The leaf size (length and/or width) in sunlight of *Croton, Ph. cordatum* and Bowstring-Hemp became smaller as air velocities declined. This can be seen for *Croton* and *Ph. cordatum* in Fig. 1 and 2. The widths of the newly developed leaves of Bowstring-Hemp became reduced in high sunlight with less air movement, but their lengths were similar. Commercial florists producing foliage plants have traditionally associated increased leaf size to improved environmental conditions.

Stomates of all plants in the still air and at 0.45- and 0.6-mph wind velocities remained open on sunny days throughout the daylight hours. Similarly, the stomates of all plants on trial closed partially to completely after 15 minutes exposed to wind velocities of 4.4 and 3.2 mph and remained closed throughout the period of air flow.

The largest quantities of chlorophyll were found in plants of each species grown under shade at recommended light intensities. The quantitative measurement of chlorophyll in African-violet *Ph. cordatum* and *Bowstring-Hemp* in full sunlight showed smallest levels in plants at low air flow rates and progressively larger quantities in leaves in each species as wind velocities increased (Table 2).

DISCUSSION

Increasing the velocity of air movement permitted shade-requiring plants to be grown at higher than recommended light levels without reducing plant quality. Plants requiring very low light levels benefit most from increased air movement, and those normally tolerant of higher light intensities showed no improvement. In this study it was not possible to obtain normal growth of African-violet in full sunlight at any increased velocity of air movement tested. Plants at 1500 ft-c under normal greenhouse conditions made considerably more growth than those under other treatments. The chlorophyll contents showed a similar trend (Table 2). *Saintpaulia* in sunlight or low wind rates had large necrotic areas on leaves within 30 days after initiation of the study. Visible leaf injury decreased in sunlight as air velocities increased, but growth and chlorophyll contents still were less than for those plants shaded.

Plants of *Ph. cordatum,* Bowstring-Hemp and *Croton* in sunlight at increased wind velocities were similar but slightly superior in compactness to those in the greenhouse at recommended light intensities for each species. Measurements of *Ph. cordatum* internodes showed plants grown at increased wind velocities and in full sunlight to average ¼ inch shorter than shaded plants. Chlorophyll contents of shaded plants generally were slightly higher than those in the sunlight at increased air velocities. Plant growth differences of the same species were small between plants shaded to recommended light levels and those exposed to increased wind velocities. Leaf size of plants at recommended light levels were similar to those in sunlight at increased wind velocities. Leaf sizes of *Ph. cordatum,* Bowstring-Hemp and *Croton* appeared to be more dependent on leaf temperatures than light intensity, since shaded leaves had leaf temperatures and sizes comparable with those of leaves in sunlight at higher air velocities.

LITERATURE CITED

1. ANSARI, A. Q., and W. E. LOOMIS. 1959. Leaf temperatures. *Amer. J. Bot.* 47: 713-717.
2. BOYSEN-JENSEN P. 1932. Die Stoff Production der Pflanzen. Gustav Fisher verlag. Jena.
3. GATES, D. M., and C. M. BENEDICT. 1963. Convection phenomena from plants in still air. *Amer. J. Bot.* 50:563–573.
4. GRAF, A. B. 1963. Exotica 3. Roehrs Company, Rutherford, N. J.
5. LEOPOLD, A. C. 1964. Plant growth and development. McGraw-Hill, New York.
6. MACKINNEY, G. 1941 Quantitative determination of chlorophyll a and b. *J. Biol. Chem.* 140:315.
7. POST, K. 1949. Florist crop production and marketing. Orange Judd, New York.
8. WOLPERT, A. 1962. Heat transfer analysis of factors affecting plant temperatures. Significance of leaf hairs. *Plant Physiol.* 37:113–120.

