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Growth rates of tomato seedlings and seasonal radiation*

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Summary

During the years 1970 to 1972, 34 batches of tomatoes were sown at regular intervals. Until the plants flowered, their fresh weight was determined once or twice a week. The data were used to calculate daily growth percentages and the number of days required by the plants to develop from 0.1 to 10 g fresh weight per plant. For each of the growing periods the radiation totals and the average radiation per day were calculated. The data obtained were related to each other and compared with the information obtained by other research workers.

The growing methods used resulted in substantially higher growth rates and higher light efficiency than were known from previous work carried out under natural light conditions (Brouwer, 1973). However, the same very high relative growth rates have been recorded more recently in growth chambers with artificial irradiation (Hurd & Thornley, 1974).

Nevertheless, there are still unknown factors which have caused a disproportionate reduction in the light efficiency of many batches during the summer period. Further investigations into these aspects are necessary.

Introduction

Plant growth, and especially the rate of growth of young tomato seedlings, varies with the time of year. This well-known phenomenon has been described and quantified by a number of research workers (Blackman et al., 1955; Bunt, 1972; Cooper, 1966, 1967; Hegarty, 1973; Hodgson, 1967; Voldeng & Blackman, 1963). Apart from the effects of temperatures, the amount of daily radiation is generally regarded as the direct cause of growth variations.

The data are presented as annual growth curves and occasionally as light efficiency curves. There are very large variations in the absolute growth rates recorded by different workers (Warren Wilson, 1966).

The data in this publication are of a similar nature, although the aim has been to achieve maximum growth rates in all seasons. A plentiful supply of water and automated fertilization proved to be crucial for this. The temperature regime was also found to be very important.

Thirty-four sowings were made between 1970 and the end of 1972. In many

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cases the treatment giving the quickest growth was chosen from an experiment as the basis for the annual cropping programme. The starts of the treatments were also selected in such a way that an evenly distributed annual cycle was obtained (see also de Lint & Klapwijk, 1973, 1974).

Samples were taken from the different batches, twice a week in summer and once a week in winter. This means that five to eight observations were made for each sowing from the moment of emergence until the first truss came into flower. The data obtained were used for plotting growth curves. Those sections of the growth curves representing the development of the plants from 0.1 g to 10 g fresh weight per plant were analysed further and related to the amounts of light received.

The information obtained is discussed and compared with the data obtained by other research workers.

Materials and methods

Tomatoes of the cv 'Moneymaker' were sown directly into 3-litre black plastic pots filled with peat compost. The compost consisted of a mixture of 85 % sphagnum peat and 15 % black sedge peat. To each cubic metre of the mixture were added 5 kg of ground dolomite lime stone, 1.5 kg compound fertilizer (14-14-14), 0.5 kg Sporumix PG (25 % MgO, 0.3 % Cu, 0.1 % B, 0.6 % Mo and 0.5 % Mn), and 25 g Fe 138 (chelated iron).

After emergence, the seedlings were thinned to 8 to 10 per pot, leaving a uniform stand of plants in each pot. When the plants developed they were thinned again to avoid overcrowding. The thinnings were used as samples for the determination of fresh weights. Other growth characteristics were not measured as these can be deduced adequately from the fresh weight figures (de Lint & Klapwijk, 1974).

The plastic pots were placed on glasshouse staging in 2 cm of liquid feed in which they remained for the duration of the experiment. Root development was satisfactory even in the layer of peat which was submerged in the nutrient solution (de Lint & Klapwijk, 1974). The nutrient solution was prepared from a compound fertilizer (13-5-13-5) and its concentration was automatically controlled at about 1 atm osmotic pressure by resistance measurement. The pH and electric conductivity of the nutrient solution were determined in the laboratory once a week. The solution in the glasshouse staging was replaced twice a day in summer and once a day in winter.

The glasshouse used for the experiments was a Venlo type block of average height, metal clad, with a bay width of 4.8 m and two-sided half-length ridge ventilation. Light transmission was 70 % maximum.

