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Instituut voor Cultuurtechniek en Waterhuishouding
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EVAPOTRANSPIRATION FROM POTATOES

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CONTENTS

INTRODUCTION

Evapotranspiration from cropped surfaces is governed not only by the meteorological conditions, but also by factors related to the crop itself and to the soil physical conditions. In irrigation practice, as well as in many hydrological investigations, it is very important to determine the actual as well as the potential water use of a crop from meteorological data. Particularly for arable crops the practical application is still partly a matter of speculation, since a number of aspects are still more or less unknown.

During a number of years sprinkling irrigation experiments with potatoes were performed at the experimental farm of the Institute. The set up of these experiments was not primarily for transpiration research, but to obtain information on the increase in yield due to sprinkling. The available data of soil moisture conditions and crop development were given in a number of internal reports of the Institute.

The recent developments in transpiration research made it valuable to use the data from these sprinkling experiments in a study of the effects of crop development and of moisture conditions on the water use by potatoes.

AVAILABLE DATA

Soil type and soil moisture data

The experiments were performed on a coarse sandy soil with an humus content of 6% in the top layer of 30 cm, the mean humus content of the layer from 30 - 60 cm was 2.5 - 3.0%. The available amount of soil moisture in the top layer of 1 m was 100 mm. About 72 mm is available from the humous top layer of 40 cm. The coarse sand with gravel in the layers below 60 cm do not contribute very much to the total amount of available water. The soil moisture characteristics of the various layers are given in fig. 1. The effective rootzone of the potato crop is in fact restricted to the humous top layer of 40 cm.

During the sprinkling experiments the soil moisture content in the various layers was determined periodically by soil sampling. In most

cases the soil samples were taken from the layers 0 - 20 cm, 20 - 40 cm and 40 - 60 cm. In a few cases also data from the 60 - 80 cm layer were present, but these data did hardly show any variation in moisture content with time. For this reason the change in water content of the profile was in most cases calculated for the top 60 cm.

In 1964 most of the soil sampling data concern only the top layer of 0 - 20 cm. In order to obtain information concerning the mean moisture content in the effective rootzone of the crop and to obtain data of the change in soil moisture in the profile the relations shown in fig. 2 were used to derive from the top layer of 20 cm the required data.

The absence of soil moisture data from the deeper layers will give an overestimate of evapotranspiration using the water balance equation when under wet conditions discharge to these deeper layers is present.

Irrigation frequency

The application of sprinkling irrigation was based on the moisture extraction from the top layer of 40 cm. Generally the following moisture treatments were present: a. irrigation after 25% of moisture extraction; b. after 50% of moisture extraction; c. after 75% of moisture extraction and d. a testfield without sprinkling irrigation. The various moisture treatments will be indicated as v_3, v_2, v_1 and v_o respectively. In 1962, 1965 and 1966 the weather conditions were such that only the v_3 field received additional water by sprinkling irrigation. In table 1 the moisture treatments during the various years which are used in the present paper are given.

Table 1. The soil moisture treatments during the years of the experiments

Year	Irrigation after a moisture extraction of 25%	50%	75%	No irrigation
1959	v_3	-	v_1	v_o 1)
1961	v_3	v_2	v_1	v_o
1962	v_3	-	-	v_o
1963	-	v_2	-	v_o
1964	v_3	v_2	v_1	v_o
1965	v_3	-	-	v_o
1966	v_3	-	-	v_o

1) An irrigation gift after flowering

Crop development

Each year the planting date, the date at which the crop came up and the harvesting date were given. Particularly during the first 4 years not too much attention was given to the collection of data concerning crop height and soil cover. During these years only two or three data of soil cover or crop height during growth were given. More attention to crop development was given in the last three years, in which both data were given periodically. The relation between height and soil cover of the potato crop derived from these data is presented in fig. 3. This relation is useful to get additional information concerning crop height or soil cover during the first four years.

The maturation of the crop at the end of the growth was described periodically by the percentage of dead leaves.

Meteorological data

The meteorological data required for the calculation of evapotranspiration, such as duration of bright sunshine, temperature, humidity, wind velocity and precipitation were measured daily at the meteorological observation field of the experimental farm of the Institute.

CALCULATION OF EVAPOTRANSPIRATION

Actual evapotranspiration can be calculated for practical purposes with a combined aerodynamic and energy balance approach (RIJTEMA, 1965), taking into account the properties of the crop and the soil. The general equation is:

$$E_{re} = E_T^{re} + E_I = \frac{\Delta H_{nt}/L + \gamma \left\{ E'_a + f(z_o, d)\, u\, R_c E_I \right\}}{\Delta + \gamma \left\{ 1 + f(z_o d)\, u\, R_c \right\}} \tag{1}$$

where: E_{re} is the real evapotranspiration, E_T^{re} the real transpiration from the crop, E_I the evaporation of the precipitation intercepted by the crop, Δ the slope of the temperature - saturated vapour pressure curve, H_{nt} the net radiation, L the latent heat of vaporization, γ the psychrometer constant, $E'_a = f(z_o d)\, u\, (\varepsilon_a - e_a)$, ε_a the saturated vapour pressure at air temperature, e_a the actual vapour pressure, $f(z_o, d)$ a function depending on the roughness length (z_o) and the zero plane displacement (d) of the evaporating surface, u the wind velocity measured at 2 m height and R_c the diffusion resistance of the crop.

When it is assumed that R_c equals zero, the maximum possible evaporation (E_{wet}) from the surface under consideration can be calculated. Equation (1) transforms in that case into:

$$E_{wet} = \frac{\Delta H_{nt}/L + \gamma\, E'_a}{\Delta + \gamma} \tag{2}$$

The evaporation term E_I is difficult to determine exactly, particularly in periods with much precipitation, when the crop does not become dry between the successive showers. The calculated amount of interception is too high in that case. Since the calculated evaporation (E_{wet}) of a wet crop surface with the same properties as the crop considered gives the maximum value, the value of E_I may not exceed E_{wet}.

Based on this argument RIJTEMA (1968) combined the equations (1) and (2) which resulted in the following expression:

$$E_{re} = E_T^{re} + E_I = \frac{\Delta + \gamma}{\Delta + \gamma \left\{ 1 + f(z_o, d) u R_c \right\}} (E_{wet} - E_I) + E_I \qquad (3)$$

Data derived from literature

No data of the relation between precipitation and the amount intercepted by a potato crop were available. However, an error in the value of E_I is not disastrous, as the term E_I operates in equation (3) as a correction factor, of which the effect on E_{re} strongly depends on the value of the ratio $(\Delta + \gamma) \left[\Delta + \gamma \left\{ 1 + f(z_o, d) u R_c \right\}\right]^{-1}$. For this reason the interception data of tall grass given by RIJTEMA (1965) were used.

The value of $f(z_o, d)$ depends on crop height and on wind velocity. The combined effect has been expressed for a grass crop by RIJTEMA (1965) as:

$$f(z_o, d) = g(\ell) \; . \; h(u) \qquad (4)$$

where: $g(\ell)$ is a function of crop height with the same dimensions as $f(z_o, d)$ and $h(u)$ is a dimensionless factor, which depends on wind velocity. Calculations of SZEICZ, ENDRÖDI and TAJCHMAN (1968) for a potato crop resulted in similar values for $g(\ell)$ and $h(u)$ as those given by RIJTEMA for the grass cover. Values of $g(\ell)$ and $h(u)$ used in the present paper are given in table 2 in relation to respectively crop height and wind velocity.

Table 2. Values of $g(\ell)$ in relation to crop height and values of $h(u)$ in relation to wind velocity at 2 m height

Crop height (cm)	0	2	5	10	20	30	40	50	70	90
$g(\ell)$	0.18	0.23	0.47	0.74	1.00	1.12	1.22	1.32	1.42	1.50
Wind velocity ($m.sec^{-1}$)	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0
$h(u)$	1.32	1.17	1.05	0.96	0.90	0.86	0.79	0.75	0.72	0.69

The diffusion resistance R_c takes into account the geometry of the evaporating surface, as soil cover and leaf area, the stomatal

opening under influence of light intensity and the transport resistances in the liquid flow path. RIJTEMA (1968) assumed that the combined effect of these factors can be given with the expression:

$$R_c = R_c^{\ell} + R_c^{c} + R_c^{\psi} \tag{5}$$

where: R_c^{ℓ} is the diffusion resistance term depending on light intensity, R_c^{c} the factor depending on soil cover and R_c^{ψ} the factor giving the effect of soil moisture conditions on the value of R_c.

RIJTEMA (1965) used the mean radiation intensity during the balance period as a measure for the light dependent factor, controlling stomatal opening under field conditions. The relation between R_c^{ℓ} and mean radiation intensity during the day-time hours is given in table 3.

Table 3. Values of the diffusion resistance R_c^{ℓ} and mean radiation intensity during the day-time hours

Radiation intensity cal. $cm^{-2}.min^{-1}$	0.10	0.15	0.20	0.25	0.30	0.38	> 0.38
R_c^{ℓ} mm Hg. day. mm^{-1}	3.77	2.76	1.94	1.21	0.66	0.0	0.0

RIJTEMA and RYHINER (1968) give some data of R_c^{c} in relation to soil cover for spring wheat. Calculations of FEDDES (1968) of values of R_c^{c} in relation to soil cover for spinach and red cabbage resulted in similar values as those given by RIJTEMA and RYHINER. The scatter in the data is rather large which is mainly caused by the distribution of the precipitation during the experiments, which effects the evaporation from the bare soil. The data used in the present study are given in table 4.

Table 4. Values of the diffusion resistance R_c^c and soil cover

Soil cover %	10	20	30	40	50	60	70	80	90	100
R_c^c mm Hg. day. mm^{-1}	2. 33	1. 72	1. 27	0. 90	0. 60	0. 35	0. 18	0. 08	0	0

Reconstruction of crop development data

The relation between crop height, soil cover and the point of time within the growing season is more or less fixed by crops harvested once a year. Between the various years a shift in time can be present, depending on the starting point of growth in spring time.