Effect of Soil Moisture on the Recovery of Sandblasted Tomato Seedlings[1]

D. V. Armbrust, J. D. Dickerson, and J. K. Greig,[2]
Agricultural Research Service, U. S. Department of Agriculture, Manhattan, Kansas

Abstract. Increasing the length of time that 4-week-old tomato seedlings are exposed to a 13.4-m/sec (30 mph) windspeed and an abrasive flux of 0.2 ton/rod width/hr decreases the dry weight of tops, decreases height of the tops, delays first bloom, lowers potential yields, and increases the number of plants killed irrespective of the pre- or post-soil moisture level. Irrigation or rainfall immediately after exposure can reduce the damage.

INTRODUCTION

WIND and sandblast injury to vegetable crops is a serious problem where large acreages of vegetables are grown on sandy soils. Wind alone can cause damage and desiccation (10) but wind laden with sand and soil is much more destructive. Studies dealing with abrasive injury to cotton seedlings (1), grass and alfalfa seedlings (7), green bean seedlings (9), and to established wheat stands (11) have provided some information on soil abrasive injury to plants. No previous work on the effect of soil moisture on the recovery of sandblasted plants could be found but its importance is mentioned (1). This study was undertaken to determine the effect of soil moisture level before and after abrasive injury to tomato seedlings.

MATERIALS AND METHODS

Tomatoes, *Lycopersicon esculentum* L. var 'Homestead 24', were grown in the greenhouse in 61- by 15- by 23-cm flats filled with sandy loam soil. The plants were fertilized according to recommended cultural practices.

Treatment variables were pre-exposure soil moisture level (low—6 to 12 atm tension, medium—⅓ to 6 atm tension, and high < ⅓ atm), post-exposure soil moisture level (low, medium, high), and length of exposure (0, 5, 10, and 15 minutes) to a 13.4-m/sec (30 mph) windspeed and 0.2-ton/rod width/hr abrasive flux. Treatments were arranged factorially and replicated 3 times.

Two-week-old plants were thinned to 4 plants per flat and the pre-exposure soil moisture levels imposed. Soil moisture levels were maintained by

---

[1] Received for publication October 7, 1968. Contribution from the Soil and Water Conservation Research Division, Southern Plains Branch, Agricultural Research Service, USDA, in cooperation with the Kansas Agricultural Experiment Station. Department of Agronomy Contribution No. 1054 and Department of Horticulture and Forestry Contribution No. 429.

[2] Research Soil Scientist, USDA; Engineering Research Technician, USDA; Associate Professor, Horticulture and Forestry Department, Kansas State University, respectively.

J. Amer. Soc. Hort. Sci. 94:214–217. 1969.

daily weighing and adding water when the lower limit was reached.

Four-week-old plants were exposed in the wind tunnel using the same equipment as Skidmore (9). After exposure the flats were returned to the greenhouse and post-exposure soil moisture levels established.

Date of first bloom on each flat was recorded. When plants were 8 weeks old, the height, number of live plants, number of buds, number of blooms, fresh weight of tops, and dry weight of tops were recorded.

Results

Linear regression coefficients (Table 1) revealed that post-exposure soil moisture level was significantly related to dry weight of tops, number of buds and flowers, age at first bloom, and height at the 1% level but not to per cent of plants killed. Pre-exposure soil moisture level was not related to any of the variables measured and length of exposure time was significantly related only to per cent of plants killed. Number of buds and flowers and per cent of plants killed are the only data discussed because linear regression revealed a significant relation between number of buds and flowers and all other variables except per cent of plants killed (Table 1).

Pre-exposure soil moisture level, post-exposure soil moisture level, and length of exposure time had a significant (1% level) effect on all dependent variables measured (Table 2). The significant interactions reveal that the effect of any one main effect cannot be discussed without specifying the level of the other two main effects.

Increasing the soil moisture level before or after exposure increased the number of buds and flowers (Fig. 1) regardless of length of exposure. Exposure for more than 5 minutes reduced the number of buds and flowers regardless of the moisture treatment. Increasing the soil moisture after exposure increased the number of buds and flowers more than increasing the soil moisture before exposure, except when exposed for 15 minutes.

