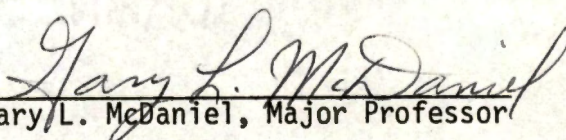
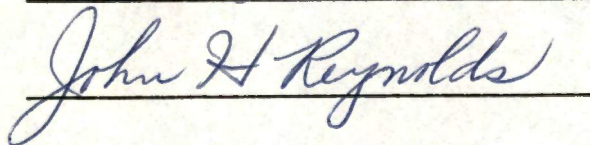


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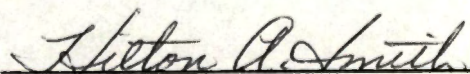
I am submitting herewith a thesis written by Mitzi Gwyn Miller entitled "The Response of Snapdragons, Antirrhinum majus L., to Summer Greenhouse Growing Conditions in Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ornamental Horticulture and Landscape Design.


Gary L. McDaniel, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:


Vice Chancellor
Graduate Studies and Research

THE RESPONSE OF SNAPDRAGONS, ANTIRRHINUM MAJUS L., TO
SUMMER GREENHOUSE GROWING CONDITIONS
IN TENNESSEE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee

Mitzi Gwyn Miller

December 1974

ACKNOWLEDGMENTS

The author is sincerely grateful to Dr. R. B. Rutland, formerly of the Department of Ornamental Horticulture and Landscape Design, for the use of his project as a thesis topic.

Appreciation is expressed to Dr. G. L. McDaniel, Department of Ornamental Horticulture and Landscape Design, for his ideas in writing this thesis.

The author is especially thankful to Dr. J. Reynolds, Department of Plant and Soil Science, for his valuable advice and loan of equipment.

To Dr. D. B. Williams, Department of Ornamental Horticulture and Landscape Design, the writer expresses thanks for his support in this project.

Appreciation is expressed to the author's husband for his help in the computer analysis of data.

The author expresses appreciation to all the members of the Department of Ornamental Horticulture and Landscape Design for their help and support.

ABSTRACT

Differences in daily transpiration rates for snapdragons on days of differing humidity, temperature, and light in summer were found. Daily transpiration rates also differed significantly among cultures.

Stomatal closure on bright, hot days occurred at different leaf relative hydrations among the cultivars. The lower transpiring cultivar 'Oklahoma' maintained the higher leaf relative hydration.

The snapdragon cultivar 'Panama' grown in summer under two shading levels and two soil depths showed that plants grown under 50 percent shade or at the 15 cm soil depth produced better quality plants than those grown under 63 percent shade or at the 30 cm soil depth.

Measurements of leaf relative hydrations, leaf diffusive resistances, and leaf temperatures were capable of determining differences in plant water relations on days of differing humidity, temperature, and light and at different times on a bright day. However, differences between shade and soil depth treatments were not as conclusive.

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PART I. DAILY TRANSPIRATION RATES AMONG SNAPDRAGON CULTIVARS AND
PERCENT LEAF RELATIVE HYDRATION AND PERCENT OPEN STOMATA IN
RESPONSE TO SUMMER GREENHOUSE CONDITIONS

CHAPTER I

INTRODUCTION

Snapdragons, Antirrhinum majus L., accounted for only 0.3 percent of the floral crop production in Tennessee in 1970, less than half that of the national average of 0.7 percent, and far below that for Kentucky, the highest producer, at 3.7 percent (16). Snapdragons grown in southern areas in summer are reduced in quality (48). Consequently, year-round production of snapdragons is currently not popular in Tennessee.

The purpose of these studies was to obtain basic information to determine relative effects of high temperature, high light intensity, and low atmospheric moisture as factors of water stress in snapdragon crops. Improvement in quality of summer crops will facilitate marketing and increase potential profits to the grower.

The first experiment was performed to determine if there were any differences in daily transpiration rates among cultivars under different conditions of temperature, light intensity, and relative humidity in summer. Also, stomatal apertures and leaf relative hydrations were related to cultivar response.

CHAPTER II

LITERATURE REVIEW

I. EFFECTS OF WATER STRESS ON SNAPDRAGONS

Snapdragons, Antirrhinum majus L., grown during the summer are reduced in quality in southern areas (47, 48). Snapdragons grow best at 10°C night/12°C day temperature (37, 38, 48). Some cultivars are capable of producing high quality plants when grown at 15°C night/20°C day temperatures in houses with chrysanthemums and even as high as 20°C night/25°C day temperatures during long summer days. In southern areas, however, where daytime temperatures reach 30°C-35°C, along with high solar radiation (1.0 to 1.5 langley per minute (ly/min)), and high vapor pressure deficits (30 to 50 millibars (mb)), snapdragons are often wilted on bright days even when soil water supply is adequate (47, 48). This causes a reduction in growth and quality.

When plants wilt, photosynthesis stops and several growth processes are inhibited (30, 35, 64, 65), such as cell enlargement and reductions in leaf area expansion (30, 65). Usually wilting results from high soil water stresses caused by depletion of available soil water supply. However, snapdragons often wilt at mid-day in summer when temperatures and light intensities are high, even when bench soil has adequate water content (48). Temporary mid-day wilting has been attributed to excessive transpiration rates on hot, bright days (13, 30). This may cause localized soil water stress (59) while the bulk of the soil possesses adequate water for growth. Thut and Loomis (60) found

that in many plant species growth is reduced more often by excessive transpiration rates than by low soil water contents.

Plants of many species wilt when their leaf relative water contents are between 80-85 percent of their fully turgid conditions. Stomata usually begin to close as the leaf water content decreases, even before wilting is observed. Stomata are generally closed when the wilting point is reached (65) resulting in reduced photosynthetic rates.

II. EFFECT OF STOMATAL APERTURES AND LEAF RELATIVE HYDRATIONS ON PHOTOSYNTHETIC RATES

Photosynthetic rates have been correlated with stomatal apertures (39, 51) and leaf water contents (6, 51). Photosynthetic rates for Coffea arabica have been directly correlated with light intensities up to 0.7 gram calorie per centimeter squared per minute ($\text{gm cal/cm}^2/\text{min}$) and inversely correlated at light intensities above 0.9 $\text{gm cal/cm}^2/\text{min}$ (39). Nutman (39) attributed the phenomenon to mid-day stomatal closure caused by high light intensities. However, on several occasions fairly high rates of photosynthesis were obtained even when stomata appeared to be closed (51).

Brilliant (6) has shown that photosynthesis was greatest when leaf relative hydrations were reduced 5-15 percent in Hedera helix and Impatiens parviflora. Also, Schneider and Childers (51) have found that stomata were more sensitive to leaf water deficiency than was the rate of growth of the fruit in Stayman and McIntosh apples.

III. FACTORS CONTROLLING TRANSPIRATION

Transpiration is controlled by stomatal response to several interacting environmental factors such as soil water availability, relative humidity, air temperatures, and light intensities (26, 35, 52).

Water availability has been found to affect transpiration from bean and rye shoots, through changes in leaf water content and changes in leaf diffusive resistances, by the osmotic reaction of the stomata independent of the light sensitive stomatal mechanism (32). As soil water becomes limiting, leaf relative water content is reduced, causing stomatal closure and reduced transpiration (26, 52). Excessive transpiration rates exceeding water absorption by the roots has been attributed to localized soil water stress at the roots even though the bulk soil possesses adequate water for growth. This condition also results in reduced stomatal apertures from loss in leaf water contents (30, 59).

Wilson (62) found that relative humidities above 50 percent have a very small effect on stomatal apertures in still air; however, relative humidities have a large effect when wind velocities are considered (18, 35). Relative humidities as related to vapor pressure deficits account for only 14 percent of the amount transpired by rye and bean leaves as stomatal apertures increase to maximum width (31). When stomata are fully open, vapor pressure deficits also become one of the major factors in determining transpiration (32).

Stalfelt (54) found no differences in stomatal apertures after lengthy illumination of Vicia fabia from 5°C to 35°C. However, in

some species, such as broad beans and peas, stomatal apertures were found to be smaller at 36°C (24). Reduced stomatal apertures have also been reported for Allium cepa and Coffea arabica which showed pronounced stomatal closure at 35°C without apparent water stress (22). Heath and Orchard attributed stomatal closure at high temperatures (30°C-35°C) to increases in the intercellular space CO₂ concentration, as a result of higher respiration causing increased CO₂ sensitivity (22).

Light induces stomatal opening through the photosynthetic reduction of CO₂ concentration in the stomatal mesophyll (35, 65). Transpiration rates have been found to increase linearly with increases in light intensities (31, 32, 47). Kuiper (31, 32), in experiments with bean leaves, found that transpiration rates for light intensities below 5×10^4 ergs per second per centimeter squared (ergs/sec/cm²) increased linearly due to decreased stomatal diffusive resistances, i.e., increased stomatal apertures. These resistances were lowest when stomata were fully open. Above 5×10^4 ergs/sec/cm², at which stomata were fully open, a linear relationship still held. Further increases in transpiration rates were found to be from increased leaf temperatures, caused by irradiation (31) and vapor pressure deficits (32).

IV. DIFFERENCES IN TRANSPIRATION RATES AMONG SPECIES AND VARIETIES

There are differences in transpiration rates among species and varieties (11, 12, 14, 28, 53, 57). In studies of 21 deciduous fruit species, Kelly (28) found wide differences in transpiration rates. Differences in transpiration rates for several varieties of bell pepper, sugarcane, and peaches have also been reported (12, 56).

