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M. F. MILLER, *Director*

The Effect of Root Temperature Upon The Absorption of Water by The Cucumber

R. A. SCHROEDER

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TABLE OF CONTENTS

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INTRODUCTION

The growing of vegetable crops is an important industry in many of the northern states. It has been estimated by the Hothouse Vegetable Growers National Association that there is an investment of 125 millions of dollars in such enterprises in the United States.

For many years the chief crops that were grown during the fall and winter months were leaf lettuce and radishes. With the development of the head lettuce industry on the west coast, along with other sources of competition, greenhouse growers found it desirable to substitute other crops for leaf lettuce and radishes. Market demands have made the cucumber one of the most promising of the vegetable crops for this use.

In the actual growing of cucumbers under the fall and winter environmental conditions, many new production problems were encountered. One of the most serious of the problems involved is the control of the injury (Figures 1, 2, and 3) which frequently affects the commercial plantings at about the time the plants are beginning to set the cucumbers which are to form the peak production of the vines.

This injury is characterized by a wilting and drying of the apical end of the developing fruit, and death of a varying number of leaves per plant, as well as a varying amount of the individual leaves. The damage is most often initially evidenced by a loss of green color of the leaves and fruit. It is generally most severe at the lobes of the older leaves and at the tip of the young developing fruit. Later the tissue affected loses its turgidity, becomes brown, and finally is completely killed. As the injury progresses in severity it also affects an increasing amount of surrounding tissue until finally the entire leaf or fruit is killed.

The killing of a varying amount of the apical part of the fruit means, of course, that the fruit is of no value for commercial purposes. The death of a varying amount of leaf area frequently reduces the metabolic activity of the plant to a point where it cannot support a commercially profitable crop of cucumbers.

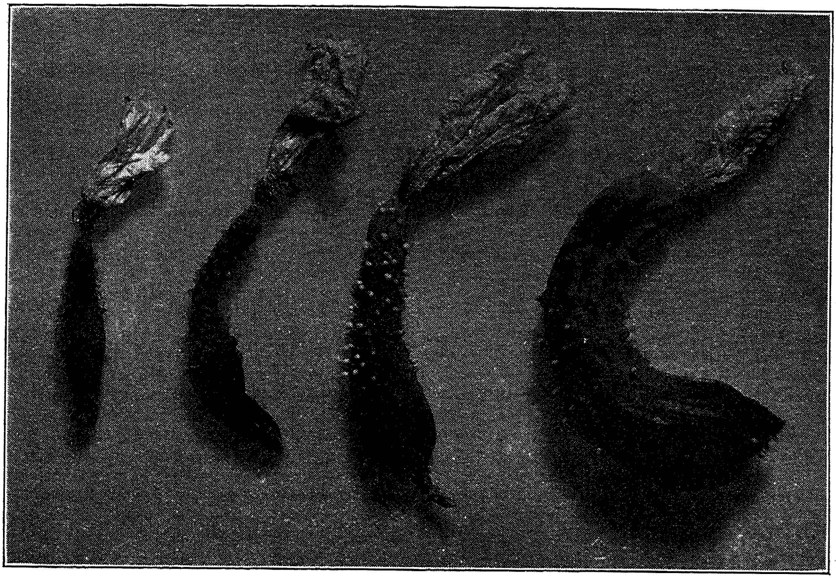

Fig. 1.—Typical cucumber fruit injury.

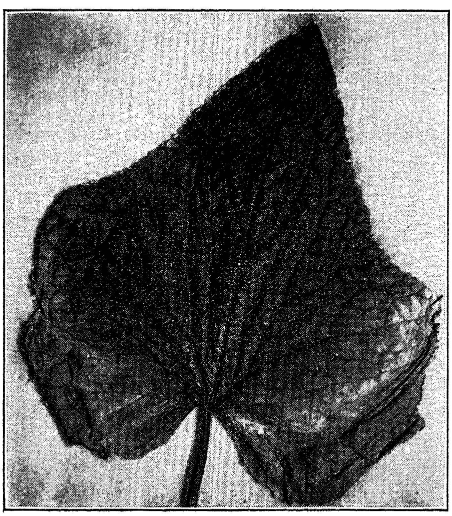

Fig. 2.—Typical cucumber leaf injury.

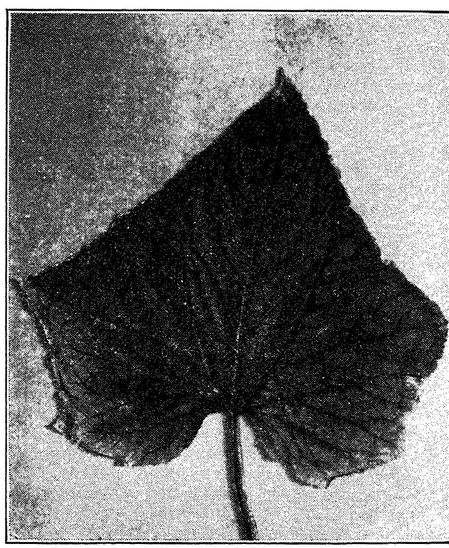

Fig. 3.—Typical cucumber leaf injury.

Preliminary Work

The symptoms of the injury indicated that it was probably physiological in nature rather than the result of an attack of a pathogene. These observations resulted in the growing of cucumber plants in pot culture under different nutritional conditions. Plants were grown in sand and supplied with varying amounts of nitrogen, phosphorus, and potassium individually and in combination. The results showed that there was no pronounced correlation between the treatments tried and the occurrence of the typical leaf and fruit injury.

In an attempt to associate soil type with the injury, cucumbers were grown with negative results in the following media: (1) Sand, (2) clay, (3) well-rotted manure, and (4) several combinations of the three.