The scantily available data and those derived from fig. 3 were plotted versus time. A curve was drawn through these points. An example of the used procedure for the data of the v_3 and v_o fields in 1961 is given in fig. 4. From these curves the mean crop height and mean soil cover for each balance period could be estimated.

Soil moisture conditions

The effect of climate and soil moisture conditions on the reduction in transpiration was calculated from the relation between the diffusion resistance R_c^{ψ} and the potential suction ψ_{ℓ}^{pot} in the leaves. According to RIJTEMA (1965) this relation can be given by the expression:

$$R_c^{\psi} = f(\psi_{\ell}^{pot}) = f\left\{ E_T^{pot} (R_{pl} + {}^{b}/k) + \psi \right\} \qquad (6)$$

where: E_T^{pot} is the potential transpiration rate, calculated with equation (3), assuming R_c^{ψ} equals zero but taking into account the values of R_c^{ℓ} and R_c^c; R_{pl} the transport resistance for liquid flow in the plant, b a geometry factor of the root system depending on rooting depth, root intensity and root activity, k the capillary conductivity at mean suction ψ in the effective rootzone of the crop.

It appears from data given by RYHINER (1969) from experiments with potatoes in 1967 and from calculations performed with the 1959 data that for a full grown potato crop the value of R_{pl} equals 1 atm. day. mm^{-1} and the value of b 3.10^{-4} atm. The relation between R_c^{ψ} and ψ_{ℓ}^{pot} calculated from these data is given in fig. 5. The data

derived from the irrigated fields show a tendency to give somewhat lower values, which might be caused possibly by irrigation losses. These losses give an overestimate of the evapotranspiration from the water balance, which results in too low values of R_c^{ψ}.

The relation between the potential (ψ_l^{pot}) and the real (ψ_l^{re}) suction in the leaves is shown in fig. 6. The deviation in the straight line given in this figure indicates that reductions in transpiration are already present at low suctions in the leaves.

Maturation

In maturing plant communities a substantial reduction in transpiration is present even when the crop is well-irrigated and well-fertilized. This is mainly caused by leafage and the increase of the percentage of dead leaves when maturation proceeds. Estimates of the percentage of dead leaves were used to describe the course of maturation during the growth.

In the model describing the contribution of the diffusion resistance of the crop maturation was considered to effect the internal transport resistance highly. This was based on the argument that the dead leaves do not contribute in the transpiration process, so for a same flux per unit of surface the internal transport pathways are decreasing with increasing percentage of dead leaves.

The data of 1964 were used to calculate the effect of the percentage of dead leaves on the value of R_{pl}. The relation between the percentage of leaves which are still alive and the internal transport resistance is given in fig. 7. Though the scatter of the data is rather large, it will be clear that with a decreasing percentage of living leaves below 50% the value of R_{pl} increases considerably. The curve drawn in this figure is also used in the calculation of evapotranspiration in the other years.

RESULTS AND DISCUSSION

For comparison the calculated evaporation from a continuous wet crop surface (E_{wet}), the evapotranspiration obtained by equation (3) (E_{re}) and the derived one from the water balance (E_{wb}) are given

in fig. 8. Moreover the total amount of precipitation and sprinkling water is given for each balance period expressed as a mean value per day, as well as mean suction in the effective rootzone of 40 cm at each sampling date. With respect to the results a number of aspects must be discussed.

Soil cover

The curve used for the determination of the effect of soil cover on transpiration was derived from experiments performed under normal weather conditions, without preventing evaporation from the bare soil. The results will be correct as a consequence, when no extreme situations in the distribution of precipitation are present. It means that systematic deviations will occur under either extremely dry or extremely wet conditions. Under extremely dry conditions the calculated values of E_{re} will be higher than those derived from the water balance when a partial soil cover is present. This is demonstrated in the results obtained from the v_o fields in 1959, when during the first balance periods hardly no precipitation was present.

The opposite situation was present in 1963, when during the first two balance periods the distribution of precipitation was very regularly with a large number of small showers, which affected the evaporation from the bare soil in a favourable way. In these situations the data derived from the water balance approach the calculated value of E_{wet}. A more or less similar situation was present in 1965.

In the other years the distribution of precipitation was in such a way, that a reasonable approach during the first stages of growth was obtained.

Moisture conditions

The calculated values of E_{re} and the data from the water balance agree reasonably well. It shows that the actual transpiration rate can be calculated under practical conditions when the given relation between diffusion resistance and ψ_{ℓ}^{pot} is used.

The distribution of precipitation as well as the time of irrigation within the balance periods might affect the soil moisture conditions in such a way, that the real mean suction in the rootzone is much smaller

than the mean value calculated from the soil moisture data at the beginning and at the end of the balance period. This situation can be present particularly on the irrigated field, as sprinkling was applied very often one or two days after sampling, resulting in a sharp decrease in suction, directly after sampling. Due to this the calculated values of E_{re} are too low at the irrigated fields. This effect increases with increasing irrigation frequency, as is clearly shown in data of 1964 in particular. In addition to this, a small drainage to the deeper layers might be present, resulting in an overestimate of the water balance data. The values derived from the water balance exceed the calculated E_{wet} data under extremely wet conditions, showing that discharge must be present during these periods.

Maturation

The relation between the internal plant resistance R_{pl} and the amount of living leaves, given in fig. 7, as description of maturation, did give acceptable results in all the other years when due to the proceeding of maturation large reductions in transpiration were present. It means that a fairly good approach for the effect of maturation can be obtained by increasing the value of R_{pl} in the calculation model.

Comparison with other data

GARDNER and EHLIG (1963) give the relation between the relative transpiration rate $\{(E_T^{re}) \cdot (E_T^{pot})^{-1}\}$ and the mean suction in the leaves for various crops. The suction, at which the transpiration rate starts to reduce, varies from 4 bars for a pepper crop to 12 bars for cotton.

The relative transpiration rate of the potato crop in the present study is plotted in fig. 9 versus the mean suction in the leaves. The figure is given for three classes of soil cover. The ratio decreases more slowly under conditions of a low soil cover than under conditions of a complete soil cover. This is mainly due to the fact that under conditions of a partial soil cover the calculated values of E_T^{pot} are much lower than for a full cover crop, so the effect of suction on transpiration becomes less.

The shape of these curves agrees well with those found by GARDNER and EHLIG. However, the reduction in the transpiration starts already at 1 atm. suction, which value is much lower than the corresponding values for the crops given by GARDNER and EHLIG. The main reason might be the way in which the potential transpiration rate was determined. GARDNER and EHLIG did their experiment under controlled constant climatic conditions and they determined the potential transpiration rate when the crop was well supplied with water. In fig. 9 the potential transpiration rate was calculated with equation (3) assuming that the influence of the resistances in the liquid path could be neglected. In the experiments from GARDNER and EHLIG the effect of internal resistances under conditions of optimum water supply was automatically taken into account, which results in a higher suction in the leaves when the reduction in transpiration starts.

SZEICZ, ENDRÖDI and TAJCHMAN (1968) calculated from experimental data with potatoes in Germany (TAJCHMAN, 1967) the mean monthly surface resistances from the ratio of monthly totals of evaporation (LE) and the available net energy (H_{nt} - G), using an emperical relation given by MONTEITH (1965). This emperical expression gives the relation between surface resistance r_s in the range $0.25 < r_s < 10.0$ sec cm^{-1}, and the ratio transpiration over available energy as:

$$\log_{10} r_s = 1.40 - \frac{2LE}{H_{nt}-G} \qquad (7)$$

The surface resistances derived by these authors with equation (7) from the data in 1965 in Germany are given in fig. 10 in relation to the time of the year. The crop resistance of potatoes in the present study was calculated according to soil cover, light intensity and soil moisture conditions in the rootzone. These data calculated for 1965 are also presented in fig. 10. The data from both places deviate strongly during the early stages of growth, which is mainly due to the very wet conditions in Germany when the crop was still partly covering the soil. The water balance data and those calculated, as presented in fig. 8, for 1965 did show a large deviation due to the wet conditions in this year. When the crop is completely covering the soil at both locations

identical values of this surface resistance were found. This result shows that the procedure followed in the present study leads to very acceptable values of the surface resistance, when taking into account soil cover, radiation intensity, moisture conditions and maturation.

SUMMARY

Data from sprinkling irrigation experiments with potatoes were used to calculate the actual and potential evapotranspiration from the crop during the growing season, using standard meteorological data. During the experiments the moisture extraction from the effective rootzone was determined by soil sampling to get the time of sprinkling irrigation for the fields with different moisture treatments.

The water use by the crop for the different periods was also derived from the water balance and the comparison with the calculated values did give a good agreement in periods without extreme conditions of precipitation. This showed that the derived relationships between crop height and surface roughness, between soil cover, light intensity, crop, as well as soil characteristics and diffusion resistance and between maturation and internal plant resistance were reasonably established.

