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Spatial Variability of Soil Water and Evapotranspiration

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Spatial variability in evapotranspiration from a crop covered field exposed to homogeneous climatic conditions is partly caused by field variability in soil physical properties and partly by field variability in pertinent crop properties. The present paper presents an analysis of the spatial variability in soil water content and evapotranspiration for two 0.5 ha grass fields of different soil texture, viz. a coarse sand and a sandy loam. Soil physical properties and soil water profiles were determined 1 m apart at 16 points systematically located in each field. The analysis of soil water profiles in relation to soil physical properties indicates an appreciable variability within a range of 1 m. For this reason a relatively simple model was used to simulate the variability pattern of the evapotranspiration, taking into account the variability in plant available water content. The results of the simulations are compared with the evapotranspiration patterns determined on the basis of a short term water balance.

Introduction

In modelling hydrological processes including evapotranspiration it is generally assumed that the soil physical properties including hydraulic properties are uniform and that the field of interest can be characterized by sampling over a few locations and by an appropriate averaging procedure. However, this may lead to large errors since fields which generally are considered as homogeneous relative to most agricultural practices often have a significant spatial variation in hydraulic properties as a result of soil forming processes and previous agricultural activities. Various methods including stochastic modelling have been applied as approaches for analy-

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zing problems related to field variability. In the present paper the variability in soil water retention is taken into account and a simple model adopted in analyzing the spatial variability in evapotranspiration.

Test Sites and Soil Sampling

In the present experimental study two test sites were selected for their contrasting soil types. Test site Jyndevad is characterized as coarse sand, and is situated in an outwashed plain landscape in southern Jutland. Test site Tåstrup is sandy loam, situated in a moraine landscape on Zealand.

The two fields were covered with a first year grass. Main cuts were performed at Jyndevad on June 6, July 18, August 12, and on October 2; likewise, at Tåstrup on June 12, July 4, August 9, September 11 and on October 28.

Leaf area indexes (LAI) were determined weekly at the corners of the 50 × 100 m test sites, Fig. 1.

Soil water profiles in each field were monitored by using the neutron scattering method at 24 access tubes, Fig. 1. At Jyndevad measurement were performed at 10, 20, 40, 60, 80 and 100 cm depth twice weekly, and at Tåstrup at 10, 30, 50, 70, 90, 120, 160, 210 and 260 cm depth once a week.

Soil sampling was performed at each measuring point. Undisturbed soil cores (100 cm^3) were taken approximately 1 m from the access tubes. At Jyndevad sampling depths were 10, 30 and 50 cm. At Tåstrup sampling depths were 10, 30, 50, 70 and 90 cm. At each sampling point and depth 3 cores were taken adjacent to each other. The soil water content was determined at pF 1.0, 1.5, 2.0, 2.5, 3.0 and 4.2, and at Jyndevad, in addition, at pF 1.3 and 1.7. Variation among the 3 adjacent cores was in all cases only a few per cent. A detailed description of the soil sampling and experimental analysis is given by Hansen *et al.* (1986). Spatial variability of the soil water properties at the two test sites has been published elsewhere by Jensen and Hansen (1986).

Soil Water Content Variability

A consequence of the experimental design is that it is not possible to take into account the variations which take place within a distance of 1 m. At the D-points, Fig. 1, three access tubes form a triangle with a side length of 1 m. For each triangle the average value of the three corresponding measurements is therefore assumed to represent one measuring point. This reduces the number of points where the soil water content is determined to 16 in each field. From these 16 observation points average soil water profiles were calculated for each date and the results are shown in Figs. 2 and 3. Also, averages ± 2 times the standard deviation are shown.

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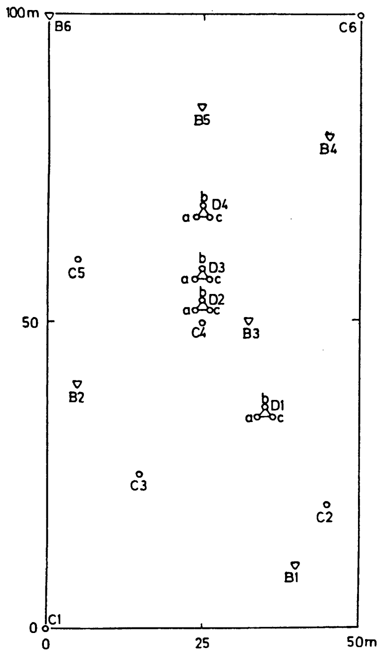

Fig. 1. Test site and location of access tubes.

