LIMITATIONS AND PERSPECTIVES OF LYSIMETER RESEARCH

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SUMMARY

Most lysimeters have limitations. Imperfections may cause that the hydrological phenomena observed do not fully represent what occurs in nature. Some are: 1) discontinuity of the vegetation on the lysimeter and surrounding it, or a lack of vegetation around it; 2) heterogenity of the soil, possibly due to the small size of the lysimeter; 3) too great a difference between the waterregime in the lysimeter and in the surrounding area; 4) the being filled in, versus monolith.

The lack of weighing possibility is a limitation reducing the figures on evaporation to one a year. This shortcoming might be compensated for by installing electrical resistance units and thermistors for determination of water content in the lysimeters at any moment. Increase of the number of observation periods also results from the use of the natural drainage period, which is at least also applicable for grass on light soils.

The drainage-rainfall-formula for hydrological years, applied for concerning periods elsewhere, seems to be promising. An analytical, schematic approach on the base of evaporation formula, water book-keeping and soil and crop parameters, the latter connected with crop height, enables to compute actual evapotranspiration for periods of a month or shorter. This method has given satisfactory results. The lysimeters which satisfy certain requirements, can provide the necessary constants, thus enabling extrapolation of results to application elsewhere.

RESUMO

Multaj lizimetroj havas limigojn. Malperfektajoj kauzas ke la observataj hidrologiaj fenomenoj ne tute reprezentas tiujn kiuj okazas en la naturo. Kelkaj estas: 1) interrompiteco de la vegetacio sur kaj cirkau la lizimetro au manko de cirkauanta vegetacio; 2) malhomogeneco de la grundo, eble sekve de malgrandaj mezuroj de la lizimetro; 3) tro granda diferenco inter la akvoregimo en la lizimetro kaj tiu de la ekstera tereno; 4) la disfositeco de la grundo.

La manko de peseblo estas limigo kiu reduktas la nombron de ciferoj pri elvaporigo al unu jâre.

La lasta manko estas kompensebla kiam oni instalas elektrajn rezisto-elementojn kaj termistrojn por determini la akvoenhavon en la lizimetroj je ciu ajn momento. Plinombrigon de la observperiodoj oni povas atingi ankau per aplikado de la metodo de naturaj drenperiodoj, kiu almenau estas aplikebla ankau ce greso sur sablaj grundoj.

Aplikado de la drenakvo-pluvakvo-formulo pri hidrologiaj jaroj por aliaj lokoj estas promesa. Analiza, skema metodo surbaze de la elvaporig-formulo, akvolibrotenado kaj grund- kaj plantar-parametroj (la lastaj rilatigitaj al la alteco de la plantaro), ebligas kalkuli la efektivan elvaporigon en periodoj de unu monato au pli mallongaj. Tiu ci metodo donis kontentigajn rezultojn. La lizimetroj kiuj kontentigas certajn postulojn, povas liveri la necesajn parametrojn, tiel ebligante ekstrapoladon de rezultoj al aliaj lokoj.

1. INTRODUCTION

Most lysimeters have limitations. These are of to two kinds. The first is a number of imperfections which cause the hydrological and even agricultural phenomena to be not fully representative of what occurs in the field, for example the lack of a surrounding crop, absence of a watertable, too small a size, etc. Some of them can be avoided.

The second kind of limitation concerns the absence of weighing possibilities, which implies that generally only one correct yearly figure on evaporation can be obtained. This concerns the hydrological year, beginning and ending at a time, when the soil may be supposed to have the same moisture content. In the Netherlands we take the cycle March 1st-February 28th or April 1st-March 31st.

2. Limitations

Discontinuity of vegetation

If the surface of the lysimeters—cropped or bare—is not continuous with the surrounding area, evaporation is influenced by border effects, which will cause an error which can be considerable with small lysimeters. Since radiation is considered to be the most important factor controlling evaporation, directly or indirectly, a partly or totally lacking of a vegetation will lead to overestimated values.

For the lysimeters at Wageningen I calculated the extra radiation the grass cover received due to the circular flange and pitwall (together 16 cm wide) (Makkink 1957 a). This border caused a gaplike interruption in the vegetation of the lysimeters and the surrounding grass. The grass was supposed to stand upright.

period 1953	grass length, cm	extra radiation %
24/4 — 2/5	8.5	14
22/5 —30/5	13	17
19/6 —27/6	8	10
17/7 —25/7	11	16
14/8 —22/8	8	14
11/9 —19/9	7	16
8/10—16/10	6	18

If the grass would hang over the gap equally on both sides, the lysimeter would receive 30.5 % extra radiation. The extra radiation can lead to corresponding extra evapotranspiration.