Manganese, boron, zinc and iron were sprayed individually and in combination on the cucumber leaves in an attempt to associate any possible deficiency of mineral elements and the appearance of the injury. The results showed no beneficial effect from the application of the above elements.

Frequently commercial cucumber crops are rather severely infested with thrips. In order to determine any correlation between thrips injury and the typical leaf and fruit injury, sprays were applied which gave practically a complete control of thrips. The results demonstrated that the injury could occur just as severely on plants completely free of thrips as upon plants heavily infested.

Numerous attempts were made, all resulting in failure, to isolate a pathogenic organism from the affected plant areas.

It was observed during the course of the various tests that the cucumbers which were grown on raised benches were comparatively free of the injury as compared to those grown in ground beds. Syringing the plants appeared to reduce the amount of the injury. Plants grown in the spring were not nearly as severely damaged as those grown in the fall and winter. The injury made its most severe appearance on days of intense sunlight which followed a more or less extended period of cloudy weather.

These observations and the work of Clements and Martin[2*] on the effect of soil temperature upon the transpiration of *Helianthus annus* suggested the possibility of an association between soil temperature and the appearance of the characteristic leaf and fruit injury of cucumbers.

*Superscript numerals refer to Bibliography page 27.

REVIEW OF LITERATURE

Clements and Martin,[2] studying the transpiration of *Helianthus annus* as affected by soil temperature, found that it varied very little with soil temperatures between 55° and 100° F. Below 55° F., however, the reduction in transpiration was rapid and at 38° F. was reduced to one-half. The rate continued to be reduced with a lowering of the temperature until it reached zero at 32° F. Additional tests demonstrated that the stomata did not begin to close until the soil temperature reached 40° F. and were completely closed at 37° F.

Sachs[6] surrounded the root system of a tobacco plant with ice, exposed the plant to conditions of high transpiration and in that manner caused the plant to wilt in a brief period of time. When the soil was heated, the plant completely recovered.

Kramer[4] made simultaneous determinations of absorption, transpiration and leaf moisture. His results indicated that the time of minimum leaf moisture approximately coincided with the time of maximum transpiration. It was further demonstrated that changes in the rate of transpiration affected, in the same direction, the absorption of water.

In studying the cause of absorption lag, Kramer[5] by using potometer tests found that the lag was greatly reduced by the removal of the root system. He concluded that the living cells between the epidermis and the xylem offer considerable resistance to the passage of water and that the resistance was greater at low than at high temperatures.

Kramer[3] and Arndt[1] studied the difference between the quantity of water that can be absorbed through dead roots as contrasted to the quantity absorbed through living roots. It was found that the water absorbed was materially increased, for a time, by killing the roots. The length of time depended, at least in part, upon the kind of plant and the severity of the treatment.

Arndt,[1] working with cotton plants under greenhouse conditions, found that when the plants were grown in water culture wilting occurred at a root temperature of between 10° and 18° C., and when the plants were grown in soil the wilting occurred at a root temperature of between 17° and 20° C. He also states that the amount of lowering necessary is dependent upon the air temperature, relative humidity and sunlight intensity.

Arndt[1] and Kramer[5] suggest that the reduction in water absorption by plant roots at low temperatures may be caused by the increased viscosity of both protoplasm and water at such temperatures.

EXPERIMENTAL METHODS USED

The effect of soil temperature upon the absorption of water by the cucumber plant was attacked in two general ways:

1. Plants were grown at different soil temperatures for a definite period of time, after which the soil temperature of some of the plants was lowered and the effects noted.
2. Measurements were made of the amount of water that cucumber roots absorb at various temperatures.

A. Soil Temperature Studies

For the constant soil temperature studies three tanks each capable of holding twelve four-gallon stone crocks were constructed. The tanks were filled with water to a level which was one inch below the top of the crock. The soil level in the crock was one inch below the water level outside. The temperature of the water was controlled by a DeKotinsky thermo-regulator to within one degree Fahrenheit. In the series held at a temperature lower than the mean air temperature, the water was cooled by forcing cold water through a coil of copper tubing in the bottom of the water bath. For the treatment in which the plants were to be grown at a high temperature and later changed to a lower temperature, the water bath was equipped with both heating and cooling units. A uniform temperature was maintained throughout each tank by constantly circulating the water with automobile water pumps driven by an electric motor.

The soil moisture in all of the treatments was maintained at the optimum as nearly as is possible by close observation. Whenever the soil temperature was to be lowered, the temperature of the water bath was lowered in late afternoon and the plants in all of the treatments watered with water at the desired soil temperature, care being taken not to over- or under-water any of the treatments.

B. Root Absorption Studies

Measurements of the actual amount of water absorbed by a cucumber root were made in two different ways. Potometer tests using plants which had been grown in water culture was one means of measurement. The plants were sealed in wide-mouth bottles by utilizing three-hole rubber stoppers. From the edge of stopper a slit was made to one of the holes, permitting the stem of the plant to be placed in the opening without injury. A second hole equipped with a glass tube permitted the rapid emptying of the bottle and refilling with water of a different temperature. The third hole held a 25 cc. burette used to measure the number of cc. absorbed by the root system. The plant was sealed in the bottle by using adhesive tape and grafting wax.

The other method of measurement involved decapitating a water-culture-grown cucumber plant, leaving about 6 cm. of stem and attaching the root system to a 25 cc. burette. The suction which was used in these root absorption tests was one-half atmosphere and was obtained by means of a leveling mercury bottle.

In every case where the above described typical leaf and fruit injury appeared, the soil temperature of the cucumbers was 60° F. or below. Therefore, 60° F. was chosen as the temperature with which to attempt to induce the typical injury under controlled conditions. Eighty-five degrees F. was chosen arbitrarily as the growing temperature for the remaining experimental plants.

