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# Soil-Plant-Water Relationships for Flue-Cured Tobacco

Bryan W. Maw, James R. Stansell, and Benjamin G. Mullinix

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## Abstract

Type 14 flue-cured tobacco 'NC 2326' was grown under various conditions of available soil water in order to further understand how a tobacco crop would develop over the growing season under those conditions and to determine when a period of drought would be most detrimental to flue-cured tobacco production. Tobacco plant growth under various treatments of drought and no-drought was documented by measuring certain plant characteristics. As an assessment of growth over time bi-parameter least squares regression curves were fitted to the means of the values measured. As an assessment of drought on tobacco production, all measurements taken during the growing season were averaged over the entire season. Of those drought periods considered, the most detrimental time for tobacco was during weeks eight and nine, the second most detrimental time during weeks 10 and 11, and the third most detrimental time during weeks six and seven following transplanting. These periods coincided with periods of potentially rapid growth of leaves and stalk. Root depth and leaf weight, however, continued to develop throughout the season, up to weeks 13 and 14. Visual observations of the tobacco were not a clear indication of growth because, even though plants under certain drought treatments appeared to be healthy, they did not reach their full potential of growth, compared with plants under no drought.

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## Introduction

As profit margins decline in the production of flue-cured tobacco, those farmers who survive will be the ones who pay strict attention to all aspects of their tobacco crops, including the need for irrigation. In Georgia, approximately 90 percent of the flue-cured tobacco grown is irrigated (Sumner 1989). Growing tobacco under prescribed irrigation can be an important way of reducing costs, and improving crop management, especially if chemigation (the application of chemicals through the irrigation system) may be conducted by the same means.

The importance of irrigation in tobacco production has been described by Gude (1976). Water is involved in all plant growth processes, and a continuous supply of water is required. During the early establishment of a tobacco plant, growth is slow and reserves of available soil water should be sufficient to support the plant through the first six weeks. In later stages of rapid growth, the amount of available water through rainfall or irrigation may permanently affect development of the plant, either in yield or leaf quality. When tobacco plant leaves are maturing, water is required to prevent excessive wilting and promote uniform ripening. In hot, dry weather, irrigation may be used to offset leaf damage from sun scorch and reduce false ripening. Water should be available, even at harvest time, to ensure leaf turgidity, since tobacco may not cure as readily when leaves are harvested in a wilted condition.

Water requirements for flue-cured tobacco growth have been estimated by several people (Carreker et al. 1964; Sparrow et al. 1966; Long 1979). It is the consensus of opinion that tobacco plants benefit from having water available when it is needed, but water in excess of plant requirements is not recommended. It is reported that an imposition of drought from 14 to 30 days after transplanting is beneficial in stimulating root development. This imparts tolerance to subsequent periods of drought. There is also evidence of increased yield as a result of this drought (Papenfus1987).

Water may also affect tobacco leaf maturity (Gaines et al.1983). Ample water contributes to an increase in sugar content, alkalinity, ash content, and potassium content, while at the same time decreasing nitrogen, nicotine, and chlorine within the tobacco leaf. Grade and yield of tobacco leaf improve during years of adequate soil water and decline during years of insufficient soil water. Leaf chemical content correlates positively with grade and yield, except for alkaloids. Excess soil water by rainfall or irrigation, however, may change the leaf chemistry away from a desired level. Irrigation

Bryan W. Maw is Associate Professor, James R. Stansell is Professor Emeritus, Biological and Agricultural Engineering Department, and Benjamin G. Mullinix is Agricultural Research Statistician, Statistical and Computer Services, University of Georgia, Coastal Plain Experiment Station, Tifton, GA. This research is supported by Hatch, State, and USDA funds allocated to the University of Georgia College of Agricultural Experiment Stations and by additional funds from the Georgia Agricultural Commodity Commission for Tobacco.

may even be a tool for moderating leaf nitrogen levels (thus modifying starch and alkaloids) prior to harvest, in order to obtain a more desirable leaf chemistry.

Many crops have been modeled mathematically as an aid to further understanding and managing the crop under different growth conditions. SOYGRO (Wilkerson et al. 1985) and COMAX/GOSSYM (Dale 1986) are two such models for the crop growth of soybeans and cotton. Several authors have developed models for tobacco (Chen 1970; Wann et al. 1978; Wixley and Shaw 1981; Vepraskas 1988; and Schneider 1993). Chen (1970) modeled the growth of small tobacco plants; Wann et al.(1978) used a dynamic growth model to simulate dry matter accumulation in tobacco; Wixley and Shaw(1981) used a model to understand the impact of soil pests on tobacco crops. Vepraskas(1988) examined root growth in coarse-textured soils, and Schneider(1993) developed a mechanistic simulation model of flue-cured tobacco for predicting leaf dry weight and leaf surface area by position on the stalk as well as total stem, stalk, and root dry weights.

Maw et al. (1985), Shirmohammadi et al. (1986), and Tsai and Maw (1988) evaluated characteristics for mathematically modeling flue-cured tobacco growth under the influence of soil water deficit. Such information could be used to help schedule limited irrigation water most advantageously.

## Objectives

In order to advocate the most effective use of a limited water supply during flue-cured tobacco production, the objectives of this study were established:

1. To describe flue-cured tobacco growth under various drought treatments over time from transplanting to harvest by deriving growth curves, using two-parameter least squares regression for measured characteristics of flue-cured tobacco plants.
2. To determine when a period of drought during the growing season would be most detrimental to flue-cured tobacco production by averaging over the entire season the values of measured characteristics from flue-cured tobacco plants under various drought treatments.

## Materials and Methods

### Site

Tobacco was grown for three years, 1986–88, within the boundary of a high-rise rainout shelter (Maw and Stansell 1986), at Tifton in the Southeastern Coastal Plain of the United States, latitude 31.5 N. All conditions of growth for the tobacco were typical of field conditions (Anonymous 1983), except for the prescribed availability of soil water. A roof automatically moved over the tobacco plants when rain began to fall. The planting pattern favorably compared with that of a typical field of tobacco. Tobacco was planted on a 60 × 120 cm grid over a total area of 18 plots, each 2.4 × 2.4 m.

The plots were separated from each other by 10 cm thick solid concrete walls. The walls acted as barriers against lateral water movement from one plot to another, to a depth of 1.1 m. A network of drain tubes under the walls also prevented movement of subterranean water between plots. Vertical water movement was stopped by an impervious layer of hard clay, 1.2 m below the ground surface. Soil in the plots was, by nature of design and construction of the walls, an undisturbed soil profile of Tifton loamy sand (table 1), a member of the fine loamy, siliceous, thermic family of Plinthic Paleudults.

**Table 1. Soil Engineering Index Properties for Tifton Loamy Sand**

| | | | | Percentage Passing[c] Sieve Number | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Depth (cm) | Available Water (cm/cm) | USDA Texture[a] | AASHTO[b] Class | 70–96 | 62–94 | 53–85 | 34–85 | Liquid[d] Limit | Plasticity[e] Index |
| 00–25 | 0.03–0.08 | Loamy sand | A–2 | 70–96 | 62–94 | 53–85 | 11–27 | - | NP |
| 25–35 | 0.08–0.12 | Sandy loam | A–2 | 70–95 | 56–89 | 55–89 | 20–35 | <25 | NP–7 |
| 35–97 | 0.12–0.15 | Sandy clay loam | A–2, A–6 | 70–98 | 65–94 | 60–89 | 22–53 | 22–40 | 10–22 |

*Source:* Soil Survey of Tift County, Georgia, USDA SCS. 1983.
a. United States Department of Agriculture Classification.
b. American Association of State Highway and Transportation Officials (AASHTO)–M145.
c. AASHTO–T88 and American Society for Testing Materials (ASTM)–D2217.
d. AASHTO–T89 and American Society for Testing Materials (ASTM)–D423.
e. AASHTO–T90 and American Society for Testing Materials (ASTM)–D424.

## Treatments

Nine treatments with two replications arranged in RCB design, re-randomized each year, were imposed on tobacco growing in the plots (table 2). The nine treatments consisted of a 4 × 2 factorial involving four periods of drought and two levels of trigger soil water pressure used to trigger irrigation, plus one field treatment. Treatments 1 and 2 both imposed a drought during weeks six and seven. Treatments 3 and 4 both imposed a drought during weeks eight and nine. Treatments 5 and 6 both imposed a drought during weeks 10 and 11. Treatments 7 and 8 both imposed no drought. Treatment 9 (Field treatment or control treatment) was irrigated as prescribed by a local farmer to a neighboring crop of tobacco, according to visually observing the vigor of plant growth and the moisture of the soil. In order to encourage root penetration (Anonymous 1983), no irrigation was added to the naturally occurring soil water during weeks two through five following transplanting.

**Table 2. Treatments of Drought Imposed During the Tobacco Growing Season**

| Treatment (Number) | Soil Water Pressure (kPa) | Drought Period (weeks after transplanting) | DP-None Effect[a] | DP-Wk 8,9 Effect | SWP-Hi Effect | SWP-Lo Effect | Field Effect |
|---|---|---|---|---|---|---|---|
| 1 | -25 | 6 and 7 | | | | 1/4 | |
| 2 | -100 | 6 and 7 | | | 1/4 | | |
| 3 | -25 | 8 and 9 | | 1/2 | | 1/4 | |
| 4 | -100 | 8 and 9 | | 1/2 | 1/4 | | |
| 5 | -25 | 10 and 11 | | | | 1/4 | |
| 6 | -100 | 10 and 11 | | | 1/4 | | |
| 7 | -25 | None | 1/2 | | | 1/4 | |
| 8 | -100 | None | 1/2 | | 1/4 | | |
| 9 | Field | None | | | | | 1 |

a. Weighting factors to determine the contribution of various treatments to the particular effect.

## Application of Water to the Soil

Except during the two-week periods of drought caused by the described treatments, soil water was maintained between field capacity (water held in the soil against gravity) and one of two trigger levels of soil water pressure, -25 kPa (SWP-25) for treatments 1, 3, 5 and 7, or -100 kPa (SWP-100) for treatments 2, 4, 6, and 8 (table 2). Tobacco plants would extract water from the soil until the soil water pressure reached the treatment trigger level, and then sufficient water was applied to replenish the soil water to field capacity.

