Influence of Temperature on Rates of Respiration and Photosynthesis in Cotton Seedlings

JAMES McD. STEWART[1] and GENE GUINN[2]

Oklahoma State University, Stillwater

Each year there is a considerable economic loss to the cotton grower as a result of seedling diseases early in the growing season. Guinn & Hunter (1964) found that chilling caused an accumulation of sugar in the young cotton plant and apparently correlated this with growth of *Rhizoctonia solani*. It has been shown (Guinn & Hunter, 1964; Guinn & Stewart, 1965) that root temperature is more important than air temperature in causing sugar accumulation. At both high and low air temperatures cold rooted plants accumulated sugar while warm rooted plants maintained a constant low level of sugars.

The experiments presented in this paper were conducted (1) to determine if root respiration is more sensitive to chilling than leaf and cotyledon respiration, and (2) to determine if the sugar accumulation is the result of relatively high photosynthetic activity at low temperature.

Methods and Materials

Cotton seeds *(Gossipium hirsutum,* cv. Stoneville 62) were planted in vermiculite on each of five consecutive days for each experiment so that all plants would be similar in size and age at the time of use. As each set of seeds germinated (5 days), six seedlings were transferred to each of two polyethylene buckets containing a modified Hoagland's solution (Hoagland & Arnon, 1950). For root and cotyledon experiments plants were grown in the greenhouse for one week after transplanting, while plants used for leaf experiments were grown for two weeks. Photosynthesis and respiration were measured at 5° intervals from 5 to 25 C using standard Warburg methods (Umbreit, et al., 1964) and apparatus. Measurements were made on successive days using a different temperature each day. For root respiration determinations, all tissue below and including, the first lateral root was used. Each flask contained the entire root of one plant. The volumes of the roots were determined by water displacement and subtracted from the volumes of the flasks. For leaf and cotyledon respiration determinations, five discs of 2 cm diameter were leaned against the center well of each flask. A strip of fluted filter paper with 0.2 ml of 20% KOH was added to the center well of half the flasks. To the remainder was added a fluted strip plus an equivalent amount of water. Results were expressed as ul. 0_2/mg-hr.

In photosynthetic experiments six 1-cm diameter discs were floated adaxial side down in 0.2 ml of the modified Hoagland's solution. In initial experiments Pardee's (1949) CO_2 buffer was used to maintain a constant CO_2 atmosphere. This system was temperature dependent, however, and inadequate for the desired CO_2 concentration at the lower temperatures. Kreb's (1951) system, supplemented with arsenite (Roughton & Clark, 1951), was then used. Five ml of 4M diethanolamine solution was saturated with 100% CO_2 at the temperature desired. An additional 10 ml of the diethanolamine was mixed with this and the total equilibrated with 1% CO_2 in air at the appropriate temperature. One milliliter of the equilibrated buffer was added to the center well and side arm of each of the flasks. The flasks were equilibrated with a stream of 1% CO_2 in air at

[1]Graduate Student
[2]Plant Physiologist, Crops Research Division, ARS, USDA, and the Okla. Agricultural Exp. Sta.

the appropriate temperature for 20 minutes before the manometers were closed. (Manometer fluid should move only a few millimeters if equilibrium has been attained.) Light intensity was 1500 ft-candles at flask level. The results were expressed as ul. 0_2/ mg-hr.

Results and Discussion

A comparison of the respiration rates of roots, cotyledons and leaves is given in figure 1. Respiration in the root is much higher on a dry weight basis at 25° than in either leaf or cotyledon. The fact that the relatively heavy tap root was included in the root weight makes the difference even more significant. In an experiment using only laterals detached from the tap root the respiration rate at 25° was 4.1 ul. 0_2/ mg-hr., approximately a third higher than the rate shown in figure 1. The increased rate is unlikely to be due entirely to effects of mechanical damage because at 5° the respiration rate of lateral roots was less than the respiration rate of the complete root system. This indicates that respiration in young roots is more sensitive to chilling temperatures than respiration in leaves or cotyledons.

