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USE OF AGROHYDROLOGICAL SIMULATION MODELS IN QUANTITATIVE LAND EVALUATION

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ABSTRACT

A quantified land evaluation procedure, being part of a mixed qualitative/quantitative approach is described. The procedure is based on the model SWACROP (SWATRE and CROPR), which simulates moisture regime and crop production. Quantitative measures for water-related land qualities are obtained. The land qualities dealt with are workability, moisture deficit and aeration. The potential production and actual water-limited yields for different crops are calculated. When simulations are carried out for many years, probability graphs for specific occurrences can be generated for each land quality. Finally, possible ways of applying the procedure are touched upon.

INTRODUCTION

The aim of the EC-project 'Use of modern physical field methods and computer simulation for land evaluation purposes' is to develop a quantitative land evaluation procedure for defining land productivity potentials in Europe. The procedure for evaluating water-related land qualities (e.g. moisture deficit, aeration and workability) and productivity has been developed using dynamic simulation models, with the intention that the methodology can be applied to the 1 : 1 000 000 EC Soil Map. Data from experimental fields in the UK have been collected (Carter, 1988) to test simulation models that are already operational. The data have also been used to extend the models so that they can include different crops and perform simulations for more than one year. Existing Dutch experimental data have also been used. The experimental sites are located on major EC soil units that are also found widely distributed all over Europe.

It is not wise to use elaborate methods for evaluating areas that have clear restrictions for a specific land utilization type. For this reason, the mixed qualitative/quantitative approach has been developed (Van Lanen et al., 1988). The qualitative methods define less-favoured areas. For the remaining map units, the quantitative part of the procedure can be applied, using the model SWACROP for quantifying the water-associated land qualities and production. The model SWACROP consists of a soil-water flow model (SWATRE) and a crop production model (CROPR). The objectives of this paper are to describe how agrohydrological models for quantitative land evaluation procedures are implemented, and to present some preliminary results from the Dutch and English examples.

MODEL DESCRIPTION

The soil-water flow model SWATRE describes one-dimensional (vertical), transient, unsaturated water flow in a heterogeneous soil-root system using the Darcy flow equation and the continuity equation (Belmans et al., 1983; Feddes et al., 1988). These equations are combined into:

$$\frac{\delta h}{\delta t} = \frac{1}{C(h)} \frac{\delta}{\delta z} \left[k(h) \left(\frac{\delta h}{\delta z} + 1\right) \right] - \frac{S}{C(h)} \qquad (1)$$

where:

h = pressure head (cm)
t = time (d)
C = differential moisture capacity, $d\Theta/dh$, with Θ being the volumetric soil water content (cm^{-1})
z = vertical coordinate (cm)
k = hydraulic conductivity (cm/d)
S = water uptake by roots (d^{-1})

This partial differential equation is solved numerically by a finite-difference scheme. The boundary condition at the top of the schematized soil profile is defined as a maximum evaporation flux, calculated using daily meteorological data. Calculated daily, potential evapotranspiration is divided into soil evaporation and transpiration. For the bottom-boundary, either the water table or a known soil water potential or flux can be used. The soil profile is divided into several compartments, in the middle of which nodal points (points at which the solution to Equation 1 is found) are located. These compartments are, for instance, 10 cm thick. Hydraulic properties of the soil, such as moisture retention and hydraulic conductivity, are major data needed to solve Equation 1. The term for root water-uptake S (sink term) is calculated as a function of the maximum transpiration rate and the reduction factor α (Feddes et al., 1988):