Soil water pressure was monitored with gypsum resistance blocks in each plot (Delmhorst Instrument Company, Towaco, NJ) at depths of 100, 230, 380, 530, 810, and 1070 mm. The 230 mm depth resistance block was used to trigger irrigation. When soil water pressure reached the trigger level in each plot, a calculation was made of the amount of water necessary to replenish a 600 mm soil profile to field capacity, based upon measurements taken from resistance blocks at each layer of soil within the 600 mm depth. Water was applied to the surface by a metered hose. Examination of soil water pressure at depths below 600 mm, as measured by the two deepest resistance blocks, indicated very little depletion of soil water, suggesting that tobacco roots did not draw much water from below 600 mm. Table 3 gives the cumulative annual water amounts applied to treatments.

**Table 3. Average Cumulative Water Applied for each Treatment over the Growing Seasons 1986–88**

| Cumulative Water (mm) | Treatment | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1st Year | 326 | 288 | 328 | 237 | 349 | 438 | 356 | 425 | 421 |
| 2nd Year | 421 | 338 | 306 | 279 | 303 | 239 | 443 | 304 | 179 |
| 3rd Year | 377 | 314 | 380 | 219 | 250 | 251 | 338 | 360 | 181 |
| Mean | 375 | 313 | 338 | 245 | 301 | 309 | 379 | 363 | 283 |

According to the Soil Conservation Service (Anonymous 1979), the water-holding capacity of Tifton loamy sand is 3%–8% of the total volume of soil for the first 250 mm, 8%-12% for the 250–350 mm depth, and 12%–15% for the 350–970 mm depth (table 1). Hook (1985) summarized laboratory and field measurements of soil water limits on a field adjacent to the rainout shelter (table 4). These results are 11.1% for 0–200 mm depth, 11.0% for 200–300 mm depth, 13.5% for 300–450 mm depth, and 15.8% for 450–600 mm depth. From table 4, in terms of mm, the available water for Tifton loamy sand was calculated as 77 mm for the entire 600 mm of the soil profile. The lower limit, or wilting point, is generally accepted as -1500 kPa (15 bars), although true wilting point depends on the extraction capabilities of the crop (Hook 1988). Drained upper limit (field capacity) is typically 33 kPa for a disturbed soil sample and 6 kPa for an in-situ measurement of Tifton surface soil. Soil water deficit (field capacity - water content) when irrigation was triggered at SWP-25 was approximately 20 mm and at SWP-100 was approximately 30 mm (calculated from equations in table 4).

**Table 4. Physical Properties of the Tifton Loamy Sand Growth Plot Soil**

| Depth (cm) | Bulk Density ($g/cm^3$) | Pore Volume | Upper Limit | Drained[a] Wilting[b] Point | Observed WC[c] Highest | Observed WC[c] Lowest | Coefficients of water release curves[d] $A_0$ | $A_1$ | $A_2$ |
|---|---|---|---|---|---|---|---|---|---|
| | | % Volume | | | | | | | |
| 0–20 | 1.54 | 42 | 15.0 | 3.9 | 14.0 | 2.5 | $7.9090\times10^{-2}$ | $-4.6078\times10^{-2}$ | $3.3806\times10^{-2}$ |
| 20–30 | 1.72 | 35 | 17.5 | 6.5 | 15.5 | 3.0 | $9.7490\times10^{-2}$ | $-2.8303\times10^{-2}$ | $3.5749\times10^{-2}$ |
| 30–45 | 1.68 | 37 | 20.0 | 6.5 | 17.5 | 5.0 | $1.2460\times10^{-1}$ | $-4.3502\times10^{-2}$ | $1.2157\times10^{-2}$ |
| 45–60 | 1.66 | 37 | 25.0 | 9.2 | 20.0 | 7.0 | $1.3986\times10^{-1}$ | $-4.1792\times10^{-2}$ | $1.0470\times10^{-2}$ |
| 60–90 | 1.62 | 39 | 29.0 | 9.0 | 23.0 | 9.5 | $1.9465\times10^{-1}$ | $-4.7758\times10^{-2}$ | $8.4354\times10^{-3}$ |
| 90–120 | 1.60 | 40 | 29.0 | 9.0 | 23.0 | 15.0 | $2.7324\times10^{-2}$ | $-3.8040\times10^{-2}$ | $4.8007\times10^{-3}$ |

*Source:* Hook 1985.

a. Field gravimetric water content following 48 hours of drainage under plastic after 16 hours of flooding.
b. Laboratory water content following desorption of disturbed sample on a ceramic plate at 15 bars.
c. Ninety-nine percent confidence limits for all gravimetric WC samples taken at the study sites over five years (256 samples/depth).
d. Coefficients derived for polynomials describing water content as a function of LPSI, the log soil water (-mbar); $WC = A_0 + A_1 \bullet LPSI + A_2 \bullet LPSI^2$.

## Tobacco Plant Establishment and Management

The tobacco (variety ‘NC 2326’) was transplanted, eight plants per plot, during the last week in March (week one) and, with the exception of water availability according to treatments, was grown according to recommendations (Anonymous 1983). The cultural operations, as well as tobacco plant growth stages, are shown by weeks after transplanting in table 5. For those plants allowed to mature, tobacco leaves were harvested at five weekly intervals according to their maturity and position on the stalk. The first harvest of bottom leaves happened to be conducted during the first full week of July in all three years.

**Table 5. Approximate Dates for Phenological Changes that Occurred During the Three Tobacco Growing Seasons of this Study and the Approximate Time of Selected Management Operations**

| Week | Date | Stage of Growth | Operation |
|---|---|---|---|
| 1 | Last week in March | 4 leaves, 5 cm high | transplanting/fertilizer |
| 2 | 1st week in April | | water withheld |
| 3 | 2nd week in April | 5 leaves, 6 cm high | budworm control began |
| 4 | 3rd week in April | | |
| 5 | 4th week in April | | side dress fertilizer |
| 6 | 1st week in May | 10 leaves, 14 cm high | irrigation began |
| 7 | 2nd week in May | 12 leaves, 18 cm high | |
| 8 | 3rd week in May | buds fully formed | |
| 9 | 4th week in May | flowering began | |
| 10 | 5th week in May | 18 leaves, 70 cm high | aphid control began |
| 11 | 1st week in June | rapid growth | topping of flowers |
| 12 | 2nd week in June | plants shoulder high | sucker control began |
| 13 | 3rd week in June | | |
| 14 | 4th week in June | senesence began on lower leaves | |
| 15 | 1st week in July | suckers grew rapidly, if not controlled | 1st priming |
| 16 | 2nd week in July | | 2nd priming |
| 17 | 3rd week in July | plants maturing rapidly | 3rd priming |
| 18 | 4th week in July | most leaves mature | 4th priming |
| 19 | 1st week in August | | 5th priming |
| 20 | 2nd week in August | | |

**Measurement of Plant Characteristics**

Weather and plant data were collected at weekly intervals during the growing season, beginning the first full week of May (week six). A selected number of plants were measured each week either non-destructively or destructively (table 6), so that no plant was measured on consecutive weeks. Non-destructive measurements were for characteristics including leaf width, leaf length, stalk internodal distance, stalk diameter, and stalk height. Destructive measurements were for characteristics including root depth, root weight, leaf area, leaf weight, stalk weight, cured leaf grades, and cured leaf chemical constituencies.

Irregular sampling was necessary because, as the tobacco plants grew, not only were there insufficient plants available to sacrifice from each plot each week, but also—even if there had been sufficient plants—it would not have been possible to undertake such a complex measurement program, considering the limited available resources. Table 6 shows the number of plants sampled for each week for each year . The most data were taken during the first year (1986). Then preliminary analyses of data from the first year suggested that fewer plants could be sampled during the second year without loss of information. Finally, during the third year there was a 22% increase in the number of plants non-destructively sampled. Regarding the effect of sampling on treatments, the mean sample date was not different for the nine treatments (table 6). Therefore, the means of each treatment can be compared with each other.

As a result of sampling at irregular times, measurements were made that would allow determination of the treatment effect means for drought period, trigger soil water pressure and field, with their standard errors, from which appropriate tests could be made. Irregular sampling caused interactions to be confounded.

Plant roots were dug with a spade, preserving the main roots, to a depth of 600 mm. The roots were washed and weighed and the longest remaining roots measured. For leaves, the midrib was included. Whereas roots may be used as an indicator of the extent to which a plant had to search for soil water, the procedure of digging roots destroyed many secondary roots, leaving only the primary root mass.

Stalk height was measured for each plant, after the flowers had been removed (topped). For fresh weights, collection and weighing took place before 08.00 h. For dry weights, fresh material was dried in an oven at 100°C for 48–96 h. For leaf area, leaves were passed through a leaf area meter (Lamda Instruments Corp., 4421 Superior Street, P.O. Box 4425, Lincoln, NE 68504, Model LI–3100). Grades and chemical constituents of cured leaf were both qualified for leaves of plants harvested in the conventional manner at the appropriate time of harvest (Anonymous 1983) and cured before being analyzed. For grades, leaves at each appropriate position on the stalk were given grades by USDA tobacco graders. For chemical analyses, those of total nitrogen, reducing sugars, total alkaloids and starch, were conducted on the cured leaf, two out of the three years. Where leaves were divided into position, the bottom leaves included the first three leaves from the bottom of the stalk, the lower position included leaves 4–11, the middle position included leaves 12–18, and the upper position included leaf 19 and those above leaf 19.