Some plants having low transpiration rates are more drought tolerant (14, 28, 57) and have higher photosynthetic rates. Downes (14) found that tropical grasses have lower transpiration rates than temperate grasses and that they also produce more dry weight for the amount of water used. A study of two peach varieties, Mayflower and Elberta, also have shown that transpiration rates were greater for the earlier variety, Mayflower, but photosynthetic activity was greater for the late variety, Elberta (12).

CHAPTER III

MATERIALS AND METHODS

Four snapdragon cultivars were studied to determine differences in daily transpiration rates, mid-day leaf water content, and mid-day stomatal closure under summer greenhouse conditions.

Cultivars 'Oklahoma', 'Panama', 'Houston', and 'Texas' were selected for treatment. The project was carried out in an unshaded glasshouse in mid-summer. The greenhouse was cooled by an evaporative pad system.

Single plants were grown in a vermiculite:pea gravel medium (1:1) with a supplementary addition of dolomitic limestone in six-inch styrofoam pots. Ten plants were selected for each cultivar, seven for daily transpiration rate data and three for leaf relative hydration and open stomata studies. The selected plants were pruned of florets and suckers.

The soil surface of each pot was covered with plastic and the drainage holes sealed with plastic clay to prevent soil water loss other than by transpiration. The soil moisture level was maintained at container capacity (14) throughout the experiment by replacing the amount transpired daily with one-half strength Hoagland's #1 solution (23).

The total leaf area in square decimeters (dm^2) of each plant was determined by leaf length and width measurements. The leaves were measured at the beginning and the end of the experiment (25). The

final values were correlated to total leaf areas obtained from a Hayashi Denko Automatic Area Meter. A regression coefficient was calculated for each cultivar. Total measured leaf areas for each plant were corrected using the appropriate regression coefficient. Daily total leaf areas were assumed to increase linearly during treatment.

Greenhouse temperatures and relative humidities and outside cloud cover were noted at 8 a.m., 10 a.m., 12 noon, 1 p.m., and 4 p.m. to coordinate environmental conditions with transpiration rates, leaf water content, and number of open stomata. Relative humidity was expressed as vapor pressure depression (VPD) in millibars (mb) (36).

I. DAILY TRANSPIRATION

Daily transpiration was determined gravimetrically (30, 51) and expressed in grams per decimeter squared per day ($\text{gm}/\text{dm}^2/\text{day}$) (47). An analysis of variance and a Duncan's New Multiple Range Tests were performed for a three day sampling of differing environmental conditions (56).

II. LEAF WATER CONTENTS

Leaf water content was expressed as percent leaf relative hydration using Weatherley's equation (63):

$$\frac{\text{Wilted weight} - \text{dry weight}}{\text{Hydrated weight} - \text{dry weight}} \times 100 = \text{percent relative hydration.}$$

Individual leaf wilted weights were recorded immediately after removing the leaf from the plant. Each leaf was placed in a 50 ml beaker half filled with distilled water. The leaves were kept at 40°C

overnight. The fully turgid leaf weights were recorded and the leaves were then dried at 60°C for two days before recording dry weights.

III. STOMATAL IMPRESSIONS

Stomatal impressions of the lower surface of the leaf at the same node opposite the leaf taken for water content were made with plastic cement (49). After drying, the impressions were peeled off and mounted on microscope slides, impression side up. Thirty counts per slide, two slides per cultivar, were made. Stomata that were not tightly closed were counted as open. The total number of stomata and the number of open stomata were recorded. Ratios of the number of open stomata to the total number of stomata counted were calculated. The ratios were expressed as percent open stomata.

CHAPTER IV

RESULTS AND DISCUSSION

Daily transpiration rates (Figure 1) for four snapdragon cultivars ('Oklahoma', 'Panama', 'Houston', and 'Texas') were significantly different on days of differing humidity, temperature, and light (Table 1). Higher transpiration rates on brighter days were consistent with previous investigations which have shown that for 'Panama' daily transpiration rates increased linearly with total daily net radiation over a range of 150 to 400 cal/cm²/day (47).

Significant differences among cultivars were also evident (Table 1). Daily transpiration rates for 'Oklahoma' were significantly lower than those for the other cultivars, particularly on the brighter days. At high summer light intensities (10,000 foot-candles) and high temperatures (35°C days), snapdragons are often wilted at mid-day (47). Since cloud cover reduces wilting by reducing transpiration, a cultivar with a low transpiration rate would be subject to less wilting and effect an overall water use economy for higher photosynthetic rates (14, 47).

Since no correlations have been found between the number of stomata and transpiration rates (10), leaf relative hydrations and the number of open stomata were studied at several conditions of humidity, temperature, and light to determine the effect on daily transpiration among cultivars. A comparison of the four cultivars at mid-day on two

TABLE 1

DAILY TRANSPIRATION RATES OF FOUR SNAPDRAGON CULTIVARS
UNDER THREE CONDITIONS OF HUMIDITY, TEMPERATURE,
AND LIGHT

Cultivar	Cloudy Day ¹ (gm/dm ² /day)	Hazy Day ² (gm/dm ² /day)	Bright Day ³ (gm/dm ² /day)
Oklahoma	10.1 a ⁴	18.3 a	23.7 a
Panama	11.3 ab	21.7 b	28.6 b
Texas	11.8 b	22.2 b	29.0 b
Houston	13.2 c	22.0 b	29.2 b
Daily means	11.59 c ⁵	21.05 b	27.63 a

¹7 mb VPD, 26°C, 80 percent cloud.

²10 mb VPD, 28°C, 16 percent cloud.

³12 mb VPD, 30°C, 6 percent cloud.

⁴Cultivar means followed by a common letter in each column are not significantly different at $p = 0.05$.

⁵Daily means followed by a common letter are not significantly different at $p = 0.05$.

different days (Table 2) showed that percent leaf relative hydrations on the cloudy day (30 percent cloud cover) were significantly higher than those on the bright day (0 percent cloud cover). Higher leaf relative hydrations on the cloudy day concur with observations that wilting in snapdragons is reduced during the summer by cloud cover (47). Percent leaf relative hydrations among cultivars on the cloudy day were not significantly different; however, on the bright day 'Oklahoma' had a significantly higher percent leaf relative hydration at 92.4 percent.

Further investigations showed more stomata open on the cloudy day than on the bright day. The percent open stomata varied significantly among cultivars on the cloudy day, but not on the bright day. Approximately 60 percent of the stomata were open on the cloudy day, while 15 percent were open on the bright day.

A comparison of percent leaf relative hydrations and percent open stomata for the four cultivars at mid-day and mid-afternoon on a bright day (Table 3) also showed stomatal closure at approximately the same leaf relative hydrations as shown in Table 2 for the bright day. At mid-afternoon leaf relative hydrations were essentially the same as at mid-day for 'Oklahoma' and 'Houston' but leaf relative hydrations had increased significantly for 'Panama' and 'Texas'. Leaf relative hydrations were of the same order as shown in Table 2 for the bright day.

No significant differences were found for values of percent open stomata for 'Oklahoma', 'Panama', 'Houston', and 'Texas' from mid-day to mid-afternoon (Table 3). Only 'Texas' had a significantly higher

TABLE 2

A COMPARISON OF FOUR SNAPDRAGON CULTIVARS AS TO PERCENT LEAF RELATIVE HYDRATION AND PERCENT OPEN STOMATA UNDER TWO DIFFERENT CONDITIONS OF HUMIDITY, TEMPERATURE, AND LIGHT AT MID-DAY IN SUMMER

Cultivar	Hazy Day ¹		Bright Day ²		p = 0.05	
	Percent Open Stomata	Percent Leaf Relative Hydration	Percent Open Stomata	Percent Leaf Relative Hydration	Percent Open Stomata	Percent Leaf Relative Hydration
Oklahoma	16.5 c ³	94.2 a	9.6 a	92.4 a	NS	S
Panama	94.5 a	95.1 a	14.1 a	90.4 b	S	S
Houston	59.6 b	94.7 a	10.1 a	89.6 bc	S	S
Texas	63.0 b	94.5 a	19.6 a	88.8 c	S	S

¹36 percent cloud, 26°C, 19 mb VPD.

²0 percent cloud, 28°C, 25 mb VPD.

³Means followed by a common letter are not significantly different at p = 0.05.

TABLE 3

A COMPARISON OF FOUR SNAPDRAGON CULTIVARS AS TO PERCENT LEAF RELATIVE HYDRATION AND PERCENT OPEN STOMATA AT MID-DAY AND MID-AFTERNOON ON A BRIGHT DAY IN SUMMER

Cultivar	Mid-Day ¹			Mid-Afternoon ²			p = 0.05	
	Percent Open Stomata	Percent Leaf Relative Hydration	Percent Open Stomata	Percent Leaf Relative Hydration	Percent Open Stomata	Percent Leaf Relative Hydration	Percent Open Stomata	Percent Leaf Relative Hydration
Oklahoma	28.9 a ³	91.9 a	3.6 a	92.0 a	NS	NS	NS	NS
Panama	24.6 a	90.4 a	3.6 a	91.5 ab	NS	S	NS	S
Houston	19.3 a	91.0 a	1.6 a	91.2 bc	NS	NS	NS	NS
Texas	57.0 a	88.0 b	8.9 a	89.4 c	S	S	S	S

¹ 1 p.m., 10 percent cloud, 28°C, 11 mb VPD.