More plants under low pre-exposure soil moisture survived than those under medium pre-exposure soil moisture when the length of exposure was less than 15 minutes (Fig. 2). All plants exposed 15 minutes with low pre-exposure soil moisture and low post-exposure soil moisture were killed. The plants growing on the high pre-exposure soil moisture were not killed by sandblasting but were blown out of the ground because of shallow root development. Increasing soil moisture after exposure increased survival regardless of length of exposure.

When the soil moisture was high prior to, or after exposure, survival was 90% or better (Fig. 2).

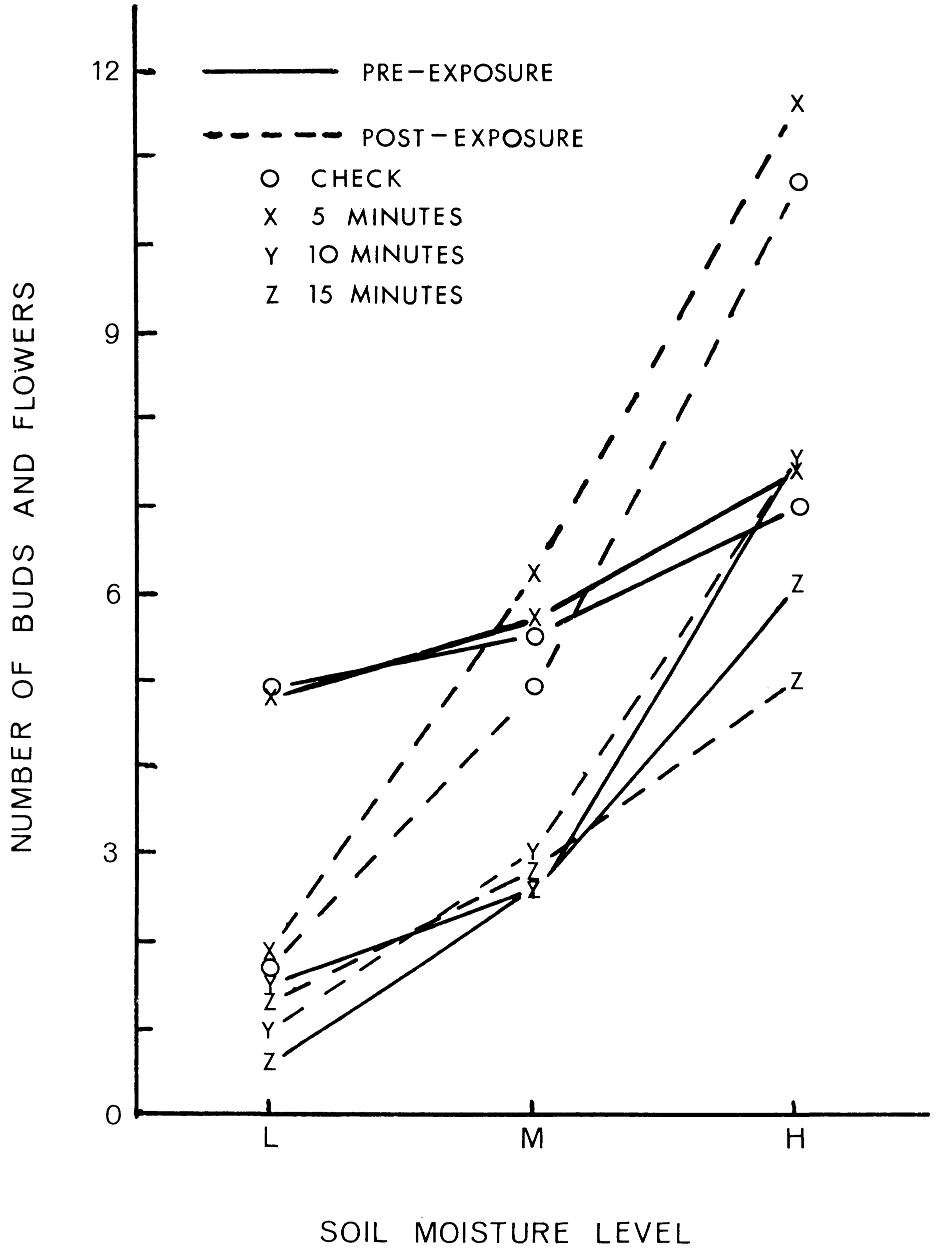

Fig. 1. Effect of pre- and post-exposure soil moisture levels on number of buds and flowers when seedlings are exposed to abrasive injury for 0, 5, 10, and 15 minutes.