Heterogenity of the soil

Another limitation inherent to the small size of most lysimeters is the heterogenity of the soil. Three of the lysimeters at Wageningen (sand, clay and peat) have been provided with a concentric steel rim inside the bottom piece, placed in such a way that the area inside the rim was equal to the area outside it. Observation showed that drainage as well as infiltration from below were very different in the central and peripheral halves. Some-

soil type	number	K-value m/24 h			
		min.	average (1)	max.	extreme values
sand	8	0.06 —	0.16 —	0.35	—
peat	12	0.26 —	0.52 —	0.74	(1.52, 4.10)
clay	12	< 0.01 —	0.38 —	1.14	(2.41, 2.70, 2.72, 3.10)

times the central part had a higher quantity of drainage than the peripheral part, but in another period the reverse occured. No regularity could be detected. Perhaps the distribution of cracks, rootholes and wormholes determined the phenomenon.

Heterogenity of the soil was also found between the lysimeters filled with monoliths of the same parcel. A determination of the permeability (K-value) of the soil in the 32 lysimeters at Wageningen in wintertime showed very divergent values for each soil type, notwithstanding the fact that the monoliths were taken a few meters from each other on the same field.

Deviating waterregime

Another limitation can be due to the fact that the waterregime of a lysimeter is not the same as that of the surroundings. Then evapotranspiration will also differ. To obtain representative values for the actual evapotranspiration of a certain area, the availability of water within the lysimeter should be about the same as that without.

Many lysimeters have no water table and have a modest depth. Since the drainwater flows out when the critical hydrostatic pressure surpasses the surface tension of the water in the soil pores, the drainage in an interrupted soil column will occur at a higher moisture content than in a column in situ, where a negative suction is present at the concerning depth (Colman, 1946). Crop yield and consumption of minerals can be considerably increased in comparison with lysimeters in which the correct soil suction is imitated (Wallihan 1940). In lysimeters with a naturally regulated water table this problem does not exist. Lysimeters with free drainage should be so deep that the roots do not reach the zone with abnormal water conditions.

If a moist water regime prevails in a lysimeter and a dry one in the surroundings, there is not only a difference in evapotranspiration due to the different water conditions in the soil, but the evapotranspiration from the lysimeter is also increased according to the advective heat from the surrounding dry area (Penman 1956). If in such a situation the potential evapotranspiration of the lysimeter is calculated with Penman's formula, the result will be below the observed value, because the formula does not account for advective heat (Makkink 1957b).

Disturbed soil

A much discussed limitation is caused by the filling in of the soil into the lysimeter. From a comparison of the structure of the dune sand in the

(1) without extreme values.

lysimeters at Castricum and of the not disturbed soil outside it, there was a smaller variety of pore space categories in the disturbed soil than in the undisturbed soil (Peerlkamp 1948). After 10 years the difference seemed to have become smaller (Wind, being printed).

Since the wider pores are responsible for faster percolation and for better aeration, a difference in structure will influence the conditions of crops and soil life and, therefore, may cause a difference in evaporation. No observations are made on the magnitude of such a difference.

3. Amplification and better utilization

To increase the number of data on evaporation for lysimeters which cannot be weighed there are two ways.

Moisture determinations

Measurements of soil moisture in the successive layers of the soil in the lysimeter can regularly be made by installing electric resistance units and thermistors or by making use of the newly developed method with gamma rays.

