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PRODUCTION OF POTATOES

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CONTENTS

1. INTRODUCTION

The formative development of the plant is extremely important to the grower, as it determines to what extent and during which period of the year the crop is able to convert the available solar energy into photosynthetic products.

The agronomist is confronted with the problem of discovering the limits with regard to production, considered from the factors which can be affected by human agency. When analysing the productivity of field crops one should like to be informed on both maximum and actual production per unit of soil surface. As availability of water is under many conditions a limiting factor for production, special attention will be given to the effect of moisture conditions on the dry matter production of a potato crop. The relation between transpiration and dry matter production is particularly important with respect to irrigation practice.

The economical value of the production is largely affected by the distribution of the produced dry matter over the various organs of the plant. These parts of the plant, which are not of economical interest are in a certain sense ballast, but a necessity, however, to obtain good yields of the main product. In this respect some attention will be given to the distribution of dry matter over the various parts of the plant for the potato crop.

2. AVAILABLE DATA

During a number of years sprinkling irrigation experiments with potatoes were performed at the experimental farm of the Institute. A description of the available data concerning moisture content, irrigation frequency, crop development and transpiration were published in an earlier paper (ENDRODI and RIJTEMA, 1969).

During three years periodical harvests of the potato crop were present. In particular these data will be used to test an approach to net photosynthesis of this crop, during the various stages of crop development. The plant density was about 48, 000 plants per ha. The crop production was calculated for the same periods as those which were used in the study on transpiration (ENDRODI and RIJTEMA, 1969).

3. PHOTOSYNTHESIS OF A POTATO CROP

Quantitatively, the synthesis of compounds other than carbohydrate may be ignored during the growth of a field crop. This means that dry matter production is mainly the result of net photosynthesis. The photosynthetic process consists of several processes and for the present discussion the following remarks have to be made:

a. photosynthesis is a photochemical process associated with the activation of light energy for the reduction of CO_2. This process is influenced by light and not by CO_2 or temperature;
b. photosynthesis is affected by a diffusion process for the transport of CO_2 from the external air to the chloroplasts. The rate of the diffusion process depends mainly on the CO_2 concentration in the external air and in the leaf mesophyll, as well as on the various resistances in the various path-ways. Light can affect the diffusion rate only indirectly through an influence on the stomatal diffusion resistance (GAASTRA, 1959);
c. photosynthesis is influenced by biochemical processes reducing CO_2 to carbohydrates. These processes are strongly affected by temperature and not by light and CO_2. The efficiency of the biochemical processes and the respiration rate of the plant, determine in fact the internal CO_2 concentration.

The partial processes are affected in a different way by external conditions. Each of these processes may limit the production rate under field conditions, so it is necessary to take all these factors in consideration when calculating dry matter production.

Since light energy is the factor which can be determined with the greatest ease and accuracy, it is useful to take this variable as the main factor in a production function, while the other variables are used as correction factors.

For this reason the approach given by DE WIT (1965) of photosynthesis of leaf canopies was used as basic term for the production function. De Wit's approach is mainly based on solar radiation and leaf distribution functions. For a set of standard conditions he calculated the daily photosynthetic rate for very clear days as well as for overcast ones, assuming that the light intensity on overcast days is 0.2 times the corresponding value H_c on very clear days. The light energy H_c is expressed in cal cm^{-2} day^{-1} for the range of 400 to 700 mμ. Moreover, the external transport resistance r_a was assumed to be 0.5 sec cm^{-1}. The daily photosynthetic rate under De Wit's standard conditions at 52° northern latitude is given in table 1.

Table 1. The daily totals of light on very clear days (H_c) in cal $cm^{-2}day^{-1}$ (400 - 700 mμ), the photosynthetic rate on very clear days (P_c) and on overcast days (P_o) in kg CH_2O $ha^{-1}day^{-1}$ for 52°north. r_a = 0.5 sec cm^{-1}

Date	15 Jan.	15 Febr.	15 March	15 Apr.	15 May	15 June	15 July	15 Aug.	15 Sept.	15 Oct.	15 Nov.	15 Dec.
H_c	63	119	195	295	375	416	402	337	243	151	81	52
P_c	131	209	299	404	485	526	512	446	350	247	157	114
P_o	52	92	143	203	250	274	265	227	172	113	65	43

The daily production rate during each period was calculated, following the procedure proposed by De Wit, as $P = F P_o + (1-F) P_c$ kg CH_2O day^{-1} ha^{-1}, in which F, the fraction of time that the sky is clouded, is obtained from $(H_c - H_a).(0.8 H_c)^{-1}$. H_c is the mean value of the radiation on clear days and H_a the actual mean value, equalling 0.5 H_{sh}, where H_{sh} is the global radiation. The production calculated in this way will be considered as the potential production (P_{pot}).

The calculated potential production is plotted in fig. 1 versus the dry matter production obtained from the periodical harvests of the frequently irrigated potato fields in 1961 (variety Libertas), 1962 (variety

