

SHORT COMMUNICATIONS

SOME EFFECTS OF TEMPERATURE ON CARBOHYDRATE UTILIZATION AND PLANT GROWTH*

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Present evidence suggests that, in a wide variety of crop plants, growth and net assimilation rate may be determined by the ability of the plant to utilize or store the products of photosynthesis rather than by the capacity of the assimilatory surface to produce them (Humphries 1963; Humphries and Thorne 1964; Thorne and Evans 1964; Burt 1964). Humphries (1963) further suggests that temperature, by varying the ability of the plant to utilize the assimilate, may partly govern the photosynthetic rate of the plant.

In his experiments Humphries (1963) used rooted detached leaves of dwarf bean in which the main "sinks" for assimilate were the developing roots; the effects of temperature on "sink strength" were studied by varying the temperature of the nutrient solutions around the roots. Although the decreased photosynthetic rates at the low root temperature may be attributed to decreased rates of carbohydrate utilization by the roots it is also possible that decreased rates of mineral uptake by, and export from, the roots may have been involved (Humphries 1951; Jacobsen, Overstreet, and Carlson 1957; Nielsen, Halstead, and MacLean 1960); decreased rates of mineral uptake by the leaves may have led to lower photosynthetic rates either directly (Tsuno and Shimizo 1962) or indirectly by reducing the rates of carbohydrate flow from the leaves (Tsuno and Fujise 1965).

In order to further evaluate the effects of temperature on sink strength an experiment was carried out with the potato plant (*Solanum tuberosum* L.) in which the effect of temperature on carbohydrate utilization was studied by varying the air temperature around the developing tubers only.

Plant Culture

Potato plants (cv. Sebago) were grown in nutrient culture in the manner previously described (Burt 1964), the plants being grown in an air-cooled glasshouse throughout. During the actual experimental period, the nutrient solutions were changed every 4 days, and the nitrogen level of the solution was maintained at 84 p.p.m. (6 m-equiv. NO_3^- per litre).

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Treatments and Experimental Design

The experiment contained two treatments which commenced on November 5, 1964 (day 0 of the experimental period). In each treatment the developing tubers were maintained in air at temperature regimes of 17–32°C (treatment A) or 7–13°C (treatment B); ambient air and nutrient solution temperatures were unaffected by the differences in air temperature surrounding the tubers whereas the temperature of the air surrounding the stolons was approximately 2°C lower in treatment B than in treatment A.

At each harvest the plants were divided into leaf laminae, stem+petioles, roots, and tubers. After measuring leaf area on an air-flow planimeter (Jenkins 1959) each fraction was oven-dried for 2 days at 80°C and weighed.

TABLE 1
DRY WEIGHTS OF THE PLANT AND OF THE PRINCIPAL PLANT PARTS

Plant Part	Dry Weight (g/plant)			Least Significant Difference at $P = 0.05$
	Day 0	Day 8, Treatment A	Day 8, Treatment B	
Total plant	39.73	59.20	50.71	
Increment	—	19.47	10.98	6.42
Tubers*	16.33	35.33	27.33	
Increment	—	19.00	11.00	4.22
New tubers†	0.00	0.47	1.09	
Increment	—	0.47	1.09	0.34
Leaf	9.79	10.27	9.99	
Increment	—	0.48	0.20	1.66
Stem and stolon	9.99	9.58	8.76	
Increment	—	-0.41	-1.23	4.48
Root	3.61	3.56	3.53	
Increment	—	-0.05	-0.08	0.25

* Tubers present at day 0 only.

† Tubers initiated after day 0 only.

One day prior to day 0 all but the five largest tubers on each plant were removed and the volumes of each of the remaining tubers estimated from linear measurements (Burt 1964). After calculating the total tuber volumes per plant it was then possible, by selecting and removing a further two tubers from each plant, to ensure that all of the plants within each block had the same tuber volume at day 0; mean tuber volumes (three plant replicates) were 271 and 274 cm³ (least significant difference at $P = 0.05$ equals 12) for treatments A and B respectively.

