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) heterogeneity 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) interrompita vegetacio sur kaj kirkau la lizimetro au manko de cirkauanta vegetacio; 2) malhomogeneco de la grundo, ebie sekve de malgrandaj mezuroj de la lizimetro; 3) tro granda diferenca inter la akvovemiso en la lizimetro kaj tiu de la ekstera tereno; 4) la disfosteco de la grundo.

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

La lasta manko estas kompensebla kiam oni instalas elektrajn rezistec- elementojn kaj termistron por determini la akvovemhon en la lizimetro 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 plantaro-parametroj (la lastaj rilatigitaj al la alteco de la plantaroj), ebligas kalkuli la efektivan elvaporigon en periodoj de unu monato al pli mallongaj. Tiu ci metodo donis kontentigan rezulto a.

La lizimetroj kiuj kontentigas certajn postulojn, povas liberi 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 1957a). This border caused a gaplike interruption in the vegetation of the lysimeters and the surrounding grass. The grass was supposed to stand upright.

<table>
<thead>
<tr>
<th>period 1953</th>
<th>grass length, cm</th>
<th>extra radiation %</th>
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<tbody>
<tr>
<td>24/4 — 2/5</td>
<td>8.5</td>
<td>14</td>
</tr>
<tr>
<td>22/5 — 30/5</td>
<td>13</td>
<td>17</td>
</tr>
<tr>
<td>19/6 — 27/6</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>17/7 — 25/7</td>
<td>11</td>
<td>16</td>
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<tr>
<td>14/8 — 22/8</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>11/9 — 19/9</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>8/10—16/10</td>
<td>6</td>
<td>18</td>
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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.

Heterogeneity of the soil

Another limitation inherent to the small size of most lysimeters is the heterogeneity 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
<table>
<thead>
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<tbody>
<tr>
<td></td>
<td>min.</td>
<td>average (1)</td>
</tr>
<tr>
<td>sand</td>
<td>8</td>
<td>0.06 — 0.16</td>
</tr>
<tr>
<td>peat</td>
<td>12</td>
<td>0.26 — 0.52</td>
</tr>
<tr>
<td>clay</td>
<td>12</td>
<td>&lt;0.01 — 0.38</td>
</tr>
</tbody>
</table>

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

Heterogeneity 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 water regime**

Another limitation can be due to the fact that the water regime 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.

![Graph of water content vs. weight for clay lysimeter](image)

**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.
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 inhomogeneity 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 \(-50 \text{ cm} \) or \(-70 \text{ cm} \) (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)).
4. PERSPECTIVES

Empirical extrapolation to field conditions

In the other paper given in this symposium I quoted W. Ind's 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 cycle 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:
\[ E = E_p \mid (E_p \leq A) \] (1a)
\[ E = E_R \mid (E_p > A) \] (1b)

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

\[ \Sigma E = \Sigma E_p \mid (E_p \leq A) + \Sigma E_R \mid (E_p > A) \] (2)

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

\[ E_p = E_Z + E_X \] (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 water loss \( E_p \) (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:

\[ E_Z = g_Z E_p \] (4a)
\[ E_X = g_X E_p \] (4b)

and for a partly covered soil, therefore,

\[ E_p = (g_Z + g_X) E_p \] (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 \( \Delta w_vX \), \( v \) indicates that the soil is at maximum field tension. \( w_r \) cannot exceed \( w_vZ \) for bare soil or \( w_vX \) of cropped soil.

\[ E_R = R + w_r + \Delta w_vX \] (6)

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

\[ \Sigma E + \Sigma (g_Z + g_X) E_p \mid (E_p \leq A) + \Sigma (R + w_r + \Delta w_vX) \mid E_p > A \] (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 \( g_X = 0 \) and \( \Delta w_vX = 0 \) in the equation (7). Since a wet soil evaporates according to \( E_0 \),

\[ g_Z = E_0 / E_p \] (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.

$E_o$ 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 0. In period 5 $g_X$ is 0, 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 0;
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 \( \omega, \omega_x, g_X \) and \( g_Z \).

\( \omega_x \) must be found in continually bookkeeping of the water content of the soil, starting at the end of the winter. For the relation of \( \omega_x, g_X \) and \( g_Z \) with time, curves must be drawn (Fig. 5). In order to obtain those the assumption was made, that \( g_X \) and \( \omega_x \) depend on the height of the crop. This magnitude, being simple, can easily and regularly be measured. In first approximation \( \omega_x \) 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 \( \omega_x \); for \( g_X \) we need at least two such determinations.

\( \omega_x \) can be determined with equation (6) if we select a period with a limited amount of available water since the beginning of growth. Then

\[
\sum E_R = V = \sum (R_t + \omega_x + \Delta \omega_x),
\]

in which \( R_t + \Delta \omega_x = \omega_x \), and this can be calculated. \( g_X \) can be determined with equation (4b):

\[
\sum E_p = V = \sum g_X E_p
\]

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

\[
g_Z = E_a / E_p \tag{8}
\]

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 0.

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**Fig. 6** Curves of \( g \) against height (h) for wheat (T) and of \( \omega_x \) 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 \( \omega_x \) kontrau la alto (h) ce aveno (H). La punktoj prezentas observitajn valorojn. Lizimetroj Rottegatspolder.
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 concerns 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

![Graph](image)

**Fig. 8** Actual evaporation of fallow soil in monthly periods in 1951-1958 incl.; lysimeters Rottegatspolder. Computed values ($\Sigma E_R$) 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.

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.

**LITERATURE**