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Controlled Cooling of Onion Umbels by Periodic Sprinkling[1]

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ABSTRACT

Low onion (*Allium cepa* L.) seed yields frequently occur without obvious reasons, particularly with hybrid varieties. Solutions to the problem need to be found to insure seed for bulb onion production. Water and temperature stress in the umbel may be factors during hot, dry, sunny weather. We investigated the relationship of umbel temperature to ambient and umbel conditions and the effects of periodic wetting of the umbels. Onions were grown in a field experiment at Kimberly, Idaho on Portneuf silt loam soil (Durixerollic Calciorthids; coarse-silty, mixed, mesic) using commercial practices except that periodic sprinkling was provided with a rotating-head sprinkler irrigation system when temperatures exceeded certain levels. Sprinkling for five min reduced floret temperatures as much as 15 C below ambient. The florets remained cool for 20 to 40 min, depending on umbel maturity, wind speed, and air temperature and humidity. Nearly mature umbels were hotter and required more sprinkling to keep cool. Five min of sprinkling every 20 to 30 min usually provided adequate cooling. A specially-designed temperature sensor was found to successfully simulate the behavior of an onion floret during wetting and drying, permitting direct control of the initiation, duration, and frequency of sprinkling. Excessive temperatures did not occur during the experiment, so seed yields were similar on sprinkled and unsprinkled plots. While we have shown that periodic sprinkling will provide umbel cooling and minimize undesirable effects on pollination, similar studies need to be conducted in hotter, major seed producing areas to establish economic benefits.

Additional index words: **Evaporative cooling, Sprinkler cooling, Irrigation controllers, Umbel temperatures, Onion seed, *Allium cepa* L.**

ONION seed is produced in several regions of the western United States where summers are hot, dry, and sunny. This climate generally favors high seed yields, but onion seed producers frequently have experienced erratic yields and sometimes complete failures, particularly with hybrid varieties, for no obvious reasons (Campbell et al., 1968; Franklin, 1970; and Nye et al., 1971). Sustained seed production is required for the production of bulb onions for market, which in 1977 in the United States was 1.6 million metric tons (U. S. Department of Agriculture, 1977). Poor seed yields lead to increased production costs and difficulty in obtaining growers.

The onion plant (*Allium cepa* L.) is a biennial which produces a bulb the first year and a seed stalk (scape) the second year. The scape, a long, hollow, cylindrical stalk, supports the flowering umbel, which contains many florets arranged to form a spherical surface. The umbel of most commercial varieties is quite densely packed.

The internal water status and temperatures in seed onion plants were investigated by Miller et al. (1971) and Tanner and Goltz (1972) at the University of Wisconsin, where many of the hybrid lines have been developed. Field studies at Hancock, Wisconsin in 1969 and at Parma, Idaho in 1970 showed that radiant heating on the surface of the onion umbel produced temperatures that could cause tissue degeneration and a sun scald condition. The temperature rise was inversely proportional to the two-thirds power of wind speed and was dependent upon the direction of wind relative to that of the sunlight. The Wisconsin data indicated that the umbel transpiration was only about 3% of the total for the onion plant and, furthermore, that onion plants had lower transpiration rates than most agronomic plants (Miller et al., 1971; Goltz et al., 1971; Goltz and Tanner, 1972). They concluded that severe water stress might develop in the umbel under hot, dry, sunny weather because of the anatomy and physiology of the plant. This could cause poor seed yields in climates otherwise favorable for seed production.

Inadequate pollination sometimes seems to cause poor seed set (Nye et al., 1971). The onion flower requires insect pollination for seed development and, while not the natural pollinator, colonies of honey bees are commonly used as pollinators in commercial onion seed production. Pollination problems may be more severe for hybrid than for non-hybrid seed production, since pollen must be carried from male fertile to male sterile flowers which are generally grown

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in different rows. Drying weather can cause the secreted onion nectar to become highly concentrated, making it less desirable to bees, and can decrease stigma receptivity and pollen viability (Waters, 1972; and Waller, 1974).

In many seed-producing areas, root and bulb diseases are a serious problem. Although the onion plants survive and flower, the damaged root system can lead to what is sometimes called "physiological drought," even when soil water is adequate. The addition of heat stress in the umbel could compound the problem.

In 1970, the general nature of the onion seed problem and results of the Wisconsin research were brought to our attention. Because of our proximity to a major onion seed producing area in southwestern Idaho and eastern Oregon, we subsequently investigated the relationship of irrigation management to hybrid onion seed yields, as reported by Brown et al. (1977). We further proposed sprinkler cooling as a way of solving some of the problems. Sprinkling could significantly cool onion umbels because of their relatively low natural transpiration and because their spherical shape is conducive to strong radiative heating. However, at the beginirng of this project, the suitability of sprinkling onion umbels was uncertain because of the possibility of diluting the nectar or otherwise interfering with pollination. Therefore, the specific objectives of this investigation were to determine the temperature of umbels with and without periodic sprinkling under arid conditions, to determine the optimum length and frequency of sprinkling, to assess the relationship of umbel maturity to cooling needs, to assess the effects on nectar dilution, and to develop suitable means of initiating and controlling sprinkling.

EVAPORATIVE COOLING

Evaporative cooling with sprinkler irrigation and the concurrent changes in the microclimate have been investigated with other crops (Kohl and Wright, 1974; Jensen, 1975; Seginer, 1971; Unrath, 1972). Cooling occurs with over-the-crop sprinklers, when sensible heat is converted to latent heat during the evaporation of water from droplets in the sprinkler spray and on wetted surfaces.

The minimum temperature attainable by evaporation in an adiabatic cooling process is the thermodynamic wet-bulb temperature. This temperature, predictable from psychrometric theory, is called the psychometric wet-bulb temperature. How fast water droplets in a sprinkler spray will attain the wet-bulb temperature is difficult to establish theoretically. However, Pair et al. (1969) found that the temperature of sprinkler irrigation spray was generally about at the wet-bulb temperature upon impact with the soil or plant, regardless of the initial water temperature before ejection from the sprinkler nozzle.

Some cooling of plant tissues occurs during normal transpiration. Greater cooling occurs if the total evapotranspiration from wetted plant parts exceeds the natural transpiration. Increased evaporation accompanying sprinkling also increases the humidity of the ambient air. The magnitude of the combined effect depends on the drying capacity of the air and on diffusion processes. Because the water droplets are in the air for only a short time after leaving the sprinkler nozzle, usually 2 sec or less, their effect on the temperature and humidity of the ambient air is limited. Seginer (1971) and Robinson (1973) estimated water losses from the increase in electrical conductivity of irrigation water during sprinkling and found that under arid conditions, with standard agricultural rotating sprinklers, about 5% of the water discharged evaporated from the spray. Kohl et al. (1974) found that the air temperature downwind from an operating sprinkler lateral was generally cooled less than 0.6 C below ambient, and that the accompanying increase in the vapor pressure of the air was less than 0.8 mb. They concluded that such changes in air temperature and humidity were not likely to cause any significant change in plant growth or evaporative loss of water in adjacent nonwetted areas.