EXPERIMENTAL RESULTS

Soil Temperature Studies

The first series of experimental plants to be held at a constant soil temperature were grown during the spring of 1937. The original plan was to grow one series of twelve plants at a soil temperature of 60° F., another series of twelve plants at a soil temperature of 85° F., and the third series of plants at a soil temperature of 85° F. until they reached a height of 5 to 6 feet and then attempt to induce typical injury symptoms by lowering the soil temperature to 60° F.

The seed which was planted in soil at a temperature of 60° F. was approximately 7 days longer in germinating than the series started at 85° F. In six of the twelve crocks all of the plants were attacked by damping-off and it was necessary to transplant into their place plants started in pots at the same time as the other experimental plants but which were growing in a soil of 85° F. After the plants had grown at 60° F. for a period of 30 days, it was impossible to maintain them at that temperature because of difficulty with the cooling apparatus. For the next 60 days they were grown at 70° F. During the 30-day growing period at 60° F., the plants had reached a height of approximately 5 inches, while the plants growing at 85° F. were approximately 3 feet tall.

Figure 4 shows the two rows of plants 90 days from seeding. The first 30 days the plants were grown at 60° F. and the last 60 days at 70° F. Figure 5 shows the same two rows of plants the day following the lowering of their soil temperature to 60° F. Figure 6 is an individual plant after being subjected to the above treatment.

The two rows of plants in the center of Figure 7 had been grown at a soil temperature of 85° F. for 90 days. In Figure 8 the same plants are shown the day following the lowering of the soil temperature to 60° F. Figure 9 shows an individual plant of the same series.

Fig. 4.—Series 1. Cucumber plants grown at a soil temperature of 60° F. for 30 days and then at 70°F. for 60 days.

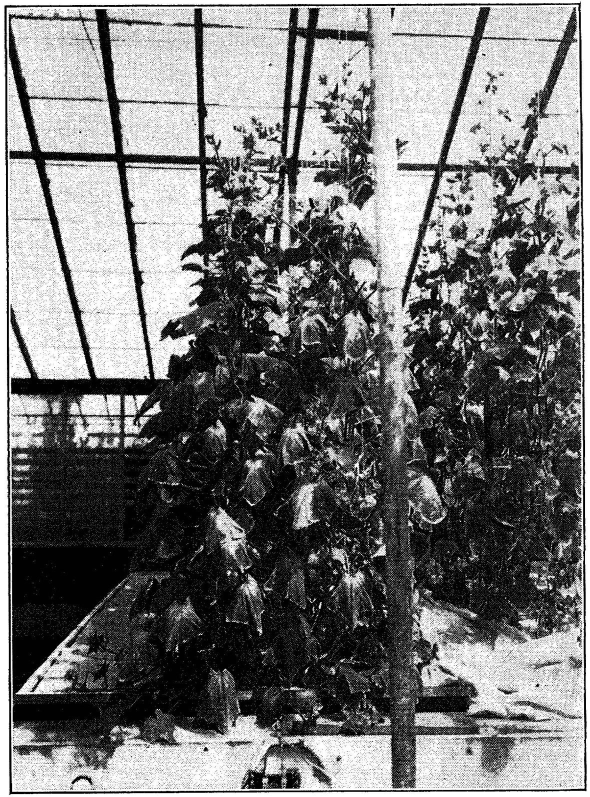

Fig. 5.—Series 1. Cucumber plants in Figure 4, one day later at a soil temperature of 60° F.

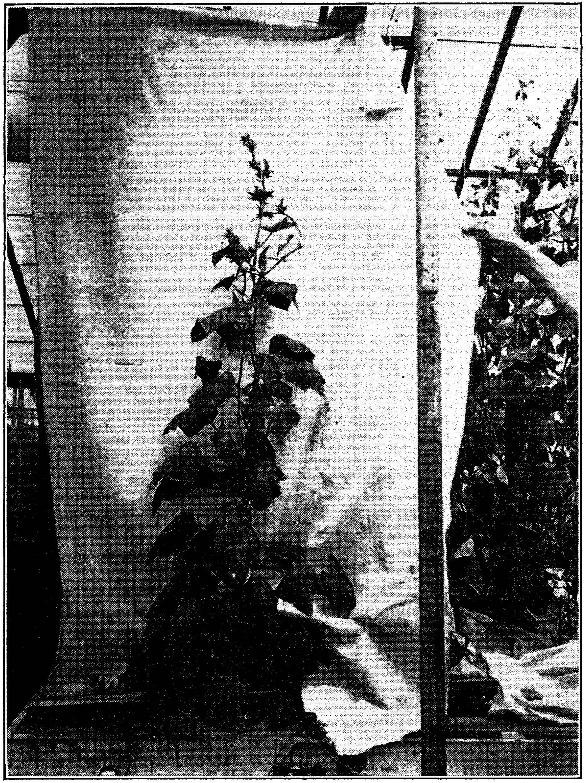

Fig. 6.—Series 1. An individual plant of those shown in Figure 5.

Fig. 7.—Series 1. Cucumber plants grown at a soil temperature of 85° F. for 90 days.