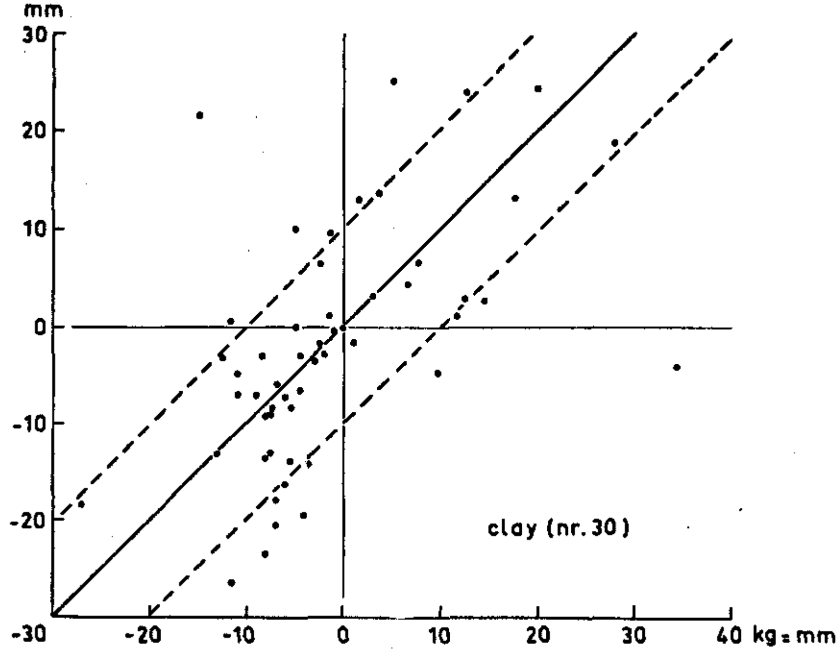

Fig. 1 Changes of water content electrically measured (ordinate) plotted against changes in weight (abscissa) with lysimeter nr. 30 (clay) at Wageningen in 1956. Measurements mostly twice a week.
Sangigoj de la akvoenhavo, elektre determinita (ordinato) metita kontrau sangigoj de la pezo (absciso) ce lizimetro n-ro 30 (argilo) apud Wageningen en 1956. Determinoj kutime du fojojn en semajno.

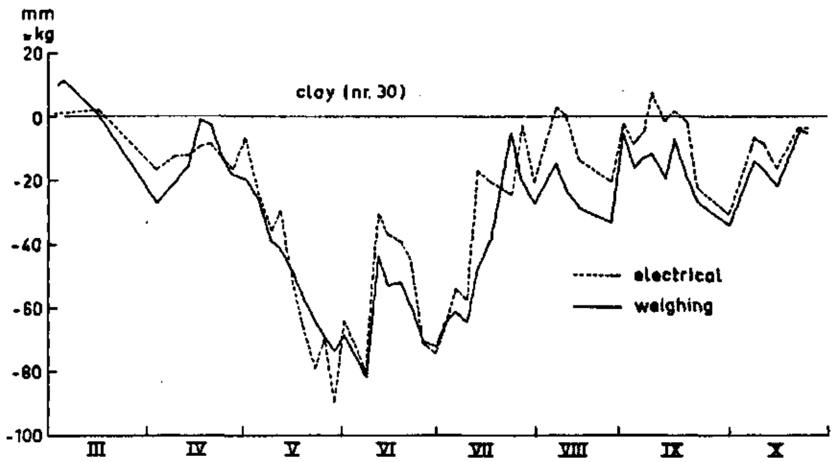

Fig. 2 Differences of water content (electrically measured) and of weight since January 17th throughout 1956 with lysimeter nr. 30 (clay) at Wageningen.
Diferencoj de la akvoenhavo (elektre determinita) kaj de la pezo depost la 17-a de januaro 1956 ce lizimetro n-ro 30 (argilo) apud Wageningen.

In a number of lysimeters at Wageningen one set of nylon resistance units and thermistors were installed throughout the profile. Measurements of the electric resistance twice a week, reversed to changes in moisture content, made a comparison possible with the changes of weight of the lysimeters in the corresponding periods. The data showed a considerable scattering, when plotted one against the other (Fig. 1). This can be due to the inaccuracy of the electric method, to hysteresis or to inhomogeneousness of the soil block. The time curve of a lysimeter with a clay soil shows that after the summer dryness there is a systematic discrepancy, which grows smaller towards winter (Fig. 2). It seems that with rewetting of the clay the electrical resistance suggests a higher moisture content than there is really present. This may be due to a phenomenon like hysteresis. For the time being this method cannot replace weighing.

Natural drainage periods

Penman and Schofield (1941) introduced for the fallow soil in the lysimeters at Rothamsted the "natural drainage period", being the period between two successive moments when drainage stops. For this period E = R—D if the rainfall (R) is taken according to the quantities which made drainage (D) cease (not at the same moments the latter occurs). Those periods are determined by nature, not by the investigator.

For cropped lysimeters with a rather extended root zone, it is difficult to state which quantities of rain were the last that maintained drainage. For a number of lysimeters with a constant water table at —50 cm or —70 cm (all with grass) it was investigated whether E, calculated from the waterbalance sheet of the natural drainage periods was equal to E based on weighings.

Or in other words whether there was no change of weight in natural drainage periods.

For a sandy soil (Fig. 3) the scattering is rather small, for peat soil, however, greater and for clay soil (Fig. 4) considerable. The length of the periods with sand was 9—33 days (average 18), with peat soil 15—55 days (average 32), and with clay soil 15—110 days (average 34). The natural drainage period method, therefore, merits further application for light soils with a constant water table and perhaps also with a naturally changing water table and with free drainage. Those periods must not be too short.