² 4 p.m., 10 percent cloud, 29°C, 23 mb VPD.

³ Means followed by a common letter are not significantly different at p = 0.05.

number of stomata open at mid-day than at mid-afternoon. This is consistent with the much lower leaf relative hydration found in this cultivar. By mid-afternoon there were no differences in the number of stomata open among the cultivars as only approximately two to four percent of the stomata remained open in all the cultivars.

A comparison of Table 2 and Table 3 shows that there are significant differences in leaf relative hydrations at high light intensities. The high leaf relative hydrations maintained by 'Oklahoma' apparently resulted from stomatal closure at higher leaf relative hydrations than for the other cultivars. This could provide for higher rates of photosynthetic activity. Brilliant (6, 35) suggested that there are optimum leaf relative hydrations for photosynthetic activity. High rates of photosynthetic activity have also been found even if stomata are fully closed (13, 51). Consequently, stomatal closure at high leaf relative hydrations could account for higher photosynthetic activity among snapdragon cultivars.

A comparison of the two cultivars 'Panama' and 'Oklahoma' (Table 4) grown in winter under long days and high temperatures showed that 'Oklahoma' produced better quality plants than 'Panama'. Stem lengths for 'Oklahoma' were approximately 30 cm longer, spike lengths approximately 3 cm longer, and florets per spike numbered approximately 10 more per spike. Both cultivars met the minimum requirements for the top or "blue" grade designation as suggested by the Society of American Florists (34); however, 'Panama' was of lower quality than 'Oklahoma'.

Transpiration rates on a cloudy and bright day showed the same relationship as those during the summer. Transpiration rates were

TABLE 4

A COMPARISON FOR QUALITY AND DATA OF HARVEST OF TWO CULTIVARS OF SNAPDRAGON
AND THEIR DAILY TRANSPIRATION RATES ON A CLOUDY AND A
BRIGHT DAY IN FEBRUARY

Cultivar	Stem Length (cm)	Spike Length (cm)	Number of Florets	Transpiration ¹		Harvest Date ⁴
				Cloudy Day ²	Bright Day ³	
Oklahoma	120.78	20.90	25.1	18.58	21.81	2-28/ 3-13
Panama	91.62	17.63	16.7	22.18	27.35	2-21/ 2-28
p = 0.05	S	S	S	S	S	S

¹Gm/dm²/day.

²25 percent cloud, 2833 fc, 26.5°C, 20.2 VPD.

³0 percent cloud, 4235 fc, 30°C, 18.3 VPD.

⁴Planting date: November 29-30.

higher on bright days and lower on cloudy days. 'Oklahoma' maintained a lower transpiration rate than 'Panama'. The two week delay in harvesting 'Oklahoma' would be consistent with delay in flowering experienced in summer snapdragon crops, which were shaded to reduce transpiration (41).

CRANESEAT CREST

CHAPTER V

SUMMARY AND CONCLUSION

Differences in daily transpiration rates on days of differing humidity, temperature, and light were found. Daily transpiration rates were highest on the brightest days.

Daily transpiration rates also differed significantly among cultivars. The cultivar 'Oklahoma' maintained a significantly lower daily transpiration rate, particularly on the brightest day.

The lower daily transpiration rates exhibited by 'Oklahoma' over those of the other cultivars could be a factor in producing higher quality snapdragons during the summer.

Stomatal closure on bright, hot days occurred at different leaf relative hydrations among the cultivars. 'Oklahoma' maintained higher leaf relative hydrations than the other cultivars during periods of high evaporative demand. Stomatal closure at higher leaf relative hydrations prevented excessive plant water losses and reduced wilting. 'Oklahoma' with the higher leaf relative hydrations on bright days could have higher rates of photosynthesis than those cultivars with lower leaf relative hydrations even though the stomata were closed.

It was suggested from this experiment that in selecting summer snapdragon cultivars, a cultivar with a low transpiration rate would produce better quality plants in summer as they would not be as susceptible to excessive water losses.

PART II. RESPONSE OF THE SNAPDRAGON CULTIVAR 'PANAMA' TO SHADING
AND SOIL DEPTH TREATMENTS GROWN DURING THE SUMMER
IN A GREENHOUSE

CHAPTER VI

INTRODUCTION

The second experiment studied the effects of two shading levels (50 percent and 63 percent) and two soil depths (15 cm and 30 cm) on the quality of a snapdragon crop grown in summer. Since the quality was lower and the daily transpiration rate higher for the cultivar 'Panama' than that for 'Oklahoma', 'Panama' was selected for treatment.

Leaf diffusive resistances, leaf relative hydrations, and leaf temperatures were determined during growth on days of differing temperatures, light intensities, and relative humidities to correlate growing conditions with plant quality.

CHAPTER VII

LITERATURE REVIEW

I. SHADING

It is a standard commercial practice to use various shading techniques during summer months, particularly in southern areas, to reduce light intensities in greenhouses (2, 9, 41, 34, 44). Reduced light intensities have been used to enhance qualities of some important commercial greenhouse crops, such as increased stem length in chrysanthemum (34) and roses (2). Post also found that stem length was increased considerably by using cloth covers over field grown snapdragons in summer (41).

Snapdragon cultivars are classified into four groups according to their response to temperature, photoperiod, light intensity, and optimum flowering time (33, 37, 44, 50). Group IV cultivars do best under high temperatures, high light intensities, and long days from July through September.

Snapdragons grown in summer under conditions of high light intensities with concomitant elevated temperatures were found to be reduced in quality over those grown in winter (21). Hanan found significant differences in plant sizes and mean grade correlated to mean daily radiation (gm-cal/cm^2). Light intensities of 537 gm cal/cm^2 during the summer produced significantly lower quality snapdragon flowers than light intensities of 193 gm cal/cm^2 in winter. Snapdragons grown

in summer mature earlier, with an apparent loss in quality (21, 50). However, the summer cultivar 'Florida' has been shown to exceed the winter cultivar 'Wintergreen' in growth at high temperatures and long days of summer (50).

During summer, at high light intensities and average daily maximum temperatures of 30-35°C, snapdragons are often wilted at mid-day (47). Even before wilting is observed, stomata close and photosynthetic rates are reduced (39, 51). Reduction of light intensities by shading or cloud cover have been found to reduce wilting (7, 47). Nutman (39) found that mid-day depressions in photosynthetic activities in Coffea arabica were reduced by cloud cover.

II. ALUMINUM SCREEN

Aluminum screening may reflect or absorb proportionally greater amounts of infrared radiation than other wavelengths which are more conducive to plant growth. The reflection coefficient is the rate of the light reflected from a surface to the total incident light. Generally, it varies with the angle of incidence and with wavelength of light and may be used to refer to diffuse or specular reflection. The reflection coefficient of aluminum from incandescent light is 0.77-0.81 for diffusing light and 0.79-0.83 for specular light. Conversely, the coefficient of absorption of solar radiation is 0.15 which is the ratio of the intensity loss by absorption to the total original intensity (61).

III. TOTAL NET RADIATION AVAILABLE

About $1.3 \text{ cal/cm}^2/\text{min}$ of radiation reaches the earth's surface, of which 52 percent is in the infrared region above 700 nm (65). Forty-four percent of the remaining radiation is from 400 to 700 nm, and four percent is ultraviolet. Therefore, on a clear day on a surface perpendicular to the sun's rays, about $0.6 \text{ cal/cm}^2/\text{min}$ of incident radiation is available for photosynthesis.

IV. SOIL WATER CONTENT

Soil water suction, soil water content usually expressed in pressure units, of soil in benches of different depths can be assumed to follow Richard's "outflow" law (19, 42):

If soil water suction is expressed in terms of height of a water column, suction at the upper surface at cessation of drainage is equal to the depth of the soil. Thus, if there is no evapotranspiration, the soil water suction at any height above the bottom remains constant indefinitely (19).

By selecting different depths of soil, soil water suction can be varied in the upper surface of benches (19).

In studies of constant water table and surface irrigated snapdragon crops using several different soil types and soil depths, Hanan and Langhans (19) found that soil water suction could be maintained close to expected values for depths up to and including 30 cm for peat-perlite mixes. Soil moisture contents were not constant in the surface-irrigated plots as it decreased after each watering and cessation of excess water drainage following each watering. Drainage was considered to be complete eight hours following irrigation. The change in soil

water suction was greatest in the shallowest depths (8 and 13 cm). Frequent irrigations were used to retain soil water contents at bench capacity for the shallowest depths (19).

A large snapdragon plant can transpire up to 40 gm of water on a clear, bright day. A 122 cm by 3048 cm bench containing 3,600 plants transpires approximately 144 liters of water per day. Sufficient water must be supplied, as snapdragons quickly lose turgidity and wilt (33). Hanan found that the amount of water required to produce one snapdragon plant increased from 4.2 liters to 6.9 liters due to increased irrigation frequency at 30 cm soil water suction levels over that for 300 to 600 cm levels (22). Although water use efficiency was reduced through increased irrigation, frequent irrigation was found necessary to maintain soil water content at required levels during periods of high evaporative demand to prevent wilting (21, 33, 40) since photosynthesis and other important growth processes stop when plants wilt (33).

Water consumed per snapdragon flower spike was found not to be significantly different under different light intensities ranging from 193 to 547 gm-cal/cm². About five liters of water is necessary to produce one snapdragon floret spike, regardless of solar radiation. At higher solar radiation levels the time required to produce a crop is reduced (21).

