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# ACTUAL EVAPOTRANSPIRATION IN RELATION TO LEAF AREA

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The ratio of leaf area to ground area required for maintaining potential evaporation has been studied in a 4-year investigation, and the influence of leaf area index on the water use and the actual water balance is discussed.

The actual evapotranspiration from a land surface depends on the climatic conditions (evaporative demand) and the availability of water for evaporation. Evaporation from uncropped surfaces or from surfaces having limited leaf coverage will in most cases be less than evaporation from surfaces carrying a dense vegetation. This is especially true when soils containing much plant-available water are considered.

The ratio of leaf area to ground area (LAI) required for maintaining potential evaporation has not yet been established. Results from a 4-year investigation period regarding this question are presented in this paper. The influence of leaf area index upon the water use and the actual water balance is discussed.

## EXPERIMENTAL TECHNIQUE

The experiments were carried out at The Climate and Water Balance Station "Højbakkegaard" situated about 20 km west of Copenhagen, Denmark. The soil is a clay loam soil, containing 15–20 % clay (0–2 $\mu$m), 10–15 % silt (2–20 $\mu$m), about 70 % sand, and 2–3 % organic matter in the upper 20–25 cm soil layer. The field capacity of the soil is 25–30 volume per cent, and the plant available water amounts to 15–20 volume per cent. Plant roots penetrate down to 130–170 cm, depending on the species and treatment.

In the years 1969–1973, the experimental crops were barley, fodder sugar beets, and rye grass. Two rye grass plots were available except in 1971. One of these plots was cut every 1-2 weeks with a roto-mower, and resembled a grazing field (Grass S). The other one was cut at intervals of 4–6 weeks (Grass L). The cutting intervals were determined by the growth stage of the crops. All crops were fertilized as in common agricultural practice.

Each of the plots was 10 by 20 m in area. The soil water content was measured at two positions in each plot by the neutron scattering method. The topsoil water content was determined according to the function given by Kristensen (1973). Three aluminum access tubes extending to 150 cm depth were installed 1 m apart at each measuring position. Measurements were taken at 7- to 10-day intervals during the growing season at 10, 30, 50, ... 150 cm depths. The soil water content was calculated for 20 cm soil layers.

Simultaneous with the soil water measurement two sub-plots, each 2 by 2 m in area, were harvested on each crop-carrying plot. The total weight of green leaves was determined, and the specific leaf area was calculated by measuring the length and average width of a number of representative leaves, and their weight.

A short term water balance was made for all periods with soil water content less than field capacity. The actual evapotranspiration ($E_a$) was calculated from:

$$E_a = P + \triangle S,$$

where P is precipitation and $\triangle$ S is the change in soil water content for all soil layers having water content below field capacity. The precipitation was measured at the nearby climate station by rain gauges placed so that their 200 $cm^2$ collecting orifices were at ground level.

The actual evapotranspirations are compared with the potential ones ($E_p$) estimated according to Penman (Penman 1948, Aslyng 1965), and ($E_l$) measured from the water balance recorders described by Aslyng & Kristensen (1961).

## RESULTS AND DISCUSSION

The change in LAI with time during the growing season is illustrated in Fig. 1. No measurements of LAI was carried out in 1971, and none for grass in 1969 either. The LAI of short grass is assumed to be 1,0 and for long grass 0,5 just after cutting. The influence of the climatic conditions each year is reflected in

