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CHANGES IN STEM DIAMETER OF HERBACEOUS AND WOODY PLANTS AS A MEASURE OF INTERNAL WATER BALANCE[1]

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ABSTRACT

A high sensitive electronic dendrometer was used in studying the water relations and factors affecting the internal water balance of herbaceous plants. A potato *(Solanum tuberosum L.)* and a tobacco plant, *(Nicotiana tabacum L.)* with non-woody stem structure, as well as a privet tree *(Ligustrum vulgare L.)*, with woody-stem structure, showed the following changes in stem diameter: rapid changes in response to light, diurnal variations due to climatic conditions, and long term changes due to soil water conditions.

Shrinkage in stem diameter was observed as soon as lights were turned on. This shrinkage was faster in the afternoon, when other climatic conditions were suitable for high transpiration. A rapid increase in stem diameter and transpiration rate was observed in both herbaceous and woody-stem plants immediately after irrigation. As soil water was depleted the rate of increase in stem diameter and transpiration declined. At low soil water content the stem started to shrink. These variations in stem diameter, due to changes in climatic and soil water conditions, were good indicators of the internal water balance for both herbaceous and woody-stem plants.

INTRODUCTION

A number of investigators (1, 3, 5, and 9) have used various types of dendrometers for measuring diurnal and seasonal stem diameter changes to satisfy different purposes. Actual dates of the beginning and end of seasonal activity, fluctuations of reversible variations in diameter, shrinkage associated with the maturation of wood and factors affecting growth and their specific effects have been determined.

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Changes in the diameter of tree trunks determined hourly with calipers appear to have been first measured by P. Kaisser who published his results as early as 1879, and was cited by MacDougal in 1936(6). Kaisser was able to determine the actual dates of the beginning and the end of seasonal activity, and the factors affecting the growth of plants. MacDougal (6), using a special type of dendrograph, found long-term changes in the trunk diameter of forest trees, and correlated the amount of wood built into the stem with different climatic conditions.

Zeiger and Childers (13), Verner (11), Verner and Kochan (12), Hilgeman (3), and others have been more concerned with the growth of fruit trees and its relation to yield. They have tried to find an efficient irrigation practice. Trunk growth measurement alone was not felt to be a satisfactory index on which to base irrigation scheduling, because the rate of growth was influenced by climatic factors as well. Chen *et al.* (2) used a linear transducer to detect the growth of soybean stems under water stress conditions. They found close correlation between changes of stem diameter, xylem tension and leaf water stress. Klepper *et al.* (4) used similar instrument on cotton and obtained close relationship between stem diameter, leaf water potential, leaf relative water content and net radiation at the top of the canopy. The growth of plant does not bear a simple relationship to soil moisture or climatic conditions, but depends upon a complex of factors which appear to vary throughout the season (8, 10). The present experiments show the effects of soil moisture and climatic conditions on stem diameter fluctuations and transpiration rates of plants with woody and non-woody stem structures.

MATERIALS AND METHODS

Used in this experiment were two of non-woody stem plants potato *(Solanum tuberosum L.)*, and tobacco *(Nictiana tabacum L.)*, and a woody stem plant, privet tree *(Ligustrum vulgare L.)*, growing in pots in Columbia silty loam soil in greenhouse. The plants were transferred to laboratory and were exposed to artificial light 12 or 14 hours every day with no temperature and humidity control. Transpiration rates of the plants were determined by continuous recording or daily measurement of the weight. Soil moisture potential was measrured by tensiometers and/or miniature gypsum resistance units installed in the soil at the middle depth of each pot, where root activity was assumed to be maximum.

Continuous variations in the stem diameter of plants were recorded with a special electronic dendrograph made of a very sensitive linear-variable differential transformer (LVDT). It was 10 mm long and 5mm in diameter and was mounted on a plastic frame surrounding the plant stem (Fig. 1). The frame was supported by four wire legs installed