Between May and September 1970 and 1971, the average maximum day temperature was 35 to 37 °C. In 1972, the thermostat was moved from between the plants to an insulated, aspirated screen. As a result the summer temperature dropped to 30 to 32 °C. During the winter months the temperatures gradually dropped to an average maximum day temperature of 22 to 24 °C. The average minimum night temperature was 20 to 22 °C between March and October and gradually decreased in winter to 14 to 16 °C. No CO_2 enrichment was applied.

Table 1. Sowing dates, fresh weights (g/plant) and days after sowing of the observations.

Experiment No.	Sowing date	Fresh weights after . . . days															
		days	g	days	g	days	g	days	g	days	g	days	g	days	g	days	g
1	14 Jan. '72	6	0.0176	13	0.0478	20	0.141	28	0.616	34	2.50	42	8.80	49	29.9	56	84.3
2	3 Feb. '72	6	0.0133	8	0.0251	14	0.136	22	0.560	29	3.40	36	14.5	43	62.1	50	108
3	25 Feb. '72	7	0.0172	14	0.214	21	2.21	28	21.4	32	44.8	34	64.6				
4	26 Feb. '71	14	0.164	18	0.567	21	1.14	24	3.25	27	7.43	38	89.5				
5	17 March'72	7	0.0249	13	0.155	18	0.895	21	2.63	28	27.2	35	121				
6	19 March'70	6	0.0235	13	0.285	18	1.57	21	4.37	25	13.4	34	113				
7	7 April '72	6	0.0191	14	0.270	19	2.43	21	4.13	28	34.2	35	130				
8	26 April '71	11	0.118	16	0.540	18	1.31	22	3.69	28	28.5	36	101				
9	6 May '70	5	0.0113	9	0.0950	14	0.622	16	4.42	19	4.42	22	12.7	33	162		
10	10 May '71	11	0.120	16	0.458	22	2.75	29	20.8	36	75.8						
11	28 May '71	12	0.200	14	0.480	18	2.32	25	19.7	31	78.2						
12	15 June '70	7	0.0305	14	0.455	18	2.11	24	15.3	37	207						
13	18 June '71	10	0.105	14	0.613	17	1.50	21	5.37	31	69.2						
14	9 July '71	10	0.123	14	0.535	19	4.29	24	13.3	31	65.7	35	108				
15	20 July '72	15	0.310	19	1.88	22	4.99	27	21.2	41	221						
16	29 July '71	11	0.114	15	0.416	19	1.67	25	13.7	32	53.3	39	152				
17	30 July '71	11	0.177	12	0.232	14	0.436	21	5.79	25	20.3	28	41.6	38	166		
18	13 Aug. '70	8	0.0459	13	0.320	15	0.844	18	2.41	22	8.65	35	134				
19	18 Aug. '71	12	0.263	15	0.800	19	3.68	22	11.5	26	33.7	29	62.1				
20	20 Aug. '71	10	0.0810	13	0.289	17	1.20	20	4.01	24	12.6	32	61.6	38	98.1		
21	31 Aug. '72	11	0.139	14	0.236	18	0.806	21	2.64	25	9.55	28	20.3	32	47.2	36	86.2
22	10 Sept. '71	6	0.0233	11	0.130	14	0.337	17	0.845	21	2.88	31	28.8	38	62.8	42	98.6
23	21 Sept. '71	13	0.0800	18	0.433	22	1.57	27	5.20	29	7.50	35	25.5	39	45.7	43	84.4
24	1 Oct. '70	6	0.0740	8	0.0264	11	0.0732	15	0.234	19	0.651	22	1.33	29	4.85	56	66.0
25	1 Oct. '71	10	0.0990	14	0.255	17	0.625	21	1.70	26	6.00	30	19.9	35	30.8	41	60.8
26	5 Oct. '72	15	0.0857	18	0.170	25	1.01	29	3.20	34	6.92	43	26.1	49	53.3	57	104
27	19 Oct. '72	11	0.0364	15	0.125	20	0.235	29	1.33	35	3.36	43	12.5	47	27.4	54	45.5
28	2 Nov. '72	15	0.130	21	0.290	26	0.900	29	1.54	33	3.50	40	8.90	49	20.6	60	51.9
29	5 Nov. '71	13	0.0453	20	0.116	27	0.295	34	0.665	42	1.86	52	4.52	62	10.3	76	28.0
30	17 Nov. '72	14	0.0375	24	0.124	32	0.513	40	1.42	46	4.47	53	7.30	60	12.4	67	24.2
31	18 Nov. '70	15	0.0420	23	0.134	30	0.277	36	0.453	43	1.09	51	3.36	70	28.6		
32	2 Dec. '71	15	0.0489	25	0.125	35	0.361	49	1.62	56	3.17	63	8.18	71	24.6	77	53.3
33	3 Dec. '70	7	0.0124	14	0.384	19	0.0629	36	0.520	55	5.28	84	90.6				
34	23 Dec. '71	14	0.0327	28	0.154	35	0.408	42	1.06	50	3.92	56	9.05	64	34.1	71	90.6