**Table 6. Sample Sizes for Selected Treatments and Three Years by Week, and Weighted Week Means for Nondestructive (N) and Destructive (D) Sampling**

| Treatment or Year | Type of Sample | Week | | | | | | | | | | | | | | | Totals | | Wtd Week Mean[a] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Row | Trt | Row | Trt |
| DP-Wk 6,7 | N | 16 | 23 | 20 | 20 | 12 | 12 | 12 | 12 | 5 | 8 | 5 | 7 | 6 | 4 | 2 | 164 | | 10.74 | |
| | D | - | 2 | 8 | 5 | 6 | 4 | 5 | 5 | 8 | 7 | - | 3 | - | 0 | - | 53 | 217 | 11.79 | 10.98 |
| DP-Wk 8,9 | N | 15 | 24 | 19 | 20 | 12 | 11 | 12 | 12 | 5 | 7 | 5 | 5 | 4 | 7 | 2 | 160 | | 10.72 | |
| | D | - | 4 | 10 | 1 | 8 | 5 | 9 | 13 | 10 | 1 | - | 4 | - | 2 | - | 67 | 227 | 11.79 | 11.04 |
| DP-Wk 10,11 | N | 16 | 24 | 20 | 18 | 12 | 12 | 12 | 12 | 6 | 6 | 6 | 5 | 6 | 5 | 2 | 162 | | 10.72 | |
| | D | - | 5 | 8 | 4 | 7 | 1 | 7 | 13 | 7 | 4 | - | 2 | - | 1 | - | 59 | 221 | 11.53 | 10.93 |
| DP-None | N | 15 | 23 | 19 | 20 | 12 | 12 | 12 | 12 | 6 | 6 | 6 | 5 | 5 | 6 | 2 | 161 | | 10.77 | |
| | D | - | 3 | 10 | 3 | 7 | 5 | 7 | 10 | 6 | 3 | - | 5 | - | 2 | - | 61 | 222 | 11.79 | 11.05 |
| SWP-25 | N | 32 | 48 | 40 | 40 | 24 | 24 | 24 | 24 | 10 | 13 | 13 | 10 | 11 | 12 | 4 | 329 | | 10.73 | |
| | D | - | 6 | 18 | 8 | 16 | 7 | 16 | 19 | 18 | 10 | - | 8 | - | 2 | - | 128 | 457 | 11.80 | 11.03 |
| SWP-100 | N | 30 | 46 | 38 | 38 | 24 | 23 | 24 | 24 | 12 | 14 | 9 | 12 | 10 | 10 | 4 | 318 | | 10.75 | |
| | D | - | 8 | 18 | 5 | 12 | 8 | 12 | 22 | 13 | 5 | - | 6 | - | 3 | - | 112 | 430 | 11.60 | 10.97 |
| Control | N | 8 | 12 | 10 | 10 | 6 | 6 | 6 | 6 | 2 | 4 | 2 | 3 | 3 | 2 | 1 | 81 | | 10.63 | |
| | D | - | 2 | 4 | 1 | 3 | 3 | 3 | 4 | 4 | 2 | - | 2 | - | 0 | - | 28 | 109 | 11.64 | 10.89 |
| 1986 | N | 34 | 34 | 16 | 17 | 18 | 17 | 18 | 18 | 6 | 6 | 6 | 7 | 6 | 6 | - | 209 | | 10.29 | |
| | D | - | 4 | 40 | 2 | 31 | 6 | 31 | 33 | 35 | 5 | - | 5 | - | 5 | - | 197 | 406 | 11.61 | 10.93 |
| 1987 | N | - | 36 | 36 | 35 | 18 | 18 | 18 | 18 | 9 | 10 | 9 | 9 | 9 | 9 | - | 234 | | 11.06 | |
| | D | - | 6 | - | 6 | - | 6 | - | 6 | - | 6 | - | 5 | - | - | - | 35 | 269 | 11.86 | 11.17 |
| 1988 | N | 36 | 36 | 36 | 36 | 18 | 18 | 18 | 18 | 9 | 15 | 9 | 9 | 9 | 9 | 9 | 285 | | 10.77 | |
| | D | - | 6 | - | 6 | - | 6 | - | 6 | - | 6 | - | 6 | - | - | - | 36 | 321 | 12.00 | 10.91 |
| Total | N | 70 | 122 | 128 | 102 | 85 | 71 | 85 | 99 | 59 | 48 | 24 | 41 | 24 | 29 | 9 | 728 | | 10.72 | |
| | D | - | 16 | 40 | 14 | 31 | 18 | 31 | 45 | 35 | 17 | - | 16 | - | 5 | - | 268 | 996 | 11.70 | 10.99 |

a. wtd Week Mean = [sum over weeks (week # * sample size)]/total sample size.

**Table 7. Available Soil Water at the End of the Periods of Drought for the Three Years Measured**

| | Depth of soil (mm) | | | | Total accumulation in top 600 mm soil | Total deficit (mm) |
|---|---|---|---|---|---|---|
| | 0–150 | 150–300 | 300–450 | 450–600 | | |
| *Field Capacity (mm)* | 16.5 | 16.5 | 20.2 | 23.7 | 6.9 | 0.0 |
| *Drought during weeks 6 & 7* | | | | | | |
| Treatment 1 | | | | | | |
| 1st Year | 0.0 | 12.5 | 12.5 | 15.7 | 40.7 | 36.1 |
| 2nd Year | 0.0 | 0.0 | 15.5 | 12.2 | 27.7 | 79.1 |
| 3rd Year | 0.0 | 0.0 | 7.5 | 7.5 | 15.0 | 61.9 |
| Average | 0.0 | 4.2 | 11.8 | 11.8 | - | 49.1 |
| Treatment 2 | | | | | | |
| 1st Year | 0.0 | 5.0 | 14.0 | 14.5 | 33.5 | 43.4 |
| 2nd Year | 0.0 | 2.5 | 11.5 | 13.7 | 27.7 | 49.1 |
| 3rd Year | 0.0 | 0.2 | 13.5 | 9.7 | 23.5 | 53.4 |
| Average | 0.0 | 2.6 | 13.0 | 12.7 | - | 48.1 |
| *Drought during weeks 8 & 9* | | | | | | |
| Treatment 3 | | | | | | |
| 1st Year | 0.0 | 0.0 | 8.0 | 0.0 | 8.0 | 68.9 |
| 2nd Year | 0.0 | 0.0 | 3.5 | 7.0 | 17.0 | 66.4 |
| 3rd Year | 0.0 | 4.7 | 8.7 | 10.5 | 24.0 | 52.9 |
| Average | 0.0 | 1.6 | 6.7 | 5.8 | - | 62.7 |
| Treatment 4 | | | | | | |
| 1st Year | 0.0 | 1.2 | 0.0 | 11.2 | 12.5 | 64.4 |
| 2nd Year | 0.0 | 6.7 | 3.5 | 3.2 | 13.5 | 63.4 |
| 3rd Year | 4.7 | 4.2 | 11.0 | 12.5 | 32.5 | 44.4 |
| Average | 1.6 | 4.1 | 4.8 | 9.0 | - | 57.4 |
| *Drought during weeks 10 & 11* | | | | | | |
| Treatment 5 | | | | | | |
| 1st Year | 0.0 | 0.0 | 5.0 | 3.0 | 8.0 | 68.9 |
| 2nd Year | 0.0 | 0.0 | 2.7 | 2.2 | 5.0 | 71.9 |
| 3rd Year | 0.0 | 0.0 | 5.2 | 0.0 | 5.2 | 71.6 |
| Average | 0.0 | 0.0 | 4.3 | 1.7 | - | 70.8 |
| Treatment 6 | | | | | | |
| 1st Year | 0.0 | 0.0 | 0.0 | 1.5 | 1.5 | 75.4 |
| 2nd Year | 0.0 | 2.0 | 1.7 | 6.2 | 10.0 | 66.9 |
| 3rd Year | 0.0 | 0.7 | 1.5 | 14.2 | 16.5 | 60.4 |
| Average | 0.0 | 0.9 | 1.1 | 7.3 | - | 67.6 |

Under results, the data are presented as means of recorded values of all characteristics during the season, except for leaf number and stalk height (tables 8–13), which are maxima. For example, leaf length implies the mean length of all measurements taken during the growing season. While leaf length is weighted towards the higher values, it still gives the comparative effects of drought, as required. Similarly, since it was considered inappropriate to extrapolate crop yield from the final cured weights of tobacco from such small plots as were used, crop dry weight (dry weight/leaf × number of leaves/plant × 13454 plants/ha) was used instead for comparative rather than absolute purposes, on a larger scale than by weight per leaf. In addition to the measured leaf area

**Table 8. Mean Root Depth and Root Weight for Different Treatments**

| | Treatments | | | | | | | | | | SWP | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | SE[a] | -25 | -100 |
| *Root Depth (cm)* | | | | | | | | | | | | |
| 1st Year | 44.0 | 40.6 | 56.5 | 41.0 | 35.5 | 44.7 | 35.8 | 35.5 | 34.8 | 8.72 | 40.8 | 40.2 |
| 2nd Year | 33.5 | 33.8 | 31.5 | 26.6 | 35.3 | 22.8 | 31.0 | 34.8 | 27.7 | 4.72 | 32.8 | 29.5 |
| 3rd Year | 45.1 | 25.0 | 28.0 | 28.5 | 26.8 | 24.8 | 30.5 | 25.5 | 35.5 | 6.69 | 32.6 | 25.9 |
| SE[b] | 7.12 | 6.60 | 8.06 | 6.60 | 6.60 | 7.12 | 6.60 | 6.60 | 6.77 | | 3.56 | 3.37 |
| Mean | 40.9 | 33.1 | 38.7 | 32.0 | 32.5 | 30.8 | 32.4 | 31.9 | 32.7 | | | |
| Mean of Means | 36.9 | | 35.4 | | 31.6 | | 32.2 | | | 33.5[d] | 35.4[e] | 31.9 |
| SE[c] | 2.81 | | 3.01 | | 2.81 | | 2.70 | | | 1.33 | 2.54 | |
| *Root Dry Weight (g)* | | | | | | | | | | | | |
| 1st Year | 77 | 53 | 112 | 27 | 41 | 85 | 49 | 50 | 47 | 21 | 63 | 52 |
| 2nd Year | 80 | 63 | 33 | 49 | 67 | 34 | 66 | 79 | 47 | 29 | 61 | 56 |
| 3rd Year | 76 | 64 | 60 | 83 | 63 | 26 | 56 | 93 | 49 | 38 | 64 | 66 |
| SE[b] | 30 | 29 | 31 | 29 | 29 | 30 | 29 | 29 | 33 | 15 | 15 | |
| Mean | 78 | 60 | 68 | 53 | 57 | 48 | 57 | 74 | 48 | | | |
| Mean of Means | 68 | | 56 | | 52 | | 65 | | | 59[d] | 63[d] | 58 |
| SE[c] | 12 | | 13 | | 12 | | 12 | | | 6 | 11 | |
| *Mean Root Dry Weight/Mean Root Fresh Weight (%)* | | | | | | | | | | | | |
| Mean | 32.4 | 32.3 | 32.3 | 33.7 | 32.3 | 29.1 | 31.7 | 34.1 | 33.8 | 32.2[d] | 32.1 | 32.0 |

a. Between the nine treatments within a year.
b. Between the three years within a treatment or trigger soil water pressure.
c. Mean and SE for mean of means (first four).
d. Mean and/or SE for the variable.
e. Mean and SE for trigger soil water pressure (last two).