If the soil water content for a given point, depth and date, is above (or below) the average value for that particular depth and date, then the soil water content on the following measuring date is likely also to be above (or below) the average value for that date. Crossovers are very infrequent, except in cases where the soil water content of the considered point and depth is nearly equal to the average value. In several cases there are no crossovers at all. This tendency was proven statistically significant by a simple run-test, testing against the null-hypothesis that crossovers are completely random.

This pattern of variation was expected because of the spatial variation in soil physical properties, especially the spatial variation in the soil water properties. By using the soil water content at pF 2.0 as field capacity the soil water deficit was introduced, i.e. the soil water content at field capacity minus the actual soil water content. This, however, resulted in an increase in the variance, which strongly indicates an appreciable variation in the field capacity within a range of 1 m (the distance separating the access tubes from the soil sampling points). Such a variation is likely to exist not only in field capacity but also in other soil physical properties. Consequently, it may be unrealistic to simulate temporal changes in soil water content at a given point by using soil physical properties obtained from nearby soil sampling.

The variability pattern found in the soil water content may, on the other hand be simulated by taking into account the variability found in soil physical properties.

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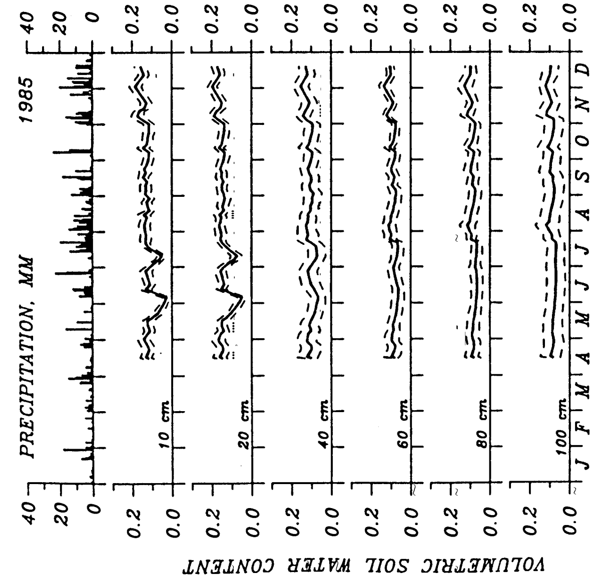

Fig. 2.
Precipitation and average profile of soil water content, Jyndevad. Average of 16 points and ±2 times the standard deviation.

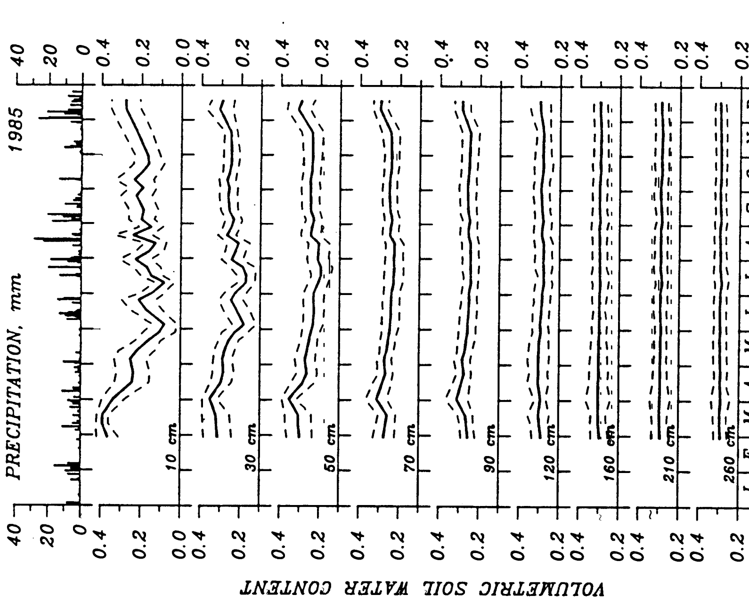

Fig. 3.
Precipitation and average profile of soil water content, Tåstrup. Average of 16 points and ±2 times the standard deviation.