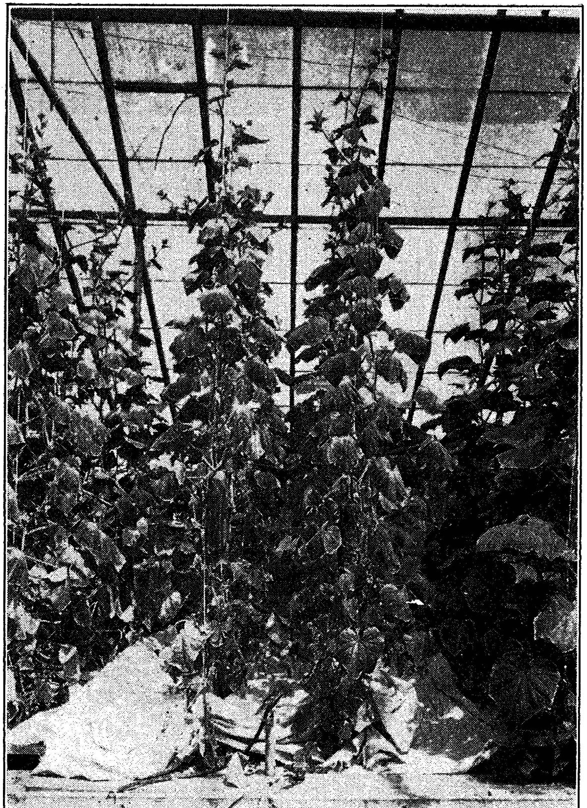

Fig. 8.—Series 1. Plants in Figure 7 one day later at a soil temperature of 60° F.

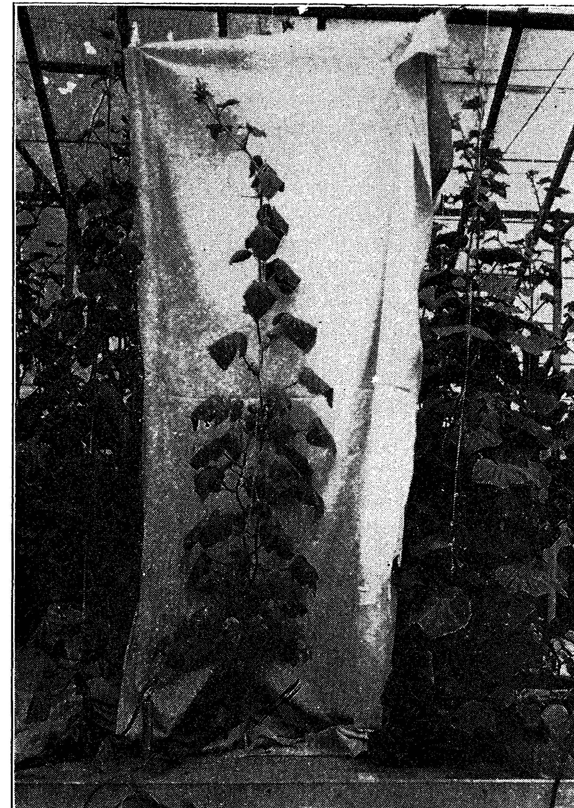

Fig. 9.—Series 1. An individual plant from those shown in Figure 8.

Fig. 10.—Series 1. Cucumber plants grown at a soil temperature of 85° F. for 90 days.

Fig. 11.—Series 1. Plants in Figure 10 one day later still at a soil temperature of 85° F.

The two rows of cucumber plants on the right of Figure 10 were grown at a soil temperature of 85° F. for 90 days. Figures 11, and 12 show the same plants still at a soil temperature of 85° F. The photographs were taken at the same time Figures 5, 6, 8, and 9 were photographed, the soil temperature of which had been lowered to 60° F.

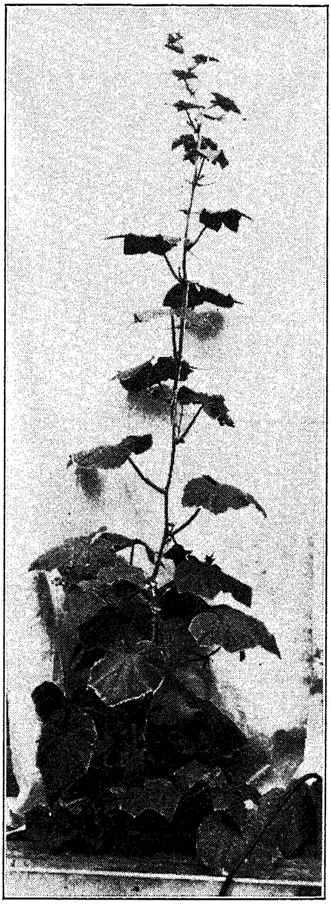

Fig. 12.—Series 1. An individual plant from those shown in Figure 11.

The air temperature in the greenhouse the first day that the soil temperature was lowered was 80° F. at 8 A. M., and reached a maximum of 92° F. at 1 P. M. Wilting was first evident on plants with a soil temperature of 60° F. at 9:30 A. M. and became more severe with additional time and increasing air temperature.

Fig. 13.—Series 2. Constant soil temperature studies. Reading left to right in units of two rows.
60° F. for 60 days. 85° F. for 60 days. 85° F. for 60 days.

Fig. 14.—Series 2. Constant soil temperature studies photograph taken one day after that of Figure 13. Reading left to right in units of two rows. 60° F. for 61 days; 85° F. for 60 days then lowered to 60° F.; 85° F. for 61 days.

The second series of plants from the left of Figure 13 were grown at a soil temperature of 60° F. for 60 days. The average height was approximately 7 inches. The remaining 4 rows in Figure 13 were grown at a soil temperature of 85° F. for 60 days. The difference in height of the plants in the third row from the left is caused by a difference in the fertility of the soil.

Figure 14 shows the same group of plants after the soil temperature of the center rows was lowered to 60° F. The air temperature on the day the photograph was made ranged from 75° F. at 8 A. M. to 92° F. at 1:30 P. M.

Figs. 15-16-17-18.—Typical cucumber leaf injury. Leaf taken from experimental plant after root temperature had been lowered to 60° F.

Figures 15, 16, 17, 18, 19, and 20 are photographs of leaves showing different degrees of characteristic injury. The leaves were selected from the experimental plants which had been subjected to a soil temperature of 60° F.

Figs. 19-20.—Typical cucumber leaf injury. Leaf taken from experimental plant after root temperature had been lowered to 60° F.