**Table 9. Mean Stalk Height, Stalk Weight, Stalk Diameter, Internodal Distance, and Number of Leaves/Plant for Different Treatments**

| | Treatments | | | | | | | | | | SWP | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | SE[a] | -25 | -100 |
| *Stalk Height (cm)* | | | | | | | | | | | | |
| 1st Year | 94 | 92 | 78 | 73 | 84 | 100 | 94 | 98 | 97 | 9.9 | 88 | 92 |
| 2nd Year | 93 | 103 | 107 | 108 | 101 | 97 | 113 | 123 | 98 | 14.0 | 103 | 108 |
| 3rd Year | 89 | 75 | 70 | 84 | 69 | 71 | 89 | 81 | 73 | 12.5 | 79 | 78 |
| SE[b] | 12 | 12 | 12 | 13 | 13 | 12 | 12 | 12 | 12 | | 6 | 6 |
| Mean | 92 | 90 | 85 | 88 | 85 | 89 | 99 | 101 | 89 | | | |
| Mean of Means | 91 | | 87 | | 88 | | 100 | | | 91[d] | 90[e] | 93 |
| SE[c] | 5 | | 5 | | 5 | | 5 | | | 2 | 4 | |
| *Stalk Dry Weight (g)* | | | | | | | | | | | | |
| 1st Year | 104 | 78 | 139 | 61 | 66 | 117 | 89 | 85 | 74 | 25 | 93 | 83 |
| 2nd Year | 96 | 92 | 71 | 85 | 91 | 53 | 95 | 134 | 93 | 38 | 88 | 91 |
| 3rd Year | 82 | 62 | 65 | 73 | 73 | 30 | 96 | 71 | 47 | 32 | 79 | 59 |
| SE[b] | 32 | 31 | 34 | 31 | 31 | 32 | 31 | 31 | 33 | | 16 | 16 |
| Mean | 94 | 77 | 92 | 73 | 77 | 67 | 93 | 97 | 71 | | | |
| Mean of Means | 85 | | 82 | | 72 | | 95 | | | 81[d] | 87[e] | 78 |
| SE[c] | 13 | | 13 | | 13 | | 13 | | | 6 | | 11 |
| *Mean Stalk Dry Weight/Mean Stalk Fresh Weight (%)* | | | | | | | | | | | | |
| Mean | 17.9 | 16.4 | 19.1 | 18.5 | 17.8 | 17.9 | 18.5 | 16.8 | 19.6 | 18.0[d] | 18.3 | 17.3 |
| *Stalk Diameter (mm)* | | | | | | | | | | | | |
| 1st Year | 18.2 | 18.0 | 17.6 | 15.6 | 18.5 | 18.4 | 18.5 | 19.5 | 17.4 | 0.44 | 18.2 | 17.9 |
| 2nd Year | 26.4 | 26.0 | 26.8 | 26.3 | 27.7 | 25.5 | 30.4 | 30.6 | 24.5 | 0.27 | 27.8 | 27.3 |
| 3rd Year | 20.9 | 20.8 | 20.7 | 23.1 | 20.3 | 19.8 | 23.8 | 20.1 | 19.2 | 0.73 | 21.4 | 21.0 |
| SE[b] | 0.54 | 0.59 | 0.53 | 0.57 | 0.55 | 0.52 | 0.66 | 0.54 | 0.45 | | 0.29 | 0.28 |
| Mean | 21.8 | 21.6 | 21.7 | 21.7 | 22.2 | 21.2 | 24.2 | 23.4 | 20.4 | | | |
| Mean of Means | 21.7 | | 21.7 | | 21.7 | | 23.8 | | | 22.1[d] | 22.5[e] | 20.1 |
| SE[c] | 0.23 | | 0.22 | | 0.22 | | 0.24 | | | 0.10 | 0.20 | |

**Table 9 (continued)**

| | Treatments | | | | | | | | | | SWP | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | SE[a] | -25 | -100 |
| *Internodal Distance (cm)* | | | | | | | | | | | | |
| 1st Year | 4.9 | 4.4 | 3.6 | 3.8 | 4.2 | 4.3 | 4.5 | 4.5 | 4.3 | 0.14 | 4.4 | 4.3 |
| 2nd Year | 4.6 | 4.8 | 5.2 | 4.9 | 5.2 | 5.1 | 5.3 | 6.1 | 4.4 | 0.12 | 5.1 | 5.3 |
| 3rd Year | 4.6 | 4.5 | 4.0 | 5.0 | 4.1 | 4.1 | 5.1 | 4.3 | 4.0 | 0.08 | 4.4 | 4.5 |
| Mean | 4.7 | 4.6 | 4.3 | 4.6 | 4.5 | 4.5 | 5.0 | 5.0 | 4.3 | | | |
| Mean of Means | 4.7 | | 4.4 | | 4.5 | | 5.0 | | | 4.6[d] | 4.6[e] | 4.7 |
| SE[c] | 0.05 | | 0.05 | | 0.05 | | 0.05 | | | 0.02 | 0.04 | |
| *Number of Leaves/Plant* | | | | | | | | | | | | |
| 1st Year | 20.2 | 21.2 | 21.2 | 21.2 | 20.8 | 20.3 | 21.5 | 21.4 | 21.2 | 1.03 | 20.9 | 20.9 |
| 2nd Year | 22.1 | 23.0 | 21.7 | 24.0 | 21.9 | 23.5 | 21.1 | 21.6 | 22.6 | 0.76 | 21.7 | 22.9 |
| 3rd Year | 25.1 | 21.0 | 19.1 | 21.0 | 20.5 | 21.3 | 21.0 | 22.0 | 22.9 | 1.56 | 21.4 | 21.3 |
| SE[b] | 1.16 | 1.16 | 1.20 | 1.20 | 1.20 | 1.14 | 1.16 | 1.18 | 1.16 | | 0.34 | 0.34 |
| Mean | 22.5 | 21.7 | 20.7 | 22.1 | 21.1 | 21.7 | 21.2 | 21.7 | 22.3 | | | |
| Mean of Means | 22.1 | | 21.4 | | 21.3 | | 21.5 | | | 21.6[d] | 21.3[e] | 21.7 |

a. Between the nine treatments within a year.
b. Between the three years within a treatment or trigger soil water pressure.
c. Mean and SE for mean of means (first four).
d. Mean and/or SE for the variable.
e. Mean and SE for trigger soil water pressure (last two).

**Table 10. Mean Leaf Length, Leaf Width, Leaf Area, and Estimated Leaf Area per Leaf for Different Treatments**

| | Treatments | | | | | | | | | | SWP | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | SE[a] | -25 | -100 |
| *Leaf Length (cm)* | | | | | | | | | | | | |
| 1st Year | 46.7 | 45.1 | 46.0 | 42.4 | 48.8 | 46.8 | 44.9 | 50.7 | 45.0 | 4.66 | 46.6 | 46.3 |
| 2nd Year | 52.9 | 48.8 | 47.7 | 49.9 | 51.7 | 49.3 | 54.0 | 54.2 | 47.3 | 6.53 | 51.7 | 50.6 |
| 3rd Year | 43.3 | 46.4 | 42.0 | 43.0 | 42.1 | 41.8 | 44.8 | 42.0 | 40.1 | 4.97 | 43.1 | 43.4 |
| SE[b] | 10.1 | 10.1 | 9.5 | 9.7 | 9.8 | 9.1 | 9.7 | 10.1 | 8.6 | | 8.47 | 8.42 |
| Mean | 47.7 | 47.0 | 45.1 | 45.7 | 47.3 | 45.6 | 48.5 | 48.9 | | | | |
| Mean of Means | 47.3 | | 45.4 | | 46.5 | | 48.5 | | | 46.6[d] | 47.2[e] | 46.7 |
| SE[c] | 7.14 | | 6.75 | | 6.69 | | 6.98 | | | 3.21 | 4.88 | |
| *Leaf Width (cm)* | | | | | | | | | | | | |
| 1st Year | 21.6 | 20.3 | 21.8 | 19.2 | 23.5 | 21.9 | 24.2 | 20.6 | 26.0 | 2.42 | 22.1 | 21.4 |
| 2nd Year | 26.0 | 23.1 | 22.4 | 24.0 | 27.1 | 24.0 | 26.5 | 26.0 | 22.4 | 3.48 | 25.5 | 24.3 |
| 3rd Year | 19.1 | 21.9 | 18.8 | 20.2 | 18.1 | 19.0 | 20.8 | 19.2 | 18.4 | 2.38 | 19.2 | 20.1 |
| SE[b] | 5.1 | 5.1 | 4.4 | 4.8 | 5.5 | 4.9 | 5.1 | 5.3 | 4.4 | | 4.37 | 4.32 |
| Mean | 22.2 | 22.0 | 20.9 | 21.5 | 22.7 | 21.4 | 23.2 | 22.9 | 20.4 | | | |
| Mean of Means | 22.1 | | 21.2 | | 22.1 | | 23.1 | | | 21.9[d] | 22.3[e] | 22.0 |
| SE[c] | 3.61 | | 3.21 | | 3.67 | | 3.66 | | | 1.65 | 2.51 | |
| *Leaf Area (cm²)* | | | | | | | | | | | | |
| 1st Year | 928 | 869 | 999 | 787 | 1102 | 959 | 939 | 992 | 869 | 23 | 993 | 914 |
| 2nd Year | 900 | 967 | 800 | 761 | 965 | 684 | 879 | 1210 | 775 | 43 | 886 | 906 |
| 3rd Year | 718 | 631 | 579 | 731 | 637 | 421 | 760 | 530 | 464 | 25 | 674 | 578 |
| SE[b] | 33 | 31 | 28 | 27 | 34 | 31 | 29 | 34 | 24 | | 16 | 16 |
| Mean | 849 | 822 | 793 | 760 | 901 | 688 | 859 | 911 | 703 | | | |
| Mean of Means | 836 | | 785 | | 791 | | 886 | | | 812[d] | 851[e] | 799 |
| SE[c] | 13 | | 11 | | 13 | | 13 | | | 6 | 11 | |
| *Estimated Leaf Area (cm²)* | | | | | | | | | | | | |
| 1st Year | 670 | 610 | 670 | 542 | 780 | 692 | 648 | 819 | 620 | 121 | 693 | 668 |
| 2nd Year | 992 | 806 | 749 | 849 | 997 | 851 | 1006 | 996 | 743 | 190 | 939 | 875 |
| 3rd Year | 576 | 722 | 542 | 601 | 522 | 538 | 640 | 568 | 499 | 121 | 570 | 609 |
| SE[b] | 281 | 273 | 226 | 248 | 290 | 247 | 270 | 287 | 210 | | 233 | 229 |
| Mean | 753 | 730 | 651 | 689 | 762 | 682 | 789 | 786 | 616 | | | |
| Mean of Means | 742 | | 670 | | 722 | | 788 | | | 718[d] | 740[e] | 722 |
| SE[c] | 196 | | 168 | | 191 | | 197 | | | 87 | 134 | |

a. Between the nine treatments within a year.
b. Between the three years within a treatment or trigger soil water pressure.
c. Mean and SE for mean of means (first four).
d. Mean and/or SE for the variable.
e. Mean and SE for trigger soil water pressure (last two).