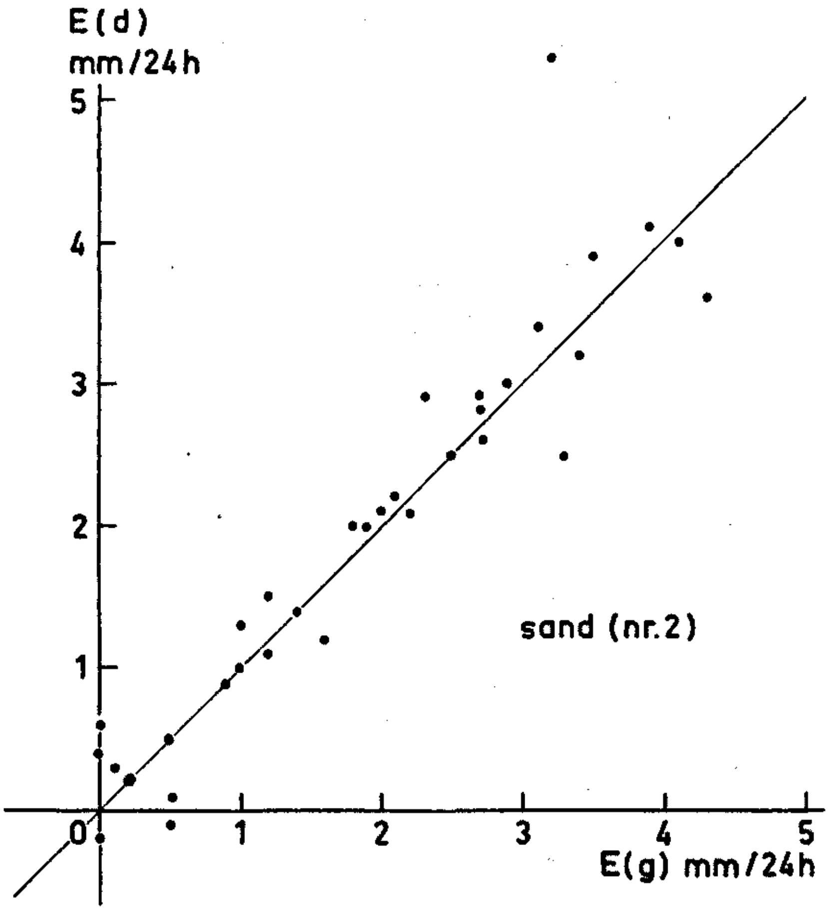

Fig. 3 Evapotranspiration per day of grass on lysimeter nr. 2 (sand) with a constant water table at -50 cm at Wageningen in 1952 and 1953. Values according to the waterbalance sheet of natural drainage periods (ordinate E (d)) plotted against values according to weighings (abscissa E (g)).

Evapotranspiro po tago el greso sur lizimetro n-ro 2 kun konstanta akvonivelo je -50 cm apud Wageningen en 1952 kaj 1953. Valoroj el la akvobilanco pri naturaj drenperiodoj (ordinato E (d)) metitaj kontrau valoroj el pezadoj (absciso E (g)).

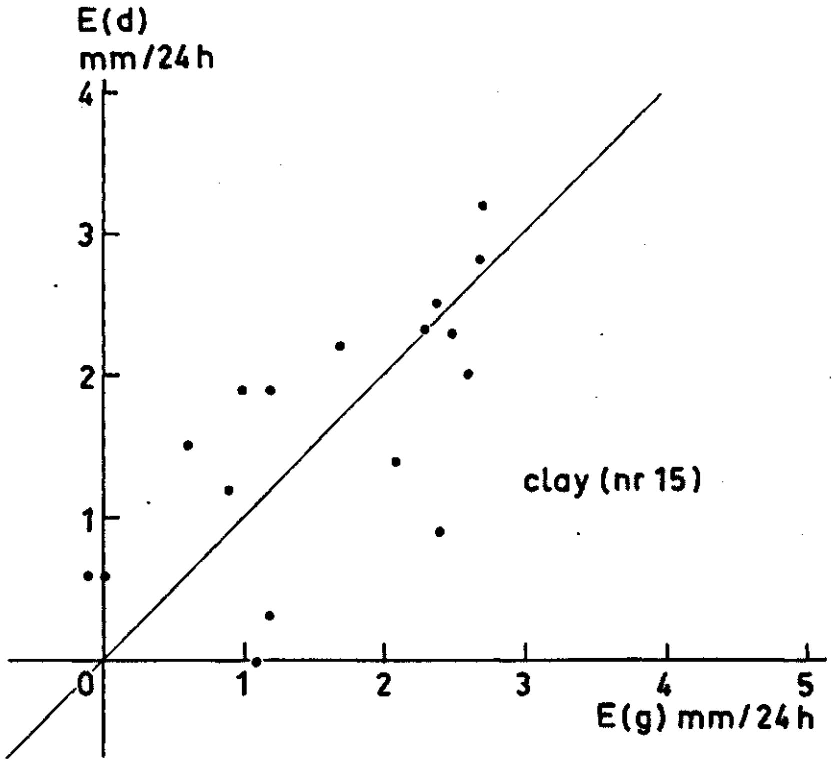

Fig. 4 As figure 3 for lysimeter nr. 15 (clay) with a constant water table at -70 cm; Wageningen 1952 and 1953.
Kiel figuro 3 pri lizimetro n-ro 15 (argilo) kun konstanta akvonivelo je -70 cm; Wageningen 1952 kaj 1953.

