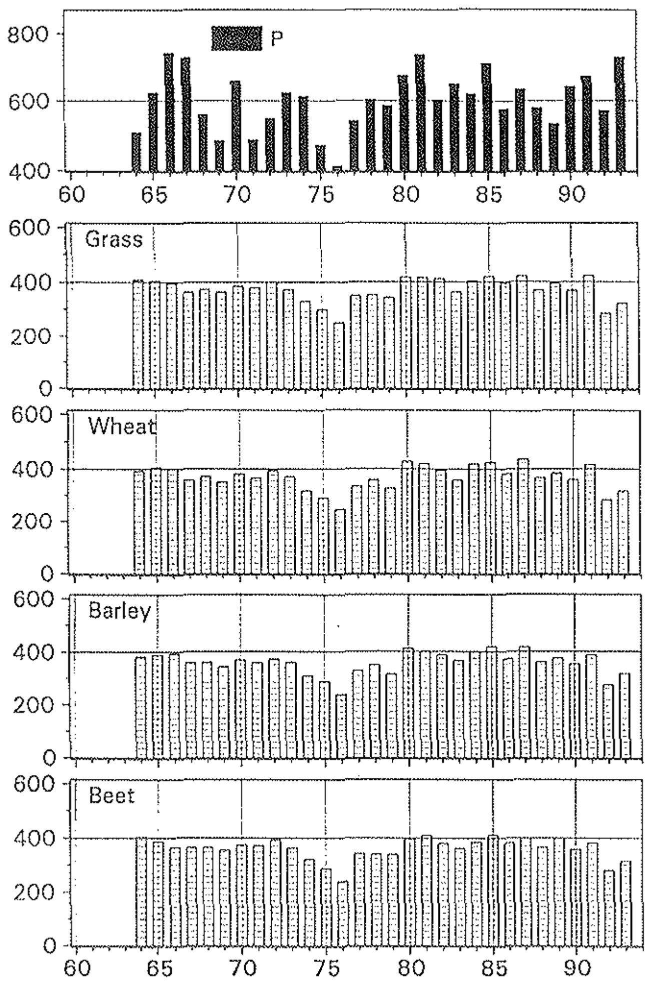

Fig. 7. Annual P, and E_a for crops on Sand soil, mm.

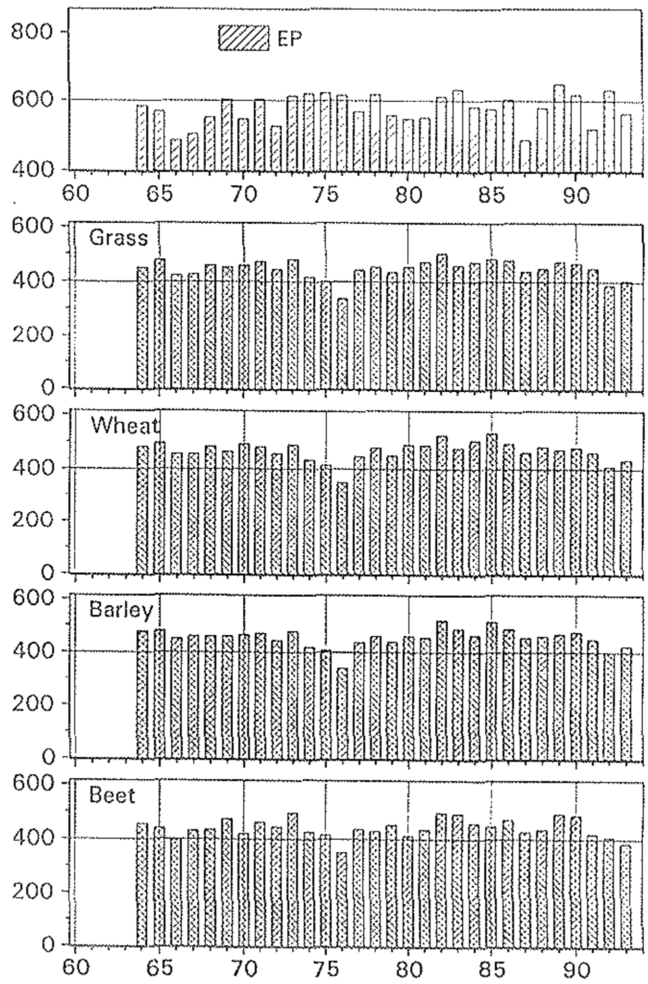

Fig. 8. Annual EP, and E_a for crops on Loam soil, mm.

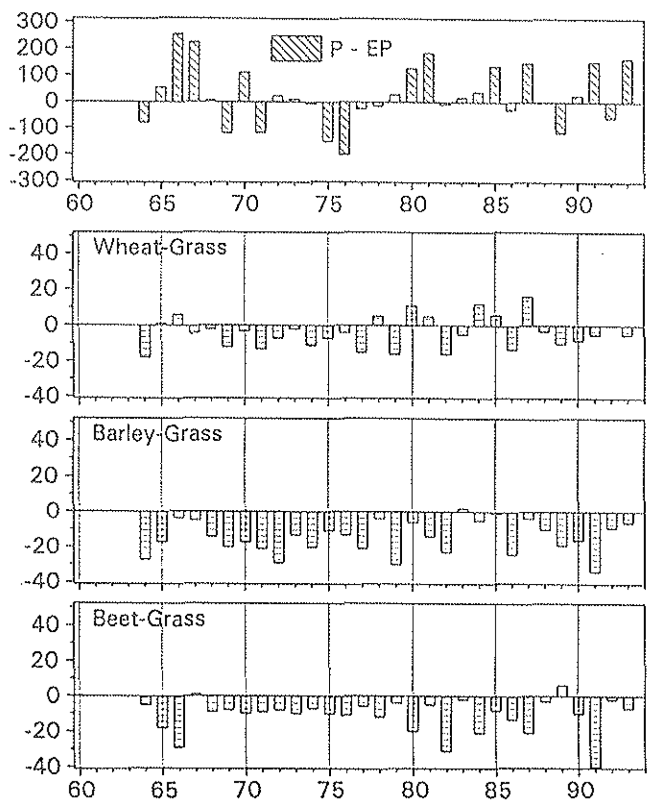

Fig. 9. Annual differences of P - EP, and E_a for crops on Sand soil, mm.

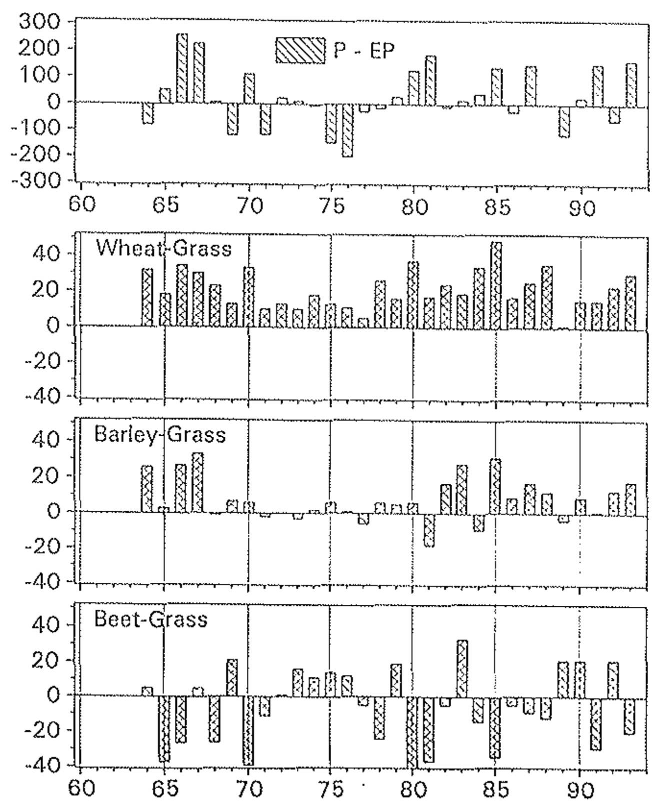

Fig. 10. Annual differences of P - EP, and E_a for crops on Loam soil, mm

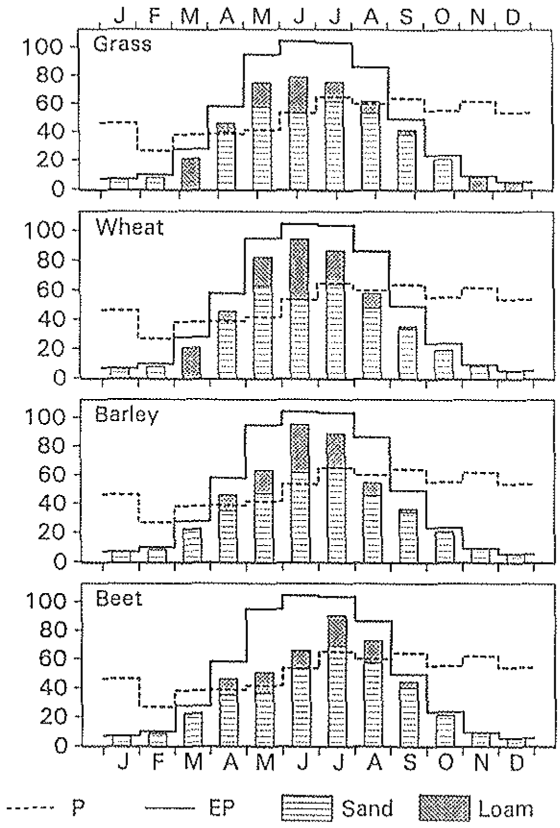

Fig. 11. Mean monthly values, 1964-1993

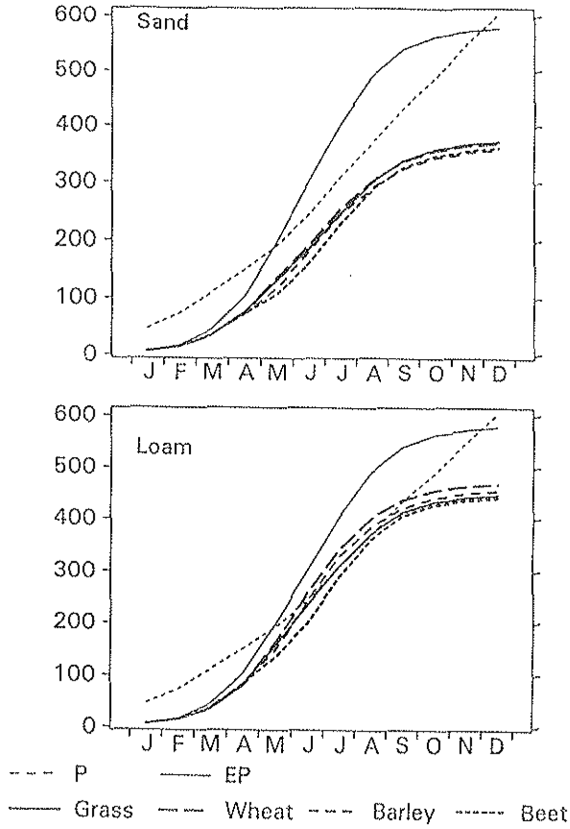

Fig. 12. Cummulated mean monthly values, mm.

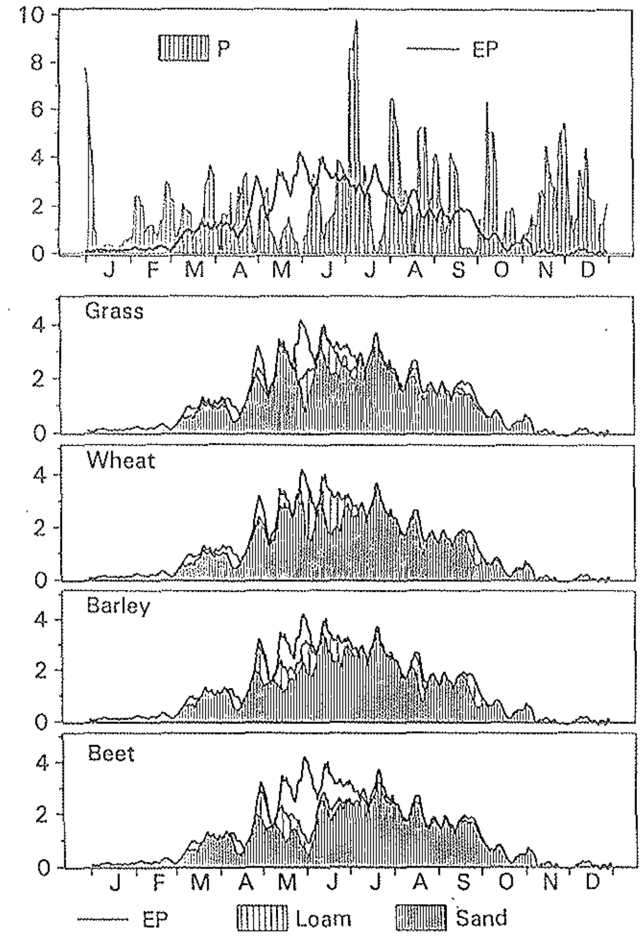

Fig. 13. 7-days moving average of daily P, EP and E_a 1966.

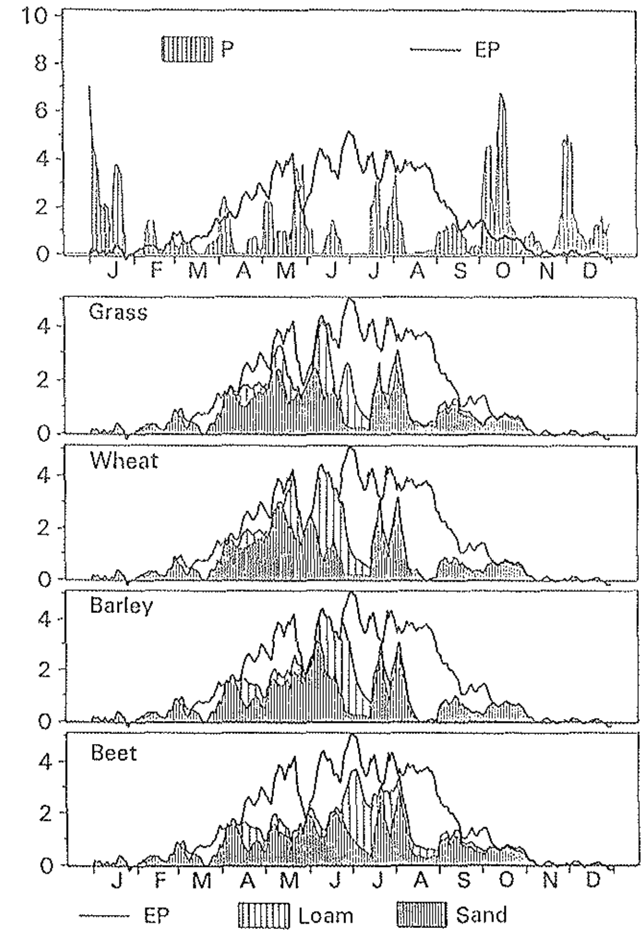

Fig. 14. 7-days moving average of daily P, EP and E_a 1976.

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TRANSPORT OF WATER AND SOLUTES IN THE UNSATURATED ZONE

In order to optimize crop production and at the same time minimize nutrient losses, or to predict environmental impact from different land use, it is important to both measure and model transport of water and solutes in the unsaturated zone.

For simulation of water transport one needs the knowledge of water content vs matric potential for the different layers of the soil. This relation (the water rentention curve, WRC) is determined in the laboratory or in the field. Although beeing a well established procedure it is quite time consuming to determine the WRC. The hydraulic conductivity for the soil as a function of either water content or pressure head is also needed. Experimental determination of this parameter is tedious, and no routine in applied research. Water retention and hydraulic conductivity could also be predicted from grain size and bulk density data. Predicted data are of course not as accurate as experimental data.

Matric potential is measured by tensiometers, which could be equipped with electrical transducers connected to a data logger. One main problem with tensiometers is their sensitivity to freezing. The standard method for measurement of water content in the field is the use of neutron probe. Although robust and reliable this method requires personel on spot for all measurements. For some years it has been possible to measure water content by the TDR-method. The use of multiplexing and automated evaluation makes it possible to "continuously" and easily monitor the water content in soil profiles also under freezing conditions. The use of electrical measurements of both matric potential and water content makes it possible to measure in remote locations, and continuously register extreme events when they do occur. It is also possible to obtain on line information by connecting the logger or TDR-unit via a modem and a telephone line (or mobile phone) to a PC at the office.

The transport of solutes is more complicated to get information on. Sampling of water for analysis is both time consuming and costly. In addition precipitation and rapid changes of water content in soil influences mobilization of pollutants. The time of sampling is important to detect events of potentially high leaching. When modelling solute transport the dispersion parameters of the soil must be determined, which is not a trivial task. Generalized information on dispersion parameters of soils are comparatively scarce. In addition to the difficulties recognized above comes the spatial variability of the different soil parameters as well as the influence of preferential flow paths and macropore flow. This will however be dealt with in other sessions of this meeting.

One study on the influence on dispersion parameters from soil characteristics and different water contents has been performed and will briefly be presented .

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PREFERENTIAL FLOW IN A SANDY SOIL

Soil structural features or macropores (e.g. cracks, worm channels, root holes) can cause rapid non-equilibrium or 'preferential' flow of water and solutes. This macropore flow may be especially significant in structured clays, where the soil matrix is relatively impermeable. Preferential flow also occurs in coarse-textured sandy soils, but for different physical reasons such as heterogeneity (e.g. textural lenses, soil layering), hysteresis and hydrophobicity. This paper presents some preliminary results of plot tracer experiments carried out in a layered sandy soil in Halland, Sweden, to investigate and quantify the impact of preferential flow pathways on solute transport.

Materials and Methods

The field site consists of two tile-drained (7 m spacing, 90 cm depth) plots, each 0.09 ha in size. Drain flow is continuously measured by tipping buckets connected to dataloggers. Flow proportional drainage water samples are collected for water quality analyses. In addition, 20 ceramic suction cup samplers installed in the plots at two depths (50 and 90 cm) are sampled weekly. Potassium bromide was applied to the plots in September 1992 at a rate equivalent to 1.68 g Br^- m^{-2}. Bromide concentrations in soil and drainage water were then measured during the following 16 months, until concentrations fell below the detection limit.

The occurrence of preferential flow is demonstrated here by comparing field measurements with the uncalibrated predictions of a physically-based deterministic transport model based on Richards' equation and the convection-dispersion equation.

Results and Discussion

The model satisfactorily predicted the accumulated drain discharge and the overall soil water balance. However, the temporal dynamics of drain discharge could not be reproduced, in that observed drain hydrographs were much peakier than those predicted. Peak water flows were rapidly transmitted through the profile with little attenuation, indicating preferential flow. The model also failed to reproduce the rapid breakthrough of Br^- to the suction cups at 90 cm depth. Instead, the Br^- concentrations predicted at 50 cm depth closely matched those found at 90 cm. Br^- concentrations measured in drain flow were smaller than those measured in suction cups at the same depth, again suggesting the existence of two pore systems with contrasting chemical signatures. Br^- leaching to drains was overestimated by the model, largely due to an overestimation of concentrations in the second winter season. This was attributed to a loss of Br^- in lateral groundwater seepage, which is not accounted for in the model.

The causes of the preferential flow behaviour at the Mellby field site are as yet uncertain. The topsoil is known to be slightly water repellent which may generate unstable wetting fronts. The soil is also texturally layered (sandy loam over loamy sand) which may lead to 'fingering' at the horizon interface. The subsoil is also highly heterogeneous, with coarser sand and clay lenses. Understanding and modelling such a complex system will certainly be a challenge and is the subject of ongoing research.

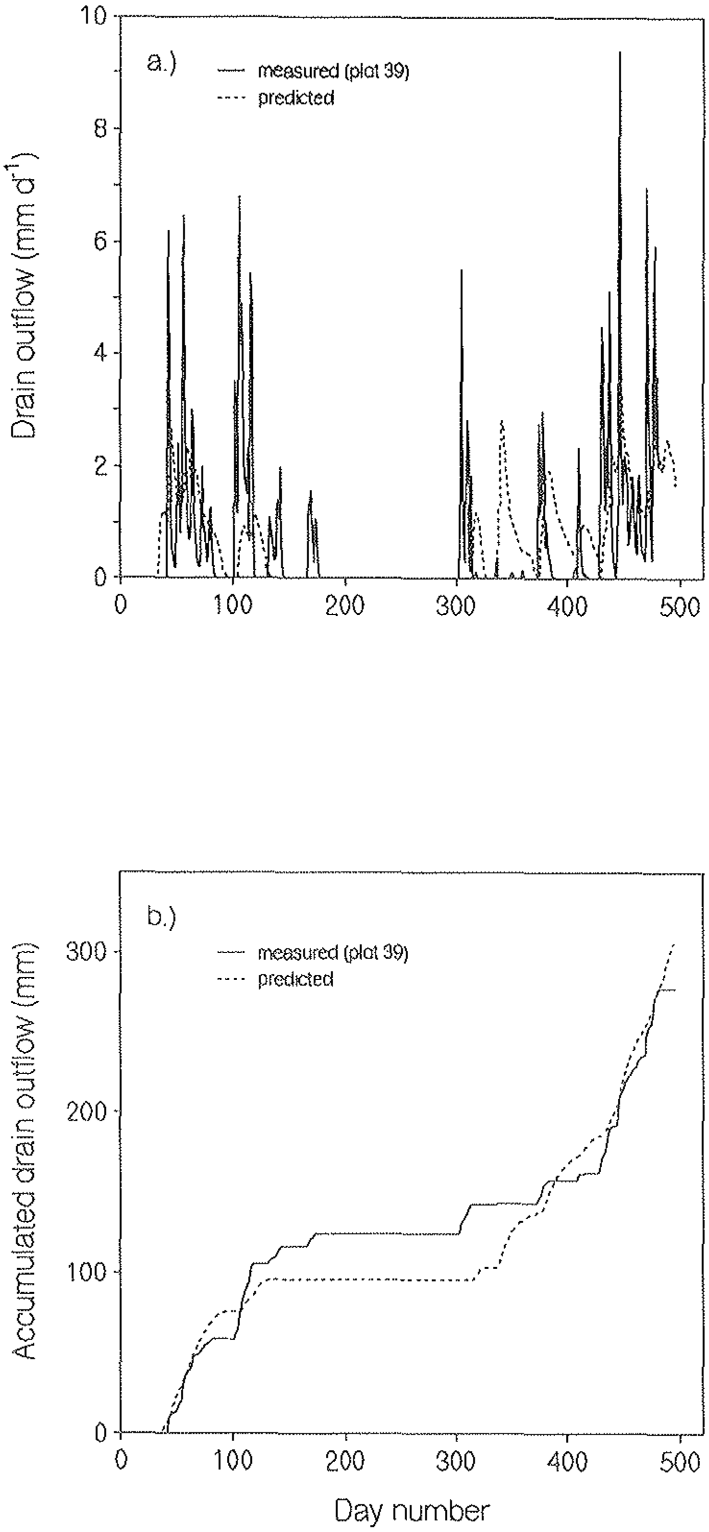

Figure 1 Measured and predicted drain flows a.) rates b.) accumulated (Day 1 = 1st October 1992)

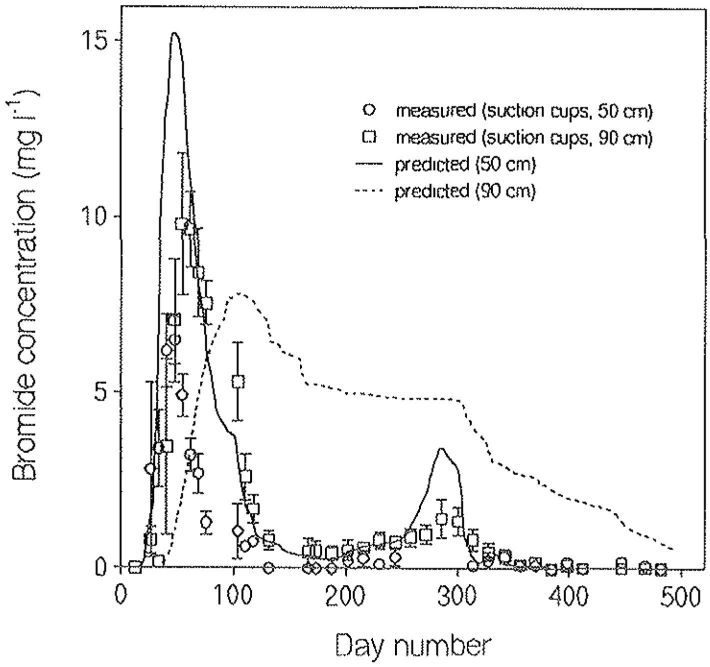

Figure 2 Measured and predicted bromide concentrations in soil water (Day 1 = 1st October 1992)

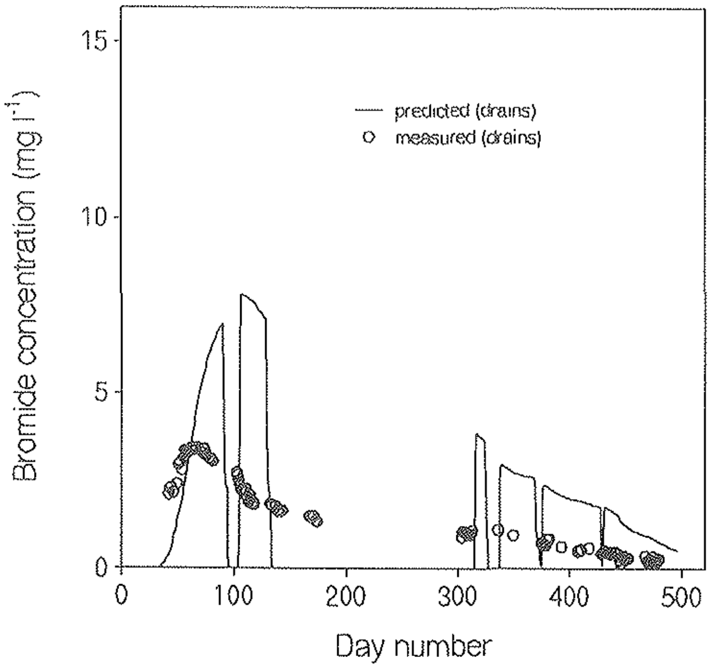

Figure 3 Measured and predicted bromide concentrations in drainage water (Day 1 = 1st October 1992)

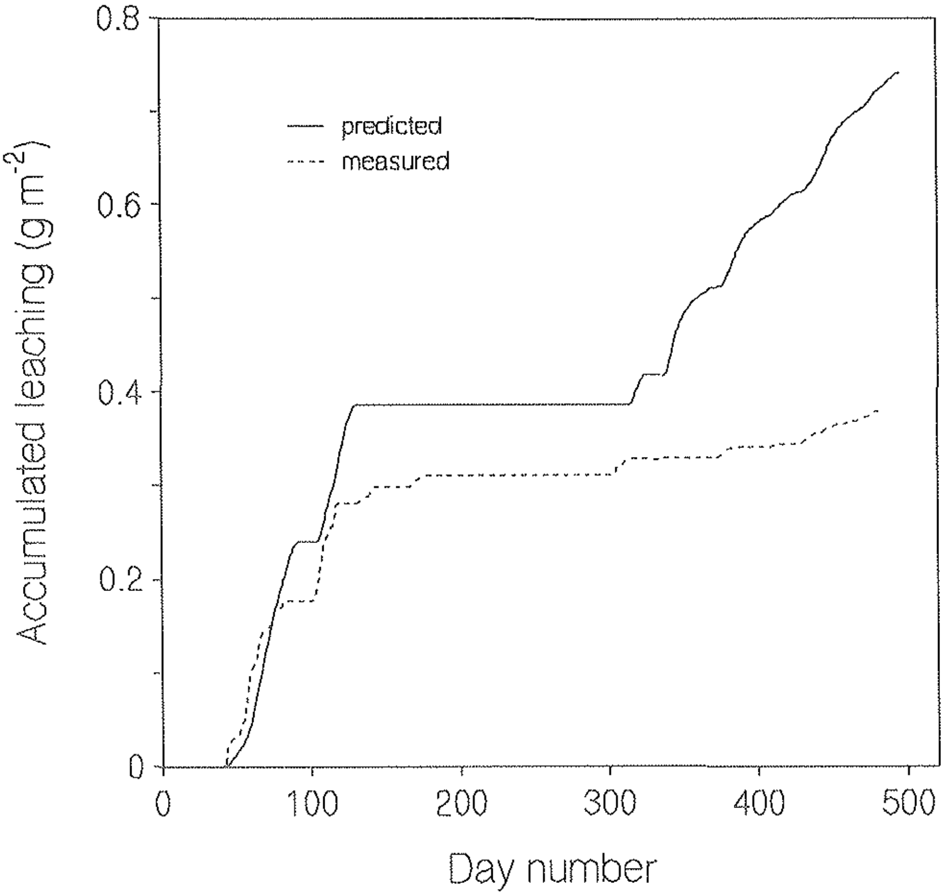

Figure 4 Measured and predicted bromide leaching to drains (Day 1 = 1st October 1992)

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TRANSPORT OF WATER IN HETEROGENEOUS SOILS: A FIELD STUDY OF FLOW PATTERNS

Field studies with application of both weakly and moderately adsorbing tracers to the soil surface have shown that the amount of water and solutes transported through the root zone, as well as transport velocities, can be greatly increased owing to preferential flow. The macropore structure is often a prime cause but other factors such as differing initial and boundary conditions may also predispose a soil to produce bypassing of infiltrating water. The interaction between states and processes regulating the spatial structure of flow patterns in soil is not well understood.

Dye-tracing field experiments were carried out to assess flow pathways of water in different Danish soils with different initial moisture content and with different soil structure in the top layer. 25 mm of water containing 4 g l^{-1} of the weakly adsorbing dye Brilliant Blue (C.I. 42090) were applied within 60 minutes onto each plot (1.6 by 1.6 m). The plots were excavated one day after water application. The spatial structure of flow patterns were examined on vertical and horizontal 100 by 100 cm soil profiles. The following statements and conclusions are based on a preliminary analysis of the results:

* Distinct dye patterns showed preferential flow in all investigated soil types, ranging from a coarse sandy soil developed on an outwash plain to sandy loam soils developed on moraine.
* Dye penetrated to larger depths in structured soils than in nonstructured soil.
* Initial moisture content had a less pronounced effect on flow patterns than soil structure. Dye penetrated to larger depths in wet soils than in dry soils.
* Experiments conducted in the spring after conventional seedbed preparation on autumn ploughed structured sandy loam soils showed, generally, dye penetration to depths between 100 and 150 cm. The maximum depth of penetration and the amount of preferential flow channels was smaller on these soils when examined right after harvest.
* Continuous preferential flow pathways reaching a depth of more than 1 m in wet, structured soils were made up, exclusively, by cracks created by the plow (in the top soil) combined with worm holes below ploughing depth. A few cracks were activated as major preferential flow pathways below ploughing depth in these soils when examined in a very dry condition right after harvest.
* The soil structure after ploughing, combined with surface relief and conditions in the boundary layer between tilled and untilled soil, seem often to impose a sort of scale on the flow patterns.
* Rotary cultivation to a depth of 5-7 cm significantly reduced the number and depth of active preferential flow channels. Rotary cultivation to a depth of 15 cm prevented the activation of preferential flow channels in the sub soil.

The results exemplify the complicated patterns of water and solute movement with high spatial resolution. A major drawback of the applied method is the necessity of excavation which means that experiments cannot be repeated at the same location. A quantitative estimation of the significance of preferential flow is not possible based on the present experiment.

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MACROPOROSITY AND WATER MOVEMENT UNDER DIFFERENT TILLAGE PRACTICES

Reduced tillage is recommended as a management method to reduce erosion and phosphorus runoff to surface waters. The better control of erosion in reduced tillage is usually ascribed to the crop residue cover on soil surface, which protects soil against raindrop detachment and surface runoff. A satisfactory macroporosity and pore continuity are also important to reduce the amount of surface runoff, especially on clay soils with low water permeability.

Bulk density and penetration resistance in the middle and lower parts of the top soil are usually greater and porosity lower under reduced tillage than ploughing. This may result in lower infiltration, and subsequently, higher runoff. Obviously, this may be the case during the first years after new tillage methods are introduced. However, there may be a transition period after which water infiltration is improved in unploughed soil. The formation of continuous macropores, especially biopores such as earthworm burrows, seems to be a major factor in this process.

Several studies have shown that reduced tillage favours earthworms, particularly deep burrowing species, such as *Lumbricus terrestris*. The surface opening and continuous burrows of *L. terrestris* are considered to be the most important channels for preferential flow of water and solutes. The burrows of other earthworm species can be relatively continuous, and may also contribute markedly to water movement in soil. Earthworm burrows and other continuous macropores, like cracks and voids, apparently counteract the higher compactness in the top layer of unploughed soil. A well operating drainage reduces the risk of soil compaction in reduced tillage, and apparently hastens the the formation of continuous pores. Increased aggregate stability at the surface of unploughed soil may also improve macropore continuity by reducing slaking.

Morphological measurements of macropores, and the study of their spatial distribution are useful to understand and model the significance of macropores for soil processes, especially for preferential water flow, under different tillage systems. Preliminary results have shown that the pattern of earthworm burrows is random under reduced tillage. Similarly, the water flow has had a random character at short distances. On ploughed soil, with more intensive and deeper tillage, the pattern of burrows may be different, and subsequently the characteristics of preferential flow. The consequences of the possible differences in water flow under reduced tillage and ploughing are discussed.

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LEACHING AND TRANSFORMATIONS OF NEWLY APPLIED FERTILIZER NITROGEN IN SOIL AFTER HEAVY RAINFALL

Leaching of nitrogen occurs when a large amount of water drains through a soil with high nitrate N content. These two preconditions are met if fertilizer application in spring is followed by heavy rain. To study what proportion of applied fertilizer can be leached in these circumstances, a laboratory study was done by applying ^{15}N-labelled fertilizer to intact soil cores followed by a simulated heavy rainfall.

Eight undisturbed cores in PVC pipe (19 cm i.d., 60 cm long), were collected from a sandy soil, a clay soil and a peat soil at the end of May. The cores were obtained by placing a cutting tip to a 65 cm piece of the pipe and hitting by a large plastic hammer. The cores were prepared for collection of drainage water and brought to a room with 5 °C temperature. The soils were brought to maximum water-holding capacity. After drainage ceased, calcium nitrate solution 10 atom-% ^{15}N-labelled at a rate equivalent to 120 kg/ha N was injected to a depth of 5 cm in four cores of each soil. After two weeks the rest of the four cores of each soil were fertilized similarly. Deionized water was applied to the columns an amount corresponding to 70 mm rain during two days. Drainage was collected daily, and the ^{15}N content in the water was determined. After drainage ceased, in seven days, the columns were sectioned into 6 cm (topsoil, 0-24 cm) and 9 cm segments (subsoil, 24-60 cm). The earthworm channels were counted, and macropores of each soil segment were determined. Also the total ^{15}N content and ^{15}N content in the mineral N of each segment were determined.

Most of the water applied to the columns percolated through the soil in two days. When simulated rain was applied immediately after fertilizer application, a total of 30 %, 20 %, and less than 0.1 % of the applied N was leached in sand, clay, and peat, respectively. When rain was applied two weeks after fertilizer application, the amount of leached N was reduced by 1/3 in sand and by about 2/3 in peat. In clay soil, incubating the fertilizer in the soil seemed to increase leaching. However, the result of clay is based only on three cores out of eight. The other five cores were impermeable, so that no drainage was observed. Also in the three permeable clay soil cores, a large variation in permeability was observed explaining the illogical results. After the first day of drainage, the concentration of fertilizer N in the water from all the cores was rather constant. High content of unlabelled N in the drainage from the peat soil compensated the low content of fertilizer N. As a result, the differences between the three soil types in the total amounts of nitrogen leached were smaller.

In all of the columns, the highest content of fertilizer N was found in the segment 12-18 cm. Incubating the soils with fertilizer had only a minor effect on the depth of movement of the fertilizer N frontier. The most important factor affecting the distribution of fertilizer N in the column was soil type. In sandy soil and in those clay soil columns that were permeable, the frontier had reached the lowest segment of the column. In those clay soils that were impermeable, the frontier was stopped by the impermeable layers. In peat soil, the frontier reached the segment 24-33 cm. Almost all of the fertilizer N remaining in the soil was in inorganic form. This indicates that the decrease in the total amount of leaching of fertilizer N by two-week incubation was caused by diffusion of inorganic fertilizer N in the soil in stead of biological immobilization.

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NITROGEN LEACHING UNDER DIFFERENT WATER REGIMES IN A 4-YEAR LYSIMETER EXPERIMENT.