**Table 11. Mean Measured Leaf Dry Weight, Leaf Dry Weight/Leaf Fresh Weight, Leaf Density, and Crop Weight for Different Irrigation Treatments**

| | Treatments | | | | | | | | | | SWP | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | SE[a] | -25 | -100 |
| *Leaf Dry Weight (g)* | | | | | | | | | | | | |
| 1st Year | 11.2 | 10.1 | 11.5 | 9.0 | 14.7 | 11.3 | 11.6 | 12.4 | 8.8 | 0.38 | 12.2 | 10.9 |
| 2nd Year | 8.2 | 9.4 | 6.5 | 6.1 | 9.4 | 5.6 | 7.9 | 12.5 | 7.7 | 0.47 | 8.0 | 8.4 |
| 3rd Year | 6.5 | 5.5 | 5.7 | 6.7 | 6.2 | 3.6 | 6.6 | 4.5 | 4.4 | 0.27 | 6.2 | 5.1 |
| SE[b] | 0.39 | 0.38 | 0.39 | 0.30 | 0.48 | 0.36 | 0.34 | 0.48 | 0.31 | | 0.20 | 0.20 |
| Mean | 8.6 | 8.3 | 7.9 | 7.3 | 10.1 | 6.8 | 8.7 | 9.8 | 7.0 | | | |
| Mean of Means | 8.45 | | 7.6 | | 8.45 | | 9.25 | | | 8.3[d] | 8.8[e] | 8.1 |
| SE[c] | 0.16 | | 0.14 | | 0.17 | | 0.17 | | | 0.07 | 0.14 | |
| *Mean Leaf Dry Weight/Mean Leaf Fresh Weight (%)* | | | | | | | | | | | | |
| Mean | 17.1 | 17.0 | 17.0 | 16.4 | 17.6 | 16.3 | 17.1 | 16.9 | 18.1 | 17.0[d] | 17.2 | 16.7 |
| *Leaf Dry Weight/Leaf Area (mg/cm²)* | | | | | | | | | | | | |
| 1st Year | 11.1 | 10.0 | 14.1 | 8.0 | 11.6 | 13.1 | 8.9 | 12.5 | 8.6 | 1.17 | 10.6 | 10.6 |
| 2nd Year | 9.8 | 8.8 | 7.7 | 7.7 | 8.7 | 7.8 | 8.7 | 10.4 | 8.7 | 1.65 | 8.7 | 8.7 |
| 3rd Year | 9.1 | 8.1 | 9.2 | 8.4 | 9.2 | 8.4 | 8.5 | 8.1 | 8.7 | 0.67 | 9.0 | 8.2 |
| SE[b] | 3.4 | 1.8 | 1.6 | 1.6 | 2.2 | 1.6 | 1.9 | 3.2 | 1.6 | | 2.05 | 1.83 |
| Mean | 9.8 | 8.9 | 8.9 | 8.0 | 9.2 | 9.1 | 8.7 | 9.7 | 8.7 | | | |
| Mean of Means | 9.3 | | 8.4 | | 9.2 | | 9.2 | | | 9.0[d] | 9.2[e] | 8.9 |
| SE[c] | 1.88 | | 1.10 | | 1.33 | | 1.83 | | | 0.73 | 1.13 | |
| *Crop Dry Weight (kg/ha)* | | | | | | | | | | | | |
| 1st Year | 3044 | 2881 | 3280 | 2567 | 4114 | 3086 | 3355 | 3570 | 2510 | 332 | 3448 | 3026 |
| 2nd Year | 2438 | 2909 | 1898 | 1970 | 2770 | 1771 | 2243 | 3633 | 2341 | 323 | 2337 | 2570 |
| 3rd Year | 2195 | 1554 | 1465 | 1893 | 1710 | 1032 | 1865 | 1332 | 1356 | 364 | 1809 | 1453 |
| SE[b] | 411 | 386 | 391 | 321 | 491 | 359 | 337 | 49<br>6 | 324 | | 206 | 198 |
| Mean | 2559 | 2448 | 2214 | 2143 | 2864 | 1963 | 2488 | 2845 | 2069 | | | |
| Mean of Means | 2503 | | 2179 | | 2414 | | 2666 | | | 2399[d] | 2531[e] | 2350 |
| SE[c] | 282 | | 253 | | 304 | | 300 | | | 132 | 220 | |

a. Between the nine treatments within a year.
b. Between the three years within a treatment or trigger soil water pressure.
c. Mean and SE for mean of means (first four).
d. Mean and/or SE for the variable.
e. Mean and SE for trigger soil water pressure (last two).

based on destructive sampling, leaf area has been estimated (Maw and Mullinix 1992) based on non-destructive sampling of leaf length and leaf width (0.62(LxW)). Since a much larger database spread over the growing season was available for non-destructive sampling, compared with destructive sampling (table 6), the calculated area was different from the measured area, but is presented to confirm the order of largest to the smallest of the measured leaf area. Leaf density has been calculated using leaf weight / measured leaf area. Grade values are a weighted index allocated to the USDA letter grades according to the usefulness of the grades, on the market (Bowman et al. 1988). This grade value is weighted within a cure and across all cures for each treatment. It is also weighted according to the weight of tobacco at a particular grade. The results of fresh weight have not been included, but the means of dry weight / fresh weight (%) allow the means of fresh weight to be calculated. For each characteristic the mean of means for treatments are compared with the mean of treatment 9.

Under discussion, the first objective of the study has been met by combining data for the three years (1986–88) and analyzing the data using PROC GLM (SAS, 1989). Sampling dates were converted to weeks after transplanting ($X$). The values of $X$ were changed to $x$ [$x = X$-Mean($X$); $x$ is the deviation about the mean of $X$, where $X$ is weeks after transplanting (Draper and Smith 1981)]. Presented in graphical form are the weekly means for

**Table 12. Mean Leaf Length, Leaf Width, Estimated Leaf Area and Leaf Density by Position on the Stalk for Different Irrigation Treatments**

| | | Treatments | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1, 2 | 3, 4 | 5, 6 | 7, 8 | 9 | 1, 3, 5, 7 (SWP-25) | 2, 4, 6, 8 (SWP-100) |
| *Leaf Length (cm)*[a] | | | | | | | | |
| Bottom | Mean | 28.1 | 29.2 | 29.5 | 31.2 | 28.3 | 29.7 | 29.2 |
| | SE[b] | 5.04 | 5.28 | 4.94 | 5.46 | 7.26 | 3.70 | 3.63 |
| Lower | Mean | 46.4 | 45.2 | 47.2 | 49.1 | 44.5 | 47.5 | 46.4 |
| | SE | 6.29 | 5.65 | 6.02 | 6.16 | 7.09 | 4.24 | 4.30 |
| Middle | Mean | 55.9 | 52.3 | 53.3 | 56.3 | 50.4 | 54.3 | 54.7 |
| | SE | 6.69 | 7.03 | 6.26 | 6.81 | 8.41 | 4.87 | 4.59 |
| Upper | Mean | 50.9 | 50.0 | 46.9 | 47.9 | 44.6 | 49.2 | 48.8 |
| | SE | 5.87 | 5.80 | 5.94 | 5.85 | 7.30 | 4.09 | 4.21 |
| Overall | Mean | 47.3 | 45.4 | 46.5 | 48.5 | 43.9 | 47.2 | 46.7 |
| | SE | 3.57 | 3.88 | 3.35 | 3.59 | 4.27 | 2.45 | 2.43 |
| *Leaf Width (cm)*[a] | | | | | | | | |
| Bottom | Mean | 13.6 | 14.9 | 14.5 | 15.6 | 14.4 | 14.8 | 14.5 |
| | SE[b] | 2.84 | 3.23 | 3.12 | 3.43 | 4.40 | 2.30 | 2.16 |
| Lower | Mean | 23.0 | 22.6 | 24.6 | 25.3 | 22.5 | 24.2 | 23.6 |
| | SE | 3.28 | 2.74 | 3.51 | 3.37 | 3.85 | 2.26 | 2.33 |
| Middle | Mean | 25.2 | 22.6 | 23.8 | 25.0 | 21.6 | 24.2 | 24.2 |
| | SE | 3.38 | 3.29 | 3.14 | 3.37 | 4.00 | 2.39 | 2.26 |
| Upper | Mean | 21.7 | 20.5 | 18.2 | 19.1 | 17.5 | 20.0 | 19.9 |
| | SE | 3.04 | 2.80 | 2.87 | 2.84 | 3.36 | 2.01 | 2.09 |
| Overall | Mean | 22.1 | 21.2 | 22.1 | 23.1 | 20.4 | 22.3 | 22.0 |
| | SE | 1.81 | 1.61 | 1.84 | 1.83 | 2.16 | 1.26 | 1.25 |
| *Estimated Leaf Area ($cm^2$)*[a] | | | | | | | | |
| Bottom | Mean | 287 | 330 | 323 | 370 | 308 | 337 | 318 |
| | SE[b] | 111 | 122 | 124 | 137 | 169 | 91 | 84 |
| Lower | Mean | 740 | 688 | 801 | 857 | 672 | 788 | 755 |
| | SE | 182 | 147 | 186 | 188 | 188 | 125 | 125 |
| Middle | Mean | 954 | 812 | 859 | 957 | 732 | 900 | 896 |
| | SE | 191 | 183 | 175 | 193 | 217 | 135 | 128 |
| Upper | Mean | 750 | 691 | 585 | 626 | 526 | 668 | 669 |
| | SE | 168 | 153 | 157 | 151 | 167 | 109 | 115 |
| Overall | Mean | 742 | 670 | 722 | 788 | 616 | 740 | 722 |
| | SE | 98 | 84 | 96 | 99 | 105 | 68 | 66 |
| *Dry Leaf Density (mg/$cm^2$)*[a] | | | | | | | | |
| Bottom | Mean | 8.8 | 8.6 | 9.2 | 8.1 | 7.2 | 9.5 | 7.9 |
| | SE[b] | 2.94 | 1.64 | 2.38 | 1.58 | 1.77 | 1.95 | 1.09 |
| Lower | Mean | 8.6 | 7.7 | 8.2 | 8.1 | 8.3 | 8.0 | 8.3 |
| | SE | 0.99 | 0.72 | 0.80 | 0.99 | 1.20 | 0.65 | 0.61 |
| Middle | Mean | 10.2 | 8.6 | 10.0 | 10.4 | 8.9 | 9.9 | 9.8 |
| | SE | 2.24 | 1.11 | 1.02 | 2.48 | 1.54 | 1.23 | 1.39 |
| Upper | Mean | 9.7 | 9.8 | 10.0 | 10.2 | 10.1 | 10.4 | 9.5 |
| | SE | 1.32 | 0.94 | 1.25 | 1.18 | 1.79 | 0.94 | 0.76 |
| Overall | Mean | 9.34 | 8.40 | 9.20 | 9.18 | 8.66 | 9.17 | 8.93 |
| | SE | 0.94 | 0.55 | 0.67 | 0.92 | 0.80 | 0.59 | 0.53 |

a. For the purpose of this study, leaves were allotted accordingly: Bottom leaves 1–3; Lower leaves 4–11; Middle leaves 12–18; Upper leaves 19+.
b. SE for mean of means is composited from 1 2, 3 4, 5 6, 7 8, 9, SWP-25, and SWP-100.