Table 2. Relationship between fresh weight ranging from 0.1 - 10 g per plant (y) and time (x) according to the equation log y = ax + b.

Experiment No	Regression coefficient (a)	Constant (b)	Correlation coefficient (r)
1	0.0805	– 2.4349	0.9982
2	0.0939	– 2.2270	0.9975
3	0.1317	– 2.4683	0.9961
4	0.1287	– 2.5772	0.9988
5	0.1497	– 2.7441	0.9999
6	0.1409	– 2.3592	0.9987
7	0.1478	– 2.5388	0.9932
8	0.1397	– 2.4645	0.9988
9	0.1683	– 2.5860	0.9986
10	0.1250	– 2.3129	0.9998
11	0.1517	– 2.4544	0.9968
12	0.1515	– 2.4379	0.9992
13	0.1310	– 2.1260	0.9934
14	0.1301	– 2.0716	0.9894
15	0.1512	– 2.6906	0.9932
16	0.1303	– 2.3065	0.9935
17	0.1444	– 2.3470	0.9986
18	0.1577	– 2.4970	0.9957
19	0.1425	– 2.2090	0.9944
20	0.1222	– 1.9838	0.9871
21	0.1276	– 2.3134	0.9961
22	0.1010	– 1.8425	0.9886
23	0.0950	– 1.9434	0.9920
24	0.1012	– 2.1720	0.9944
25	0.0944	– 1.8166	0.9860
26	0.0787	– 1.9778	0.9849
27	0.0689	– 1.9165	0.9960
28	0.0593	– 1.6181	0.9829
29	0.0426	– 1.6552	0.9925
30	0.0500	– 1.9002	0.9859
31	0.0504	– 2.0826	0.9983
32	0.0503	– 2.2164	0.9979
33	0.0488	– 2.0757	0.9978
34	0.0651	– 2.6665	0.9994

Results

If the fresh weight figures obtained from the sample determinations are plotted on a logarithmic axis against the time, practically straight lines are obtained. The growth lines only level out with fresh weight figures in excess of about 100 g.

A certain rate of growth which may be expressed as a daily growth percentage (RGR) is therefore maintained by the young plants for a long time. During the time when the young plant develops from 0.1 to 10 g fresh weight, the daily growth percentage is constant.

Table 3. Data on growth of young tomato plants (gathered from Table 1) and on radiation.