4. Perspectives

Emperical extrapolation to field conditions

In the other paper given in this symposium I quoted Winds application of the lysimeter-formula of hydrologic years to areas with the same or a similar vegetation.

This procedure has led to promising results and therefore deserves wider application.

Analytical extrapolation to field conditions

Another procedure of extrapolation can be developed on an analytical basis. It enables calculation of actual evapotranspiration in periods of a month or shorter. With this method the year cyclus is divided into short periods (pentades or days, according to expected errors). For each period the evapotranspiration is either potential (E_P) or sub-potential (E_R), depending on the amount of available water (A). In a formula:

$$E = E_P \mid (E_P \leqq A) \quad (1a)$$

$$E = E_R \mid (E_P > A) \quad (1b)$$

For a longer period, for example a month, the summarized formula is then:

$$\Sigma E = \Sigma E_P \mid (E_P \leqq A) + \Sigma E_R \mid (E_P > A) \quad (2)$$

A fallow soil and a dense crop may be considered as special cases of a soil that looses its water to the atmosphere due to both evaporation and transpiration. In the case of potential waterloss, therefore

$$E_P = E_Z + E_X \quad (3)$$

if the index Z concerns potential evaporation from bare soil and X potential transpiration from any kind of crop.

For a short and dense grass cover, optimally provided with water, the potential waterloss (E_p, index minuscule) can easily be calculated according to Penman (1956) or to Makkink (1957b). To relate E_Z and E_X to E_p a factor g_X resp. g_Z is added, the value of which depends on the degree of bareness of the soil resp. the height or the density of the crop. Thus:

$$E_Z = g_Z E_p, \quad (4a)$$

$$E_X = g_X E_p \quad (4b)$$

and for a partly covered soil, therefore,

$$E_P = (g_Z + g_X) E_p \quad (5)$$

When the evapotranspiration is sub-potential the available water limits water loss to the atmosphere. In this case the water loss can comprise the rain (R), the actual amount of water in the root zone or in the upper layer from which evaporation occurs (w_r) and the amount of water which is reached by root growth during the short period ($\triangle w_{vX}$, v indicates that the soil is at maximum field tension). w_r cannot exceed w_{vZ} for bare soil or w_{vX} of cropped soil.

$$E_R = R + w_r + \triangle w_{vX} \quad (6)$$

From (2), (5) and (6) we obtain the general formula:

$$\Sigma E + \Sigma(g_Z + g_X) E_p \mid (E_P \leqq A) + \Sigma(R + w_r + \triangle w_{vX}) \mid E_P > A) \quad (7)$$

It is possible to distinguish five periods:

1) a period between ploughing and the appearance of the crop (period with fallow soil)
2) a period between the appearance of the crop and the moment the crop is equivalent to a dense, short grass cover ($g_X = 1$); period with more or less covered soil
3) a period when the soil is "completely covered" with a green crop ($g_X > 1$)
4) a period between ripening and harvest when the crop is yellowing and drying)
5) a period between harvest and ploughing; soil fallow with remainings of the crop on and in the soil.

In period 1 $g_X = O$ and $\triangle w_{vX} = O$ in the equation (7). Since a wet soil evaporates according to E_o,