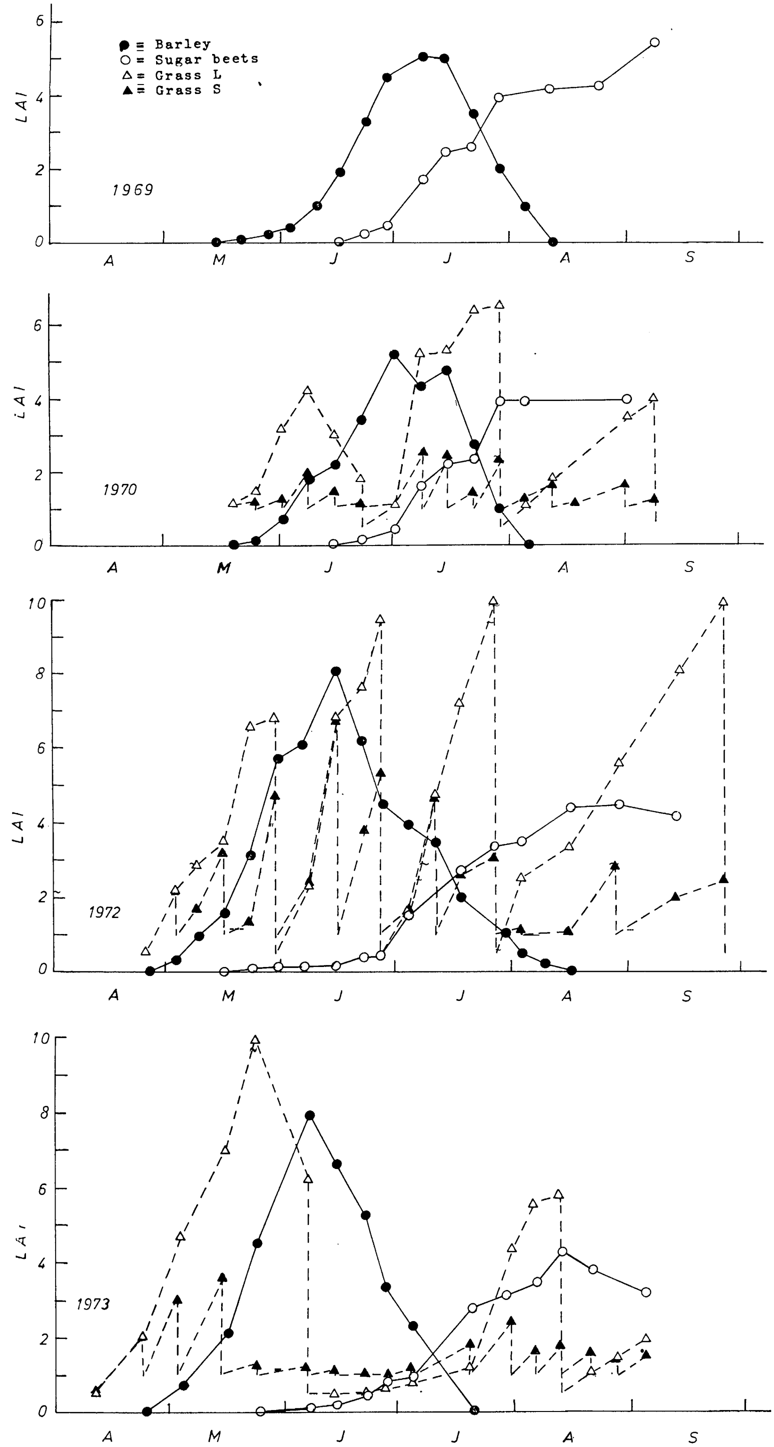


*Fig. 1.*
Variation in leaf area index (LAI) with time (1969–1973).

the LAI of the grass. A long dry period in May-June 1970 and June-July 1973 retarded the growth and regrowth of the grass, resulting in a very slow increase in LAI.

The difference in time of leaf coverage by barley and sugar beets is clearly demonstrated. In all the years the LAI for barley had passed its maximum value before the LAI for sugar beets has reached its maximum. This was especially pronounced in 1973, where the drought in June-July accelerated the decay of barley leaves, resulting in an active leaf area index of zero at about