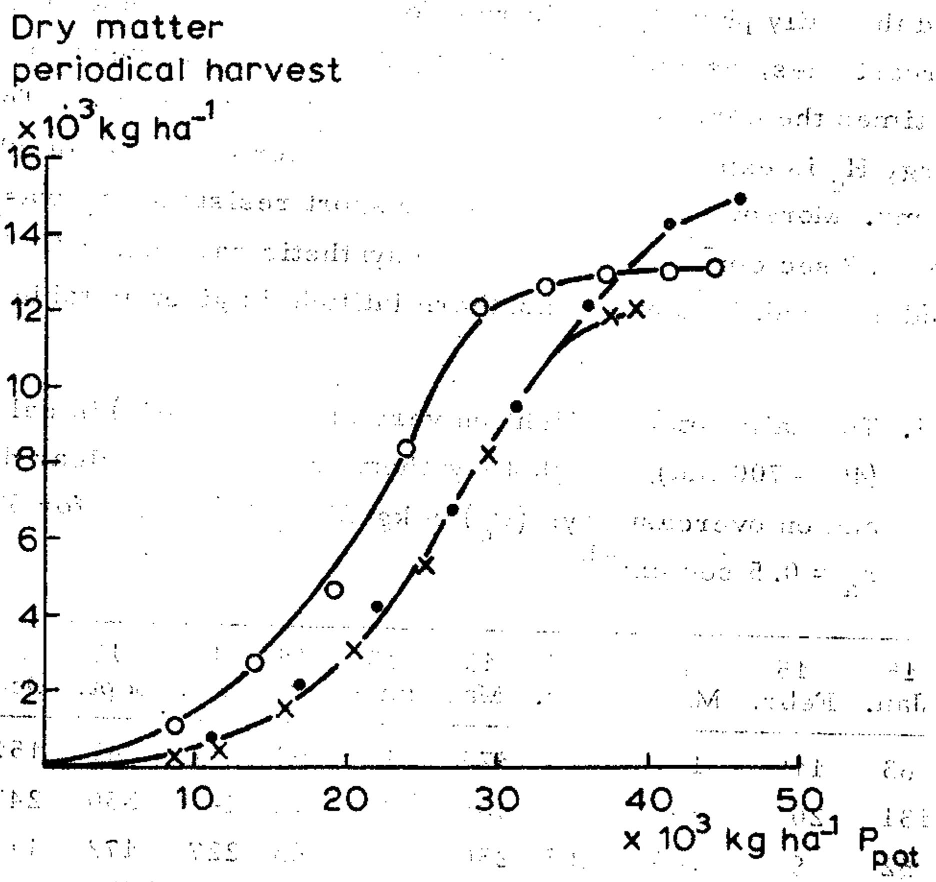

Fig. 1. The relation between the calculated potential production and the data obtained from periodical harvests

• 1961 Libertas

x 1962 Surprise

o 1964 Surprise

Surprise) and 1964 (variety Surprise). The potential production was calculated, starting from the day that the crop came up. The curves for 1961 and 1962 coincide, but the 1964 curve deviates continuously from the other one. The main reason of this deviation might be the difference in the temperature conditions during the early stages of growth, which was in 1964 about 3° centigrade higher.

The calculation of the potential production only holds for a crop which completely covers the soil. Partial soil cover results in a waste of light available for photosynthesis during the early stages of growth. The effect of soil cover on production can be eliminated by multiplying the calculated potential production by the fraction of the surface area covered by the plants.

The values of the potential production have to be corrected in relation to the effect of the various resistances in the diffusion path-way. De Wit estimated the effect on photosynthesis of the exchange resistance r_a between the bulk air and the effective canopy surface. The data of the exchange resistance r_a and the production in kg CH_2O ha^{-1} hr^{-1} are given in table 2. The relative production rate with respect to the production when $r_a = 0.5$ sec cm^{-1} is also presented. Assuming that the sum of the surface resistance (r'_s) and the mesophyll resistance (r'_m) of the canopy equals under these conditions 4.4 sec cm^{-1}, than the corresponding ratio of the total sum of resistances with respect to $r_a = 0.5$ sec cm^{-1} is presented in the last column of this table.

Table 2. The external resistance r_a, the corresponding production rate, the relative production rate and the ratio of the total resistances

r_a sec . cm^{-1}	P kg CH_2O ha^{-1} hr^{-1}	Relative production	$\frac{0.5 + 4.4}{r_a + 4.4}$
0.25	42.3	1.05	1.05
0.50	40.3	1.00	1.00
1.00	37.4	0.93	0.91
1.50	34.4	0.85	0.83
2.00	31.2	0.77	0.77

It appears from table 2 that the production rate at other values of the external transport resistance r_a can be approximated as:

$$P = \frac{0.5 + 4.4}{r_a + 4.4} P_{pot} \quad (1)$$

It has been shown (RIJTEMA, 1965) that the surface resistance of some crops, with respect to transpiration equals to zero under conditions of high light intensity and optimum water supply. As the diffusion coefficients of H_2O and CO_2 differ considerably, it is not necessarily a consequence that for these crops the surface resistance for CO_2 diffusion also equals zero. When considering the production calculated after De Wit as the potential one, it includes that the given value of 4.4 sec cm^{-1} gives a minimum value of the sum of r'_s and r'_m. In the further discussion this value of 4.4. sec cm^{-1} will be indicated for convenience as r'_m, but it must be kept in mind, that it partly includes a stomatal term.

For the potato crop under consideration it has been shown (ENDRODI and RIJTEMA, 1969) that even under optimum conditions of water supply the surface resistance for transpiration is not equal to zero, indicating also a higher surface resistance value for CO_2 transport. This surface resistance value is calculated as:

$$r'_s = (D_{H_2O}/D_{CO_2}) \cdot r_s \qquad (2)$$

where r'_s is the surface resistance for CO_2 transport, D_{H_2O} and D_{CO_2} the diffusion coefficients of H_2O and CO_2 respectively and r_s the surface resistance determined from the transpiration data, taking into account only the light depending term as well as the suction dependent term, as the soil cover term has been eliminated already.

The production rate can be expressed under these conditions by the equation:

$$P = \frac{0.5 + 4.4}{r_a + r'_s + 4.4} \cdot s_c \, P_{pot} \qquad (3)$$

where s_c is the fraction of soil cover.

The efficiency of the photosynthetic process and the respiration rate determine the internal CO_2 concentration (BIERHUIZEN and SLATYER, 1964). The lower the minimum CO_2 concentration in the intercellular space, the more efficient the plant is in photosynthesis.