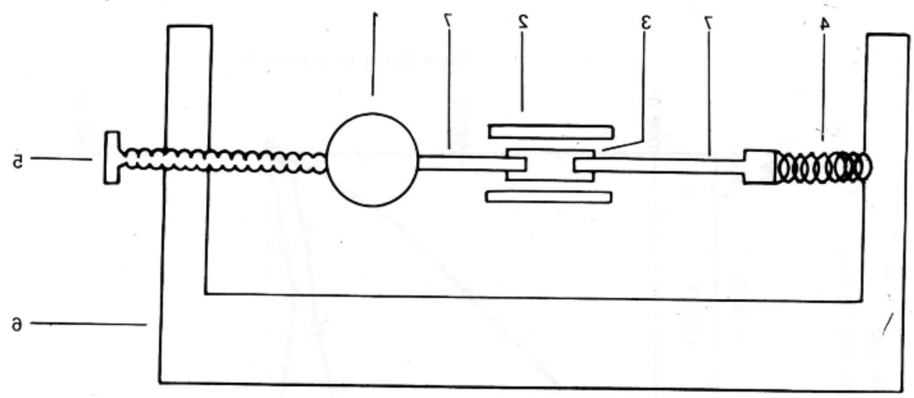

Fig. 1. Top view of the transformer with adjustable screw:

1. plant stem
2. transformer
3. the core inside the transformer
4. coil spring
5. adjusting screw
6. plastic frame
7. plastic rod

into the soil so that it could move freely as the plant moved. The transducer's core was connected to two plastic rods at both ends: One rod was always in contact with one side of the stem, and the other, was attached to a small coil spring which pushed the core against the stem at all times. An adjusting screw was installed against the other side of the stem opposite to the core. Any shrinkage or swelling of the plant stem displaced the core and altered the millivolt output of the transducer. A millivolt recorder was used to record these electric signals. This instrument had the sensitivity of 1.08×10^3 millivolts per millimeter and was capable of recording any changes in stem diameter as low as 2.5×10^{-6} mm.

RESULTS AND DISCUSSION

I. Measurements on potato plant:

Two successive irrigation cycles were applied to potato plants which were growing under artifiical light from 6:30 A.M. to 8:30 P.M. (P. D. T.)*. Rapid changes in plant water status in response to light were observed by diurnal cycling of stem diameter. When soil moisture was readily available, appreciable changes in stem diameter occurred, (Fig. 2). Continuous measurement of the stem diameter of plant was started when the soil water potential was about-0.3 bar for the first irrigation cycle. Transpiration rate and soil

* Pacific daylight time.