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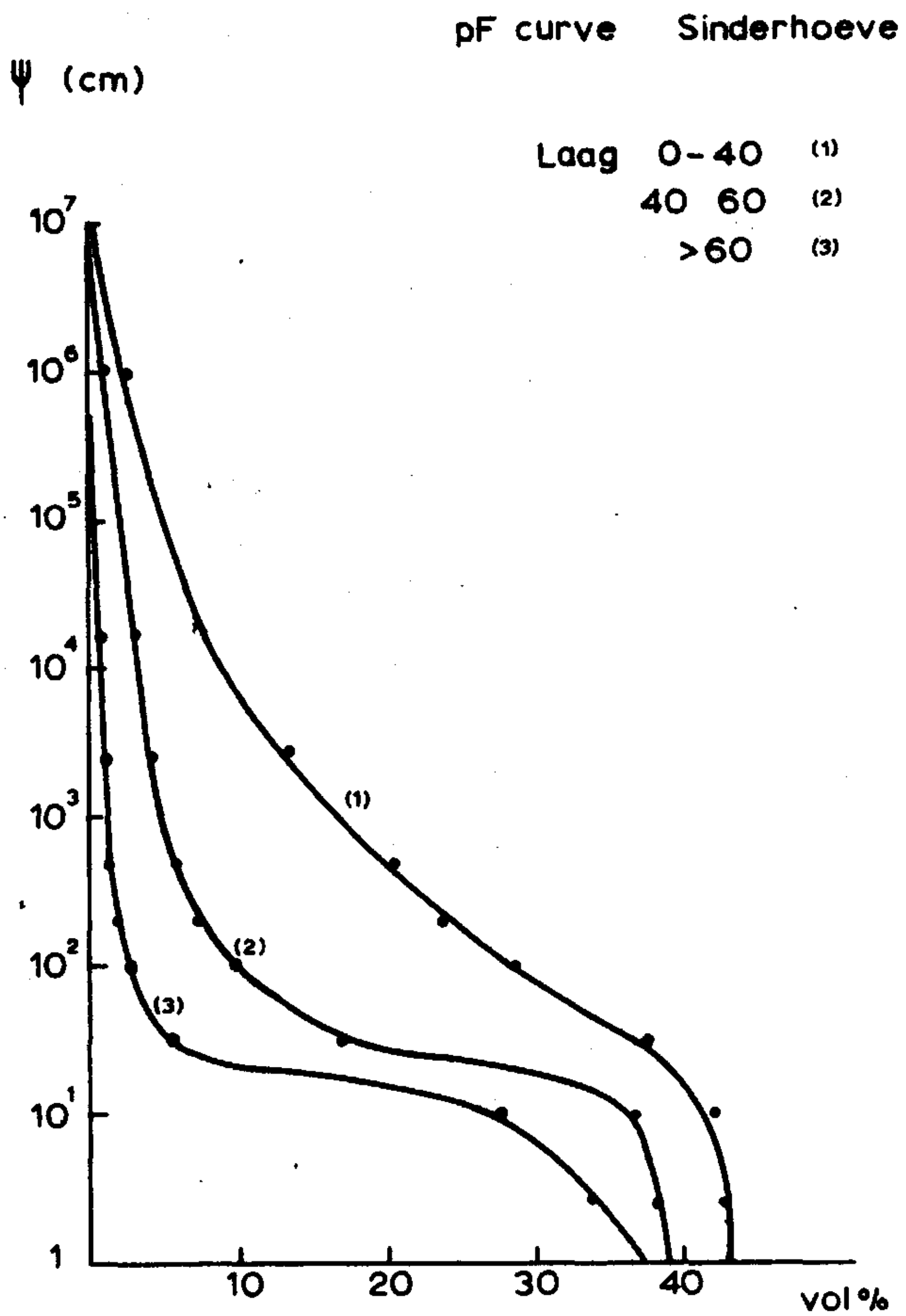

Fig. 1. Soil moisture characteristics
1 0 - 40 cm layer
2 40 - 60 cm layer
3 60 cm

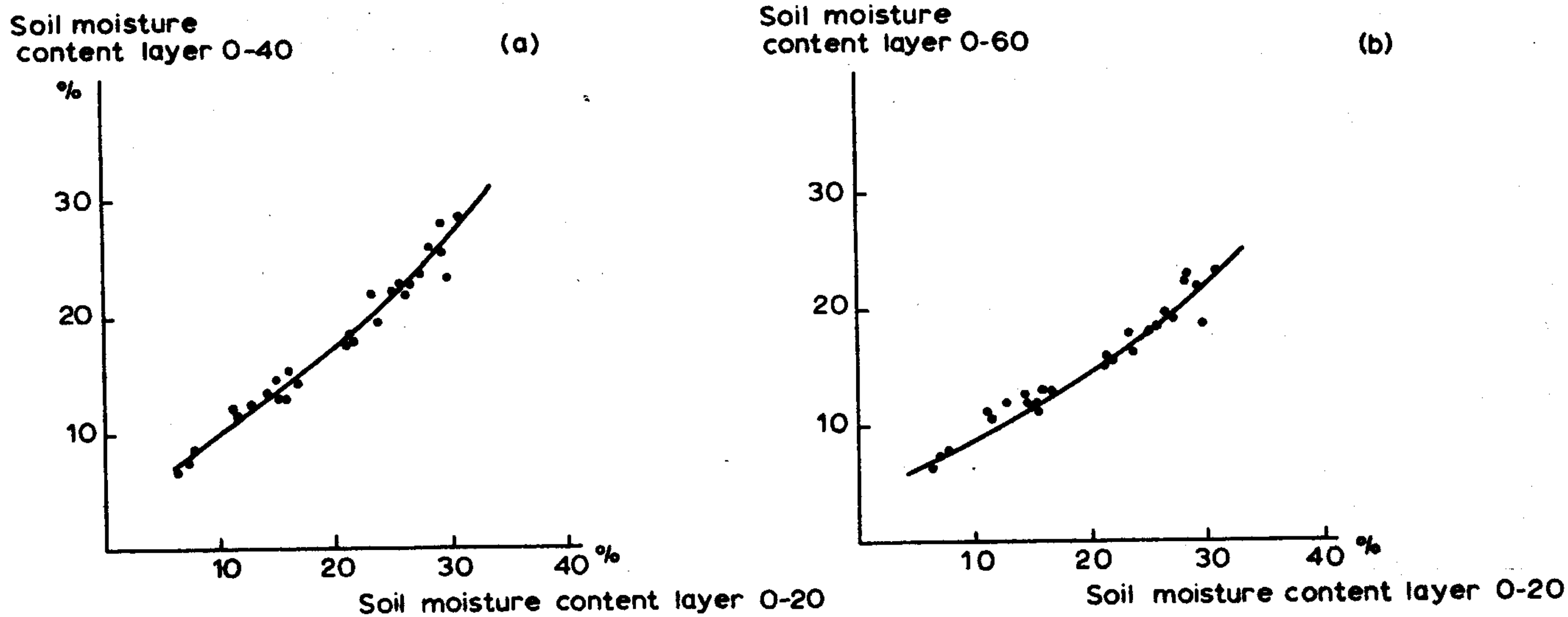

Fig. 2. Relation between the soil moisture content from 0 - 20 cm and the mean moisture content in the layer 0 - 40 cm (a) and 0 - 60 cm (b)

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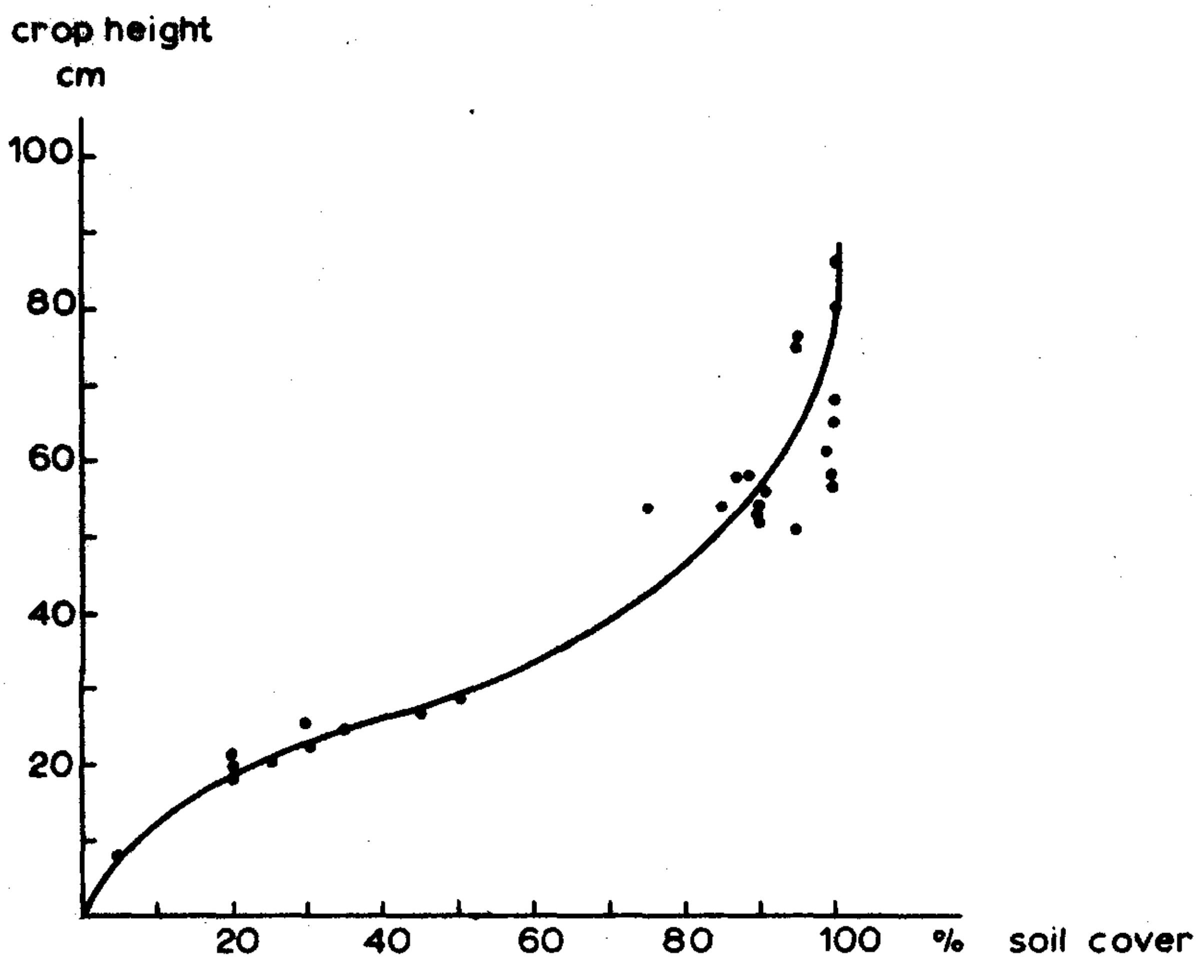

Fig. 3. Relation between crop height and percentage of soil cover for a potato crop