De Wit assumed in his calculations that the internal carbondioxyde concentrations $[CO_2]_i$ equals zero. References presented by BIERHUIZEN and SLATYER (1964) show that this internal CO_2 concentration might vary from 0 - 250 p.p.m., depending on plant species and temperature. The reduction in production, due to a smaller efficiency can be given by the ratio of the CO_2 gradients. Under these conditions the actual production (P_a) can be given as

$$P_a = \frac{0.5 + 4.4}{r_a + r'_s + 4.4} \cdot \frac{300 - [CO_2]_i}{300} s_c P_{pot} \qquad (4)$$

The dry matter production derived from the periodical harvests is plotted in fig. 2 versus the calculated production according to equation (3). The data give a linear relationship with a slope of 0.68, showing that the photosynthetic efficiency is less than agrees with the assumptions of De Wit. The result indicates that the mean internal CO_2 concentration is in the order of 95 p.p.m. It must be realized that this mean internal value is determined by a very low value during day time hours and a high value, due to respiration, during night time.

The deviation from linearity at the end of the growing season is mainly due to the effect of the increasing number of dead leaves, which do not participate in the photosynthetic process. This increasing number of dead leaves affects production in two ways. Firstly, it has as a consequence that the internal resistance of the canopy as a whole increases and secondly it causes a reduction in the photosynthetic efficiency of the complete canopy, which might be also partly due to an increased respiration rate.

Using the curves drawn at the end of the growing season, an estimate has been made of both effects by means of an iterative procedure. The estimated effect of dead leaves on the internal resistance is presented in fig. 3, showing an gradually increasing effect on the value of the internal canopy resistance. The effect of dead leaves on the photosynthetic efficiency is given in fig. 4.

The calculated production of fields with a limited water supply must agree with the results obtained from periodical harvests, when the approach, given in equation (4), for the calculation of production is correct. This approach has been tested for the less frequently irrigated fields as well as for the field without irrigation and the results were compared with the data derived from the periodical harvests in 1964. Due to the reduction in transpiration (ENDRODI and RIJTEMA, 1969) a large variation in the value of r'_s was present. Moreover, the distribution of the

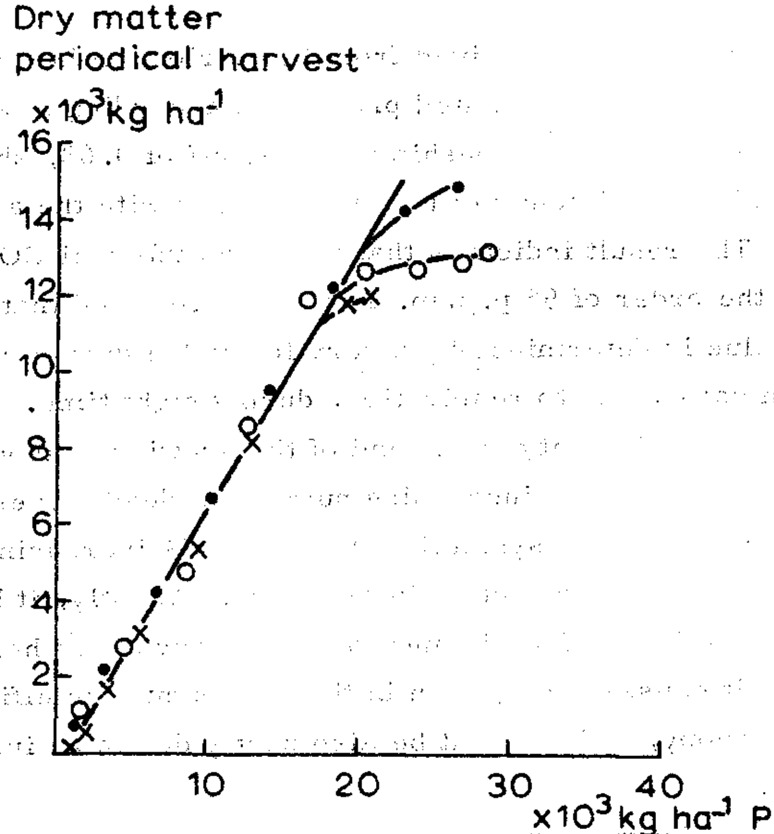

Fig. 2. The relation between the production, calculated with eq. 3 and the data obtained from periodical harvests

• 1961 Libertas

x 1962 Surprise

o 1964 Surprise

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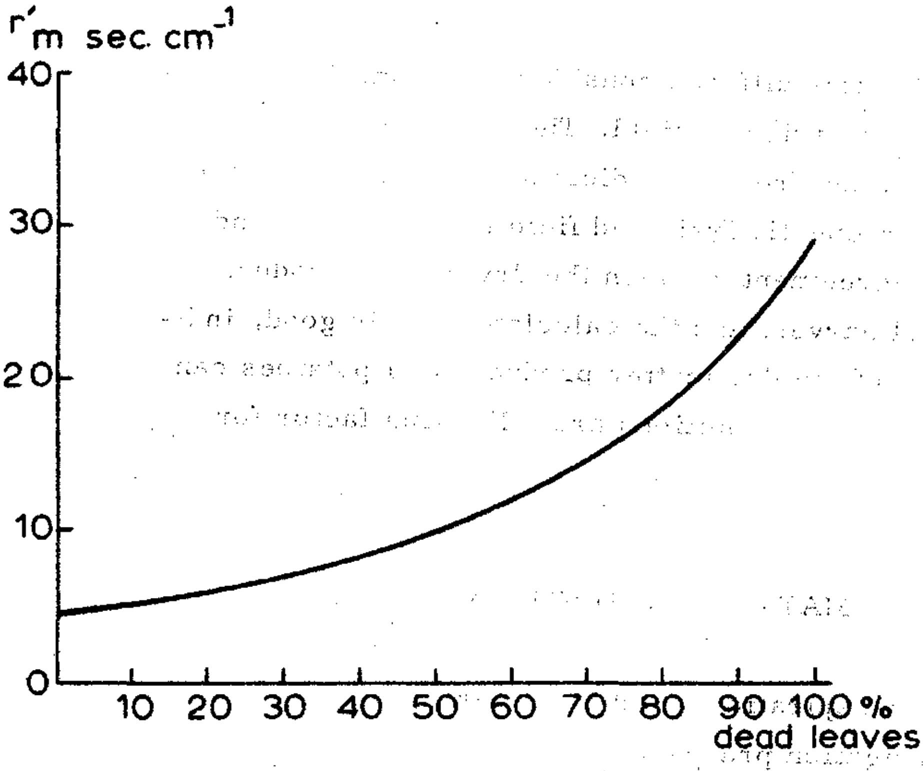