$$g_Z = E_o / E_p \quad (8)$$

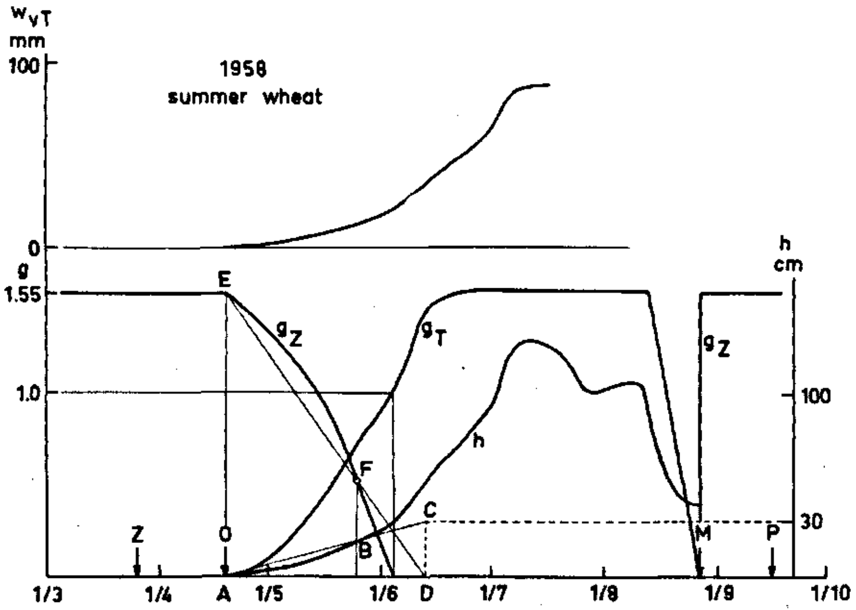

Fig. 5 Above: curve of w_v for wheat (T) against time. Below: curves of g for wheat (T) and fallow soil (Z) and of height (h) of wheat against time. Arrows at the bottom point to dates of sowing (Z), appearance (O), mowing (M) and ploughing (P). Lysimeters Rottegatspolder in 1958.
Supre: kurbo pri w_v de tritiko (T) kontrau la tempo. Malsupre: kurboj pri g de tritiko (T) kaj de nuda tero (Z) kaj de la alto (h) de la tritiko kontrau la tempo. La sagoj ce la bazo montras al datoj de semado (Z), de elterigo (O), de falcado (M) kaj de plugado (P). Lizimetroj en Rottegatspolder en 1958.

E_o representing the evaporation from a free water surface. In period 2 equation (7) works fully. In periods 3 and 4 in the equation (7) g_{pZ} is O. In period 5 g_X is O, but w_{vX} has a value between w_{vZ} (of bare soil) and w_{vX} of the crop at the moment of harvest, because the roots are still present and are able to transport water from deeper layers to the upper evaporation layer.

There have been made a few assumptions in order to run a water bookkeeping:

1) no rain water percolates through cracks and holes out of reach;
2) all water till pF 4.2 evaporates with the same ease;
3) w_{vZ} is provisionally considered to be a constant soil factor;
4) w_{vX} is supposed to be proportional to the height of the crop at every moment;
5) g_X is increasing with height of the crop but approaches a limit;
6) g_X decreases rectilinear with time during ripening;
7) when $g_X = 1$, g_Z is considered to be O;
8) g_Z gradually decreases with increase of g_X;
9) capillary rise is not taken into consideration because the water table can be supposed to be at a considerable depth.

There are a number of factors which change with time w^r, w_{vX}, g_X and g_Z.

w_r must be found in continually bookkeeping of the water content of the soil, starting at the end of the winter. For the relation of w_{vX}, g_X and g_Z with time, curves must be drawn (Fig. 5). In order to obtain those the assumption was made, that g_X and w_{vX} depend on the height of the crop. This magnitude, being simple, can easily and regularly be measured. In first approximation w_{vX} relates rectilinearly with height, g_X curvilinearly (Fig. 6). Therefore we need only one determination of evapotranspiration by means of a conventional method (V) to obtain w_{vX}; for g_X we need at least two such determinations.

w_{vX} can be determined with equation (6) if we select a period with a limited amount of available water since the beginning of growth. Then $\Sigma E_R = V = \Sigma(R + w_r + \triangle w_{vX})$, in which $w_r + \triangle w_{vX} = w_{vX}$, and this can be calculated. g_X can be determined with equation (4b):

$$\Sigma E_p = V = \Sigma g_X E_p$$

For this two periods without soil evaporation and an abundant amount of water will suffice. The course of g_Z with time can now graphically be found, recognizing that at the moment of appearance of the crop

$$g_Z = E_o / E_p \qquad (8)$$

and that at the moment $g_X = 1$ (see time curve of g_X) the vegetation is equivalent to a dense short grass cover, so that g_Z may be considered to be O.