Experiment No	Dates at which fresh weights were reached			Number of days 0.1-10 g	RGR (% per day)	Total radiation 0.1-10 g (cal cm^{-2})	Radiation per day (cal cm^{-2})
	0.1 g	1.0 g	10 g				
1	1 Feb.	14 Feb.	26 Feb.	25	20.4	2433	97
2	16 Feb.	27 Feb.	8 March	21	24.1	2720	130
3	7 March	15 March	22 March	15	35.4	3713	248
4	10 March	18 March	26 March	16	34.2	2980	186
5	29 March	6 April	11 April	13	41.2	3330	256
6	29 March	5 April	12 April	14	38.3	3407	243
7	17 April	24 April	1 May	14	40.5	4835	345
8	6 May	14 May	21 May	15	37.9	7050	470
9	15 May	21 May	27 May	12	47.3	4972	414
10	21 May	29 May	6 June	16	33.3	6828	427
11	7 June	14 June	20 June	13	41.8	4133	318
12	24 June	1 July	8 July	14	41.7	5280	377
13	27 June	5 July	12 July	15	35.2	8687	579
14	17 July	24 July	2 Aug.	16	34.9	6320	395
15	31 July	6 Aug.	13 Aug.	13	41.6	4933	379
16	8 Aug.	15 Aug.	23 Aug.	15	35.0	4455	297
17	8 Aug.	15 Aug.	22 Aug.	14	39.4	4156	297
18	22 Aug.	29 Aug.	4 Sept.	13	43.8	5462	415
19	26 Aug.	3 Sept.	10 Sept.	15	38.8	5127	342
20	28 Aug.	5 Sept.	13 Sept.	16	32.5	5547	347
21	10 Sept.	18 Sept.	26 Sept.	16	34.1	3966	248
22	18 Sept.	28 Sept.	8 Oct.	20	26.2	5032	252
23	1 Oct.	12 Oct.	22 Oct.	21	24.4	4261	203
24	13 Oct.	23 Oct.	1 Nov.	19	26.2	2352	124
25	10 Oct.	20 Oct.	30 Oct.	20	24.3	3172	159
26	17 Oct.	30 Oct.	12 Nov.	26	19.9	2668	103
27	1 Nov.	16 Nov.	30 Nov.	29	17.2	1850	64
28	12 Nov.	29 Nov.	16 Dec.	34	14.6	1902	56
29	20 Nov.	14 Dec.	6 Jan.	47	10.3	1739	37
30	5 Dec.	25 Dec.	14 Jan.	40	12.2	1788	45
31	9 Dec.	29 Dec.	18 Jan.	40	12.3	1919	48
32	26 Dec.	15 Jan.	4 Feb.	40	12.3	2053	51
33	25 Dec.	15 Jan.	4 Feb.	41	11.9	2338	57
34	18 Jan.	2 Feb.	17 Feb.	30	16.2	2529	84

The basic data of 34 batches sown from 1970 until the end of 1972 are shown in Table 1. The accuracy of the determinations within each sowing is given in Table 2.

These data have been used to calculate the dates on which the plants should have reached a weight of 0.1 and 10 g, the number of days between these dates and the average daily growth percentage (Table 3).

The total and average amounts of daily radiation were determined for these periods with figures obtained from the meteorological reports of the Royal Dutch Meteorological Institute at De Bilt and of the Research Station at Naaldwijk.

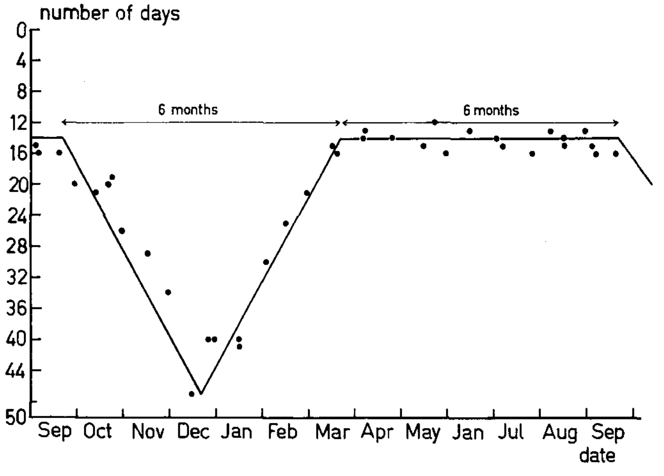

Fig. 1. Tomatoes, 34 sowings in 1970 to 1972. For each sowing the number of days in which the plants developed from 0.1 to 10 g fresh weight plotted against the dates on which the plants reached a fresh weight of 1 g per plant.