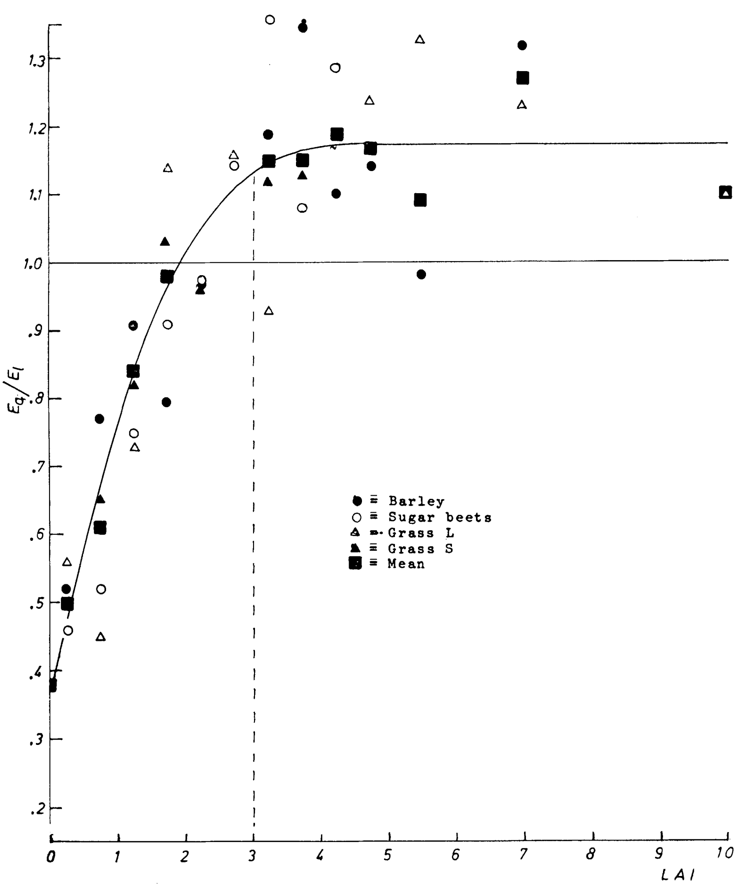


*Fig. 2.*

Ratios of actual to potential (water balance recorder) evapotranspiration as a function of the leaf area index (LAI).

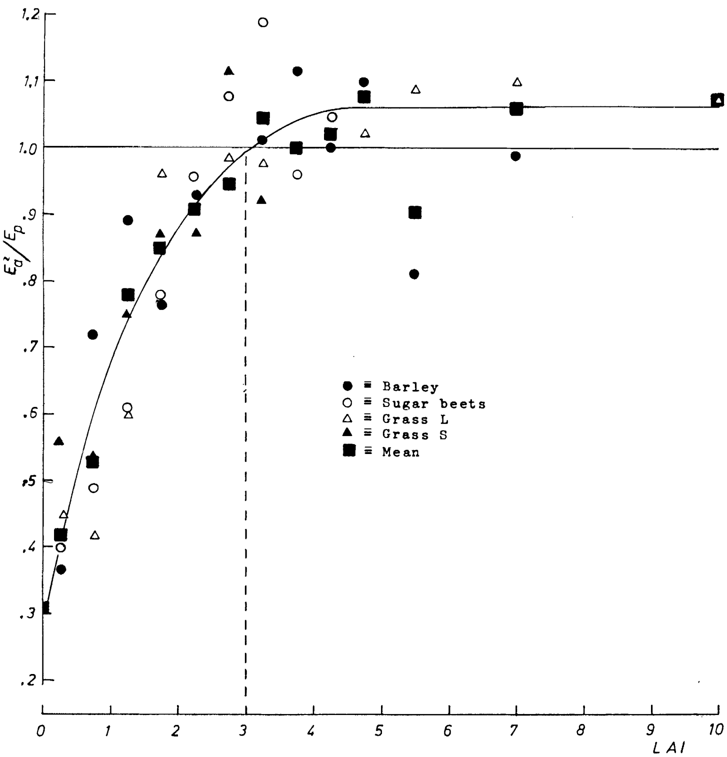


*Fig. 3.*

Ratios of actual to potential (Penman) evapotranspiration as a function of the leaf area index (LAI).

July 20, while in the moister year, 1972, green barley laeves persisted up to the middle of August.

The evapotranspiration from areas with different degrees of leaf covering depends also on the distribution of rainfall and the availability of the soil water. In periods with frequent showers, the evaporation from bare soil or from areas having limited leaf covering approaches that of areas with dense vegetation. During dry periods, on the other hand, evaporation from bare soil may approach zero, and the one from insufficient covered areas may be significantly less than the evapotranspiration from areas having sufficient leaf cover, if the latter is not lacking water.