$$S_i = \alpha(h_i) \cdot S_{max} \qquad (2)$$

$$S_{max} = T_p / z_r \qquad (3)$$

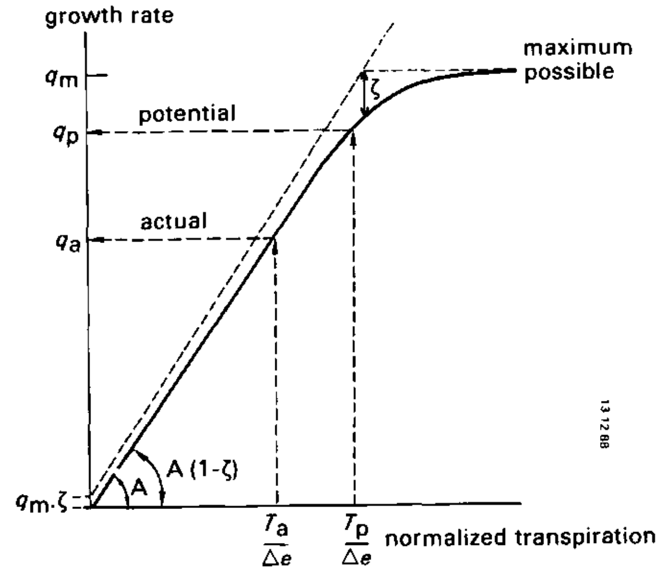

Fig. 1 Growth rate versus water use.

where:

S_i = sink term for compartment i (cm/d)
α = reduction factor; function of pressure head h, related to compartment i
S_{max} = maximum transpiration rate (= maximum possible extraction) (cm/d)
T_p = potential transpiration (cm/d)
z_r = rooting depth (cm)

The crop production model CROPR (Fig. 1) computes the daily actual and potential dry matter production as a function of actual and potential transpiration respectively (Feddes et al., 1978). Optimum nutrient supply is assumed, and the effects of weeds or diseases are not taken into account. The output of CROPR contains water-limited yields, which are assumed to be representative of high input agricultural systems. In Figure 1, the daily growth rate (q as dry matter in kg ha^{-1}) is expressed as a function of normalized transpiration ($T_p/\Delta e$, where Δe represents the vapour pressure deficit in Pa). The left asymptote indicates the productivity of a crop that is well supplied with nutrients, and the upper horizontal asymptote indicates the production level under conditions of adequate water supply, but with other limiting factors, such as solar radiation. Daily actual (potential) dry matter growth rate $q_{a(p)}$ (kg ha^{-1} d^{-1})

is calculated as:

$$\left(1 - \frac{q_{a(p)}}{A\,\frac{T_{a(p)}}{\Delta e}}\right)\left(1 - \frac{q_{a(p)}}{q_m}\right) = \zeta \qquad (4)$$

where:

A = maximum water use efficiency (kg Pa m^{-3})
$T_{a(p)}$ = actual (potential) transpiration rate (m d^{-1})
q_m = maximum possible growth rate (kg m^{-2} d^{-1})
ζ = a mathematical parameter ($\zeta \approx 0.01$)

QUANTIFICATION OF LAND QUALITIES

The models are used to calculate moisture regime and crop production for a specific soil unit. The results are used to analyse measures for the water-related land qualities: workability, moisture deficit and aeration (Fig. 2). The described procedure is developed using experimental data from Dutch and English soils, but the procedure can be used for each soil unit of the 1 : 1 000 000 EC Soil Map.

Workability

The workability of the soil is related to the moisture regime of the topsoil. Van Wijk and Feddes (1986) derived the workability of the topsoil from the pressure head at 5 cm depth and a threshold value (workability limit). When the soil- and crop-specific threshold value of the pressure head below which fieldwork can take place is known, workability on a daily basis can be derived from simulated pressure heads. Fieldwork is assumed to take place when no deterioration of the soil structure occurs.

Planting/sowing and emergence dates

Knowing the probable occurrence of workable days, then the earliest possible planting date or sowing date for each crop and each simulated year can be predicted. For instance, four workable days are considered necessary for planting potatoes on an average Dutch farm, and for sowing spring cereals one day is considered to be sufficient (Van Wijk and Feddes,1986).

Emergence of the crops depends on soil temperature and soil moisture conditions. For potatoes and spring cereals, a daily heat-sum increment is calculated as a function of temperature and pressure head (h) at 5 cm

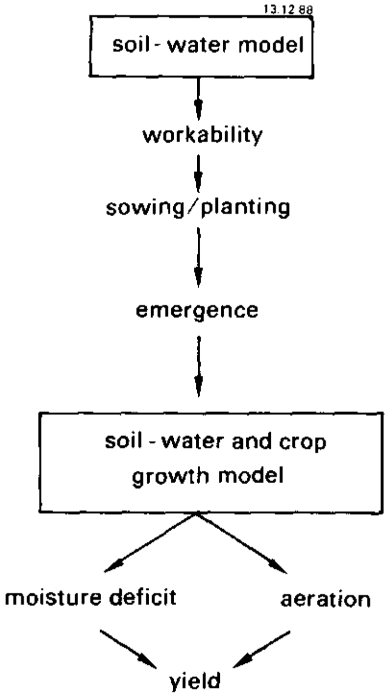

Fig. 2 Flow diagram for quantifying land qualities and production.