Fig. 3. The estimated relation between the internal diffusion resistance and the percentage of dead leaves in the canopy

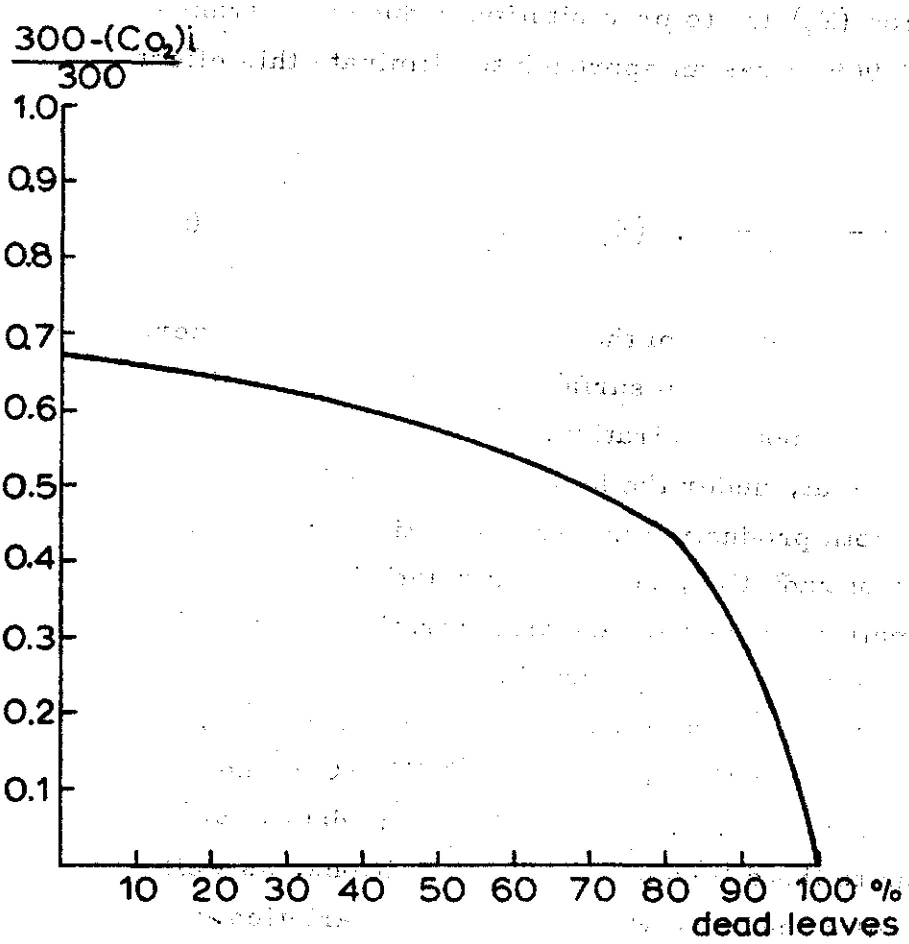

Fig. 4. The estimated relation between the photosynthetic efficiency and the percentage of dead leaves in the canopy

number of dead leaves with time differed considerably from the corresponding data of the frequently irrigated field. The comparison of the calculated data with those obtained from periodical harvests is presented in fig. 5. The data of the frequently irrigated field in 1961, 1962 and 1964 are also given. The agreement between the dry matter production according to the periodical harvest and the calculated one is good, indicating that a fair approach of the dry matter production of potatoes can be obtained, even when moisture conditions are a limiting factor for production.

4. TRANSPIRATION AND DRY MATTER PRODUCTION

The relation between transpiration and dry matter production is of particular interest for irrigation practice, since the optimum irrigation gifts with respect to the production can be determined from this relation. The evaporation of intercepted precipitation, however, affects this relation, as the evaporation (E_I) due to precipitation reduces the transpiration rate. RIJTEMA (1969) gives an approach to eliminate this effect, using the expression:

$$\dot{E}_T^{re} = \frac{E_{wet}}{E_{wet} - E_I} \cdot (E_{re} - E_I) \qquad (5)$$

where $\dot{E}_T^{re}$ is the transpiration rate from the crop, when E_I equals zero, E_{wet} the evaporation rate when the crop surface is continuously wet and E_{re} the calculated real evapotranspiration.

DE WIT (1958) concludes that, under the humid climatological conditions in the Netherlands, both production and transpiration are mainly determined by the amount of radiation, so a linear relationship has to be present between dry matter production and transpiration, as far as no other factors become limiting for crop growth.

The relation between total dry matter production (P) and the values of $\dot{E}_T^{re}$, derived from the transpiration data given by ENDRODI and RIJTEMA (1969) is presented in fig. 6. The scatter in the data is very large, which is partly due to the different climatic conditions, as well as partly due to existing differences between the various varieties.