An estimate of the influence of the leaf area index upon the actual evapotranspiration can, for the reasons mentioned, only be made for periods with no

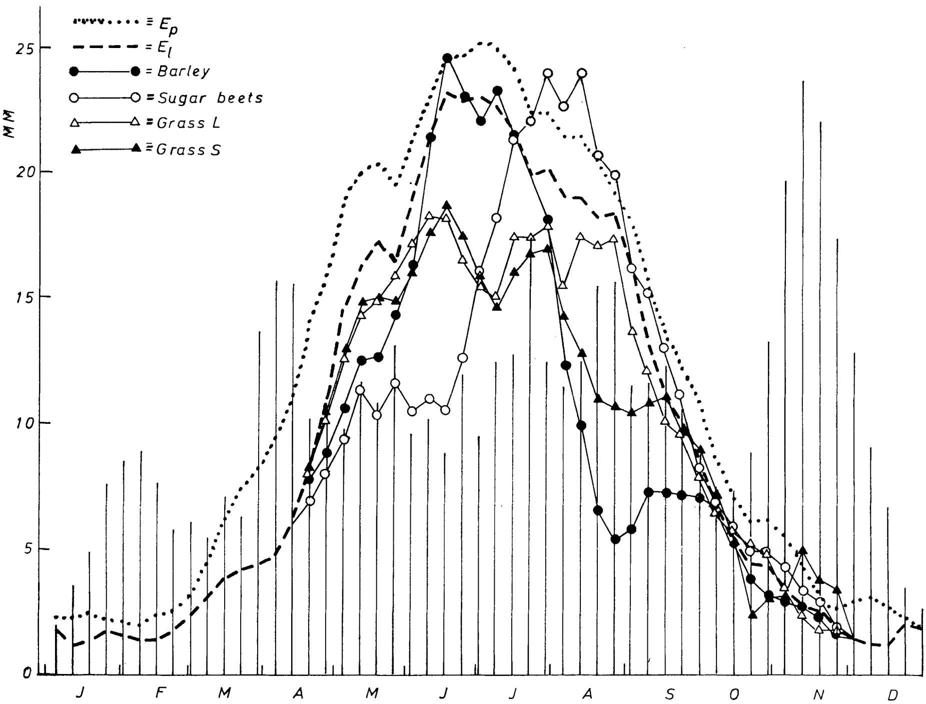


*Fig. 4.*
Averaged (5-year) weekly evapotranspiration (curves) and rainfall (vertical lines).

or little rainfall. The ratios of $E_a$ to $E_l$, where $E_a$ is the evapotranspiration from different vegetations, and $E_l$ the potential evapotranspiration from the water balance recorders, are shown as a function of LAI in Fig. 2. $E_l$ is measured from grass with ample water supply, as a maximum deficit of only about 30 mm was allowed. The age of the vegetation was at least 1 week, achieved by alternating the cutting of the two water balance recorders. The maximum $E_a$ from dense crops exceeds the $E_l$ by about 15 %, in spite of the precautions mentioned.

A similar presentation based on $E_p$ is given in Fig. 3. The calculated potential evapotranspiration is based on direct measurements of net radiation and soil heat flux (Aslyng 1965). The maximum $E_a$ apparently agrees better with the $E_p$ than with the $E_l$. The results presented in Figs. 2 and 3 indicate that a LAI of about 3 is sufficient (or necessary) for potential evapotranspiration. The crops and treatments involved apparently require about the same degree of leaf covering in order to give potential evapotranspiration.

In judging the results, an uncertainty in estimating $E_a$ must be recognized. This is due mainly to the natural variance of the radioactive source, which for the instrument and count rates employed is of the order of 3 mm (plus/minus) when the whole (0–160 cm) soil profile is considered. This, in connection with a possible lack of available water in periods with high evaporative demand, may account for the scatter of the results presented in Figs. 2 and 3.

The reduced leaf area in parts of the growing season (Fig. 1) may influence the actual evapotranspiration of the whole growing season, and thereby the actual water balance. The weekly evaporations and evapotranspirations are shown in Fig. 4. The points are 5-year averages smoothed out by calculating 3-week running averages.

The calculated potential evapotranspiration ($E_p$) is larger than the measured one ($E_l$) all the year round. The phase difference between barley and sugar beets is also demonstrated in Fig. 4. The evapotranspiration from these crops exceeds $E_l$ in periods with high LAI, and reaches or exceeds the $E_p$ also. The grass crops apparently were not able to maintain potential evapotranspiration except in the spring and autumn. Grass S evaporated considerably less than Grass L in the late summer. This is most likely due to shallower root systems and increasing soil water deficit, which retard regrowth and leaf formation more in the frequently cut vegetation than they do in the less frequently cut one.

Fig. 4 also shows the weekly precipitation (vertical lines). In the first part of the growing season, the evapotranspiration from areas with incomplete leaf cover (sugar beets) varies proportional to the rainfall, while in the late summer (barley) proportionality was not found. This difference may be explained by a more concentrated rainfall with intervening dry periods in the period last mentioned.