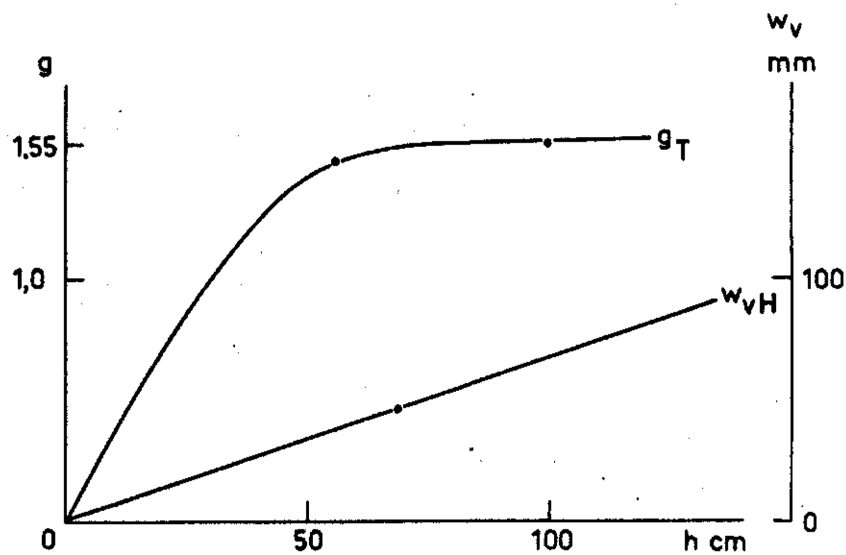

Fig. 6 Curves of g against height (h) for wheat (T) and of w_v against height (h) for oats (H). The dots represent observed values. Lysimeters Rottegatspolder.

Kurboj de g kontrau la alto (h) ce tritiko (T) kaj de w_v kontrau la alto (h) ce aveno (H). La punktoj prezentas observitajn valorojn. Lizimetroj Rottegatspolder.

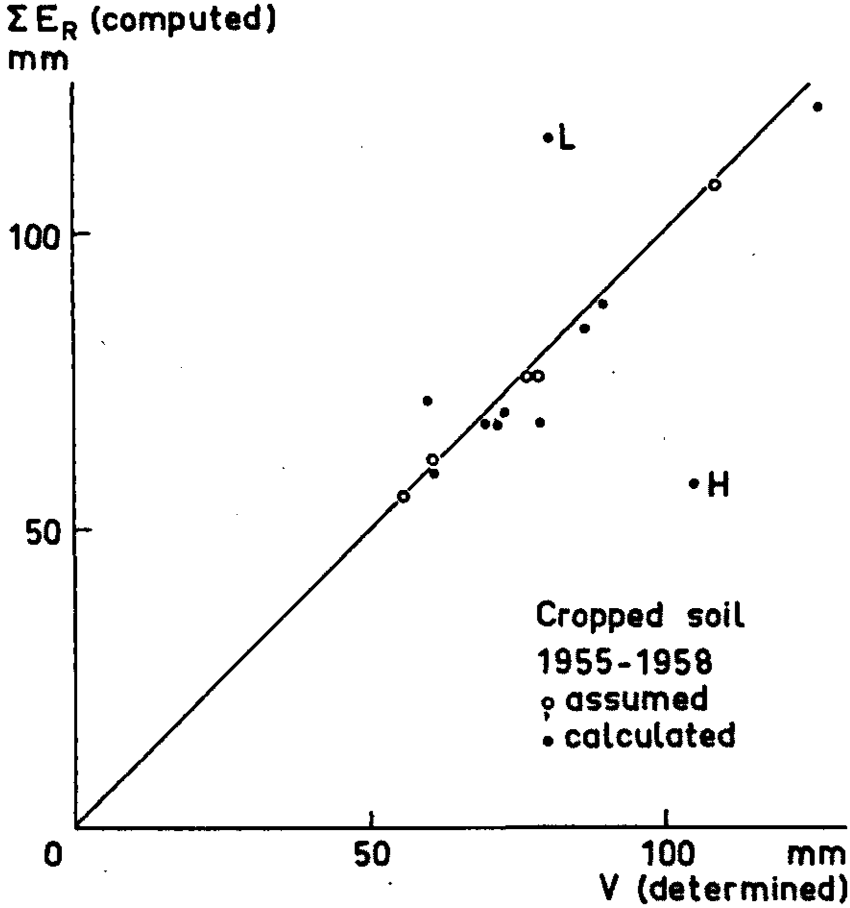

Fig. 7 Actual evapotranspiration of cropped soil in monthly periods en 1955-1958 incl.; lysimeters Rottegatspolder. Computed values (ΣE_R) plotted against observed values (V). Assumed values according to observation: o. L.: lodging of wheat; H: oats, when no capillary rise of water or root growth after growth stop of top is supposed.

Efektiva evapotranspiro el plantita tero en monataj periodoj en 1955-1958 inkl.; lizimetroj Rottegatspolder. Kalkulitaj valoroj (ΣE_R) metitaj kontrau observitaj valoroj (V). Valoroj adaptitaj al la observoj: o. L: ekkuso de tritiko; H: aveno, se oni ne supozas kapilaran akvolevigon au plukreskon de la radikaro post ceso de la kresko de la tigo.

