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NEDERLAND 59 (17) 1–8 (1959)

SOME REMARKS ON FACTORS DETERMINING THE WATER REQUIREMENT IN TOMATO PLANTS UNDER CONTROLLED CONDITIONS

by

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(Received 14.12.'59)

The following comments are based upon the observations communicated in (1). As an introduction we will first point out some features of the experiments.

Initially, the pots were brought to field capacity, and during the experiment gradually dried, owing to evaporation of the soil and transpiration of the growing plants. When the water content in the soil had decreased to a certain level as indicated by the total water loss determined by daily weighing, the initial water level was restored. As mentioned in the article, it has been aimed at four different average levels of water content (A, B, C and D). The more these average levels differed from field capacity (indicated as 100%), the larger the range of water contents passed by during the course of the experiment, and the rarer the new supplies of water. The temperature also influenced the frequency of water supply, because it influenced the rate of transpiration.

Since normally, during the experiment the pots were not covered in order not to interfere with gas exchange in the soil, the daily measured loss in weight represented evapo-transpiration, the combination of evaporation and transpiration. The water loss per day was expressed in mm/day per pot. Since the water loss was large in relation to the gain in weight of the plant, the latter could be neglected.

Once a week, transpiration has been measured during one day by providing each pot with a plastic cover. These measurements are necessarily less accurate than the evapo-transpiration values, mainly for two reasons. First, since they were made only four times in 28 days, while the evapo-transpiration values were recorded every day. Secondly – and probably most important – these weekly measurements did not actually take place at exactly the average water content aimed at, since they had no definite time distance to the previous intermediate water supply.

In fig. 1, we have plotted the evapo-transpiration values against soil moisture at various temperatures. The curves point to fairly linear relationships, the slopes of which strongly increase with temperature.

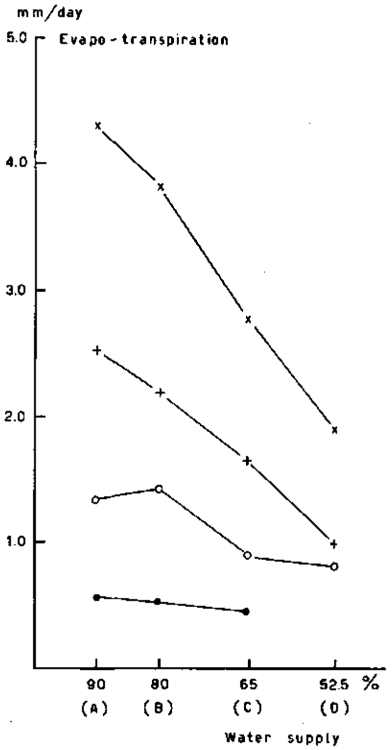


FIG. 1. The effect of air temperature and water supply on evapo-transpiration in mm/day, measured daily.
×——× 25.7 °C, +——+ 20.0 °C,
o——o 15.6 °C, ●——● 10.4 °C.
The water supply is given on the abscissa as mean available soil moisture content in %.

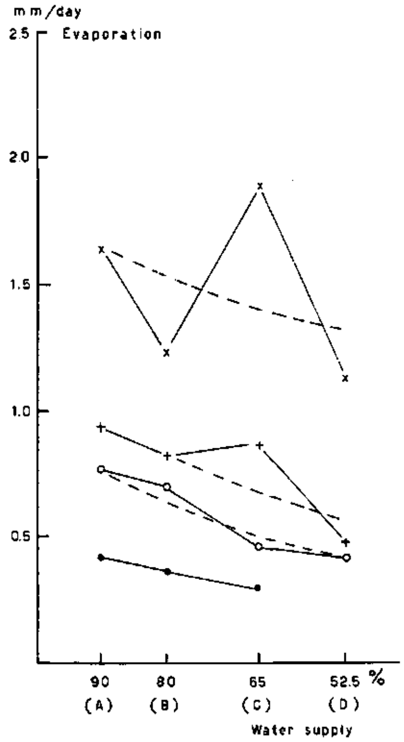


FIG. 2. The effect of air temperature and water supply on evaporation of the soil in mm/day, measured once a week.
×——× 25.7 °C, +——+ 20.0 °C,
o——o 15.6 °C, ●——● 10.4 °C.
The water supply is given on the abscissa as mean available soil moisture content in %.