While sprinkling has little effect on air temperature, the wetted plant foliage can be cooled significantly (Jensen, 1975). In California's Imperial Valley, the temperature of alfalfa plants was kept below 34 C while sprinklers were operating (Robinson, 1970) and plant temperature was reduced as much as 21 C during August.

Since we began our research in 1970 on the evaporative cooling of onions with sprinklers, results of similar research with other crops have been published. Gilbert et al. (1970) reduced air temperature 3 to 6 C and increased relative humidity 10 to 20% in vineyards. Leaf temperatures were lowered 8 to 14 C and grape temperatures, 6 to 7 C. Unrath (1972) reduced fruit temperature of Red Delicious apples 2 to 10 C with a low volume over-tree sprinkler system near Charlotte, NC. In addition to the initial cooling provided by contact with the cooled water, there was a residual cooling accompanying evaporation of water held on the plants. Radiative heating increased the temperature of exposed fruit more than exposed leaves, because of transpirational and other differences; consequently, sprinkling cooled the fruit more than the leaves.

EXPERIMENTAL PROCEDURES

Common hybrid onion lines furnished by commercial seed companies were planted in research plots at the Snake River Conservation Research Center (SRCRC), Kimberly, Idaho. Some onion seed research plots in the major onion seed area near Parama, Idaho, maintained by Dr. N. D. Waters of the University of Idaho, were also used. Fertilizing, planting, irrigating, cultivating, and harvesting practices, as previously reported in detail by Brown et al. (1977), were similar to those used in commercial production. Sprinkler water was applied for cooling when air or umbel temperatures exceeded certain predetermined levels. Wind speed, wind direction, and air temperature were recorded in the field with a portable mechanical weather station (Meteorological Research Incorporated, MRI, Model 1072).* A Sling psychrometer was used to periodically measure humidity.

Surface and interior temperatures of umbels were measured with a fine wire chromel-constantan beaded thermocouple, T/C (Omega Engineering, Inc.). Tanner et al. (1972) used a T/C system that permitted direct measurement of the temperature elevation of individual florets above ambient. We developed a

*Trade names and model numbers are provided for convenience of the reader and do not imply endorsement or recommendation by the U.S. Department of Agriculture.

hand-held probe (illustrated on the left side of Fig. 1) to measure the temperature difference between a floret and a thermal mass. It could be held similarly to a large pen or small soldering iron. A section of hollow plexiglass tubing was used as a handle and vinyl-insulated, chromel-constantan (20-gauge rip cord) lead wire was threaded through the handle to extend about 4 cm beyond the tip. This was secured to the handle with nylon clamps and vinyl tape. The extended lead wire was separated and stripped to form a "Y". A fine-wire T/C was then suspended midway between the two arms of the "Y" and the leads were wrapped around and soldered to the resepctive arms. The arms of the "Y" had some spring action providing a means of obtaining good contact between the T/C bead and the onion ovary or other plant part.

When a T/C broke, which happened frequently because of entanglement in the umbel, it was removed and a new one installed with a small battery pack soldering iron. Initially 0.025-mm (0.001 inch, 50 gauge) T/C's were used but because of excessive breakage, the next larger size, 0.050 mm, was used for most of the experiment. It was desirable to keep the diameter as small as possible to prevent conducting heat away from or to the point of measurement. Chromel is stronger and has a lower thermal conductivity than copper, and therefore lends itself to this application. The larger T/C's permitted more pressure to be applied when making contact, were easier to install and use, and gave essentially the same results as the smaller ones. The reference junction for the probe was inserted in a large well-insulated thermal mass, with about 10 m of wire leads permitting a convenient measurement range. We monitored the temperature of the thermal mass with a separate T/C, using an electronic reference junction compensator.

A single-channel, millivolt strip chart recorder with adjustable zero and span was used to record the T/C measurements. Umbel surface temperatures were usually measured at the top of the ovary near the base of the style at various positions on the umbel and under various ambient conditions with the hand-held probe. Ambient air temperature was intermittently measured by holding the probe in the air near the umbel for 5 to 10 sec, to give an average air temperature. The temperature difference between the ovary and air, ΔT, was calculated from the two separate measurements.

To measure ovary temperature during the sprinkler trials, we threaded fine wire thermocouples, similar to those used with the hand-held probe, through the ovaries of fully opened florets on various sprinkled and nonsprinkled umbels. Florets in the usual umbel "hot spots" were selected. T/C wire leads were brought to the onion plant and anchored to the scape with cellophane tape and a "Y" was formed as illustrated on the right side of Fig. 1. A fine sharp needle was inserted through and then withdrawn from the selected ovary. One lead of the 0.050-mm T/C was carefully threaded through the needle puncture until the junction was within the ovary. The fine wires were then wrapped around and soldered to the respective posts of the "Y" formed from the lead wire. It was easy to determine when good T/C contact was achieved, because the recorder trace was stable when the junction was within the ovary. Head-mounted magnifying lenses (4×) were used to facilitate the threading and soldering operations. The reference junctions of the several thermocouples were connected to copper wires and placed in a solidly packed, crushed ice bath enclosed in an insulated container. A multipoint strip chart millivolt recorder was used to obtain simultaneous records of 12 ovary temperatures during flowering and seed development, from about 1 July to 1 August. Temperatures were recorded on days with a potential for high ΔT's. If the threading of the ovary caused a floret to wither after a few days, the T/C was moved to a new floret.

Sprinkler cooling was provided with a conventional solid-set sprinkler system using relatively small, 2.4-mm (3/32-in), nozzles in impact rotating heads mounted on 76-cm (30-in) risers spaced on a 9 × 9-m grid. The average rate of water application was about 5.6 mm/hour, depth equivalent.

A timing clock with two adjustable cams and a 30-min cycle was initially used to control sprinkling duration and interval between sprinklings. Sprinkling durations of 2 to 10 min were used to evaluate the rate and degree of cooling and subsequent rewarming. When ambient air temperature as sensed in a ventilated shelter at about the height of the onion umbels on the edge of the plot reached about 30 C, the cam timer initiated sprinkling for the set time. If air temperature still exceeded the preset level at the end of each cycle, sprinkling cycles were continued.