Snapdragons can be grown successfully over a range of soil water contents of 13-48 percent of the total soil volume (33), with optimum content at 30 percent (20). However, snapdragons were found to grow successfully in peat-perlite mixes at 60 percent soil water contents (33).

V. SOIL-PLANT WATER RELATIONSHIPS

Generally soil water contents are measured in determining soil-water plant relationships. However, plant water contents are also determined by evaporative demand, rooting density and distribution, and other plant characteristics (30). Plant water deficits would best be a measure of the plant, not the soil (13).

As a water deficit develops, leaf-water potentials decrease, stomatal resistances increase, and leaf temperatures increase as a result of repartition of the incident solar energy (13). Al-Ani and Bierhuizen (1) found that leaf diffusive resistances could be used to measure soil-water plant relationships. Leaf-air temperature differences with leaf relative hydrations have also been used as indirect measures of stomatal resistances (22).

Leaf relative hydrations have been found to be least responsive in peas as the plants reach maturity, but at the same time, leaf diffusive resistances become more responsive (13). Leaf temperatures were found to be above air temperatures as diffusive resistances increased and leaf relative hydrations decreased. Leaf-air temperatures and leaf diffusive resistances were found to be more dependent on climatic conditions at the time of measurement than leaf water potentials (13).

Stomatal resistances are not greatly affected until critical leaf water potentials are reached. As leaf water potentials decreases further increase rapidly (52), Kanemasu and Tanner (26) found that stomatal resistances of bean leaves for adaxial stomata increased as

leaf water potentials decrease to minus eight to minus nine bars, while abaxial stomatal resistances remained relatively constant until leaf-water potentials decreased to about minus 11 to minus 12 bars then rapidly increased. Stomata appear to close in a very narrow range of leaf-water potentials (26).

CHAPTER VIII

MATERIALS AND METHODS

The cultivar 'Panama' was selected for treatment, with the cultivar 'Oklahoma' used for the guard rows. The experiment was carried out in a greenhouse in mid-summer. The greenhouse was cooled during the day by an evaporative pad system. A randomized complete block, with individual sampling, statistical design was used (56). Three replications were tested.

Snapdragon seeds were germinated using standard propagation procedures (33, 44). Six-week-old seedlings were transplanted directly to benches on June 12, 1973, with four plants per 15 by 20 cm spacing (33). There were 90 plants per treatment plot with two guard rows around each plot.

The soil media used was Chem Rock B, a commercial Cornell mix (5), consisting of peat, perlite, and vermiculite (1:1:1). The benches were irrigated daily using a continuous fertilizer injector system (29, 40, 44) providing a nutrient level of 150 parts per million (ppm) nitrogen from Peters (15-10-30) plus 50 ppm nitrogen from Peters calcium nitrate ($\text{Ca}(\text{NO}_3)_2$) (40). Soil water content was kept at "bench capacity" throughout the experiment (19).

Treatments included two shading levels, 50 percent and 63 percent, and two soil depths, 15 cm and 30 cm. The 50 percent shading level was obtained by using Continental's "Kool-Ray" shading compound on the greenhouse glass and the 63 percent level with the addition of

aluminum screen over the individual plot. A distance of 15 cm by 25 cm between the plant tops and the screen was maintained throughout the experiment. Standard greenhouse benches were used for the 15 cm soil depth. The 30 cm depths were obtained by constructing 30-cm deep frames to modify the standard benches.

I. SHADING FACTOR FOR ALUMINUM SCREEN

The shading factor for the aluminum screening was measured on a bright day at mid-day outside the greenhouse and the amount of infrared transmitted by the aluminum screen was determined using a RG10 glass filter. Light intensities for each individual treatment plot inside the greenhouse were also measured at mid-day on a bright day.

II. SOIL WATER CONTENTS

Soil water contents for the two soil depths were determined gravimetrically (8) and water content at one-third bar was determined using the porous plate method (43).

Soil water contents, relative humidity, air temperature, light intensity, and solar radiation were monitored on those days on which stomatal diffusive resistance, leaf temperatures, and leaf water contents were measured. Relative humidity was determined using a Taylor Instrument Company Sling Psychrometer. Light intensity was measured with a Weston Sunlight Illuminator Meter, Model 756, and solar radiation was measured with a Beckman and Whitey Thermal Radiometer, Model TON 188.

Stomatal diffusive resistance, leaf temperatures and leaf relative hydrations were determined on several days of differing humidity, temperature, and light and at mid-morning, mid-day, and late afternoon on a bright day. Stomatal diffusive resistances and leaf temperatures were measured with a Lambda Instrument Company Diffusive Resistance Meter, Model LI-60 (3, 26, 27). Leaf relative hydrations were determined as previously described.

Individual snapdragon plants were harvested July 31-August 10, 1973, at which time lower florets had been open approximately one week (21, 33, 50). Twenty-two plants per treatment plot were harvested. Harvest data (21, 50) included stem length, floret spike length, stem dry weight per centimeter, floret dry weight per 10 florets, number of florets per spike, and stem strength (dynes).

Stem dry weights were determined using a 20 cm segment of stem without leaves taken from the plants just below the floret spike. Stem strength was measured using an Allo-Kramer shear press with a 21 second downward stroke and a 1,000 pound (445×10^6) dynes) ring on a 5 cm stem segment taken just below the floret spike (50).

CHAPTER IX

RESULTS AND DISCUSSION

I. SOIL WATER CONTENT

Soil water contents were extremely high due to the nature of the soil medium (Table 5). This type of soil retains large amounts of water, yet has enough pore space to provide adequate aeration (8). Soil samples of the top 10 cm for each soil depth during a bright day showed soil water contents for the 15 cm deep benches were approximately 340 percent and for the 30 cm deep benches approximately 290 percent water. Field capacity for the soil mix was determined at one-third bar to be 127 percent water. Although the 30 cm deep bench had a larger water reserve, the 15 cm deep bench had the higher water content at the upper surface in the vicinity of the major portion of the plant root systems.

II. SHADING

The "Kool-Ray" shading compound on the greenhouse glass reduced the light intensity approximately 50 percent (Table 6). The addition of the aluminum screening reduced the light intensity approximately 12.5 percent producing a shading level close to the theoretical 63 percent of the total outside solar intensity. The variability between plots was largely due to several overhead structures which limited full sunlight reaching some plots.

TABLE 5

PERCENT SOIL WATER CONTENT FOR A BRIGHT DAY IN SUMMER
FOR A SNAPDRAGON CROP AT TWO SOIL DEPTHS¹

Time	15 cm Percent Water	30 cm Percent Water	p = 0.05
a.m.	346.7	293.9	
noon	340.3	274.0	
p.m.	336.3	293.2	
Means	340.8	286.7	S

¹Bench capacity determined by porous plate method was 127.1 percent water (43).

TABLE 6
PERCENT OF TOTAL LIGHT INTENSITY PER PLOT AT
MID-DAY IN SUMMER

Plot	Percent of Total Light Intensity ¹
50 percent shade	
I	57
III	58
VI	45
VIII	51
XI	54
XII	49
Mean ²	52.3
63 percent shade	
II	46
IV	43
V	35
VII	35
IX	41
X	43
Mean ²	40.5

¹Outside light intensity 9,200 fc.

²Significant (0.341) at $p = 0.05$ level.

Several attempts to determine if proportionately more infrared was reflected than visible wavelengths by the aluminum screening showed no differences in the amounts of infrared and visible wavelengths reflected. Sixty-six percent (Table 7) of the total net radiation ($\text{gm-cal/cm}^2/\text{min}$) was infrared. The aluminum screening reduced the total radiation approximately 25 percent, 65 percent of that being infrared. Actually only 52 percent of the total net radiation is infrared (65). The error is probably due to the geometry of the measuring apparatus as a mount had to be constructed to hold the RG 10 filter which was smaller than the normal surface of the radiometer.

III. PLANT WATER RELATIONSHIPS

Comparison of a Cloudy and a Bright Day

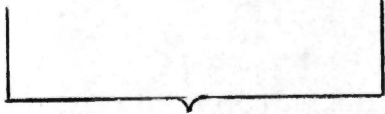
There were differences among treatments, soil depth and shading levels, in percent leaf relative hydration, leaf temperatures, and stomatal diffusive resistances. Daily cloud cover and time of day accounted for the most pronounced differences.

Percent leaf relative hydration on a heavily overcast day and a bright day (Figure 2) showed that the leaf turgidity was greater on the overcast day than on the bright day. There were no differences between treatments on the overcast day; however, on the bright day there were significant differences between shade treatments. The percent leaf relative hydrations were significantly lower at the 50 percent shading level than the 63 percent shading level. Shading on the bright day reduced water losses.

Leaf temperatures (Figure 3) for those two days were significantly

TABLE 7

PERCENT INFRARED TRANSMITTED BY ALUMINUM SCREENING
AT MID-DAY IN SUMMER OF TOTAL NET RADIATION¹

Percent Infrared RG 10 Filter	Percent Visible Screen	Percent Infrared RG 10 Filter Plus Screen
66.4	73.5	47.8
		
Percent Infrared Screen		
65.1 ²		

¹Total light intensity 8300 fc. Total radiation 1.32 gm-cal/cm²/min.

²Theoretical percent infrared in total net radiation is 52 percent (65).