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Evapotranspiration Variability

Evapotranspiration was calculated from a short term water balance. Input to this water balance is the change in soil water storage, calculated from the soil water profiles and the precipitation, shown in Figs. 2 and 3. Inspection of Figs. 2 and 3 reveals that appreciable soil water deficit developed only during the period until the first cut was taken. Consequently, only the period until first cut was considered, as regards the variability of evapotranspiration in relation to soil water properties. At Jyndevad and at Tåstrup the 0-50 cm and 0-60 cm layers, respectively, are assumed to contribute to evapotranspiration. Percolation out of these layers is assumed to take place only if the calculated evapotranspiration exceeds the potential evapotranspiration. The potential evapotranspiration is at Jyndevad obtained from measurements with an evaporimeter of the type HL315, and is at Tåstrup obtained by using the Penman combination equation, utilizing data from the near-by climate station. The short term water balance used on single points gave for the first cut the results given in Table 1.

In Fig. 5 the solid line represents evapotranspiration estimated from the short term water balance, and the bars represent ± 2 times the standard deviation. At Jyndevad it is noticable that the variability in evapotranspiration increases as the crop develops and the soil dries out. At Tåstrup large variations exist throughout the whole period. This indicates that at Jyndevad the soil physical properties plays a major role, while at Tåstrup other factors contribute to the variability in evapotranspiration. Uneven growth – especially around the access tubes during the first part of the period – may account for a large part of the variability. Later in the season growth was satisfactory; at that time the water supply was sufficient.

A simple evapotranspiration model was introduced in an attempt to estimate the importance of variability in the soil physical properties on evapotranspiration. The model is described by Aslyng and Hansen (1982) and Hansen (1984). Crop is characterized by a crop surface area and an efficient root depth. Soil is characterized by plant available water (AWC), which in the simulations has been estimated as the soil water content between pF 2.0 and pF 4.2. The model operates with various reservoirs from which water is extracted. The most important equations and variables are given in Table 2. The top soil reservoir is part of the root

Table 1 – Results of short term water balance, mm, 1 cut

Precipitation	Potential Evapotransp.	Evapotranspiration μ	Evapotranspiration σ	Percolation μ	Percolation σ
Jyndevad					
34.7	111.9	76.0	5.5	4.8	2.6
Tåstrup					
54.1	158.6	92.1	6.0	0.0	–

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Table 2 – Main equations in the evapotranspiration model.

Crop area index

$C = C_m \min\{1, 0.1(e^{2.4t/T} - 1)\}$

Interception storage capacity

$S_i^* = 0.5C$

Root zone capacity

$S_r^* = \max\{S_t^*, \theta^* d_r\}$

Partition of pot. evapotranspiration

$E_S^* = E_p e^{-KC}$

$E_C^* = E_p(1 - e^{-KC})$

Soil evaporation

$$E_s = \begin{cases} E_s^* & S_t \geqq E_s^* \\ 0.15E_s^* & S_t < E_s^* \end{cases}$$

Evaporation of interception

$E_I = \min\{S_I, E_c^*\}$

Potential transpiration

$E_T^* = E_c^* - E_I$

Actual transpiration

$$E_T = \begin{cases} E_T^* & S_r \geqq \alpha S_r^* \\ E_T^* S_r/(\alpha S_r^*) & 0 < S_r < \alpha S_r^* \\ 0 & S_r \leqq 0 \end{cases}$$

C = *Crop area index*
C_m = *Maximum crop area index*
t = *Time from onset of growth*
T = *Time from onset of growth until C_m is reached*
S_i^* = *Interception storage capacity*
S_r^* = *Root zone capacity*
S_t^* = *Top soil capacity*
θ^* = *Plant available water content*
d_r = *Efficient root depth*
E_S^* = *Potential soil evaporation*
E_C^* = *Potential crop evapotranspiration*
E_p = *Potentiel evapotranspiration*
K = *Extinction coefficient*
E_s = *Soil evaporation*
S_t = *Top soil storage*
E_I = *Evaporation of interception*
S_I = *Interception storage*
E_T^* = *Potential transpiration*
E_T = *Actual transpiration*
S_r = *Soil water storage*
α = *Constant*

zone reservoir. Water in surplus of the capacity of the interception storage and the root zone storage capacity is transferred to a through-flow reservoir where the surplus remains for 3 days; and if not transpirated during that period it percolates out of the root zone. Specific calculation is performed when the root zone water storage has been exhausted and the soil is rewetted. Half of the supplied water is then evapotranspirated at a potential rate after which calculations again are performed in the normal manner.