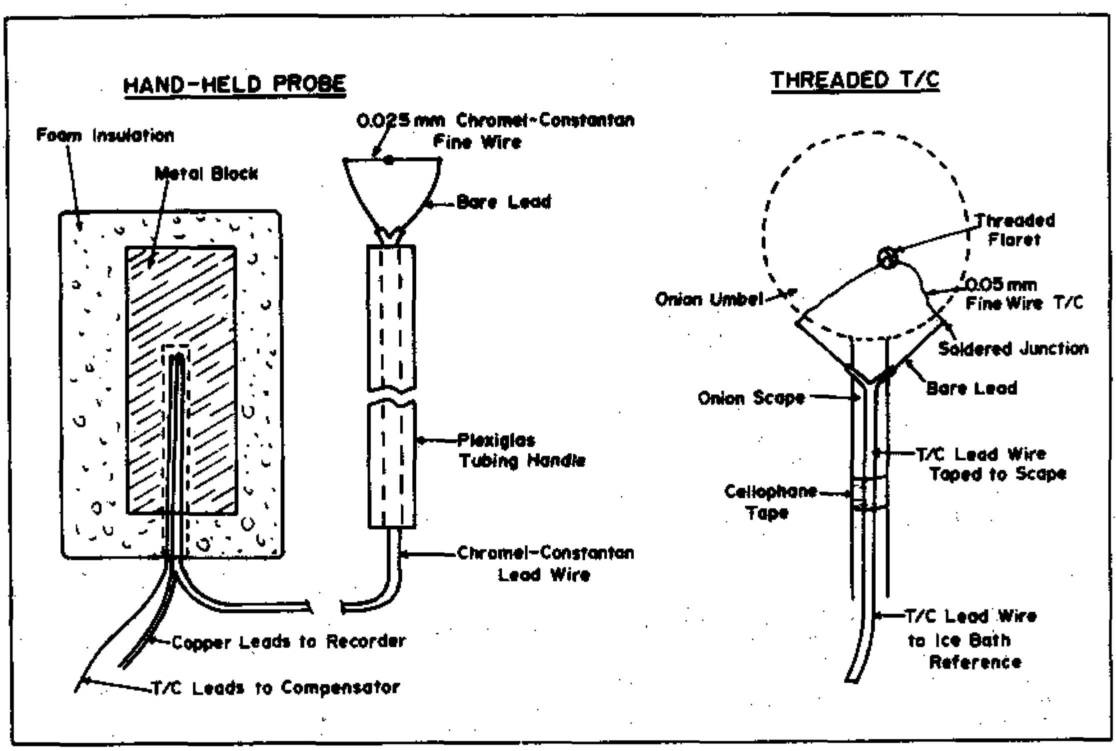

Fig. 1. *Diagram of fine-wire thermocouple (T/C) systems, hand-held probe and threaded ovaries, for measuring the temperature of selected florets and other plant parts.*

RESULTS AND DISCUSSION

Umbel Temperatures. The results of some temperature scans over an umbel in the seed development stage obtained with the hand-held probe on a sunny day in late July, are shown in Fig. 2. The highest ΔT (13 C) and 'hot spot" temperature (40 C) were observed about 0930 (approximate solar time) when there was little wind. The hot spot then coincided quite closely with the "sun spot" (location of most direct solar beam) on the southeast side of the umbel about 60 angular degrees up (considering the largest horizontal diameter of the umbel as an equator). By 1250 the hot spot had shifted to a more southerly position, also close to the sun spot, but the hot spot was then 3 C less and ΔT was 4 C less than at 0930, even though air temperature was 2 C higher, because of the higher wind speed. By 1430, when the wind speed had increased even more, the hot spot was even cooler and ΔT was only 4 C, even though air temperature had increased to 32 C. Furthermore, because of wind conditions, the hot spot was not then coincident with the sunspot. This case demonstrates the effectiveness of a moderate westerly wind in decreasing the ΔT at the sun spot during the afternoon when daily air temperatures usually are maximum. If ambient air temperature had been about 40 C, the ΔT observed at 0930 could have been detrimental to developing ovaries (C. E. Peterson and K. W. Trammell, unpublished data). However, air temperatures at Kimberly rarely exceed 40 C and there is usually at least a moderate westerly wind. We did not observe any sun scald, sometimes called "dollar spot," on the umbels or any other excessive heat damage during our studies from 1970 to 1973 at Kimberly.

Some representative ΔT's as measured at Kimberly with the hand-held probe in 1971 and with the threaded ovaries in 1973 are given in Table 1. The data are arranged to show the nature of ΔT relative to floret maturity. The associated wind conditions are also shown because of the importance of wind speed and direction on ΔT. The temperature response of a nearly mature floret to various wind conditions on 3 sunny days is shown at the bottom of the table. These data and others showed that mature florets for comparable wind conditions were as much as 7 to 10 C warmer

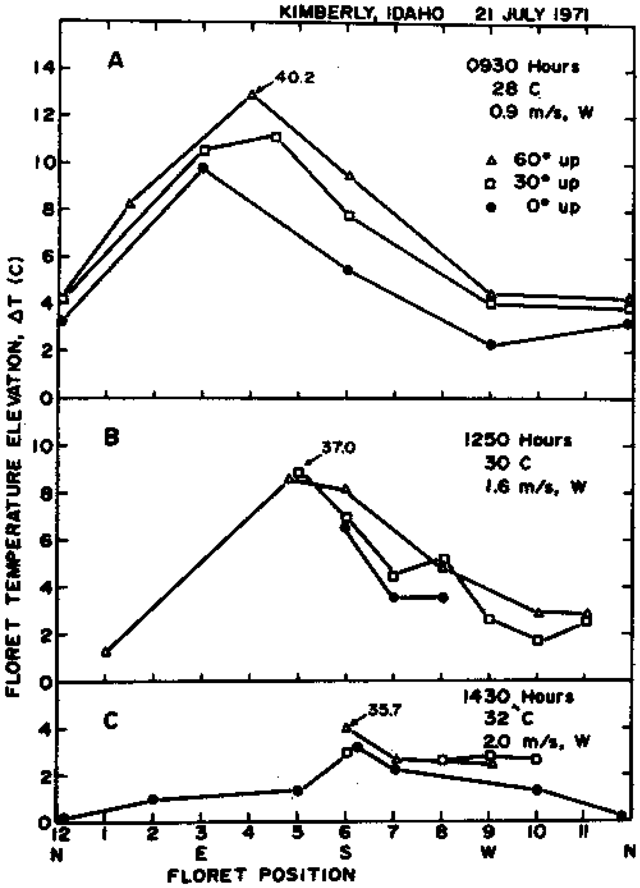

Fig. 2. Examples of temperature elevation, ΔT, of fully open and maturing florets at various directional positions on an onion umbel during the day as wind speed and air temperature conditions changed, Kimberly, Idaho. Temperatures were obtained with a hand-held probe at the various directional and angular elevations above the umbel equator (plane of maximum circumference).