It appeared from the discussion on the photosynthesis of the potato crop, however, that the diffusion process highly affects the dry matter

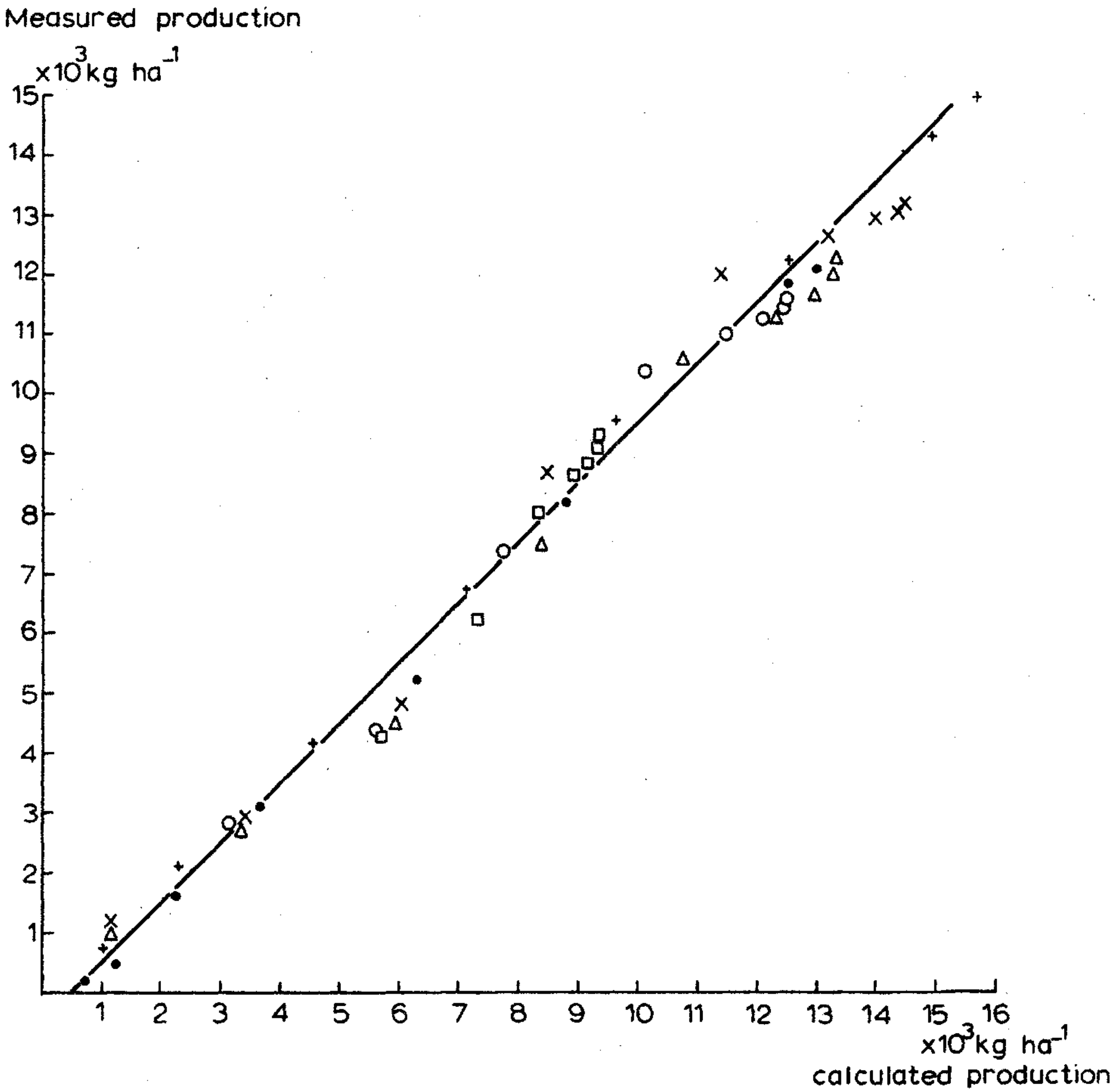

Fig. 5. The relation between the calculated actual production with eq. 4 and the data obtained from periodical harvests

+ 1961 Libertas	◻ 1964 Surprise v_o
• 1962 Surprise	○ 1964 Surprise v_1
× 1964 Surprise v_3	Δ 1964 Surprise v_2