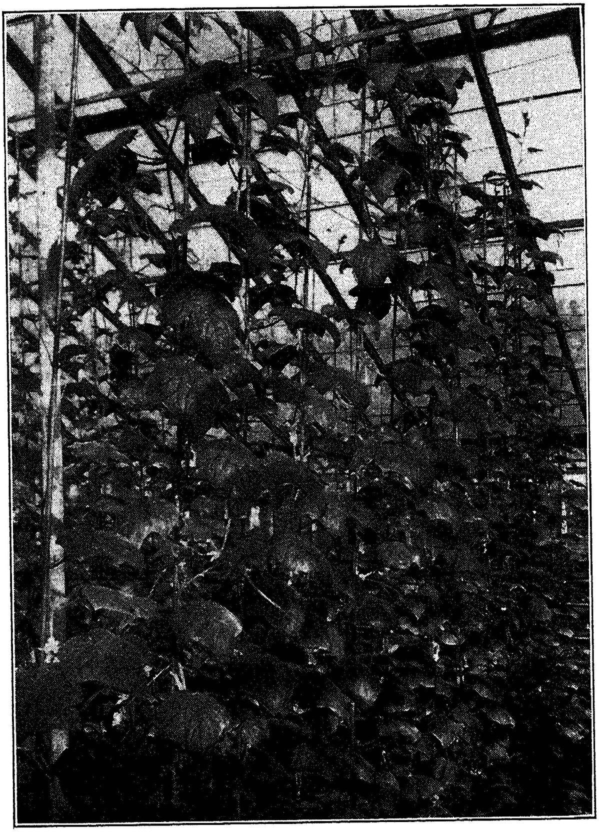

Fig. 21.—Cucumber plants grown under greenhouse conditions at a soil temperature of 70° F.

The potometer tests Figure 22 were made in order that the amount of water absorbed by a plant at one temperature could be compared with the amount of water absorbed by the same plant at a different root temperature. Tables 1 to 8 inclusive give the data obtained from these determinations.

Several plants were used in each test in order that the plants might be compared one with the other and in that manner compensate to a degree any change in environmental factors affecting transpiration. For all of the data presented the determinations were made on days of full sun with a temperature generally varying from around 80° F. for the opening runs to a high of approximately 98° F. during the mid-day determinations. During the course of the experiments the root temperature studied included 60°, 65°, 70°, 85°, 90°, and 100° F. The results do not readily lend themselves to the graphing

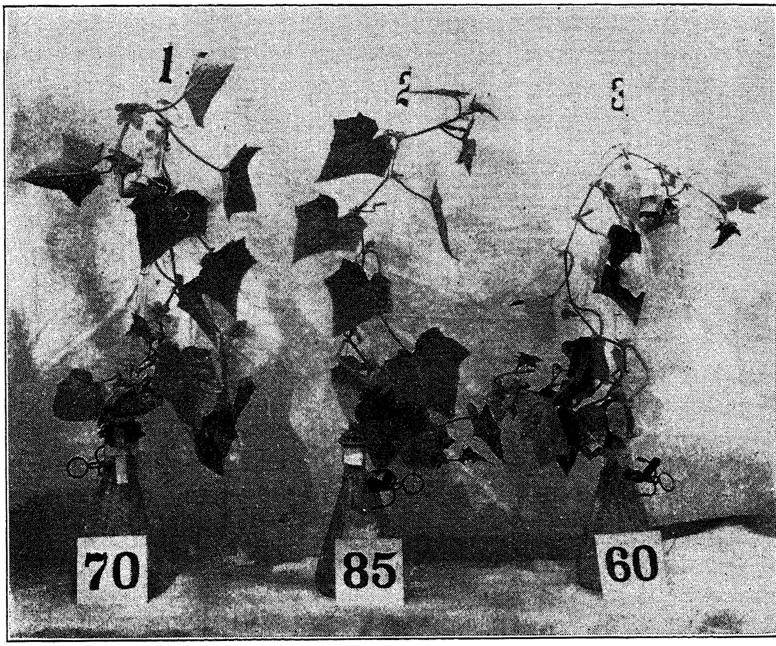

Fig. 22.—Potometer test plants. Showing the method used and the response to 70° F., 85° F., and 60° F.

of a curve of the amount of water absorbed by cucumber roots at the above temperatures, but distinct differences are readily seen. For example, the amount of water absorbed at a root temperature of 70° F. as contrasted to the amount absorbed at 60° F. varied greatly with the individual, but plants 4, 5, 6, 7, 8, 13, and 14 showed an increase of 56, 56, 35, 37, 100, and 13 per cent respectively.

It is very significant that with one exception all the experimental plants wilted when subjected to a root temperature of 60° F. and showed no visible wilting at the higher temperatures studied. The exception was plant 21, which did not wilt at 60° F. Reference to Tables 7 and 8 shows that the amount of water absorbed by this plant per unit of time was not greatly affected by differences in root temperature.

A possible explanation of these results might be found in the observation that the basal part of the stem was rather severely cracked. Apparently this provided an excellent means for water to reach the xylem without being absorbed by the roots.