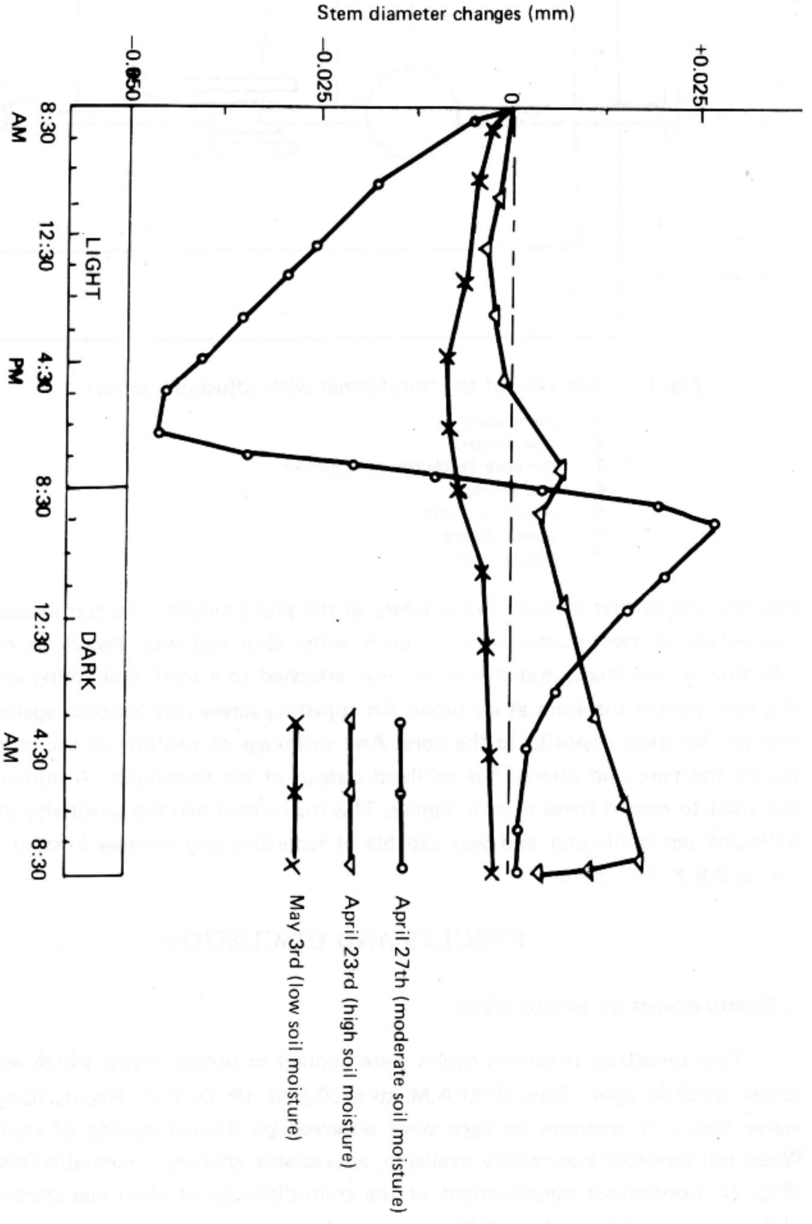

Fig. 2. Diurnal variations of stem diameter in potato plants for three different soil moisture tensions in the first irrigation cycle.

water potential readings were taken at 8:30 every morning after the lights were turned on, (Fig. 3). The stem expanded during the first three days after the first irrigation, when the soil moisture supply was quite high. The rate of expansion decreased as the soil water potential decreased, and subsequently the stem began to shrink. Transpiration rate was high during the first day and decreased as the soil became drier. Kozlowski (5) and Namken *et al.* (7) found a decrease in stem diameter of small trees and cotton plants respectively during soil drying cycle. The present experiment also showed a good correlation between soil moisture content and changes in stem diameter. The difference between maximum and minimum stem diameter was larger when the soil moisture supply was moderate (water potential between −1 to −3 bars). The plant was irrigated again after 13 days, and soil water potential was brought to about −0.2 bar. The plant stem started to expand as soon as water was applied. The maximum expansion took place in the first irrigation cycle. Later, the stem started to shrink which was continued more rapidly than in the first cylce.

Transpiration rate was maximum two days after the second irrigation, and dropped more rapidly during the second than during the first irrigation cycle. The first sign of wilting appeared when moisture potential was −2 bars, in contrast to −5 bars during the first irrigation cycle. The low potential in the first irrigation cycle influenced the availability of water in the second irrigation cycle so that the plant wilted more rapidly and at higher water potential in the second cycle. There was a greater stem growth in the first cycle than in the second, although the soil water potential was higher at the end of the second cycle (−3 bars) than that at the end of the first cycle (−7.2 bars). The plant gained 3.43×10^{-2} mm in stem diameter and transpired 464 g water during the first three days after the first irrigation at an average soil water potential of −1 bar. During the same length of time in the second irrigation cycle, the plant lost 4.29×10^{-2} mm in stem diameter and transpired 160 g water at an average soil water potential of −1 bar. This showed that the plant didinot recover from a long-term water stress in a short period.

Contraction of the stem diameter depends on the increases in tension developed in the plant and transmitted to the stem (2). When soil moisture was depleted during second irrigation cycle, diurnal stem contraction predominated, with no recovery. Hence, the trend was consistently toward development of internal water deficits every day. Therefore, shrinkage of stem due to severe water stress obscured any increase associated with real growth of the stem.

II. Measurements on tobacco plant:

Two successive irrigation cycles were applied to a tobacco plant which was grown under artificial lights from 6:30 A. M. to 8: 30 P. M. (P.D.T.). Stem thickness and trans-