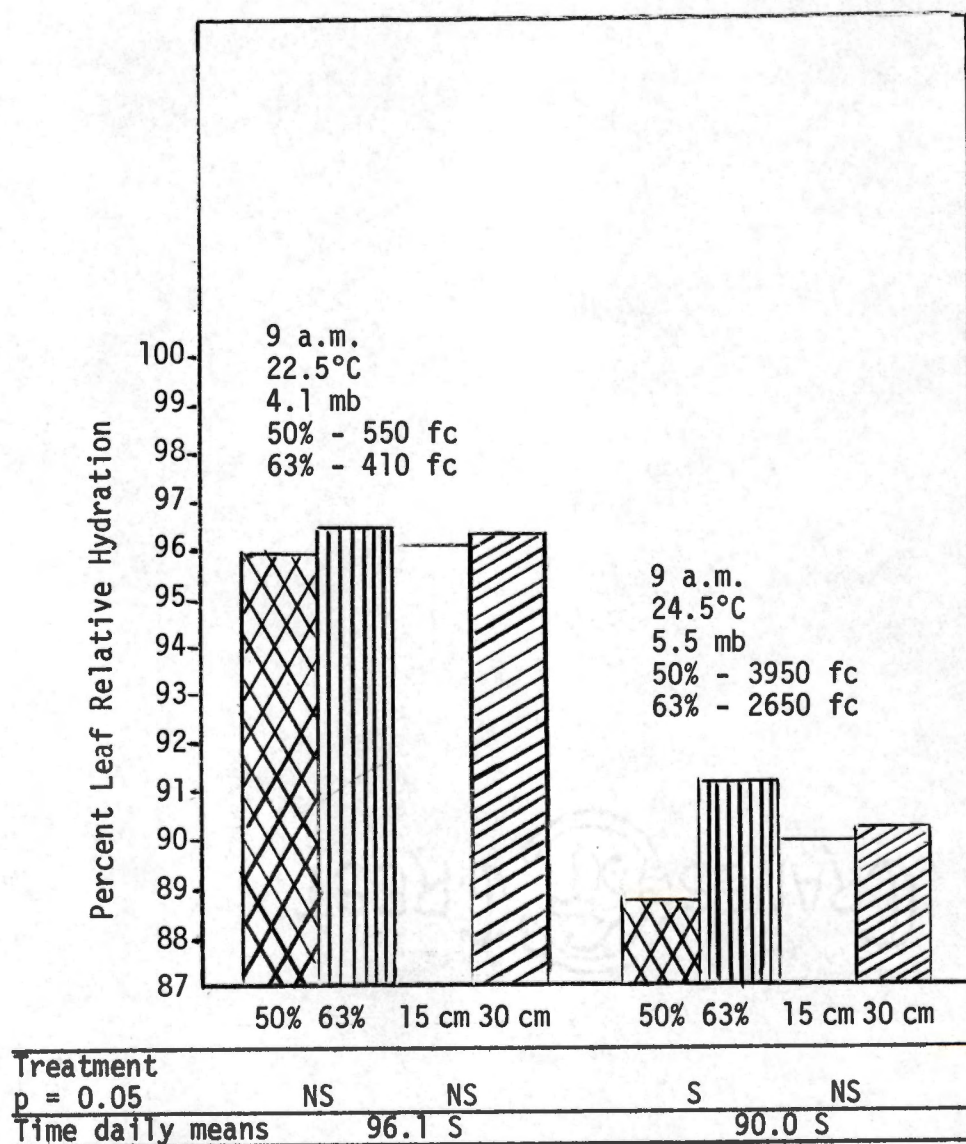


Figure 2. Percent leaf relative hydration for the snapdragon cultivar 'Panama' comparing a heavily overcast day and bright day in summer at mid-morning.

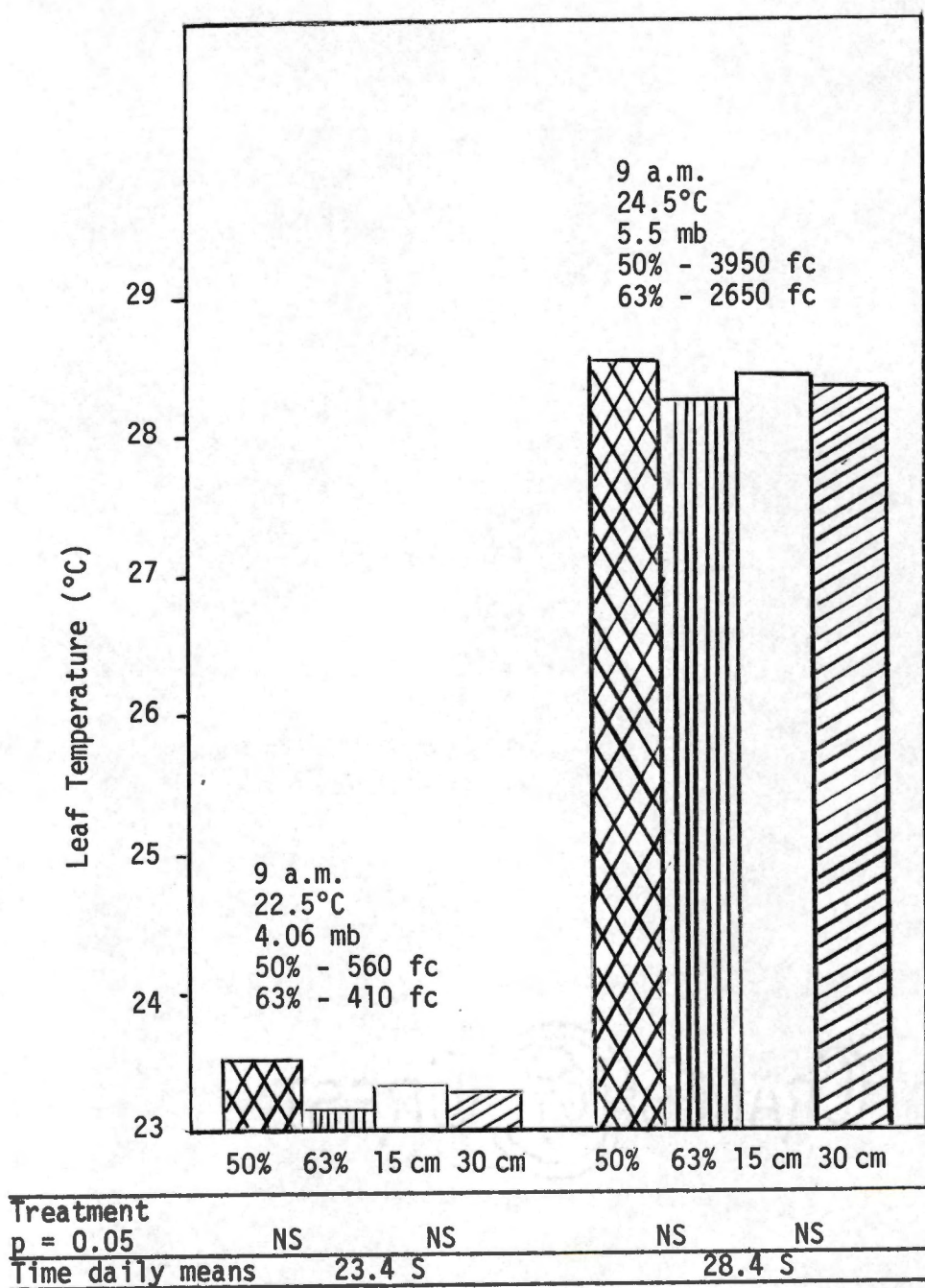


Figure 3. Leaf temperatures of the snapdragon cultivar 'Panama' comparing a heavily overcast day and a bright day in summer.

different; however, there were no differences among treatments on the two days. On the overcast day leaf temperatures were approximately 1°C above ambient air temperatures, whereas on the bright day leaf temperatures were approximately 4°C above ambient temperatures. Leaf temperatures on the bright day were not affected significantly by shading levels or soil depths. Leaf temperatures reflect the intensity of light and effect of transpiration in controlling leaf temperatures (17, 18, 31, 32).

Leaf diffusive resistances (Figure 4) on the overcast day were much lower (approximately 0.6 sec/cm) than on the bright day (approximately 1.8 sec/cm). There were no significant differences among treatments for either day. Apparently light intensities around 2600 fc were high enough to cause decreased stomatal apertures.