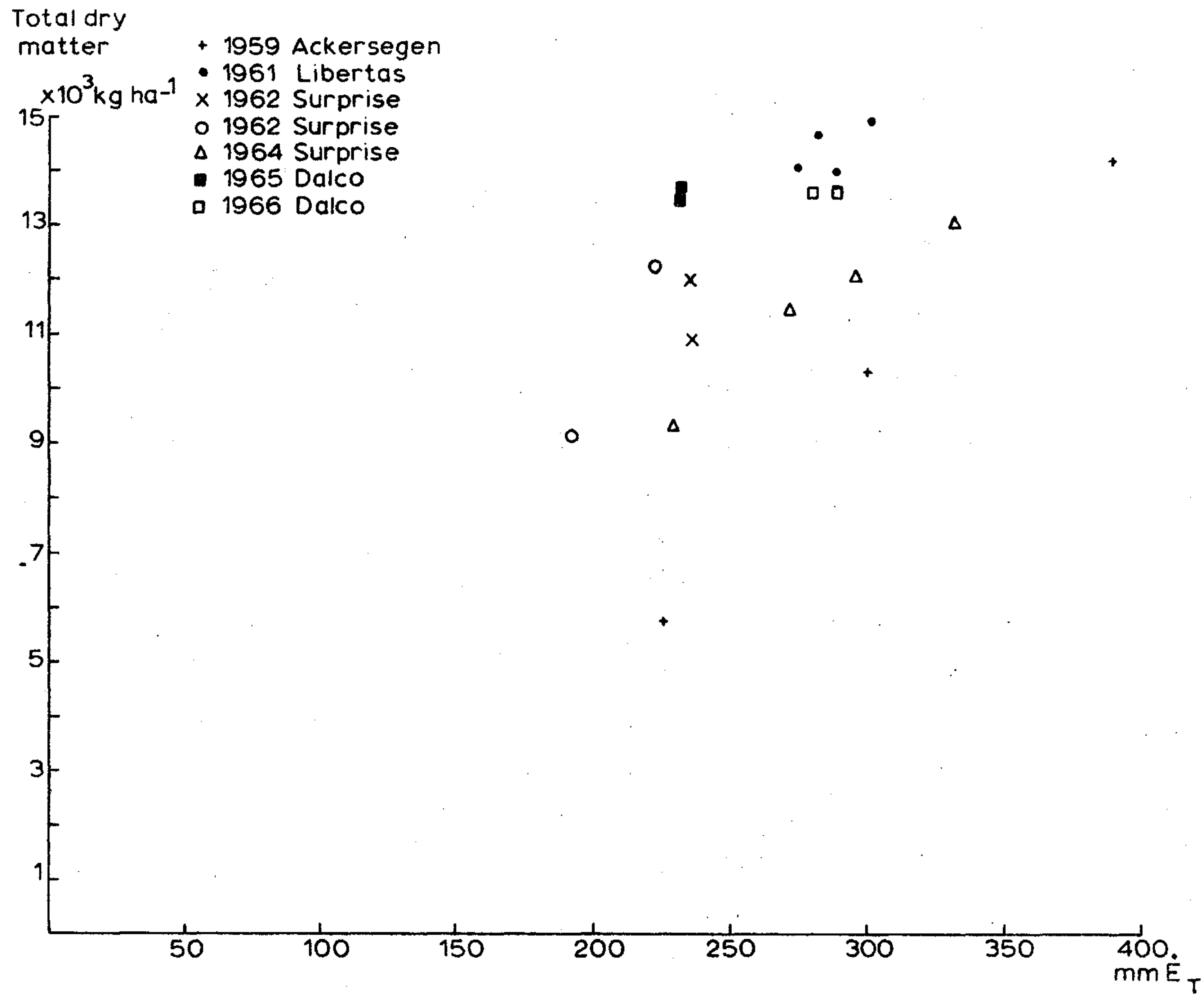

Fig. 6. The relation between transpiration and total dry matter production

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production. When considering the diffusion process as the limiting factor for production it has been shown (BIERHUIZEN and SLATYER, 1965; RIJTEMA, 1966) that a linear relationship between the total dry matter production and the ratio transpiration over mean vapour pressure deficit (ε_a - e_a) can be expected, which is independent of the climatic conditions. The relation between total dry matter production and the transpiration - vapour pressure deficit ratio is presented in fig. 7. The results in this figure show, that the scatter in the data in fig. 6 is mainly due to differences in climatic conditions in the various years.

The relation between dry matter production and the transpiration-vapour pressure deficit ratio appears to be practically independent of the potato variety used in the experiments during the various years.

The somewhat deviating results obtained from the irrigated fields under the extreme dry conditions in 1959, can be mainly explained by the procedure used for the determination of the mean suction in the root zone of the crop (ENDRODI and RIJTEMA, 1969). Large amounts of irrigation water were given a few days after soil sampling, while the mean suction during the various balance periods was determined from the soil sampling data. Due to this procedure the mean suction was seriously overestimated, which resulted in an underestimate of the real transpiration rate.

5. DISTRIBUTION OF DRY MATTER

Though the total dry matter present at harvest gives a good indication of the growing conditions, the farmer will be much more interested in the yield of those parts of the plant, which are of economical interest. These yields, however, strongly depend on the distribution over the various parts of the plant. The relation between total dry matter production and the dry matter present in the potato tubers of the different varieties is presented in fig. 8. The data presented in this figure were obtained from periodical harvests, as well as from some other experiments, concerning timing of irrigation. The relationship is a linear one in the range of practical importance. Small differences between the varieties might be present, but the scatter in the data is such, that