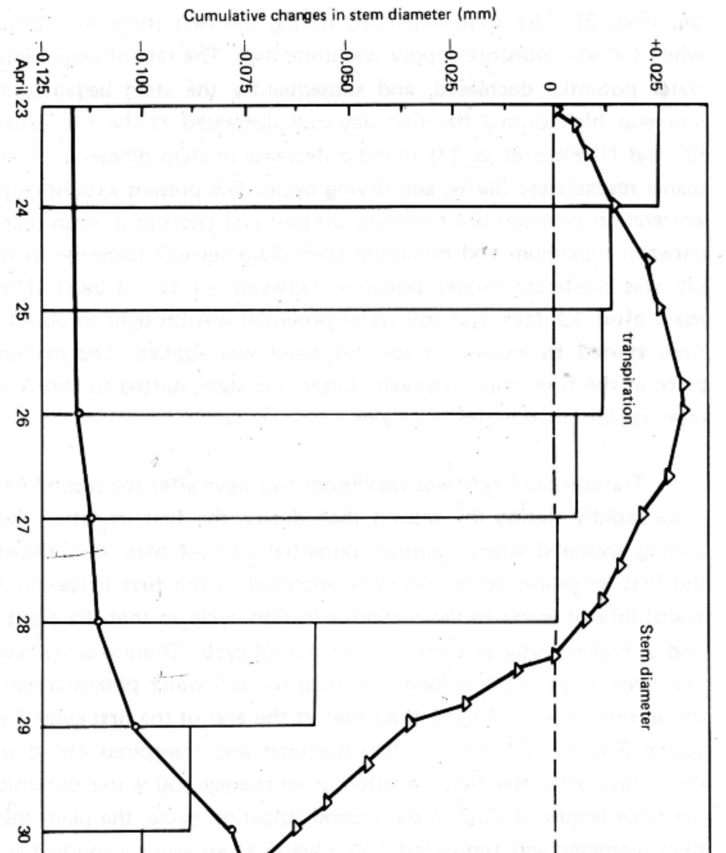

Fig. 3. Stem diameter variations and transpiration rate of potato plants as affected by soil moisture in the first irrigation cycle.