The amount of water absorbed by the plants studied at a root temperature of 65° F. was not significantly different from the amount

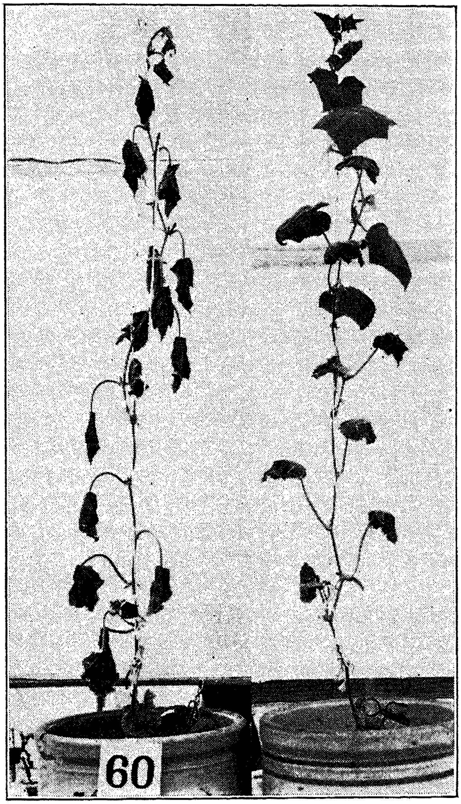

Fig. 23.—Potometer test plant (left) after being at root temperature of 60° F. for one hour. (Right) same plant after recovering.

absorbed by the same plants at a temperature of 70° F., nor did the plants show any evidence of wilting at the lower temperature.

The degree of wilting varied with the environmental conditions and the individual plants. In some cases 50 per cent of the leaf area was completely killed. The plant on the left in Figure 23 had been held at a temperature of 60° F. for 60 minutes when the photograph was taken. Its root temperature was then raised to 70° F., the plant syringed and placed in a white-washed greenhouse so that it could recover. The same plant is shown on the right in Figure 24 one day later. As can be readily seen the amount of permanent damage is quite marked.

This reduction in leaf area can safely be assumed to affect the amount of water absorbed at the root temperature to which the plant was later subjected. The fact that plants 3 and 15 gave less water absorption at 70° F. than at 60° F. is probably explainable by their reduced leaf area after being at a root temperature of 60° F.

TABLE 1.—POTOMETER TEST 1.

	Plant 1	Plant 2
Beginning Temperature	60° F.	85° F.
Water Absorbed (cc.) at		
10:30 A. M.	0.0	0.0
1:30 P. M.	6.4	11.5
Temperature Changed to	85° F.	60° F.
Water Absorbed (cc.) at		
1:30 P. M.	0.0	0.0
4:30 P. M.	9.0	3.2

TABLE 2.—POTOMETER TEST 2.

	Plant 3	Plant 4	Plant 5
Beginning Temperature	60° F.	70° F.	90° F.
Water Absorbed (cc.) at			
10:15 A. M.	0.0	0.0	0.0
12:15 P. M.	20.7	12.2	27.4
Temperature Changed to	70° F.	90° F.	60° F.
Water Absorbed (cc.) at			
12:20 P. M.	0.0	0.0	0.0
2:20 P. M.	12.0	14.4	16.0
Temperature Changed to	90° F.	60° F.	70° F.
Water Absorbed (cc.) at			
2:20 P. M.	0.0	0.0	0.0
4:20 P. M.	26.0	7.8	25.0

TABLE 3.—POTOMETER TEST 3.

	Plant 6	Plant 7	Plant 8
Beginning Temperature	60° F.	70° F.	85° F.
Water Absorbed (cc.) at			
9:30 A. M.	0.0	0.0	0.0
10:30 A. M.	28.0	30.0	35.0
Temperature Changed to	70° F.	85° F.	60° F.
Water Absorbed (cc.) at			
11:30 A. M.	0.0	0.0	0.0
1:30 P. M.	38.0	42.0	17.5
Temperature Changed to	85° F.	60° F.	70° F.
Water Absorbed (cc.) at			
1:30 P. M.	0.0	0.0	0.0
3:30 P. M.	50.5	23.3	25.0

TABLE 4.—POTOMETER TEST 4.

	Plant 9	Plant 10	Plant 11	Plant 12
Beginning Temperature	65° F.	65° F.	70° F.	70° F.
Water Absorbed (cc.) at				
9:30 A. M.	0.0	0.0	0.0	0.0
9:45 A. M.	4.2	3.4	2.5	2.7
10:00 A. M.	7.2	4.7	5.0	5.8
10:15 A. M.	10.7	8.1	8.2	9.3
10:30 A. M.	13.5	11.0	11.2	12.6
10:45 A. M.	16.5	14.0	14.3	16.0
11:00 A. M.	19.6	17.6	18.9	19.9
11:15 A. M.	22.7	20.9	21.5	23.8
11:30 A. M.	25.6	23.5	24.8	27.3
Temperature Changed to	70° F.	65° F.	65° F.	70° F.
Water Absorbed (cc.) at				
11:30 A. M.	0.0	0.0	0.0	0.0
11:45 A. M.	5.0	3.7	3.7	4.4
12:00	*	8.2	7.4	7.3
12:15 P. M.	...	11.3	11.7	13.0
12:30 P. M.	...	15.2	15.6	16.9
12:45 P. M.	...	19.1	19.5	20.8
1:00 P. M.	...	23.0	23.3	24.4
1:15 P. M.	...	26.1	26.3	27.8
1:30 P. M.	...	33.5	30.2	32.1
Temperature Changed to	65° F.	65° F.	70° F.	70° F.
Water Absorbed (cc.) at				
1:30 P. M.	0.0	0.0	0.0	0.0
1:45 P. M.	7.8	3.5	3.4	3.5
2:00 P. M.	12.9	7.2	6.9	7.0
2:15 P. M.	16.9	10.3	9.8	9.7
2:30 P. M.	20.2	13.3	12.6	12.4

*Break in system.

TABLE 5.—POTOMETER TEST 5.

	Plant 13	Plant 14
Beginning Temperature	60° F.	70° F.
Water Absorbed (cc.) at		
11:15 A. M.	0.0	0.0
11:30 A. M.	3.0	7.4
11:45 A. M.	5.0	14.8
Temperature Changes to	70° F.	60° F.
Water Absorbed (cc.) at		
1:00 P. M.	0.0	0.0
1:15 P. M.	5.0	6.5
1:30 P. M.	10.5	13.0
1:45 P. M.	15.7	18.8
2:00 P. M.	21.0	25.0

TABLE 6.—POTOMETER TEST 6.