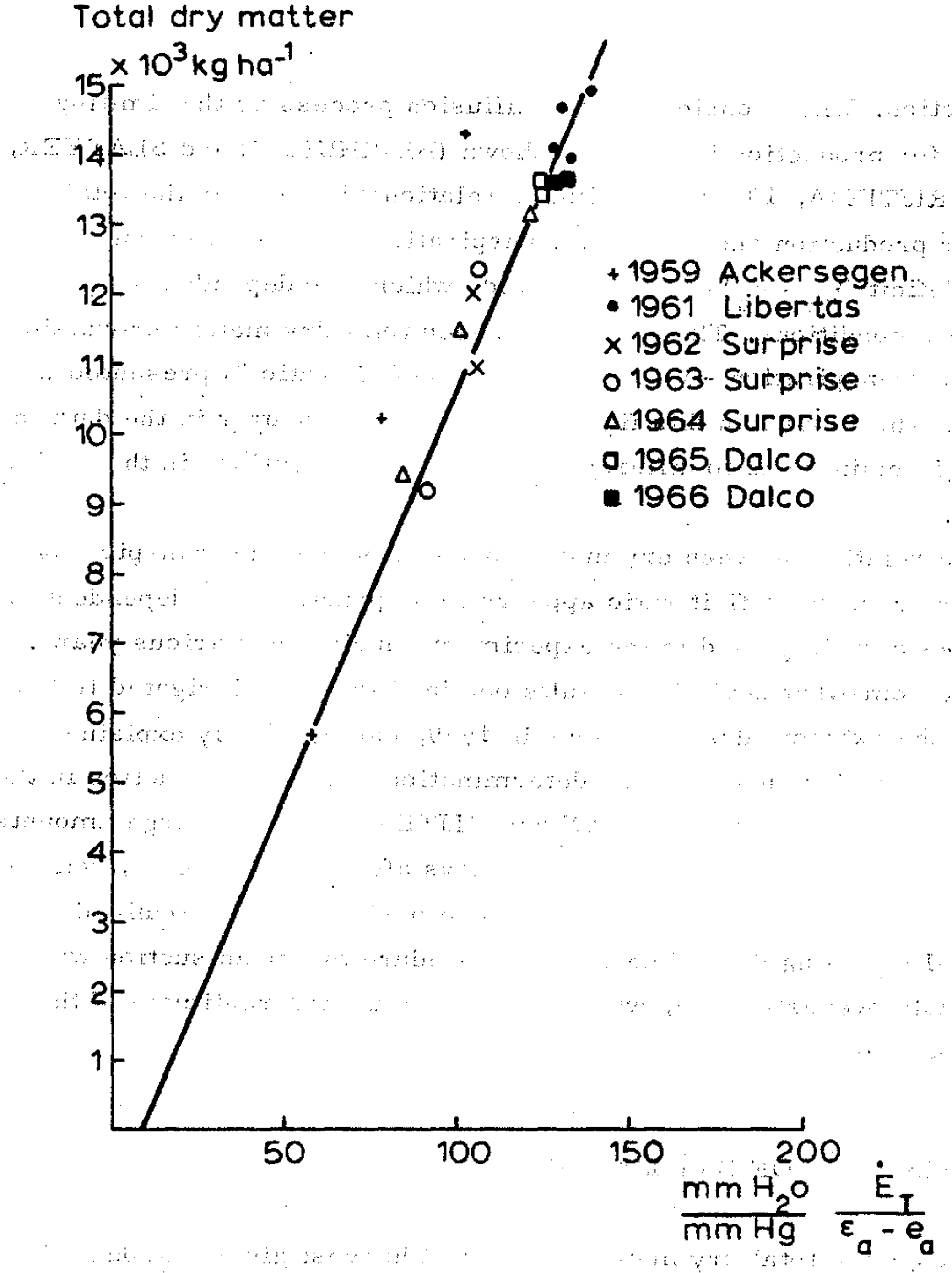

Fig. 7. The relation between total dry matter production and the transpiration - vapour pressure deficit ratio

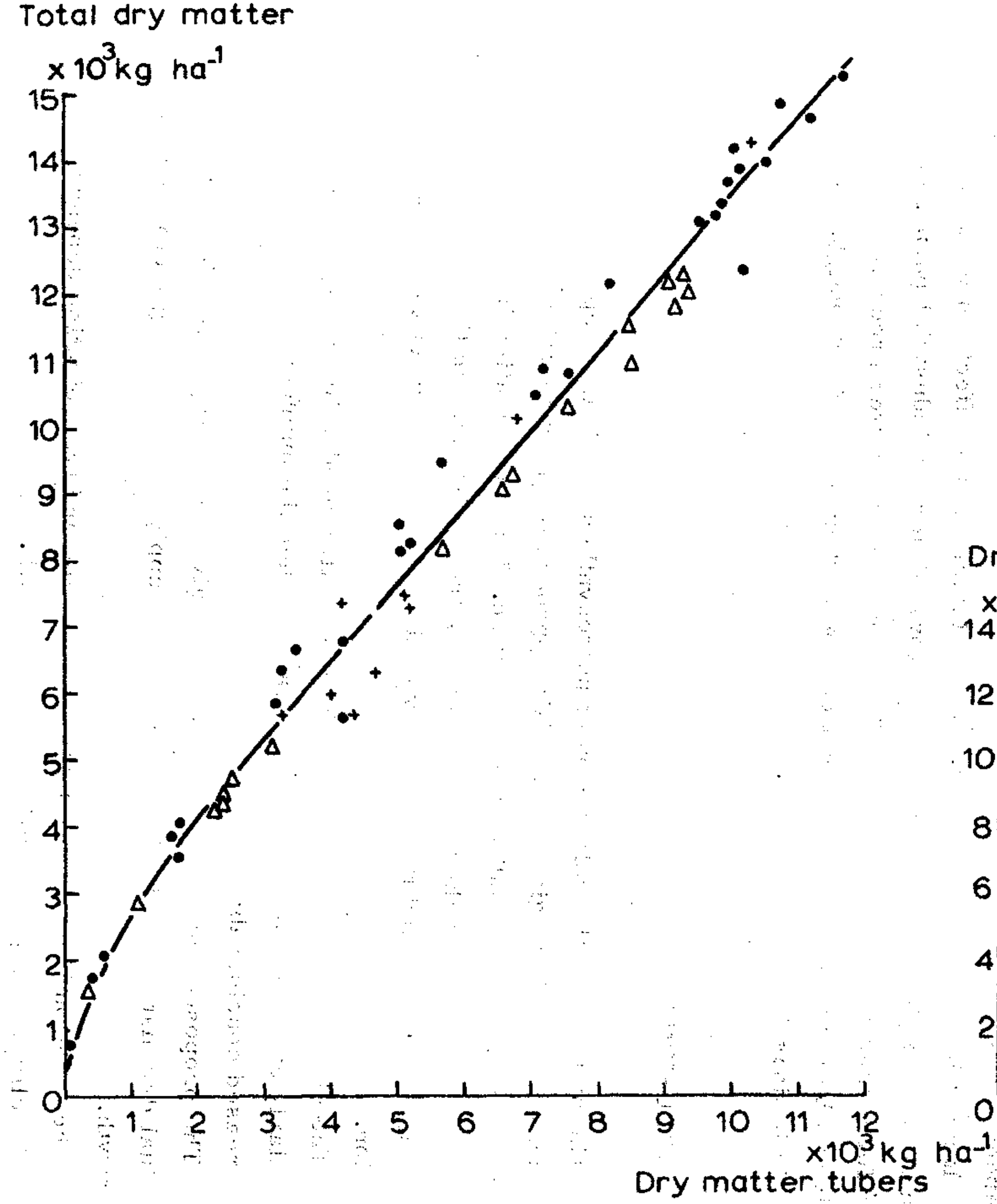

Fig. 8. The relation between total dry matter production and dry matter present in the tubers