Table 1. Examples of the temperature elevation (ΔT) of onion florets above ambient air temperature relative to the time of day, floret condition, umbel position, wind speed and direction, and air temperature. A few temperatures of bean (*Phaseolus vulgaris* L.) leaves measured in an adjoining plot are listed for comparison. Kimberly, Idaho.

Date	Solar time	Floret condition	Umbel position	Wind speed & direction	Air temp	ΔT
	hour	†	‡	m/s	C	C
7/21/71	0930	fof	0430, 60°	0.9, W	28	12.2
7/22/71	1300	mf	0400, 50°	3.0, W	29	4.6
		fof	0400, 50°	3.0, W	29	3.1
	1430	mf	0500, 45°	2.5, W	31	4.4
		scape	0900	2.5, W	31	5.7
	1435	bean	sunlit	2.5, W	30	−1.6
		bean	shaded	2.5, W	30	−0.6
7/23/71	0845	mf	0400, 50°	0.7, —	26	14.2
		nof	0400, 50°	0.7, —	26	12.9
	0900	mf	0430, 30°	1.0, W	26	12.8
		nof	— —	1.0, W	26	5.8
		fof	0500, 35°	1.0, W	26	8.9
	0915	mf	0430, 30°	1.0, W	26	12.5
		fof	0500, 45°	1.0, W	26	10.5
	0930	mf	top	1.0, W	26	8.2
		fof	top	1.0, W	26	5.8
7/23/71	1230	mf	0400, 75°	1.3, W	31	10.4
		fof	0500, 75°	1.3, W	31	10.3
		mf	0800, 45°	1.3, W	30	5.7
		fof	0800, 45°	1.3, W	30	4.3
		scape	0600	1.3, W	30	5.0
	1245	bean	sunlit	0.9, W	30	−2.1
7/26/71	1130	mf	0500, 45°	2.2, NW	27	7.1
		fof	0500, 45°	2.2, NW	27	7.1
		mf	0900, 0°	2.2 NW	27	−1.0
		bean	sunlit	2.2, NW	27	−3.6
	1400	mf	0600, 45°	4.5, NW	31	5.7
		fof	0800, 35°	4.5, NW	31	1.3
		fof	top	4.5, NW	31	7.3
	1410	bean	sunlit	4.5, NW	29	−5.5
7/26/73	1400	mf	0600, 60°	2.0, NW	30	8.8
7/30/73	1315	mf	0600, 60°	2.0, SE	30	9.8
7/31/73	1300	mf	0600, 60°	0.5, NW	29	22.5

† nof—newly opened floret; fof—fully opened floret; mf—mature floret, flower parts dried-up, seeds developing. ‡ Clockwise position (1200 for north, 0600 for south) and angular degrees above the equitorial plane of the umbel.

than adjacent fully- or newly-opened florets. Also, differences in the ΔT of newly-opened and mature florets were more pronounced at lower wind speeds. The data in Table 1 show the wide range of ΔT's that can be observed on umbels. Differences seemed to depend on umbel shape, size, and stage of maturity and the relative position of a floret to the general surface of the umbel. Large temperature differences existed even between adjacent florets on the same umbel.

The temperature of some fully-exposed bean leaves (*Phaseolus vulgaris* L.) measured in plots near the onions are also listed in Table 1 to show the marked contrast in ΔT under the same ambient conditions. Because of the effects of plant shape and transpiration, the fully exposed bean leaves were cooler than ambient, while umbels were much warmer. An example of the dramatic nature of the radiative heating of umbels occurred on one relatively cool and partly cloudy day. At about 1245 hours, while in a cloud shadow, the floret temperature was 26.1 C, air temperature was 23.0 C and wind speed ranged from 0.75 to 1.5 m/s. About 20 min after this foret was exposed to the sun the temperature was up to 39.8 C, while air temperature remained relatively unchanged. As another cloud passed over, the floret temperature decreased to the former level.

Some ΔT's measured at Kimberly and Parma are plotted in Fig. 3 as a function of wind speed. These measurements fit well within the predicted bounds of the practical temperature elevations predicted by the relationship of Tanner et al. (1972), as shown for comparison. On the occasions when we obtained data at Parma, the wind speed was relatively strong and favorable for cooling, so rather low ΔT's were observed. When low wind speeds were experienced at Kimberly, the wind direction was generally favorable for cooling, so relatively low ΔT's resulted. The two highest ΔT's were measured when the sunspot was nearly opposite the point where the wind impinged on the umbel.

Tanner et al. (1972) reported rather large ΔT's for Parma, Idaho. Their data were obtained under relatively calm conditions and during a short portion of the flowering period. In 1970, during 3 clear days about 3 July, they measured ΔT's at the hot spot as high as 25 C. Several ovary temperatures reached 50 C and an extreme of 60 C was observed. Light easterly winds prevailed much of the time during their measurements. Such temperatures could be deleterious to ovary development and could cause the sunscald of umbels sometimes found in seed onion fields. Such damage does frequently occur at Parma and was observed the year that they obtained their data there. The combination of conditions that produced the high