Comparison of Mid-Morning, Mid-Day, and Late Afternoon

A comparison of percent leaf relative hydration at mid-morning and mid-day on a bright day showed there were no significant differences at the two times (Figure 5). However, by late afternoon percent relative leaf hydrations were significantly higher. Percent relative hydration for the 50 percent shading level was significantly lower than that for the 63 percent shading level except at mid-day. At mid-day percent leaf relative hydration for the 30 cm soil depth treatment was significantly lower than for the 15 cm soil depth. This could be explained by the higher soil water availability in the 15 cm deep soil in the vicinity of the roots during this period. Apparently at light intensities of 5000 fc, soil water factors become limiting which was

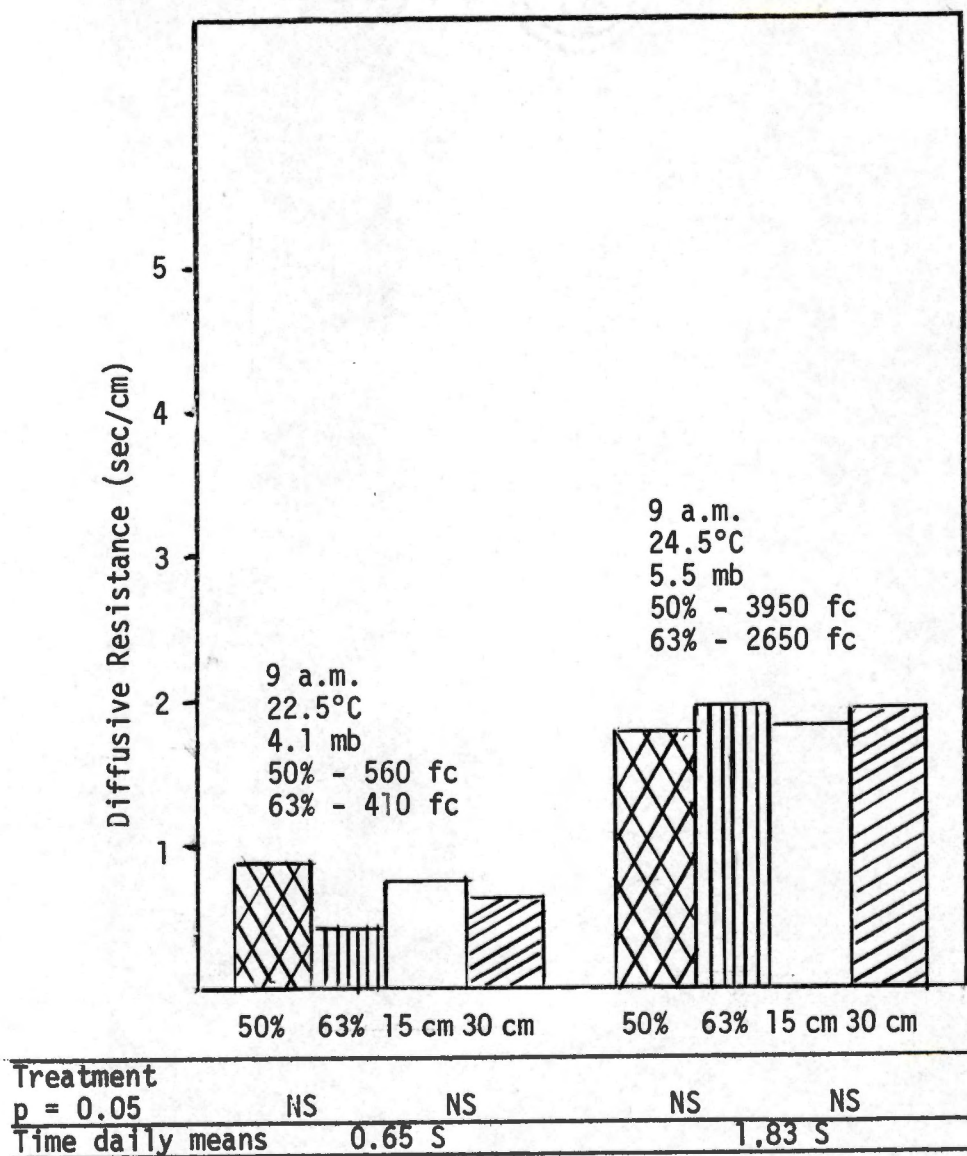


Figure 4. Leaf diffusive resistance of the snapdragon cultivar 'Panama' comparing a heavily overcast day to a bright day in summer.

more important than a reduction in light intensity by shading. More soil water availability at the roots was evidently more important than soil water reserve in providing adequate moisture under conditions of high evaporative demand. In the late afternoon shading levels were very close to being significantly different. Plants under the 63 percent shade had recovered most from the excessive water losses at mid-day.

Leaf temperatures (Figure 6) were already 4°C above air temperatures by mid-morning and remained 4°C above air temperature at mid-day. By late afternoon the leaf temperatures were actually lower than air temperature by 0.5°C . Significant differences in leaf temperatures occurred only at mid-day, where they were higher for the 50 percent shade treatment than for the 63 percent shade treatment. Transpiration was sufficient to maintain leaf-air temperature differentials at 4°C at high light intensities; however, at mid-day with a maximum light intensity of approximately 5500 fc, additional shading reduced leaf temperatures significantly.

Leaf diffusive resistances (Figure 7) were significantly larger at mid-day than at mid-morning and late afternoon. Although there were no significant differences among treatments at any one time of day, leaf diffusive resistances for the 50 percent shading level at mid-day were higher than at the 63 percent shading level. Leaf diffusive resistances remained rather high in the late afternoon and leaf water contents increased as the water uptake by the roots balanced water loss by transpiration under conditions of reduced evaporative demand.

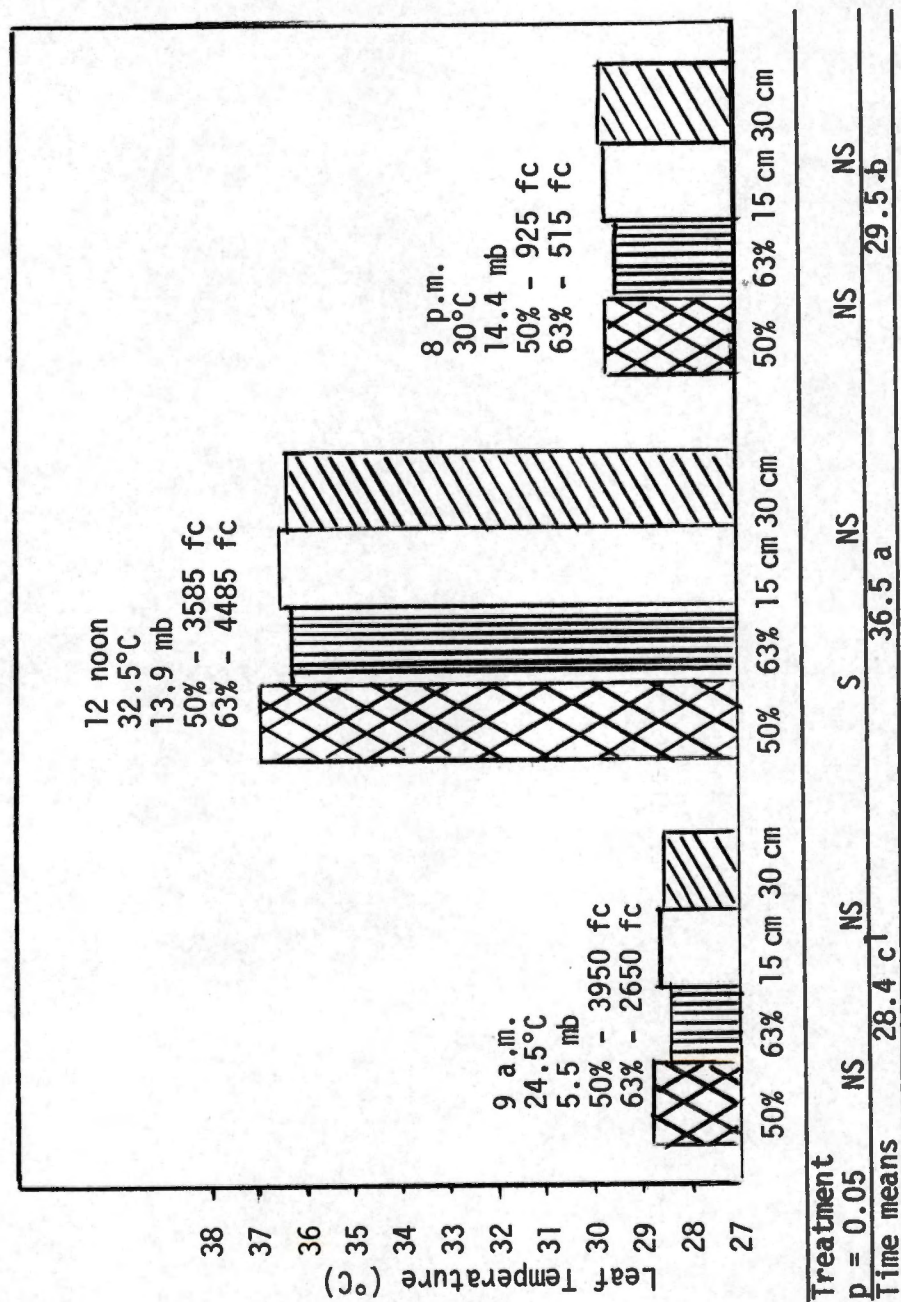


Figure 6. Leaf temperature of the cultivar 'Panama' at two different soil depths and two different shading levels at mid-morning, mid-day, and late afternoon on a bright day in summer.

¹Means followed by a common letter are not significantly different at $p = 0.05$.