In 72 weighing type lysimeters (diam. 80 cm and depth 110 cm), containing 4 different soil types, the interaction effects of irrigation and fertilizer rates (30, 95, 160 kg N ha^{-1}) on nitrogen leaching, barley yield, and evapotranspiration were investigated. The rainfall during May to July in the 1990 and 1991 years was near normal, whereas the 1992 and 1993 seasons were relatively dry. The effects of irrigations are, therefore, reported separately for the two first and the last two years.

On average for the first two years 100 and 80 mm irrigation water increased the evapotranspiration with only by 15 mm at the 30 kg N ha^{-1} which increased to 46 mm at the highest fertilizer rate (160 kg N ha^{-1}). The corresponding values for the leaching volumes of the added water was 75 and 43 mm. In the last two years(1992 and 1993) , the evapotranspiration, on average for the two years, increased to 72 and 99 mm at the two above mentioned fertilizer rates and the leaching volumes decreased to 29 and 19 mm. This was caused by high yield responses to the applied irrigation of 120 and 100 mm in 1992 and 1993, respectively. The irrigations, 4-6 times at the rate of 20 mm each, were given before the middle of July, whereas the increased leaching from applied irrigation generally appeared during the autumn rain. A hysteresis effect was observed during the drying-rewetting processes of the soil.

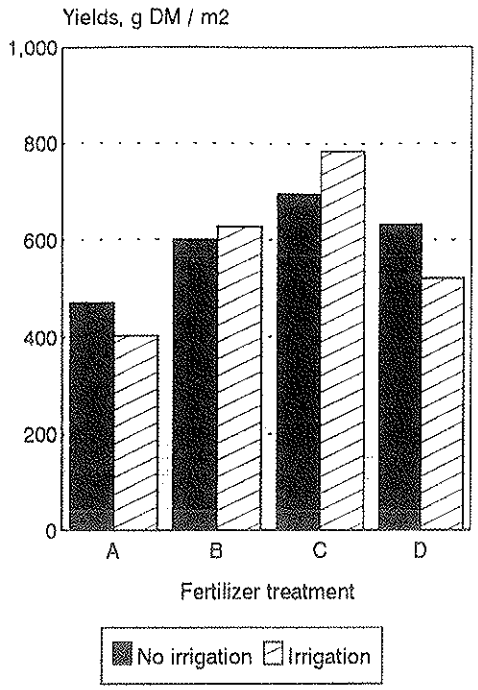
As a consequence of higher yield levels at the increasing fertilizer application rates, nitrate leaching decreased in some cases. The overall means of nitrate leaching were 26.5, 24 and 23.5 kg N ha^{-1} y^{-1} at the fertilizer rates of 30, 95 and 160 kg N ha^{-1}, respectively. The nitrogen leaching losses were smallest in a sandy soil and largest in a sandy loam, morainic soil apparently due to high off-season N-mineralization in the later soil. Two clay soils, either as monoliths (undisturbed) or as in-filled cylinders (1989) gave somewhat higher leaching losses of nitrogen than did the sandy soil, but the nitrogen losses in the clay soil were less than the sandy loam, morainic soil.

Irrigation with 80-120 mm increased the nitrate leaching in most of the years, in all soils and at all fertilizer rates, although the total effect of irrigation on nitrogen losses were generally small, averaging < 4 kg N ha^{-1} y^{-1}.

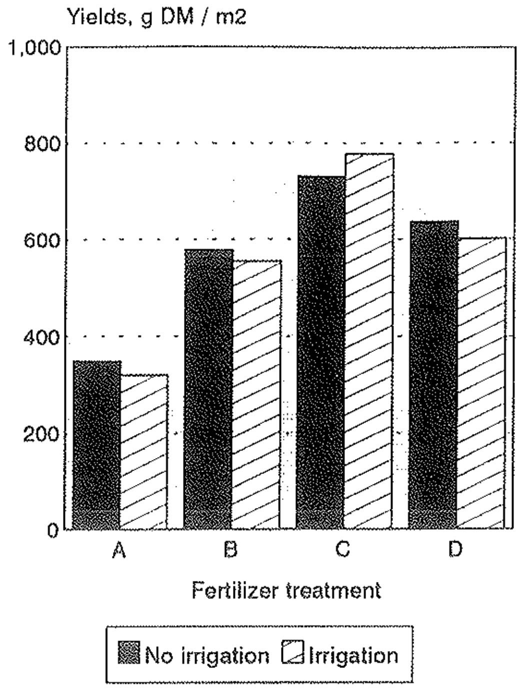
It is concluded that the very high yield levels in this lysimeter experiment resulted in small nitrogen losses by leaching.

Barley yield. Averages of 4 soils

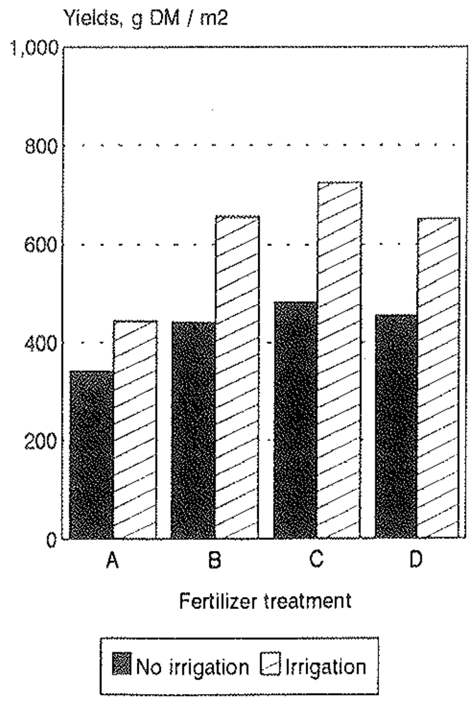
1990



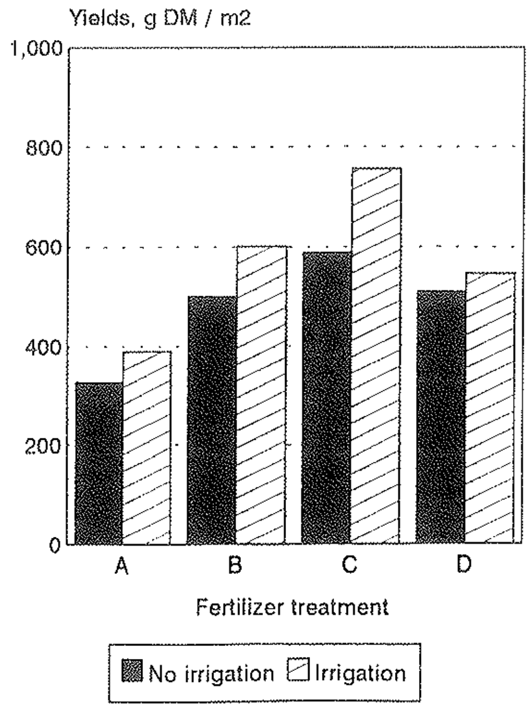
1991



1992

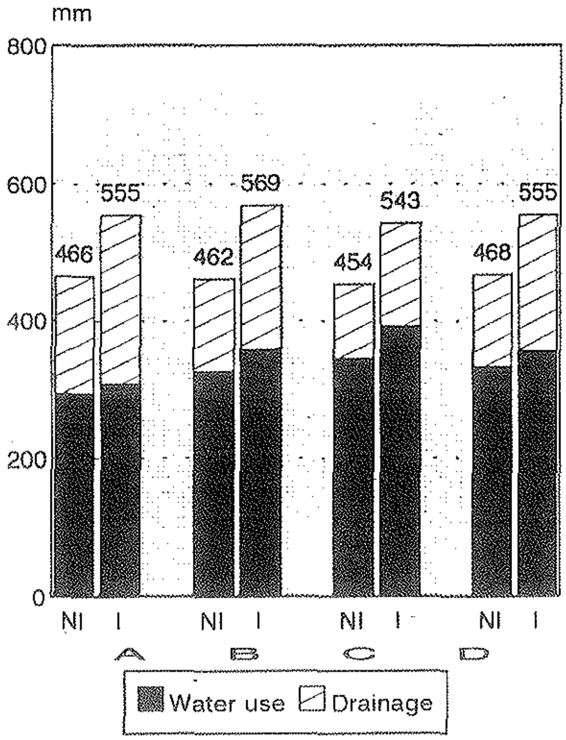


1993

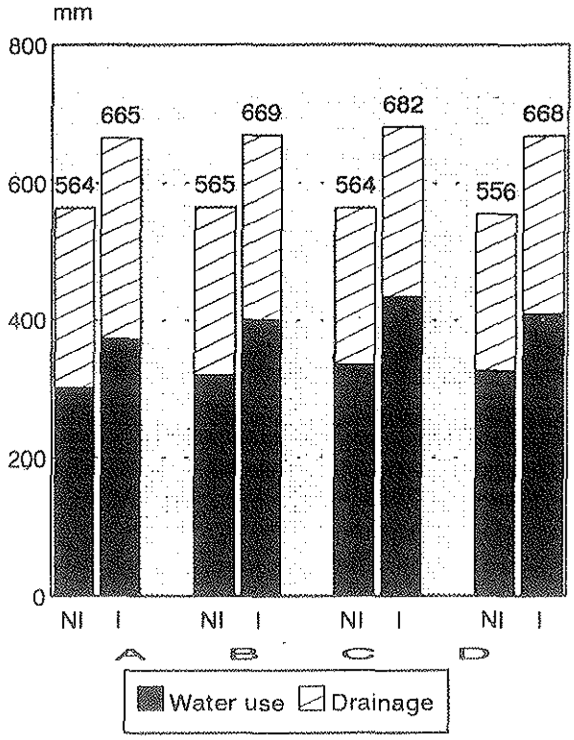


Water use and drainage

1990-1991



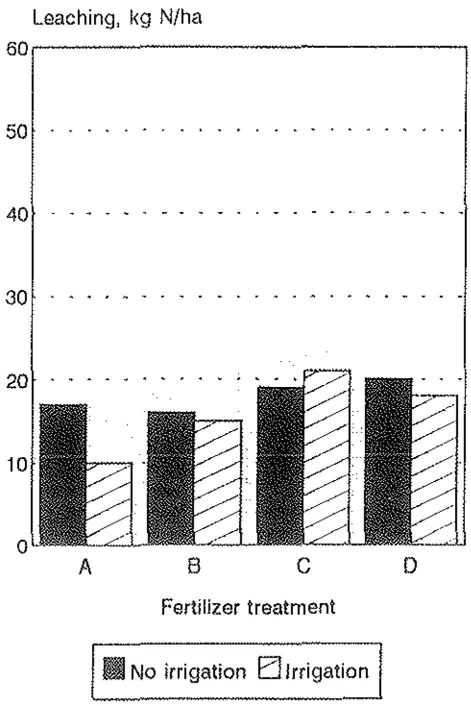
1992-1993



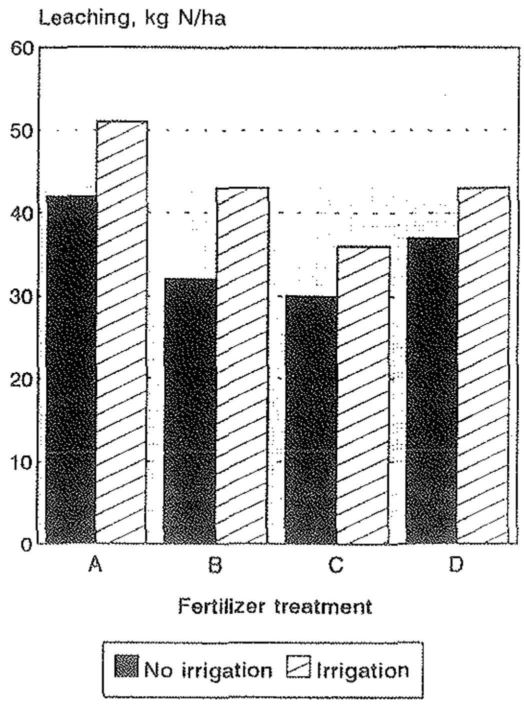
NI = No Irrigation
I = Irrigation

Nitrate leaching, 4 years average

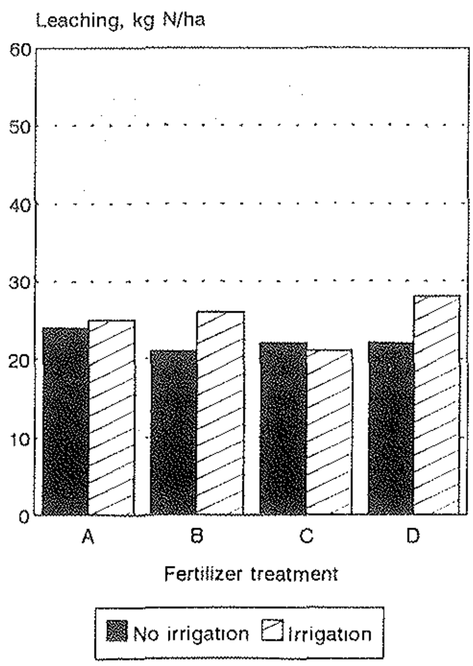
Sand



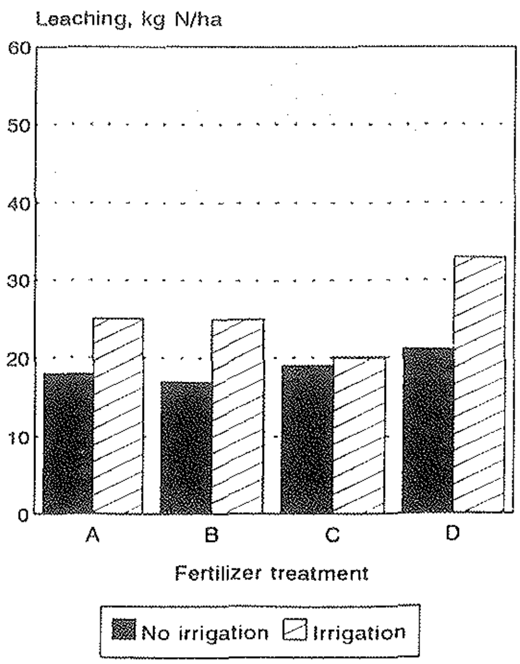
Sandy loam

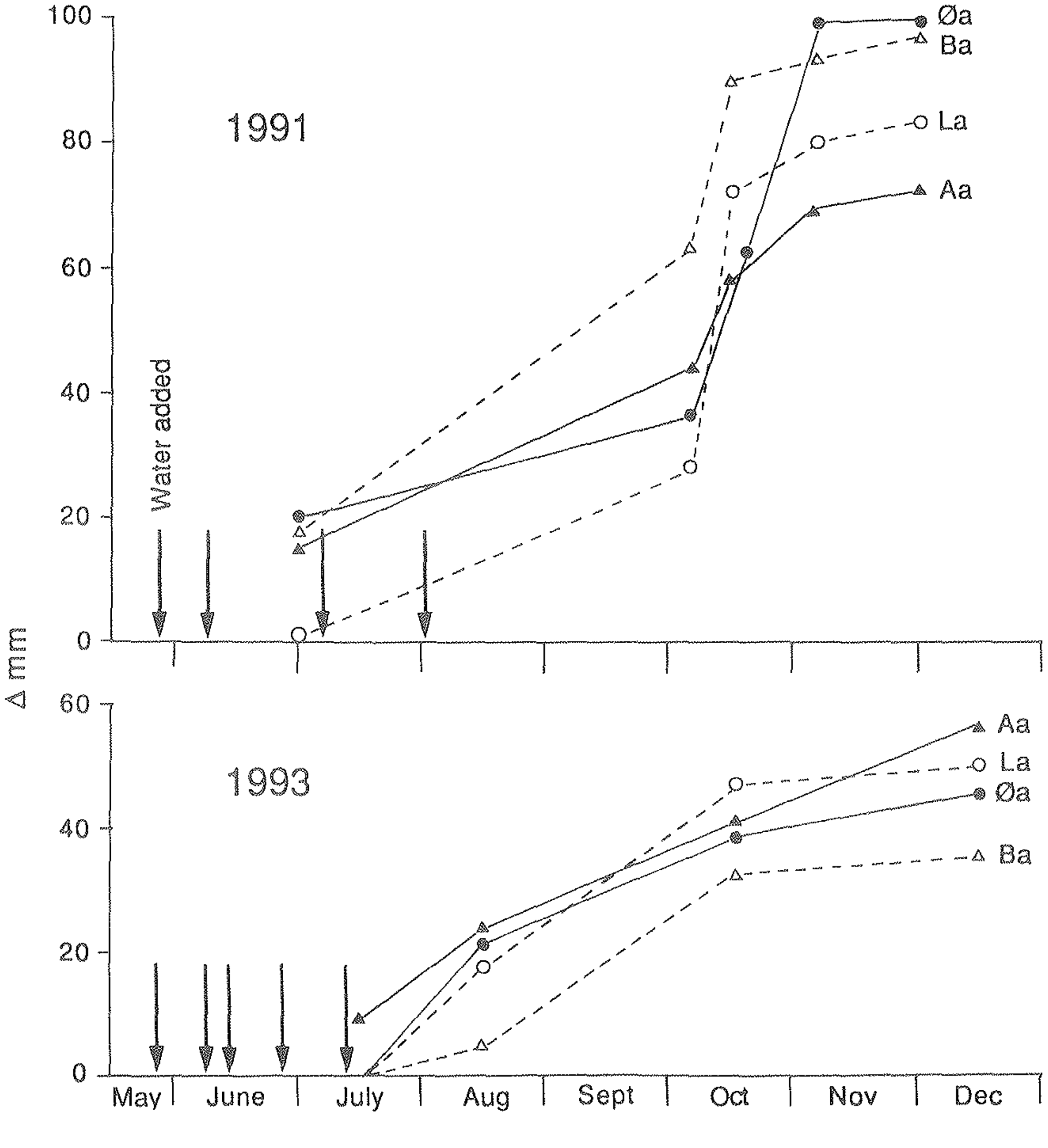


Silt loam



Silty clay loam





Additional runoff from irrigations at the lowest fertilizer rate (a). Summation curves for 1991 and 1993. A = sandy loam, L = sand, B = silt loam, Ø = silty clay loam.

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IRRIGATION NEEDS AND STRATEGIES ON SOILS OF SOUTH-EAST NORWAY

Rainfall deficits occur during the period May-July in many, but not all, years in south-east Norway, which is the country's major agricultural region. Farmers require information on when and how much to irrigate their crops, and on the likely yield benefits which may be obtained. Answers to these questions depend upon crop type, development stage, soil type and prevailing weather conditions (evaporative demand).

Drought sensitive growth stages have been identified for a wide range of arable and horticultural crops, using a technique in which drought is imposed at different stages of growth by means of mobile shelters. Yields from these treatments are compared with those on a fully irrigated control. An irrigation priority ranking of the various crops is given.

Irrigation needs are dependent upon the soil's available water capacity (AWC), which varies with soil texture, humus content and maximum rooting depth. The proportion of AWC which can be utilized before yields start to decline varies to some extent between crops. Arable crops are in many cases more tolerant than vegetable crops with sparser roots. Water balance calculations suggest that considerable savings in irrigation water use, and in consequent drainage losses, may be achieved by withholding irrigation until between 50% and 75% of AWC has been depleted. Whether this is acceptable from the grower's viewpoint depends upon the effects on yield and product quality.

An assessment of likely yield benefits of irrigation has been made using long-term series of weather data. Relative evapotranspiration (actual/potential) has been used as an index to quantify the degree of drought which plants encounter. Different weightings of this index have been found by means of regression against yields measured on field plots subjected to various degrees of drought, expressed in relation to a fully irrigated control. Results have been extrapolated for soil groupings with different AWC.

Assuming a high irrigation intensity and otherwise optimum conditions for crop growth, irrigation may on average be expected to increase yields on the most drought-prone soils by about 30%, 40% and 50% for grass, cereals and potatoes, respectively. Corresponding figures for the more drought-resistant soils are only 8%, 10% and 14%. On the former soils, responses to irrigation may be expected in about 90% of all years, but in only half on the latter soils. Withholding irrigation until 50-75% of AWC has been utilized gives on average about 5% lower yields than high intensity irrigation.

Implications of irrigation for nutrient cycling are generally positive, due to greater fertilizer use efficiency and reduced risk of leaching after the end of the growing season. Exceptions to this rule occur on soils with very low water-holding capacity, when high irrigation intensity is followed by high rainfall incidence. This may cause serious nutrient leaching during the growing season. In such cases fertilizer should be given in split applications, or else irrigation intensity should be reduced.

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Table 1. Mean, maximum and minimum monthly values (mm) of open surface evaporation and rainfall measured during the growing season at Kise, S.E. Norway, over the period 1963-94.

	MAY	JUNE	JULY	AUG.	SEPT.	MAY-SEPT.
EVAPORATION						
Mean	64	85	83	66	40	336
Max.	95	127	137	116	66	473
Min.	36	40	62	46	24	269
RAINFALL						
Mean	42	62	70	72	64	311
Max.	80	179	146	138	153	499
Min.	10	11	5	8	17	174

Table 2. Effects of drought imposed at different times in the growing season, on yield levels of various crops, expressed as percentages of a fully irrigated control treatment.

CROP	EARLY-SEASON	MID-SEASON	LATE-SEASON
Red beet	115	93	88
Carrot	113	78	85
Swedes	104	88	88
Main-crop potato	112	100	84
Semi-early potato	98	82	87
Cabbage	96	86	88
Peas	89	63	89
Squash	88	77	68
Onions	81	83	93
Oilseed rape	98	72	92
Barley	102	74	106
Wheat	82	64	91
Oats	89	75	78

(After Riley & Dragland 1988, 1991)

Table 3. The effect on relative yield levels (% of fully irrigated control) of withholding irrigation until different degrees of soil moisture deficit have been reached. Results based on sheltered trials in which plots received no rainfall.

CROP	DEGREE OF MOISTURE DEFICIT	
	45 mm (50% of AWC)	67 mm (75% of AWC)
Carrot	74	67
Onions	79	72
Swedes	81	73
Wheat	85	81
Cabbage	91	86
Barley	95	89
Potato	96	89

(After Riley 1989 & unpublished results)

Table 4. Classification of droughtiness of some common Norwegian soil types, according to plant available water in the root zone.

DROUGHT CLASS	mm AWC	SOIL TYPES
VERY PRONE	50	Coarse sands and gravels, shallow and gravelly sandy loams.
PRONE	70	Loamy sand, sandy loam, shallow loams and loams/silty clays with low humus content.
MEDIUM	90	Humus-rich loams, clay loams and silty clay loams with medium topsoil depth.
RESISTANT	110	Humus-rich loams and clay loams with deep topsoil, silty loams and shallow peat.
VERY RESISTANT	130	Silt soils, humus-rich, deep silty clay loams and heavy clays, and deep peats.

Table 5. Equations used to calculate relative yields (% of potential) obtainable with varying degrees of relative evapotranspiration (EA/EP) during drought sensitive growth stages.

GRASS	$Y=EA/EP \cdot 100$	(EA/AP for whole growth period)
CEREALS	$Y=30 \cdot (EA/EP)_1+80 \cdot (EA/EP)_2-30$	(1=4-6 weeks 2=7-10 weeks)
POTATOES	$Y=170 \cdot (EA/EP)-70$	(EA/EP 4-14 weeks after emergence)

(After Riley 1989, 1992 & unpublished results)

Table 6. Average yield responses (%), water requirements and consequent extra percolation (mm) assuming irrigation at different levels of soil moisture deficit (% of AWC), calculated for a soil with medium moisture storage capacity (AWC = 90 mm).

CROP	YIELD RESPONSE			IRRIGATION WATER			EXTRA PERCOLATION		
% of AWC:	25%	50%	75%	25%	50%	75%	25%	50%	75%
GRASS	14	11	9	140	104	66	81	53	26
CEREALS	19	15	8	89	67	38	52	33	14
POTATOES	28	26	20	105	71	50	60	30	16

(Calculated over 30-year period using data from Kise)

Table 7. Average yield responses (%), water requirements and consequent extra percolation (mm) calculated for intensive irrigation of soils with very low and very high moisture storage capacity (AWC = 50 and 130 mm).

CROP	YIELD RESPONSE		IRRIGATION WATER		EXTRA PERCOLATION	
AWC:	50 mm	130 mm	50 mm	130 mm	50 mm	130 mm
GRASS	28	8	160	116	85	61
CEREALS	39	10	99	80	52	46
POTATOES	54	14	110	87	61	46

(Calculated over 30-year period using data from Kise)

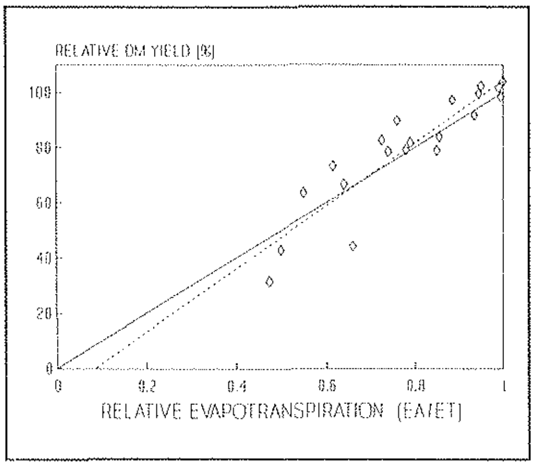

Fig. 1. Relative yields of grass (% of fully irrigated) plotted against relative evapotranspiration (EA/EP) during whole growth period.

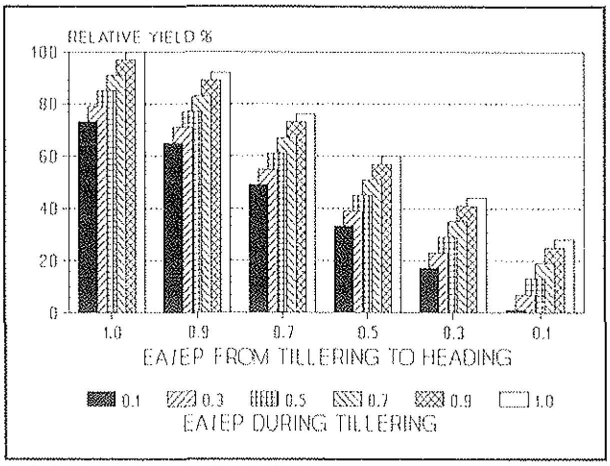

Fig. 2. Relative cereal yields (% of fully irrigated) plotted against relative evapotranspiration (EA/EP) in growth periods with high drought sensitivity.

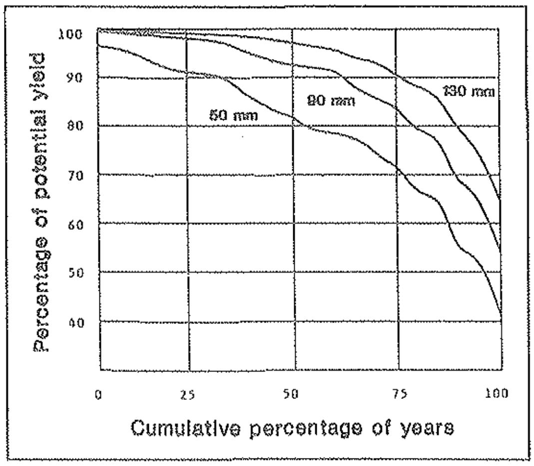

Fig. 3. Cumulative frequency of grass yields obtainable in absence of irrigation (% of potential), on soils with varying AWC (50,90,130 mm).

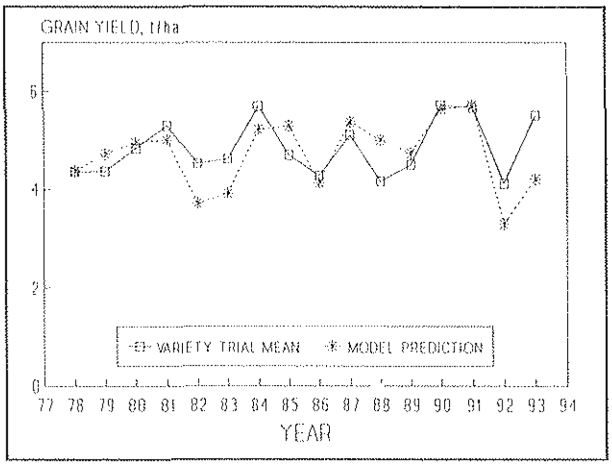

Fig. 4. Mean yields of cereal variety trials in SE Norway and values calculated with "drought model", using weather data from Kise and assuming AWC=110 mm.

Table 8. A comparison of the effects of N fertilizer level, soil moisture holding capacity, total precipitation amount and irrigation intensity on simulated values of N leaching during the growing season of cabbage. (After Riley & Guttormsen 1994).

N-FERT.	MOISTURE CAPACITY		RAINFALL AMOUNT		IRRIG. INTENSITY	
kg N/ha	High	Low	Low	High	Low	High
0	20	24	23	21	16	28
100	45	75	57	63	42	78
200	67	129	89	107	71	125
300	95	195	130	160	112	179

(Results are means of 16 simulations in which the factors are combined using input data obtained in two years at two sites.)

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SUBSURFACE DRAINAGE RUN OFF AND DEEP PERCOLATION ON CLAYEY MORAINE.

Leaching of plant nutrients and pesticides from soils and their fate in the environment is of great concern to the public. The loss by surface run off and by subsurface drainage run off can be measured directly, whereas the total leaching and deep percolation to the ground water can only be estimated by modelling downward water movement through the soil.

The internal drainage of almost all Danish clayey soils of morainic origin is insufficient and normally a perched water table is present near the soil surface. To improve plant production most soils are drained by a system of parallel subsurface drains at about one meters depth and spaced at 12-18 m. The partition of the total water percolation through the root zone to drainage run off and deep percolation to the primary ground water depends on the precipitation events, the evapotranspiration rate and the physical properties of the soil over and below the drain depth.

Subsurface drainage

A simplified drainage situation is sketched in Figure 1. The soil has a high saturated hydraulic conductivity in the upper layer which is normally the case on clayey moraine soils especially when an argillic horizon is present. From one meters depth an isotropic low permeable soil layer (aquitard) of a thickness of D meter is overlaying a highly permeable layer at the depth of z_2. The permanent ground water level is below z_2 and the water flow is downward.

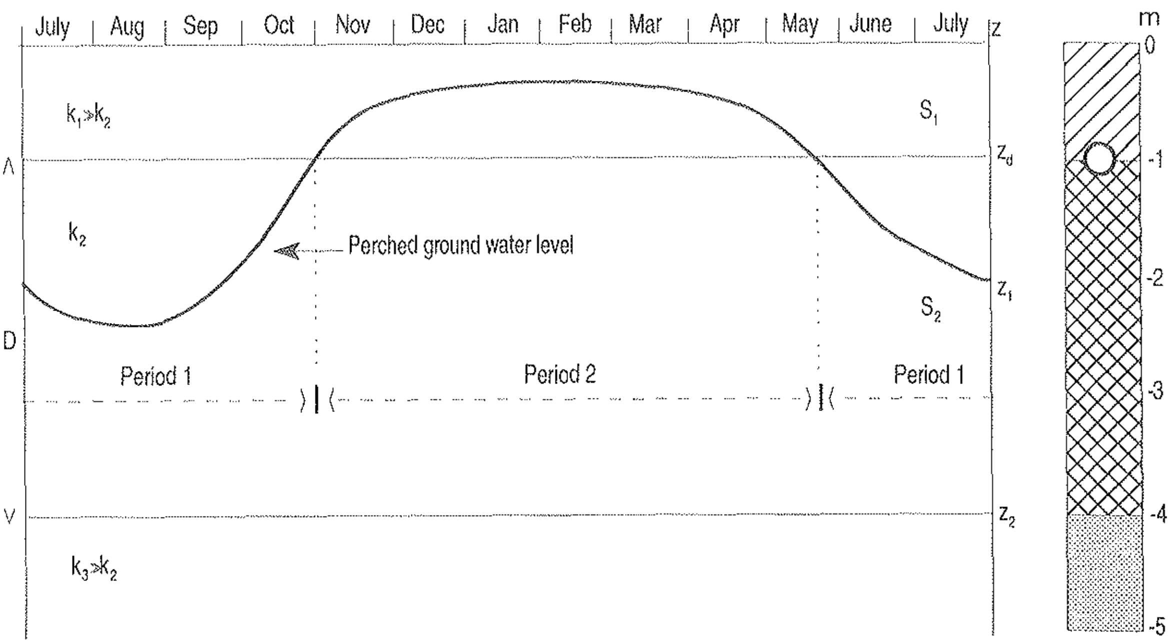

Figure 1. Sketch of a simple drainage situation throughout the year on a clayey moraine soil with a subsurface drain on top of a 3 m aquitard.

The perched ground water level is fluctuating throughout the year due to the downward water movement and the seasonal variation in the precipitation surplus. In Figure 1 a drain is placed at z_d on the top of the low permeable layer and the perched ground water level is considered midway between two drains.

In period 2 the ground water level z_l is higher than z_d and drainage run off occurs. As the hydraulic conductivity above the drain is supposed to be much higher than below the drain the flow towards the drains takes place in the upper layer only. The drainage discharge A_d then depends on the hydraulic head, $H_1=z_d-z_1$, the hydraulic conductivity k_1, the specific yield of the upper layer S_1 and the drain space L.

$$A_d = f(H_1, k_1, S_1, L)$$

For this drainage situation the steady state drainage run off can be estimated by the equation of Fukuda (1957)

$$A_d = - 1.5 \; k_1 \; H_1/L$$

At a hydraulic conductivity, k_2 below the drains and a thickness D of the aquitard the rate of downward water flow (deep percolation) depends on the hydraulic head $H_2=z_2-z_1$ which here is equivalent to the thickness of the water saturated layer. The deep percolation A_u in the period 1. and 2. are

$$A_u = -k_2H_2/(z_2-z_1) = -k_2 \qquad \text{and} \qquad A_u \sim -k_2H_2/D \;\; \text{respectively.}$$

The specific yield of the soil layer below the drain depth and above the ground water level, S_2 can be considered as a water reservoir that is filled gradually in the autumn when the precipitation exceeds the sum of evapotranspiration and water movement through the low permeable layer. The specific yield is approximately equal to the soil air content at pF 2.

Several models on drainage discharge and deep percolation have been developed, i.e. MACRO (Jarvis, 1991) and SHE (Abbot et al., 1986). Normally the soil layering is rather complicated, the variation in soil structure and hydraulic heads are very high and the cost of measuring the physical parameters to be used in the equations is far too high to accomplish.

Leaching experiments

In 1971 the Danish Institute of Plant and Soil Science started measuring the subsurface drainage discharge and nitrate concentration of drainage water on several clayey soils in Denmark (Hansen & Pedersen, 1975). It was obvious that only a fraction of the precipitation surplus was passed the drains and that deep percolation on many sites exceeded the drainage run off. In order to calculate the total nitrate leaching it was necessary to calculate the precipitation surplus by water balance models.

The downward water movement was modelled by WATCROS (Aslyng & Hansen, 1982) or the modified WATCROS model EVACROP (Olesen & Heidmann, 1990). Based on climatic observations and soil and crop parameters the models calculated the daily values of evapotranspiration, the soil moisture content and the percolation at 1 m depth. Soil surface corrected precipitation rates were used. The models do not take surface run off into consideration, but under Danish conditions this is normally very small and can be ignored without any great error to the results.

By calculating the total nitrate leaching it is assumed that the nitrate concentration of the deep percolation was the same as for drainage water. Investigation by the use of porous cup samples has confirmed that on an average this is normally the case (Simmelsgaard, 1985c). In this paper only the hydrological aspects of the investigations are discussed.

Figure 2 shows an example of estimated total water percolation through the root zone together with the precipitation and the measured drainage run off. The drainage run off normally ceases early in the spring. The perched ground water level drops 1-2 m in the summer period or disappears totally. In the autumn the field capacity of the root zone and the reservoir below drain depth must be recharged and the charging rate must exceed the rate of deep percolation before any drainage water run off occurs.