	Plant 15	Plant 16	Plant 17
Beginning Temperature	60° F.	70° F.	85° F.
Water Absorbed (cc.) at			
10:00 A. M.	0.0	0.0	0.0
10:15 A. M.	8.8	15.7	15.0
10:30 A. M.	14.5	31.6	24.4
Temperature Changed to	70° F.	85° F.	60° F.
Water Absorbed (cc.) at			
11:00 A. M.	0.0	0.0	0.0
11:15 A. M.	6.7	21.0	6.7
11:30 A. M.	13.0	37.0	11.5
Temperature Changed to	85° F.	60° F.	70° F.
Water Absorbed (cc.) at			
1:00 P. M.	0.0	0.0	0.0
1:15 P. M.	10.2	13.0	10.0
1:30 P. M.	17.2	21.0	18.2
Temperature Changed to	60° F.	70° F.	85° F.
Water Absorbed (cc.) at			
2:00 P. M.	0.0	0.0	0.0
2:15 P. M.	6.5	15.7	10.2
2:30 P. M.	15.0	29.0	20.5

TABLE 7.—POTOMETER TEST 7.

	Plant 18	Plant 19	Plant 20	Plant 21	Air Temp.
Beginning Temperature	70° F.	70° F.	70° F.	70° F.	
Water Absorbed (cc.) at					
9:15 A. M.	0.0	0.0	0.0	0.0	81° F.
9:30 A. M.	16.5	8.1	16.2	11.5	81° F.
Temperature Changed to	60° F.	70° F.	85° F.	100° F.	
Water Absorbed (cc.) at					
10:00 A. M.	0.0	0.0	0.0	0.0	83° F.
10:15 A. M.	16.8	8.4	19.0	14.4	87° F.
Temperature Maintained at ...	60° F.	70° F.	85° F.	100° F.	
Water Absorbed (cc.) at					
10.15 A. M.	0.0	0.0	0.0	0.0	87° F.
10:30 A. M.	15.9	8.4	18.0	14.0	90° F.
Temperature Changed to	70° F.	85° F.	100° F.	60° F.	
Water Absorbed (cc.) at					
10:55 A. M.	0.0	0.0	0.0	0.0	92° F.
11:10 A. M.	19.0	10.0	21.0	14.0	94° F.
Temperature Maintained at ...	70° F.	85° F.	100° F.	60° F.	
Water Absorbed (cc.) at					
11:15 A. M.	0.0	0.0	0.0	0.0	95° F.
11:30 A. M.	18.9	9.8	20.0	15.7	97° F.
Temperature Changed to	85° F.	100° F.	60° F.	70° F.	
Water Absorbed (cc.) at					
11:50 A. M.	0.0	0.0	0.0	0.0	98° F.
12:05 P. M.	19.0	9.8	10.0	11.9	98° F.
Temperature Changed to	100° F.	60° F.	70° F.	85° F.	
Water Absorbed (cc.) at					
1:35 P. M.	0.0	0.0	0.0	0.0	94° F.
1:50 P. M.	22.8	1.4	15.4	16.0	94° F.
Temperature Maintained at ...	100° F.	60° F.	70° F.	85° F.	
Water Absorbed (cc.) at					
1:55 P. M.	0.0	0.0	0.0	0.0	95° F.
2:10 P. M.	22.4	1.4	15.4	15.5	96° F.

TABLE 8.—POTOMETER TEST 7.

	Plant 18	Plant 20	Plant 21	Air Temp.
Beginning Temperature	60° F.	70° F.	60° F.	
Water Absorbed (cc.) at				
2:30 P. M.	0.0	0.0	0.0	98° F.
2:45 P. M.	15.0	17.0	14.0	99° F.
3:45 P. M.	52.0	72.8	66.5	94° F.
4:15 P. M.	71.0	96.8	89.0	92° F.
4:45 P. M.	92.0	122.0	111.0	92° F.

Root Absorption Studies

In the root absorption series of tests, a measurement was made of the amount of water that could be pulled through the roots at a definite temperature and suction. The plants used were grown in water culture so the temperature to which the roots were subjected could be changed rapidly. The tops of the plants were cut off, leaving only about 6 cm. of stem attached to the roots. The connection between the stem and burette was made by using a short piece of glass tubing which fitted snugly over the stem. The union was wrapped first with adhesive tape, on top of which was placed several thicknesses of "Parafilm." Finally the entire connection was painted with grafting wax.

The majority of the leaks which occurred in the system outlined had as their origin small breaks on the remaining stem stub. It was necessary to discard the data obtained from such roots because apparently water was taken up through these openings rather than entirely through the roots.

Tables 9 to 14 inclusive give the data obtained from these studies. These data clearly substantiate the results obtained in the potometer tests as well as the effects noted in the series of tests where cucumber plants were grown at a constant root temperature and later changed to a detrimental lower temperature. The actual per cent reduction in water absorption at lower root temperature as in the potometer studies is not constant but it is significant in every case. Tests were made to determine if water actually was being absorbed by the roots or if the suction was merely pulling the water out of the roots. This was done by comparing the volume of the roots with the total amount of water absorbed. The volume of Root 1 was 65 cc., while the total amount of water pulled through it was 100 cc. This result is typical of the results obtained on the other roots which were tested in this manner.

TABLE 9.—ROOT ABSORPTION TEST 1.

	Root 1	Root 2
Beginning Temperature	85° F.	55° F.
Water Absorbed (cc.) in		
4 hours	9.8	1.7
Temperature changed to	55° F.	85° F.
Water Absorbed (cc.) in		
30 minutes	1.9	1.9
2 hours	2.9	5.8
4 hours	4.9	9.3

TABLE 10.—ROOT ABSORPTION TEST 2.