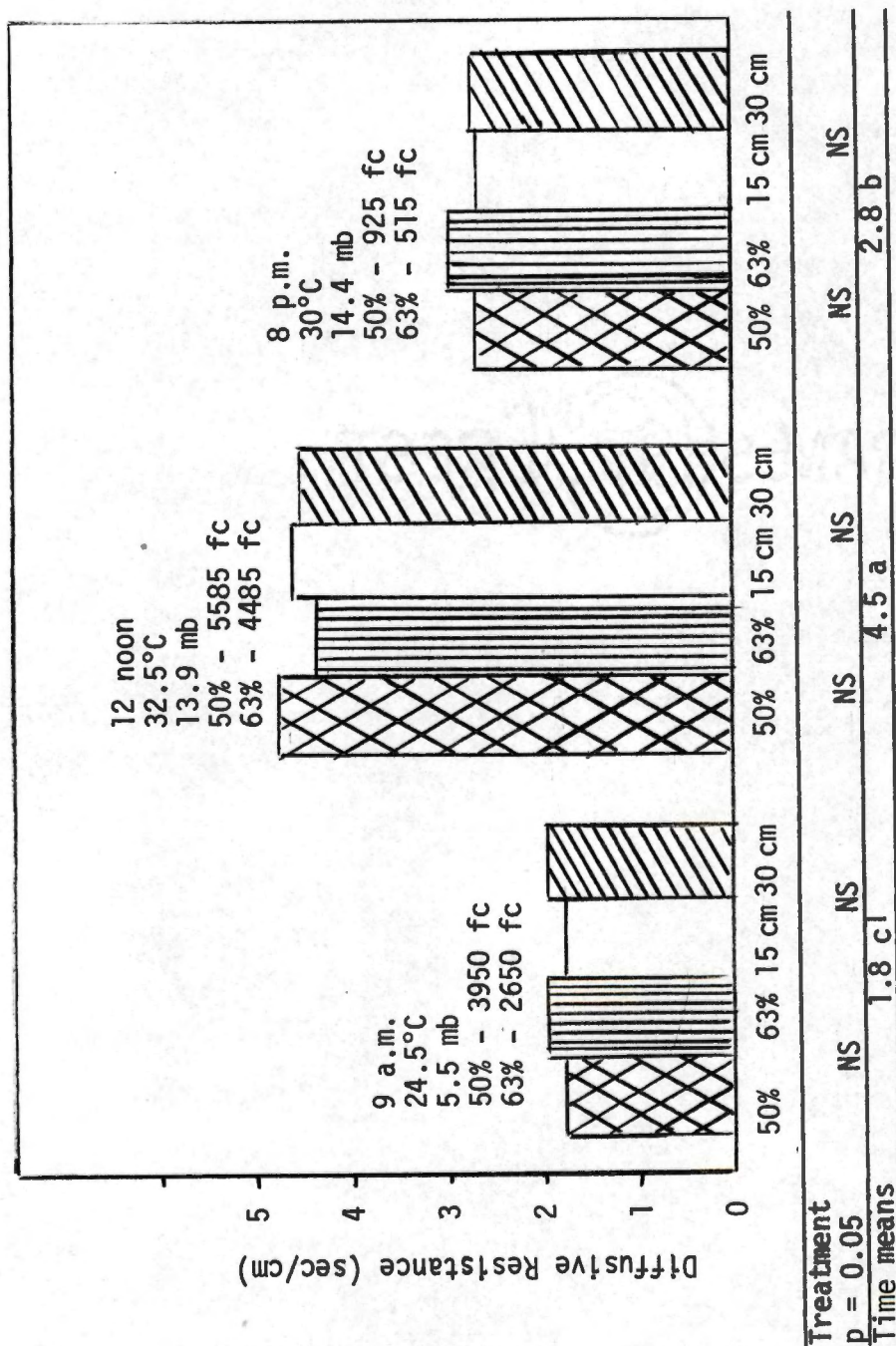


Figure 7. Leaf diffusive resistance for the snapdragon cultivar 'Panama' at two different soil depths and shading levels on a bright day in summer.

¹Means followed by a common letter are not significantly different at $p = 0.05$.

Environmental Correlations

Correlations between light intensity and percent leaf relative hydration, leaf temperatures, and leaf diffusive resistances (Figure 8) showed that as light intensity increased, leaf percent relative hydration decreased, leaf temperatures increased, and leaf diffusive resistances increased. Similar correlations were found for percent leaf relative hydration, leaf temperature, and leaf diffusive resistance with vapor pressure depression (Figure 9) and air temperature (Figure 10).

Vapor pressure depression, air temperature, and light intensity were significant as factors in determining leaf diffusive resistances and leaf temperatures. However, vapor pressure depression and air temperatures were not significant as factors for leaf relative hydrations. Light intensity was the controlling factor at these environmental conditions.

Although the snapdragon plants were near maturity when data was obtained, leaf relative hydrations were the most sensitive to the water status of the plant. Distinction between treatments could be made. Leaf diffusive resistances and leaf temperatures were significant only at different times; however, at high light intensities distinctions between shading levels could be made by leaf temperatures.

Harvest Date

Harvest data (Tables 8 and 9) showed that generally higher light intensities and soil water contents produced significantly better quality plants. Higher light intensities accounted for greater stem

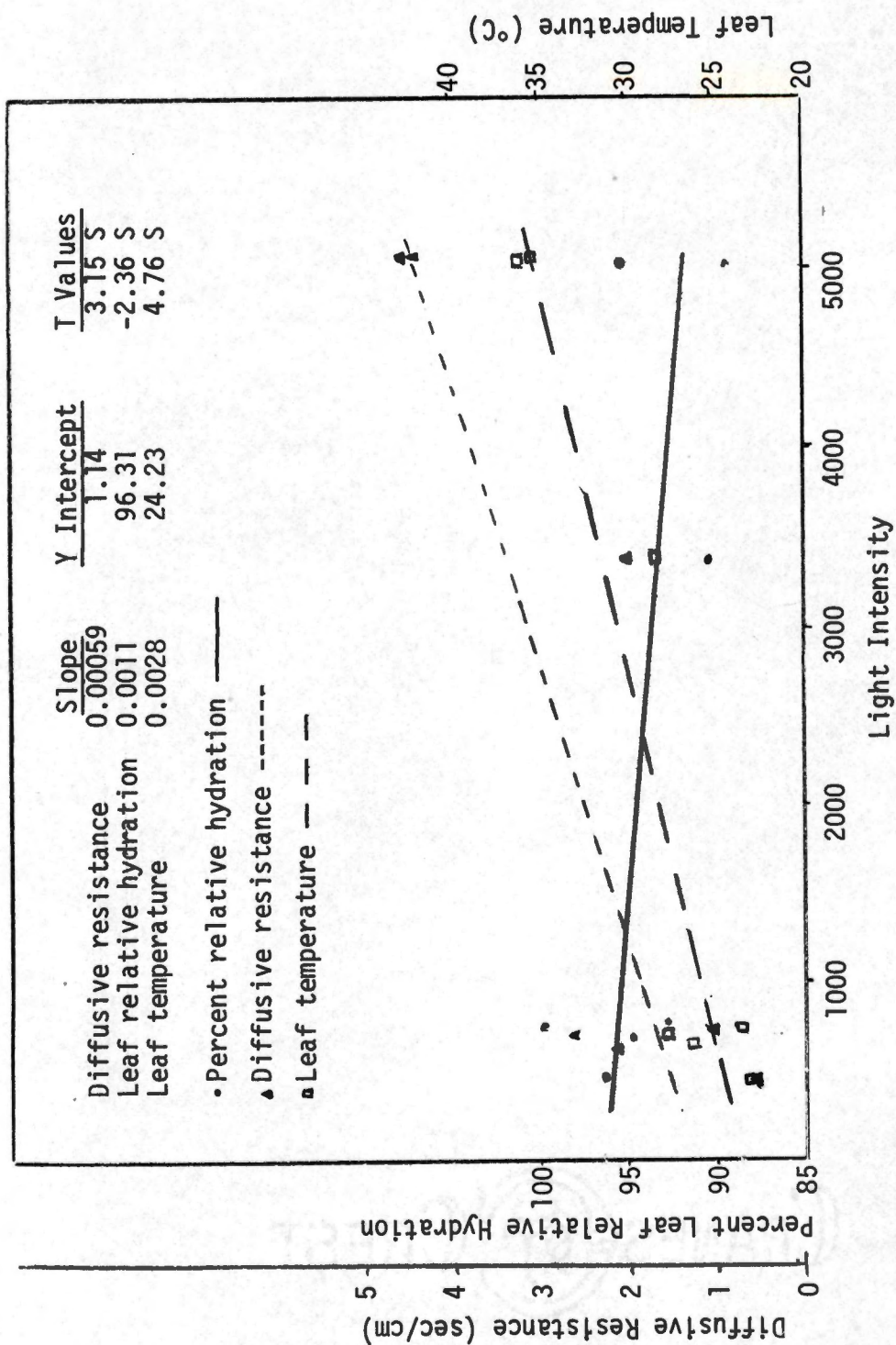


Figure 8. Correlation of diffusive resistance, percent leaf relative hydration, and leaf temperature to light intensity.