depth. When the required heat-sum is achieved, it is assumed that the crop will emerge. Germination is retarded if the topsoil is too wet ($h > -100$ cm for potatoes and $h > -50$ cm for spring cereals) or too dry ($h < -500$ cm).

Permanent grassland starts normal growth when the required heat-sum is reached. This heat-sum increment decreases if the groundwater table is too high. For winter cereals, emergence is a function of temperature and daylength (Groot, 1987).

The calculated emergence marks the beginning of the growing season in the simulation. The length of the growing season is an important factor defining water-limited actual yield. Therefore, calculations of both beginning and end of the season (depending on harvest conditions) are included in the procedure.

Aeration

Aeration of the root zone is calculated in a similar way to the workability, using threshold values (Bouma and Van Lanen,1987). The crop- and soil-specific aeration limit is defined as the air-filled porosity below which roots cannot function optimally due to lack of oxygen. When this threshold value is known, days with or without sufficient aeration can easily be derived from the simulated air content of the root zone.

Moisture deficit

To obtain potential production, enough water must be available during the growing season. Even under Dutch climatic conditions, moisture stress often occurs. In the proposed procedure, moisture deficit is expressed as the difference between the potential and the actual transpiration rate. This value can be obtained for each simulated day, but is usually given as a cumulative value for the whole growing period.

Harvestability

This factor can be dealt with in the same way as workability in the spring (with other threshold values). Although a harvest date can be set, it is advisable to check whether harvesting can in fact take place at that time. Severe problems can occur if harvesting has to be delayed because the soil is too wet.

Production

The CROPR model calculates the growth rate for each day, as well as the final cumulative potential and actual yields (dry matter production) for the whole growing season. The dry matter is divided over the different plant organs using empirical formulae. The harvestable yield is given, for example, as tuber, grass or grain yield.

Frequency distributions and occurrence probabilities

The simulation can be carried out for only one season, but then no between-year variation due to different climatological conditions can be predicted. When the models are run for more years (e.g. 20 or 30), a frequency distribution of events can be given. It is also possible for some of the land qualities to give an occurrence probability of a specific entity (e.g. occurrence of a workable day in the period from 1 to 10 April).

Sites

Two Dutch (Sinderhoeve and Lelystad site) and two of the six English experimental sites have so far been considered. The Sinderhoeve soil is a coarse, sandy, fluvioglacial soil with a deep water table (Humic Podzol), and the Lelystad soil is a clay loam with a shallow water table (Calcaric Fluvisol). The English soils, for which simulation has been performed, belong to the Cuckney and Evesham series. The Cuckney soil is a deep, coarse, sandy soil, overlying sandstone, with a deep water table (Luvic Arenosol), and the Evesham series consist of clay soils with shallow (probably perched) groundwater (Calcaro-gleyic Cambisol). The crops on the experimental sites were potatoes, grass, spring and winter cereals.

PRELIMINARY RESULTS

Models always need a validation phase. In this case, data sets for two years were available. The data of the first year were used to calibrate the model. For the calibration, only a limited number of model parameters were involved. The data of the second year were then used for verification. A few calibration results are given in Figure 3, and some verification results are presented in Figure 4.

When an acceptable agreement is found, it is assumed that the models are valid for a long time series (number of years). Daily meteorological data (30 years for the Netherlands and 24 years for the UK) were used to perform the simulations.