Finally w_{vZ} can be determined with (6) from one dry period with bare soil after ploughing. This highly schematic model was checked for the drainage lysimeters in the Rottegatspolder, where the actual evapotranspiration V was already determined for periods of about a month.

For wheat the relationship of w_{vX} with height of oats was used, for oats the relationship of g_X with height of wheat was used. E_p was calculated according to Makkink (1957b).

For the cropped periods data of 4 years with wheat or oats were at the disposal (Fig. 7), for the fallow periods date of 7 years (Fig. 8).

Of the 16 periods with a cropped soil (Fig. 7) 5 were used to determine the necessary parameters. Of the other 11 dots two deviate largely. The higher one concerns a wheat crop lodging after heavy rains; the lower one concernes oats in a very dry period. In this latter case capillary transport within the soil block or root growth during ripening can explain the deviation.

The fallow periods show greater scattering (Fig. 6). This is partly due to snow and ice (crosses) influencing the checking values more than the

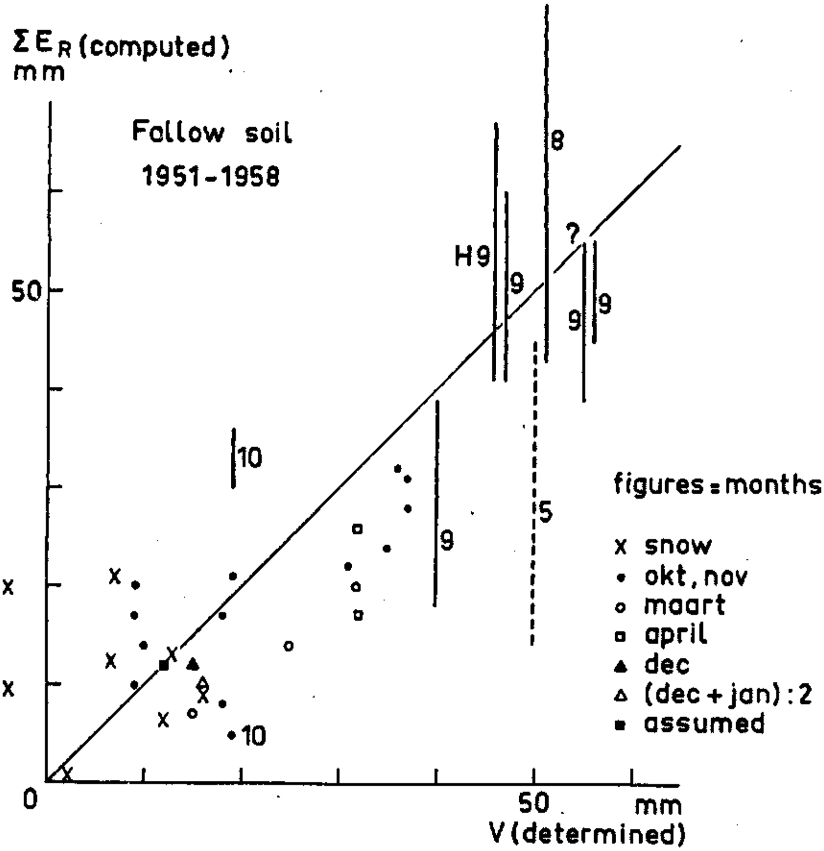

Fig. 8 Actual evaporation of fallow soil in monthly periods in 1951-1958 incl.; lysimeters Rottegatspolder. Computed values (ΣE_R) plotted against observed values (V). Vertical lines connect values obtained with or without supposing water conduction by the roots of the stubble ?:higher value uncertain.

Efektiva elvaporigo el nuda tero en monataj periodoj en 1951-1958 inkl.; lizimetroj Rottegatspolder. Kalkulitaj valoroj (ΣE_R) metitaj kontrau observitaj valoroj (V). Vertikalaj linioj konektas valorojn akiritajn kun au sen la supozo ke la radikaro de la stoplo kondukas akvon. ?: plej alta valoro necerta.

computed ones. Partly due to the uncertainty how to evaluate numerically the influence of remainings of roots after harvest, the results are depicted with vertical lines. Another problem is how to handle periods in winter in which vapour transport, due to a gradient of soil temperature, is likely.

This analytical approach seems promising. Therefore all lysimeters where a waterbalance sheet for short periods can be obtained, should be used to provide the soil and crop parameters for the computed water book-keeping. Even in its first rough, approximative version, this method will enable to differentiate the yearly value R-D of not weighable lysimeters into values for smaller periods. It will also enable to compute actual evaporation anywhere for those crops and soils, of which the necessary parameters have been once for all determined.

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