The LAI and efficient root depth development used in the simulations are shown in Fig. 4. In addition, the observed LAI values are shown. Simulations were started on April 1 when the soil in its initial condition is assumed to be at field capacity and root zone storage to be equal to top soil capacity, which is set to 10 mm. Interception and through-flow reservoirs were assumed to be empty.

The α-value is set to 0.5. Sixteen simulations were performed for each test site corresponding to the AWC values obtained from the soil sampling.

In Fig. 5 the result of the simulations are shown as the average accumulated evapotranspiration and the average ±2 times the estimated standard deviation. At the end of the period the average simulated evapotranspiration was 79.7 and 92.5

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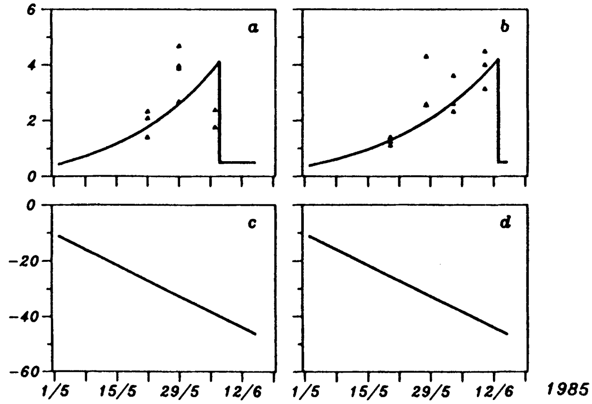

Fig. 4. Development of LAI and efficient root depth at Jyndevad, (a) and (c) respectively, and at Tåstrup, (b) and (d) respectively. Simulated: solid line, field experiment △.

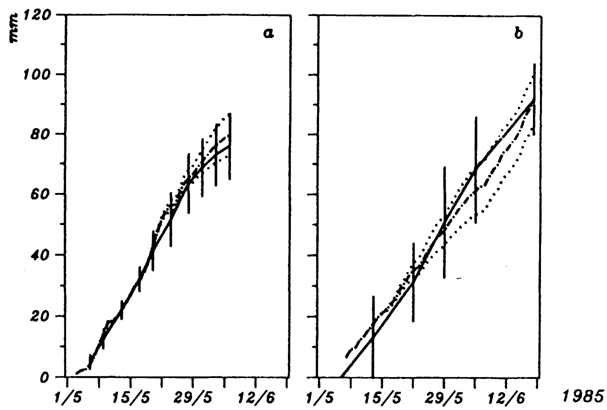

Fig. 5. Accumulated evapotranspiration at Jyndevad (a) and at Tåstrup (b). Estimated from short term water balance: average: solid line, ±2 times the standard deviation: bars. Simulated: average: dashdotted line, ±2 times the standard deviation: dotted lines.

mm, and the standard deviation was 3.5 mm and 4.2 mm at Jyndevad and Tåstrup, respectively. Simulations showed no percolation out of the root zone. The short term water balance showed slight percolation at Jyndevad and no percolation at Tåstrup (Table 1). Jyndevad simulations showed promising results as both the average and the standard deviation were of the right size. The standard deviation was less than that obtained from the short term water balance. This was expected because other factors than the AWC contribute to the variation, e.g. variations in the crop. In addition, the errors of measurement contribute. At Tåstrup the results of the simulations were not as satisfactory; this may, to a large degree be due to uneven growth during the first cut, reflected in the experimental data.

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Conclusion

An appreciable spatial variability in the soil water content was found within two different fields of contrasting soil types, viz. a coarse sand and a sandy loam. Introducing the soil water deficit using the soil water content at pF 2.0 obtained approximately 1 m apart from the soil water measurements did not reduce this variability; on the contrary, it increased it. This was attributed to an appreciable spatial variability in the soil physical properties within the range of 1 m.

Such a spatial variability makes it unrealistic to simulate temporal changes in soil water content at a given point, utilizing information about the soil physical properties obtained at a nearby point. It might be possible to simulate the observed variability pattern of the soil water content found within the field, utilizing information on the variability pattern found in the soil physical properties.

In this paper the variability pattern in the evapotranspiration found within the field was simulated with an acceptable result, using a simple evapotranspiration model and introducing the variability pattern observed in the available soil water content.

Acknowledgement

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