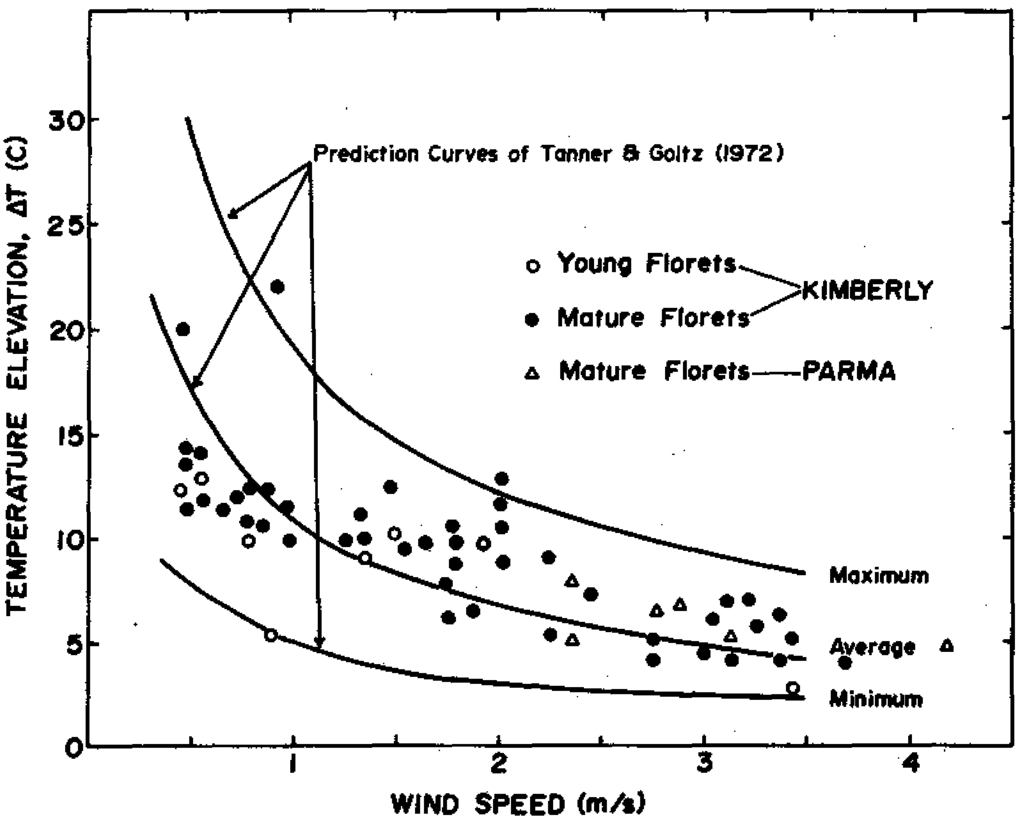

Fig. 3. Temperature elevations, ΔT, of young and maturing onion florets at the umbel "hot spot" as a function of wind speed measured during the flowering and seed-set period (1971 to 1973, Kimberly and Parma, Idaho) with the prediction curves of Tanner and Goltz (1972) shown for comparison.

umbel temperatures during their studies did not exist during any of the periods in which we measured umbel temperatures. Maximum temperatures at Parma average 6 to 10 C higher than at Kimberly during midsummer and wind speeds there are about 50% less, with wind direction tending to be more easterly. The usual Parma conditions would produce much higher umbel temperatures than Kimberly conditions, especially during the afternoon.

Tanner et al. (1972) reported that the cooling efficiency of the wind is not only a function of its speed, but also where it impinges directly (the stagnation point) on the umbel relative to the hot spot. Based on their results, the highest umbel temperatures would be expected on the upper southwest portion of the umbel during the afternoon under calm conditions or with light southeasterly or northwesterly wind because maximum air temperatures usually occur a few hours after solar noon.

Our results certainly agreed with theirs in indicating that ovary temperatures of onion umbels could reach levels damaging to seed development. In addition, our several years of data showed that ΔT's tended to increase with umbel maturity. Ovary temperatures, therefore, could be highest when seeds are developing and the umbel surfaces become tightly packed. This would help explain why, in addition to "dollar spot", seed growers sometimes have an apparently good seed set with fully developed seed coats, but containing nonviable embryos.

Measuring umbel temperatures to automatically control sprinkler cooling to prevent umbel damage may be a safer approach than predicting from weather data. The prediction of temperature elevations requires measurement of several meteorological variables and may be insufficiently accurate to consistently prevent damage. The ovary ΔT's are dependent on umbel conditions and only a few hours of extreme temperatures could seriously damage an otherwise good crop. Instrumentation requirements would also be similar. With the recent availability of relatively small infrared thermometers, it may also be possible to develop means of indirectly monitoring umbel temperatures to control sprinkling.

Sprinkler Cooling. Preliminary measurements in 1971 on sprinkler-irrigated plots indicated that a short period of sprinkling decreased umbel surface temperatures 15 to 20 C. Temperatures remained lower for 20 to 60 min, depending upon plant and climatic conditions. Since it was desirable to sprinkle only enough to cool the umbels, further tests were conducted to evaluate the optimum frequency and duration of sprinkling.

Extensive temperature data were collected for umbels under varying conditions. Several cases are presented here to illusrtate the general nature of the results. Figure 4 shows the temperatures of selected florets, as measured with threaded thermocouples, for sprinkling durations ranging from 2 to 10 min. Four to five min of sprinkling was sufficient to cool the umbels. Increasing the sprinkling time to 10 min produced small additional temperature reduction and cooling lasted only 10 to 12 min longer. Furthermore, the extra cooling could lower tissue temperatures below optimum for growth and the extra water could wash nectar and pollen from the umbels. The general nature of the curves illustrates the effects of differing windspeed and floret conditions.

The cooling effects of wind speed and water retention by the umbel are illustrated in Fig. 5 for a fully open floret. With a 3 m/s wind, the floret was only 5 C above ambient before sprinkling. Sprinkling cooled it to 11 C below ambient, just 1 C above the wet-bulb temperature, and it rewarmed to ambient in 20 min. On the following day, with less wind, the dry floret was 11 C above ambient. Sprinkling cooled it to 10 C below ambient which was 6 C above wet-bulb temperature, and it rewarmed to ambient in 40 min. Therefore, although higher wind-speeds increased the initial cooling, they also dried the umbels faster.

The temperatures of an ovary at an umbel "hot spot" during four consecutive sprinkling cycles, covering a 2-hour period, are shown in Fig. 6 to illustrate the temperature response of a nearly mature umbel. The ovaries were fully enlarged and very little flower material remained to retain water. Sprinkling was started when air temperature reached 30 C and lasted for 5 min of a 30-min cycle. In contrast to the cases shown in Fig. 5, rewarming began almost immediately after sprinkling ceased and within 15 min the ovary temperature was back up to ambient and it reached the initial dry temperature at least 5 min before the end of the 30-min period. If the ambient temperature

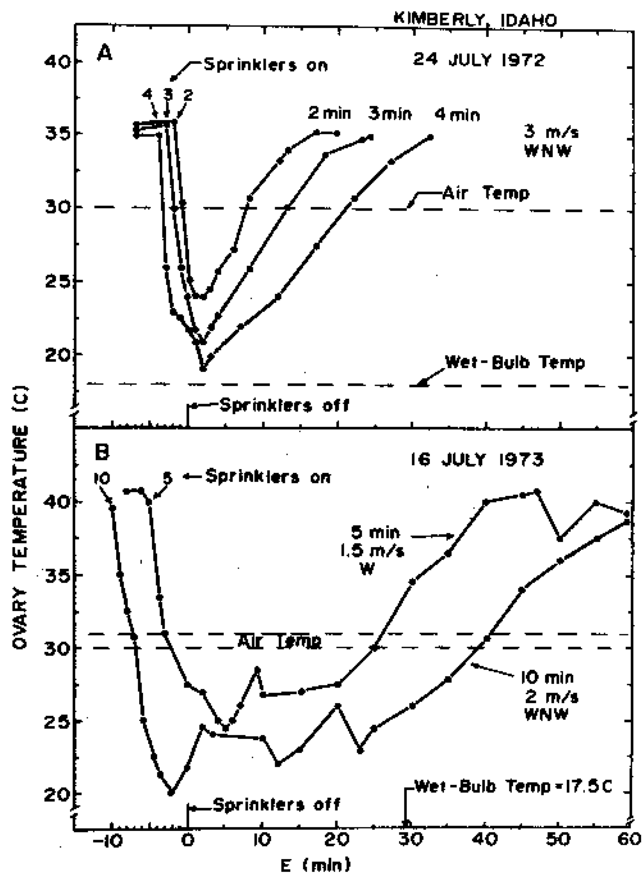

Fig. 4. The ovary temperature response of onion florets on two different dates as a function of varying sprinkling times with wind speed and direction as noted (m/s, WNW, etc.).

had been higher, a 30 min cycle may have been too long to prevent the development of lethal temperatures in some ovaries.