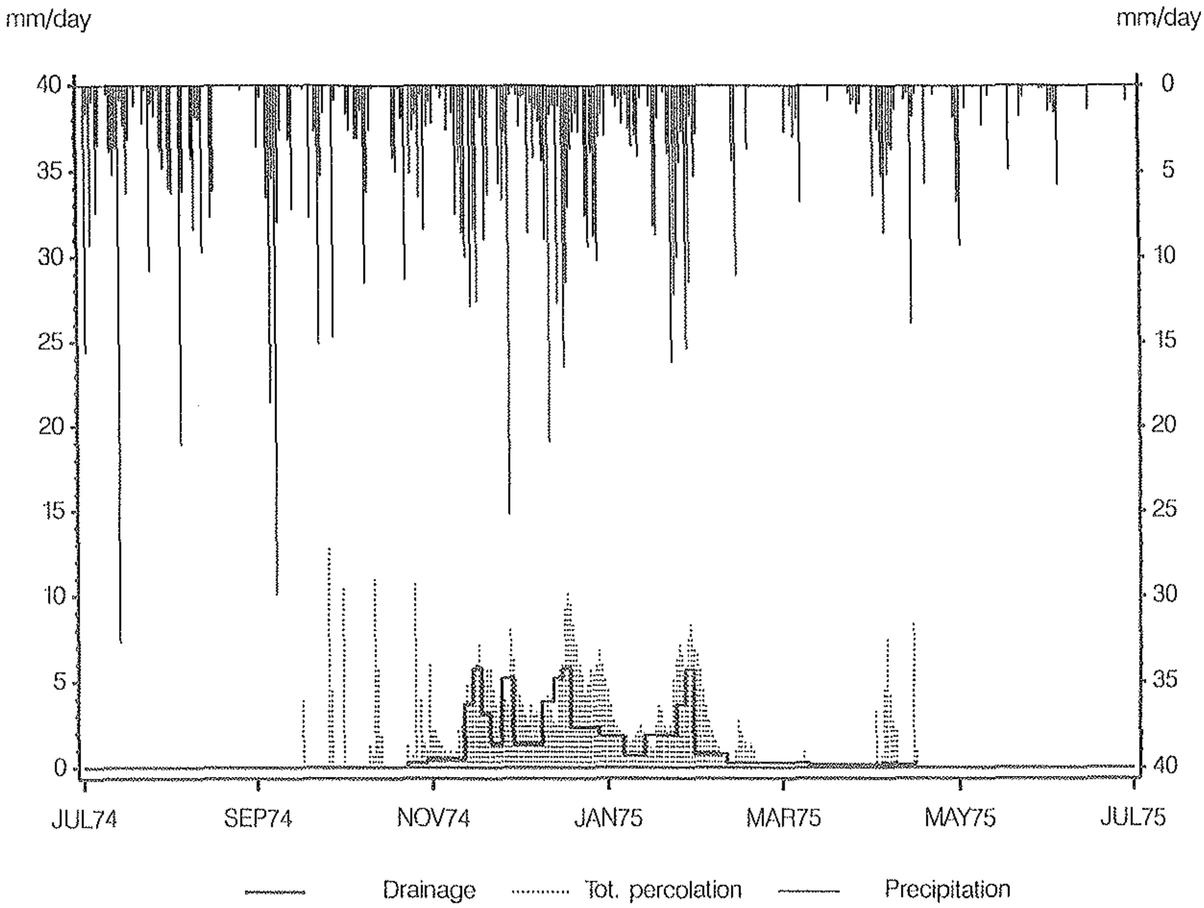

Figure 2. Precipitation, drainage run off and total percolation at Sdr. Stenderup in 1974-75.

The deep percolation is calculated as a difference between the estimated total percolation and the measured drainage discharge. For 7 experimental sites of which 5 have been investigated for 20 years the average precipitation, deep percolation and drainage discharge are presented in Figure 3. The average yearly precipitation varies between 613 and 1219 mm and the drainage run off varies between 45 and 344 mm. The annual deep percolation was 141- 425 mm and seemed to be more constant than the drainage run off.

The water balances for the 7 sites are shown in Figure 4. The precipitation is highest in the western and central part of Jutland (Åbenrå, Agervig and Silstrup) compared to the eastern part (Næstved). The actual evapotranspiration is about the same on all sites. Therefore

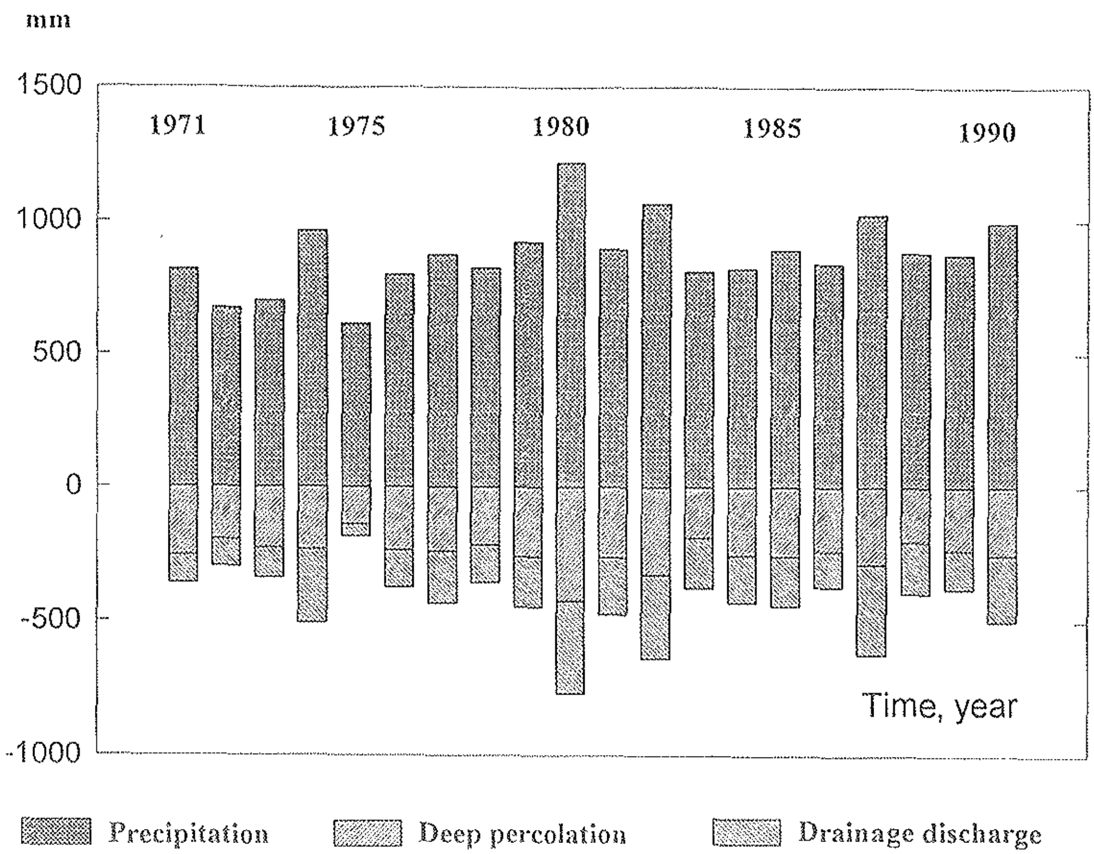

Figure 3. Annual precipitation, deep percolation and drainage discharge as an average of 7 subsurface drained sites in the period 1971-1990. After Simmelsgaard (1994).

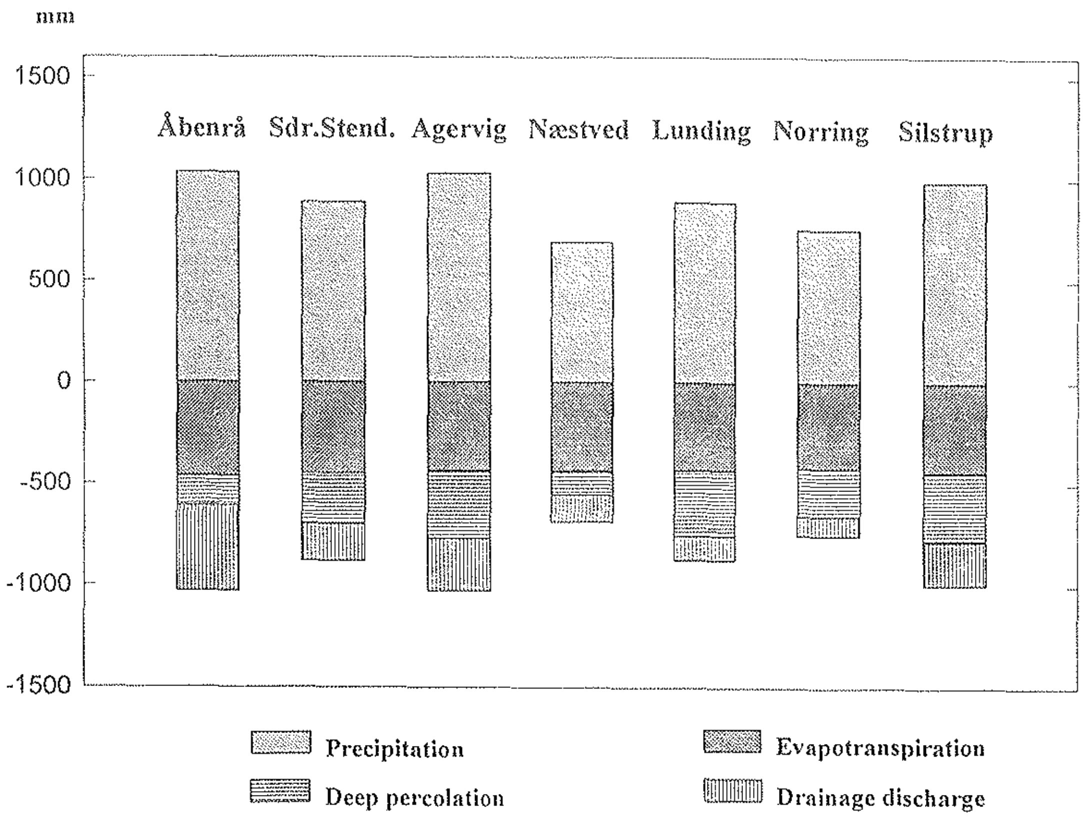

Figure 4. Average annual water balance at 7 subsurface drained sites. After Simmelsgaard.

according to the precipitation. The average drainage discharge varies from 254 mm at Næstved to 561 at Åbenrå and the drainage discharge amounted to 26-73 % of the total percolation.

The water balance studies for the 7 sites over the 13 to 20 year period were used for studying the relationship between drainage discharge and soil physical properties on the sites. Figure 5 shows the drainage discharge as a function of the total yearly percolation at Åbenrå. The interception on the x-axis of 59 mm can be considered as a rough measure of the reservoir below drain depth. The slope 0.83 is a measure of the proportion of the total percolation that is collected by the drains after the reservoir has been filled up. If the soil had been totally impervious at drain depth the slope would have been 1.0 and the interception 0.

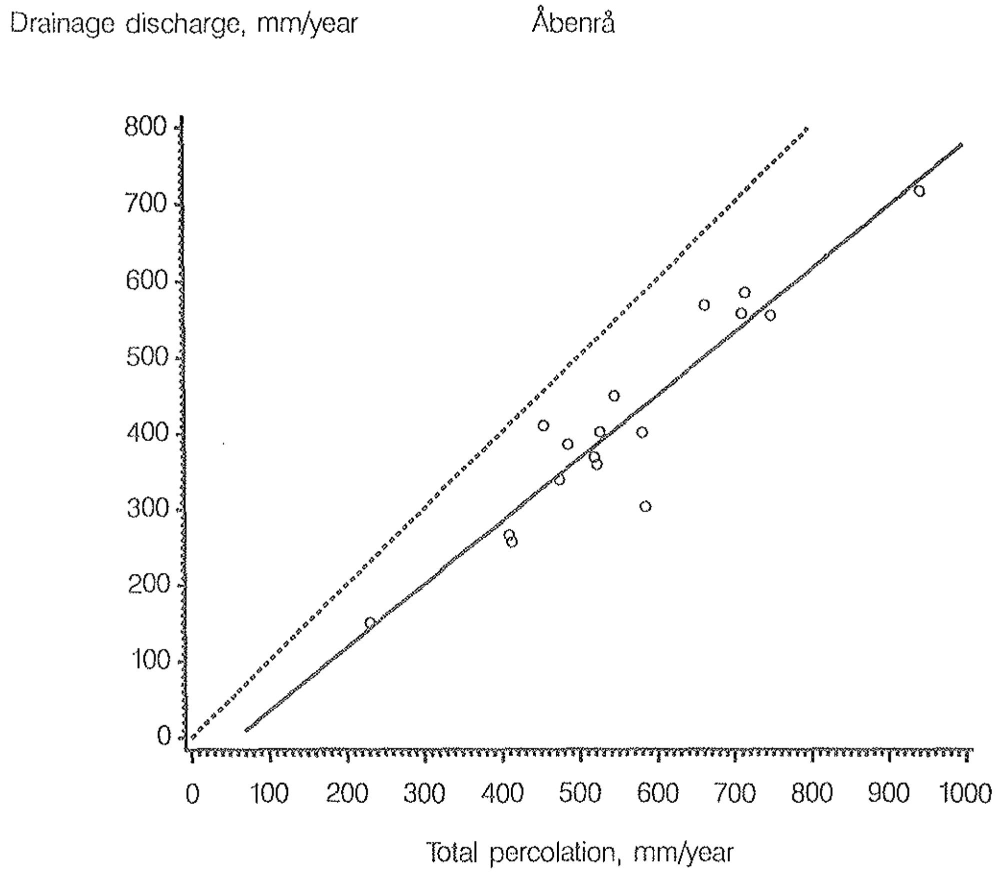

Figure 5. Annual subsurface drainage discharge as a function of estimated total percolation through the root zone on a clayey moraine soil at Åbenrå in the period 1974-91. The interception on the x-axis is 59 mm and the slope is 0.83 (r^2 = 0.88). Notice the curve for the 1:1 slope.

The intercepts on the x-axis' and the slopes for all the 7 sites are given in Table 1 together with some soil parameters for the depth of 100-140 cm. For most sites the reservoir below drainage depth is less than 100 mm. At Agervig this basic deep percolation is about 250 mm. The high value can be explained by an increasing clay content with depth and that the low permeable layer is situated rather deep in the horizon.

The high slopes and the small intercept at Åbenrå and Næstved are certainly due to a very low permeability of the soil layers just below the drains. In general the soils with the highest clay content have the smallest intercepts and the highest slopes.

Table 1. Soil parameters at 110-140 cm depth, and regression analysis of drainage run off as a function of total annual water percolation on 7 experimental sites in the period 1971-1991.

Site	Clay content %	$CaCO_3$ %	pH (H_2O) -	Bulk density g/cm^3	Air capacity %	Hydraulic conductivity m/day [1]	Intercept on x-axis mm	Slope -
Åbenrå	35	12	8.1	1.47	2	0.02	59	0.83
Næstved	29	< 1	7.8	1.81	2	-	59	0.70
Sdr. Stenderup	25	19	8.5	1.68	2	0.2	135	0.62
Silstrup [2]	22	-	7.1	1.63	8	1.6	-26	0.36
Lunding	23	< 1	7.1	1.72	4	-	20	0.28
Norring [3]	14	-	6.5	-	-	-	65	0.36
Agervig	13	< 1	4.6	1.86	10	0.2	250	0.71

[1] Simmelsgaard (1985a)
[2] At 65 - 100 cm depth, Hansen (1976)
[3] At 50 - 100 cm depth, Hansen & Pedersen (1975)

Summary

In order to estimate nitrate leaching by subsurface drains in 1971 the Danish Institute of Plant and Soil Science started measuring the drainage discharge and nitrate concentration of drainage water on several clayey soils in Denmark. The percolation that does not pass the drains was calculated as a difference between the total percolation and the drainage run off. Total percolation at drain depth was estimated by the water balance models WATCROS and EVACROP. The average annual drainage run off for 7 sites over a period of 20 years varied between 45 and 344 mm. At the 7 sites the average annual run of varied between 254 and 561 mm. The drainage discharge depends mainly on the annual precipitation surplus and the soil parameters below the drain depth. A linear relation between annual drainage discharge and the annual precipitation surplus on each site was assumed. The interception on the x-axis could then be considered as a reservoir that should be filled before any drainage run off occurred. The slope of the curve was then the rate of drainage run off to the precipitation surplus after the reservoir had been filled. The rate varied between 28 and 83 %.

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INFLUENCE OF IMPROVED SUBDRAINAGE ON PHOSPHORUS AND NITROGEN LEACHING FROM A HEAVY CLAY SOIL

Introduction

The route of the runoff water, whether along the surface or through the soil to subdrains, would be expected to influence phosphorus and nitrogen leaching from the field. In South-West Finland, problems of high water table and heavy surface runoff are endemic to the heavy clay soils due to low water conductivity of the clay layers. Without proper subdrainage on a sloping heavy clay soil, the resulting surface runoff induces abundant soil erosion and phosphorus losses, whereas nitrogen leaching might be reduced due to smaller percolation volume.

Materials and methods

To determine the influence of improved subdrainage (IMP) on soil erosion, phosphorus losses and nitrogen leaching, a heavy clay soil with a 29 -year-old subdrainage system and open drains to allow measurement of drainage discharge as well as surface runoff, was fitted with new drains, with topsoil or wood chips used as backfill in the drain trenches. The water discharge and nutrient concentrations in drainage water and surface runoff were compared from plots under similar cropping and soil cover, for winter periods preceding and following IMP.

Results

Before IMP, surface runoff constituted 60-90% of the total runoff (surface + drainage) but after IMP only 10 - 50%. Where topsoil was used as backfill, the estimated soil erosion and particulate P and dissolved orthophosphate P losses from ploughed soil during winter were reduced by 17%, 16% and 25%, respectively. Where wood chips were used as backfill, soil erosion and particulate P losses were not reduced. Due to the higher drainage discharge after IMP, the estimated increase in nitrogen leaching during winter was 70%. It should be noted, however, that the above estimate describes only the immediate effect of subdrainage improvement.

Conclusions

On poorly drained heavy clay soil, the leaching of dissolved orthophosphate phosphorus will diminish if the amount of surface runoff is reduced by improving the subdrainage system. Topsoil used as backfill material in the drain trenches seems to be efficient in sieving suspended clay particles and particulate phosphorus from infiltrating water. Wood chips may not efficiently reduce these losses. The greater drainage discharge after drainage improvement will lead to higher nitrogen leaching.

Table 1. Cropping in preceding summer (parenthesis) and soil cover in winter on surface (A-D) and drainage plots (1-16) before and after the drainage improvement (IMP). First test (1) between winter periods 1990-91 and 1991-92, second test (2) between winter periods 1987-88 and 1992-93.

Winter period	Plot			
Surface	A	B	C	D
Drainage	1-4	5-8	9-12	13-16
1987-88	(fallow) ploughed	(fallow) ploughed	(ryegrass) ploughed	(timothy) timothy (2)
88-89	(fallow) ploughed	(barley) ploughed	(barley) ploughed	(timothy) timothy
89-90	(fallow) ploughed	(fallow) ploughed	(ryegrass) ploughed	(timothy) ploughed
90-91	(barley) ploughed (1)	(barley) ploughed (1)	(barley) ploughed (1)	(barley) ploughed (1)
IMP				
91-92	(barley) ploughed (1)	(barley) ploughed (1)	(barley) ploughed (1)	(barley) ploughed (1)
92-93	(timothy) timothy	(timothy) timothy	(timothy) timothy	(timothy) timothy (2)

Table 2. Precipitation, total runoff, drainage water and surface runoff (mm) during the winter period before and after the subdrainage improvement (IMP). Total runoff, drainage water and surface runoff as percentage (%) of precipitation in ploughed soil, test one (1), and ley, test two (2).

	Ploughed (1)				Ley (2)			
	Before IMP		After IMP		Before IMP		After IMP	
Precipitation (mm)	284		392		447		346	
Total runoff (mm)	229		360		280		273	
Drainage (mm)	55		328		44		159	
Surface runoff (mm)	174		32		236		114	
Total runoff (%)	80.6	**	91.8	n=4	62.6		78.9	n=1
Drainage (%)	19.4	***	83.7	n=16	9.8	*	46.0	n=4
Surface runoff (%)	61.3	***	8.2	n=4	52.8		32.9	n=1

*** significantly different at the 0.1% level
** significantly different at the 1% level
* significantly different at the 5% level

Table 3. Concentratios of total solids (TS, g/l), particulate phosphorus (PP), dissolved orthophosphate phosphorus (DP), total nitrogen (TN) and nitrate nitrogen (NN), mg/l, in drainage water and surface runoff during the winter period before and after the subdrainage improvement (IMP), from ploughed soil, test one (1), and ley, test two (2). Backfill: gravel and topsoil in the upper, gravel and wood chips in the lower part.

	PLOUGHED (1)									
	Drainage, n=16							Surface runoff, n=4		
Backfill	Topsoil, n=8			Wood chips, n=8						
	Before IMP		After IMP	Before IMP		After IMP		Before IMP		After IMP
TS (g/l)	0.41	--*--	0.36	0.46		0.49		0.52	--**--	0.39
PP (mg/l)	0.20	--**--	0.17	0.13	--**--	0.29		0.27		0.27
DP (mg/l)	0.040	--*--	0.028	0.037	--s--	0.026		0.036		0.039
TN (mg/l)	6.1		7.9	2.9		3.3		3.23		2.03
NN (mg/l)	5.5		6.8	2.6		2.7		2.71		1.61
	LEY (2)									
	Drainage, n=4							Surface runoff, n=1		
Backfill	Topsoil, n=2			Wood chips, n=2						
	Before IMP		After IMP	Before IMP		After IMP		Before IMP		After IMP
TS (g/l)	0.35		0.40	0.30		0.36		0.47		0.40
PP (mg/l)	0.20		0.20	0.12		0.25		0.25		0.26
DP (mg/l)	0.034		0.027	0.027		0.018		0.034		0.077
TN (mg/l)	1.8		6.2	1.5		1.8		1.25		2.24
NN (mg/l)	1.3		5.2	1.1		1.2		0.57		0.60

** significantly different at the 1% level
* significantly different at the 5% level
s different at the 10% level

Table 4. Runoff (mm) and losses of total solids (TS), particulate (PP) and dissolved orthophosphate phosporus (DP), total (TN) and nitrate nitrogen (NN), (kg/ha), from ploughed clay soil during hypothetical winter periods with 350 mm precipitation before and after subdrainage improvement (IMP).

	Drainage		Surface		Total	
	Before IMP	After IMP	Before IMP	After IMP	Before IMP	After IMP
Runoff (mm)	68	293	215	29	283	322
TS (kg/ha)	292	1056	1116	112	1408	1168
PP (kg/ha)	0.11	0.50	0.58	0.08	0.69	0.58
DP (kg/ha)	0.03	0.09	0.09	0.01	0.12	0.09
TN (kg/ha)	3.1	16.4	6.9	0.58	10.0	17.0
NN (kg/ha)	2.8	13.9	5.8	0.46	8.6	14.4

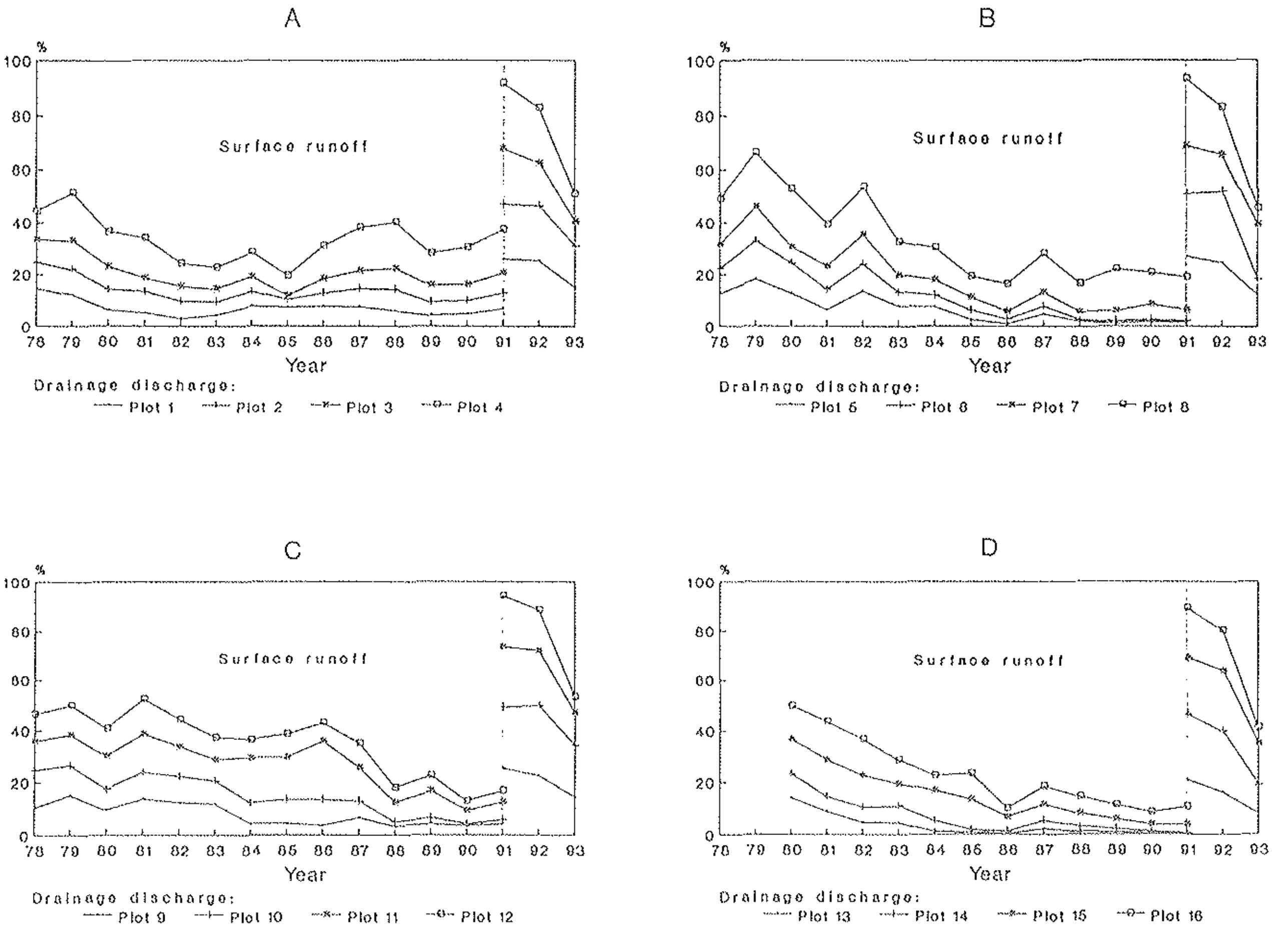

Figure 1. Distribution (%) of total runoff to drainage discharge and surface runoff in the drainage field. The surface plots (A-D, 0.5 ha each) cover four drainage plots each (1-4, 5-8, 9-12, 13-16). Dotted line: time of subsurface drainage improvement.

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INFLUENCE OF CONTROLLED DRAINAGE ON LEACHING OF NUTRIENTS FROM AGRICULTURAL FIELDS

Movement of nitrogen, mainly as nitrates, from agricultural fields via drainage waters is a very important factor in nonpoint source pollution of surface waters in Finland. According to a decision made by the Finish government in 1988, phosphorus loading from agriculture should be reduced by 30 % by 1995, combined with a significant reduction of nitrogen loading. The main problem with the fulfillment of the decision has been the lack of suitable methods for controlling the leaching of nutrients from agricultural fields.

Water table management using subirrigation and controlled drainage is a method that has recently been accepted in Midwest and Southwest regions of the USA as a tool for reducing nitrogen and phosphorus load from agriculture. Moreover, it has been found out that pesticide concentrations in groundwater were decreased by maintaining shallow water table depths. Helsinki University of Technology, Finnish Field Drainage Center and University of Helsinki have have been running a four-year research project that aims to evaluate the limitations and soil requirements to use the system in Finnish climatic conditions.

Four experimental fields have been founded to evaluate the influence of controlled drainage on nutrient load from agricultural fields: clay soil and peat soil in Southern part of Finland, loamy sand in Western and fine sand in Northern part of Finland. An interdisciplinary team conducts research to evaluate the applicability of controlled drainage in reducing the nutrient load. The objectives are as follows:

* To determine the water and nutrient balance of conventional and controlled drainage systems.
* To evaluate soil requirements and limitations to use the controlled drainage systems and to determine the effects of the use of the system on soil properties.
* To determine the influence of controlled drainage on crop growth and crop nutrient uptake.
* To evaluate the long-term effects of controlled drainage on surface and subsurface hydrology and water quality.
* To develop design guidelines to assist in the use of the controlled drainage in different soil and climatic conditions.
* To evaluate the economic feasibility of the controlled drainage systems for different soil, crop and climatic conditions.

Results clearly suggest that subirrigation and controlled drainage practices have the ability to improve groundwater quality in agricultural areas. Moreover, subirrigation and controlled drainage systems have been successful in providing good crop production as well as an excellent technique for the management of shallow groundwater quality.

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EPISODIC PRECIPITATION AND DISCHARGE EVENTS AND THEIR INFLUENCE ON LOSSES OF PHOSPHORUS AND NITROGEN FROM TILE DRAINED ARABLE FIELDS

Monitoring over a 2-3 year period revealed that a large proportion of the yearly nutrient losses through tile drainage can occur in connection with a few runoff events. Half of the total phosphorus transport from a clay-soil experimental field at Vara during 1992-94 took place during two such episodes. The first episopde occurred in January 1993 and the second, more pronounced one occurred in January 1994. Both started with intense rain on newly frozen soil. A grass cover strongly reduced the losses.

In another experimental field south of Stockholm with clay containing mud, autumn episodes with intense rain on dry soil led to pronounced nutrient losses. Five episodes during a 2-year period accounted for nearly half of the total phosphorus transport. Total phosphorus losses from this site were greater.

Although losses of nitrogen during these episodes were less pronounced than those of phosphorus, they amounted to 30% of the total losses.

Thus certain types of weather episodes can lead to large losses of nutrients from clay soils via tile drainage and pasture can strongly reduce such losses.

Table 1. Crop production and other agricultural practices at the experimental fields.

Year	Crop	Tile management	Catch crop	N fertilizer (% of normal)	Crop	Tile management	Catch crop	N fertilizer (% of normal)
Lanna 1					*Lanna 2*			
1991	oats	conventionl	no	100	oats	conventional	no	100
1992	barley	conventional	no	100	barley	conventional	no	125
1993	barley	conventional	no	100	barley	conventional	no	125
Lanna 3					*Lanna 4*			
1991	oats		yes	100	oats	conventional	yes	100
1992	barley	conventional	yes	100	barley	conventional	yes	125
1993	barley	conventional	yes	100	barley	conventional	yes	125
Lanna 5					*Lanna 6*			
1991	oats		yes	75	oats	minimized	no	100
1992	barley	conventional	yes	150	barley	minimized	no	100
1993	barley	conventional	yes	150	barley	minimized	no	100
Lanna 7					*Oxelby*			
1991	pasture grass		-	-	fallow	-	-	-
1992	pasture grass		-	-	wheat-	conventional	-	100
1993	pasture grass		-	-	fallow	-	-	-

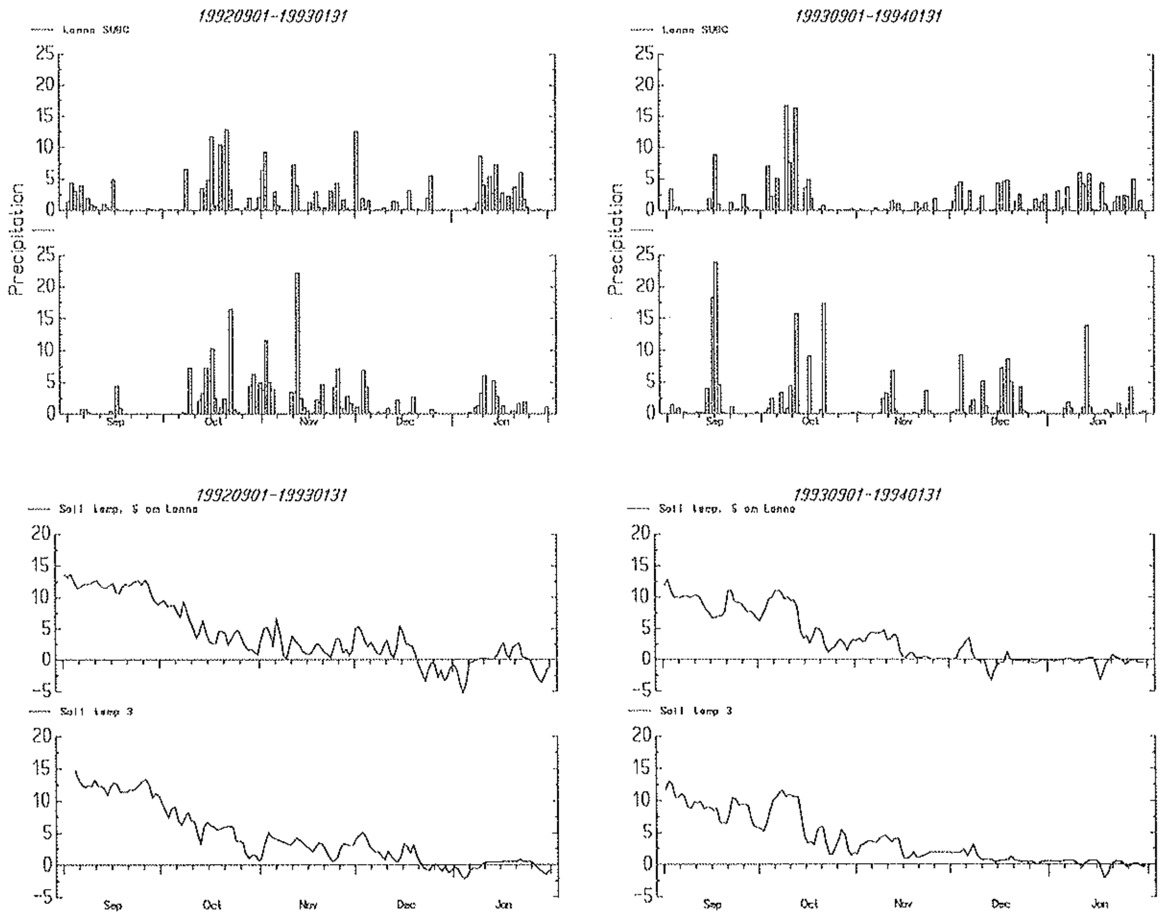

Figure 1. Precipitation (mm) and soil (5 cm) temperature (^{O}C) during September -January 92/93 and 93/94 at Lanna (above) and Oxelby (below).

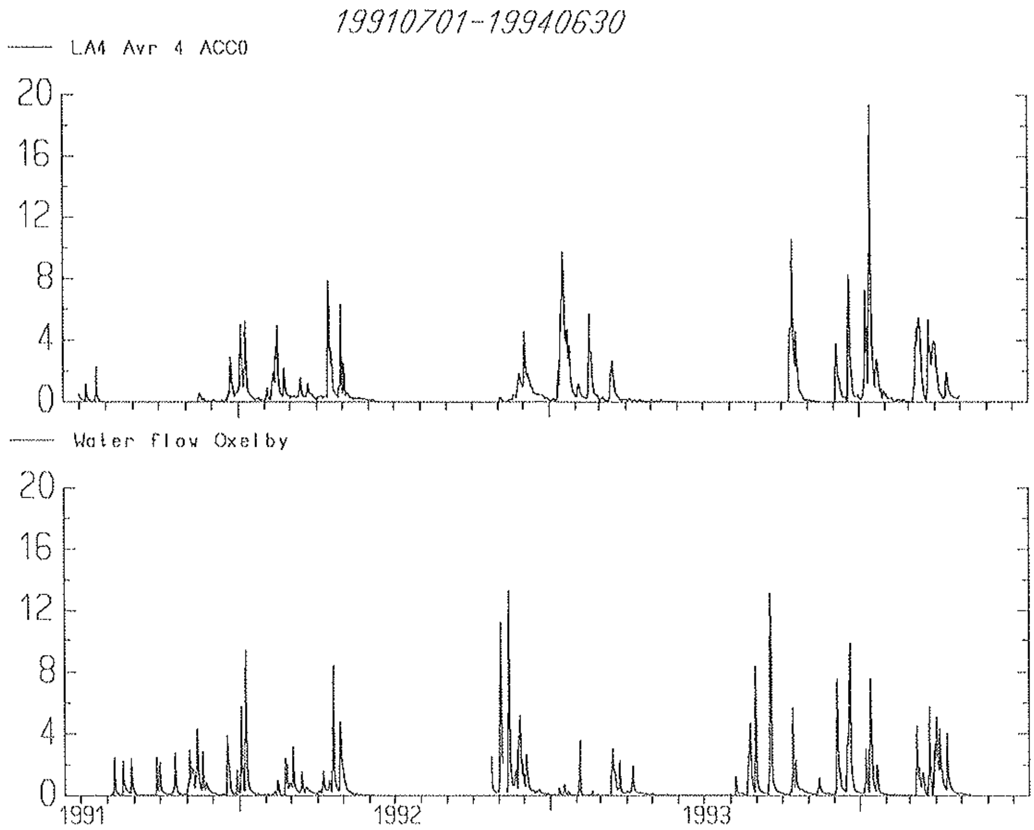

Figure 2. Water discharge (mm) from Lanna and Oxelby tile drainage.