The influence of the crops investigated upon the total water balance may be judged from the figures given in Table 1. The actual evapotranspiration differs somewhat from one year to another. However, barley seems to be rather conservative, using about 350 mm in the 7-month period reported. In the same periods sugar beets evaporate about 375 mm. The figures for grass vary more, depending on the year's climate.

The largest difference in one single year is found in 1969, where the evapotranspiration from sugar beets exceeded the one from short grass by 101 mm, while in 1970 the largest difference was only 17 mm, in spite of a rather long (but early) dry period.

The results reported in Table 1 were obtained from crops growing in a soil with a rather high capacity for plant-available water. Therefore barley and sugar beets hardly suffered from lack of water under the climatic conditions which existed. Grass, on the other hand, even in this soil was enhanced by lack

*Table 1.*
Precipitation, potential, and actual evapotranspiration (mm) in the growing seasons 1969–1973.

| | 1969 Apr. 18-Nov. 13 | 1970 Apr. 14-Nov. 6 | 1971 Apr. 13-Nov. 10 | 1972 Apr. 21-Nov. 14 | 1973 Apr. 10-Nov. 8 |
|---|---|---|---|---|---|
| Precipitation | 358.5 | 414.2 | 318.6 | 378.4 | 371.7 |
| Potential ($E_p$) | 499.0 | 489.4 | 522.1 | 446.4 | 556.9 |
| Potential ($E_l$) | 464.2 | 438.4 | 455.4 | 377.6 | 462.1 |
| Actual (barley) | 353.3 | 353.2 | 355.9 | 338.1 | 380.4 |
| Actual (sugar beets) | 384.6 | 361.6 | 377.1 | 373.8 | 404.3 |
| Actual (grass L) | 352.3 | 370.6 | 351.9 | 390.4 | 370.5 |
| Actual (grass S) | 283.3 | 359.5 | – | 348.3 | 354.8 |

of water, especially when a prolonged dry period followed the cuttings. In soils containing less plant-available water, all plant species may lack water for shorter or longer periods of time, and their actual evapotranspiration may consequently be smaller and vary more than the values given in Table 1.

The figures for actual evapotranspiration reported in Table 1 agree well with results reported earlier for similar crops grown in similar soils and under similar climatic conditions (Aslyng & Kristensen 1953, 1958), although a less accurate method was employed in these investigations.

Regarding the total water balance for soils and climates similar to those of the experimental area, an actual evapotranspiration of about 350 mm may be expected from early spring (middle of April) to late autumn (middle of November). The evaporation in the remaining part of the year amounts to 30–50 mm, which yields a yearly evapotranspiration (actual) of 380–400 mm. Selecting the value for barley is reasonable, as more than 60 % of the agricultural area in Denmark is used for grain crops, more than 75 % of which is barley.

## CONCLUSIONS

The soil water content under barley, sugar beets, short grass and long grass was followed regularly during the growing seasons of 1969–1973, using the neutron scattering method. The soil water content was determined for 20 cm soil layers through a 0–160 cm soil profile. Periodic actual evaporation ($E_a$) was calculated from a simplified water balance equation. The potential evapotranspiration was measured directly ($E_l$), and estimated according to Penman ($E_p$). Ratios of actual to potential evapotranspiration are shown as functions of the leaf area index (LAI), measured simultaneously with the soil water measurements. The average weekly potential and actual evaporations are shown graphically together with the precipitation. The whole growing season evapotranspirations are summarized in a Table.

It is concluded that the leaf area index must exceed 3 in order to achieve potential evapotranspiration from a crop. As the maximum actual evapotranspiration exceeds the measured potential one ($E_l$), but not significantly the calculated one ($E_p$), the latter is considered to be the most realistic in the growing season. The actual evapotranspiration from barley (grain crops) and from sugar beets (root crops) is rather constant from one year to another, when these crops are grown in high water capacity soils under Danish climatic conditions. Once established, these crops hardly suffer from lack of water under the conditions mentioned, while vegetation such as grass (grazing or hay) often suffers from lack of water, especially if cutting is followed by a long dry period. Short grass (frequent cuttings) is therefore more sensitive to drought than long grass (less frequent cuttings).

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