In fig. 2, the available evaporation data have been plotted in a similar way. Apart from the data at 25.7 °C, they suggest curves with slopes slightly increasing with temperature, and also with soil moisture. The evaporation values are important fractions of the evapo-transpiration, even at the highest temperature.

The values at the three lowest temperatures allow to draw average lines through the experimental data from which the single points rarely deviate more than 10 per cent.

The values at 25.7 °C require a separate discussion. They do not show a clear relationship with the water content of the soil. This may be partly due to the formation of a thin, relatively dry layer on top of the soil, and probably to some other circumstances, discussed above. Admitting a considerable uncertainty we have drawn through the available data a curve similar to those for the lower temperatures. We have used the idealized evaporation values, thus obtained for the water contents A, B, C, and D, for calculating true transpiration values, in subtracting these evaporation values from the actually measured evapo-transpiration values. This gives the transpiration data of Table I and figure 3.

TABLE I. The effect of air temperature and water supply on evapo-transpiration, evaporation, transpiration and water requirement.
The data on evapo-transpiration are those in Table I in (1), the data on evaporation are taken from the idealized curves, represented in fig. 2 while the transpiration has been calculated from the data on evapo-transpiration and evaporation mentioned above. One may obtain the data on water loss in g by multiplication of the values in mm with 8.81, being the "pot factor".

Temperature in °C Irrigation regime	25.7	20.0	15.6	10.4
	Evapo-transpiration in mm/day			
A	4.33	2.53	1.33	0.59
B	3.85	2.20	1.40	0.52
C	2.71	1.64	0.87	0.44
D	1.86	0.97	0.79	
	Evaporation in mm/day (idealized, according to broken lines in fig. 2)			
A	1.65	0.95	0.75	0.42
B	1.55	0.80	0.63	0.37
C	1.40	0.70	0.50	0.30
D	1.30	0.55	0.40	
	Transpiration in mm/day			
A	2.68	1.58	0.58	0.17
B	2.30	1.40	0.77	0.15
C	1.31	0.94	0.37	0.14
D	0.56	0.42	0.39	
	Water requirement in mm/g dry matter production			
A	94	75	44	31
B	75.5	76	42	31
C	60	57	34	33
D	37	37	41	

Furthermore, figure 4 represents the relation between true transpiration, as determined above, and the gain in dry weight. All data, without a special separation between various temperatures and moisture contents, fit a smooth curve. The curve shows a steep initial slope (indicating a large gain in dry weight for little transpiration) followed by a bend and an about four times smoother final slope, extending up to the highest figures recorded.

Departing from this curve – or its basic figures – it is interesting to calculate the water requirement in the various cases, *viz.* the amount of water transpired (Tr) per gram gain in dry weight (D). This is shown in fig. 5, and provides a remarkable – though probably understandable – picture.

At 25°, the values of Tr/D for the various water contents A, B, C, D show a linear relationship, intersecting the abscissa (Tr/D = 0) at a point E, corresponding to about 23% available soil moisture. It appears premature at the

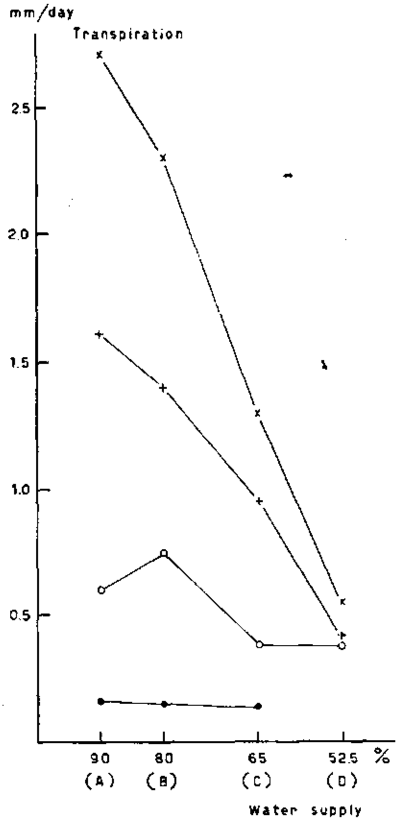


FIG. 3. The effect of air temperature and water supply on transpiration of the plants in mm/day, calculated from the data on evapo-transpiration (fig. 1) and the idealized data on evaporation, represented by the smooth curves from fig. A2 (see Table I)

×——× 25.7°C, +——+ 20.0°C,
o——o 15.6°C, ●——● 10.4°C.