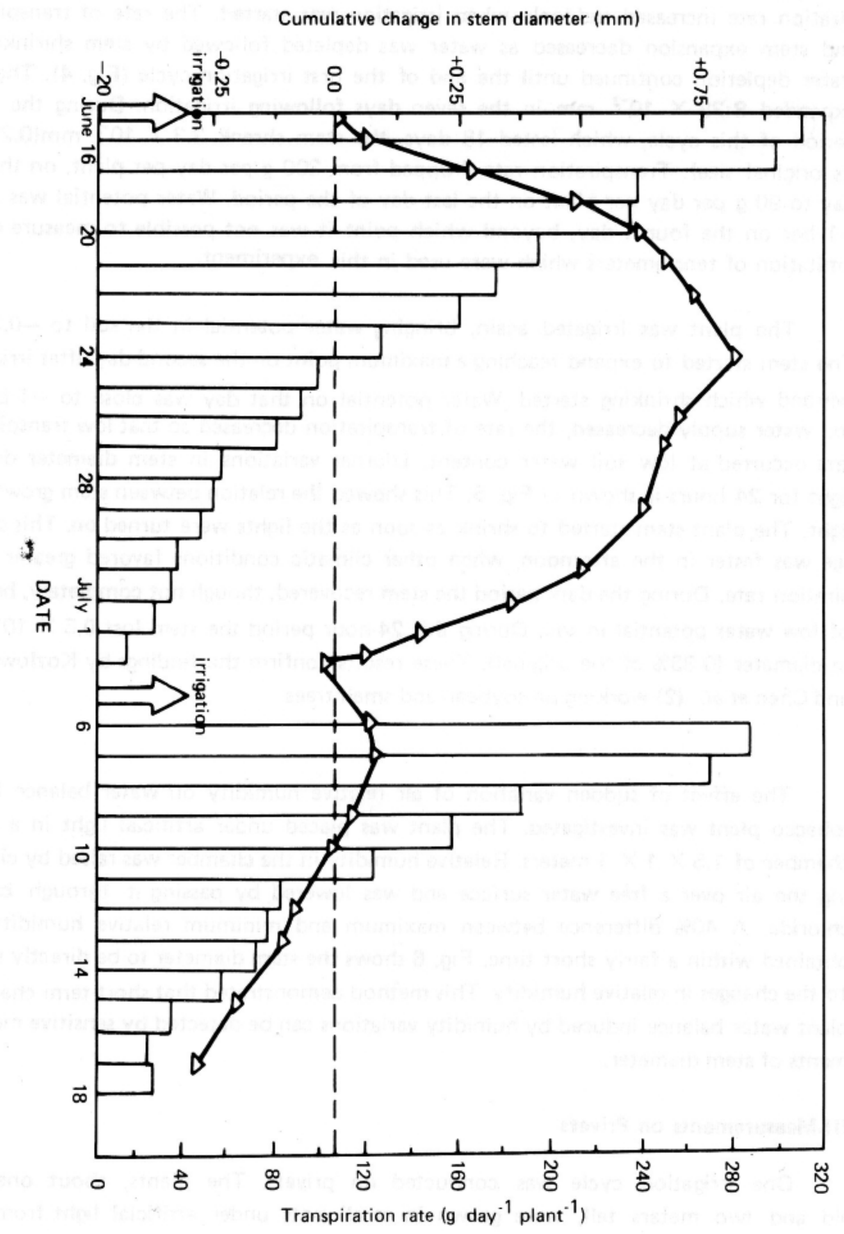

Fig. 4. Cumulative change in stem diameter of tobacco for two irrigation cycles.

piration rate increased suddenly when irrigation was started. The rate of transpiration and stem expansion decreased as water was depleted,followed by stem shirinkage as water depletion continued until the end of the first irrigation cycle (Fig. 4). The stem expanded 8:38 X 10^{-2} mm in the seven days following irrigation. During the whole period of this cycle, which lasted 18 days, the stem shrank 3.3 X 10^{-2} mm(0.22% of its original size). Transpiration rate dropped from 300 g per day per plant, on the first day to 90 g per day per plant on the last day of the period. Water potential was nearly −1 bar on the fourth day, beyond which point it was not possible to measure due to limitation of tensiometers which were used in this experiment.

The plant was irrigated again, bringing water potential in the soil to −0.3 bar. The stem started to expand reaching a maximum point on the second day after irrigation beyond which shrinking started. Water potential on that day was close to −1 bar. As soil water supply decreased, the rate of transpiration decreased so that low transpiration rate occurred at low soil water content. Diurnal variations in stem diameter due to light for 24 hours is shown in Fig. 5. This showed the relation between stem growth and light. The plant stem started to shrink as soon as the lights were turned on. This shrinkage was faster in the afternoon, when other climatic conditions favored greater transpiration rate. During the dark period the stem recovered, though not completely, because of low water potential in soil. During this 24-hour period the stem lost 0.5 X 10^{-2} mm in diameter (0.33% of the original). These results confirm the findings by Kozlowski (5) and Chen *et al.* (2) working on soybean and small trees.

The effect of sudden variation of air relative humidity on water balance in the tobacco plant was investigated. The plant was placed under artificial light in a plastic chamber of 1.5 X 1 X 1 meters. Relative humidity in the chamber was raised by circulating the air over a free water surface and was lowered by passing it through calcuim chloride. A 40% difference between maximum and minimum relative humidity was obtained within a fairly short time. Fig. 6 shows the stem diameter to be directly related to the changes in relative humidity. This method demonstrated that short-term changes in plant water balance induced by humidity variations can be detected by sensitive measurements of stem diameter.

III.Measurements on Privets

One irrigation cycle was conducted on privets. The plants, about one year old and two meters tall, were grown in small pots under artificial light from 6:30 A. M. to 8:30 P. M. (P. D. T.). The results are shown in Fig. 7. Stem diameter increased 1.3 X 10^{-2}. mm (1.06%) during nine days after irrigation, with maximum