The results of these calculations contain daily pressure heads and air content values from which workable days and days with sufficient aeration are derived, as well as the yield and the soil moisture deficit. Examples of these results are shown for some of the sites in Figures 5 to 8. Figure 5 shows the occurrence probability of workable days. For instance, for the calcaric fluvisol, the occurrence probability of aworkable day in the period from 1 to 10 April is 30 % (the mean number of workable days in that period is 3 out of 10). In Figure 6, the distribution of moisture deficits is given as a frequency distribution graph; e.g. for the luvic arenosol, moisture deficit exceeds 100 mm in 50 % of the years. Figure 7 resembles Figure 5 in terms of interpretation. Aeration is described with an occurrence probability for a day with sufficient aeration: for the calcaric fluvisol, the mean number of days

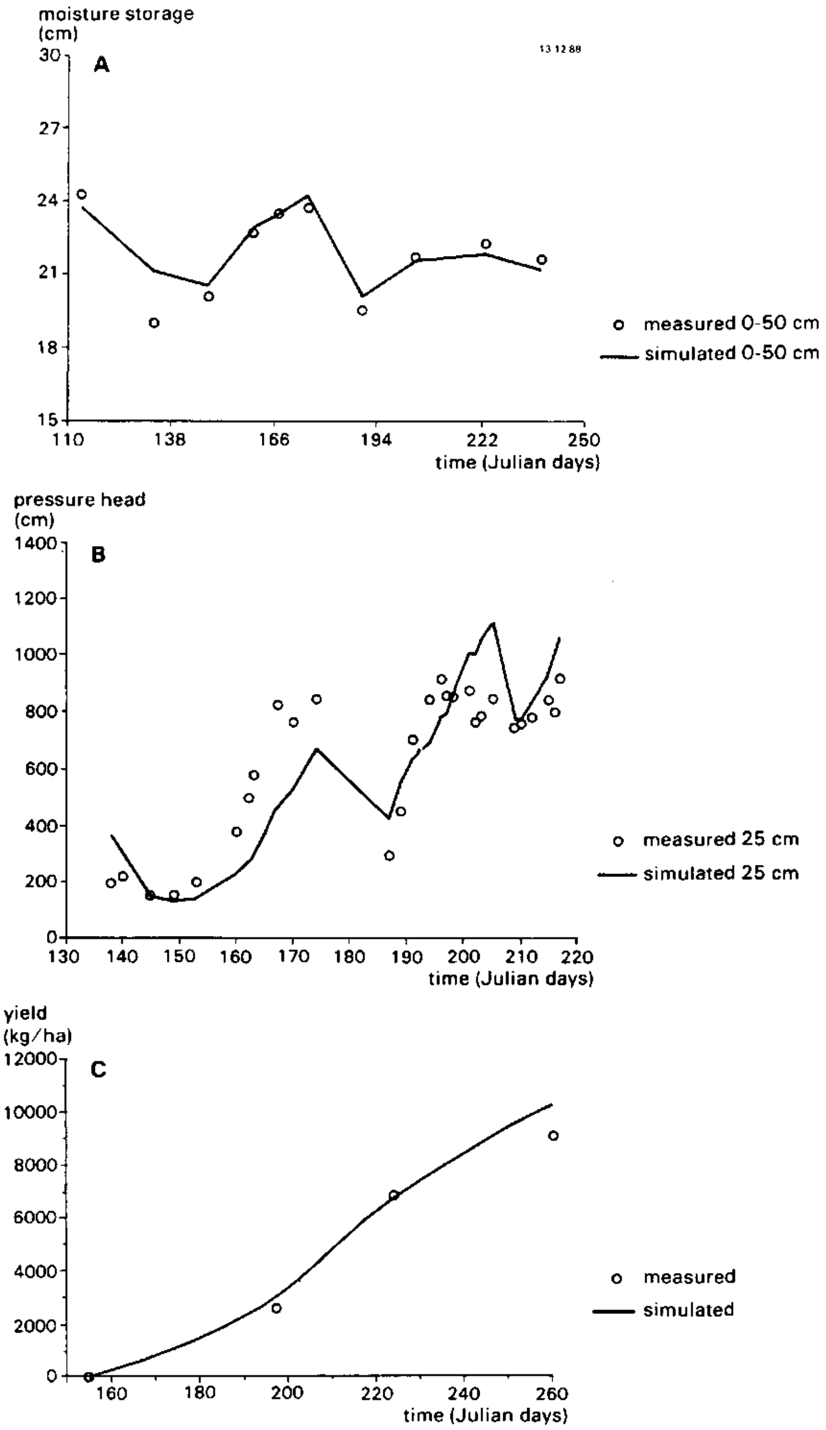

Fig. 3 Results of calibration

A Moisture storage (cm) of a calcaro-gleyic cambisol for the upper 50 cm

B Pressure head (cm) of a humic podzol at a depth of 25 cm

C Tuber yield of potatoes (dry matter in kg/ha) of a luvic arenosol

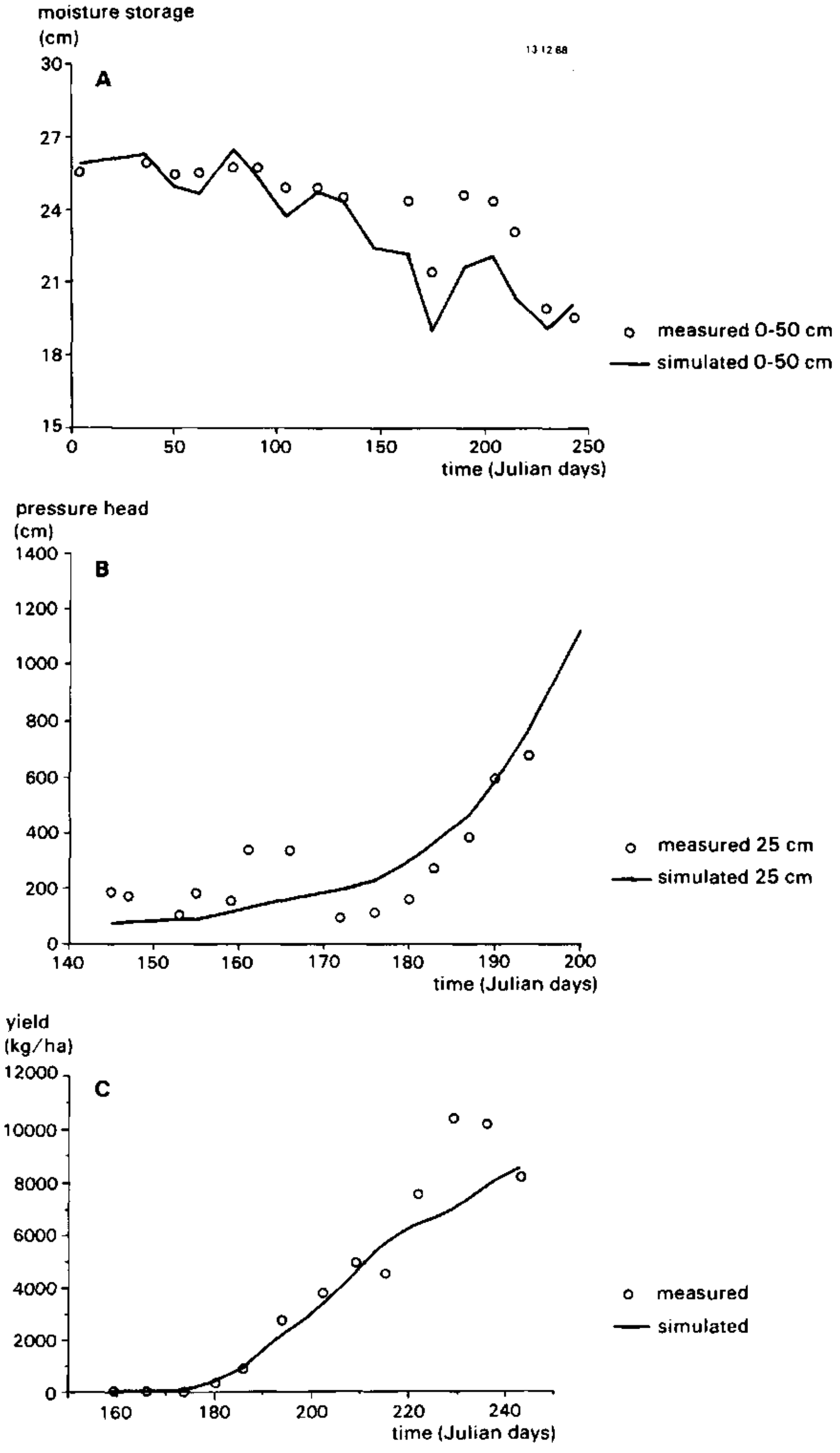

Fig. 4 Results of verification