	Root 3	Root 4
Beginning Temperature	85° F.	55° F.
Water Absorbed (cc.) in		
1 hour	10.0	0.1
2 hours	12.8	0.4
3 hours	17.5	0.9
Temperature Changed to	55° F.	85° F.
Water Absorbed (cc.) in		
1 hour	2.8	7.4
2 hours	3.2	11.6
3 hours	3.8	15.2

TABLE 11.—ROOT ABSORPTION TEST 3.

	Root 5	Root 6
Beginning Temperature	60° F.	70° F.
Water Absorbed (cc.) in		
1 hour	21.0	3.8
Beginning Temperature	70° F.	60° F.
Water Absorbed (cc.) in		
1 hour	26.3	1.1
2 hours	*	2.1

*Break in system

TABLE 12.—ROOT ABSORPTION TEST 4.

Root 7—at successive temperatures	Time required to pull 24 cc. of water through root.
60° F.	13 min. 30 sec.
70° F.	6 min. 15 sec.
70° F.	6 min. 9 sec.
60° F.	7 min. 10 sec.
60° F.	7 min. 50 sec.
70° F.	6 min. 15 sec.

TABLE 13.—ROOT ABSORPTION TEST 5.

Root 8—at successive temperatures	Time required to pull 23 cc. of water through root.
70° F.	2 min.
60° F.	3 min.
60° F.	3 min. 17 sec.
70° F.	2 min. 25 sec.
70° F.	2 min. 25 sec.
60° F.	4 min. 50 sec.

TABLE 14.—ROOT ABSORPTION TEST 6.

Root 9—at successive temperatures	Time required to pull 10 cc. of water through root.
70° F.	14 min. 30 sec.
70° F.	13 min. 10 sec.
60° F.	20 min. 30 sec.
60° F.	20 min. 20 sec.

DISCUSSION

The fall crop of greenhouse cucumbers is generally planted at a time when there is a comparatively high soil temperature. Later in the season along with the more or less extended periods of cloudy days comes a decrease in the mean daily temperature. It follows then that unless steps are taken to prevent it the temperature of the greenhouse beds decreases.

The fact that many greenhouses do not have a sufficiently large heating unit to maintain a desirable air temperature during severe weather increases the rapidity with which the soil temperature drops. Another practice that results in the decline of the soil temperature is the use of cold water in watering. The heavy watering required by a cucumber crop lowers the soil temperature very rapidly if cold water is used.

From the experimental data it becomes obvious that if the soil temperature has dropped to 60° F. and the plants are then subjected to environmental conditions which cause rapid transpiration, wilting will occur; and if this treatment is continued for a sufficient length of time, injury will result. Whether injury will occur at a specific root temperature depends upon the environmental conditions. It is probable that wilting can occur at the maximum temperature for absorption if transpiration is great enough. This emphasizes the interrelation between rate of transpiration, root temperature and wilting.

The results from these experiments suggest that the critical temperature for the water movement through a cucumber root is between 60° F. and 70° F. Higher root temperatures gave an increased absorption of water but it is doubtful that the increase is great enough under practical conditions to warrant the added expense of raising the soil temperature much higher than 70° F. The fact that during the course of the experiments cucumber plants were wilted when they had a root temperature of 90° F. by increasing their rate of transpiration substantiates the thought that it is needless to think of a root temperature high enough to prevent wilting regardless of the rate of transpiration.

Under environmental conditions which normally occur in the growing of the fall crop of cucumbers, a soil temperature of 70° F. seems to be the practical growing temperature. It was noted in the preliminary work that much of the injury to the leaves and fruit occurred on days of full sun which followed a period of cloudy weather. The crops which have been grown experimentally at a soil temperature of 70° F. have not developed the typical injury symptoms when precautions were taken to maintain a high humidity on days of potentially severe transpiration.

Factors which can decrease the flow of water through cucumber roots to some degree at least include increased viscosity of both water and colloidal cellular material and the reduction in metabolic activity which occurs at lower temperatures. The factors need not be regarded as singly affecting water absorption but quite possibly each can be regarded as contributing to the reduction.

The viscosity of water at 60° F. is 11.28 millipoise. At 70° F. it is 9.81 millipoise or an increase of 14.9 per cent at the lower temperature. The percentage difference in the water absorbed by cucumber roots at these temperatures is not consistent but a significant increase at 70° F. was regularly obtained. How great a part the increased viscosity of water plays in the total reduction of the water absorbed is problematical. The changes in the solubility of gases in water at different temperatures might also be a contributing factor.

A reduction in any water absorbed from work being done by the root cells can be logically explained by the reduction in the respiration at lower temperatures. Reduced respiration may further influence water movement by affecting the permeability of the root cells. The fact that cells are composed of colloidal material and also that colloidal material changes in physical properties with changes in temperature makes it reasonable to assume that a reduction in water movement through the root may result from increased resistance offered by the colloidal cellular material at lower temperatures.

CONCLUSIONS

1. It appears that the leaf and fruit injury which seriously affects much of the commercial fall crop of cucumbers in Missouri is caused by a deficiency of water in the affected parts. This water deficiency is the result of a set of conditions wherein transpiration is in excess of the amount of water supplied by the roots.

2. The degree of injury will vary with the condition of the plants. In general, the more vigorous the plant and the more rapid the temperature change the more severe the injury.

3. Cucumber plants will not make a satisfactory growth at a constant soil temperature of 60° F.

4. From the results of these tests, 70° F. or slightly higher appears to be the most practical soil temperature at which to grow cucumber plants.

5. Watering with cold water tends to lower soil temperature. Such a reduction in temperature may be great enough to induce typical leaf and fruit injury.

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