Ovary temperatures of sprinkled and nonsprinkled, nearly mature umbels are compared in Fig. 7. Sprinkling procedures were similar to those of Fig. 5 and 6. During the afternoon, while air temperature slowly increased, umbel temperature declined as wind speed increased. The highest ovary temperature, nearly 50 C, occurred even before air temperature reached 30 C and sprinkling was initiated, because of the location of that ovary relative to wind direction and the solar radiation beam. With 5 min of sprinkling, the umbel was cooled almost to wet-bulb temperature and ovary temperature did not fully return to the nonsprinkled temperature before the end of the 30-min periods. Sprinkling actually should have been initiated sooner and could have been discontinued earlier had the temperature of ovaries rather than of air been used to control sprinkling.

We found that sprinkling for short periods did not overly dilute onion nectar, as was earlier feared. Furthermore, results of other concurrent studies indicate that nectar dilution may actually be beneficial. Waters (1972) found that under arid conditions in blooming onion fields near Parma the nectar sugar concentration was frequently greater than 60%. Bees tended to reject such flowers and gathered less concentrated nectar so that the nectar collected from the honey crops of captured bees averaged about 48%. Waller (1974) found in a laboratory feeding study that bees preferred nectar with a sucrose concentration in the range of 30 to 50%. While measuring umbel temperatures at Kimberly, we observed that nectar secreted by young flowers would often sit exposed to the sun and drying air for an entire day if bees did not happen to visit the flowers early. Using procedures similar to those used by Waller (1974) and Waters (1972), we found that the sugar concentration of sampled flower nectar and that obtained from honey crops of captured bees was frequently greater than 60%, indicating that bees were forced to feed upon concentrated nectar. Sprinkling for about 5 min diluted the nectar to a more favorable range. The sugar concentration of nectar collected from the honey crops of bees after sprinkling ranged from 22 to 58% and averaged about 43%. Since onion flowers appear to be less attractive to honey bees than flowers of most competing plants (Waller et al., 1976), any improvement in nectar desirability would increase pollination. On the other hand, oversprinkling could unduly dilute the nectar.

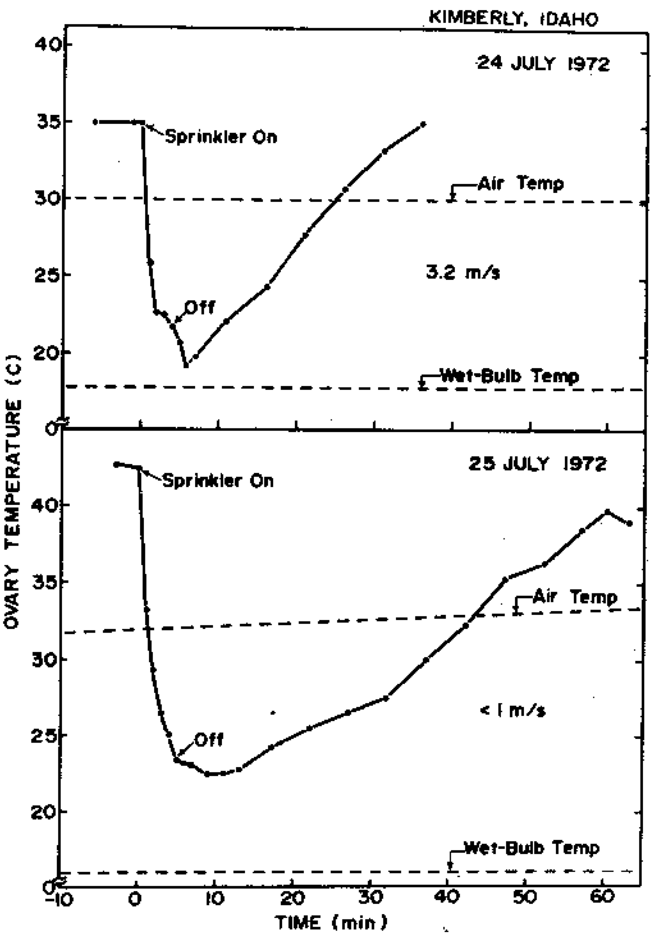

Fig. 5. Effect of wind speed on the temperature of an onion ovary at an umbel "hot spot" following about 5 min of sprinkling for cooling.

Reasonable onion seed yields and quality were obtained with sprinkler cooling. The addition of sprinkler cooling to furrow-irrigated plots slightly decreased seed yield. However, this decrease was less than that resulting from irrigating at higher soil moisture levels, which seems to be a common grower practice. Overly high soil moisture probably leads to more bulb and root rot. Sprinkler cooling did significantly increase seed weight but had no effect on germination. If the weather had been hot enough to significantly reduce seed yield or seed viability during our studies, then sprinkler cooling would probably have produced a yield benefit. More detailed yield results were reported by Brown et al. (1977).

Controlling Sprinkler Cooling. While the results clearly demonstrated the need for and benefits of sprinkler cooling, experience gained during the research also indicated the need for careful and automatic control of the initiation and duration of sprinkling. The temperature elevation of newly-opened florets does not tend to be as great as that of those that are more mature. However, it would be expected that the delicate flower parts might be very sensitive to either heat or water stress and the effects of these may be crucial to pollen viability and stigma receptivity. Excessive sprinkling during this period of flower development should be avoided to prevent overly diluting the nectar. After pollination as the ovaries enlarge, the temperature elevation is apt to be greater and the umbels retain less water thus will rewarm faster, indicating a need for more frequent wetting. Over sprinkling may not be as much of a problem during this period except that excessive cooling may reduce the growth rate and other maturation processes. Umbel temperatures of 30 to 40 C would be expected to be desirable for seed development.