A Moisture storage (cm) of a calcaro-gleyic cambisol for the upper 50 cm

B Pressure head (cm) of a humic podzol at a depth of 25 cm

C Tuber yield of potatoes (dry matter in kg/ha) of a luvic arenosol

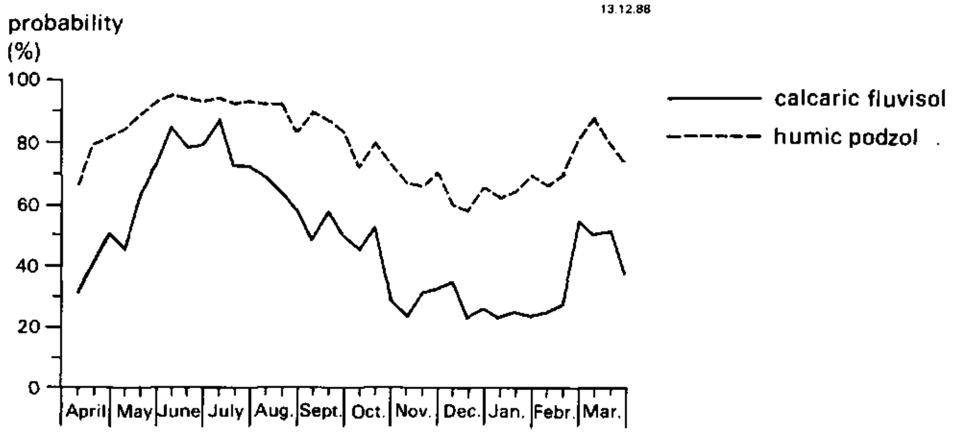

Fig. 5 Occurrence probability of a workable day for each ten-day period of the year.

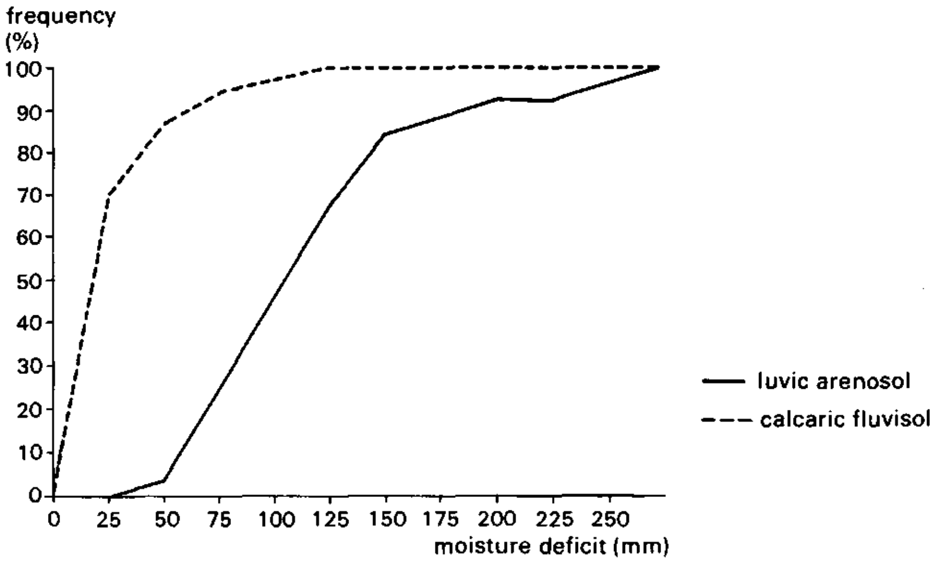

Fig. 6 Frequency distribution of moisture deficit.

with sufficient aeration for the period from 1 to 10 April is 7.5. The last graph (Fig. 8) shows the frequency distribution of harvestable yields. For the humic podzol, the tuber yield (dry matter) does not exceed 10 t ha^{-1} in 80 % of the years.