Discussion

This study demonstrates that low rates of sand movement for short pe-

Table 1. Linear correlation coefficients.

Relationship	r
Pre-exposure soil moisture level X dry weight.	.29 NS
Pre-exposure soil moisture level X number of buds and flowers	.43 NS
Pre-exposure soil moisture level X age at first bloom	–.35 NS
Pre-exposure soil moisture level X height	–.31 NS
Pre-exposure soil moisture level X percent of plants killed	–.23 NS
Post-exposure soil moisture level X dry weight	.81**
Post-exposure soil moisture level X number of buds and flowers	.73**
Post-exposure soil moisture level X age at first bloom	–.63**
Post-exposure soil moisture level X height	.86**
Post-exposure soil moisture level X percent of plants killed	–.32 NS
Length of exposure time X dry weight	–.30 NS
Length of exposure time X number of buds and flowers	–.30 NS
Length of exposure time X age at first bloom.	.41 NS
Length of exposure time X height	–.28 NS
Length of exposure time X percent of plants killed	.49**
Number of buds and flowers X dry weight	.94**
Number of buds and flowers X age at first bloom	–.77**
Number of buds and flowers X height	.93**
Number of buds and flowers X percent of plants killed	–.43 NS

**Significant at 1% level.
NS Nonsignificant.

riods can severely damage tomato seedlings and that irrigation or rainfall immediately after the damage has occurred can reduce the effect.

Rates of soil movement used in this study are within the range of soil movement for naturally occurring storms for soils of average erodibility but below those of above-average erodibility. Chepil (3) reported that the rate of soil movement 40 rods across wind-eroded fields with a 30-mph wind at a height of 5 ft was 0.1, 0.5, and 1.4 tons/rod width/hr for a silt loam of below-average and average erodibility and a loamy sand of above-average erodibility, respectively.

Information on duration and frequency of natural winds that would cause these soil movement rates is limited. Zingg (12) indicated that winds of 40 mph at a height of 58 ft (comparable to 30 mph at a height of 5 ft) of 5-minute duration would occur about once a year at Dodge City, Kansas, and once each 18 months at Wichita, Kansas. A wind of that intensity lasting 1 hr could be expected once each 18 months at Dodge City and only once each 3 years at Wichita. Detailed data on winds at other locations are not available but wind erosion damage to vegetables has been reported in South Carolina (2), New Jersey (6), and Ohio (8) nearly every year.

This information indicates that every vegetable grower should expect wind erosion damage nearly every year, and should design and develop effective control methods. Information now available indicates that barriers, well-anchored vegetative material, and sprayed-on nonvegetative films effectively protect vegetable crops (4, 5). Barriers include corn, sorghum, grasses, trees or shrubs, or snowfences. To be most effective they should be planted or constructed in rows perpendicular to the prevailing wind erosion direction and at frequent intervals. Vegetative materials include rye, wheat, and hauled-in mulches such as wheat straw and native hay. Nonvegetative materials include byproducts of the petroleum and chemical industries such as asphalt and latex. The application rates required are high and the materials are expensive, but they are effective and their use can be justified on high-income crops such as tomatoes.

Table 2. Analysis of variance, F values.