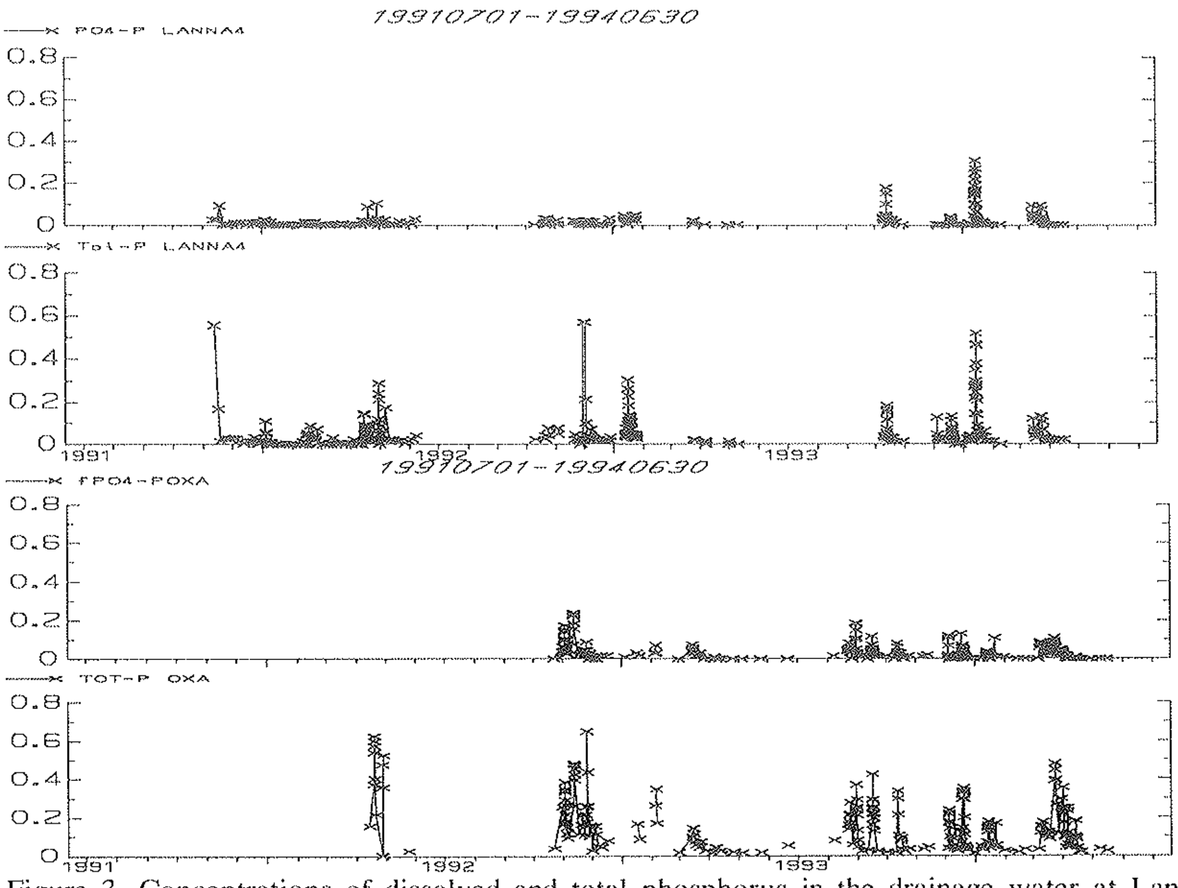

Figure 3. Concentrations of dissolved and total phosphorus in the drainage water at Lanna (above) and Oxelby (below).

Table 3. Drainage (mm) and losses of nutrients and suspended materials (kg/ha) during certain episodes as compared with yearly losses at Lanna 4 and Oxelby experimental fields.

Period	Drain	PO_4-P (filtered)	PartP	TotP	NO_3-N	TotN	Susp
Lanna 4 (spring cereals)							
920414-920420	25	0.005	0.013	0.019	1.0	-	15
930110-930127	76	0.023	0.031	0.064	4.7	5.2	43
940112-940114	32	0.062	0.042	0.110	1.5	2.0	61
Entire year 91/92	159	0.016	0.040	0.063	4.2	-	52
Entire year 92/93	168	0.033	0.065	0.106	9.5	10.3	69
Entire year 93/94	286	0.136	0.102	0.248	12.5	14.9	107
Lanna 7 (pasture)							
Entire year 93/94	188	0.013	0.042	0.064	0.8	1.9	47
Oxelby (fallow)							
921102-921104	24	0.020	0.040	0.060	0.5	0.8	40
921112-921114	24	0.039	0.047	0.092	0.4	0.6	0
930830-930831	12	0.016	0.010	0.028	0.1	0.2	0
930916-930918	25	0.028	0.012	0.059	0.2	0.3	0
931219-931221	22	0.022	0.007	0.051	0.2	0.4	0
Entire year 92/93	138	0.087	0.165	0.276	2.1	3.3	51
Entire year 93/94	262	0.093	0.227	0.408	2.0	3.7	104

Table 4. Phosphorus fractions, in percent of total phosphorus content, in drainage suspension and soil at Lanna and Oxelby.

Fraction	*Lanna* Drain-age	Soil (0-30 cm)	Soil (30-90 cm)	*Oxelby* Drain-age	Soil (0-30 cm)	Soil (30-90cm)
NH_4Cl-PO_4P	6.0	1.4	0.1	2.9	0.4	0.5
NaOH-PO_4P	6.8	14.5	7.2	11.5	27.2	37.3
NaOH org P	19.1	18.5	50.3	8.3	22.1	29.3
HCl-PO_4P	10.1	20.2	4.5	16.3	18.2	0.0
Other org. P	57.2	45.4	37.9	60.5	32.1	32.9

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EVENT STUDIES OF RUNOFF AND NUTRIENTLOSSES IN CATCHMENTS OF DIFFERENT SCALES

Runoff and nutrient losses are being measured at different scales, varying from plot studies on 1 and 125 m^2 to catchments, ranging in size from less than 1 ha to 7 km^2. Runoff is measured using a fixed profile with a known head-discharge relation. Water levels are either measured automatically using a datalogger or a mechanical recorder. Water sampling is carried out either automatically or by using a tipping bucket and is preferably event based. Additional objectives of the measurements are;

- Document differences in runoff and nutrient losses from catchments, having different soil types, topography and agricultural practices.
- Study the effect of hydrological factors on nutrient losses, especially during winter periods.

RESULTS.

The annual number of runoff events varied between 5 and 32 for 8 catchments during the period from 1987 - 1993 [1]. Whether or not surface runoff occurs in smaller catchments depends on a number of factors, the main ones being size, topography and soil type.

Some catchments only show surface runoff during snowmelt when there is frost in the soil with a 5 days duration of runoff . In other catchments surface runoff also occured after rainfall events and the annual sum of runoff periods could last up to 70 days. Runoff with drainage water showed the same pattern with high peaks of runoff , but the duration of the drainage period lasted longer after the surface runoff had stopped. Days with drainage water varied between 71 and 160 for a catchment of 0.86 ha.

Runoff intensities varied greatly for the different catchments.It is difficult to see a good relation between soil type, topography and catchment size and measured peak discharges.

Most of the nutrient losses were due to a few events each year. Documentation of these events requires a specialized sampling technique.

Often, sampling routines are based on single samples, taken according to routines with fixed time interval. These methods lead to large errors in calculated nutrient transport and erosion. [2].JORDFORSK uses an alternative method, based on volume proportional sampling. The datalogger continuously measures the discharge(q). Each time a certain, pre-set volume(P) has passed the measuring station, a sample with fixed volume(v) is taken. All the samples are mixed together in one container and produce one sample representing the average concentration(C_{mix}) during the runoff period. By special setting of the sample volume (v) and the volume (P) it is possible to carry out event studies by volume proportional sampling.

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NUMBER OF RUNOFF EVENTS BETWEEN CATCHMENTS OF DIFFERENT SCALE.

Table 1 . Number of annual runoff events 1987 - 1993 for different catchments.
107 and 51 are drainage runoff, the others surface runoff.

Catch-ment	Area (ha)	1987	1988	1989	1990	1991	1992	1993
101	0,36	8	9	3	6	7	8	-
102	3,25	14	23	13	13	20	22	-
103	0,41	0	0	3	8	7	6	-
106	0,86	20	24	16	20	29	29	-
107	0,86	28	29	16	17	31	14	-
108	0,44	11	18	8	10	19	12	-
50	5,0	-	-	-		15	31	28
51	5,0	-	-	-		7	12	12
60	700	-	-	-		10	10	12

VARIATION IN RUNOFF (MM) BETWEEN CATCHMENTS OF DIFFERENT SCALE.

Table 2. Total surface runoff (mm) 1987 - 1993. Catchment 107 and 51 are drainage water .

Catch-ment	Area (ha)	1987	1988	1989	1990	1991	1992	1993
101	0,36	33	102	71	127	31	52	-
102	3,25	88	97	30	128	29	36	-
103	0,41	0	0	10	121	27	21	-
106	0,86	238	292	178	216	242	88	-
107	0,86	357	404	123	54	165	93	-
108	0,44	188	327	130	232	244	146	-
50	5,0	-	-	-	-	29	29	55
51	5,0	-	-	-	-	89	177	149
60	700	-	-	-	-	157	157	152

HOW MANY DAYS ARE THERE SURFACE AND DRAINAGE RUNOFF EACH YEAR?

Table 3. Annual number of days with runoff in different catchments. Catchment 107 and 51 are drainage water , the other surface runoff.

Catch-ment	Area (ha)	1987	1988	1989	1990	1991	1992	1993
101	0,4	9,03	30,2	5,3	16,3	12,8	23,4	-
102	3,3	55,6	68,0	62,2	48,4	37,1	49,4	-
106	0,98	61,5	70,8	69,7	53,5	39,5	50,2	-
107	0,9	104,4	160,4	104,1	70,3	85,7	72,2	-
108	0,4	36,9	44,5	41,2	23,6	25,8	31,7	-
50	5	-	-	-	-	9,2	39,2	34,7
51	5	-	-	-	-	29,8	57,8	46,0
60	700	-	-	-	-	36,1	6,5	56,6

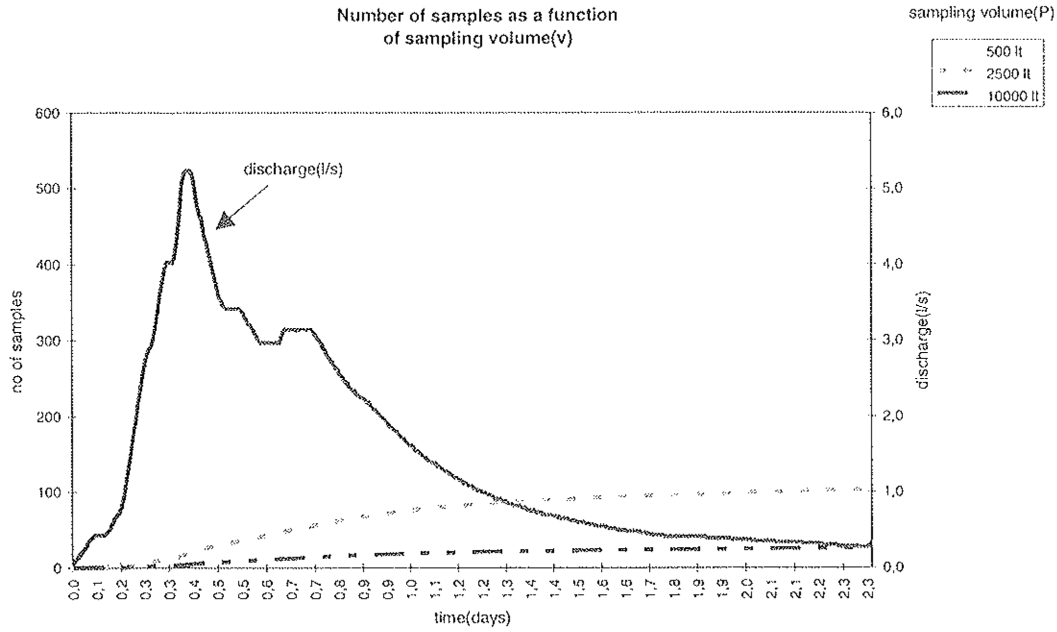

Figure (1): Number of samples collected when sampling volume (P) is set to respectively 500, 2500 and 10000 liters. In case sampling volume set at 10000 liters not enough water will be collected in sample for analysis, while at same time the period between two sampling becomes too long.

$$C_{mix} = \frac{c_1 \times v_1 + c_2 \times v_2 + \ldots c_n \times v_n}{V_{mix}}$$

C_{mix} - average concentration of runoff water in sample

V_{mix} - total sample volume. (Σ v)

$S = Q \times C_{mix}$

$$Q = \int_t^{t_n} q \, dt$$

Q - Total runoff during sampling period.
q - Discharge at time, t (l/s).
t_n - Time length for sampling period.

S - Erosion or runoff of nutrients

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SURFACE- AND DRAIN WATER RUNOFF AT DIFFERENT TILLAGE SYSTEMS, -SOIL TYPES AND WEATHER CONDITIONS.

Methods.

Surface runoff was measured in 5 "field lysimetres" and 2 small catchments on agricultural land at Ås or within 55 km from Ås. Two lysimetres and both catchments also measured drain water. Soil and nutrient losses were also measured. Observation period vary from 1984-94 to 1992-94.

Soil types were: A) levelled silty clay loam, B) levelled silty clay and C) nonlevelled loam with high aggregate stability.

Tillage systems ranged from relatively early plowing or harrowing autumn to spring tillage or notill. Weather conditions ranged from rainy winters with little snow to cold winters with heavy snow, rainy to dry summers and autumns.

Effects of soil types.

Precipitation at Ås 1961-90 was 785 mm/year but 838 mm/year 1987-93 ranging from 986 (1988) to 728 (1993).

For the period 1987-93 results were as follows: Askim (soil A): precipitation 850 mm/year, total runoff 538 mm/year (45 % surface water). Holt (soil A): precipitation 700 mm/year, total runoff 327 mm/year (30% surface water). Enerstujordet (soil C): precipitation 838 mm/year, total runoff 507 mm/year (9% surface water).

Yearly variation: Enerstujordet Ås (soil C): total runoff: maximum 725 mm minimum 325 mm, surface runoff: maximum 187 mm (38% of total) minimum 17 mm (5 % of total).

Holt (soil A, lower precipitation): total runoff: maximum 506 mm minimum 216 mm, surface runoff: maximum 192 mm (79% of total) minimum 20 mm (9% of total).

For the period 1992-apr. 1994 accumulated surface runoff was 415 to 665 mm on soil A, 305 mm on soil B and 174 mm on soil C by relatively early autumn plowing. The differences can mostly be explained by soil types.

Effects of tillage.

Spring tillage reduced surface runoff by 10-20 % on soil A but increased it by 150% on soil C compared to autumn plowing. On soil C the difference between tillage systems occurred with shallow frost, not with deep frost or unfrozen soil.

Plowing across reduced surface runoff by 20% on soil A compared to plowing along slope.

Autumn harrowing gave about the same surface runoff as atumn plowing when plowing and harrowing were done at equal times.

Sewage sludge in spring harrowed plots reduced surface runoff 10% on soil A compared to harrowing only.

Plowing or harrowing in autumn at unfavorable soil conditions increased surface runoff and soil losses substancially for a period of at least one year due to damage to soil structure.

Weather conditions.

Conditions occurring under yearly maximum runoff at Holt (soil A) for the 8 years 1986-93 were as follows: rain twice, snowmelt also twice and snowmelt+rain four times. Yearly max runoff intensity was 11 to 38 mm/day, and 12 to 100% of this was surface water.

Snow conditions during runoff, effects on water quality.

N=no snow or frost, L=little snow, D=deep snow. During the period 1992-apr. 1994; 7, 45 and 48% of surface runoff occurred under snow conditions N, L, D respectively. For drain water the numbers were 42, 48 and 10 % in the same order.

However, the surface runoff under the D-condition varied from 0 to 87% during 1987 to 1994 at Askim (soil A).

Mean concentrations of suspended solids were about 4, 2 and 0,15 mg/l for snow condition N, L and D respectively during 1992-apr. 1994.

A simple model based on snow conditions could explain a big part of the year to year variation in water quality.

It must be noted that concentrations of suspended solids in surface water were 15 times lower winter 1994 than for the wole year 1993. The main reason was a shift from runoff conditions N and L to D (deep snow condition).

Main conclusion.

Different soil types produce different amounts of surface water and they often react differently on tillage operations depending on weather conditions.

Weather, especially in winter, determines mostly the runoff conditions which in turn influence water quality.

Thus, hydrological factors may be important reasons to large natural variations in water quality, at least in areas with erosion. This must be considered when pollution problems are discussed.

INTRODUCTION, MATERIAL.

Runoff (type, intensity, time of year when it occurs, catchment conditions when it occurs) is important for the water quality in rivers and lakes. Hydrology can help to explain quality variations between years, which is to be shown in this paper.

Material is 5 "lysimetres" with plots 160 to 720 m^2 and slope 12-15%, measuring surface runoff and drain runoff (two sites). The sites Bjørnebekk and Syverud are at Ås, Askim 30 km east of Ås, Hellerud 15 km north of Oslo and Øsaker at Sarpsborg. Holt is a 2,7 ha catchment 35 km northeast of Oslo, and Enerstujordet a 9 ha catchment at Ås. Observation periods are maximum 1984-94 and differ between sites.

RESULTS.

Soil information is found in table 1. The soils at Holt, Hellerud, Bjørnebekk, Askim and Øsaker have all been artificially levelled, with low organic content and low aggregate stability as a result.

Table 1.

Soil information for experimental sites. Autumn plowing. Agrs=% water stable aggregates 0,6-6mm. TotC, TotN and TotP are total contents of C, N and P respectively.
- not measured.

Site	Clay %	Silt %	Sand %	Agrs %	TotC %	TotN %	TotP mg/kg
Holt	28	67	5	-	1,5	0,18	863
Askim	29	60	11	-	1,1	0,11	715
Bjørnebekk	(app.	as Askim)		31	-	0,11	883
Hellerud	32	65	3	-	1,9	0,16	850
Øsaker	>40%	Clay		54	-	-	-
Syverud	23	50	27	83	3,2	0,31	970
Enerstujordet	21	41	37	-	2,6	0,27	1370

Table 2.

Mean runoff values 1987-93 for the sites Holt (Ullensaker), Enerstujordet (Ås), and Askim. Precipitation for Holt and Askim are approximations.

	Sites		
Type	Holt	Enerstujordet	Askim
Surface runoff	97 (30%)	47 (9%)	242 (45%)
Drain water	230 (70%)	461 (91%)	296 (55%)
Totals	327	507	538
Precipitation	700	838	850

Runoff values are found in tables 2, 3, 4 and 5. In table 4 concentrations of suspended solids in runoff are also given. Table 2 shows great variations in relative amounts of drain and surface water between sites. Yearly variation given in table 3 is very great, especially for surface runoff.

Table 4 shows effects of various treatments (mainly tilling systems) on surface runoff. The effects vary between soil types and the weather conditions under which they were done. Surface runoff is far greater with spring plowing than autumn plowing at Syverud (high aggregate stability), while runoff is slightly smaller by spring plowing at Bjørnebekk (low aggregate stability). Aggregates are probably destroyed in top after autumn rain on this soil, causing silting and low infiltration rates both with and without frost in soil. The levelled silty clay soils in Akershus and Østfold most likely give most surface runoff in all of Norway, also because of the

Table 3.
Yearly surface runoff values (mm) at different sites. Precipitation at Ås. For two sites also drain water is given. Except Enerstujordet, the treatment is autumn plowing. Surf=surface water, Drain=drain water.
* 1994 is january-april.

Year	Prec Ås	Enerstuj Drain	Enerstuj Surf	Syv Surf	Øsak Surf	Helle Surf	Bjørn Surf	Askim Surf	Holt Surf	Holt Drain
1984	846	422	137	-	-	-	-	-	170	184
1985	821	364	171	-	-	-	-	-	110	346
1986	709	309	187	-	-	-	-	-	140	220
1987	977	676	32	-	-	-	-	291	69	425
1988	986	670	55	-	-	-	391	390	74	432
1989	741	366	17	-	-	-	209	181	20	215
1990	890	417	74	-	141	-	326	283	192	58
1991	745	364	83	59	71	-	249	268	147	169
1992	802	446	31	30	18	74	218	209	100	170
1993	728	286	39	51	61	96	157	190	76	140
1994*	267	323	10	93	184	259	282	267	168	73

Table 4.
Time period 1992-april 1994. Total runoff values (mm) by autumn plowing and relative runoff for other treatments compared to autumn plowing. Relative runoff and cons. of suspended solids in runoff at different snow conditions are also given. Explanations: Snow=0 no frost in soil and no snow, Snow=1 soil frozen or with a thin layer of snow, Snow=2 deep snow cover. Tillage: PL-AU=plowing autumn, PL-AU-L=plowing autumn late, PL-AU-AC=plowing autumn across, HA-AU=harrowing autumn, HA-SP=harr. spring, HA-SP+SL=harr. spr.+sewage sludge, PL-SP=plowing spring, DIR-SP=direct sowing spring.

	Surface water Øsak	Helle	Askim	Bjørn	Syver	Mean	Drain water Askim	Syver
mm (PL-AU)	305	419	665	631	174	404	538	711
PL-AU-L	0,7	-	-	1,2	-	-	-	-
PL-AU-AC	-	0,8	-	-	-	-	-	-
HA-AU	1,2	-	-	1,02	-	-	-	-
HA-SP	-	1,1	0,82	-	-	-	-	-
HA-SP+SL	-	1,0	-	-	-	-	-	-
PL-SP	-	-	-	0,90	2,6	-	-	0,8
DIR-SP	1,2	-	-	-	-	-	-	-
MEADOW	-	1,06	-	-	-	-	-	-
SNOW	Relative runoff for snow (%)					mean	drain	
0	2	6	8	13	4	7	50	34
1	29	50	54	50	42	45	49	46
2	69	44	38	37	54	48	1	19
	Cons. of suspended solids (g/l)					mean	drain	
0	0,39	13,0	6,9	2,3	0,13	4,5	0,4	0,007
1	2,0	1,7	2,4	2,0	0,28	1,7	0,7	0,011
2	0,10	0,18	0,20	0,16	0,021	0,13	0,12	0,009

frost in soil every year. Late autumn plowing gave high surface runoff at Bjørnebekk because of plowing at very smeary conditions one year, destroying structure. Aggregate stability and infiltration was lowest after this treatment. Harrowing autumn at Øsaker gave high surface runoff of similar reasons.

Mean monthly runoff at Askim is given in figure 1. Frost in soil was main reason for surface runoff. Table 4 and 5 show runoff and relative amounts of drain water at various snow

Table 5.
Askim 1987-apr. 1994. Yearly runoff of surface- and drain water. Drain as % of total runoff. Percentual values of runoff at different snow conditions are also given. Snow=0: no snow and no frost in soil, snow=1: snow frozen or with a thin snow cover, snow=2: soil with a relatively deep snow cover.
* 1994: only january-april.

Year	Runoff surf. mm	drain mm	drain %	Percent runoff, different values of snow: surface water snow= 0	1	2	drain water 0	1	2
1987	268	423	61	77	5	18	62	4	34
1988	398	313	44	21	37	43	54	12	34
1989	168	239	59	43	57	0	84	16	0
1990	270	241	47	9	91	0	71	29	0
1991	248	335	57	17	37	46	74	17	9
1992	167	337	67	6	94	0	32	68	0
1993	179	189	51	17	74	9	86	14	0
1994	*(260	13	5	0	13	87	0	78	22)
87-93	242	296	55	27	52	21	64	23	13

conditions.

Table 4 (last section) show that cons. of suspended solids was by far greatest when surface runoff occurred at no frost or with a thin snow cover. Deep snow cover protects the soil.
Since the amount of runoff at deep snow varies greatly from year to year the concentration in total runoff also must vary. Yearly total concentration in surface runoff (CS_T) can be estimated by the following simple model: $CS_T=C_0*Q_0+C_1*Q_1+C_2*Q_2$ where C=concentration and Q=relative runoff, and 0, 1, 2 mean snow condition 0, 1, 2 respectively. Values of C may be found in table 4 and yearly values of Q in table 5.

Total concentrations in drain water (CD_T) can be found in a similar way. When total amounts of surface (QS) and drain runoff (QD) also are known, then the mean concentration in all water (C) will be: $C= (CS_T * QS + CD_T * QD) / (QS + QD)$.

Example of use of this model at Holt is shown in fig. 2. The effects of mild winters 1990-93 are evident, and also the change back to snowrich in 1994. The hydrological cause of variation in water quality must be taken into account when pollution problems are discussed.

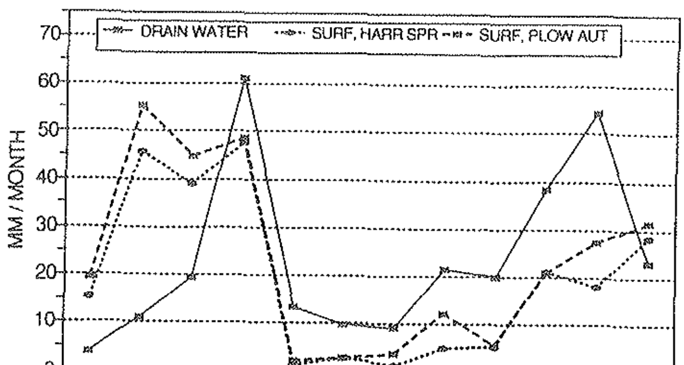

Fig. 1. Mean Monthly runoff at Askim 1987-april 1994.

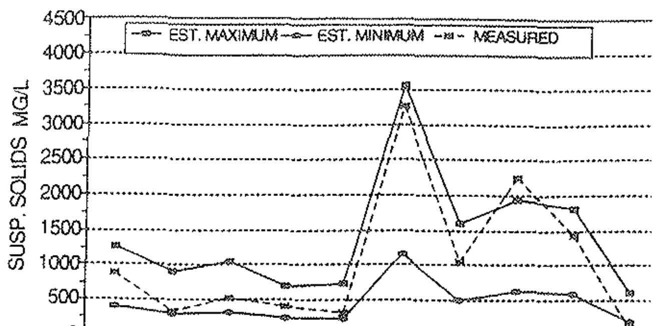

Fig 2. Holt. Measured and estimated cons. using snow factor.

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EFFECT OF SOIL TILLAGE ON EROSION AND NUTRIENT TRANSPORT IN PLOUGH LAYER RUNOFF

Non-point source loading from the fields can be roughly divided by its pathway into two main types: plough layer runoff (0-30 cm) and drainage runoff through sub-drains. As the slope of the field increases, erosion increases, and thus the proportion of loading from plough layer runoff also increases. The surface erosion from fields can be decreased by using lighter tillage methods, or by adopting unploughed cultivation. This would evidently also have a significant effect on the amount of non-point source loading. In these cases, farmers have the possibility of taking action themselves to reduce non-point source loading.

The total amounts of solids and particulate phosphorus in plough layer (0-30 cm) runoff are very dependent on the type of soil surface in the field. The effects of different cultivation methods on both erosion and surface runoff were studied under experimental conditions on fields with a surface slope of 7-8 %, where the soil in the plough layer was clay loam and the subsoil heavy clay.

The nutrient and total solids concentrations of plough layer runoff from the experimental plots were analysed and compared to the concentrations of plough layer runoff from control plots (winter wheat). The relative total solids concentrations thus calculated was 0.35-0.58 for stubble plots, 0.79-1.29 for stubble tillage, 0.90-1.09 for cross ploughing, 1.23-1.53 for normal ploughing, and 0.54-0.65 for a grass strip (control=1.0). The particulate phosphorus concentration correlated extremely well with the total solids concentration, and the relative change was similar for both.

The relative nitrogen concentration of plough layer runoff was 0.46-0.52 in stubble; 0.41--1.64 in stubble tillage, 0.66-2.79 in cross ploughing, 0.69-7.91 in normal ploughing, and 0.34-0.52 in grass strips. It is recommended that lighter tillage be used in stubble tillage. If the surface was heavily tilled to a depth of 10 cm, the runoff concentrations rose to the same level as in ploughed land. In ploughed land, the variation in the annual nitrate concentrations of plough layer runoff was considerable.

The relative soluble phosphorus (DRP) was same level in all studied cultivation methods, although differencies of the total phosphorus cocentration was great. It means, that PO_4-P concentration of plough layer runoff mainly depends from content of phosphorus in soil.

The quality of the surface of the field also had an effect on the amount of plough layer runoff. In stubble, the total amount of plough layer runoff relative to that from control plots even decreased slightly in some cases; in cross ploughed fields plough layer runoff clearly decreased; in normal ploughed fields it increased; in stubble tillage it also increased; and in the grass strips it remained at the same level.

The starting point for lowering loading is lowering of the concentrations of runoff. This alone implies the lowering of total loading, even if no other changes take place in the runoff itself. On the other hand, the amount of total runoff may not change even though the proportions of runoff may change.

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STREAMFLOW VARIABILITY AND POTENTIAL FOR REGULATION IN SMALL WATERSHEDS

Sweden has a long tradition of river regulation, mostly for the production of hydroelectric power, which covers some 50% of Swedens demand for electricity. The hydrological conditions in the country are also very favourable for river regulation due to the abundance of lakes, more than 92 000. Today it is easier to find a regulated than an unregulated larger river system in the country. In some of the main rivers as much as 70% of the mean annual runoff can be stored in reservoirs. This means rather drastic regulation amplitudes in some of the lakes, sometimes as much as 30 meters. In smaller watersheds (catchment area less than some 100 km^2) regulation effects are less pronounced.

When planning a reservoir there are many factors which have to be considered:

Streamflow variability (annual, interannual, extremes).
Physical limitations.
Ecological advantages and limitations.
Economical aspects.
Legal aspects.
Safety aspects.

If the reservoir is intended for nutrient management the streamflow variations in combination with the desired residence time determines its volume. To estimate the volume is, however, not a trivial problem due to the great variabilities in streamflow and the hydrography of the reservoir itself. Due to preferential pathways of the water within the reservoir, caused by irregular reservoir shape or stratification of the water body, the real residence time of water may be far less than the theoretical one.

The seasonal dynamics of the concentrations of nutrients in the river is another factor which effects the success of the project. In the areas in the south of Sweden, with the most intense agricultural activity, the concentrations are highest during the non-vegetation period in winter. Unfortunately this coincides with the season for high river flow which means that the residence time for this particular water may be surprisingly short. Consequently the retention of nutrients may be lower than expected.

The interaction between seasonal dynamics in river flow and nutrients were rather unfavourable for the Baltic Sea during the 1980-ies. The decade was the wettest during the period 1920-1990 and, unfortunately, the increased runoff relates to winter-time when the concentration of nutrients is high as well. Thus the load of nutrients on the Baltic Sea was above normal during the latest decade, due to climatic conditions.

The physical constraints are obvious if an artificial reservoir or a regulation of a lake are planned. There must be room for the reservoir and the environmental problems related to its operation must be controlled. But there is also a safety aspect which must not be neglected. Very small dams and reservoirs are normally not a big problem but as the water body increases the consequences of a dam failure moves into focus. The dams must therefore be designed to be able to withstand extreme hydrological conditions. The problem of design floods and dam safety are in focus all over the world and experience shows that we tend to underestimate the magnitude of the problem.

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USE, PROBLEMS AND SOLUTIONS IN SWEDISH IRRIGATION WATER MANAGEMENT

Irrigation Water Use

The irrigation in Sweden developed rapidly during the 1970's. From 1980 the withdrawals have been fairly constant within the yearly climatic variations. The estimates today are that some 6,000 farmers withdraw some 100 million m^3 for irrigation of 100,000 hectares during a dry growing season. Such draughts can be expected about every five years. Even this dry year irrigation is small compared to most agrohydrologic measures: The irrigated area represents 3.5 per cent of the cultivated area, the irrigation withdrawals correspond to less than 0.1 per cent of the usable net precipitation, less than five per cent of the total withdrawals, and are of the same order as the losses in the municipal water supply systems. About half of the irrigation water is drawn from natural streams, one quarter from groundwater and the rest from lakes, ponds and coastal waters.

Problems

Although the total irrigation withdrawals from streams correspond to only five m^3 per second (evenly distributed over four irrigation months), the stream withdrawal is the principal problem with nature conservation being the main opposing interest. It is not rare that small streams completely dry out partly because of irrigation. This causes difficulties for the County Boards who are the supervising bodies according to the Water Act as well as traditionally according to the Nature Conservation Act. With The Water Act stipulating permits for harmful irrigation withdrawals, with 95 per cent of the withdrawals being potentially illegal (only some 300 farmers have proper Water Court permits) and with practically no legal means for immediate counteraction, the conflicts are bound to arise.

Solutions

In a governmental investigation two years ago the Swedish Board of Agriculture suggested some means to overcome the most pronounced conflicts. Apart from technical measures a new paragraph in the Water Act was suggested. This has now been adopted in connection with a proposal for a new Code of Environmental Protection giving the County Boards more power to stop illegal withdrawals. More important though is the suggestion to reach concensus through river basin management. Two examples from southeastern Sweden show that this is fruitful. Only within these two basins some 250 farmers will get their legal permits. Because of joint action, joint design and joint reservoir regulation the permits will be acquired at extremely moderate costs. Above all the irrigation water will be withdrawn in full agreement with all potential opposing interests.

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SEDIMENTATION OF PHOSPHORUS AND SOIL PARTICLES IN CONSTRUCTED WETLANDS

In 1990, four first order streams in South-Eastern Norway, were damned up and their banks expanded. Four small, rectangular, shallow ponds resulted. Each had a 0.4-0.5 m deep vegetation filter, except at the inlet, where the sedimentation basins were 1 meter deep. The widths were 3-9 m, and surface area between 230-860 m^2, equal to between 0.03-0.12 % of watershed area (50-100 ha). Average yearly discharge was 0.14 s l/ha.

Samples were collected using a water proportional sampling system in the in- and outlet, and with sedimentation traps throughout the constructed wetlands (CWs).

Retention of soil particles was higher in the "winter season" (November-April) than in the "summer season" (71 % versus 47 % respectively). This was also true for phosphorus retention (42 % versus 20 %). The corresponding values for organic matter were 27 and 17 % (figure 1 and 2). High retention, despite winter storms, may be explained by a higher input of coarser soil particles, more collisions due to higher particle concentrations and little re-suspension, due to vegetation cover.

Results from the "winter season" should, however, be used with some care: They include only one sampling season from two CWs (1993/1994). The "summer season" results include two seasons from four CWs (1992 and 1993). However, higher retention in the "winter season" was confirmed by sedimentation trap results (table 1).

Texture analysis of the sediment from the vegetation filter gave a clay content of 25 % on average. There were, however, large differences between the CWs. The clay content was up to 5 times the expected, compared to formulas presented in *Handbook of NPS-Pollution* by Novotny and Chesters (1981). High content of clay and fine silt (18 %) may be explained as a function of vegetation reducing the water velocity, increasing flocculation, and the inflow of aggregated particles.

To sum up, these results show that even small CWs are able to retain soil particles and phosphorus. Constructed wetlands can be efficient tools to mitigate the effects of surplus nutrition loss and soil erosion from arable land (figure 3).

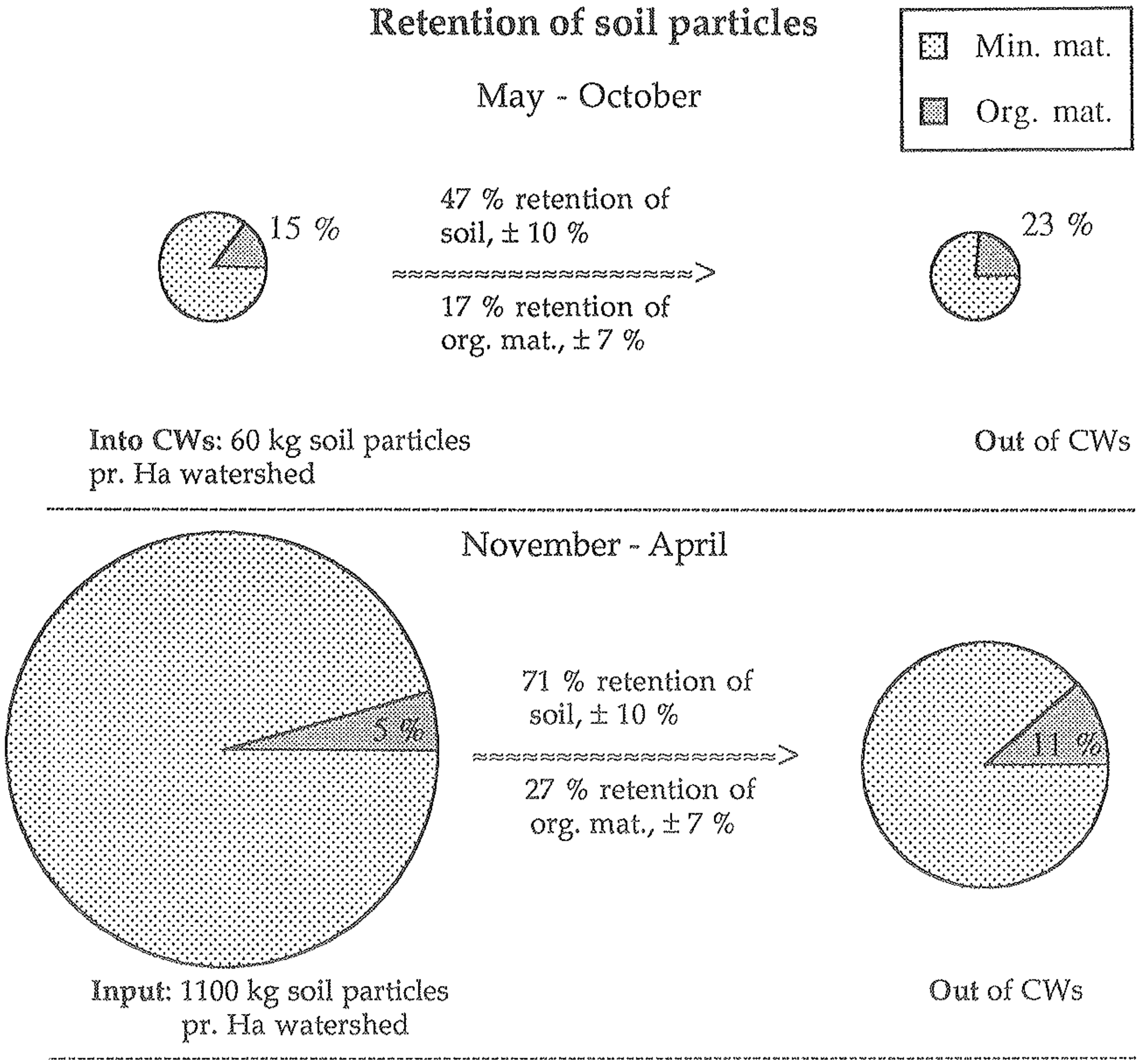

Figure 1. Soil retention for a whole year: The year is divided into a summer season and a winter season. The circles are scaled and show the relative comparison between winter and summer, inlet and outlet. The soil particle runoff in the winter season, is 18 times higher than that in the summer season.