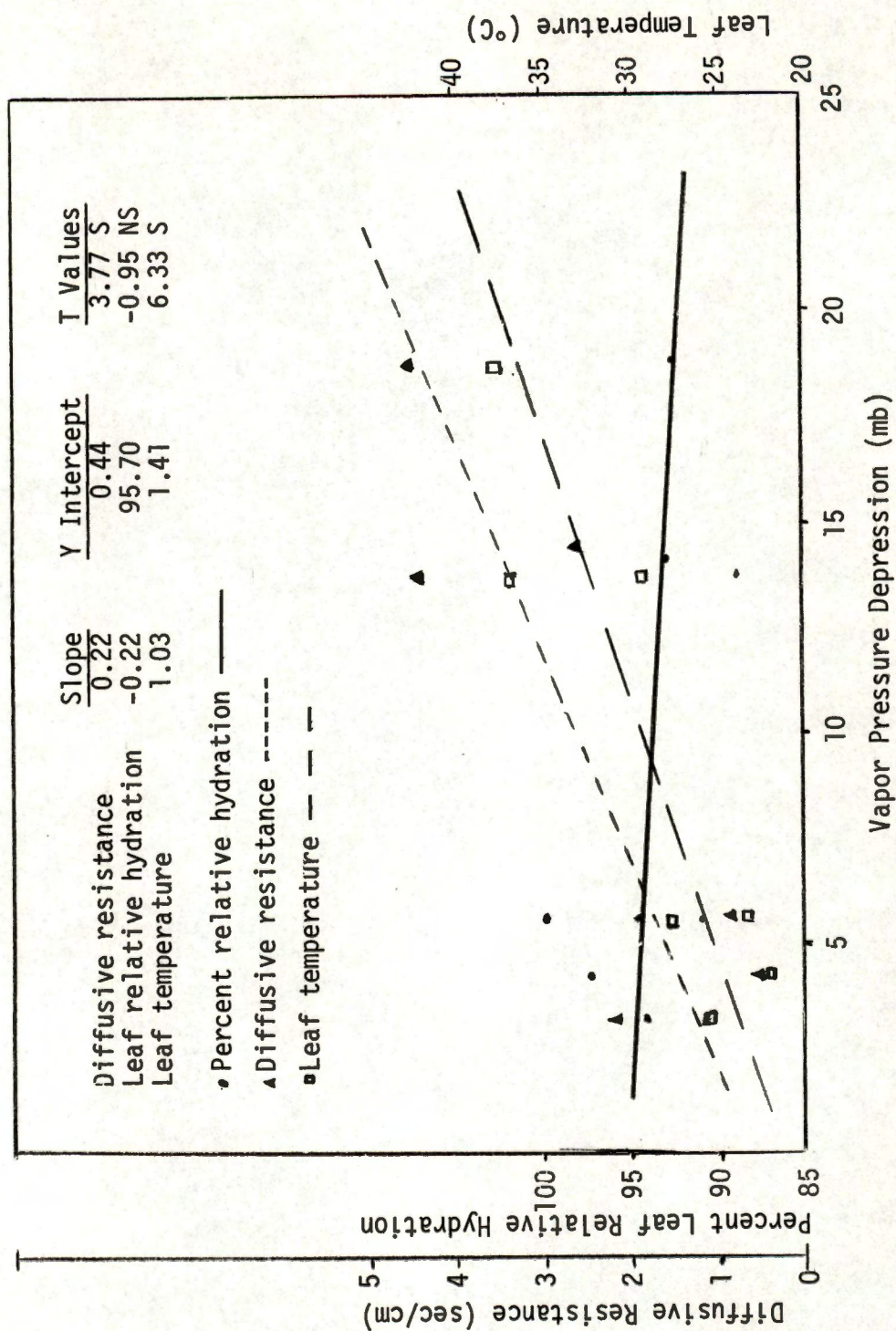


Figure 9. Correlation of diffusive resistance, percent relative hydration, and leaf temperature to vapor pressure depression.

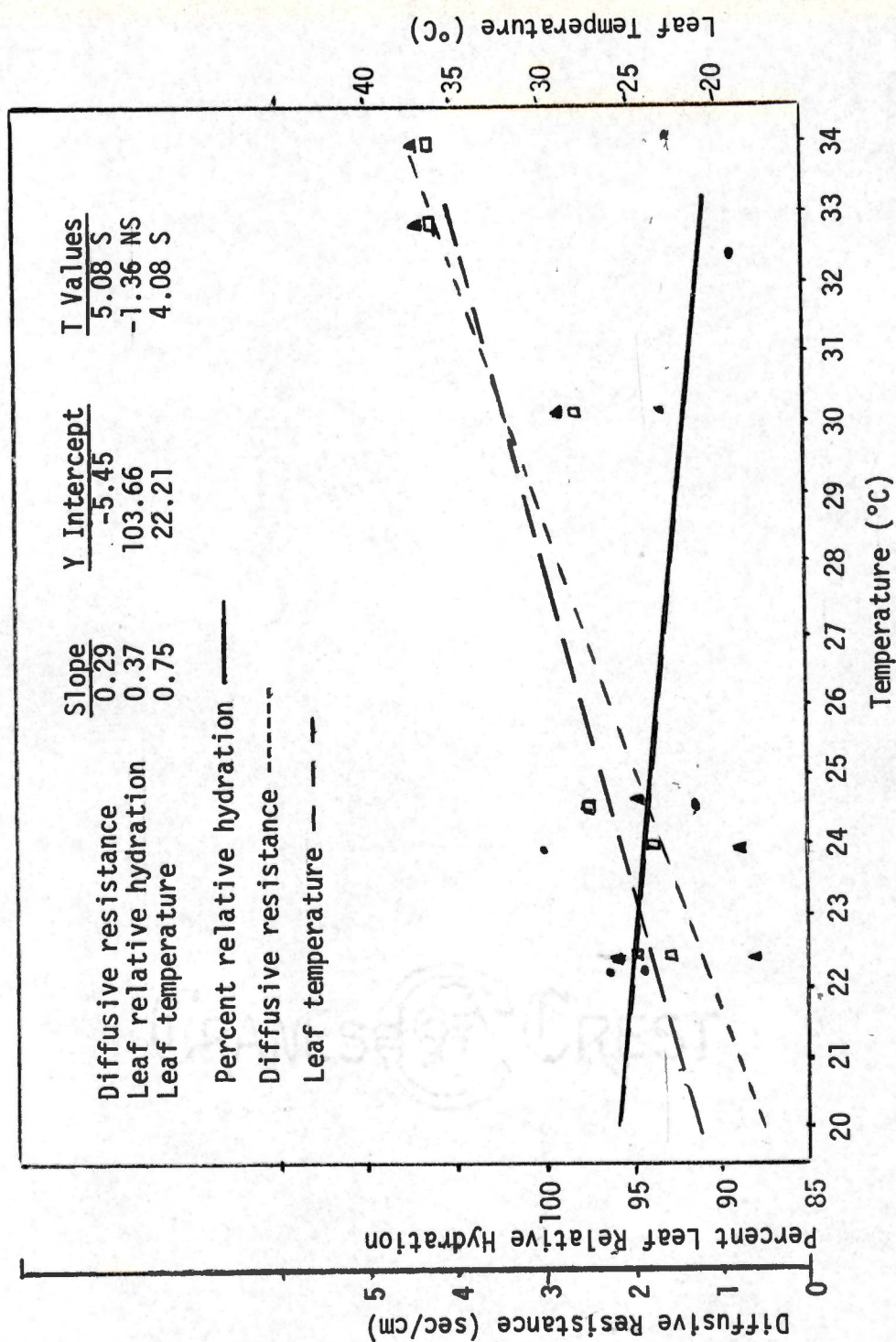


Figure 10. Correlation of diffusive resistance, percent leaf relative hydration, and leaf temperatures to air temperatures.

TABLE 8
CULTIVAR 'PANAMA' GROWN AT TWO DIFFERENT SOIL
DEPTHS IN SUMMER

Depth	15 cm	30 cm	p = 0.05
Stem length (cm)	86.8	85.4	S
Spike length (cm)	19.7	19.1	S
Stem dry weight (gm/cm)	0.0195	0.0189	NS
Floret dry weight (gm/10 florets)	0.45	0.433	S
Number of florets	19.7	19.3	NS
Stem strength (dynes)	50.3×10^6	52.1×10^6	NS

TABLE 9
CULTIVAR 'PANAMA' GROWN AT TWO DIFFERENT
SHADING LEVELS IN SUMMER

Shading Level	50 Percent	63 Percent	p = 0.05
Stem length (cm)	87.5	84.7	NS
Spike length (cm)	20.2	18.6	S
Stem dry weight (gm/cm)	0.0196	0.0188	NS
Floret dry weight (gm/10 florets)	0.44	0.44	NS
Number of florets	20.6	18.3	S
Stem strength (dynes)	54.0×10^6	48.4×10^6	S

lengths, spike lengths, number of florets, and stem strength. Higher soil water contents resulted in greater stem lengths, spike lengths, and floret dry weights. There were no interactions between shading and soil depth treatments. Although there were significant differences among treatments, they were too small to be quickly analyzed for grading. All the plants measured were above minimum requirements for the second grade or red grade as described by Laurie, et al. (34).

CHAPTER X

SUMMARY AND CONCLUSION

The snapdragon cultivar 'Panama' grown in summer under two shading levels and in two soil depths showed that there were significant differences among treatments. However, there were no interactions among shade and soil depth treatments.

The higher light intensity (50 percent shade) produced better quality plants. Stem lengths and spike lengths were longer, more florets per spike were produced, and stem strengths were greater than those for plants grown under 63 percent shade. Although stem dry weight and floret dry weight differences were not significant for the two shading levels, they were larger for the 50 percent shade. The higher light intensity permitted more photosynthetic activity without causing excessive plant water losses.

The 15 cm soil depth produced better quality plants than those grown in the 30 cm deep benches. Stem lengths and spike lengths were significantly longer and floret dry weights were significantly greater. All other measurements were larger for the 15 cm soil depth treatments, but not significantly larger. It was more important to have higher soil water contents than soil water reserve in producing better quality snapdragons in summer when temperatures and light intensities are high.

Measurements of leaf relative hydrations, leaf diffusive resistances, and leaf temperatures showed significant differences in plant water relations on days of differing humidity, temperature, and light.

All three measurements were capable of determining differences in the plant water relations at different times on a bright day. However, differences between shade and soil depth treatments were not as conclusive. Leaf relative hydrations were most sensitive to light intensity.

It was suggested from the experiment that there may be optimum light intensities for growing snapdragons at high summer temperatures and that irrigation during mid-day would reduce mid-day wilting in snapdragons.

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