Variable	Reps.	Pre-exposure soil moisture level (O)	Post-exposure soil moisture level (F)	Exposure time (T)	0 × F	0 × T	F × T	0 × F × T
Dry weight (grams)	3.03 NS	44.47**	273.69**	26.06**	3.86 NS	2.60 NS	5.32**	1.95 NS
Number of buds and flowers	3.28 NS	85.27**	215.48**	30.75**	9.80**	4.34**	7.17**	1.76 NS
Age at first bloom (days)	0.13 NS	19.15**	62.79**	19.55**	1.21 NS	6.08**	2.88 NS	1.53 NS
Height (cm)	1.44 NS	42.24**	310.17**	20.99**	0.87 NS	2.73 NS	1.61 NS	1.00 NS
Percent of plants killed	0.41 NS	7.78**	10.16**	19.57**	4.96**	5.70**	4.23**	1.72 NS

**Significant at 1% level.
NS Nonsignificant.

LITERATURE CITED

1. ARMBRUST, D. V. 1968. Windblown soil abrasive injury to cotton plants. *Agron. J.* 60:622–625.
2. CARREKER, JOHN R. 1966. Wind erosion in the Southeast. *J. Soil Water Conserv.* 21:86–88.
3. CHEPIL, W. S. 1946. Dynamics of wind erosion: V. Cumulative intensity of soil drifting across eroding fields. *Soil Sci.* 61(3):257–263.
4. ————, and WOODRUFF, N. P. 1963. The physics of wind erosion and its control. *Adv. in Agron.* 15:211–302.
5. ————, ————, SIDDOWAY, F. H., FRYREAR, D. W., and ARMBRUST, D. V. 1963. Vegetative and nonvegetative materials to control wind and water erosion. *Soil Sci. Soc. Amer. Proc.* 27(1):86–89.
6. HAYES, W. A. 1965. Wind erosion equation useful in designing northeastern crop protection. *J. Soil Water Conserv.* 20:153–155.
7. LYLES, LEON, and WOODRUFF, N. P. 1960. Abrasive action of windblown soil on plant seedlings. *Agron. J.* 52:533–536.