**Table 13. Mean Grade Values and Chemical Analyses for the Cured Tobacco over all Cures for Different Treatments**

| | Treatments | | | | | | | | | | SWP | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | SE[a] | -25 | -100 |
| *Grade Value* | | | | | | | | | | | | |
| 1st Year | 39 | 37 | 40 | 42 | 39 | 48 | 40 | 41 | 41 | | 40 | 42 |
| 2nd Year | 29 | 35 | 21 | 32 | 32 | 26 | 29 | 30 | 30 | | 28 | 31 |
| 3rd Year | 30 | 21 | 29 | 32 | 26 | 23 | 22 | 27 | 29 | | 27 | 26 |
| Mean | 33 | 31 | 30 | 35 | 32 | 32 | 30 | 33 | 33 | | | |
| Mean of Means | 32 | | 32 | | 32 | | 31 | | | 32 | 32 | 33 |
| *Total Nitrogen* | | | | | | | | | | | | |
| 2nd Year | 1.5 | 1.7 | 2.1 | 2.4 | 1.7 | 1.8 | 1.7 | 1.6 | 2.1 | | 1.8 | 1.9 |
| 3rd Year | 1.9 | 1.9 | 2.1 | 2.1 | 2.1 | 2.1 | 2.0 | 2.0 | 2.2 | | 2.0 | 2.0 |
| Mean | 1.7 | 1.8 | 2.1 | 2.2 | 1.9 | 1.9 | 1.8 | 1.8 | 2.0 | | | |
| Mean of Means | 1.7 | | 2.2 | | 1.9 | | 1.8 | | | 1.9 | 1.9 | 1.9 |
| *Starch* | | | | | | | | | | | | |
| 2nd Year | 1.8 | 1.4 | 1.4 | 1.7 | 2.0 | 1.4 | 1.9 | 1.8 | 1.2 | | 1.8 | 1.6 |
| 3rd Year | 1.7 | 1.9 | 1.5 | 1.7 | 1.5 | 1.9 | 1.5 | 1.5 | 1.5 | | 1.6 | 1.8 |
| Mean | 1.7 | 1.6 | 1.4 | 1.7 | 1.7 | 1.6 | 1.7 | 1.6 | 1.3 | | | |
| Mean of Means | 1.7 | | 1.6 | | 1.7 | | 1.7 | | | 1.7 | 1.7 | 1.7 |
| *Reducing Sugars* | | | | | | | | | | | | |
| 2nd Year | 11.8 | 11.3 | 7.9 | 9.9 | 13.9 | 10.5 | 12.0 | 11.6 | 8.6 | | 11.4 | 10.8 |
| 3rd Year | 8.0 | 6.5 | 6.7 | 6.9 | 7.6 | 6.9 | 6.7 | 6.0 | 4.9 | | 7.3 | 6.6 |
| Mean | 9.9 | 8.9 | 7.3 | 8.4 | 10.7 | 8.7 | 9.3 | 8.8 | 6.7 | | | |
| Mean of Means | 9.4 | | 7.8 | | 9.7 | | 9.1 | | | 8.8 | 9.3 | 8.7 |
| *Total Alkaloids* | | | | | | | | | | | | |
| 2nd Year | 2.5 | 3.1 | 4.5 | 3.4 | 3.4 | 2.6 | 3.3 | 3.3 | 4.4 | | 3.4 | 3.1 |
| 3rd Year | 2.7 | 2.6 | 3.0 | 3.1 | 3.1 | 3.1 | 2.9 | 3.0 | 3.7 | | 2.9 | 2.9 |
| Mean | 2.6 | 2.8 | 3.7 | 3.2 | 3.2 | 2.8 | 3.1 | 3.1 | 4.0 | | | |
| Mean of Means | 2.7 | | 3.5 | | 3.0 | | 3.1 | | | 3.1 | 3.1 | 3.0 |
| *Total Nitrogen/Total Alkaloids* | | | | | | | | | | | | |
| 2nd Year | 0.6 | 0.5 | 0.5 | 0.7 | 0.5 | 0.7 | 0.5 | 0.5 | 0.5 | | 0.5 | 0.6 |
| 3rd Year | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | 0.6 | | 0.7 | 0.7 |
| Mean | 0.6 | 0.6 | 0.5 | 0.7 | 0.6 | 0.7 | 0.9 | 0.6 | 0.5 | | | |
| Mean of Means | 0.6 | | 0.6 | | 0.6 | | 0.6 | | | 0.6 | 0.6 | 0.6 |
| *Reducing Sugars/Total Alkaloids* | | | | | | | | | | | | |
| 2nd Year | 4.7 | 3.6 | 1.7 | 2.9 | 4.1 | 4.0 | 3.6 | 3.5 | 1.9 | | 3.3 | 3.5 |
| 3rd Year | 3.0 | 2.5 | 2.2 | 2.2 | 2.4 | 2.2 | 2.3 | 2.0 | 1.3 | | 2.5 | 2.2 |
| Mean | 3.8 | 3.1 | 1.9 | 2.6 | 3.3 | 3.0 | 3.0 | 2.8 | 1.6 | | | |
| Mean of Means | 3.5 | | 2.2 | | 3.1 | | 2.9 | | | 2.8 | 2.9 | 2.9 |

a. Between the nine treatments within a year.
b. Between the three years within a treatment or trigger soil water pressure.
c. Mean and SE for mean of means (first four).
d. Mean and/or SE for the variable.
e. Mean and SE for trigger soil water pressure (last two).

five effects, and a line for each trend derived from the regression equation (figures 4–7). Week 10.75 is used as the center of regression analysis of the curves for the non-destructive measurements and week 11.7 for the destructive measurements. The curves are terminated by week 16 because the behavior of the tobacco beyond that week was influenced by the extent of maturity and harvest. Only selected characteristics are presented in graphical form, but regression coefficients and an F-test of all characteristics are presented in tabular form (tables 14–19). Both the slope and the intercept for the curves are those at the centers of regression analysis. Under the F-test a higher number suggests a closer fit of the curve to the weekly means. Since each treatment was regressed