The relationship of the data in Table 3 is shown in Fig. 1 to 4.

A comparison of the data in Fig. 1 and 2 shows that the length of the growing period from 0.1 to 10 g fresh weight per plant is determined by the amount of radiation in winter only. From the beginning of March until after mid-September, the length of the growing period remains constant to a high degree. This seems to confirm the observations by Calvert (1964) who found that in winter the rate of growth is determined largely by the amount of photosynthetic light available, but

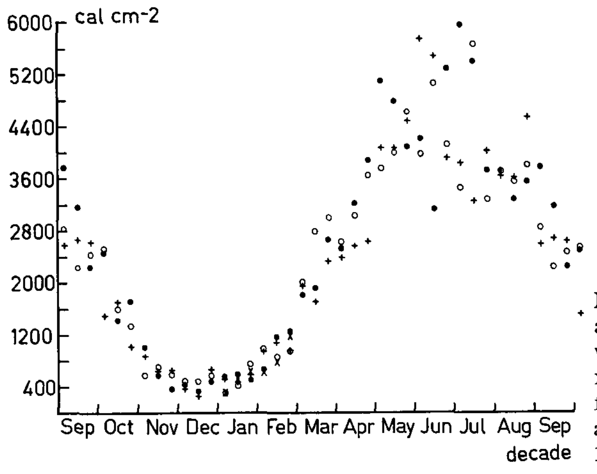

Fig. 2. The sums of the total radiation per decade (cal cm—²) at Naaldwijk (+ 1970, • 1971, O 1972, x 1973). Until 1 November, 1970, the figures were obtained from De Bilt and after this date from Naaldwijk. 1 cal = 4.2 J.

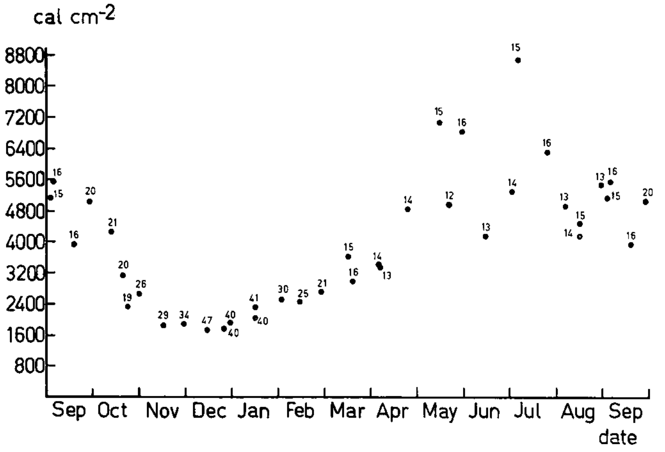

Fig. 3. Tomatoes, 34 sowings, 1970 to 1972. The sums of the total radiation (cal cm^{-2}) for each sowing during the period in which the plants increased in fresh weight from 0.1 to 10 g per plant plotted against the dates on which the plants reached a fresh weight of 1 g per plant. The figures near the points denote the number of days of the growing period of each sowing.

that in summer the young tomato plant is saturated with light and growth is limited by other factors. Fig. 3 shows this relationship in greater detail.

The position of the points in Fig. 3 shows that there was a very wide variation in the amount of radiation which reached the plants of the different batches in summer. In winter the points show a more regular pattern. Fig. 3 shows that a minimum of about 1.700 cal cm^{-2} overall radiation was received during the period when the plant developed from 0.1 to 10 g fresh weight. At the other extreme there is a batch which showed the same development with about 8.600 cal cm^{-2} radiation.