The water supply is given on the abscissa as mean available soil moisture content in %.

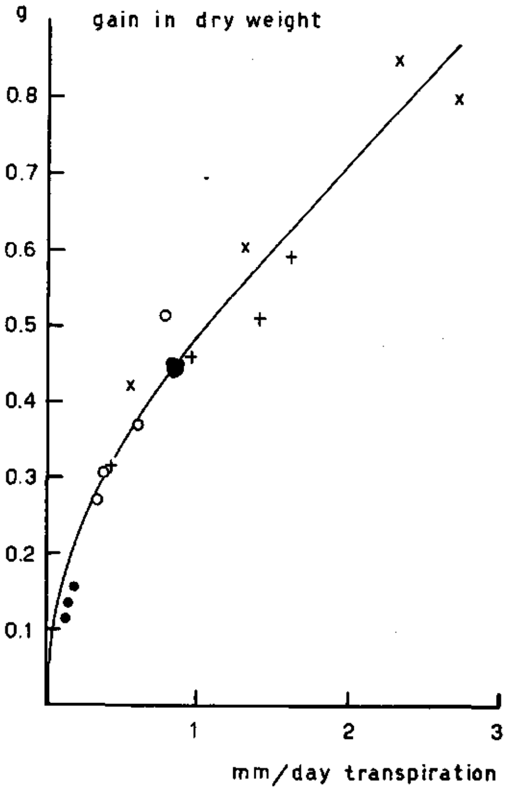
moment to speculate about the physiological meaning of this intersection point.

The curves for the lower temperatures show interesting deviations from the above. At 20°, the values of Tr/D for D, C, and B practically coincide with those at 25°, they fit the same sloping line. The value for A, however, is the same as that for B. The values for 15° and 10° more or less fit horizontal lines at two different levels. It should be noted that the D-point of the 15°-line again very well fits the sloping line through the 25°-points while the A-, B-, and C-points of the 15°-curve are situated far below this line.

The shape of the set of curves strongly indicates the presence of two mutually independent limiting factors. One is the availability of water from the soil which governs the entire behaviour at 25°. The other obviously enters as a limiting factor by decrease of temperature, and the more so the lower the temperature is. It does not seem easy offhand to express an opinion on the nature of this factor, since it affects the quotient Tr/D, and may be determined by changes in Tr as well as by those in D.

Interpreting Tr/D as "transpiration per unit plant weight", and disregarding how this plant weight has come into being, we may consider the curves obtained from the viewpoint of water relationships. At the right side of the graph we have marked the VPD-values of Table I (1), making the 15° value fit with the corresponding level of the graph. It is seen that the coincidense of the 20° value

FIG. 4. The relation between gain in dry weight in g and the transpiration, values of Table I.
×——× 25.7°C, +——+ 20.0°C,
o——o 15.6°C, ●——● 10.4°C.



with the appropriate level is excellent, the VPD value at 25° is beyond any value observed which is in accordance with the lack of a saturation level at 25°; only the VPD value at 10° would lead to the expectation of a much lower level than that actually found.

In a similar way, we have introduced the "PICHE-evaporation" values of Table I (1) at the right side of figure 5, again adjusting the 15° value to the level of the graph. In this case, both the 10° and the 20° value fit almost exactly the observed levels, while the 25° value again is far above any experimental point.[1]

We thus arrive at the somewhat unexpected conclusion that each unit of plant material, once formed, transpires exactly like a PICHE evaporimeter, as far as available soil moisture allows the required transpiration intensity. This, of course, does not claim anything about the relation between the *absolute* amounts of water evaporated by a PICHE evaporimeter, and by a plant; if required, this relation can easily by calculated. At present, we are only concerned with the limiting factors for transpiration.

Obviously, for an elementary understanding of the Tr/D graphs, no knowledge about limiting factors in photosynthesis and growth is implied. It seems that the simple presence of the structured plant material alone determines the relationship. This points to a rather loose connection between transpiration and

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[1] Since PICHE evaporation values would be expected to give a fairly true representation of VPD, the deviation of the VPD value at 10°C is unexplained!