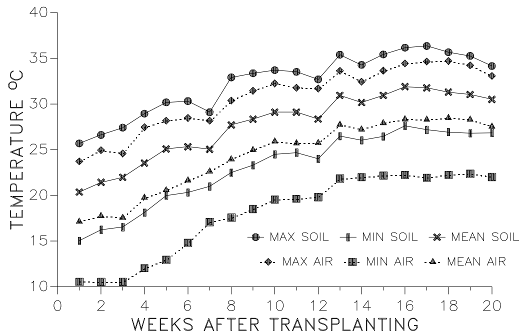


**Figure 1. Temperature of the soil and air over the tobacco season.**

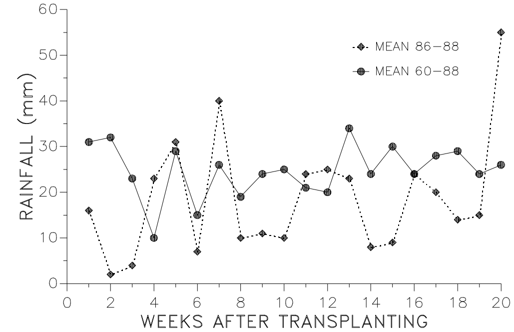


**Figure 2. Rainfall during the study as well as over the recent 29 years.**

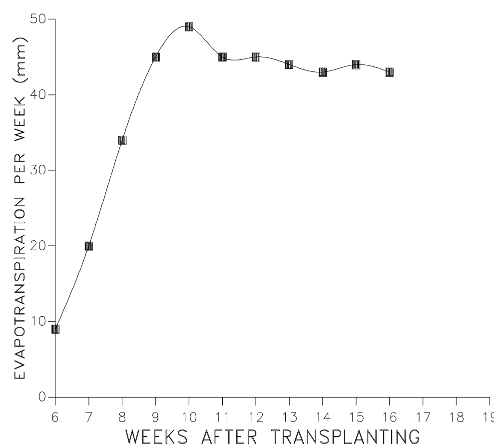


**Figure 3. Water use curve for tobacco grown with adequate available soil water.**

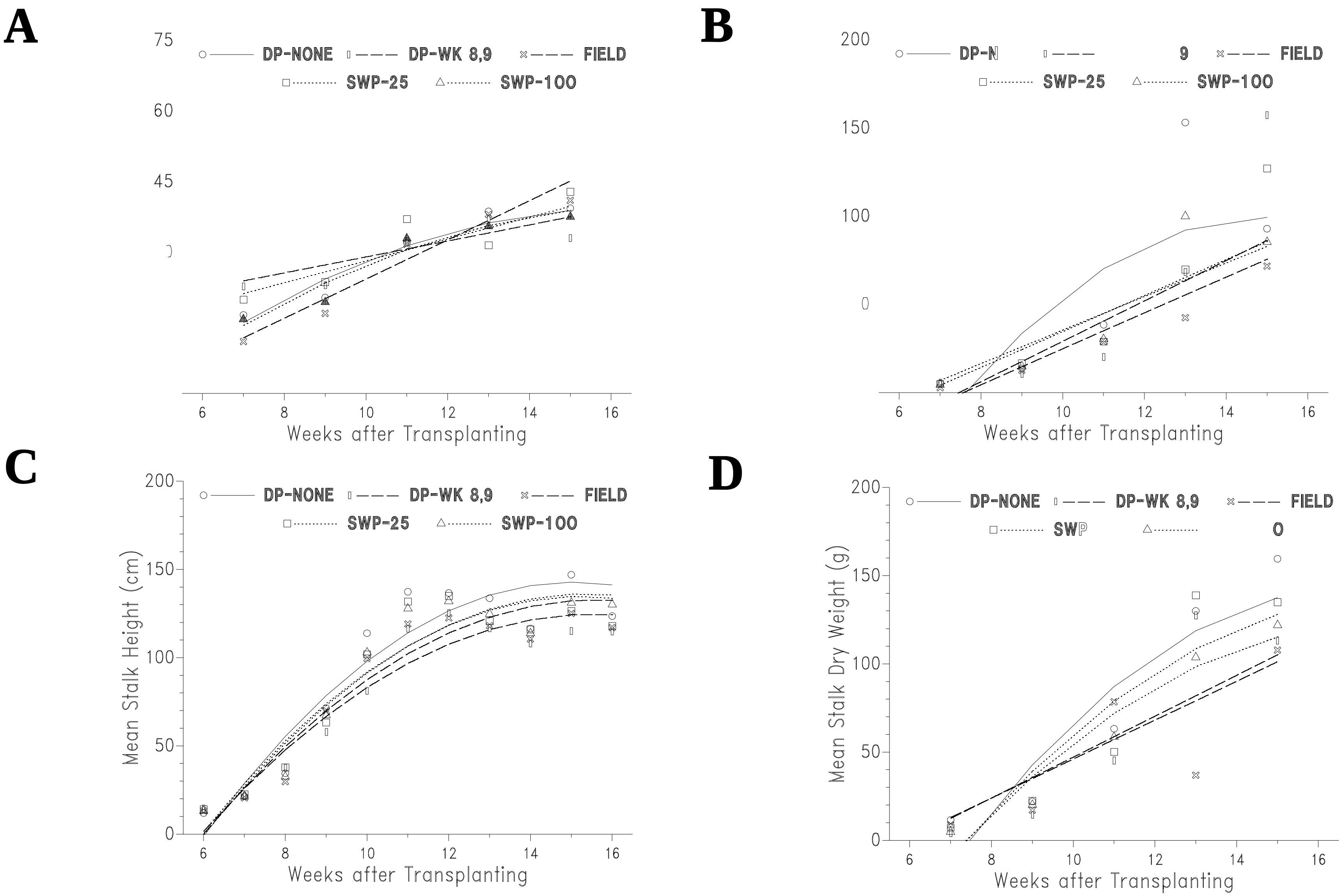


**Figure 4. Results of regression analysis relating measured growth of root depth, root dry weight, stalk height, and stalk dry weight to time of growing season. Corresponding coefficients of the equations are given in tables 14 and 15.**

A B C

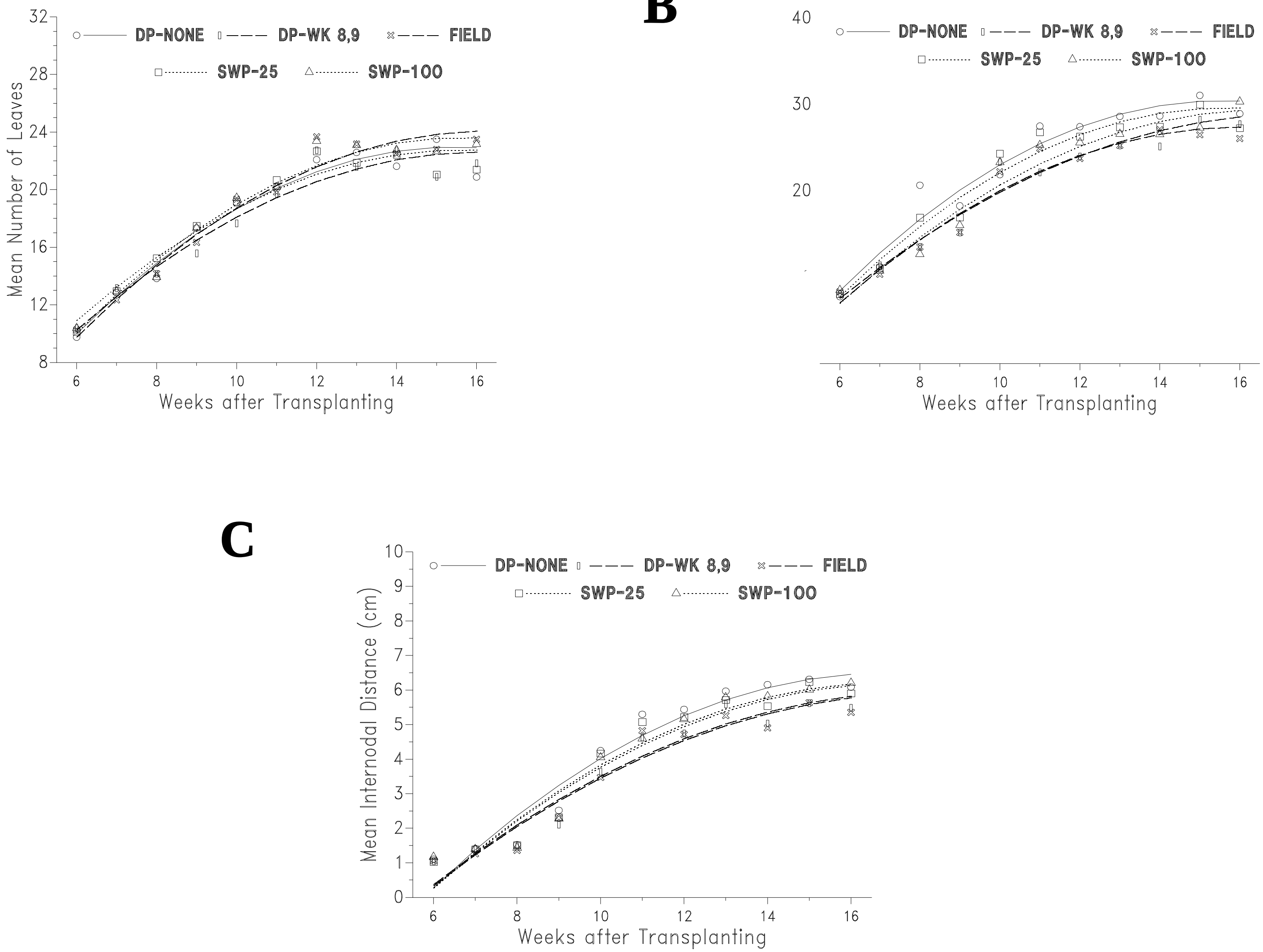


**Figure 5. Results of regression analysis relating measured number of leaves, growth of stalk diameter and internodal distance of time of growing season. Corresponding coefficients of the equations are given in table 16.**

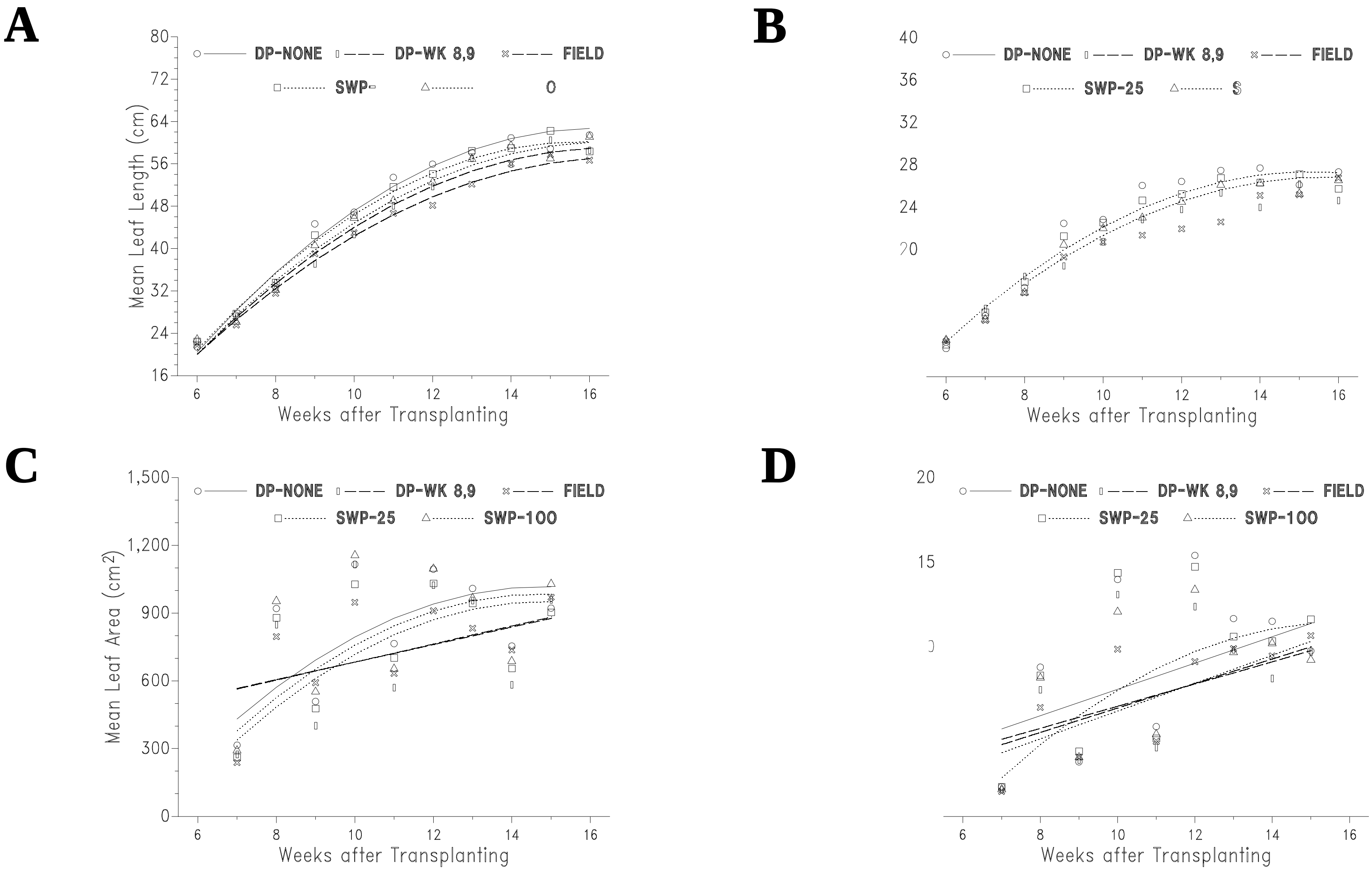


**Figure 6. Results of regression analysis relating measured growth of leaf length, leaf width, leaf area, and leaf dry weight to time of growing season. Corresponding coefficients of the equations are given in tables 17 and 18.**