While the fine wire thermocouples inserted through the ovaries were very suitable for studying umbel temperatures, the threading was a delicate and tedious task and the thermocouples were not well-suited for an

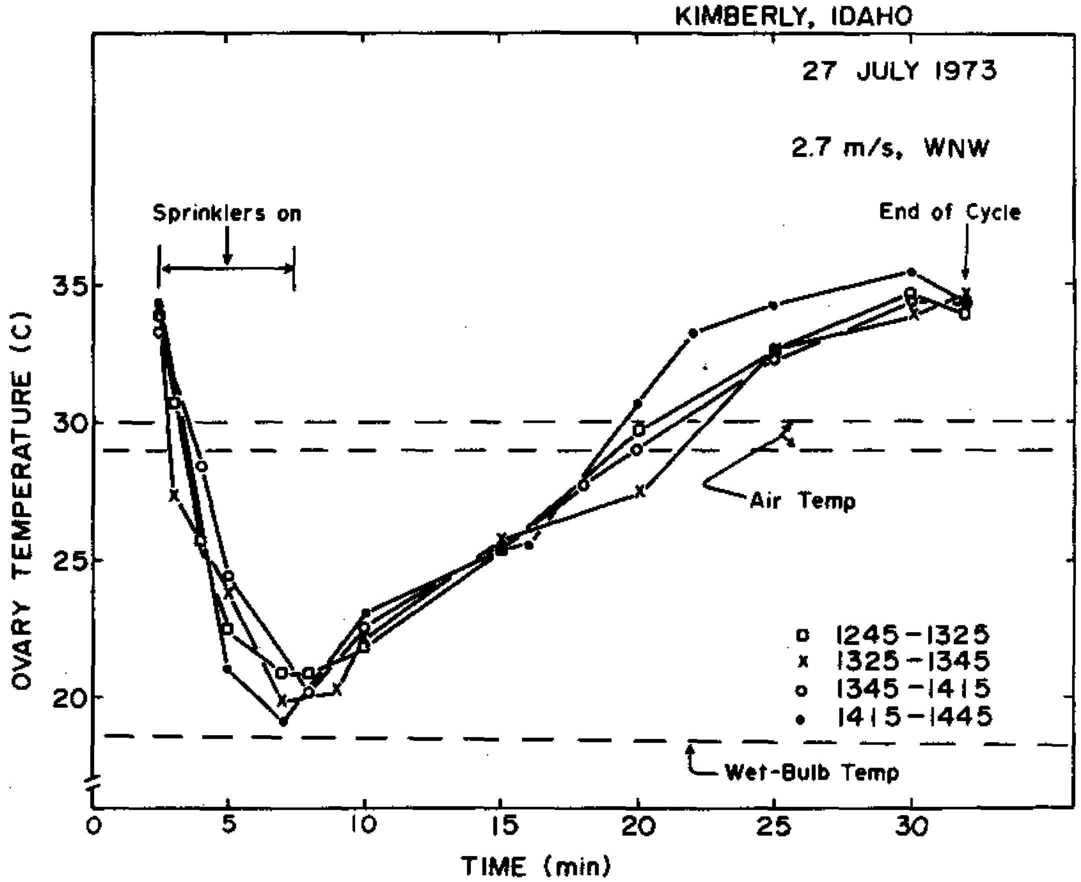

Fig. 6. Temperature of an onion ovary at an umbel "hot spot" during four consecutive 30-min cycles with 5 min of sprinkling at the beginning of each period during an afternoon with moderate wind speed.

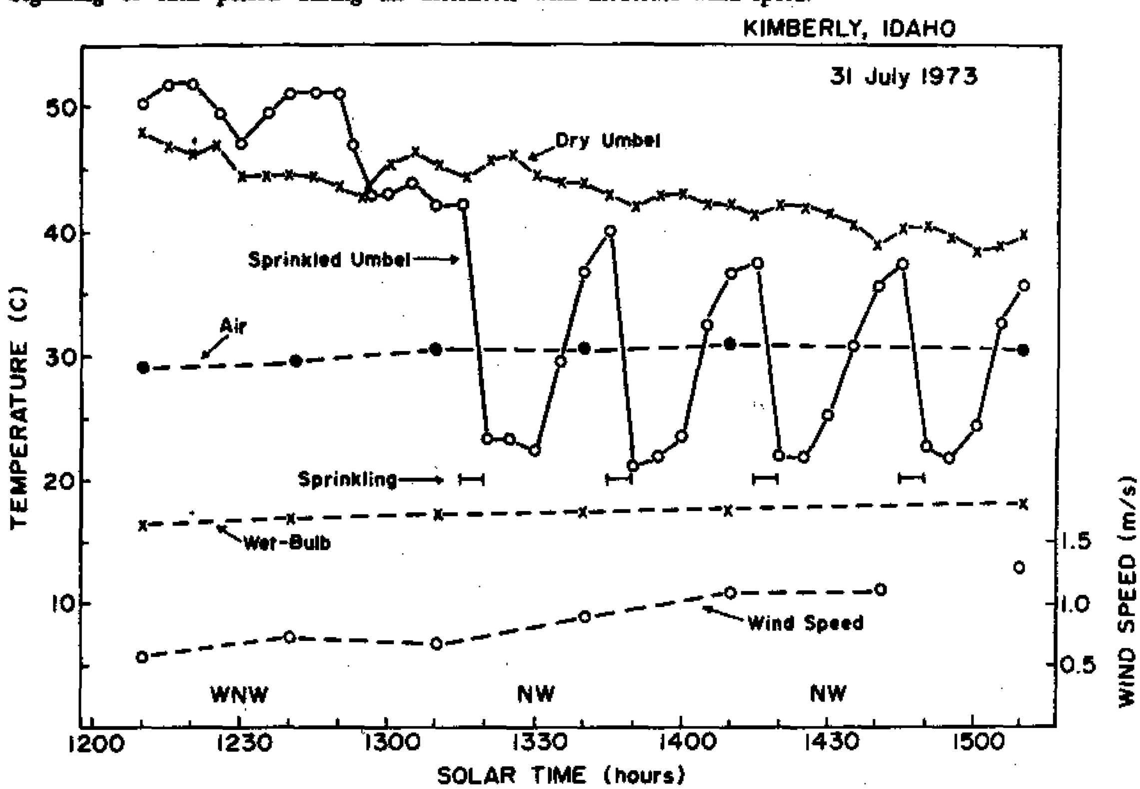

Fig. 7. Temperature response of mature onion ovaries on nonsprinkled and sprinkled umbels.