DISCUSSION

In principle, the proposed procedure can be used for all soil and meteorological conditions under consideration. Applying the models in a new area always needs a calibration and verification stage. Information

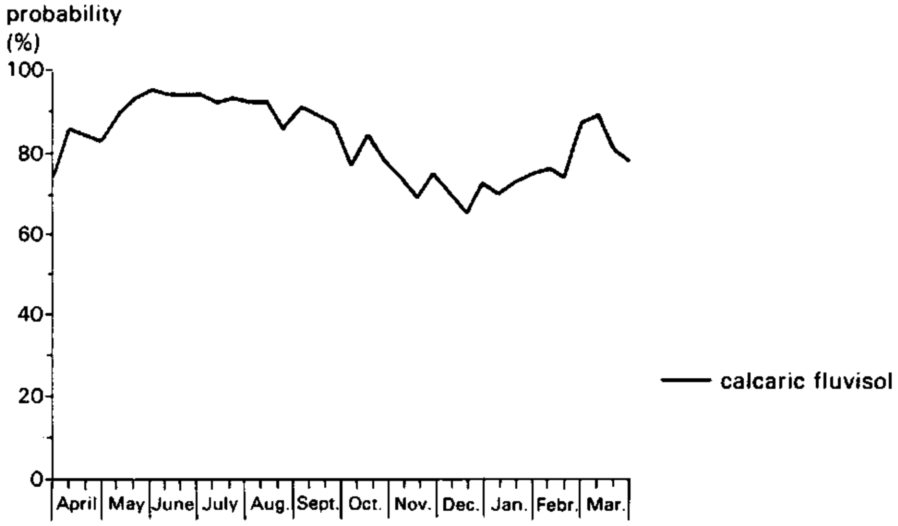

Fig. 7 Occurrence probability of a day with sufficient aeration for each ten-day period of the year.

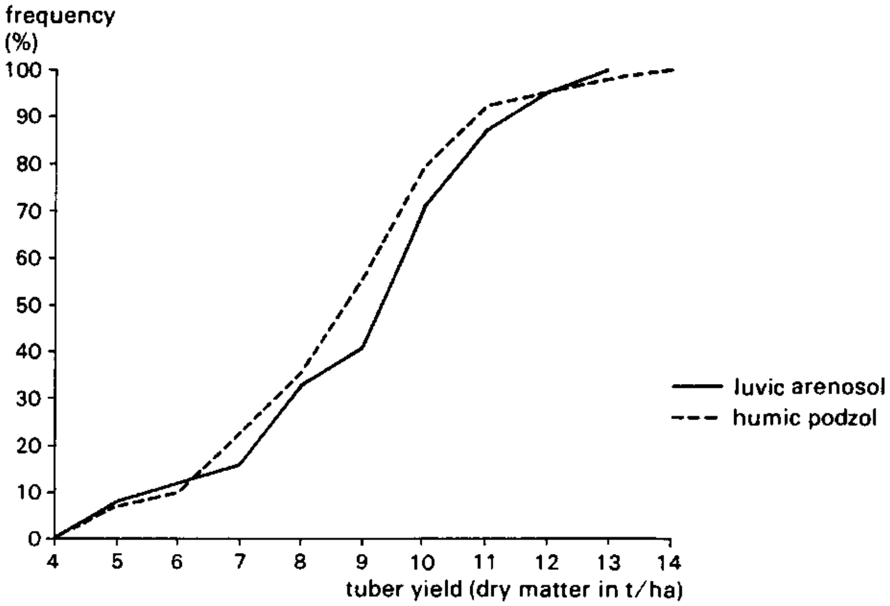

Fig. 8 Frequency distribution of tuber yield (potatoes).

exchange between modelmakers and, for example, soil surveyors or land evaluators, who have specific knowledge in the field, can play an important role in spotting problems or unexpected results.

The amount of input data needed for agrohydrological simulation modelling should not be considered as being the main obstacle. There are many ways of generating input, and of extrapolating and transferring existing data to the desired input. These methods are covered by Kabat and Hack-ten Broeke (1988). For some regions within the EC, where no facilities are available for doing detailed experiments, these methods may be especially helpful when applying the quantitative procedure.

The presented simulation techniques are not only of use for land evaluation studies. In related fields of research, for example emphasizing yield prediction, moisture availability or irrigation requirements, modelling techniques may become essential.

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