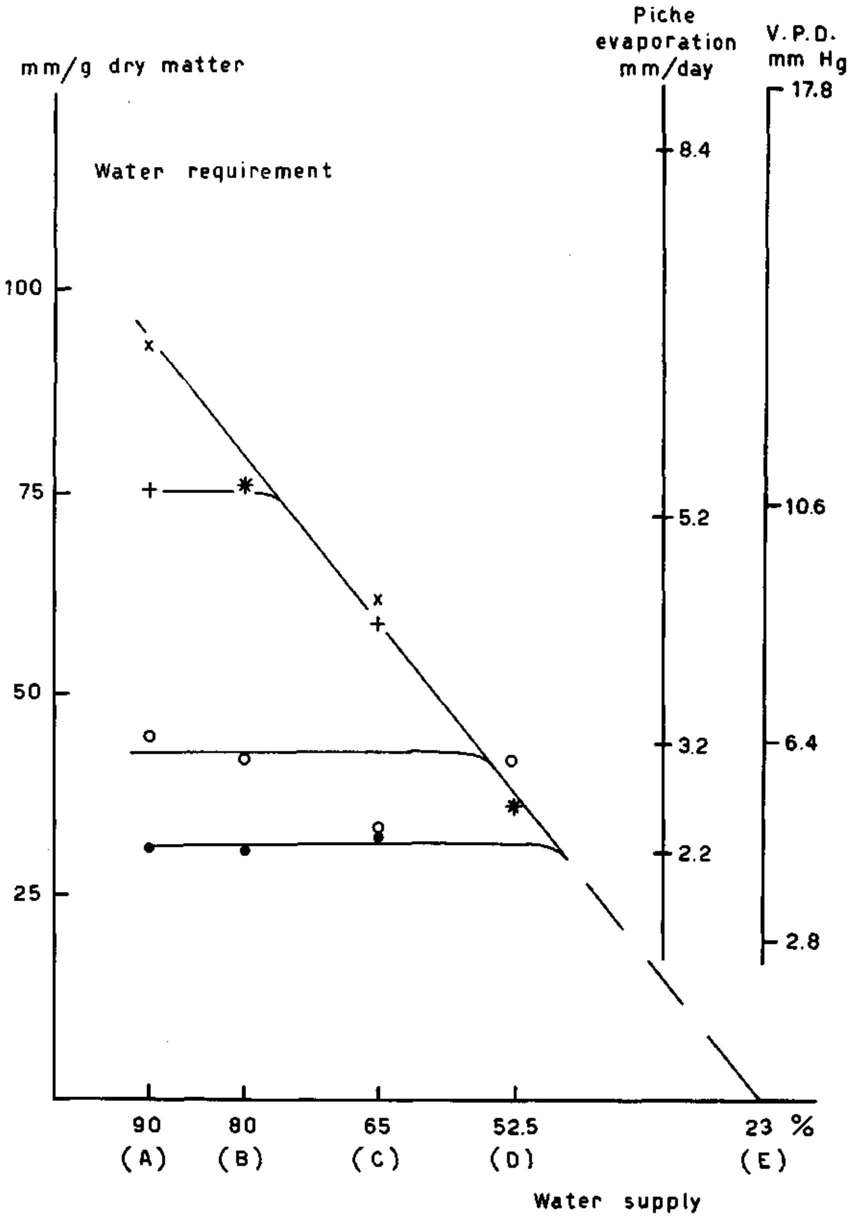

FIG. 5. The effect of air temperature and water supply on the water-requirement, expressed as transpiration in mm per g dry matter (Table I). The constant levels are compared with the data on PICHE-evaporation and the VPD-values.

×——× 25.7°C, +——+ 20.0°C, o——o 15.6°C, •——• 10.4°C.

(⁎ combination of × and +)

The water supply is given on the abscissa as mean available soil moisture content in %

synthesis (growth) which is not so remarkable since the amount of water transpired is several hundred times the gain in dry weight.

Conversely, there is probably space for the assumption that gain in dry weight and transpiration are governed in a similar way by temperature. Figures 3 and 6 show that both transpiration and dry weight have similar relationships to temperature and to soil water supply, *viz.*, fairly linear relations in both cases with increasing slopes, both in relation to temperature and to water supply. From these figures it cannot be foreseen offhand that the "BLACKMAN"-type relationships of figure 5 for water requirement result. The fact that this occurs implies that both synthesis (in general, not necessarily photosynthesis proper) and transpiration are limited by availability of water. The factors limiting this availability are either 1) soil moisture, for the points on the 25°-line, or 2) VPD, for the levels below the 25°-line.