Mixed samples show a retention rate of 47 % for soil particles in the summer season. 15 % of the soil particles into the CWs were organic matter. Only 17 % of the organic matter is retained, probably due to it´s low specific weight, and the production of organic matter in the summer.

The larger sized wetlands, relative to the watershed area, gave the best percentage retention.

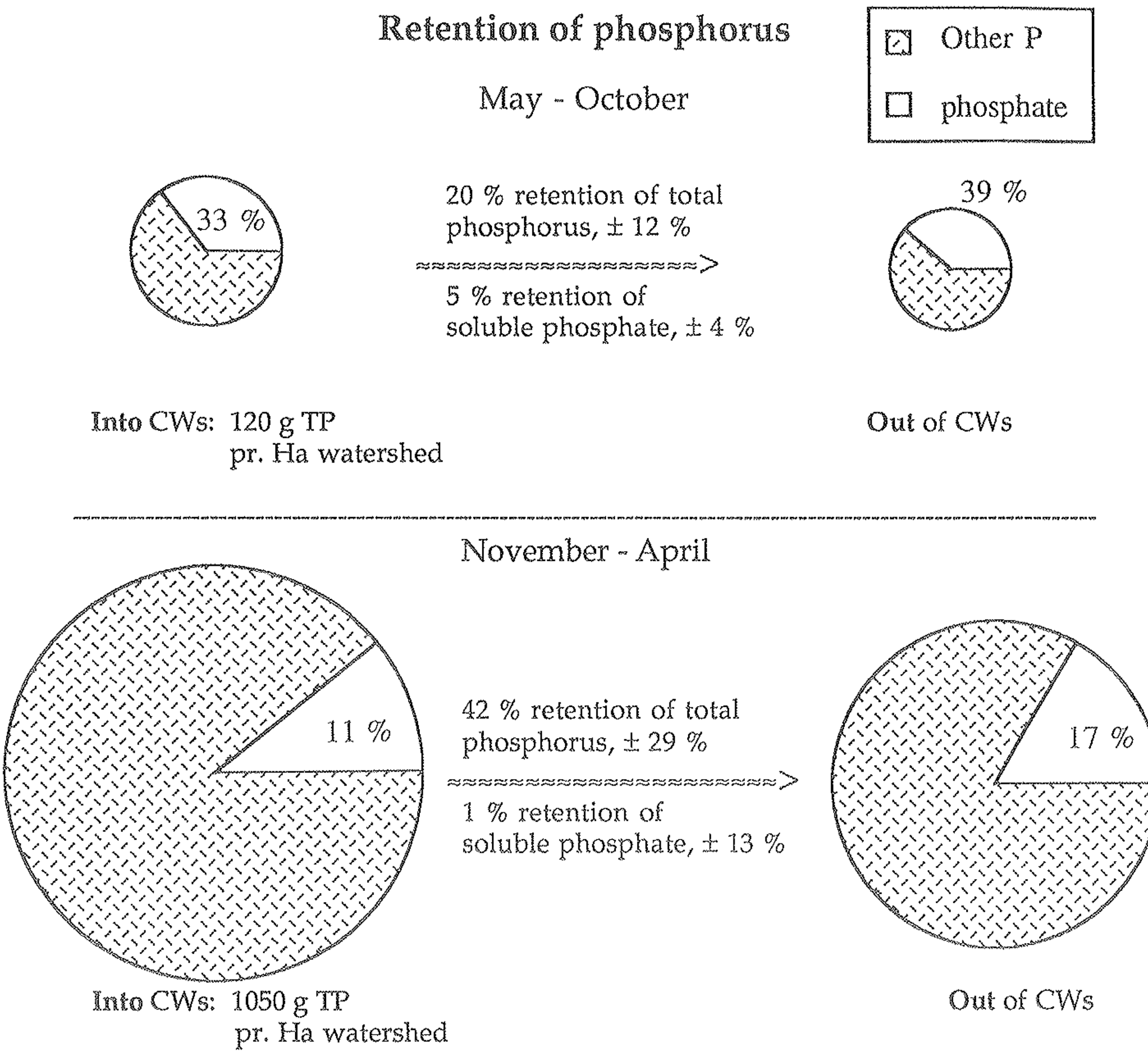

Figure 2. This figure gives the annual retention of phosphorus in the CWs. It is built up as for the soil particles. The input through the winter is 9 times the summer input.

We see that 33 % of total phosphorus is soluble phosphate in the summer inflow-water. Soluble phosphate seems to be hard to capture, unless the system is manipulated further. This may be one of the reasons for summer retention being less than the winter retention. 20 % of total phosphorus was retained during the summer season.

Concentration of soil particles in the water is quite high in the winter season. Soil particles are like glue to phosphorus, and may explain the high retention during this part of the year. 42 % of phosphorus was captured in the winter season.

Retention of soil and phosphorus (kg / m²)

Table 1. The effect of the constructed wetlands are summed up in this table. Retention is presented in confidence intervals, an average and the statistically calculated borders (±). Both retention from mixed samples and sedimentation traps results are presented in kg/m².

		Mixed samples		Sedimentation traps	
	Season	Average	P=0,05	Average	P=0,05
Soil particles	S	5840	±5800	6480	±3300
	W	100300	±200000	23510	±10900
Org. mat.	S	130	±100	510	±150
	W	1333	±9300	1170	±500
Phosphorus	S	5	±7	4	±3
	W	46	±81	18	±9

Some of the differences in the two methods are due to:
- Mixed sample results include only two season´s data in the winter (n=2).
- Sedimentation traps not covering the inlet area well enough. Sedimentation trap results will also include some of the organic matter produced in the summer.

An estimate of soil and phosphorus retention would be: 300-1000 metric tons of soil captured annually per ha of CW, and 200-500 kg phosphorus.

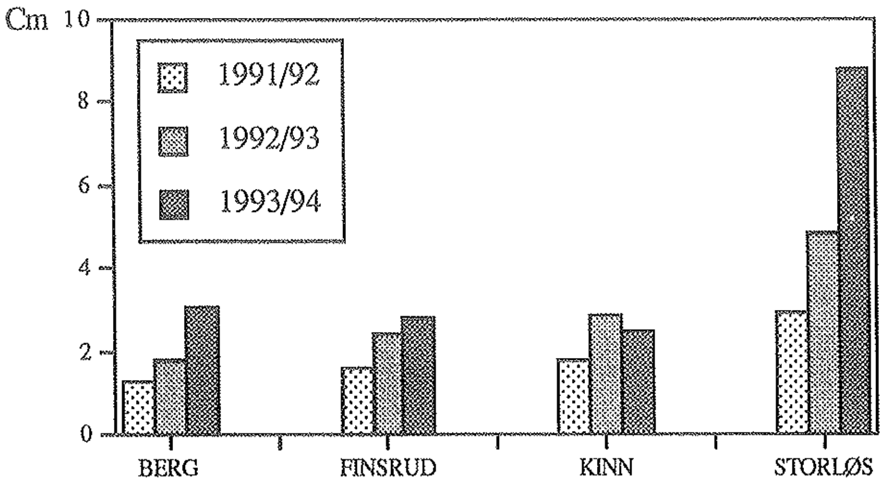

Figure 3. Annual sedimentation of soil particles in the vegetation filter of four CWs. Sedimentation rates are increasing despite decreasing depth (<0.5 m). CWs have to be emptied after 8-25 years, depending of wetland size and particle input. Soil and phosphorus may be recycled.

Braskerud, B. 1994. Tilbakeholdelse av jord, fosfor og nitrogen i fangdammer. JORDFORSK-rapport 6.24.09/4.

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EFFECT OF VEGETATIVE FILTER STRIPS ON MINIMIZING AGRICULTURAL RUNOFF IN SOUTHERN NORWAY

Abstract

Loss of nutrients and sediments from agricultural runoff causes eutrophication in surface water. The use of natural systems (Ecological Engineering), like vegetated filter strips adjacent to a streamside, can effectively filter nutrients and sediment. It is, therefore, important to study design criteria which optimize such vegetative filter strips.

This paper describes the influence of five criteria: (i) filter strip length (in slope direction - 5, 10 and 15 m), (ii) vegetation type (grass versus trees), (iii) size of catchments (500 and 5000 m^{2}), (iv) constitution of vegetation (rapid growth and withered vegetation), and (v) slope (7, 14 and 28 %). These parameters were studied after natural runoff, simulated runoff and in the laboratory.

The results show that the sedimentation process is most effective in the upper part of the filter strip. We recommend therefore filter strip length between 5 and 10 m depending on the topography and hydrology in the catchment. The results show no significant differences between forest filter strips and grass filter strips regarding their efficiency of retention. The filter strips can receive runoff from relatively large catchments (5000 m^{2}) without significantly decrease in removal level (for sediments). Rapid growth is significantly more effective than withered vegetation. Results indicate no significant differences in sedimentation between three slopes (7, 14 and 28 %). A filter strip can remove more than 30 % of the incoming nitrogen, 50 % of phosphorus and 70 % of sediment.

1 INTRODUCTION

The North Sea is threatened by high nutrient input and eutrophication caused by runoff from agriculture. The use of natural systems, like vegetative filter strips adjacent to a streamside, is one measure which can reduce non-point pollution from agriculture. It is important to study design criteria which optimize the effect of vegetative filter strips. The design criteria have been studied for 1) natural runoff 2) simulated runoff and 3) laboratory study.

2 MATERIAL AND METHODS

1) Natural runoff:

-three 4-plot field areas, established autumn 1991
-tested the influence of filter strips length (in slope direction)
    -control reception (no filter strip), filter strips with 5, 10 and 15m length
-the filter strips were planted with native grass
-runoff from each supply area was calibrated for one year
-measured the discharge rate, water samples after each runoff episode
-water samples analysed for phosphorus, nitrogen and suspended matter

2) Simulated runoff

-to create surface flow the filter strips were saturated of water
-water-based sediment and nutrient were applied to the filter strips
-simulated runoff with native grass:
    -tested the influence of filter strips with 5 and 10 m length
    -tested the influence of applied 2000 l and 20,000 l "runoff water" (corresponding to 4 mm runoff from 500 and 5000 m^2 catchment)
    -tested the influence of filter strips with rapid growth and withered vegetation
-simulated runoff with native grass and aspen with mosses:
    -tested the influence of filter strips with 5 and 10 m length
-water samples from supply and collecting gutter
-water samples analysed for phosphorus, nitrogen and suspended matter

3) Laboratory study

-filter strip model built
-added water mixed with sediment to filter strip
-tested the influence of sedimentation at different slopes (7, 14 and 28 %)

3 RESULTS AND CONCLUSIONS

-a vegetative filter strip can capture more than <u>70 % of the sediment</u>, <u>50 % of the phosphorous</u> and <u>30 % of the nitrogen</u>

-the removal of sediment and nutrient is also high during autumn and winter
    -autumn: high precipitation and runoff
    -winter: snow and freeze

-filter strips can receive runoff from relatively large catchments without significant decrease in removal level (especially for sediments)

-we recommend a filter strip length between 5 and 10 m
    -sedimentation (sediment and nutrient adsorped to sediment) is most effective in the upper part of the filter strip
    -15 m filter strip does not remove significantly greater amounts of sediment and nutrient

-rapid growth vegetation is significantly more effective than withered vegetation

-there is no apparent difference between different kinds of vegetation (grass versus aspen)

-different slopes (7, 14 and 28 %) do not influence the level of removal apparently

-further investigation of different kinds of vegetation and slope is needed

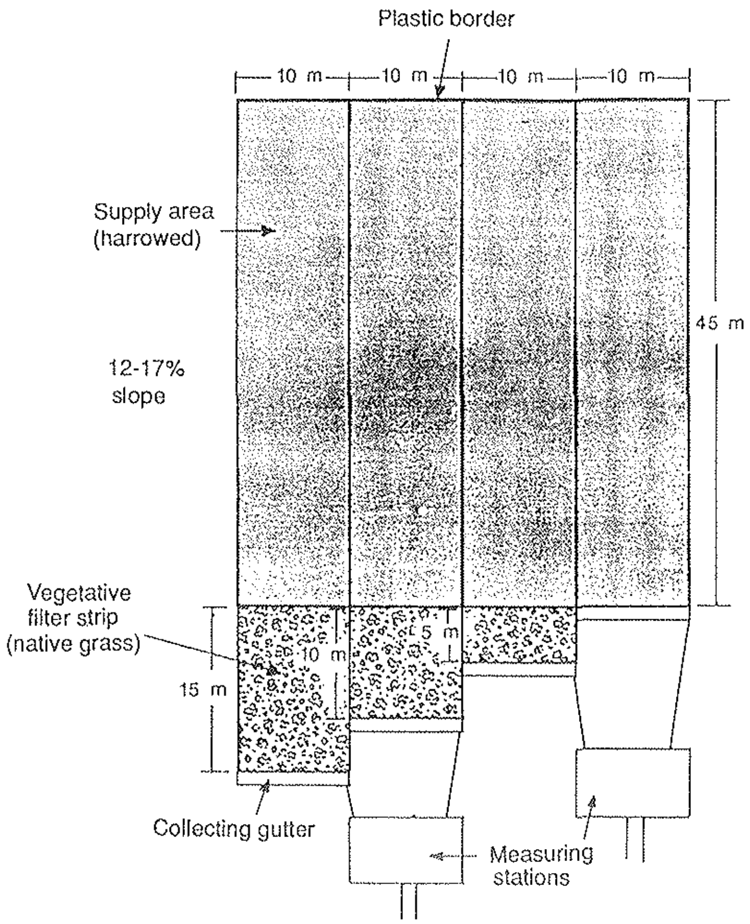

Fig. 1. Schematic presentation of field plot with natural runoff.

Tab. 1. Removal (%) of nutrient and sediment from filter strips with 5, 10 and 15 m length. Results from natural runoff during one year and two field plots (results from 15 m: one field plot)

	Tot P	PO_4	Tot N	NO_3	SS	Org.m
5 m	45-56	2-77	65-72	62-73	61-78	49-70
10 m	56-85	0-88	60-91	66-84	73-91	69-87
15 m	73	10	54	52	87	80

Tab. 2. Removal in kg / decare filter strip x year (g/m^2 x year). Results from grass filter strips with 5-10 m length (natural runoff)

Phosphorus	Nitrogen	Sediment
1,5-9,5	10-55	2000-4300

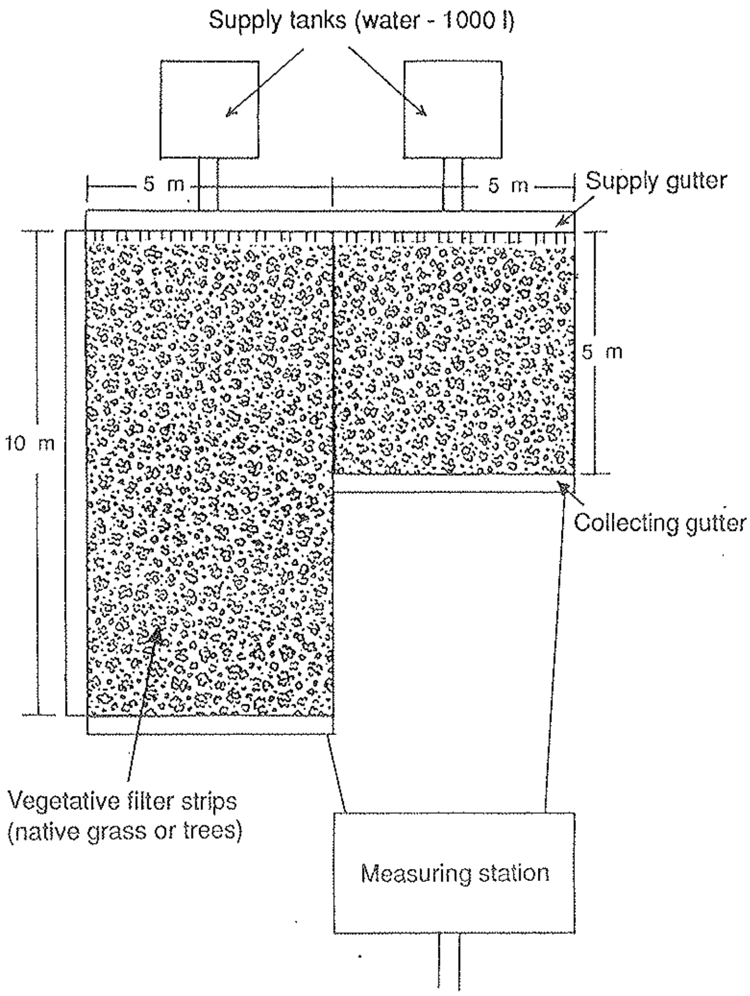

Fig. 2. Schematic presentation of field plot with simulated runoff.

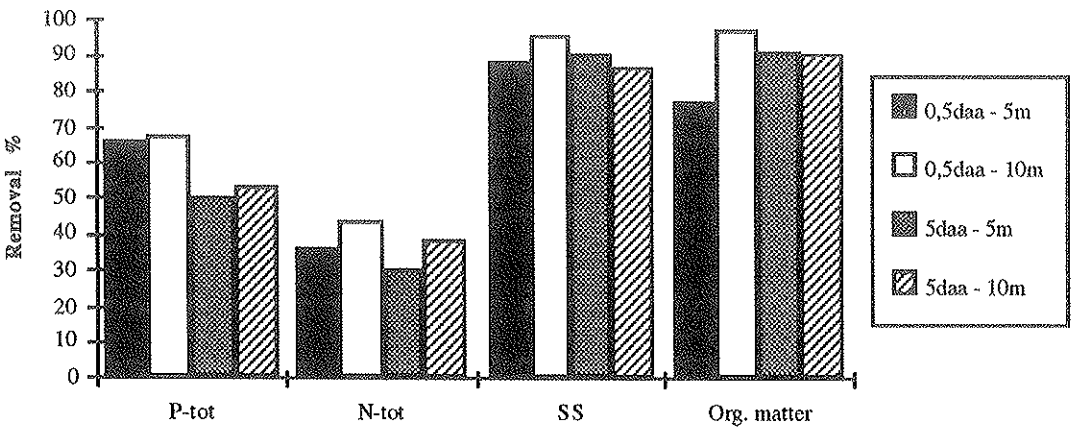

Fig. 3. Removal of nutrients and sediment in filter strip with rapid growth (simualted runoff)

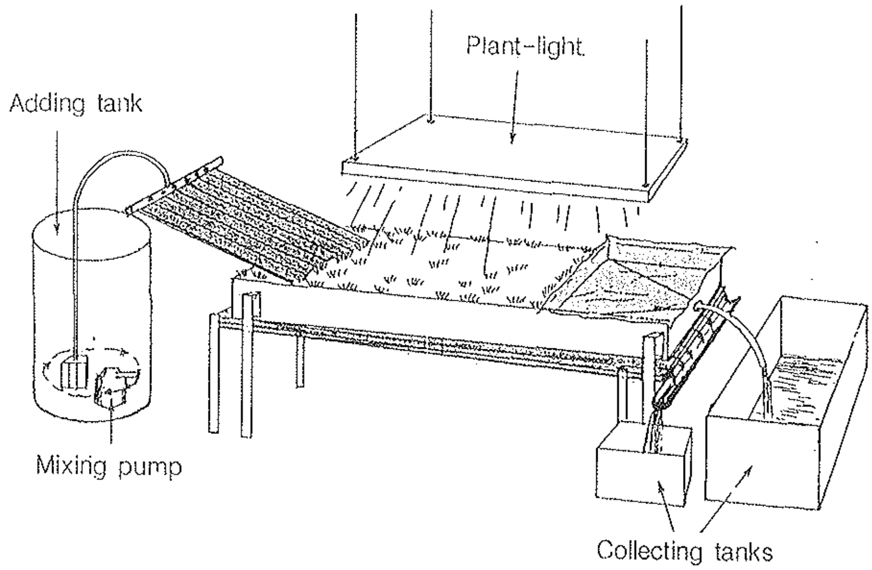

Fig. 4. Schematic presentation of laboratory study

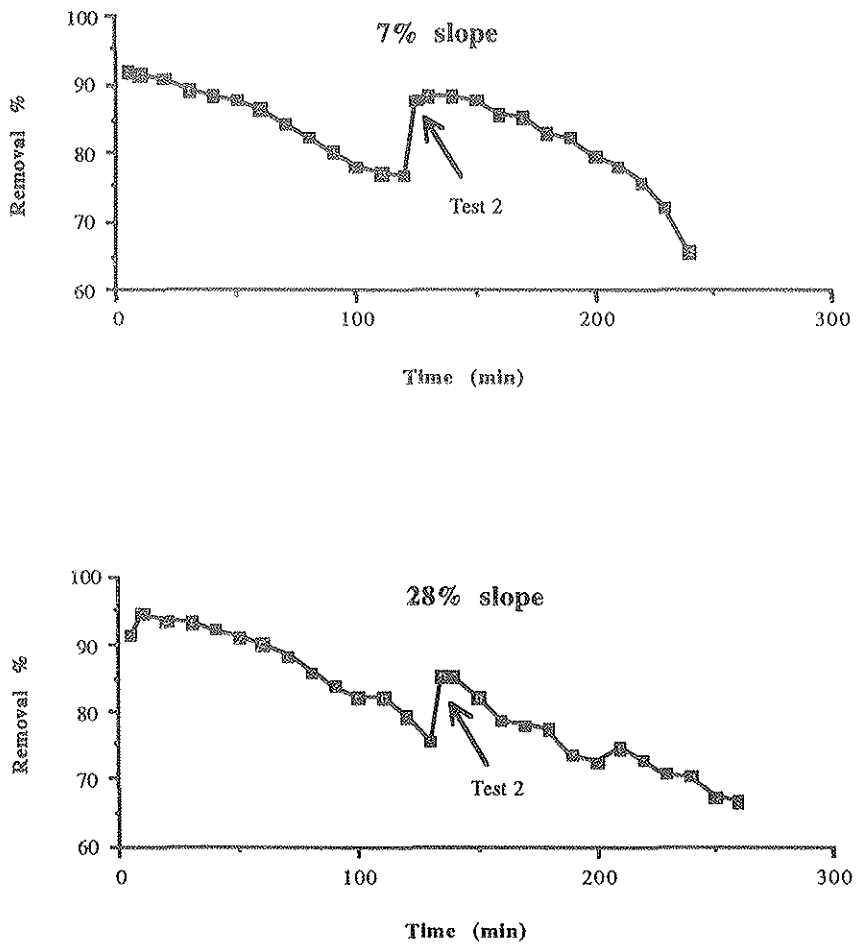

Fig. 5. Removal of sediment (%) with different slope

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BUFFER ZONES - POSSIBILITIES TO REDUCE NUTRIENT LOSSES FROM ARABLE LAND

In Finland, the largest single source of phosphorus and nitrogen in aquatic ecosystems is agriculture. Therefore, methods that decrease nutrient losses from agricultural areas are of increasing interest. These methods include cultivation practicies, and vegetated buffer strips (zones) between fields and watercourses. This paper describes an experiment at the Agricultural Research Centre of Finland to determine the effects of buffer strips on sediment and nutrient losses.

An experiment began in autumn 1991 at Jokioinen in southwestern Finland to measure the effects of grass buffer strips (GBS) and vegetated buffer strips (VBS) on sediment and nutrient losses. A 6-plot experimental field also provided a control without buffer strip (NBS) with two replications. The 60 m by 18 m runoff plots are on a clay soil with a uniform slope of 2%. Spring barley or spring oats are grown on each plot. At the lower end of each plot there is a 10-m wide strip with a slope of about 10%. On the control (NBS) barley or oats are grown on the strips, also. On the GBS treatment, a mixture of timothy grass and meadow fescue is used, and the grass is mowed and removed once each summer. The VBS treatment has a mixture of mainly common bent and yarrow grasses, and trees and shrubs were transplanted in 1991.

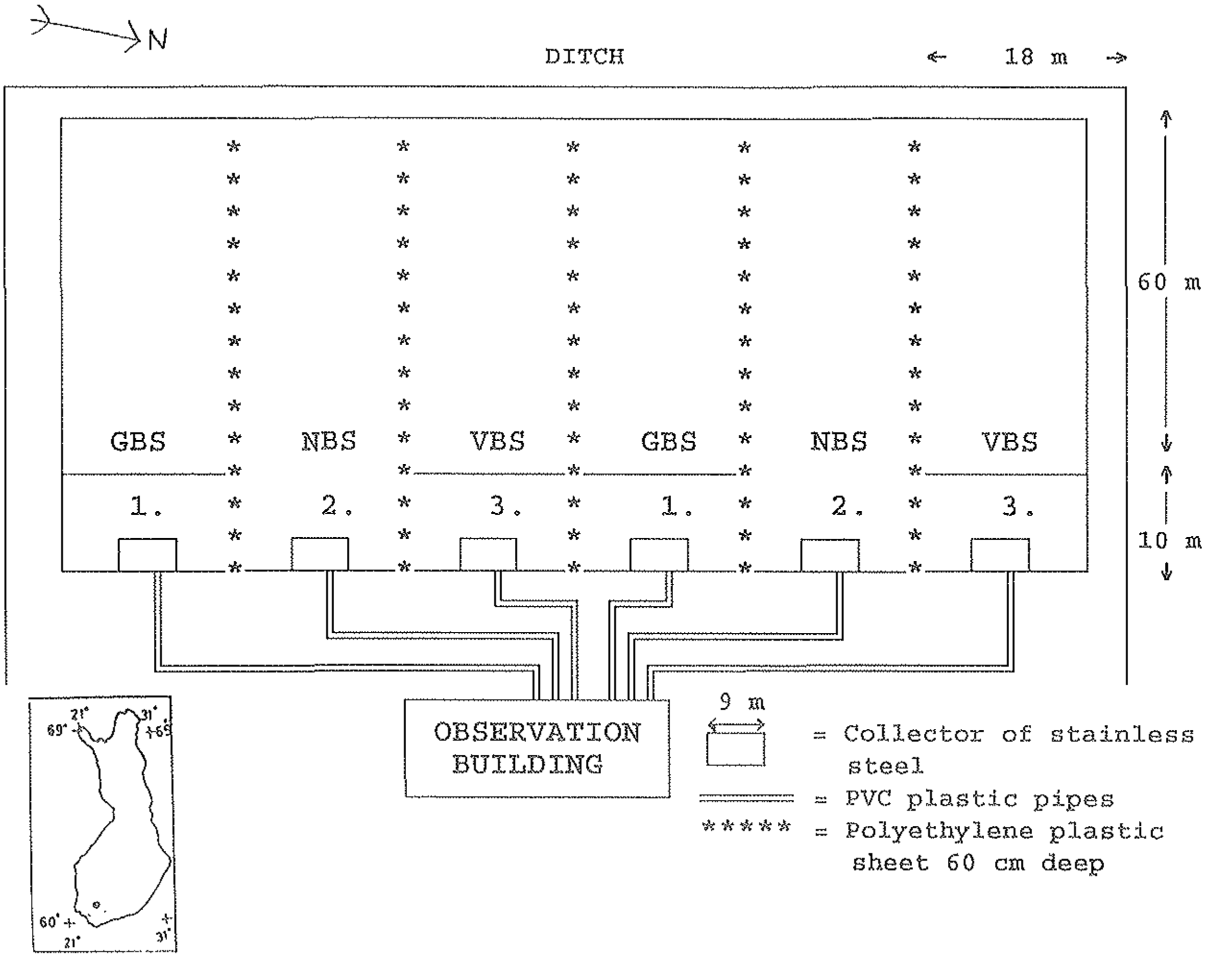
The 3-year mean surface runoff plus subsurface flow (270-300 mm) varied little among the treatments. The 3-year load of total solids was 1810 kg/ha on the NBS plots. The GBS's and VBS's decreased the suspended sediment by 30 and 43%, respectively. The sediment-adsorbed phosphorus from the GBS plots (1.2 kg/ha) was 20% less than that from the NBS plots, and that from the VBS plots (1.0 kg/ha) was over 30% less than that from the NBS plots.

On the GBS and VBS plots, 22 and 38% of total phosphorus was in the form of orthophosphate, but on the NBS plots only 17% was orthophosphate phosphorus. The runoff loss of orthophosphate phosphorus was very high from the VBS plots in the spring snowmelt period compared with the NBS and GBS plots. The high loss is because of phosphorus leaching out of the decaying grass residue on the surface of the buffer strip. As a result of these spring losses, the runoff orthophosphate phosphorus losses from the VBS plots were 90% greater than that from the GBS and NBS plots.

The load of runoff and sediment nitrogen was 18.6 kg/ha from the NBS plots. The GBS's and VBS's decreased the loss of nitrogen by 53 and 31%, respectively. The buffer strips also reducednitrate losses. The nitrate-nitrogen load from the GBS plots (5.5 kg/ha) was 60% less than that from the NBS plots, and the VBS plots (8.5 kg/ha) was 40% smaller than that from the NBS plots.

Table 1. Runoff (surface + subsurface), total solids (TS), and plant nutriet losses from NBS, GBS, and VBS plots, mean of two replicates.

Treatment/ Period	Runoff (mm)	TS	Tot-N	NO_3^--N	NH_4^+-N	Part.-P	PO_4^{3-}-P
				kg/ha			
No buffer strip (NBS)							
Autumn 1991	16	330	2.0	1.4	0.02	0.27	0.02
Spring 1992	42	190	2.5	2.0	0.06	0.14	0.06
Autumn 1992	24	210	2.9	2.4	0.04	0.20	0.04
Spring 1993	64	720	5.6	4.3	0.10	0.50	0.10
Autumn 1993	10	90	0.5	0.3	0.01	0.09	0.02
Spring 1994	115	270	5.1	3.5	0.18	0.30	0.08
Sum 1991/93	271	1810	18.6	13.9	0.41	1.50	0.32
Grass buffer strip (GBS)							
Autumn 1991	15	170	0.5	0.3	0.01	0.18	0.02
Spring 1992	61	240	1.8	1.4	0.10	0.18	0.09
Autumn 1992	33	190	1.0	0.6	0.04	0.19	0.04
Spring 1993	56	470	2.5	1.6	0.10	0.33	0.08
Autumn 1993	18	70	0.4	0.2	0.02	0.08	0.03
Spring 1994	105	140	2.6	1.4	0.16	0.23	0.08
Sum 1991/93	288	1280	8.8	5.5	0.43	1.19	0.34
Vegetated buffer strip (VBS)							
Autumn 1991	18	200	1.2	0.7	0.02	0.18	0.03
Spring 1992	67	240	3.2	2.5	0.19	0.17	0.12
Autumn 1992	25	100	1.0	0.7	0.03	0.13	0.04
Spring 1993	62	300	3.8	2.7	0.18	0.24	0.13
Autumn 1993	11	40	0.3	0.1	0.03	0.05	0.07
Spring 1994	113	150	3.3	1.8	0.28	0.22	0.22
Sum 1991/93	296	1030	12.8	8.5	0.73	0.99	0.61



Experimental treatments:

1. Grass buffer strip (GBS); Seed mixture of timothy (*Phleum pratense*) 22 kg/ha and meadow fescue (*Festuca pratensis*) 12 kg/ha was sown with a companion crop of barley in May 1991. The barley was harvested in August 1991. The grass was mowed once each summer.
2. No vegetated buffer strip (NBS); sown with barley and fertilized like cropland source area.
3. Vegetated buffer strip (VBS); sown with common bent (*Agróstis tenuis*) in June 1991. Goat willow (*Salix cáprea*), mountain currant (*Ribes alpínum*), European cranberry bush (*Vibúrnum ópulus*), birch (*Bétula*), alder (*Alnus*), maple (*Acer platanoídes*) and mountain ash (*Sorbus aucupária*) were transplanted in October 1991.

The cropland source area, above the buffer strips, was sown with barley or oats and fertilized (NPK compound fertilization: 90 kg N/ha, 18 kg P/ha and 36 kg K/ha) in May. The crop was harvested in August and the field was ploughed in September each year.

Fig. 1. Schematic diagram of experimental field.

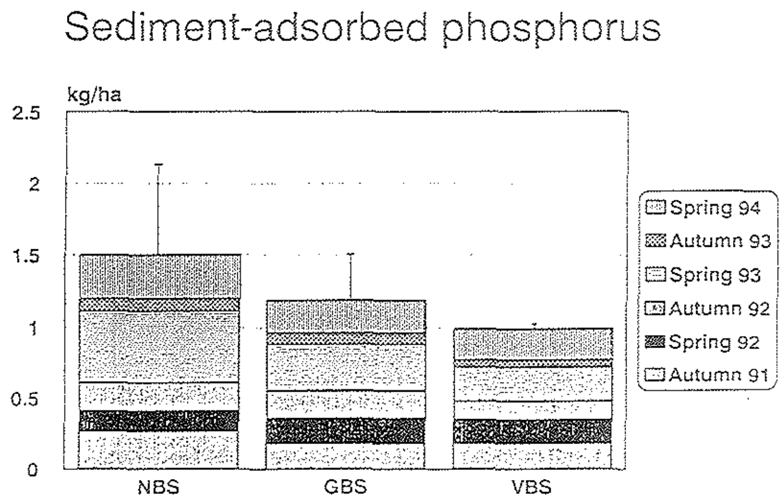


Fig. 3. Adsorbed phosphorus loads in sediment from the NBS, GBS and VBS plots, mean of two replicates with error bar showing maximum value.

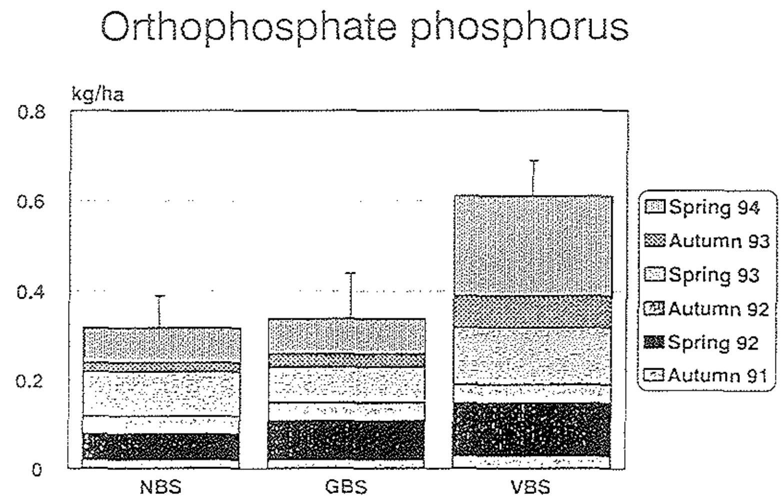


Fig. 4. Orthophosphate phosphorus in runoff from the BS, GBS and VBS plots, mean of two replicates with error bar showing maximum value.