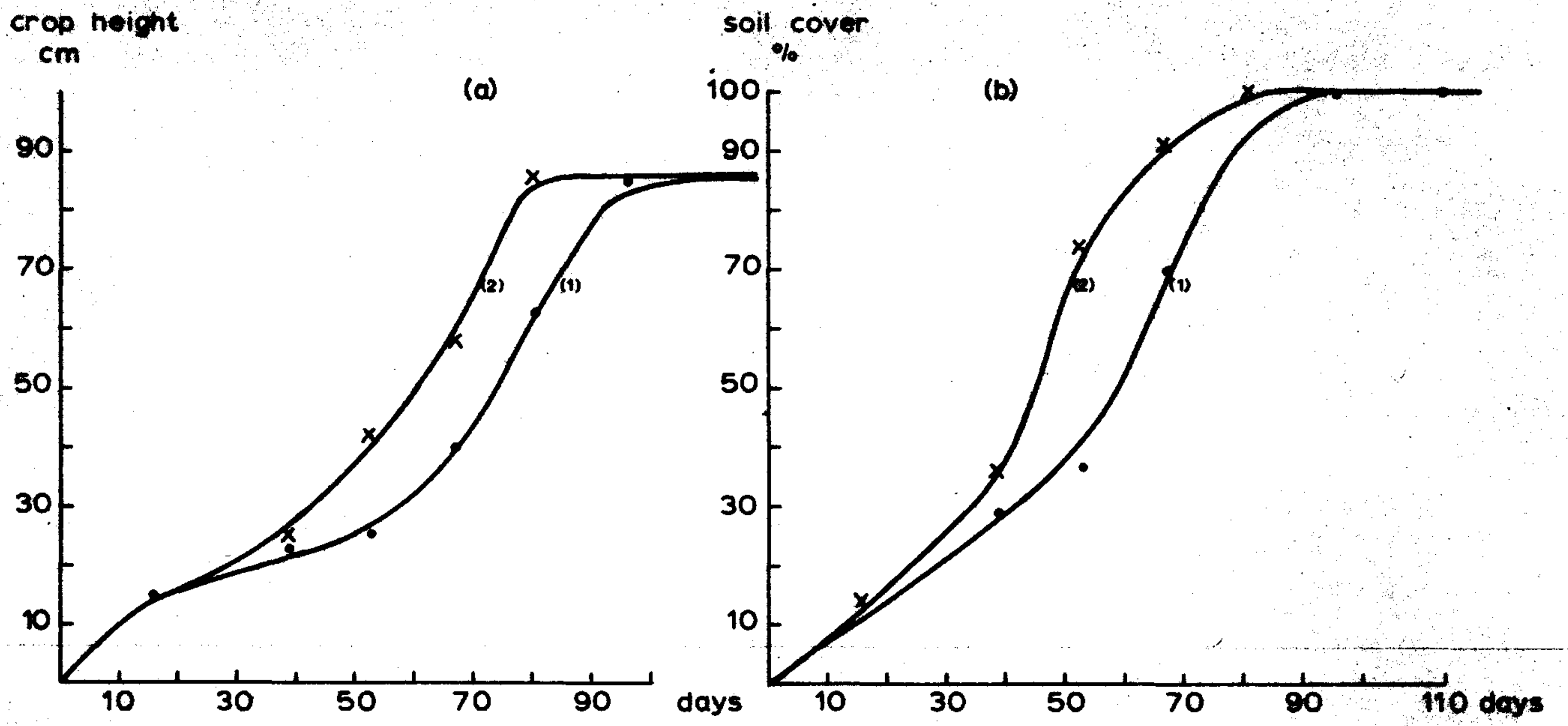

Fig. 4. The relation between crop development and time in 1961 for an unirrigated potato field (1) and a frequently irrigated one (2)
a. change in crop height with time
b. change in soil cover percentage with time

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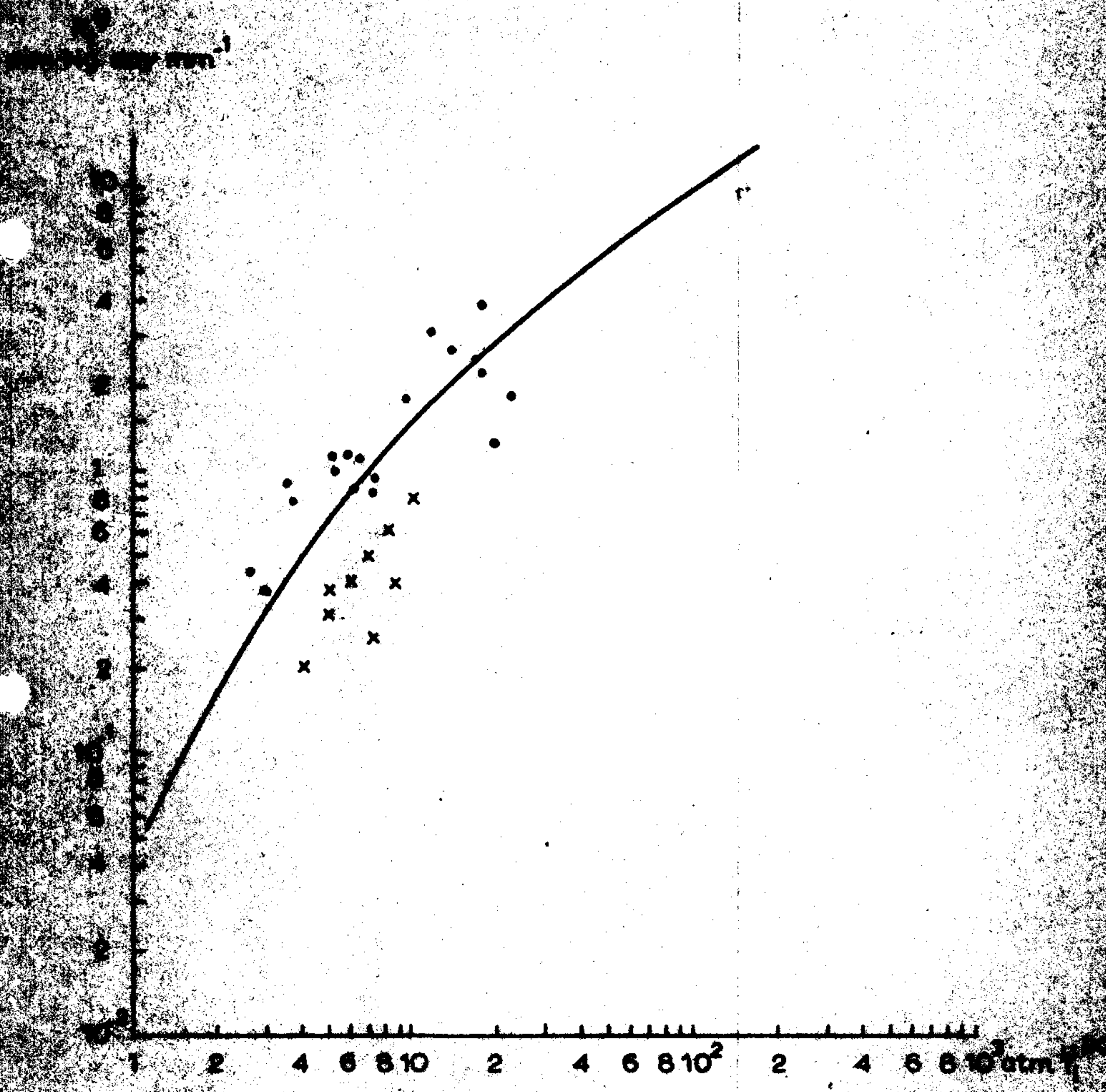


Fig. 5. Relation between the crop resistance R_c^F and the potential suction $\psi_m^{[illegible]}$ in the leaves. Part of the data was derived by Rijtema ([illegible]). The other data were derived from the experimental data in 1959 • without irrigation × with irrigation