After the unwanted tubers had been removed each of the remaining tubers was sealed in a cylindrical plastic container through which air from the glasshouse (treatment A) or cooled air (treatment B) was circulated; this air was subsequently discharged into the glasshouse.

Results

(i) *Dry Weight Changes*.—Increase in dry weight of the plants during the experiment was almost entirely due to tuber growth, significantly less plant and

tuber growth occurring in treatment B (Table 1). Although initiation of tubers continued throughout the experiment these tubers contributed relatively little to the total tuber growth.

(ii) *Leaf Area*.—Between days 0 and 8 the leaf area (dm^2/plant) increased from 17.0 to 20.1 and 18.6 in treatments A and B respectively (L.S.D. at $P = 0.05$ equals 2.3).

(iii) *Net Assimilation Rates*.—Net assimilation rates (E) were calculated from the following formula:

$$E = \frac{(W_2 - W_1)}{(t_2 - t_1)} \cdot \frac{(\log_e L_2 + \log_e L_1)}{(L_2 - L_1)},$$

where L_2 and L_1 and W_2 and W_1 are the leaf areas and plant dry weights at times t_2 and t_1 respectively. E was significantly reduced from 1.40 $\text{mg}/\text{cm}^2/\text{day}$ (treatment A) to 0.91 $\text{mg}/\text{cm}^2/\text{day}$ (treatment B) by reducing the temperature around the developing tubers (L.S.D. at $P = 0.05$ equals 0.41).

Discussion

In the experiment described it proved possible to reduce the air temperature around the developing tubers by approximately 15°C without changing the temperature of the ambient air or nutrient solution. Air temperatures around the major parts of the stolons were reduced only slightly ($< 2^\circ\text{C}$) although it is probable that small lengths of the stolons were at the same temperature as the tubers.

From the work of Swanson and Geiger (1965), who followed translocation from sugar-beet leaves in which the petioles were cooled to 1 or 2°C , it seems unlikely that a reduction in air temperature around the stolons *per se* would inhibit translocation and tuber growth for more than a few hours. Any major treatment effect must therefore be attributed to the effects of reduced temperature on the tuber growth *per se*; subsequent work has verified this.

In previous work with the potato (Burt 1964) it was shown that the developing tubers could utilize or store larger amounts of photosynthate than the other plant organs; any factor or factors which restricted tuber growth caused an accumulation of carbohydrate in the leaves and growth and net assimilation rate were reduced. In the experiment described here previous results (Burt 1964) were largely confirmed. A reduction of the air temperature around the developing tubers restricted tuber growth and reduced the net assimilation rate and growth. Unlike the previous experiment (Burt 1964), in which tuber growth was prevented by the amputation of the developing tubers, a temperature-induced restriction of tuber growth did not produce any detectable carbohydrate accumulation in the leaves (measured by the leaf weight/leaf area ratio); such an effect, if present, would be more difficult to discern in the present experiment, firstly because of the reduced numbers of plant replicates and, secondly, because tubers were not removed and the effect would therefore be smaller. As a decrease in air temperature around the tubers would considerably lighten the respiratory load of the plant (Barker 1933, quoted by James 1953), and as leaf areas were approximately equal on all treatments, the decreased net assimilation rate must be attributed to decreased rates of photosynthesis. Further work to explore this effect has been carried out. These data would confirm the findings of Humphries

(1963) that growth and net assimilation rate may be controlled by the growth of the organs constituting the major carbohydrate sinks, the size of these sinks being determined by the temperature of the air surrounding them.

Environmental factors may regulate sink strength, and therefore plant growth, by controlling either the initiation or the development of the carbohydrate sinks (or both); conditions which favour sink initiation (low mineral level and low temperature in the potato) may be very different from those which favour utilization of carbohydrate by the sinks (high mineral supply and high temperatures) (Emmert 1946; Borah and Milthorpe 1962; Slater 1964).

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