The effect of temperature on the rate of photosynthesis in cotyledon tissue is given in figure 2. The determinations were made at non-limiting CO_2 concentrations and do not represent natural rates at temperatures above 15 C (Gaastra, 1962). Surprisingly, the Q_{10} for photosynthesis is greater than Q_{10} for the initial rate of respiration in the roots (approxi-

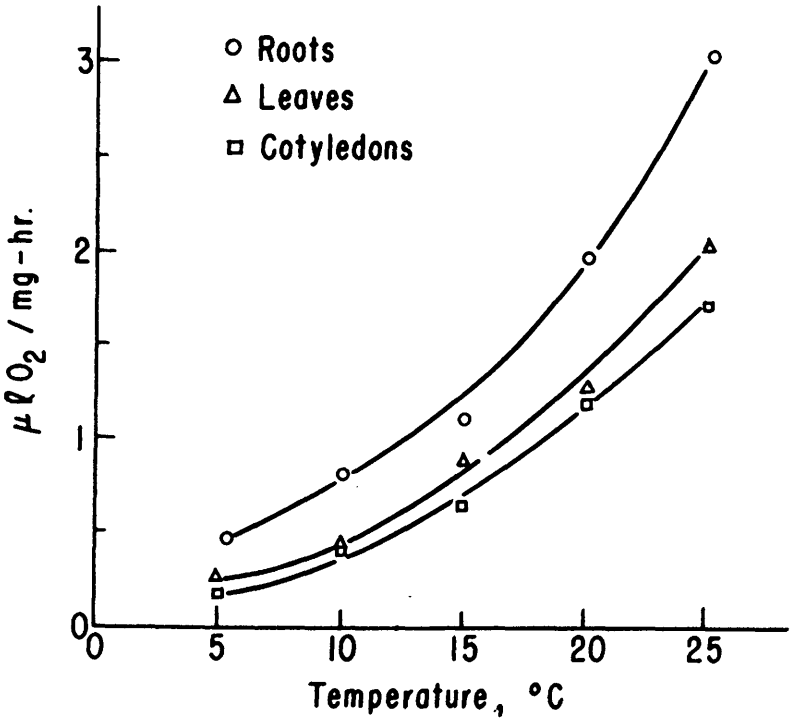

Figure 1. Effect of temperature on the initial rates of respiration in cotton seedling tissues.

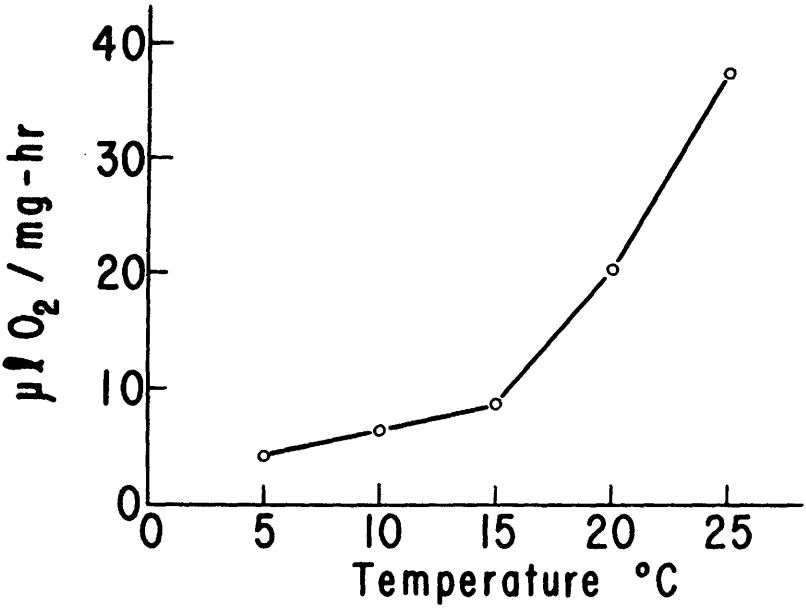

Figure 2. Effect of temperature on the rate of photosynthesis in cotyledon discs in a 1% CO_2 atmosphere.

mately 4 vs. 2.7). Thus, it is concluded that a high photosynthetic activity at low temperatures is not the primary cause of sugar accumulation.

An additional observation on root respiration, however, indicates that a decrease in the rate of respiration with time may be a factor (figure 3). After three hours the rates at all temperatures below 20° were less than half the initial rates. Depletion of reserves was not the cause of the diminished rates, because no decrease occurred at 25°. The amount of substrate utilized at 25° in 1 hour exceeded the total amount utilized during the three hours at 15°. The data shown in figure 3 suggests that the rate of respiration would approach zero with continued chilling. A loss in respiration would result in a loss of assimilation with a corresponding accumulation of photosynthetic products. This is significant in that Kursanov (1958) showed that up to 50% of assimilated ^{14}C is translocated to the roots and converted to other organic compounds.