[illegible]15.10/29

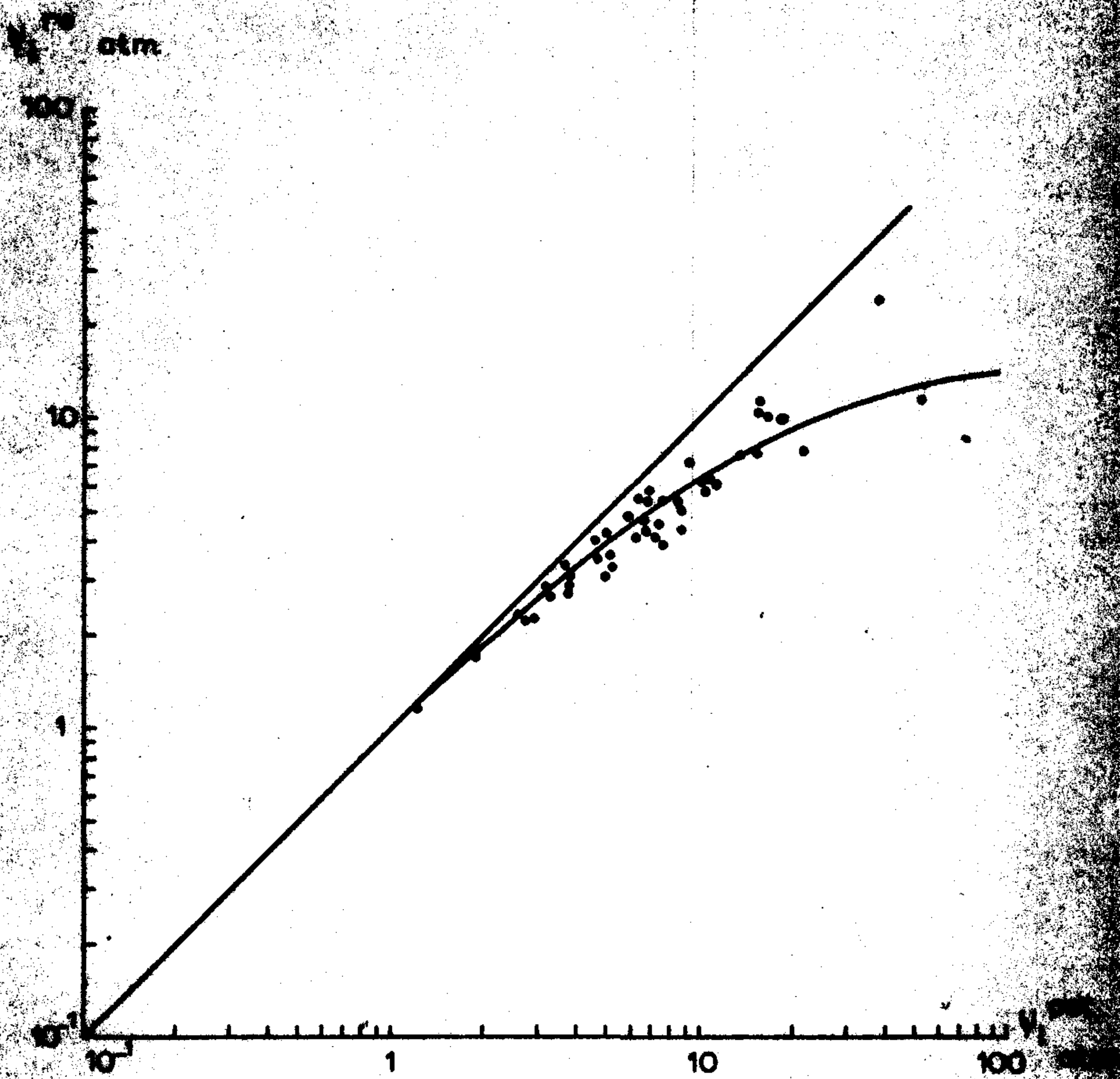


Fig. 4. Relation between the real suction (ψ_ℓ^{re}) and the potential suction (ψ_ℓ^{pot}) of the leaves for a potato crop

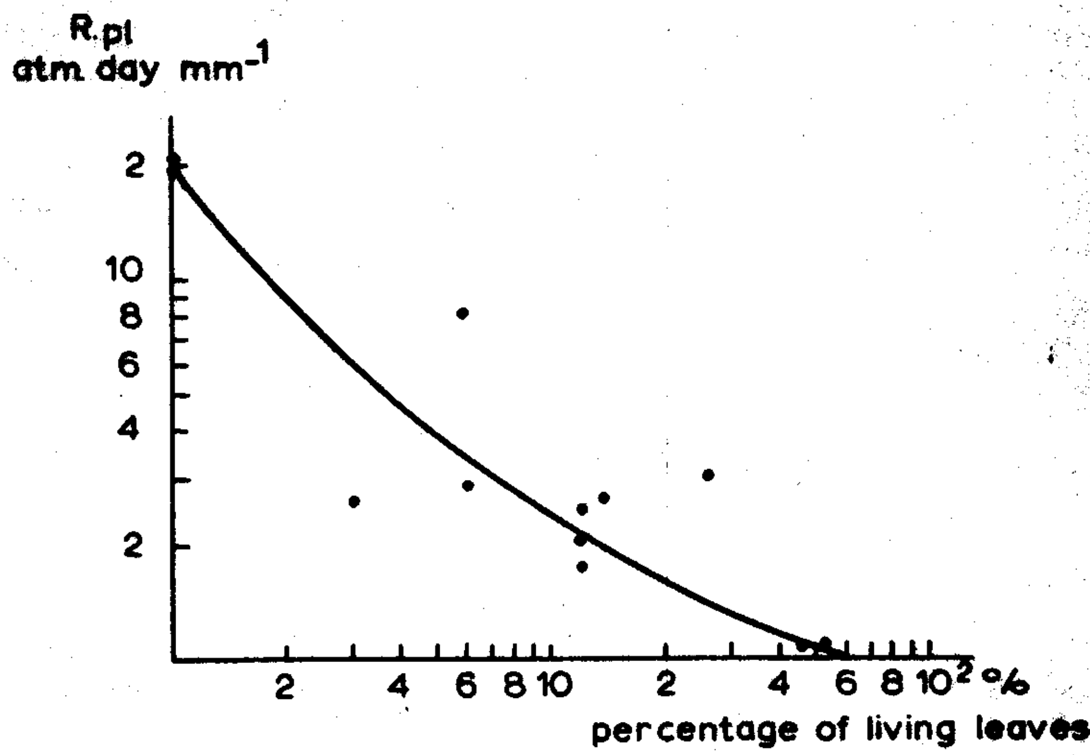
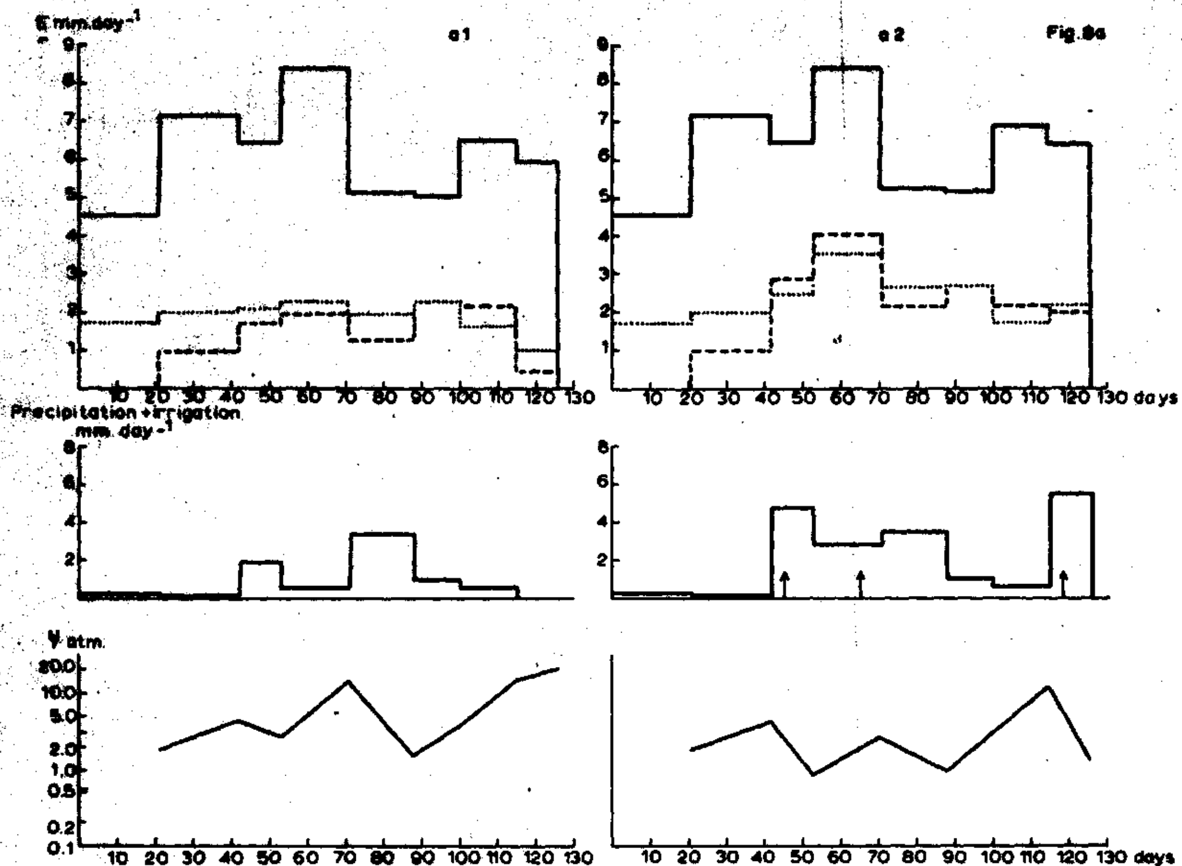


Fig. 7. The relation between the internal transport resistance of the crop (R_{pl}) and the percentage of leaves still alive