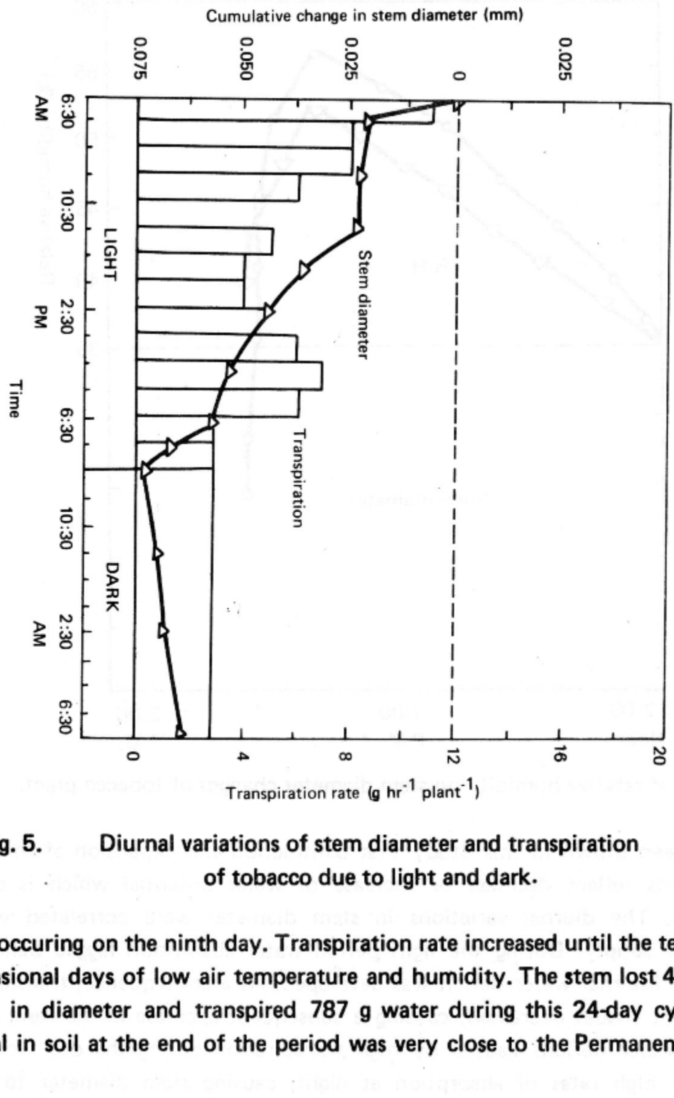

Fig. 5. **Diurnal variations of stem diameter and transpiration of tobacco due to light and dark.**

growth occuring on the ninth day. Transpiration rate increased until the tenth day except for occasional days of low air temperature and humidity. The stem lost 4.52×10^{-2} mm (3.56%) in diameter and transpired 787 g water during this 24-day cycle. The water potential in soil at the end of the period was very close to the Permanent Wilting Point.

Plant growth and yield are controlled by internal water balance of the tissues. The internal water balance depends on the relative rates of water absorption and water loss. The two processes are somewhat interdependent, but the former is mainly controlled by soil, whereas the latter is mainly governed by atmospheric factors. Therefore, it is safe to measure internal water balance of the plant itself to study its growth and yield pattern.

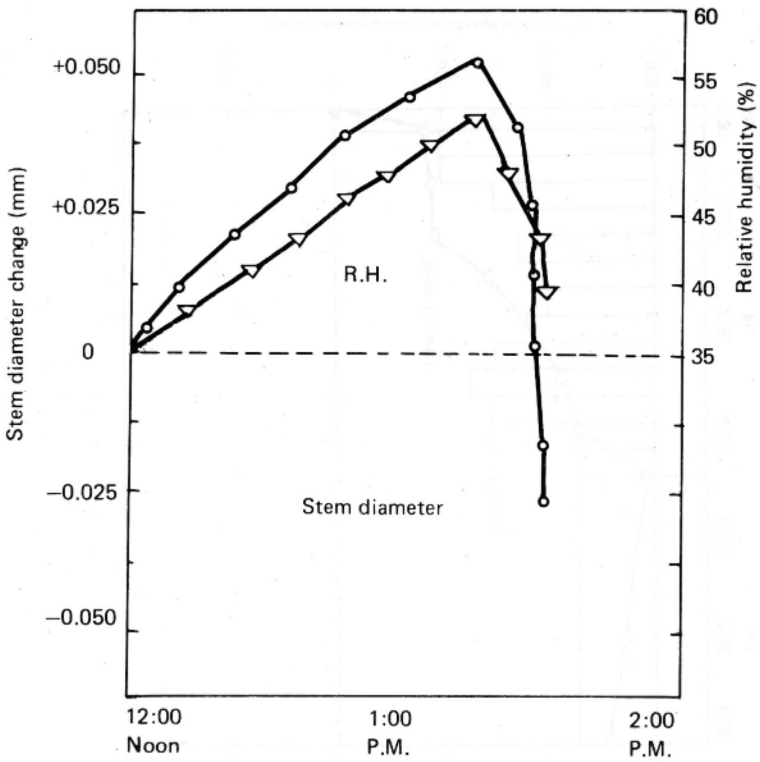

Fig. 6. Effect of retative humidity on stem diameter changes of tobacco plant.