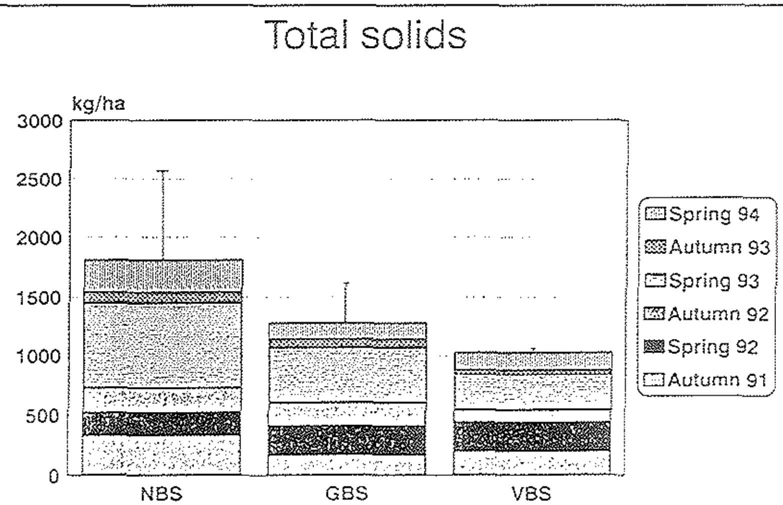


Fig. 2. Total solid loads from the NBS, GBS and VBS plots, mean of two replicates with error bar showing maximum values.

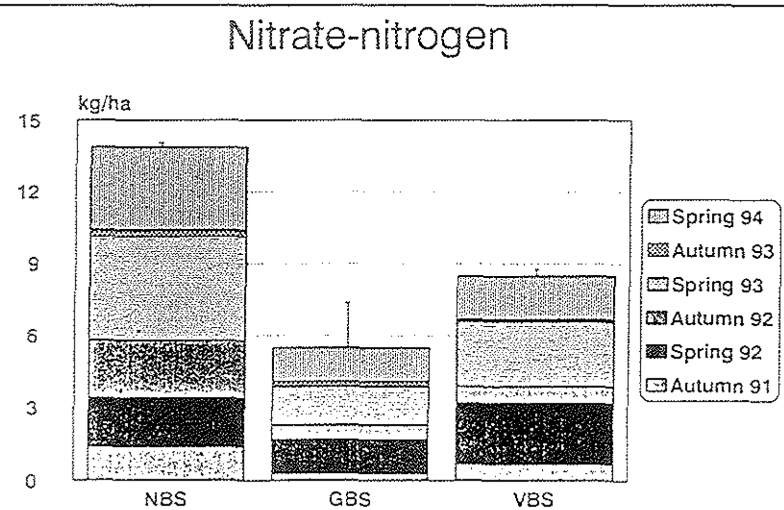


Fig. 5. Nitrate-nitrogen in runoff from the NBS, GBS and VBS plots, mean of two replicates with error bar showing maximum value.

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NITROGEN RETENTION IN STREAMS AND CONSTRUCTED WETLANDS

Nitrogen leaching from arable land is a major source (25%) for the N-load from Norway to the North Sea. Eutrophication of coastal waters and lakes makes it necessary to reduce the N-loads. N-leaching from arable land is difficult to control by conventional measures such as reducing ploughing, fertilizing, and surface runoff. Constructed wetlands, stream restoration and vegetated filter strips are alternative measures for N-removal. Results shows that these measures can be efficient. JORDFORSK has studied N-retention in constructed wetlands and streams for more than four years. Field- and laboratory studies are presented.

Constructed wetlands

In 1990 four constructed wetlands were built in small streams. Each constructed wetland consisted of a sedimentation chamber (1-2 m deep) and a wetland filter (0.5 m deep). The purification efficiency was evaluated by water proportional sampling. Results from 1993 showed annual reduction of the total N-load by 5-20%. This retention is high considering the constructed wetlands cover only 0.03-0.12% of the catchment areas. Daily N-retention was in the interval 100-700 mg N/m^2 wetland.

Field streams

Experiments were performed in a small stream during summer and early autumn when discharge was low and stable. High levels of organic matter (15 mg TOC/l) and rich growth of macrophytes and algae provided favorable conditions for denitrification. N-retention was investigated over a 100 m stretch after continuous addition of nitrate-solution for 48 hours. Nitrate concentrations varied in the interval 2-30 mg NO_3-N/l. Retention efficiency increased linearly with nitrate concentrations. Retention was in the interval 300-8000 mg N/m^2 stream*day.

Laboratory streams

Field sediment was lined in four (man-made) laboratory streams. Macrophytes and algae were grown under fluorescent lamps. Nitrate was added to a initial concentration of 20 mg NO_3-N/l. Daily sampling showed decreasing nitrate-concentrations. Nitrate-removal was dependent on nitrate concentrations, and was slower at low nitrate-concentrations. N-retention varied in the interval 50-200 mg N/m^2 stream*day. Replicate experiments conducted at different water temperatures, 5, 10 and 20°C, showed that the retention efficiency was halved when the temperature fell from 20 to 5°C.

Mesokosmos

Small units of wetland areas (with intact sediment and water) were isolated (mesokosmos) by installing cylindrical or rectangular walls. A series of experiments showed that the N-retention was dependent on nitrate concentration, content of organic matter, water velocity and water temperature. N-retention was 16-2000 mg N/m^2 *day dependent on conditions.

Conclusions and further needs for research

The referred experiments demonstrated considerable variation in N-retention (16-8000 mg N/m^2*day). Important factors for N-retention are nitrate level, content of organic matter, growth of algae and macrophytes and water temperature. The interaction of theses factors should be examined by factorial design experiments -- both in the field and in the laboratory. Since high water-velocity is considered to be critical for an active denitrifying biofilm, the effect of water velocity should be investigated. To design constructed wetlands for N-removal, a thorough understanding of the various factors influencing N-retention is necessary.

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Nitrogen Removal in Created Ponds

Background

The role of nitrogen as an environmental hazard has become increasingly important since World War II. Emissions, and increased use of nitrogen compounds, e.g. fertilizers, have an impact on eutrophication, acidification, production of greenhouse gases and on the stratospheric ozone layer. Decreasing the supply of nitrogen to coastal waters by half by 1995 has been adopted as a national goal in Sweden. However, this decrease appears to be unrealistic to attain for many years. In 1989, an interdisciplinary project in the Laholm Bay drainage basin pointed out that the goal can be attained if decreased emissions and leaching is combined with increased removal during runoff. This paper presents studies on nitrogen removal in created ponds.

Results

When area nitrogen loading is increased in a pond, total area removal also increases, but nitrogen removal expressed in percent of the load often decreases. Subsequently, low percentage removal does not indicate a poor function. However, several ponds of a certain capacity would be useful.

Periods with net removal were frequently followed by periods with release of nitrogen but in the long run all ponds except one showed a net removal during the investigation period. Annual net removal in these ponds varied between 73 and 7000 kg N ha^{-1}. Shallow ponds , as an additional nitrogen retention step after activated sludge treatment of municipal wastewater, showed an annual nitrogen removal of about 8000 kg N ha^{-1}. These results are promising especially for small towns and villages where a cost-efficient reduction can be obtained without continiuous supervision of the treatment plant. Ponds/wetlands should constitute one of several important building blocks in programs that aim to decrease river transport of nitrogen. This is true even with respect to low prcentage in ponds with high nitrogen load, since this may result in low marginal costs as a result of high area removal. In order to keep marginal costs low, planning of wetland creation/restoration must be strategic. Sites for ponds wetlands should preferably be localized where the area nitrogen load is high, because of high nitrogen concentrations. The hydrological load sets the limits for nitrogen removal processes, and is therefore crucial for designing ponds and wetlands. The dominating ebullotion gases were nitrogen and methane, the latter being the most important greenhouse gas escaping the ponds. The predominating fraction of nitrous oxide escaped from the extremely high N-loaded pond Tjärby 2 by means of diffusive flux. N_2O entered the pond via the stream that drained farmland, and would also have escaped to the atmosphere if there was no pond in the runoff system. In the pond, no N_2O production by denitrification, but rather a consumption, was indicated.

Reference

Fleischer, S., Gustafson, A., Joelsson, A., Pansar, J. & Stibe, L. 1994. Nitrogen Removal in created Ponds. Ambio, Vol. 23 No. 6, 349-357.

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EVAPOTRANSPIRATION FROM AGRICULTURAL CROPS IN LITHUANIAN LOAMY SOILS

The article presents generalized conclusions of many years (from 1965) investigations of total evapotranspiration (water consumption). Main basis of investigations was located in the central part of Lithuania, not far from Kaunas, but some investigations were done in other places of the country. Investigations were mostly done in drained loamy soils. All experiments were done in irrigation systems so irrigations norms were investigated at the same time. There were 4 usual variants: not - irrigated fields and 3 fields irrigated with three different norms: smaller, average, defined by calculations, and larger than the calculated one.

Evapotranspiration is mostly conditioned by meteorological factors and plants have less influence on it (Fig. 1). On the basis of experimental material of evapotranspiration investigations on irrigated fields with highly developed agricultural crops potential evaporation was defined. The experiments were done mostly in 1,0 sq.m. surface areas and smaller evaporators were used at the Water Balance Laboratory of the Land Reclamation Department, Lithuanian Academy of Agriculture. To calculate potential evaporation according to meteorological factors multinomial regressive equations of two types were analysed. These equations included various combinations of meteorological factors. Relative air moisture (x_1), air temperature (x_2), air moisture deficit (x_3), total solar radiation (x_4), soil surface temperature (x_5), soil temperature in 10 cm depth (x_6), average length of the day (x_7), length of solar radiance (x_8) and ratio of length of solar radiance and total length of the day in the particular period (x_9) were also members of the equations mentioned above. The actual evapotranspiration data for the five-day-periods, which were equated with the evaporation from highly developed cabbage fields, was best aproximated by the equation: $y = 0{,}52x_3 - 0{,}138x_7 + 0{,}584x_8 - 0{,}417x_9 + 16{,}1$ where regressive ratio is 0,94, actual Fisher criterion - 141,0, theoretical - 2,5, error - 3,1 mm (13,5%). Total equation influence modulus - 88,7%, air moisture deficit - 72,5%. We compared good calculation results according to one variable equation which includes only air moisture deficit (x_3): influence modulus - 86,6, correalation coefficient - 0,93, Fisher criterion -461,3, theoretical - 4,0. Equation error - 3,4 mm (14,7%), operation limits according to the total x_3 = 8,5-88,3 mb, according to y = 7,3-57,5mm.

Literature presents some data which show the connection between potential evaporation and air moisture deficit to be curved-lined, therefore, various forms of the connection were looked for (in all 17). The best results were obtained, in turn, according to the third and the second degree polynomes, progressive curve, and, in the fourth place, according to rectilinear dependence (Table 1). Statistic line of 222 members was made and generalized formula to calculate potential evaporation was calculated using evapotranspiration investigation data from various irrigated fields of highly developed agricultural crops. Introduction of biological coefficient into this formula allows to calculate evapotranspiration from the irrigated fields:

$$E = K(0{,}48\Sigma d + 9{,}4) \text{ mm/ten-day-period}, \qquad (1)$$

where K - biological coefficient, Σd- total air moisture deficit in the ten-day-period.

Biological coefficients depend on the variety and development of agricultural crop. On the ground of many years observations dependency curve of biological coefficients on time was worked out:

for late cabbages:

$$K = -0{,}0151\,x_t^2 + 0{,}6641x_t - 6{,}15; \qquad (r = 0{,}95;\ \delta = 0{,}06); \quad (2)$$

for red beets:

$$K = -0{,}0149x_t^2 + 0{,}6665x_t - 6{,}31; \qquad (r = 0{,}94;\ \delta = 0{,}08); \quad (3)$$

for cucumbers:

$$K = -0{,}0011x_t^3 + 0{,}0575x_t^2 - 0{,}8934x_t + 4{,}75; \qquad (4)$$

$$(r = 0{,}94;\ \delta = 0{,}07),$$

where x_t - number of the decade from the beginning of year (from 16 till 27); r - correlation coefficient; δ - equation error.

Biological coefficients of perennial grasses fluctuate from 0,6, at the very beginning of the vegetation period, till 1,0, when grasses are developed well. After cutting biological coefficient of perennial grasses is 0,6 in the current ten day period and 0,9 in the following ten day period. In September biological coefficients of perennial grasses are 0,8; 0,7 and 0,6.

Soil moisture influence on evapotranspiration is significant too. Our investigations show that in dry periods evapotranspiration in irrigated fields which have enough moisture is 30-60%, and sometimes more, greater than that in not-irrigated fields, where soil suffers lack of moisture. We have created methodics to evaluate the influence of soil moisture deficit influence on evapotranspiration based on the analysis of experimental materials and literature on this issue (S.Alpatjev, M Budyko, J.Eagleman, H.Hanson, S.Harchenko, P.Kuzmina, V.Mezencev, O.Shvelidze and others), which is suitable for Lithuanian climatic conditions. It is based on the S.Harchenko's recommendation and can be expressed as

$$K_w = (W_{mf} - \Delta W_{av})/(W_{mf} - W_{dm}), \qquad (5)$$

where W_{mf} - field capacity soil moisture; ΔW_{av} - average soil moisture deficit in the period; W_{dm} - moisture of drooping in the soil.

Comparison of actual water consumption with the one calculated by (1) formula is shown at the Fig. 2. We can see sufficiently good results of calculations. Correlation coefficient among the measured and calculated norms of total evapotranspiration is: for red beets - 0,92, for late cabbages - 0,89, for perennial grasses - 0,88. When calculating generally for all crops this coefficient equals 0,90, and dependency curve, in all cases, is close to bisector. Generally (1) formula can by used for practical needs, including calculation of irrigation regime. It was tested in experiments of many years. Good results were obtained when irrigation regime was calculated by water balance method, and water consumption - by (1) formula. Figure 3 shows that 2c (calculated) curve of moisture dynamics in the active soil layer fluctuates between max and min possible limits, and yields of agricultural crops were highest in those fields.

Conclusions

1. Total evapotranspiration very much depends on local conditions, therefore, regional formulas, deduced in particular locality fits best to calculate the evapotranspiration, or parameters of elsewhere deduced formulas, have to be defined localy.

2. Formula (1) can be applied for practical use under Lithuanian conditions, also for calculation of irrigation regime.

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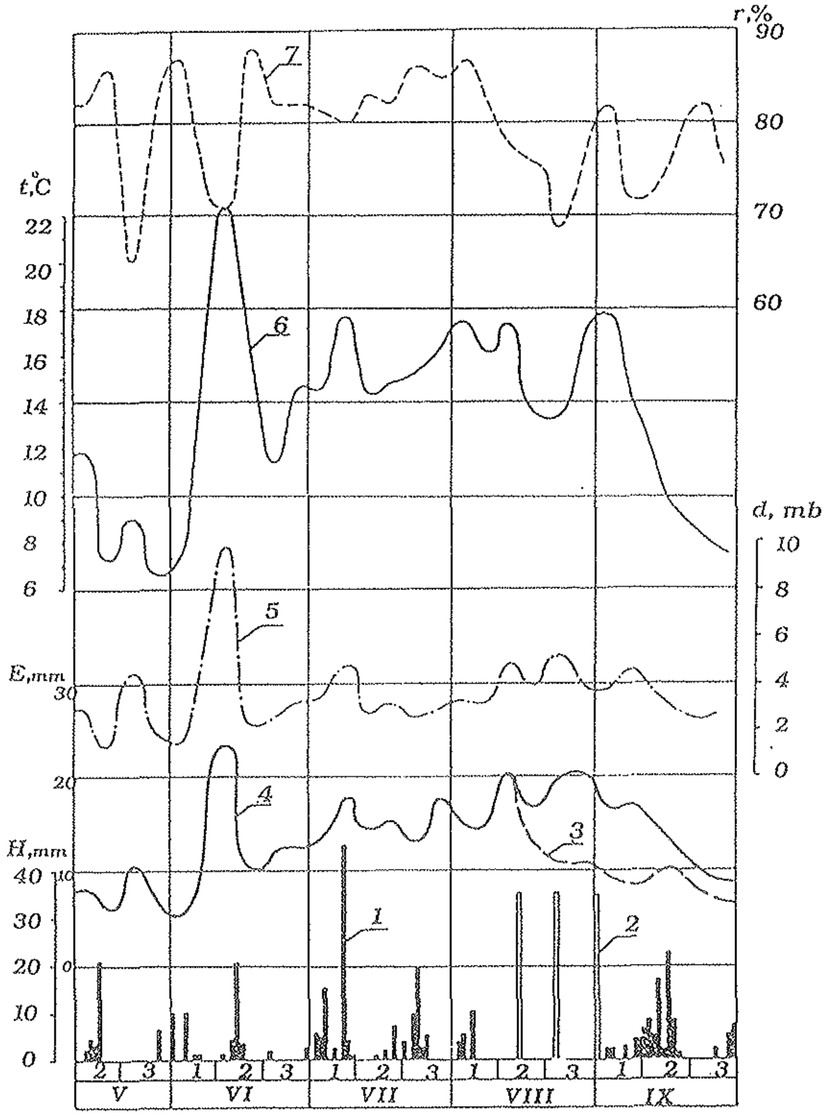

Fig. 1 Dynamics of Evapotranspiration and Meteorological Factors During Vegetation Period: 1 - precipitation; 2 - irrigation; 3 - evapotranspiration from not irrigated agricultural fields; 4 - evapotranspiration from irrigated fields; 5 - air moisture deficit; 6 - air temperature; 7 - total solar radiation.

Table 1. Formulae for Calculation of Ten Day Potential Evaporation Using Air Moisture Deficit

No	Formula	Correlation coefficient	Fisher Criterion		Error		Statistic line members
			actual	theoretical	mm	%	
	Late cabbages						
1.	$E_0 = 0,56x_3+8,5$	0,894	191,2	4,0	6,4	15,6	50
2.	$E_0 = 0,0000513x_3^3-0,01038x_3^2+1,18x_3-2,0$	0,898	64,1	2,8	6,4	15,6	50
3.	$E_0 = 0,00066x_3^2+0,474x_3+11,0$	0,895	94,3	3,2	6,4	15,7	50
	Cucumbers						
4.	$E_0 = 0,0001417x_3^3-0,03118x_3^2+2,62x_3-36,6$	0,875	30,6	3,0	7,0	17,0	32
5.	$E_0 = 16,72\exp(0,01283x_3)$	0,853	80,0	4,2	7,3	17,7	32
6.	$E_0 = 0,548x_3+4,9$	0,852	79,5	4,2	7,3	17,3	32
7.	$E_0 = 0,00181x_3^2+0,279x_3+14,0$	0,857	39,9	3,3	7,3	17,8	32
	Red beets						
8.	$E_0 = 0,52x_3+11,5$	0,902	144,1	4,2	5,2	12,1	35
9.	$E_0 = 1,902x_3^{0,7506}$	0,901	143,0	4,2	5,2	12,1	35
10.	$E_0 = -0,00047x_3^2+0,5828x_3+9,5$	0,902	70,2	3,3	5,3	12,2	35
11.	$E_0 = 137,0-78,7\ln x_3+13,6(\ln x_3)^2$	0,901	69,4	3,8	5,3	12,3	35
	Perennial grasses						
12.	$E_0 = 0,0000834x_3^3+0,01602x_3^2+1,302x_3-4,1$	0,783	53,2	2,7	6,9	20,7	10
13.	$E_0 = 17,346\exp(0,01068x_3)$	0,770	150,3	3,9	7,0	21,0	105
14.	$E_0 = 0,00179x_3^2+0,155x_3+18,0$	0,771	74,8	3,1	7,1	21,0	105
15.	$E_0 = 0,392x_3+11,0$	0,764	144,9	3,9	7,1	21,2	1
	Average for the investigated agriculturales crops						
16.	$E_0 = 0,0000672x_3^3-0,0136x_3^2+1,30x_3-4,9$	0,814	142,8	2,6	7,5	19,9	222
17.	$E_0 = 0,00113x_3^2+0,327x_3+13,9$	0,808	205,6	3,0	7,6	20,2	222
18.	$E_0 = 0,48x_3+9,4$	0,806	406,8	3,9	7,6	20,2	222

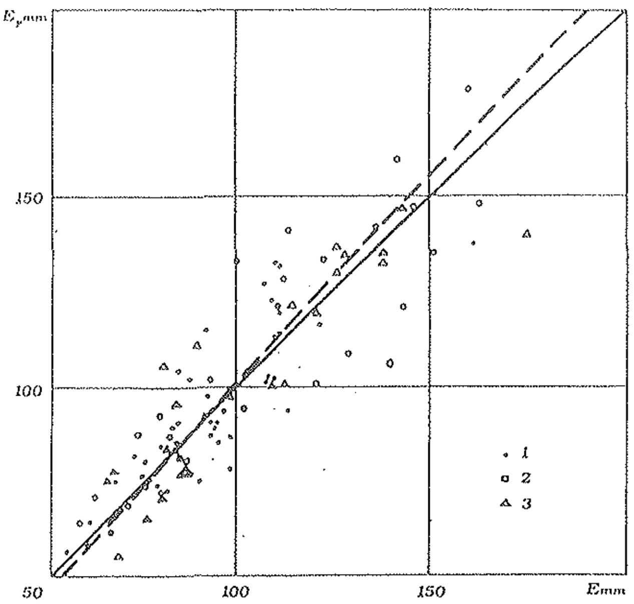

Fig. 2 Comparison of actual water consumption with the one calculated by (1) formula: 1 - on the additionally irrigated fields of perennial grasses; 2 - the same on the fields of red beets; 3 - the same on the fields of late cabbage.

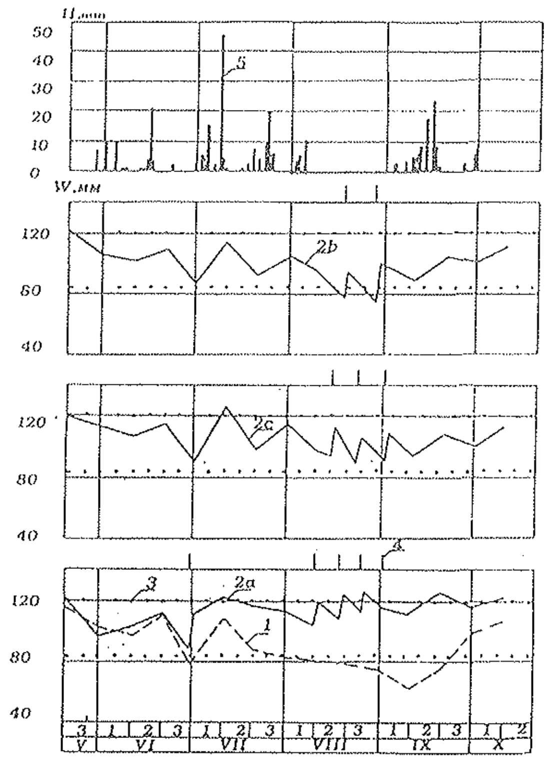

Fig. 3 Moisture Dynamics in the Active Soil Layer: 1 - soil moisture in not irrigated fields; 2a - soil moisture in the intensively irrigated fields; 2b - soil moisture in the fields with small irrigation rate; 2c - soil moisture in the fields with average irrigation rate; 3 - optimum soil moisture limits; 4 - irrigation; 5 - precipitation.

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EVAPOTRANSPIRATION FROM CEREALS AND EFFICIENCY OF FERTILIZERS

The investigations were carried out on the different soils of Estonia during the period of 1967-1990.This complex study deals with problems of cereals productivity, the influence of soil-climatic conditions, fertilization, sowing time, cultivars etc. Essential conclusions of the present work were as following :

* Relative influence of weather on productivity of cereals is twice stronger than the effect of fertilization and thrice stronger than the impact of the sowing time . It is connected with the facts , that the total precipitation during the vegetative period annually varies more than 4 - 5 times and the sum of active temperature accordingly 1.5 - 2 times.

* Evapotranspiration from cereal crops as well as lower limits of the optimum of soil moisture content depend essentially on the texture of soils, potential level of the evapotranspiration and biological peculiarities of plants. The optimal available water supply decreases during the growing period 20 - 25 per cent but also later development stages of plants moisture content in soil does not go belowe the limits of the discontinuous cappilary moisture. Influence of water deficiency on the yield of cereals during the period from tillering to earing is 1.5 - 2 time bigger than at earlier and later development stages of plants. On the average water deficiency during the intensive growing period of cereals forms 10 -35 per cent of the potential evapotranspiration rate. But in some droughty years it may be exceed up to 50 - 65 %. Only for that reason on the sandy soils and pebble rendzina the yield of cereals decreases on the average 0.8 - 1.2 Mg ha $^{-1}$, droughty years even above 1.2 - 1.8 Mg ha $^{-1}$.

* In droughty conditions the efficiency of nitrogen fertilizers is thrice lower than on the optimal supply of plant with water. At the same time the differences between biologically effective amounts of the fertilizer, ensuring the maximum level of the yield, and economically recommended amounts are bigger in the unfavourable growing conditions of plants. If the biologically effective amount of nitrogen fertilizer are approximatly 100 kg nitrogen per hectare, then from the viewpoint of the yield quality and the economical aspects the recommended fertilizer norms are within limits 50 - 70 kg ha $^{-1}$. Also, early sowing time cereals is a very essential factor limiting efficiency of fertilizers , productivity of crops and the quality of the yield.

* Depending on the soil properties, evapotranspiration from cereals on the average forms 250 - 300 mm. Consumption efficiency of water by plants appreciably decreases if the increment of total phytomass per day is lower than 40 - 50 kg ha $^{-1}$ or than the yield of cereals is lower than 2.0 - 2.5 Mg ha $^{-1}$. Consumption of water per unit of yield of cereals varies from 800 to 5500.

* Since the soil water - supplying capacity is a very important factor, which also in our region has affected productivity of cereals, then in agricultural models as well as complex soil climatic zoning programs we have used real and potential evapotranspiration index as a factor. As the result of the analysis we may note, that the pedoclimatic conditions for the growing of cereal crops in the North and South - East Estonia and on the islands are 20 -30 per cent more unfavourable than that in Central Estonia.

EVAPOTRANSPIRATION FROM CEREALS AND EFFICIENCY OF FERTILIZERS

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INTRODUCTION

The climatic conditions in Estonia vary in great extent. The total precipitation during the vegetative period may differ more than 4-5 times and the sum of temperature accordingly 1.5-2 times (Fig. 1). For that reason the yields of cereal crops are relatively unstable (Fig 2, 3). The relative influence of weather on productivity of barley is twice stronger than the effect of fertilization and thrice stronger than the impact of sowing time.

EXPERIMENTAL WORK

This practically oriented complex study (carried out 1967-1990) deals with problems of cereals productivity, the influence of soil-climatic conditions, fertilization, sowing time, cultivars.

Actual evapotranspiration (ET) from cereals on the field trials was found by the data of water balance. For that purpose water supply in the soil and the total precipitation were regularly determined during the plant growing period. Potential evapotranspiration rate (PET) was calculated on the basis of air vapour pressure deficiency data using the simple formula by A.M. Alpatiev - $PET = K\Sigma D$. In our calculations the values of biological constants (K) were before tillering of cereals - 0.60, from tillering to earing - 0.70 and after that period - 0.65.

For the detailed study of water consumption from cereals we have used the evapometers GGI-500-50. Daily values of ET and PET were established by weighing the vessels.

RESULTS

Water deficiency during the intensive growing period of cereals on the average forms 10-35% of the PET, but in some droughty years it may exceed up to 50-65% (Tab., Fig. 4). For that reason on sandy soils and rendzina the yield of cereals decreases on the average 0.8-1.2, sometimes above 1.2-1.8 Mg ha^{-1}. Evopotranspiration from cereals depends on the soil texture, PET and biological peculiarities of plants (Fig. 5-8). The optimal water supply decreases 20-25% during growing period, but even in later plant development stages moisture content in the soil does not go below the limits of the discontinuous capillary moisture (DCM).

Water supply capacity of soils and climatic conditions affected in great extent effectiveness of fertilizers (Fig. 9-11). Consumption efficiency of water by plants decreases appreciably if the increment of total phytomass is lower than 40-50 kg ha^{-1} day^{-1}, or if the yield of cereals is lower than 2.0-2.5 Mg ha^{-1} (Fig. 12-13).

CONCLUSIONS

Since the soil water supply capacity is very important factor, which also in our region limits productivity of cereals, in agricultural models as well as complex soil-climatic zoning programs we have used actual and potential evapotranspiration ratio as a factor. As the result of the analysis, we may note that the pedoclimatic conditions for the growing of cereal crops in the North and South-East Estonia and on the islands are 20-30% more unfavourable than that in Central Estonia. Pedoclimatic and ecologic-economic complex analysis is the basis for optimizing land use and preservation of natural resources.

The results of the present work may be used for calculation of ecological-economically recommended land use models and agricultural production in general.

Table. Water deficiency (%) in different soils

Phenophase of cereals	Sand	Loamy sand	Sandy loam	Drainaged soils
From sprouting to tillering	10-15	5-10	0-5	0
From tillering to earing	25-35	15-25	10-20	10-15
From earing to harvesting	15-25	10-20	5-10	0-5

10% deficiency of water supply from tillering to earing of cereals depending on the fertilization, decreases the yield by 130-190 kg ha^{-1}. The influence of water deficiency in earlier and later development stages of plants is 1.5-2 times lower than it is in the intensive growing period.

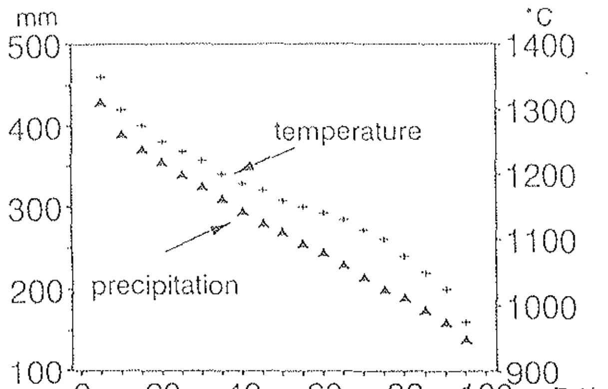


Fig. 1. Probability (P, %) of precipitation and sum of effective temp. (>5 C) during veg. period

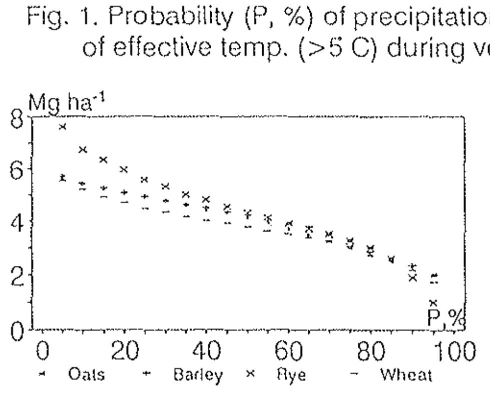
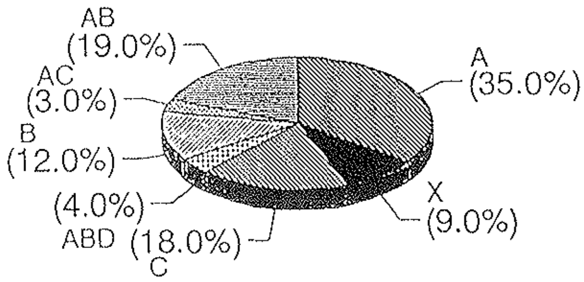
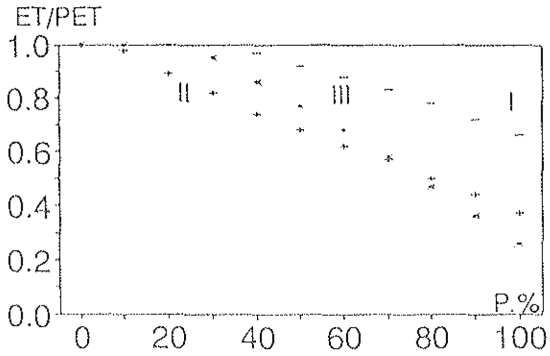


Fig. 2. Probability (P, %) of different cereal yields



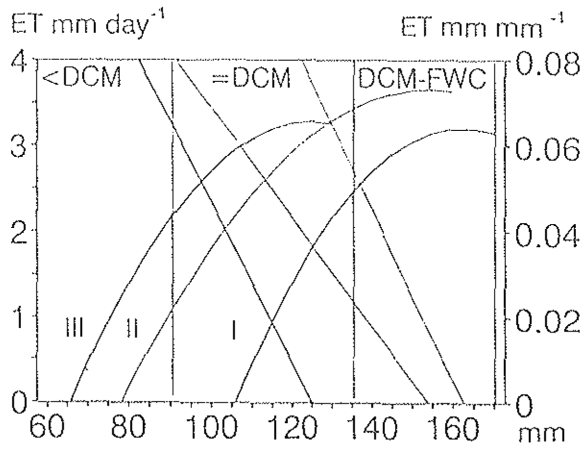
A - year B - sowing time C - fertilization
D - cultivar X - other factors

Fig. 3. Relative importance (%) of factors influencing yield of barley



I - from sprouting to tillering II - from tillering to earing III - from earing to harvesting

Fig. 4. Probability (P, %) of water supply of barley on sandy soil



I - from sprouting to tillering
II - from tillering to earing
III - from earing to harvesting
DCM - discontinuous capillary moisture
FWC - field water capacity

Fig. 5. Evapotranspiration from barley depending on the available water supply in a meter-deep soil layer

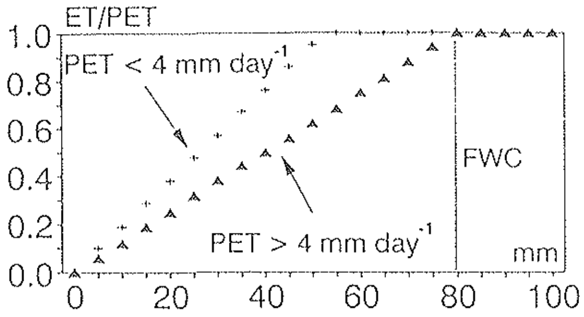


Fig. 6. Relationship between evapotranspiration index (ET/PET) and water supply of sandy soil

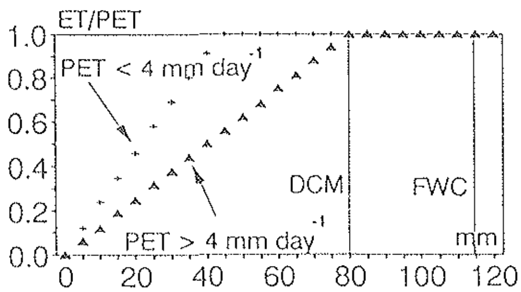


Fig. 7. Relation between evapotranspiration index (ET/PET) and water supply of sandy loam soil

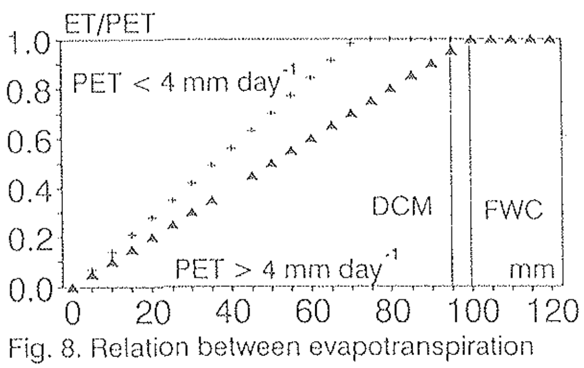
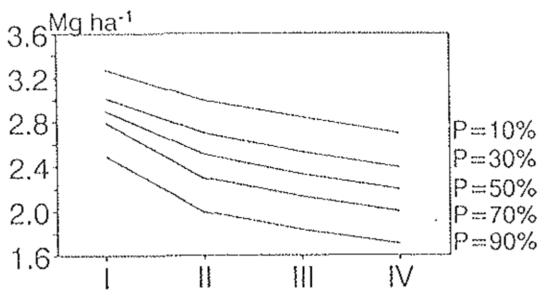
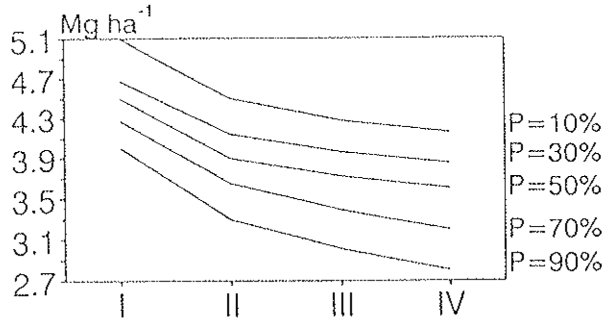


Fig. 8. Relation between evapotranspiration index (ET/PET) and water supply of clay soil



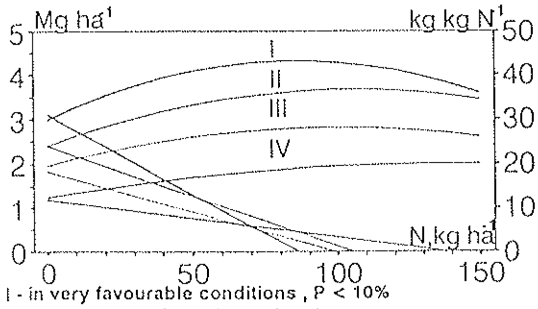
I - ET/PET = 1.0 II - RAM = 220 mm
III - RAM = 180 mm IV - RAM = 140 mm

Fig. 9. Variation of barley yield (N0P0K0) depending on available moisture supply in the soil (RAM



I - ET/PET = 1.0 II - RAM = 220 mm
III - RAM = 180 mm IV - RAM = 140 mm

Fig. 10. Variation of barley yield (N90P39K75) depending on available moisture supply in the soil (RAM



I - in very favourable conditions , P < 10%
II - average yield in early sowing time
III - average yield in later sowing time
IV - in very unfavourable conditions, P > 90%

Fig. 11. Effect of N fertilizer on the productivity of barley on the background P26 K50

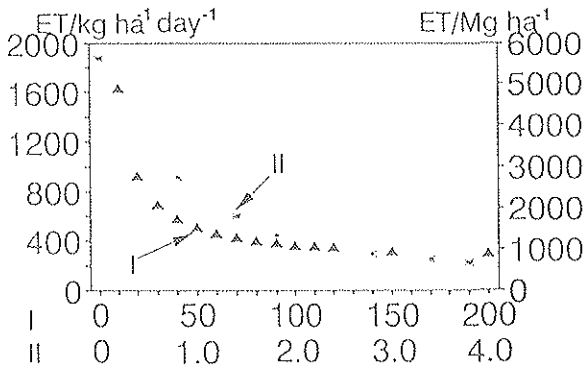
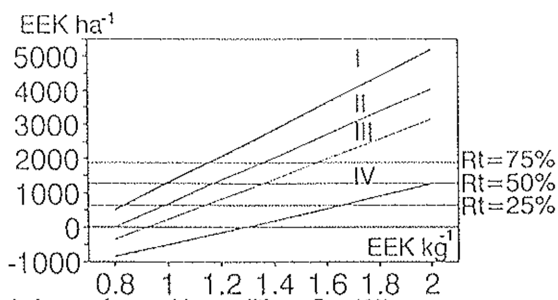


Fig. 12. Evapotranspiration coefficient as a functi of the increment of total phytomass and the yield level of barley



I - in very favourable conditions, P < 10%
II - average yield in early sowing time
III - average yield in later sowing time
IV - in very unfavourable conditions, P > 90%

Fig. 13. Profit and profitability of barley cultivating depending on the market price

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ESTIMATING EVAPOTRANSPIRATION FROM GRASSLAND IN ESTONIA

The present research work deals with the estimating evapotranspiration (ET) from cultivated grassland and possibilities to calculate potential evapotranspiration (PET) in Estonian climate. The aim is to find a proper formula for modelling water balance of the soil by personal computers.