The decrease in respiration rate with chilling could be the result of either of two factors: (1) Damage, such as enzyme inactivation, in the electron transport or phosphorylating systems, or (2) a decreased permeability of membranes to sugars within the cells which prevents transport from stele to cortex. The latter is favored in view of the work of Arndt (1937) and Kramer (1942) who showed that low temperature drastically reduces the permeability of the root to water.

Summary

The effects of temperature on the rates of photosynthesis and respiration were determined in an effort to explain sugar increases in cotton seedlings due to chilling. Root respiration was more sensitive to temperature than leaf or cotyledon respiration. The Q_{10} for the initial rate of

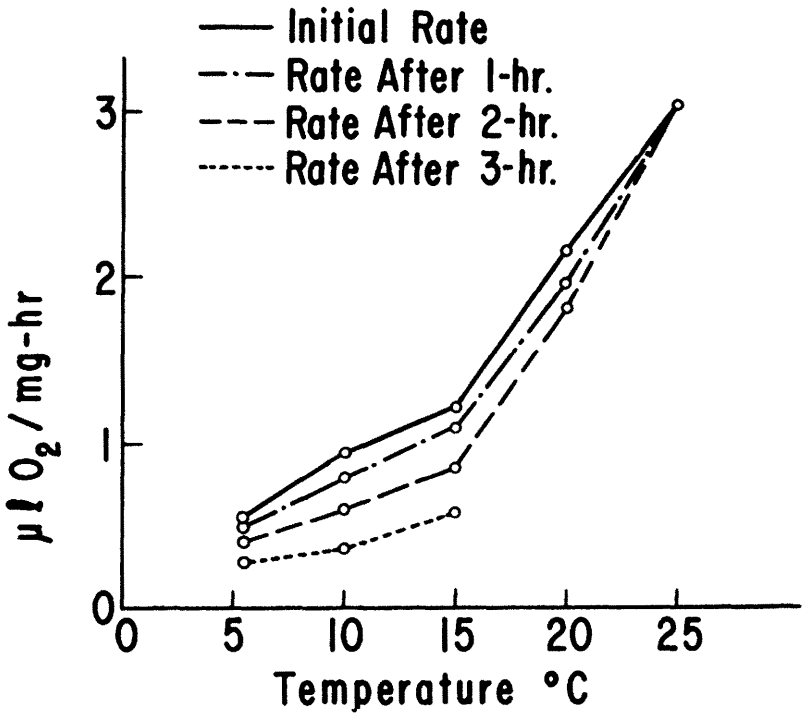

Figure 3. Respiration rates in roots as influenced by temperature and length of time at specified temperatures.

respiration in the roots was less than the Q_{10} for photosynthesis in cotyledons, but root respiration decreased with time. This decrease was not a result of depletion of reserves. It is suggested that sugar accumulation was the result of decreased respiration and utilization which in part resulted from membrane impermeability to sugars.

Literature Cited

Arndt, C. H. 1937. Water absorption in the cotton plant as affected by soil and water temperatures. Plant Physiol. 12: 703-720.

Gaastra, P. 1962. Photosynthesis of leaves and field crops. Netherlands J. of Agric. Sci. 10: 311-324.

Guinn, G. and R. E. Hunter. 1964. Possible relationship between sugar content and disease susceptibility in chilled cotton seedlings. Proc. 18th Ann. Beltwide Cotton Defoliation and Physiol. Conference. pp. 37-43.

Guinn, G. and James McD. Stewart. 1965. Some responses of cotton seedlings to chilling. Proc. 19th Ann. Beltwide Cotton Defoliation and Physiol. Conf. in press.

Hoagland, D. R. and D. I. Arnon. 1950. The water-culture method for growing plants without soil. Agr. Exp. Sta., California Circ. 347.

Kramer, P. J. 1942. Species differences with respect to water absorption at low temperatures. Amer. J. Botany 29: 828-832.

Krebs, H. A. 1951. The use of 'CO_2 Buffers' in Manometric Measurements of Cell Metabolism. Biochem. J. 48: 349-359.

Kursanov, A. L. 1958. The root system as an organ of metabolism. Proc. First (UNESCO) Internatl. Conf. Sci. Res. 4: 494-509.

Pardee, A. B. 1949. Measurement of oxygen uptake under controlled pressures of carbon dioxide. J. Biol. Chem. 179: 1085-1091.

Roughton, F. J. W. and A. M. Clark. 1951. *In:* The Enzymes. J. B. Sumner and Karl Myrback (eds.) I(2): 1251. Academic Press, New York.

Umbreit, W. W., R. H. Burris and J. F. Stauffer. 1964. *Manometric Techniques.* Burgess. Minneapolis, Minnesota.