It has been shown in this study that contraction and expansion of the stem diameter of plants reflect decrease or increase of water potential which is developed in the plants. The diurnal variations in stem diameter were correlated with light and soil water supply. During the light period water absorption lagged behind transpiration, thus, internal water deficit was developed. As a consequence, translocation of water into stem tissues decreased, causing a subsequent decrease in the stem diameter. The internal water deficits caused by high transpiration during the day were almost eliminated by high rates of absorption at night, causing stem diameter to increase during the dark period.

Considering the effects of light on diurnal cycling of transpiration, there was a long-term change in transpiration due to drying of the soil. The transpiration rate was smaller at lower and greater at higher soil water potentials. When soil water potential was decreased, diurnal stem contraction was associated with little or

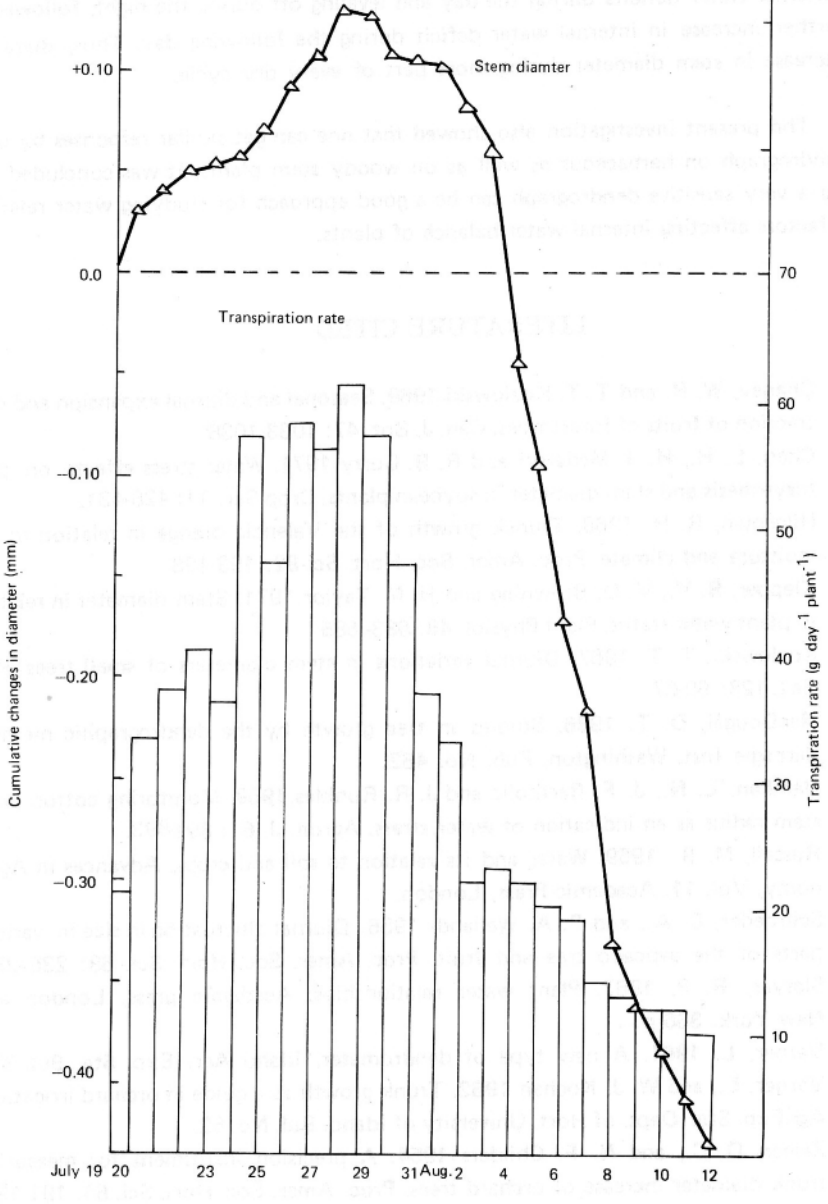

Fig.7. Cumulative stem diameter changes and transpiration rate in privet.

almost no recovery at night. Therefore, the trend was consistently toward development of internal water deficits during the day and leveling off during the night, followed by a further increase in internal water deficit during the following day. Thus, there was a decrease in stem diameter during most part of every dry cycle.

The present investigation also showed that one can get similar responses by using a dendrograph on herbaceous as well as on woody stem plants. It was concluded that using a very sensitive dendrograph can be a good approach for studying water relations and factors affecting internal water balance of plants.

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