Before (1968 - 1974) the research work has shown in Estonian conditions a world-wide known H. L. Penman formula was used for calculating PET month- and decade-values. Now we wanted to check up if the same formula suits for calculating daily values.

The experimental studies were carried out in the Eerika (1984 and 1985) experimental grassland plots (sandy-clay-loam soil) and Aardla (1988 and 1989) bolder grasslands (fine sand soil) near Tartu. A hydraulic evaporation pan GR-17, made in Russia was used. It enables to measure daily evapotranspiration in a soil monolith of 1.5 m height and the area of 2000 cm^2 (error $\pm$ 0.1mm).

If to compare PET daily values calculated by Penman formula by measured ET values during the period when the soil water conditions were optimal for vegetation, it came out the correlation was quite satisfactory (correlation coefficient $r=0.90$ and standard deviation $s=0.5$mm). The research can prove H. L. Penman formula can be used in modelling water balance in soil with quite success in Estonia as well.

During the period of 1966 - 1987 the data from 20 meteorological stations were compiled, the average PET was calculated by computer for the whole of Estonia and the corresponding map formed. It seems PET is greater on the coast and islands than on the continent. There the average PET during the vegetation period (from May to October) was 350 - 370 mm, that on the coast and islands - 380 - 420 mm. By the formed probability curves we can estimate the possible fluctuation of PET in periods of years. On the continent of Estonia PET value can be from 300 to 380 mm, on the islands accordingly 380 - 460 mm.

ESTIMATING EVAPOTRANSPIRATION FROM GRASSLAND IN ESTONIA

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INTRODUCTION

This study deals with the estimating evapotranspiration (ET) from cultivated grassland and possibilities to calculate potential evapotranspiration (PET) in Estonian climate. The aim is find a proper formula for modelling water balance of the soil by personal computers.

Before (1968 - 1974) the research work has shown in Estonian conditions a world-wide known H. L. Penman formula was used for calculating PET month- and decade-values. Now we wanted to check up if the same formula suits for calculating daily values as a time interval for modelling waterbalance by computers should not be longer than a full day (24 hours).

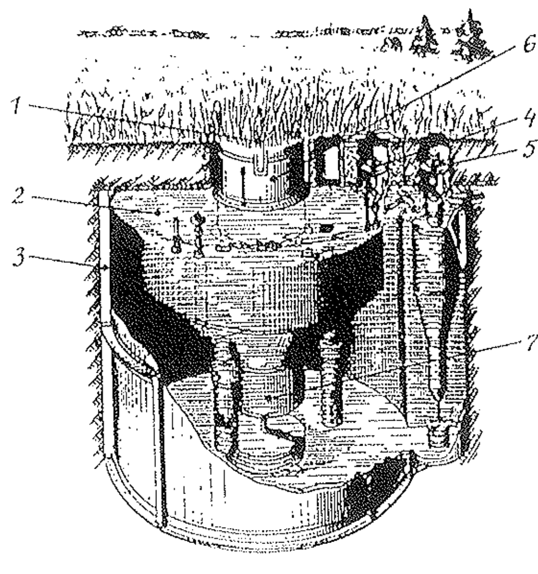


Fig.1. Hydraulic evaporation pan GR - 17
1 - soil monolith; 2 - float;
3 - water tank; 4, 5 - micrometric gauges;
6 - metallic case; 7 - gauge of percolation water

THE EXPERIMENTAL WORK

The experimental studies were carried out in the Eerika (1984 and 1985) experimental plots (58° 22' N, 26° 40' E) and Aardla (1988 and 1989) bolder grassland (58° 20' N, 26° 45' E) near Tartu. A hydraulic evaporation pan GR-17 (Fig. 1), made in Russia was used. It enables to measure daily evapotranspiration in a soil monolith of 1.5 m height and area of 2000 cm² (error ± 0.1 mm).

An evaporation pan was set up on a sandy-clay-loam grassland at Erika. Measuring ET were taken from July till September,1984. As there was very little rain that July and August,the plants suffered from drought. The actual ET was smaller than potential PET (Fig. 2). In 1985 we started the measuring on May 1, it lasted up to September 30. Precipitation had fallen equally during the vegetation period,there was no drought (Fig. 3).

In 1988 the measuring was tansferred to Aardla bolder. The evaporation pan was put on a fine sandy grassland, the measuring ET took place in July and August. Because of June-July drought the grass was damaged. Thus ET values were smaller than PET (Fig. 4). As in 1989 it was drought in July-August (Fig. 5) it was not possible to use the data that period.

Fig 2. Cumulative curves of the P, ET and PET (EERIKA 1984)

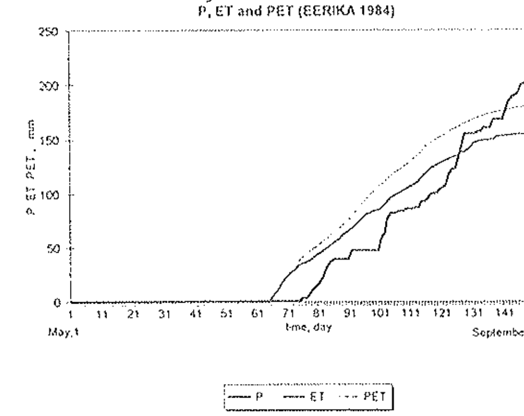


Fig 3. Cumulative curves of the P, ET and PET (EERIKA 1985)

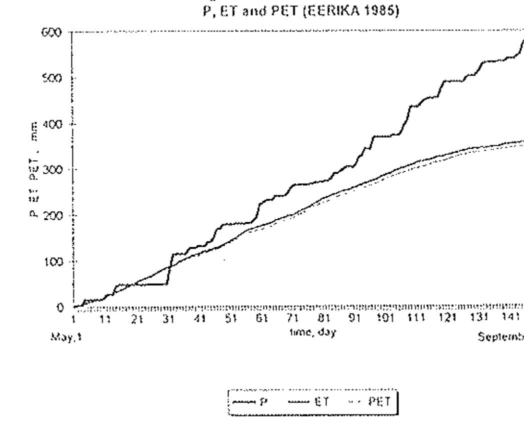


Fig 4. Cumulative curves of the P, ET and PET (AARDLA 1988)

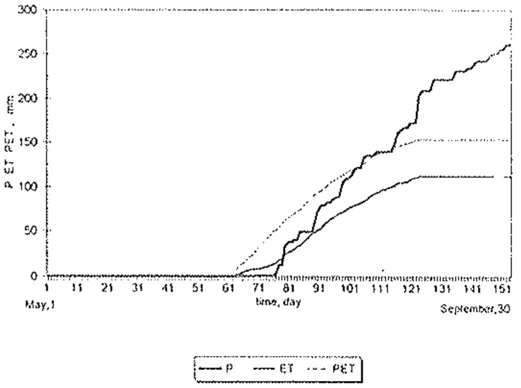
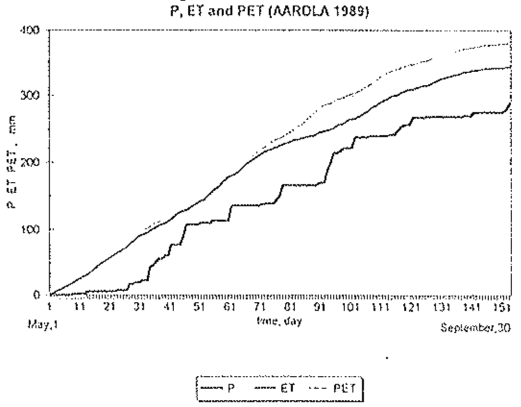


Fig 5. Cumulative curves of the P, ET and PET (AARDLA 1989)



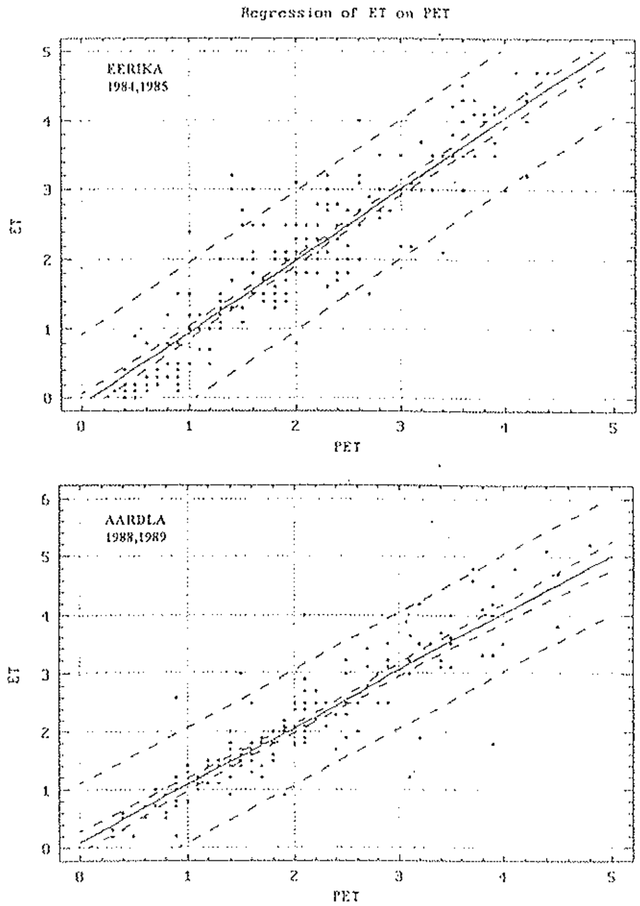


Fig. 6. Relationship between calculated PET and measured ET mm/d

RESULTS

If to compare PET daily values calculated by Penman formula by measured ET values during the period when the soil water conditions were optimal, it came out the correlation was quite satisfactory (Fig.6). At Eerika correlation coefficient r=0.91, standard deviation s=0.5 mm and regression equation : ET= 1.03 PET - 0.08. At Aardla correlation coefficient r=0.90, standard deviation s=0.5 mm and regression equation : ET=0.99 PET + 0.09. The research can prove H. L. Penman formula can be used in modelling water balance in soil with quite success in Estonia as well.

Daily values PET can be computed by Penman's combining the energy balance equation and the aerodynamic formula:

$$PET = \frac{\frac{\Delta}{\gamma} H + E_a}{\frac{\Delta}{\gamma} + 1} \quad mm/d, \qquad (2)$$

$$H = 0{,}75 \cdot R \cdot \left(0{,}23 + 0{,}54 \frac{n}{N}\right) - \delta \cdot T^4 \cdot \left(0{,}56 - 0{,}08\sqrt{e_a}\right) \cdot \left(0{,}1 + 0{,}9 \frac{n}{N}\right) \quad mm/d, \qquad (3)$$

$$E_a = 0{,}26 \cdot (0{,}5 + 0{,}537u) \cdot d \quad mm/d, \qquad (4)$$

where H is net radiation; Δ - slope of the saturated vapor pressure versus temperature curve; γ - psychrometric constant; R - extraterrestrial radiation for the latitude; n - number of observed hour of sunshine; N - number of maximum possible hours radiation for the latitude; δ -Stefan-Bolzman constant; T air temperature K°; e_a - actual vapour pressure; u - wind velocity; d - air vapour pressure deficiency.

CONCLUSIONS

During the period of 1966 - 1987 (representative period) the data from 20 meteorological stations were compiled, the average PET was calculated by computer for the whole of Estonia and the corresponding map formed (Fig. 7). It seems PET is greater on the coast and islands than the continent. There the average PET during the vegetation period (from May to October) was 350 - 370 mm, that on the coast and islands - 380 - 420 mm. By the formed probability curves (Fig. 8) we can estimate the possible fluctuation of PET in periods of years. On the continent of Estonia PET values can be from 300 to 380 mm, on the islands accordingly 380 - 460 mm.

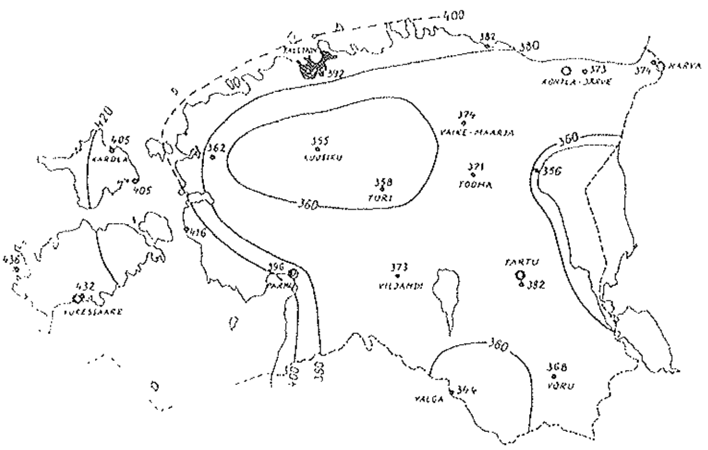
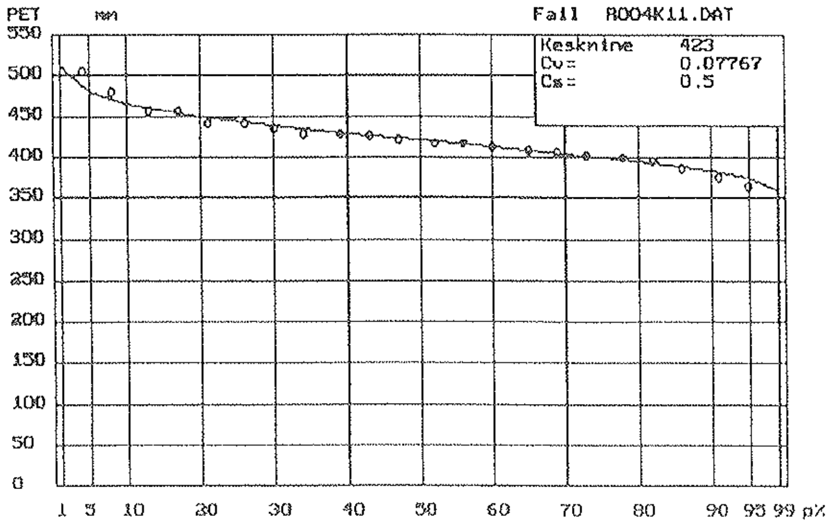


Fig. 7. Mean PET from grassland in Estonia (1966 - 1987)

A)



B)

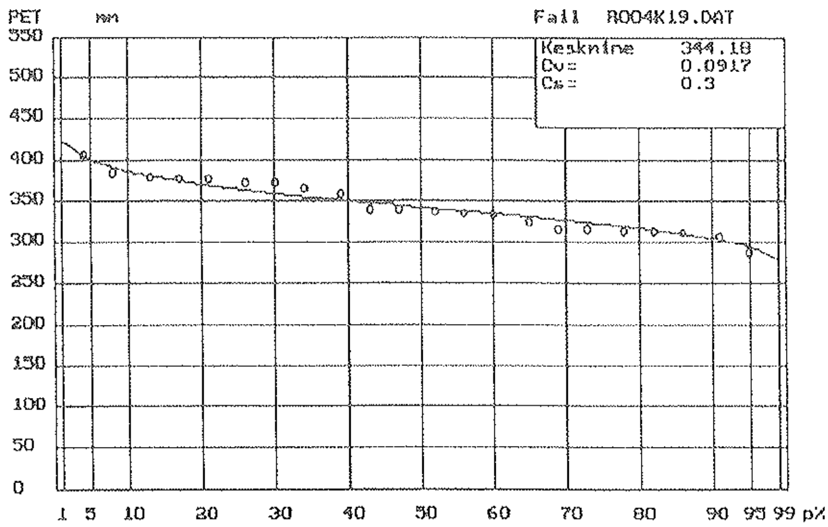


Fig. 8. Probability curves of PET:
A - Kuressaare (on the island);
B - Valga (on the continent)

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THE INTERACTION BETWEEN SOIL MOISTURE AND SURFACE CONDITIONS

Soil evaporation and the heating of air and soil depend on the exchange of heat at the ground surface. The exchange processes are regulated by the temperature and moisture conditions at the surface, which in turn are results of complicated interactions between the soil and atmosphere.

In the present study the influence of soil moisture on surface conditions was examined. The working hypothesis was that the influence of soil moisture on the vapour pressure at the soil surface can be estimated from the soil water potential in the top layer and the soil moisture gradient close to the surface.

To test the hypothesis, a small-scale field experiment was set up close to Uppsala in central Sweden. The trial was comprised of two clay plots and two sand plots, each of them 2 x 2 m^2 and 0.3 m deep. One sand and one clay plot were irrigated during dry periods while the other two plots were not irrigated and served as controls. The plots were kept bare and were surrounded by grass that was kept short.

A number of different measurements were carried out during some weeks in June 1994. Besides the standard meteorological measurements at the site (air temperature and humidity, radiation, windspeed and precipitation) soil and soil surface temperature and moisture were registered continuously. Thermocouples, for soil temperature measurements, and TDR probes, for soil water content determination, were installed in two profiles in each plot. Miniature tensiometers were used for soil water tension measurements in one profile in each plot. Soil surface temperature was determined both with thin thermocouples and with an infrared thermometer scanning over the four plots. Soil surface moisture was measured with a gas analyser on air continuously sampled from one plot at a time. Each plot was equipped with a miniature net radiometer.

A preliminary data evaluation confirmed the strong relation between soil surface temperature and soil moisture. The daily amplitude of surface temperature was up to 50 % smaller in irrigated plots as compared with dry plots.

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GRASS GROWTH AND ITS INFLUENCE ON SOIL MINERAL NITROGEN. A SIMULATION STUDY.

The SOILN-CROP model was applied on the grass *Lolium multiflorum*, Lam. to simulate the growth and its influence on the mineral nitrogen in the soil. The SOILN-CROP (Eckersten et al., 1994) model simulates nitrogen and carbon dynamics in the soil - plant - atmosphere system. Climatic factors, such as solar radiation, temperature and precipitation governs the flows of C and N. The model is divided in a plant part that simulates the crop growth and nitrogen uptake, and in a soil part simulating nitrogen and carbon turnover in the soil. The plant is divided into tissues with different functions - roots take up water and nutrient, leaves take up carbon and lose water through transpiration and stem functions as a storage organ. The growth is governed by the solar radiation intercepted by the canopy and the radiation use efficiency. Low temperature, water stress and nitrogen stress can act limiting on growth. The leaf area expansion is correlated with the total shoot biomass and root growth is a function of total plant biomass. Nitrogen uptake by the crop is governed by the daily increase of biomass and maximum N concentrations in the different plant parts. A fraction of the soil mineral-N pools is available for plant uptake at one time-step. Dead plant material is incorporated into the soil organic matter.

The model was run for the period August 25th, 1988 to April 15th, 1989, and calibrated against measured values of shoot and root biomass and nitrogen and soil mineral nitrogen. The daily leaf area expansion was given by multiplying daily above ground biomass increment by a factor of 0.046. The amount of total biomass allocated to the leaves was given by the leaf area index and a constant specific leaf area of 0.02 m^2 g DW^{-1}. The radiation use efficiency was set to 2.5 gDW MJ^{-1} to reproduce the high growth rate in September and October . Initial allocation of biomass to the roots was set to 48% and was lowered by a factor 0.0001 of total plant biomass to give a reasonable distribution of biomass and nitrogen between shoot and roots. Nitrogen was translocated to the roots to give a maximum nitrogen concentration of 1%. Maximum respective minimum nitrogen content of the leaves was 3 and 0.5% respectively. Simulated plant nitrogen content agreed with measured values, except in the spring, when 10% of the soil mineral nitrogen was available for plant uptake each day . No water stress was considered. To be able to reproduce the highest values of biomass during the autumn no litterfall from the plant was concidered. This in return gave a strong overestimation of shoot biomass in November and throughout the season. Root growth in February and March could not be predicted. Soil mineral nitrogen in the upper 30 cm was overestimated during almost the whole simulation period. In the 30-60 cm layer the nitrogen content agreed with measured values except in September and late March.

Reference: Eckersten, H., Jansson, P-E. & Johnsson, H., 1994. SOILN model. Users manual. Division of Agricultural Hydrotechnics. Department of Soil Sciences. Swedish University of Agricultural Sciences. Uppsala.

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CHANGES IN MAIN PLANT NUTRIENT BALANCE IN ESTONIA

The crop yield and soil fertility are closely related to the cycle and balance of main plant nutrients. The plant nutrient balance may be calculated on the basis of general or plant available nutrient content. The first one is called general balance and the second - active balance. In this paper all data characterise the general one.

The total content of main plant nutrient removed by yield is calculated on the base of average yield (kg of feed units per hectare of arable land) and the content of plant nutrient in feed unit (1 fu contains 25,0 g N, 5,2 g P and 23,2 g K). The volatilisation coefficient based on the laboratory experiments and data of literature is 25 % of N supplied with fertilizers. The losses of plant nutrients by leaching have been calculated as 1,5 % of N, 0,2 % of P and 4,0 % of K supplied with fertilizers, losses by erosion 1,0; 0,3 and 0,8 % consequently. In calculations of supplied main plant nutrient the losses of commercial and organic fertilizers during the storage and transportation have been taken into account.

The general balance of nitrogen and phosphorous was on optimal level, the balance of potassium was higher than optimum, according to the yield in 1985. The usage of mineral and organic fertilizers has fallen down rapidly during recent years. This is the main reason of decreasing of average yield up to 1600 fu/ha of arable land. In 1993 the general balance of nitrogen decreased up to +10,5 kg/ha, the supply by fertilizers was only 59% and the part of symbiotically fixed nitrogen increased up to 36%. The balance of nitrogen is on optimal level when the supply with fertilizers forms 115...150% of removed nitrogen. In 1985 the supply with fertilizers was 130%. In spite of the decreasing the supply with fertilizers up to 59% in 1993 the general balance of nitrogen remained positive. The balance of nitrogen stays on the positive level when other factors besides nitrogen limit yield. In 1993 the limiting factor was phosphorous - the removed amount exceeds the supplied one. The rate of decreasing of supplied phosphorous exceeded removed phosphorous, therefore the balance of phosphorous reached the negative value - 0,6 kg/ha.

The balance of potassium is regarded as an optimum, when supplied with fertilizers amount of potassium makes up 100...105% of removed. The balance of potassium was the only of main nutrient balances, which stayed as an optimum for this level of crop yield in 1993.

Summarising the results of this investigation we can state following:

- The usage of nitrogen and phosphorous in 1993 is so low that it does not satisfy the plant nutrient uptake on even such low level of crop yield.
- To achieve the optimal level of general balance and to increase the yield without pollution of environment, the rate of usage of fertilizers must be increased to the optimal level which would guarantee the whole population with main foodstuffs.
- The losses of fertilizers during the storage and transportation must be decreased.

Table. Main plant nutrient balance in Estonian arable land in 1985 and 1993.

	N		P		K	
I Removal kg/ha of arable land	1985	1993	1985	1993	1985	1993
with crop	69,0	40,0	14,3	8,4	63,1	37,2
volatilizing	34,9	9,5				
leaching	2,1	0,6	0,1	0,1	4,8	3,2
erosion	1,4	0,4	0,1	0,1	1,3	0,3
Total	107,4	50,5	14,5	8,6	69,2	40,7
II Supply kg/ha of arable land						
mineral fertilizers	104,6	18,7	21,4	4,2	74,9	25,8
organic fertilizers	35,0	11,3	10,6	3,4	43,2	14,0
symbiotically fixed	25,0	22,0				
non-symbiotically fixed	4,0	3,0				
precipitation	4,0	3,0			1,7	1,3
seeds	3,0	3,0	0,4	0,4	2,1	2,1
Total	175,6	61,0	32,4	8,0	121,9	43,2
BALANCE	+68,2	+10,5	+17,9	-0,6	+52,7	+2,5
Supplied with fertilizers %	130	59	221	88	171	98

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THE KVITHAMAR FIELD LYSIMETER
OBJECTIVES, EXPERIMENTAL DESIGN AND RESULTS

Application of animal slurry on arable land before ploughing in the autumn, has until recently been a prevailing practice in Central Norway. The objectives of our study were to compare grain yields, nutrient balances, and nutrient leaching in drain water and in surface runoff from plots where pig slurry was supplied and ploughing accomplished in autumn or spring. There were six treatments, each replicated three times:

1. Autumn ploughing, pig slurry ploughed in
2. Autumn ploughing, pig slurry harrowed in the following spring
3. Autumn ploughing, NPK-fertilizer harrowed in the following spring
4. Spring ploughing, pig slurry harrowed in subsequently
5. Spring ploughing, NPK-fertilizer harrowed in subsequently
6. Spring ploughing, nil nutrient supplied.

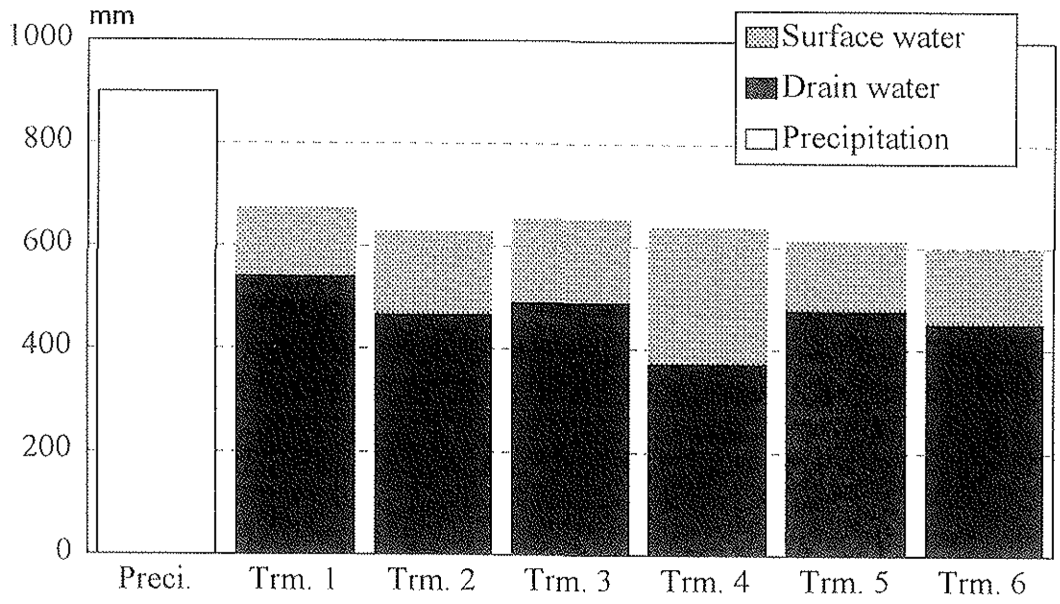
Pig slurry was supplied in a quantity of 40 metric tons per hectare/year for three treatments, which according to the chemical analyses equaled 76 kg of mineral-N, 25 kg P, 48 kg K, 11 kg Mg, 42 kg Ca and 8 kg S per hectare. At treatment 3 and 5 the same quantities of N,K,P were supplied as mineral fertilizers as at the treatments with pig slurry. Spring barley was sown on all plots.

The experimental site had a slope of 1%, and the soil type was a silty clay loam, described as an Ortic Humic Gleysol of originally marine sedimentation. The drain space was 8.0 m, and the drain depth was 1,0 m.

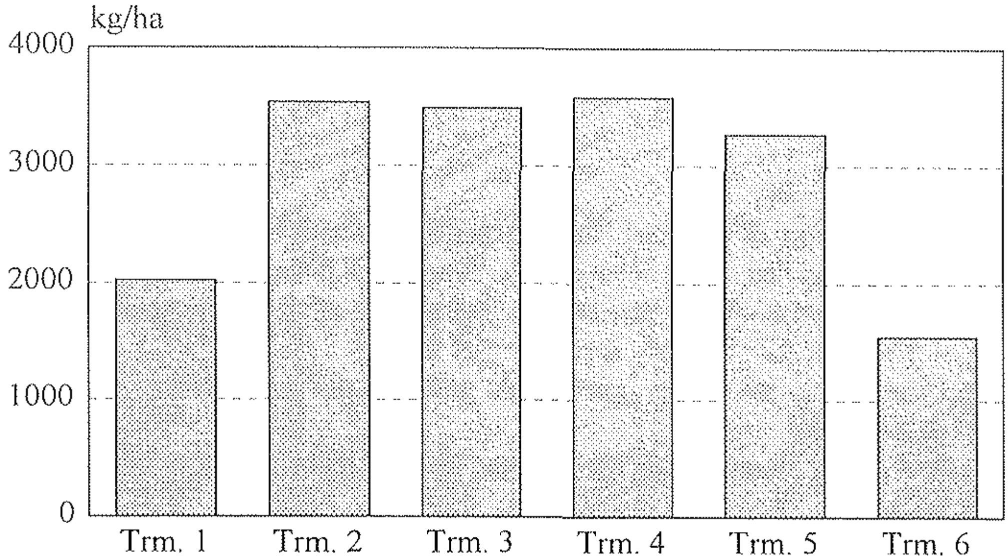
A soil test of the top layer at start showed 11% organic matter, pH=6.0, P-Al=9.0, K-Al=9.0 and K-HNO_3=150. Normal precipitation per year is 892 mm, normal temperature for July is 13.9°C and for January -3.2°C. The experiment started in October 1990, and will be ended in autumn 1994.

Results per May 06, 1994:

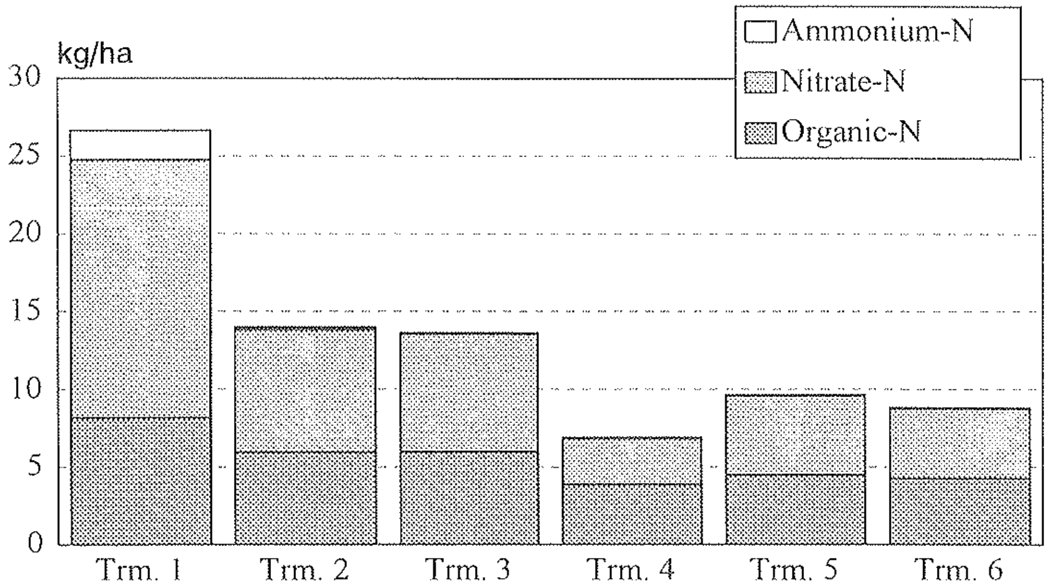
- A total precipitation of 900 mm was registered, in average per year. The corresponding drain discharge equaled 480 mm, and the surface runoff 180 mm
- Pig slurry ploughed in during autumn resulted in only 60 % of the grain yield obtained by spring plowing and subsequently application of slurry
- Autumn and spring ploughing gave equal grain yields, provided that the nutrients were applied in the spring
- Application of pig slurry during the autumn, resulted in increased nutrient leaching during winter
- Autumn ploughing gave significantly higher concentration of plant nutrients in drain water, compared to spring ploughing
- The leaching losses were: Total-N 15, Nitrate-N 10, Total-P 1.5, Phosphate-P 0.1, Sulphate-S 40, all figures in kg per hectare, in average per year, for all six treatments.



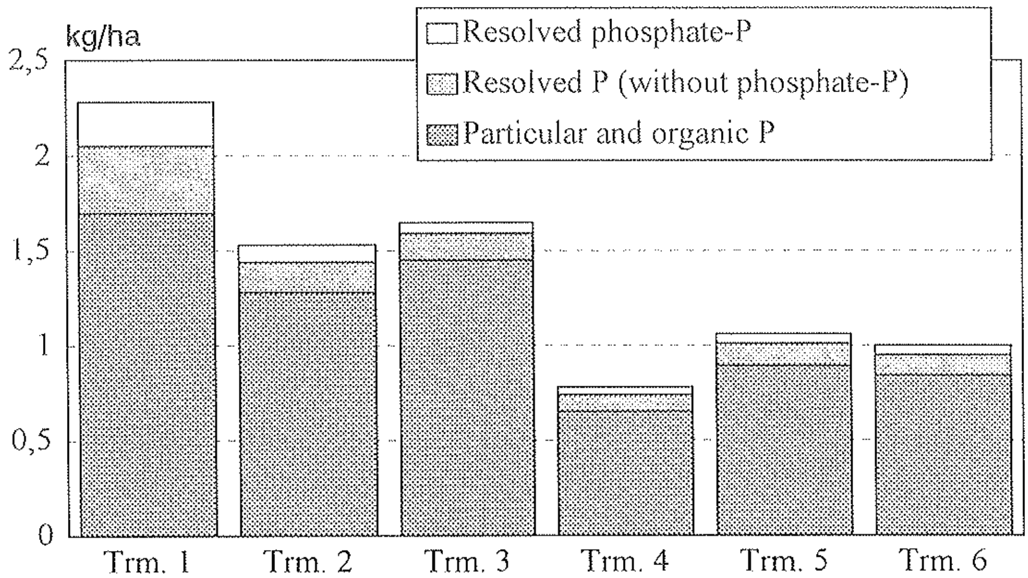
Precipitation and discharge, mm per year, from separate treatments (Trm.). For the period October 04.1990 - May 06.1994.