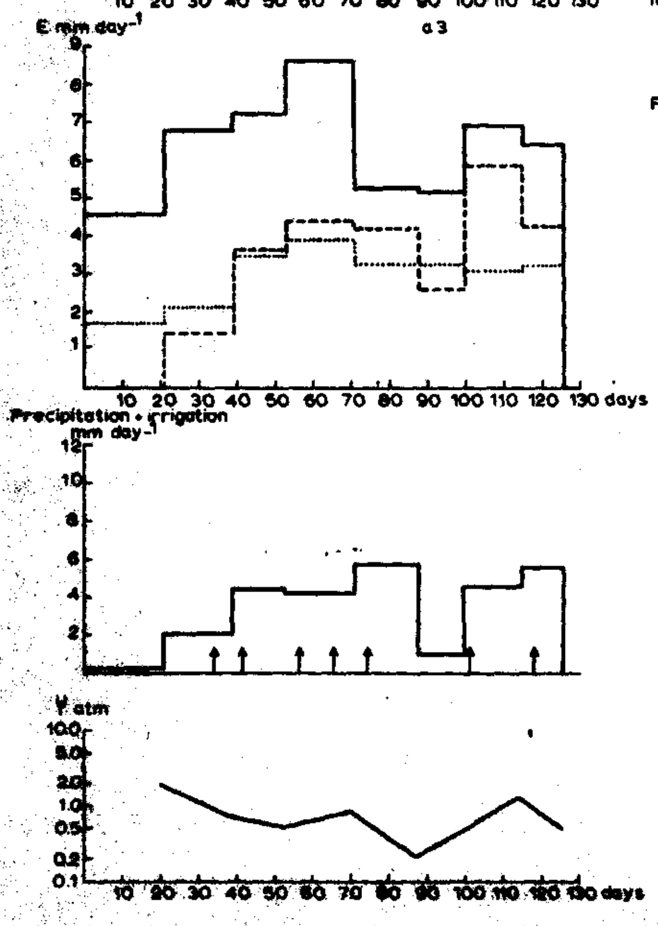
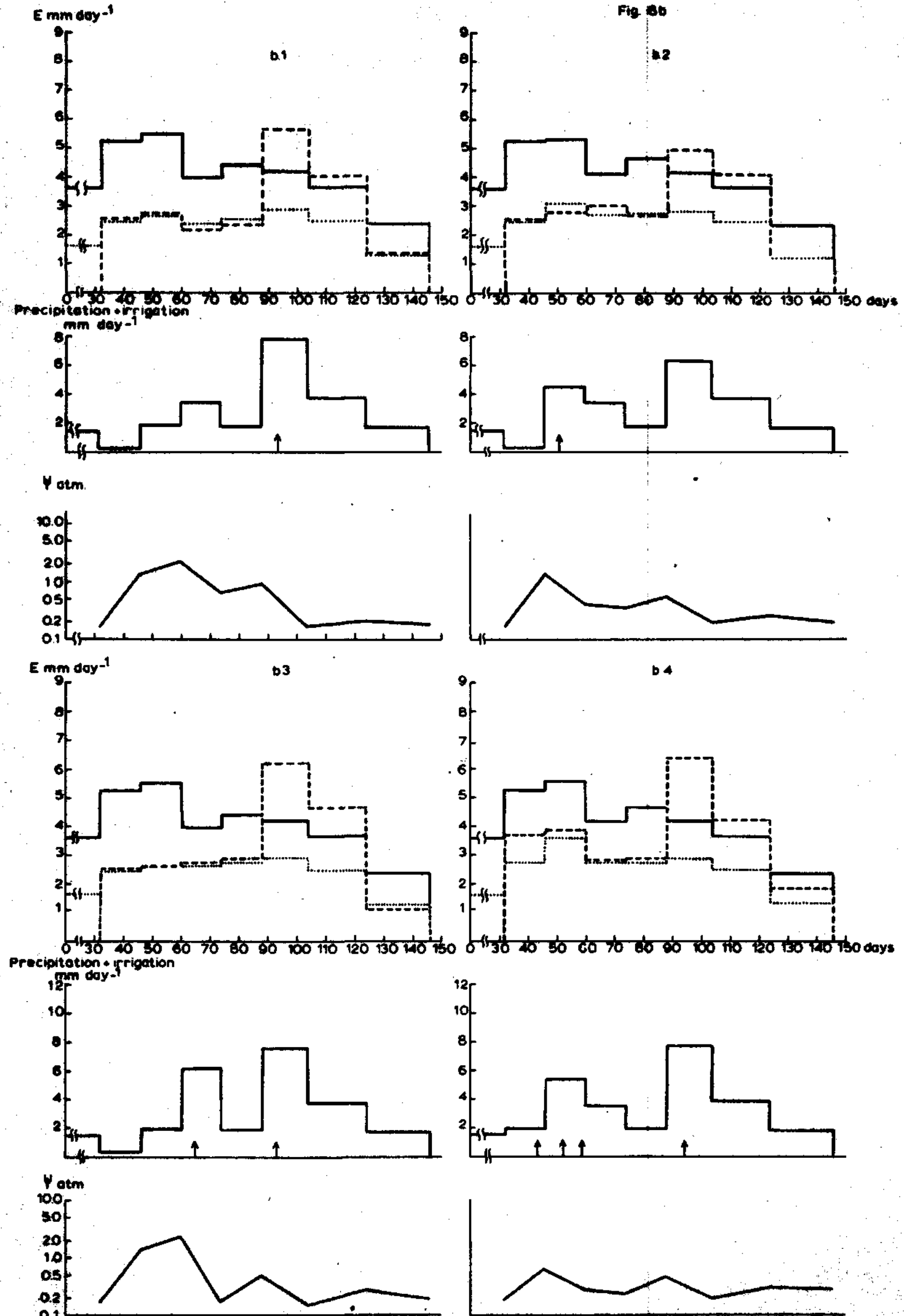


Fig. 8 The variation in E wet (———) the calculated evapotranpiration E_{re} (··········), and the data calculated from the water balance E_{wb} (-----)

The mean values of precipitation plus irrigation are given for each balance period.
The arrows give the day of irrigation.
The mean suction in the root zone at the beginning and at the end of each balance period are given.

a 1959 (1)V_0 , (2)V_1 , (3)V_3 .
b 1961 (1)V_0 , (2)V_1 , (3)V_2 , (4)V_3 .
c 1962 (1)V_0 , (2)V_3 .
d 1963 (1)V_0 , (2)V_2 .
e 1964 (1)V_0 , (2)V_1 , (3)V_2 , (4)V_3 .
f 1965 (1)V_0 , (2)V_3 .
g 1966 (1)V_0 , (2)V_3 .

Fig. 15b



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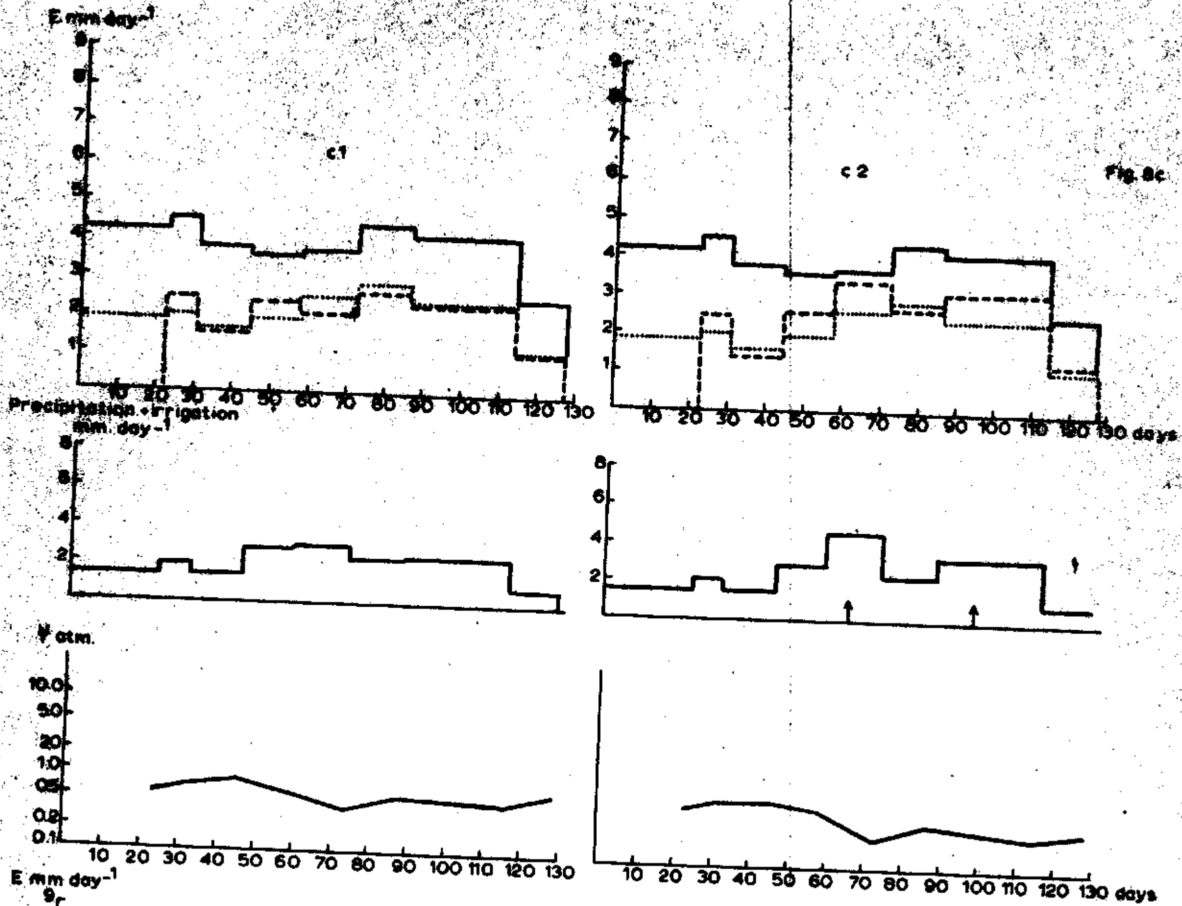