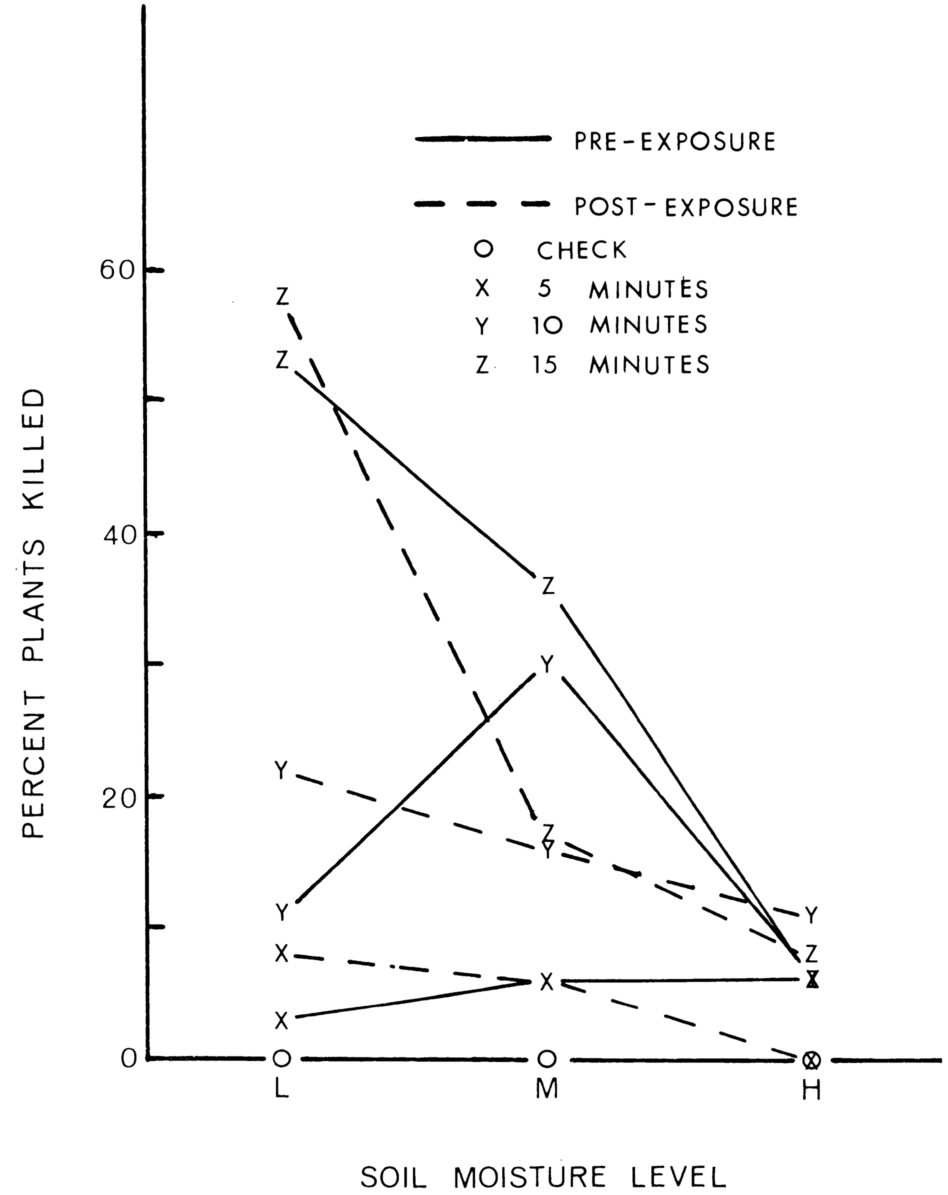

Fig. 2. Effect of pre- and post-exposure soil moisture levels on per cent of plants killed when seedlings are exposed to abrasive injury for 0, 5, 10, and 15 minutes.

Infrared Radiation Shields for Cold Protection of Young Citrus Trees[1]

J. David Martsolf[2,3] and John F. Gerber,[2]
University of Florida, Gainesville

Abstract. Aluminum-foil-surfaced shields were evaluated with individual citrus trees. These shields, highly reflective in the infrared, moderated leaf temperatures by interrupting their radiant heat loss. A horizontal shield over an individual tree provided about 1° F of cold protection on clear and relatively calm nights. Temperatures of shielded and unshielded leaves were not affected by moderate wind drift or position on the tree. Radiant cooling may induce air flow over the tree that tends to convectively equalize leaf and air temperature. Large differences did not occur between leaf temperatures on adjacent trees. Neither position nor replication produced large temperature differences between leaves at night. Analysis of the heat balance in quasi-steady state indicated that 1° differences were reasonable and that small radiation shields cannot be expected to provide more protection than the amount that leaves are radiantly cooled below air temperature.

INTRODUCTION

RADIANT heat loss cools exposed surfaces on clear nights. Blocking this radiation by a shield should increase the heat loss and moderate leaf temperature. Clouds are examples of natural shielding from a cold night sky (1).

Data from California indicate that a small shield (40 cm × 50 cm) placed 50 cm above the tree caused citrus leaf temperatures to change from about 1.8°F below air temperature to near air temperature (2). The use of "brushing" materials as radiation shields on vegetables has provided frost protection (7). Experiments with plastic enclosure (7 ft sq) with 6 ft plastic sides, revealed that the condensation of water on the film rendered it virtually opaque to infrared radiation (14). These shelters provided 2 to 7° of protection by moderating both radiative and convective heat loss. An opaque paper tent of similar size over small citrus trees provided only 2° of protection in California (1). A 4-ft-wide plastic strip rolled out over a horizontal trellis resulted in a 3° protection to grape vines on clear nights (10).

Banking small citrus trees with soil is the only widely used practice for non-bearing citrus in Florida (6). This practice provides protection below the soil line from death only. Small citrus trees were observed to be more susceptible to frost damage than mature trees (13). There is a need for an economically feasible method that will protect small trees.

MATERIALS AND METHODS

Two experiments were conducted to determine the effects of infrared shielding upon the microclimate of small citrus trees. The first experiment was conducted in Highlands County, Florida, in a grove of 4-year-old 'Valencia' oranges, *Citrus sinensis* Osbeck, budded on rough lemon, *C. jambhiri* Lush set 25 by 25 ft. The soil was Lakeland fine sand, cleanly cultivated. The site was practically flat with a slight slope toward the east, and was bordered by older groves on the north and west, and by open fields on the east and south.