These data strongly indicate that limitations for synthesis are not necessarily the same as those for photosynthesis. In the present case photosynthesis may be limited by light intensity at the higher temperatures, and by enzymatic reactions at the lower temperatures; this, however, has not been measured.

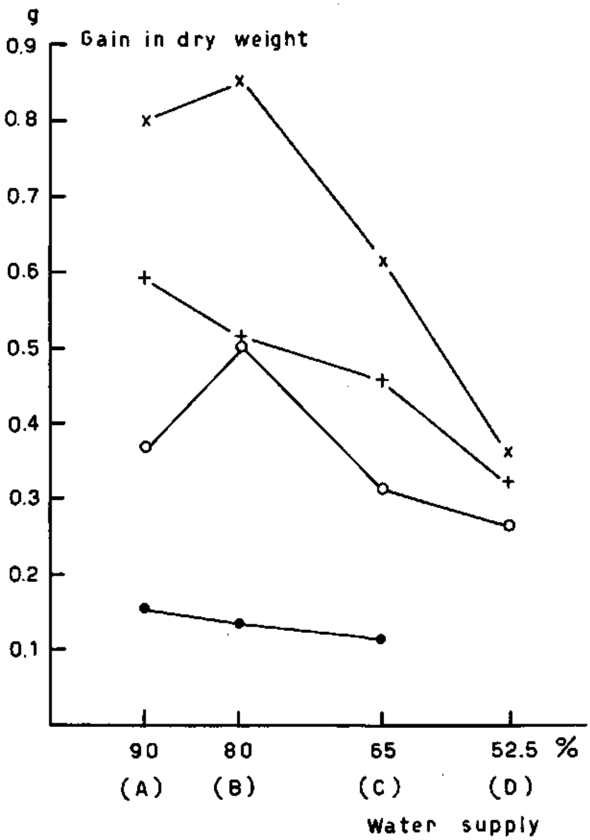

FIG. 6. The effect of air temperature and water supply on gain in dry weight in g.
×——× 25.7°C, +——+ 20.0°C, o——o 15.6°C, ●——● 10.4°C.
The water supply is given on the abscissa as mean available soil moisture content in %.

A subsequent article (2) deals with observations on the relation between dry matter production, transpiration, and soil temperature, under the A-condition of soil moisture. Also water requirement values have been determined. The soil temperature was 15°, 20°, 25°, and 30 °C respectively, while the air temperature was 25 °C. The Tr/D-values nicely confirm and extend some of the above conclusions.

Up to 25 °C soil temperature, the Tr/D-values are about the same, and about equal to the A-value at 25 °C in figure 5. Thus, the 15° and 20 °C soil temperatures yield much higher values than those in figure 5. This confirms that, in figure 5, at 15° and 20 °C, VPD determines the rate of transpiration; the other possibility, that limitation of water uptake by low root temperature determines the 15° and 20 °C levels in fig. 5 is ruled out by the observation that increase in VPD at the same root temperatures increased transpiration. It should be observed that also dry weight increased with increasing soil temperature. It is interesting, moreover, that, at 30 °C root temperature, the Tr/D-value is considerably higher than that observed at 25 °C. This is also in agreement with figure 5: the VPD value at 25 °C still allows a higher Tr-value than that at 25 °C root temperature. This shows, moreover, that at the water supply A, and 25°, root temperature is the limiting factor for water uptake and, by interference, for transpiration.

SUMMARY

Some results of a previously published experiment from this laboratory on the effect of temperature and water supply on growth, transpiration, and water requirement of tomato plants (1) are discussed. The water requirement has been recalculated from data on evapo-transpiration and dry matter production, introducing more or less idealized curves for the evaporation rate. Plotting the water requirement against water supply, typical curves of the "BLACKMAN"-type are obtained, indicating the presence of two mutually independent limiting factors. At higher temperatures the water requirement is limited by the availability of water from the soil within a wide range of water supply. The saturation levels, found at lower temperatures coincide with the corresponding PICHE evaporation measurement and with the values of vapour pressure deficit.

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