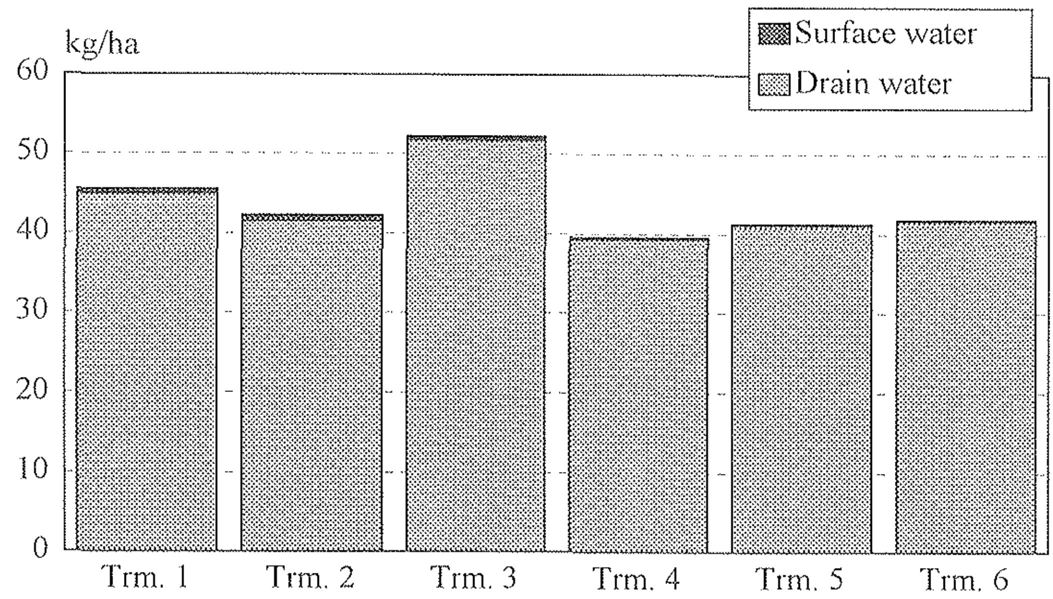
Grain yield for separate treatments, kg per hectare. Average for 4 years (1991-1994).



Loss of N in drain water per year from separate treatments, kg per hectare.



Loss of P in drain water per year from separate treatments, kg per hectare.



Loss of sulphate-S per year from separate treatments, kg per hectare.

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FOSTOP - A NEW METHOD TO IMPROVE WATER PERMEABILITY AND REDUCE PHOSPHORUS LEACHING IN HEAVY CLAY SOILS

Nutrients originating from agricultural land contribute substantially to the eutrophication of lakes and watercourses in Finland. Special attention is traditionally paid to phosphorus.

In areas with heavy clay soils and slopy fields most of the phosphorus is transported to the recipients with the surface runoff due to insufficient water permeability of such soils.

FOSTOP offers a new alternative method to reduce the phosphorus load from impermeable soil areas by trapping the surface runoff into subsurface lime filter drains. This is achieved by mixing 3 to 8 % burnt lime (CaO) into the excavated soil material before refilling the drains. The lime reacts chemically with the soil moisture, which subsequently results in a coarse and durable soil structure and thus in a significant improvement of the water permeability of the treated clay.

Laboratory tests, lysimeter studies and full scale FOSTOP applications have been performed since 1990. Observations made so far show that lime filter drains are able to retain considerable amounts of the suspended solids and the phosphorus contained in the surface runoff entering the drains. The main results from the studies can be summarized as follows:

* The water permeability of lime treated clays was 15 to 30-fold compared to untreated clays acting as references (results obtained from laboratory tests as well as field studies).
* Suspended solids and turbidity showed an 85 to 90 % reduction after the FOSTOP treatment (when compared to surface runoff).
* PO_4-P concentrations were on an average 85 to 95 % lower in the waters discharging from the lime filter drains compared to surface runoff (results obtained from three different studies). Total phosphorus reductions were somewhat lower (average 75 to 80 %).
* The FOSTOP treatment was not able to reduce nitrogen species from the studied waters.
* The lime filter drains were inactive during wintertime, but resumed their normal function rapidly after the spring thaw period.

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LEACHING OF CALCIUM BY DRAINAGE RUNOFF FROM HEAVY AND LIGHT-TEXTURED SOD GLEY SOILS OF ESTONIA

Leaching studies in Estonia began in 1927 when water samples were first analysed from the greatest eight rivers during two years. These early results showed that the mean Ca content of surface runoff was 40 mg/l. Regular study started in 1946. These results showed that by rivers-passing-areas with limestone bedrock in North Estonia 1,5 times (per ha) more Ca was leached than by the rest rivers of the country. Leaching research with funnel lysimeters on arable soils began in the 1960's. Apropos, there was shown the liming effect of acid soil on the leached Ca amount.

The investigations reported were carried out in drained sod gley soils of different texture and reaction. Research in heavy clay soil (84-88% clay) was carried out at two plots situated in the Pärnu River basin: at Vihtra plot, where the top 60 cm of soil profile is slightly acidic (pH_{KCl} =5,4-5,9), from 1969 to 1976 and at Pendre plot in strongly acidic soil (pH_{KCl} =3,8-4,4) during 1976-1979. Leaching studies in loamy sand (10% clay) with neutral reaction (pH_{KCl} =6,6-7,0) were realized at Topi plot (Saku) during 1975-1985. Water samples for chemical analyses were taken depending on the rate of drainflow, 4-9 times a month.

Based on the results obtained, the following conclusions are drawn:

* The calcium content of drainflow was the smallest during floods after snow-melting, but in the course of groundwater level lowering into subsoil layers richer in calcium, increased gradually.
* Calcium leaching by drainage runoff obviously is affected by the acidity of soil. The average annual total loss in the experiments is ranged according to the reaction of soil as follows:
  - 152 kg Ca/ha (mean of 10 years) from loamy sand with neutral reaction (pH_{KCl}=6,6-7,0),
  - 96 kg Ca/ha (7 years) from heavy clay with slightly acidic reaction (pH_{KCl} =5,4-5,9),
  - 48 kg Ca/ha (3 years) from heavy clay with strongly acidic reaction (pH_{KCl}=3,8-4,4).
* Application of lime to soil increases leaching of calcium. After liming of clay soil with slightly acidic reaction(at the rate of 2300 kg Ca/ha), the annual mean calcium concentration in drainflow was increased from 44 up to 91 mg Ca/l the next year and up to 60 mg Ca/l in the year after. The after-effect of liming was not recorded in the third, probably because of dry year.
* The large annual leaching loss of calcium by drainflow once more suggests that a noticeable decalcification of drained arable soils takes place. Therefore, recurrent liming of acidic soils is necessary.

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LEACHING OF CALCIUM BY DRAINAGE RUNOFF FROM HEAVY AND LIGHT-TEXTURED SOD GLEY SOILS OF ESTONIA

INTRODUCTION

Calcium loss from arable land, causing acidification of soil, is an important problem from the agronomic point of view. In Estonia the calcium balance of soils is greatly negative: the main part of losses presents leaching (1).

The first examination of chemical composition of runoff was carried out on eight rivers during 1927-1928 (2). The regular study on this topic was started on 16 rivers all over the country in 1946 and gradually extended to 31 rivers since 1961 (3). More thorough investigations on leaching of nutrients were undertaken by funnel lysimeters on arable lands in the 1960's (4).

Whereas about 55 per cent of agricultural lands is drained, the great part of nutrients losses have been washed out from soil by drainage runoff in Estonia. For that reason, the main purpose of the three experiments reported in the present paper was to evaluate the amount of calcium leached by drainflow from two different soil types: heavy clay and loamy sand, with different degree of soil reaction, throughout the year.

The investigations reported were part of the research which also included studies on the aspects of drainage hydrology, as well of leaching other nutrients.

2 MATERIAL AND METHODS

Investigations were carried out in sod glay soils of two different textures at three experimental plots drained by tile tube drainage with mean depth of 1,0-1,1 m.

Experimental plots in heavy clay soils Vihtra and Pendre are situated in the Pärnu River basin near Vändra at two-kilometres-distance from each other. Topi plot on loamy sand is situated in North Estonia, close to Saku. Characteristics of experimental plots are presented in Table 1.

Drainage runoff was measured by volume method. Water samples for chemical analyses were taken, depending on the rate of drainflow, 4-9 times a month. The concentration of calcium in the water was determined by flame photometer.

3. RESULTS AND DISCUSSION

3.1 Concentration of calcium in drainage runoff

Data obtained from two experiments in heavy clay soils confirm that the content of calcium in drainflow depends mainly on the runoff regime and acidity of soil. Generally, clay soils distributed in the Middle and West Estonia are poor of lime, particularly the top 60 cm of soil profile. Therefore, the concentration of calcium in drainflow is the lowest during floods and the highest by low groundwater table when discharging water has a durable contact with subsoil layers, more rich in lime (Fig.1).

At Vihtra plot the heavy clay soil with slightly acidic reaction (pH_{KCl}=5,4-5,9) was limed at the rate of 2300 kg Ca/ha at the beginning of the fifth research year. Before liming the calcium concentration of drainflow was on the average of 4 years 44 mg Ca/l (monthly mean within the range of 21-70 mg Ca/l). As a result of liming it was considerably increased: up to 91 mg Ca/l (range 67-106) next year and up to 60 mg Ca/l (range 46-73) in the year after. During the dry third year (total runoff only 69 mm) the after-effect of liming was not recorded (Table 3).

The influence of soil reaction on the calcium leaching extent from clay soil appeared clearly at Pendre experiment. Calcium concentration of drainflow from strongly acidic soil (pH_{KCl}=3,8-4,4) averaged 21 mg Ca/l during three years, that is roughly twice less than this of slightly acidic heavy clay soil at Vihtra plot.

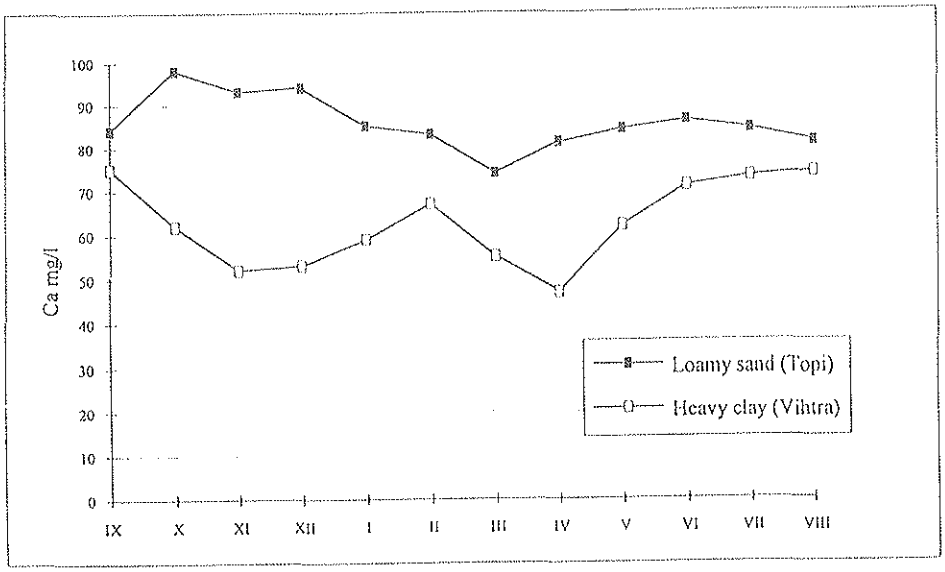

Fig.1. The monthly weighed mean concentration of calcium in drainage water

Drainage runoff from loamy sand with neutral reaction is characterized by rich calcium content. Contrary to the results in clay soils, there was high calcium content of runoff recorded also during autumn months (Fig.1). The mean values varied from 50 to 108 mg Ca/l and the annual means 75-97 mg Ca/l (Table 2). The mean of ten-years period was 87 mg Ca/l.

The rich calcium content of runoff is proper to the North Estonian calcareous soils bedding on limestone. As shown in Table 3 this is affirmed also by the data obtained from the drainage runoff study at Kuusiku (5) and lysimeter experiments at Vinni (4), where the runoff from loamy sand contained on the average of two years 79 and 96 mg Ca/l respectively. Also the runoff of North Estonian rivers was noticeably richer by calcium (62 mg/l) than the runoff from the rest part of the country (44 mg/l).

A considerable liming effect of strongly acidic sandy soil on the calcium concentration of runoff is followed from the lysimeter experiments at Ahja (Table 3).

3.2 Quantity of calcium removal

The annual distribution of calcium amounts leached by drainflow follows a pattern of runoff: two peaks, one in autumn and the second in spring (Fig. 2). Calcium losses from clay soils were during October-December 53% and March-May 35% of total annual losses and these from sandy soil 45% and 30% respectively.

The average annual total loss in the experiments is ranged accordingly to the reaction of soil as follows:

- 152 kg Ca/ha (mean of 10 years) from loamy sand with neutral reaction (pH_{KCl}=6,6-7,0)
- 96 kg Ca/ha (mean of 7 years) from heavy clay with slightly acidic reaction (pH_{KCl}=5,4-5,9),
- 48kg Ca/ha (mean of 3 years) from heavy clay with strongly acidic reaction (pH_{KCl}=3,8-4,4).

These data clearly reflect the influence of soil reaction on the extent of calcium leaching, what follows also from the data presented in Table 3 (1,4).

4 CONCLUSIONS

Based on the results obtained, the following conclusions are

- CALCIUM LEACHING BY DRAINAGE RUNOFF OBV
IS AFFECTED BY THE ACIDITY OF SOIL.
- APPLICATION OF LIME TO SOIL NOTICEABLY INC
LEACHING OF CALCIUM.
- THE LARGE ANNUAL LEACHING LOSS OF CALC
DRAINFLOW ONCE MORE SUGGESTS TH
CONSIDERABLE DECALCIFICATION OF DRAINED A
SOILS TAKES PLACE. THEREFORE, RECURRENT LIM
ACIDIC SOILS IS NECESSARY.

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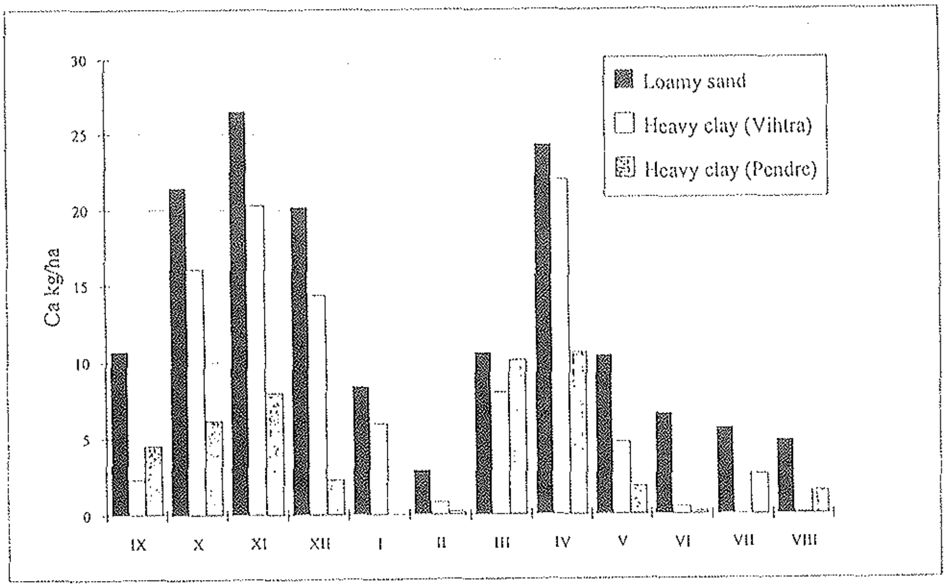

Fig.2. The mean amount of calcium washed out by the drainage water monthly

Table 1. Characteristics of experimental plots

Site, area and soil type	Depth cm	Humus %	pH_{KCl}	Physical clay % (<0,01 mm)	Spacing of drains m	Research years
VIHTRA,	0-20	3,4	5,9	45	16	1969-
1,1 ha	20-60	0,8	5,4	88		1976
Heavy clay	60-100	0,4	6,8	89		
PENDRE,	0-20	3,8	4,4	64	10	1976-
3,4 ha	20-60	1,1	3,8	87		1979
Heavy clay	60-100	0,8	4,8	90		
TOPI,	0-20	5,2	6,6	11	25	1975-
10,3 ha	20-60	0,8	7,0	10		1985
	60-100	0,3	7,5	10		

Table 2. Leached calcium losses and characteristics of observation periods (from 1 IX to 31 VIII)

Observation period	Mean Ca content mg/l	Annual Ca loss kg/ha	Precipitation P, mm	Drainage runoff Q, mm	Runoff ratio Q/P	Cultivated crops
	VIHTRA (heavy clay, slightly acidic)					
1969/70	50	113	617	227	0,37	Winter wheat
1970/71	53	58	538	110	0,20	Winter wheat
1971/72	28	37	622	131	0,21	Barley
1972/73	43	73	682	171	0,21	Barley
1973/74	91*	133	562	146	0,26	Grasses
1974/75	60	227	746	378	0,51	Grasses
1975/76	43	30	490	69	0,14	Grasses
Mean	55	96	608	176	0,29	
	PENDRE(heavy clay, strongly acidic)					
1976/77	21	57	710	268	0,38	Flax-fibre
1977/78	20	52	832	254	0,31	Barley
1978/79	21	35	664	166	0,25	Oats
Mean	21	48	735	229	0,31	
	TOPI (loamy sand, neutral)					
1975/76	87	95	571	109	0,19	Winter wheat
1976/77	91	127	625	140	0,22	Potato
1977/78	92	142	906	155	0,17	Oats
1978/79	75	138	792	185	0,23	Barley
1979/80	92	92	594	100	0,17	Barley
1980/81	85	231	1060	271	0,26	Winter rye
1981/82	76	210	740	278	0,38	Potato
1982/83	95	136	639	143	0,22	Barley
1983/84	92	181	921	197	0,21	Barley
1984/85	97	169	782	174	0,22	Potato
Mean	87	152	763	175	0,23	

Note * Ca - 2300 kg/ha was applied in autumn 1973.

Table 3. Leaching of calcium from Estonian soils

Methods, location and conditions of research	Ref. No	Research years	Average content mg/l	Leached Ca amount kg/ha
1 By surface runoff				
Estonia on the average	2	1927-28	40	112
	3	1948-62	50	138
Among this the North Estonia			62	172
The rest part of Estonia			44	118
By great rivers			41	102
2 Lysimeter experiments on arable naturally drained lands				
Vinni, loamy sand, pH KCl =6,8	4	1969-71	96	192
Ahja, loamy sand, pH KCl =4,4				
unlimed	1	1969-74	40	79
limed, Ca - 1200 kg/ha			50	100
Ca - 2400 kg/ha			60	121
Ca - 4800 kg/ha			90	181
3 By drainage runoff				
Kuusiku, loamy sand pH KCl=5,8	5	1974-75	79	170
Topi, loamy sand, pH KCl=6,8	-	1975-85	87	152
Vihtra, heavy clay, pH KCl=5,8	-	1969-76	55	96
Pendre, heavy clay, pH KCl=4,0	-	1976-79	21	48

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Biogenic and Organic Matter Run - off in the Central Lithuanian Small Stream Catchment Areas

We present results of monitoring total and mineral forms of nitrogen and phosphorus, organic compounds in streams and rivers in Kėdainiai region. These measuring were made in 1992 .. 1993 years.

Kėdainiai district, located in central Lithuania, is notable for intensive agriculture and much industry. Its area is 1677 sq.km. 67% of the total territory is agricultural land, and 72% of this land is intensively drained. The soils here are soddy gleyc, loam and clay - loam. Forest accounts for 18% of the total territory, and marshes for 1%. In the district there are fertilizer, biochemical, electrical appliance, leather processing and sugar factories, a cannery, and several dairies.

About 98% of the Kėdainiai district territory lies in the Nevėžis catgment area. 11 rivers, whose cathment areas vary from 16 sq.km. to 1165 sq.km. flow into the Nevėžis in Kėdainiai district. Hydrochemical tests and run - off measurements were made at their mouths. 6 of the cathment areas are wholly within the Kėdainiai district, the others flow in from other districts. The total stream lenth in the district is 754 km.

The eutrophication process accurs in all the tested streams. The average total nitrogen concentration is 6.0 - 8.5 mg/l. The smallest variation in nitrogen concentration (variation coefficient about 27%) occurs in the bigger rivers, whose average annual discharge is 4 - 6 cub.m/s. In small rivers, when the average annual discharge is 0.09 - 0.15 cub.m/s the variation coefficient is about 80%. Most of the nitrogen total is made up of mineral nitrogen in nitrate form.

Measuring the stream condition according to HPC (highest permissible concentration), in all the streams the HPC was exceeded total nitrogen minimum concentration, by 1.1 - 2.6 times, average, by 1.9 - 4.2 times; and maximum, by 3.8 - 13.6 times. The total phosphorus average concentration in streams flowing through agricultural land was 0.14 - 0.38 mg/l. In rivers where industrial emissions occur, the average concentration was 0.68 - 1.68 mg/l and exceeded the HPC by 3.4 - 8.4 times. The average chemical Oxygen Demand (ChOD). concentration was 28 - 48$mg \cdot O_2 / l$ and exceeded the HPC by 1.8 - 3.2 times.

In 1993 the stream run - off removed 548 - 1603 kg/sq. Km of nitrogen, and 19.5 - 275 kg/sq. Km of phosphorus. Over 1 year, the affluent streams of the Nevėžis in the Kėdainiai district carried 4000t of total nitrogen, 270 t of total phosphorus, and 11500 t of organic matter. The size of the chemical run - off was in part determined by the size of the water run - off. The highest level of biogenic matter leaching occurs in the winter and spring seasons, and the lowest level in summer.

Organic nitrogen made up 4 49% of the total nitrogen content. This figure for the stream water was higher in summer and autumn. Organic phosphorus made - up 1 -76% of the total phosphorus content. This figure was higher in the winter and spring seasons.

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Preliminary results of agricultural run-off monitoring in Latvia

Hydrological monitoring in rivers and lakes has a relatively long tradition in Latvia from the last century. Hydrological monitoring in small catchments, started after World War II (the first catchment river Vienziemīte, Zosēni Run-off Station, dates from 1947). Hydrological monitoring data of drainage fields and plots exist from the beginning of the 60's in Latvia. Due to financial problems the network was significantly decreased from 1990.

Run-off quality from small catchments was evaluated only in the small catchment of river Vienziemīte (two years data in the 80's). Run-off quality from drainage fields and plots was studded in a few cases for short time periods in the Latvia University of Agriculture and institute of Crop Husbandry, generally regarding liming of soils, waste water or slurry irrigation .

There are no national monitoring programmes and networks in Latvia specifically aimed at assessing agricultural run-off today. Results from some sampling points can be used for general evaluations of nutrient losses from arable land. On regional and catchment scale these date are of little value. To get a better information of nitrogen and phosphorus run-off from agricultural areas and the impact on the total nutrient load to Baltic Sea, a build-up of monitoring network in cooperation and with technical, financial assistance and transfer of the experience and knowledge from the Nordic countries (Sweden, Norway) is necessary. Two joint programmes between the Baltic states (Latvia, Estonia, Lithuania) and the Nordic states (Sweden, Norway) have started.

The Baltic Agricultural Run-off Action Programme (BAAP), is sponsored by the Swedish government. Part of the programme is the Baltic Environmental Agricultural Run-off Project (BEAROP) carried out by the Swedish University of Agricultural Sciences (SUAS) and JTI. The BEAROP project proposes a wide action programme to reduce the nutrient load from agricultural areas.

Other project concerning agricultural run-off is the "Drainage Basin and Load of the Gulf of Riga", sub project " Soil and nutrient loss from small catchments " financed by grants of NorFA and Norway. Participating institutions are Jordforsk, (Norway) and Latvia University of Agriculture, Latvia Hydrometeorological Agency and Latvia University. The corner stone of the programme is to build up monitoring stations directed towards nutrient run-off and nutrient balances in small catchments dominated by agricultural activities. Potential monitoring catchments have been investigated during the autumn of 1993. First water samples were collected in several catchments. Bērze site was evaluated as the best from hydrological viewpoint, were is possible with small investments to start a monitoring programme immediately.

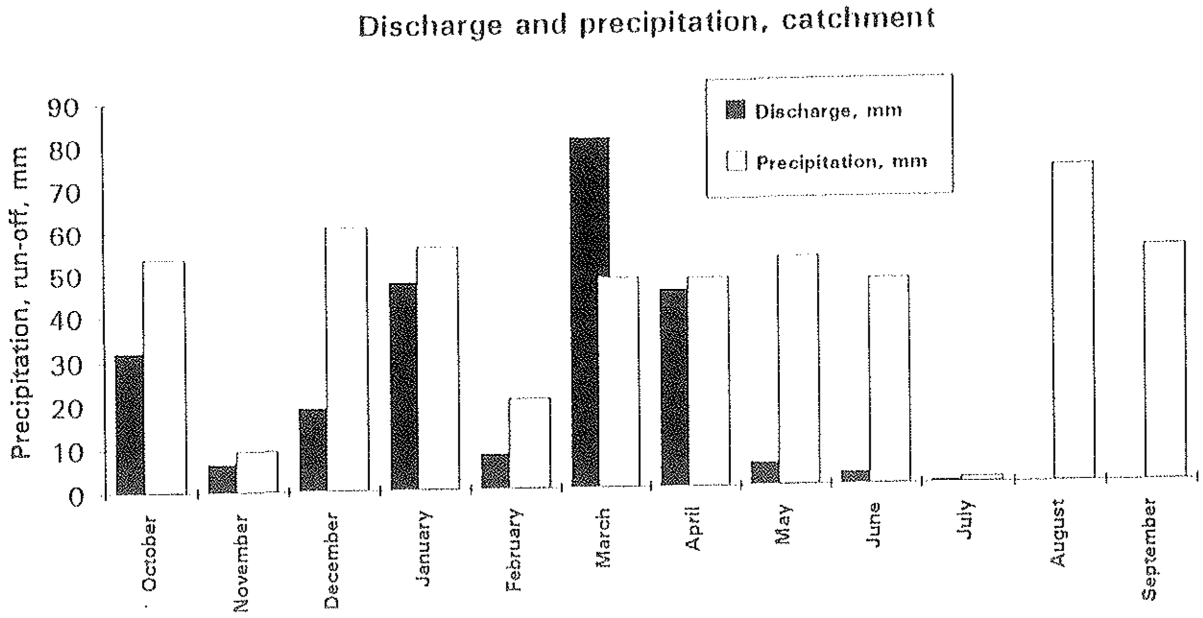
There exists catchment (368 ha) and field level (76 ha) run-off stations from 1967. Stations only need a renovation of the buildings and a technical upgrading. Soils in the catchment are soddy carbonate and gley soils, silty clay according international classification. There are hydrological data available both on the small catchment and the field scale drainage from 1967. A preliminary water sampling programme in cooperation with Jordforsk has been started in 1994.

The hydrological year October 1993 - September 1994 (Table 1) was close to the annual year according amount of precipitation and responds to wet years according amount of run-off from catchment and drainage field. The winter of 1993 and the spring of 1994 might be described as wet with a high drainage and catchment run-off. Summer period was dry, no run-off after first decade of July was recorded.

The nutrient run-off for period October 1993 - September 1994 (Figure 1, Figure 2) in the Bērze catchment (368 ha, 98 % arable land) was 11.6 kg/ha of nitrogen and 0,52 kg/ha of phosphorus. Nutrient run-off from the drainage field (77 ha) in the same period was higher - 14 kg/ha of nitrogen and 0,56 kg/ha of phosphorus. The amount of nutrient run-off might be preliminary evaluated as moderately high for the clay soil. It is necessary to obtain from farmers data on both mineral and organic fertilizers applied in 1993/1994 and soil management for the final evaluation of nutrient transport in the Bērze monitoring site.

Table 1. Nutrient (N, P) run-off from Bērze monitoring site, October 1993 September 1994.

Month	Precipitation, mm	Discharge, mm		N run-off, kg/ha		P run-off, kg/ha	
		Catchment	Drainage	Catchment	Drainage	Catchment	Drainage
October	53.6	16.0	31.9	0.895	2.168	0.023	0.099
November	9.4	4.8	6.6	0.273	0.433	0.008	0.020
December	60.8	9.7	18.9	0.556	1.149	0.020	0.053
January	55.9	55.4	47.4	3.197	2.699	0.134	0.126
February	20.5	5.8	7.9	0.336	0.422	0.015	0.020
March	47.9	68.6	81.0	4.040	4.023	0.207	0.180
April	47.8	36.7	45.0	2.157	2.699	0.095	0.041
May	52.5	2.5	5.1	0.119	0.264	0.012	0.014
June	47.1	0.5	2.7	0.011	0.123	0.002	0.005
July	1.2	0.0	0.7	0.000	0.033	0.000	0.001
August	73.2	0.00	0.0	0.000	0.000	0.000	0.000
September	54.1	0.00	0.0	0.000	0.000	0.000	0.000
Total Oct. 1993 - Sept. 1994	**524**	**200**	**247**	**11.58**	**14.01**	**0.52**	**0.56**



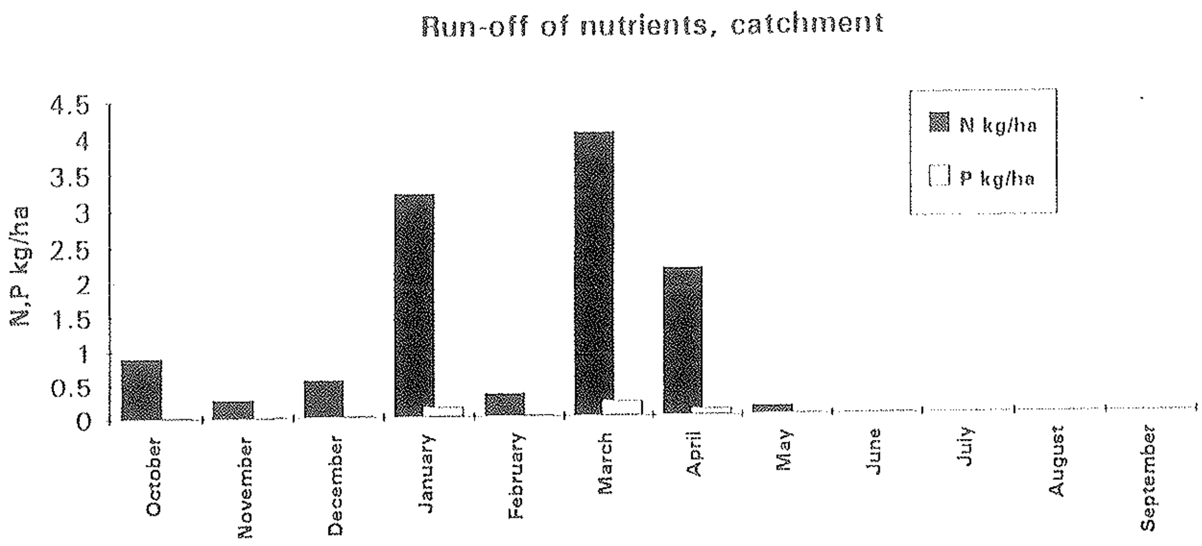
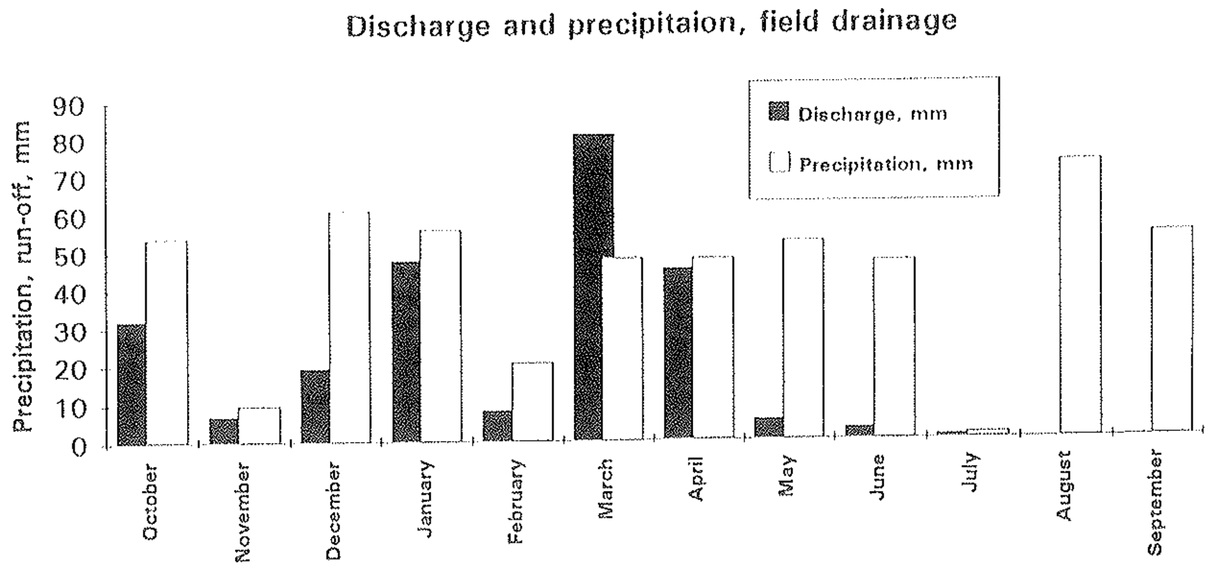


Figure 1. Discharge and precipitation, run-off of nutrients from Bērze catchment.



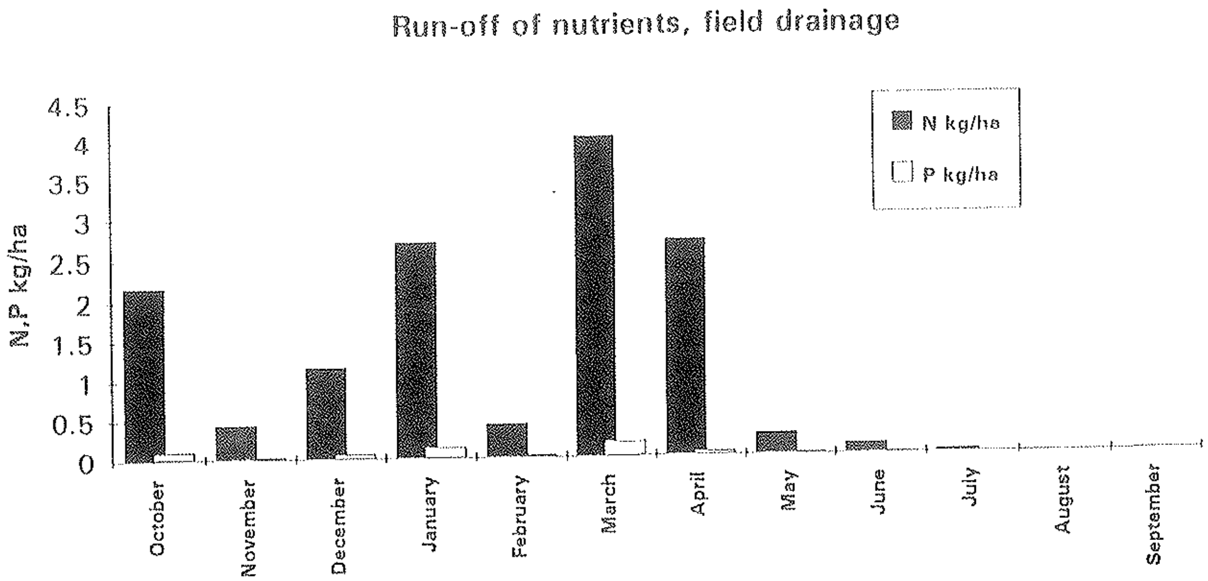


Figure 2. Discharge and precipitation, run-off of nutrients from Bērze drainage.

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DETERMINATION OF DRAINAGE PARAMETERS ON THE BASIS OF GLEYZATION DEGREE AS THE INDICATOR OF THE OVERWETTING RATE OF SOIL

Up to now is there not generally accepted universal methods for determination of drain spacing and collector size for drainage systems. A method of drainage dimensioning in Estonia and similar to Estonia conditions worked out by the author of this paper is presented here.

In Estonia the main part of soils (85%) needing drainage is situated between automorphic and bog soils. Necessity in drainage of these temporarily waterlogged mineral soils is quite different: optimum drain spacings on the occasion of the equal permeability of soils differs up to 3 times. At the same time due to the high spatial variability of soils the practical identification of overwetting rate of every drainable plot has been a serious problem.

Our and other experiments have given evidence that the gleyzation degree of soil is in correlation with the depth of groundwater level and yield loss on undrained temporarily waterlogged soil as much as with drainage runoff on the drained soil. Our experimental data had come from 15 production farms in Harjumaa, Raplamaa, Järvamaa, Pärnumaa and Viljandimaa in Estonia from 1962 to 1980.

On the basis of experiments we reached following conclusions:

- The gleyzation degree of soil can satisfactorily be used as overwetting rate indicator of temporarily waterlogged mineral soils in forest zone.
- The gleyzation degree of soils as a complex notion can be practically determined by morphological signs of the soil profile, by organic matter content in the humus horizon and by the indicator plants.
- In dependence of the gleyzation degree of soil optimum drain spacing and drainage coefficient can be determined presented for the conditions of Estonia in this paper.

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