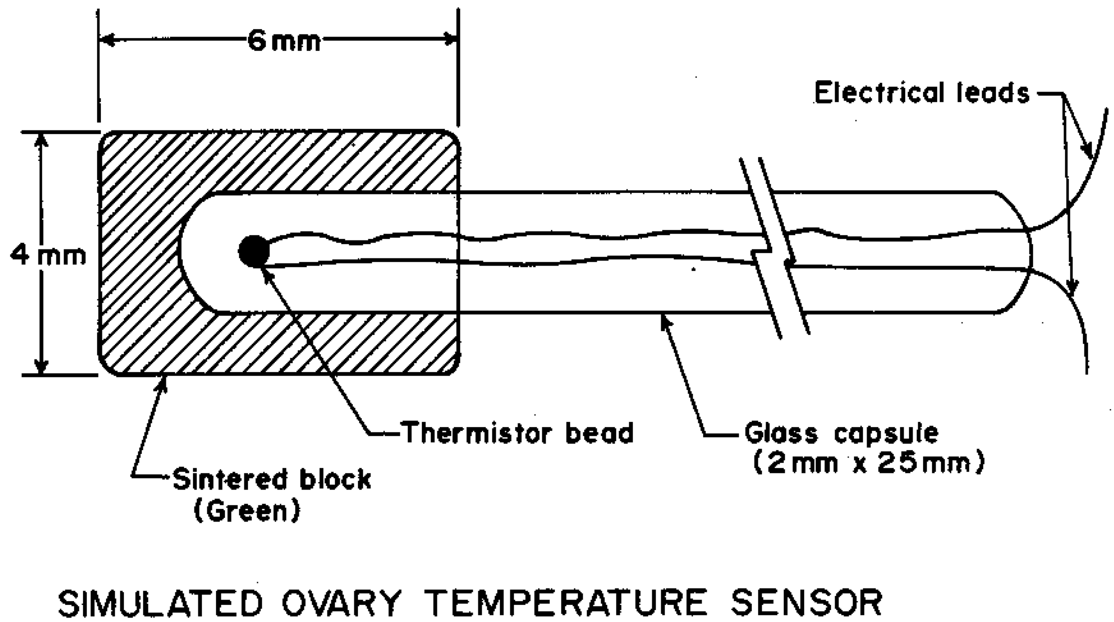

Fig. 8. Diagram of a thermistor temperature sensor developed to simulate the wetting and drying behavior of an onion umbel during sprinkling for operation of an irrigation controller.

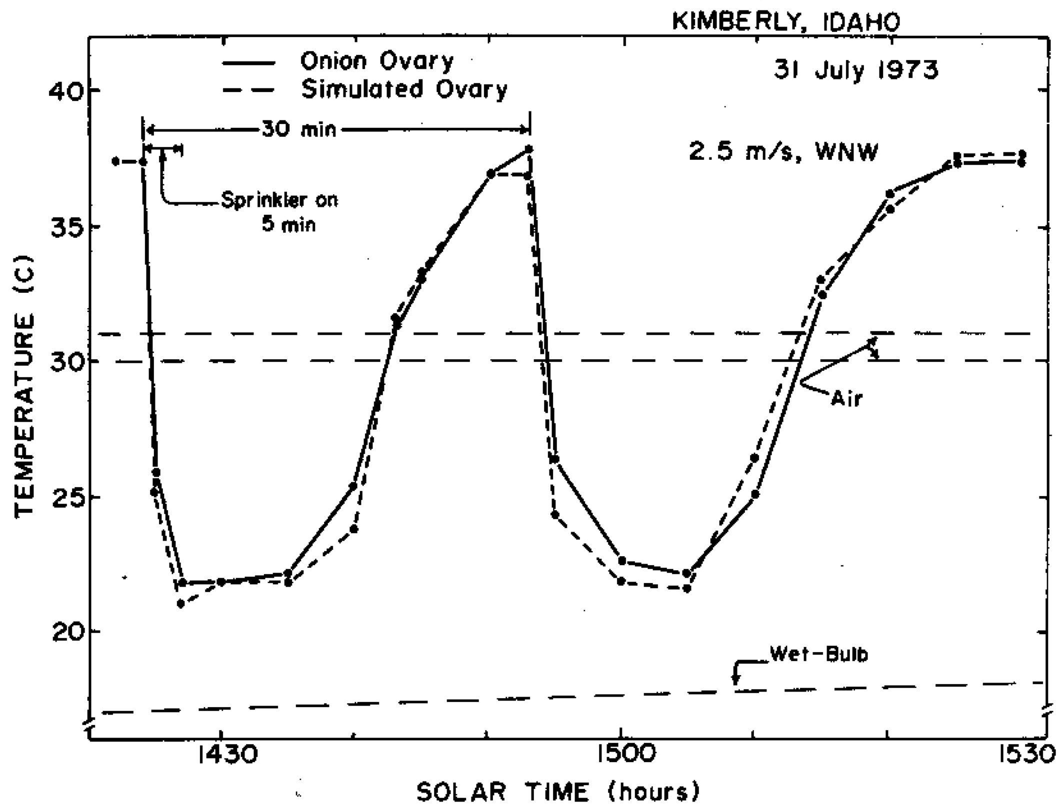

Fig. 9. Temperature response of a simulated onion ovary temperature sensor placed in an umbel, compared with that of an actual ovary during two 30-min cycles with 5 min of sprinkling.

automatic controller. Therefore, a more convenient temperature sensor was developed to permit monitoring umbel temperature and permit automatic control of sprinkling. The sensor utilized a glass-encapsulated thermistor which made it quite durable. The glass did not wet and dry like an onion ovary, so various materials were tried as coverings for the glass capsule. Fabric material tended to stay wet too long. It was found that a small block of sintered nylon, about the size of a maturing ovary and shaped to fit over the end of the glass capsule, did simulate the wetting and drying behavior of the onion flower. A diagram of the ovary temperature simulator is shown in Fig. 8.

Several of the simulated ovary temperature sensors were placed in onion umbels on the southeast, south, and southwest sides at about 60° above the horizontal. An example of temperatures obtained with one of these and an actual ovary during two sprinkling cycles is shown in Fig. 9. The sensors were connected with conventional lead wire in parallel to an electronic controller so that when the temperature of any one of them exceeded a certain level, sprinkling was initiated. The procedures worked well and could be extended to commercial application where sprinkler cooling would be beneficial in the production of onion seed. There are many possibilities for controller design with the level of sophistication depending upon the practical needs and expected benefits.

Carefully planned studies using procedures similar to those developed in this study need to be conducted in other onion seed production areas where temperatures are higher than at Kimberly, such as the Imperial Valley of California, with attention given to yield results so that the economic and practical aspects can be more definitely determined. The procedures developed should also be applicable for studying sprinkler cooling of other agronomic crops.

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