The second experiment was conducted in a grove on the campus of the University of Florida at Gainesville. The trees were 5-year-old 'Owari' satsumas, *C. reticulata* Blanco, budded onto *Poncirus trifoliata* (Lynn.) Raf., set 15 by 30 ft on Arredonda loamy sand. The grove was cleanly cultivated. Both sites were rather typical of young groves in the surrounding area.

Temperatures were measured with 24 gauge copper-constantan thermocouples and a 20-point potentiometer with automatic reference junction compensation. Thermocouples for measuring leaf temperatures have been reviewed by Waggoner and Shaw 15. They have been criticized because of radiation errors (2, 3); however, the nocturnal radiant flux density is an order of magnitude smaller than the daytime densities, thus radiation errors at night are small. The thermocouples used are shown in Fig. 1. Leaf temperatures were measured by taping the thermocouple to the underside of the leaf. This method was found to be more satisfactory than those of Lorenzen (8) and Eggert (4).

Air temperatures were measured with thermocouples mounted vertically below a cardboard shield, 4½ ft above bare soil in the middles between trees. Twig temperatures were measured by pressing a sharpened thermocouple beneath the bark next to the cambium on the upper surface; soil temperatures were measured by pressing thermocouples into the soil to a depth of 1 inch; fruit temperatures were measured by inserting a sharpened thermocouple ½ inch into the fruit. In the second experiment, only leaf temperatures were measured.

The experiment was designed so that the positions of the thermocouples on each tree were chosen from 4 adjacent trees at random by dividing each tree into 5 sections (Fig. 2). The position of the thermocouple and the recorder sequence were chosen randomly.

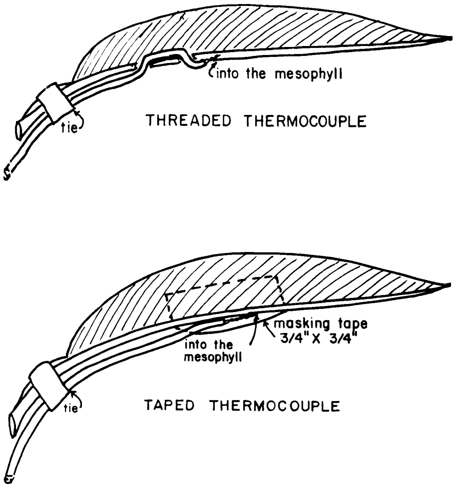

Fig. 1. Cross sections of citrus leaves with the thermocouple and leaf prepared for nocturnal leaf temperature measurement.

---

[1] Received for publication October 14, 1968. Florida Agricultural Experiment Stations Journal Series No. 3078.

[2] Research Assistant, and Associate Professor of Climatology, respectively, Department of Fruit Crops. Research completed in partial fulfillment of requirements for the MSA degree at the University of Florida.

[3] Currently Associate Professor of Agricultural Climatology, Department of Horticulture, The Pennsylvania State University, University Park.

---

8. SCHMIDT, B. L., and TRIPLETT, G. B., JR. 1967. Controlling wind erosion. *Ohio Rep. Res. Develop.* 52:35–37.
9. SKIDMORE, E. L. 1966. Wind and sandblast injury to seedling green beans. *Agron. J.* 58:311–315.
10. WHITEHEAD, F. H. 1963. Experimental studies of the effect of wind on plant growth and anatomy. III. Soil moisture relations (*Helianthus annuus*). *New Phytol.* 62:80–85.
11. WOODRUFF, N. P. 1956. Wind-blown soil abrasive injuries to winter wheat plants. *Agron. J.* 48:499–504.
12. ZINGG, A. W. 1950. The intensity-frequency of Kansas winds. *USDA, SCS-TP* 88.

J. Amer. Soc. Hort. Sci. 94:217–220. 1969.