Fig. 8c

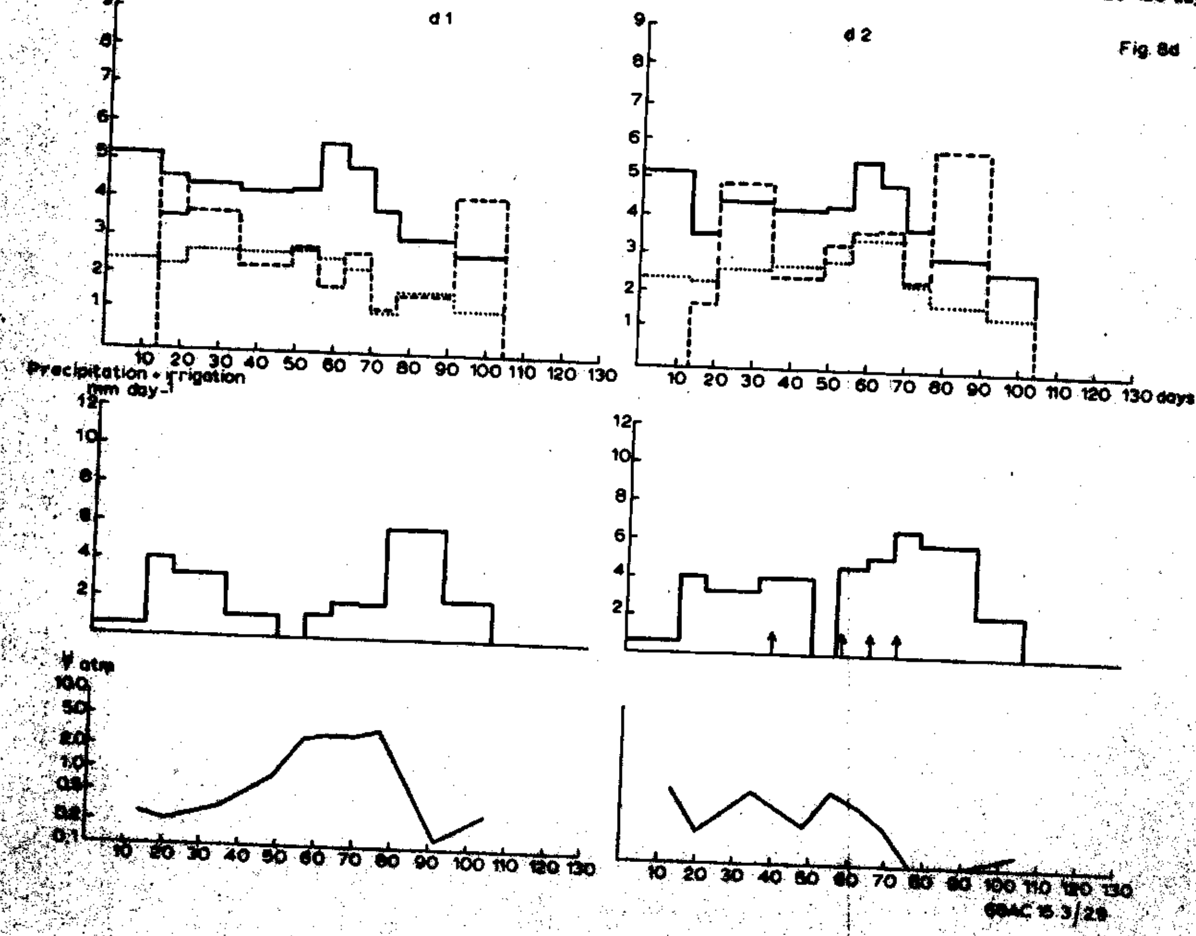

Fig. 8d

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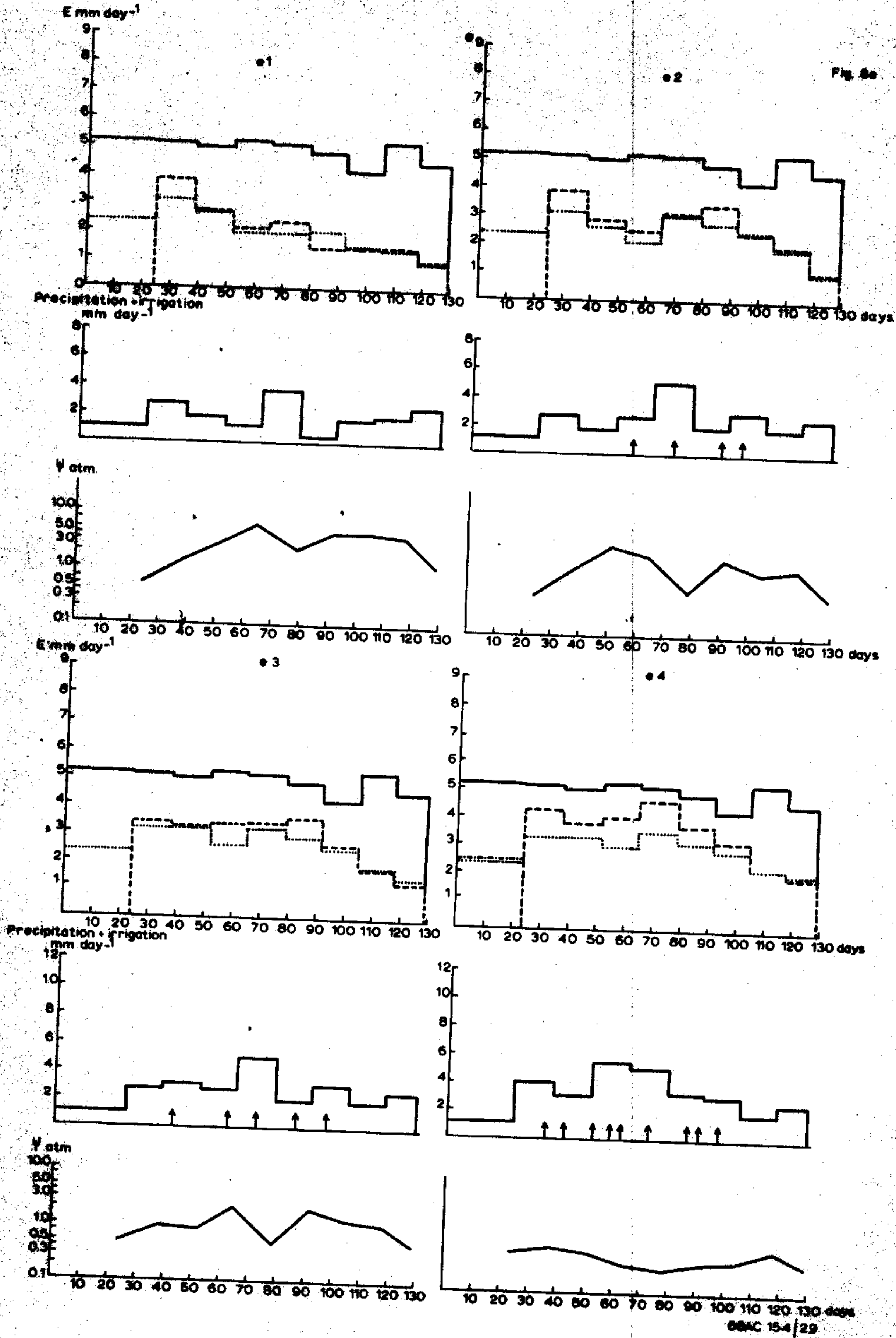

E mm day-1
e1
e2
Fig. 8a
Precipitation + irrigation mm day-1
Ψ atm.
days
e3
e4
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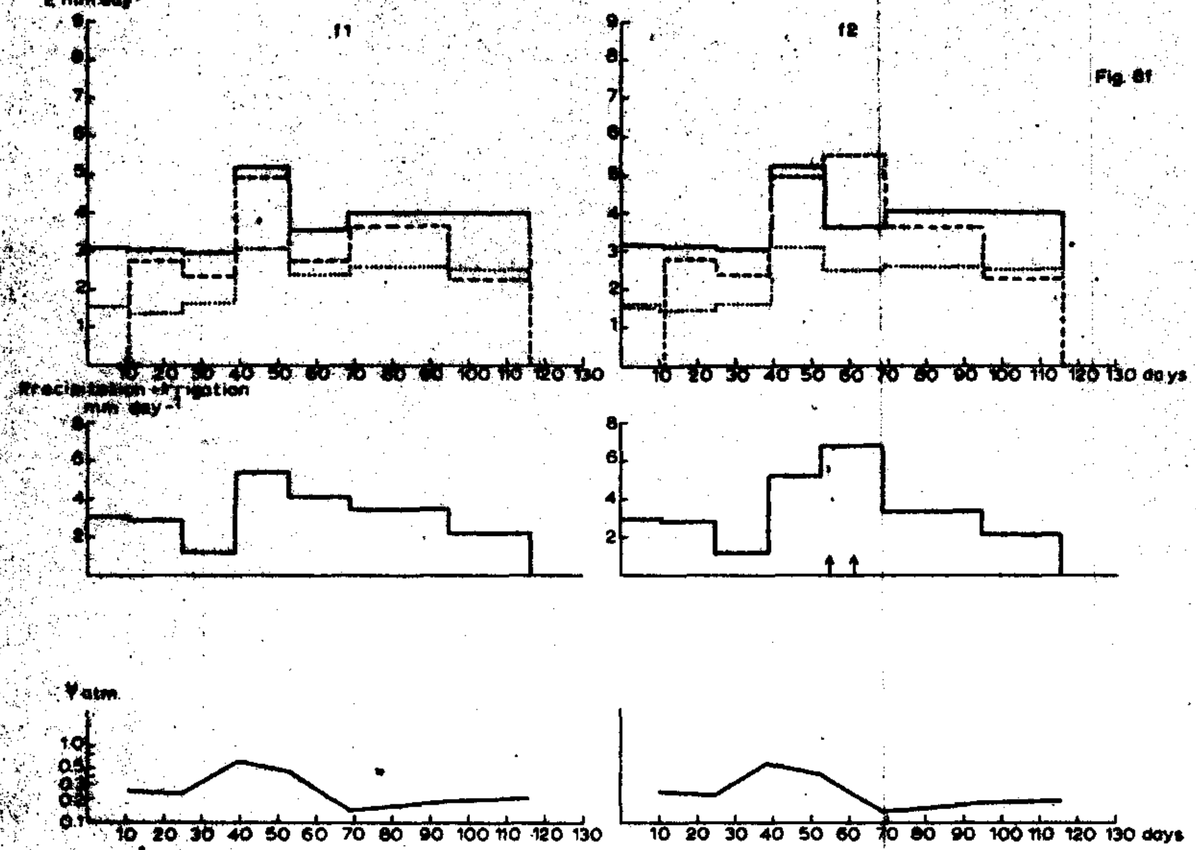