Fig. 4A shows that high radiation totals are not always accompanied by high growth rates. On the other hand, very high growth rates may be achieved with only moderate radiation levels. However, from the 11 points which have been circled and which represent favourable growth and light efficiency, it may be concluded that there is increasing growth up to the highest light values. A saturation level does not appear to have been reached, not even with the highest levels of summer radiation. Why the other 23 batches had a lower growth rate in spite of adequate light is clearly a point for further investigation (temperatures, CO_2 concentration, rooting medium).

It could be suggested that sowings which were subjected to very high radiation totals were harmed by excessive radiation. However, this is deceptive. Slow-growing batches will have received radiation over a longer period, so radiation need not have been of exceptionally high intensity, even if the total radiation figure was high. This is also shown by the change in the positions of the points in Fig. 4A and 4B.

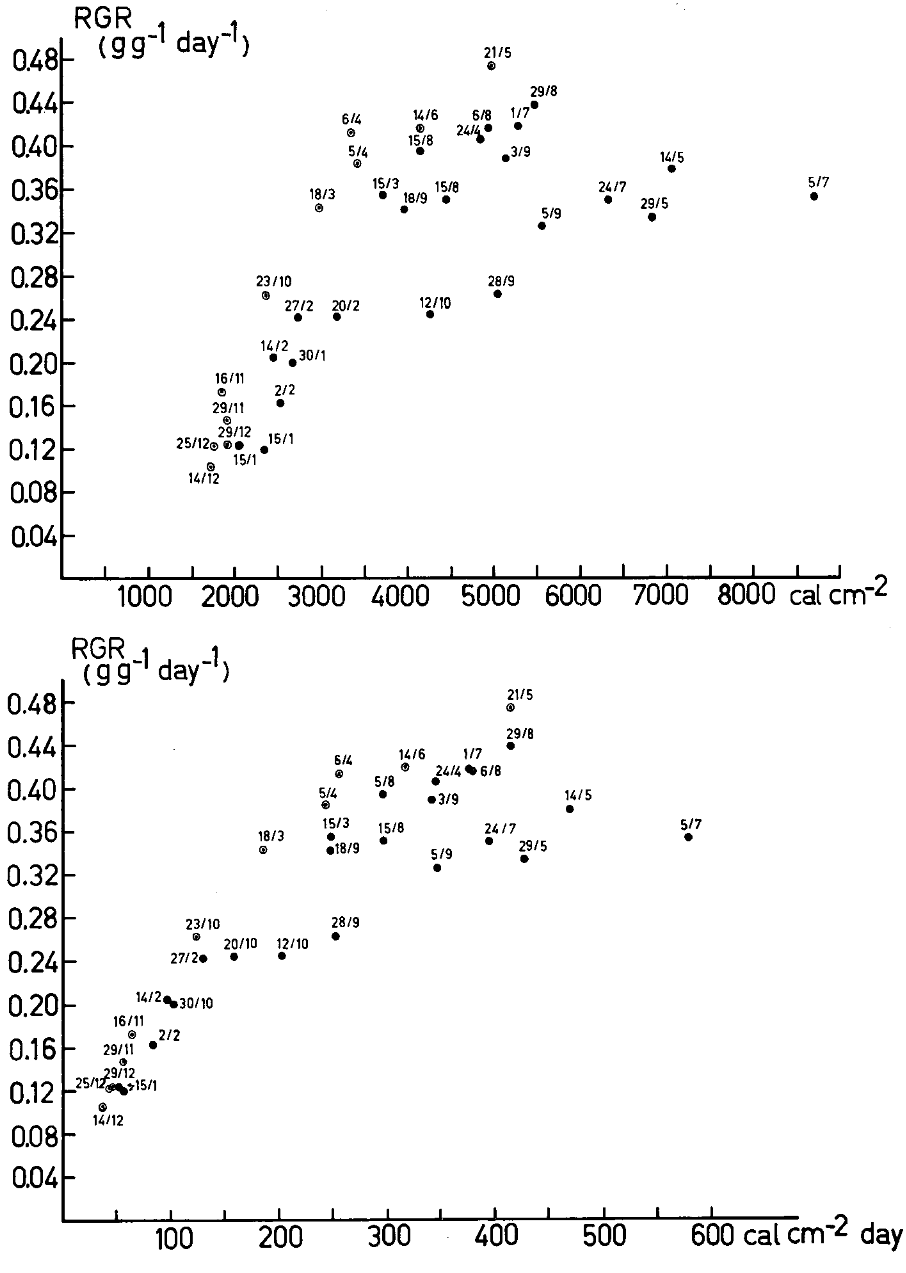

Fig. 4. Tomatoes, 34 sowings, 1970 to 1972. RGR (g g^{-1} day^{-1}) plotted against total radiation. 4A (top): Sum of the total radiation during the period in which the plants of a sowing increased in fresh weight from 0.1 to 10 g per plant.
4B (bottom): Average total radiation per day during the growing period of each sowing.

The figures near the points in Fig. 4A and 4B denote the dates on which the plants reached 1 g per plant in fresh weight. The circled points denote the eleven sowings which showed the best growth over the radiation range. The eleven points in Fig. 4B were used in Fig. 5.

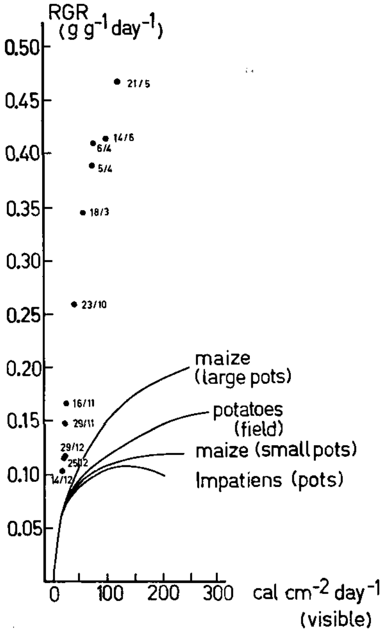

Fig. 5. RGR (g g^{-1} day^{-1}) against visible radiation (cal cm^{-2} day^{-1}). The eleven points with an indication of the dates were taken from Fig. 4B. The other graphs were taken from a compilation by Brouwer (1973).

Discussion