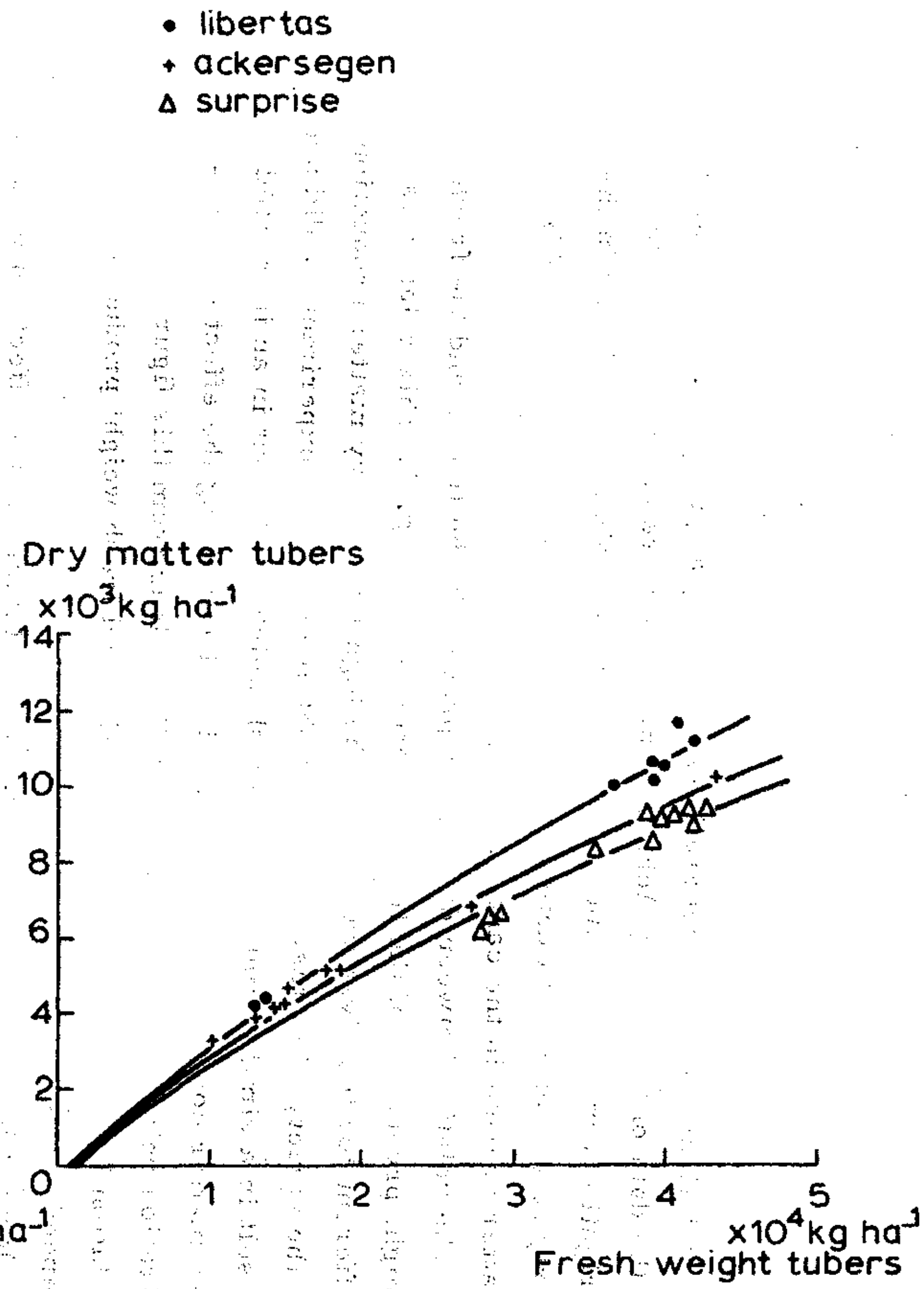

Fig. 9. The relation between dry matter production of tubers and fresh weight yield

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the relationship can be generalized for practical purposes. The scatter in the data of the variety Ackersegen, which were obtained from the irrigation timing experiments, show that the moisture conditions in the early stages of growth determine to a great extent the amount of dry matter present in the canopy.

The relation between dry matter present in the tubers and the fresh weight production of the tubers is presented in fig. 9. This relation is different for the given varieties. The high level of dry matter production of the variety Libertas, which was obtained in these experiments, did not result in a similar high level of fresh weight yield, but in an increased dry matter content of the tubers. When determining the effect of transpiration on fresh weight yield, it will be clear from this figure that the relation between dry matter production and fresh weight production depends on the variety used.

It must be realized, however, when determining the effects of drought on the potato yield, that the crop was grown either for industrial purposes or for human consumption. In the first case the dry matter production gives a better indication of drought damage, whereas the fresh weight yield it **does** in the latter case.

6. CONCLUSIONS

The method for the calculation of photosynthesis of leaf canopies, as proposed by De Wit, gives only a fair approach to the production of a potato crop, when a modification is applied. This modification includes the effect on photosynthesis of soil cover, the resistances in the CO_2 diffusion path-way and the efficiency of the crop, with respect to respiration.

The diffusion process affected the dry matter production highly, particularly at the end of the growing season, when the number of dead leaves increased considerably.

The proposed modified method did also give a good approximation of the actual dry matter production, when water supply was a limiting factor for growth.

The relation between dry matter production and transpiration depends on the climatological conditions during growth.

The linear relation between dry matter production and the transpiration - vapour pressure deficit ratio is independent of the climatological conditions. Differences in variety did not affect this relationship.

Differences in the maximum production of the varieties is mainly determined by the length of the growing season.

For practical purposes a linear relationship can be given between total dry matter production and dry matter present in the tubers. This relationship holds for different varieties.

The relation between dry matter production and fresh weight yield of the tubers depends on the variety.

7. SUMMARY

A discussion of the net photosynthesis of a potato crop was given. It appeared to be possible to calculate the actual dry matter production, even when water supply limited growth, using a modification of the procedure proposed by DE WIT (1965).

The relation between transpiration and dry matter production was dependent on the climatological conditions during growth, but not on specific differences between the varieties used in the experiments.

The distribution of dry matter over the various parts of the plants was discussed.

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