Fig. 8f

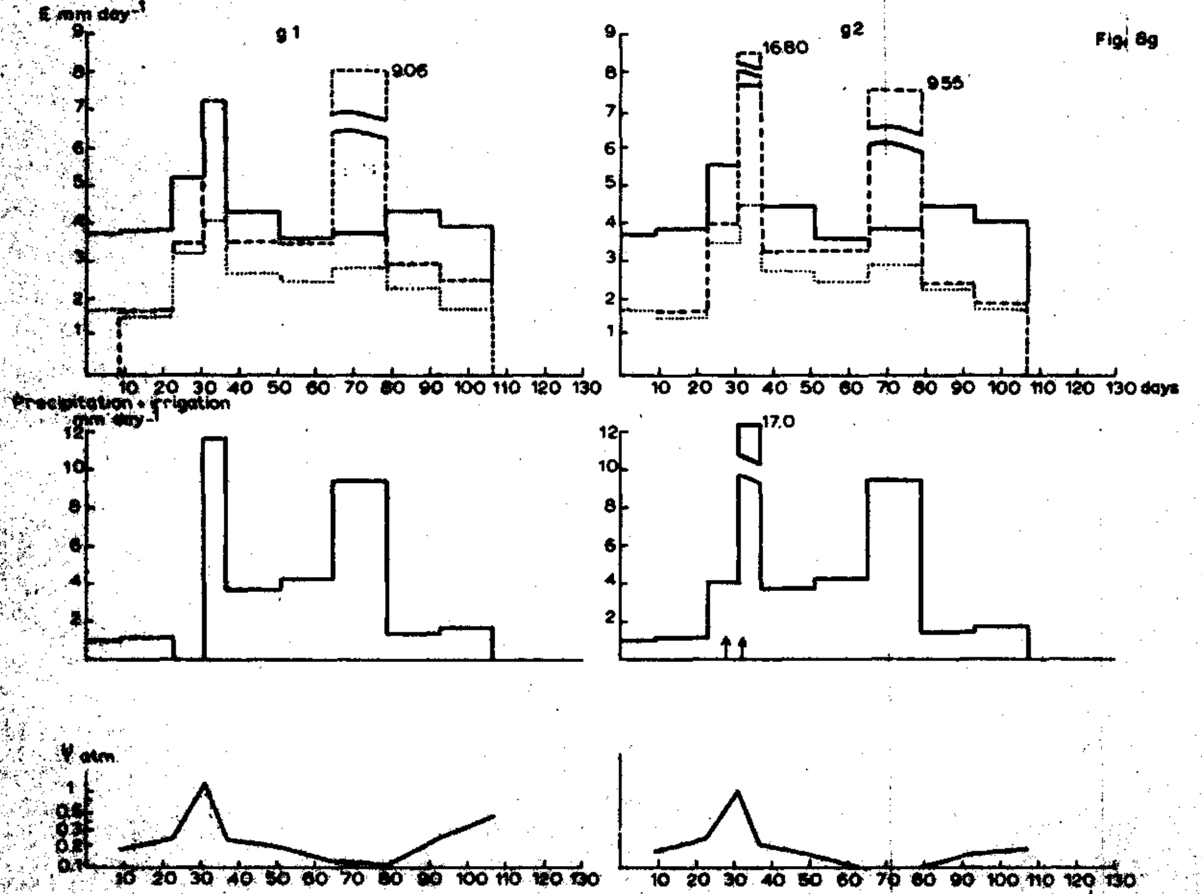

Fig. 8g

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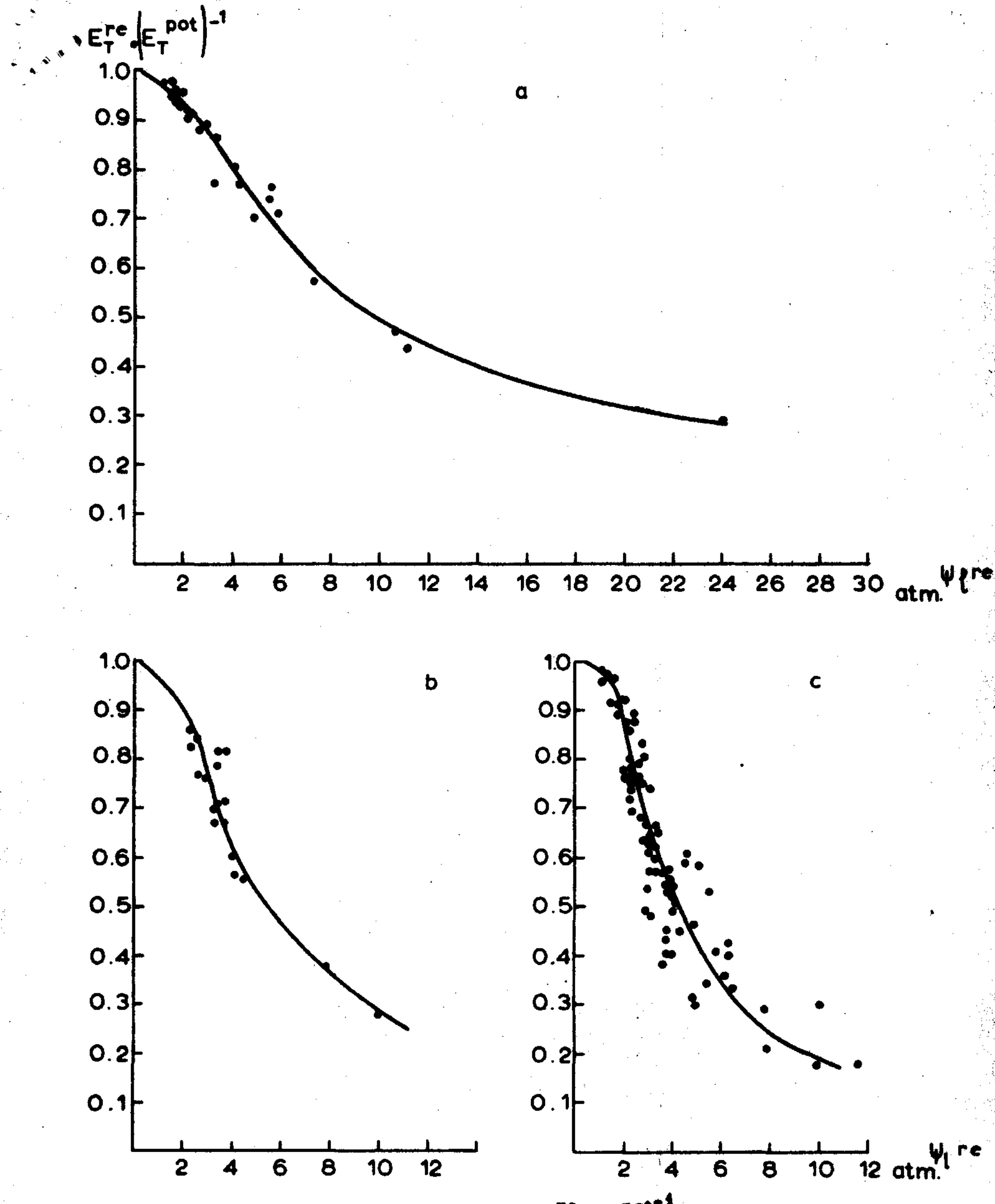

Fig. 9. The relation between the ratio $E_T^{re} \cdot E_T^{pot^{-1}}$ and the real suction in the leaves (ψ_l^{re}) for 3 groups of soil cover

a. soil cover 50%
b. soil cover between 50 and 80%
c. soil cover 80%

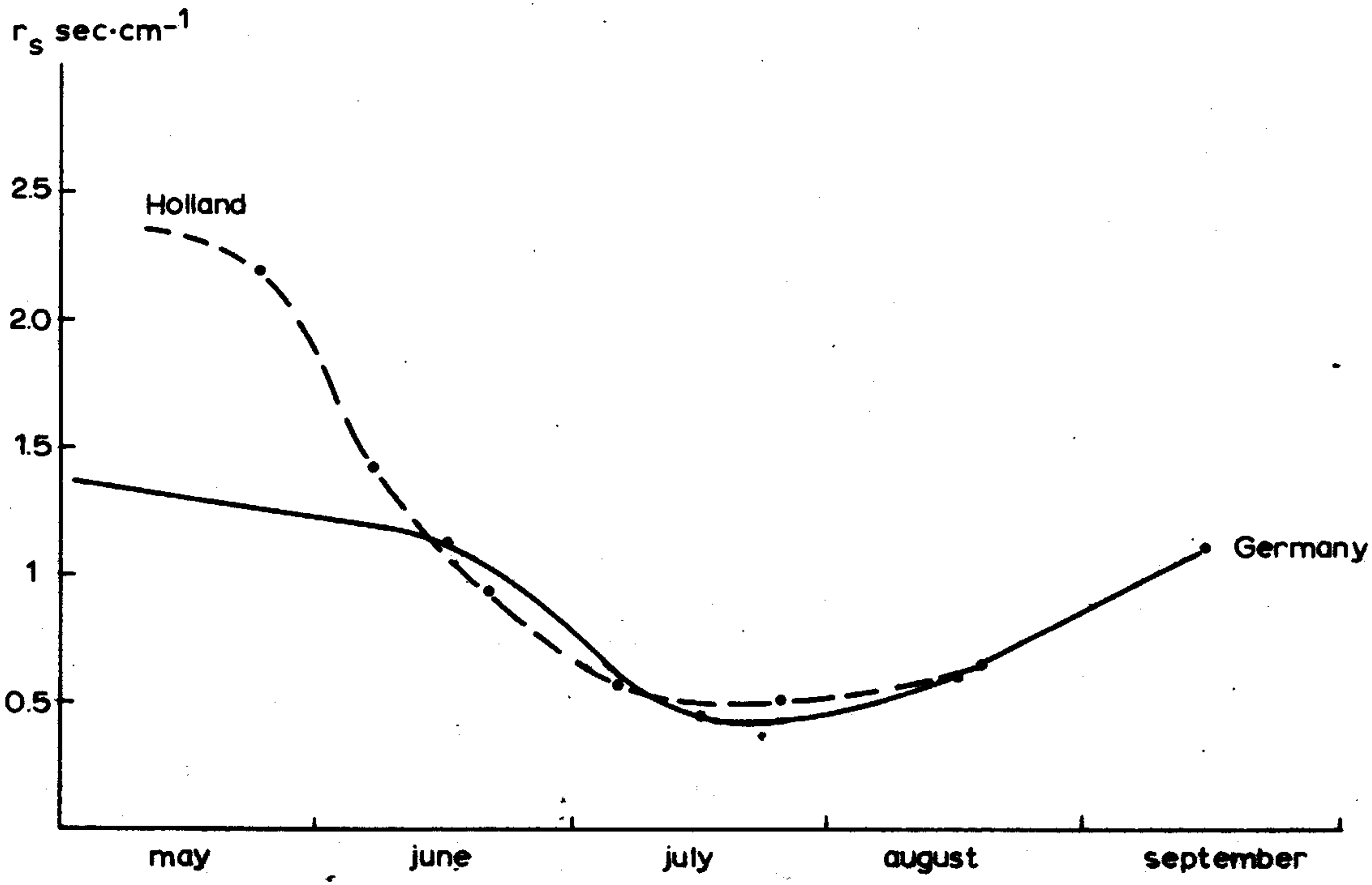

Fig. 10. Comparison of the variation in surface resistance r_s of potatoes in 1965 in The Netherlands (– – –) and in Germany (——) under conditions of a good water supply

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