Brouwer (1973) has compiled daily growth percentages (g g^{-1} day^{-1}) in relation to daily visible radiation. The radiation data from the meteorological stations used in this publication were obtained with solarimeters, and they should therefore be halved to make them comparable with Brouwer's 'visible' radiation values. In addition, it is estimated that the glasshouse structure intercepted at least 30 % of the radiation.

Fig. 5 shows some of Brouwer's curves to which have been added the data of the 11 sowings circled in Fig. 4b and plotted against the corrected radiation figures.

The relative growth rates of the 34 tomato batches in this publication differ in two respects from those shown in Fig. 4 of Brouwer's paper. Firstly, the light efficiency of these tomato plants is higher than that reported in all previous publications. Secondly, the maximum relative growth rate obtained is also much higher: Brouwer, maize, maximum 20 %; in this report, Fig. 4, up to 47.3 %.

However, the highest values (the points in Fig. 5) are not normal in this material. Particularly in summer various sowings showed appreciably lower rates of light utilisation than proved possible with others. The factors responsible for this could not be traced.

Warren Wilson (1966) reported very high photosynthetic activities of sunflowers in Australia. His figures were almost twice as high as the previously known data. It is not possible to make a straight comparison between our figures and those obtained by Warren Wilson, but an estimation shows that the figures obtained by

Brouwer with maize are about as high as those from Australia.

The data obtained by Hurd & Thornley (1974) however, obtained in growth chambers, are directly comparable. Their plants also achieved about 45 % maximum relative growth rates. It is therefore feasible to achieve very high growth rates in glasshouses with natural light as well as in growth chambers with artificial irradiation. These growth rates are of the same order as those achieved with duckweed (*Lemna minor*), viz 35 % (Hodgson, 1970) and 68 % (J. Rombach, pers. commun., 1974).

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