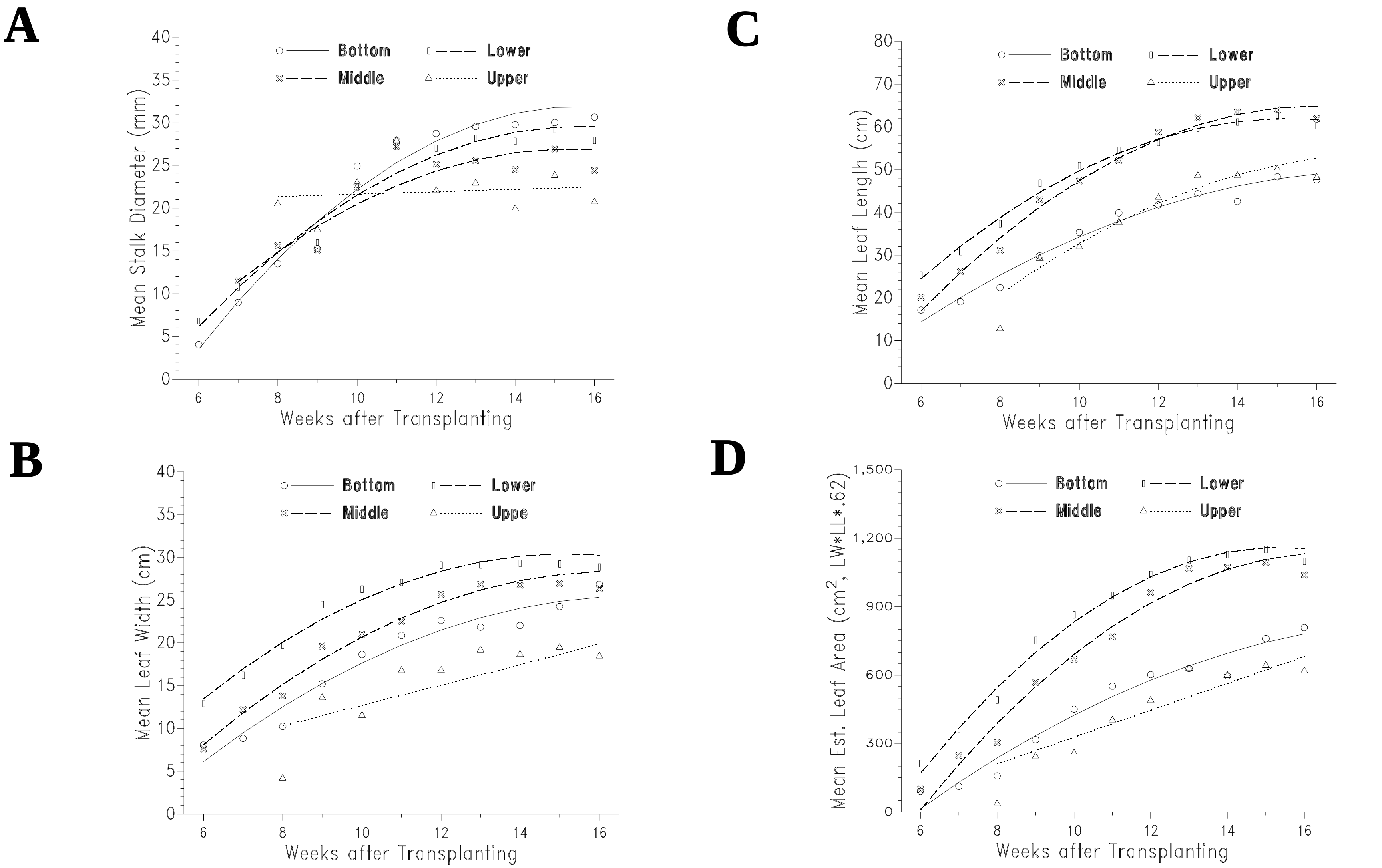


**Figure 7. Results of regression analysis relating measured growth of stalk diameter, leaf length, leaf width, and estimated leaf area by position on the stalk to time of growing season. Corresponding coefficients of the equations are given in table 19.**

**Table 14. Regression Coefficients and Selected Comparisons of Interest for Selected Treatments for Mean Root Depth, Dry Weight, Fresh Weight, and Dry Weight/Fresh Weight**

| | | Intercept | | Linear | | Quadratic | | |
|---|---|---|---|---|---|---|---|---|
| Treatment Regime | df | Beta | (SE) | Beta | (SE) | Beta | (Se) | F-test |
| *Mean Root Depth (cm)* | | | | | | | | |
| DP-None | 21 | 33.29 | (2.17)** | 2.602 | (.485)** | -0.274 | (.118)* | 14.85** |
| DP-Wk | 17 | 31.97 | (2.03)** | 1.701 | (.548)** | - | | 9.67** |
| Field | 9 | 31.46 | (1.89)** | 4.162 | (.543)** | - | | 58.88** |
| SWP-100 | 29 | 32.62 | (2.11)** | 2.718 | (.457)** | -0.242 | (.116)* | 17.90** |
| SWP-25 | 31 | 32.16 | (1.47)** | 2.321 | (.378)** | - | | 37.80** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 0.4 ns | | 1.2 ns | | 2.3* | | |
| DP-None vs Field | | 0.6 ns | | 2.2* | | 2.3* | | |
| DP-Wk 8,9 vs Field | | 0.2 ns | | 3.2** | | - | | |
| SWP-100 vs SWP-25 | | 0.2 ns | | 0.7 ns | | 2.1* | | |
| *Mean Root Dry Weight (g)* | | | | | | | | |
| DP-None | 21 | 79.53 | (14.61)** | 12.04 | (3.27)* | -1.84 | (0.80)* | 6.82** |
| DP-Wk 8,9 | 17 | 48.80 | (8.36)** | 11.44 | (2.26)** | - | | 25.59** |
| Field | 8 | 42.34 | (4.73)** | 10.16 | (1.30)** | - | | 61.10** |
| SWP-100 | 29 | 51.86 | (8.05)** | 9.51 | (2.14)** | - | | 19.88** |
| SWP-25 | 31 | 52.21 | (5.98)** | 10.17 | (1.54)** | - | | 43.67** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 1.8 ns | | 0.1 ns | | 2.3* | | |
| DP-None vs Field | | 2.1* | | 0.5 ns | | 2.3* | | |
| DP-Wk 8,9 vs Field | | 0.6 ns | | 0.5 ns | | - | | |
| SWP-100 vs SWP-25 | | 0.1 ns | | 0.3 ns | | - | | |
| *Mean Root Fresh Weight (g)* | | | | | | | | |
| DP-None | 21 | 234.49 | (32.23)** | 33.07 | (7.21)** | -4.91 | (1.76)* | 10.56** |
| DP-Wk 8,9 | 17 | 153.93 | (21.93)** | 29.35 | (5.94)** | - | | 24.45** |
| Field | 8 | 128.48 | (13.88)** | 25.78 | (3.82)** | - | | 45.62** |
| SWP-100 | 28 | 207.12 | (25.43)** | 32.18 | (5.39)** | -3.40 | (1.38)* | 17.91** |
| SWP-25 | 30 | 207.07 | (23.44)** | 33.83 | (4.70)** | -3.01 | (1.28)* | 26.65** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 2.03* | | 0.4 ns | | 2.0* | | |
| DP-None vs Field | | 2.64* | | 0.8 ns | | 2.0* | | |
| DP-Wk 8,9 vs Field | | 0.91 ns | | 0.5 ns | | - | | |
| SWP-100 vs SWP-25 | | 0.01 ns | | 0.2 ns | | 0.2 ns | | |
| *Mean Root Dry Wt/Fresh Wt (%)* | | | | | | | | |
| DP-None | 22 | 29.65 | (1.69)** | 0.819 | (.427) ns | - | | 3.69 ns |
| DP-Wk 8,9 | 17 | 28.04 | (1.76)** | 1.432 | (.475)** | - | | 9.11** |
| Field | 8 | 28.37 | (1.07)** | 1.978 | (.294)** | - | | 45.32** |
| SWP-100 | 29 | 27.83 | (1.33)** | 1.306 | (.352)** | - | | 13.79** |
| SWP-25 | 31 | 28.66 | (1.07)** | 0.995 | (.275)** | - | | 13.15** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 0.7 ns | | 1.0 ns | | - | | |
| DP-None vs Field | | 0.6 ns | | 2.1* | | - | | |
| DP-Wk 8,9 vs Field | | 0.1 ns | | 0.9 ns | | - | | |
| SWP-100 vs SWP-25 | | 0.5 ns | | 0.7 ns | | - | | |

separately, regression coefficients are compared using the respective coefficient and its standard error (SE). Included in tables 14–18, for each effect are the intercept, slope, and curvature coefficients for the equation describing the curves represented in the figures 4–6. For stalk position, effects are shown in figure 7 and table 19 for each stalk position across all the nine treatments of table 2.

The five effects examined in this regression analysis were as follows. The first was related to growth with no drought period (DP-None); the second was related to growth with a drought period during weeks eight and nine after transplanting (DP-Wk 8,9), which was

**Table 15. Regression Coefficients and Selected Comparisons of Interest for Selected Treatments for Mean Stalk Height, Dry Weight, Fresh Weight, and Dry Weight/Fresh Weight**

| | | Intercept | | Linear | | Quadratic | | |
|---|---|---|---|---|---|---|---|---|
| Treatment Regime | df | Beta | (SE) | Beta | (SE) | Beta | (Se) | F-test |
| *Mean Root Height (cm)* | | | | | | | | |
| DP-None | 68 | 123.1 | (4.41)** | 11.778 | (.869)** | -1.76 | (.213)** | 96.64** |
| DP-Wk 8,9 | 64 | 105.0 | (3.39)** | 10.358 | (.667)** | -1.36 | (.162)** | 123.85** |
| Field | 61 | 111.0 | (3.82)** | 11.220 | (.768)** | -1.43 | (.191)** | 111.58** |
| SWP-100 | 69 | 115.5 | (3.41)** | 11.407 | (.671)** | -1.56 | (.164)** | 147.68** |
| SWP-25 | 70 | 115.5 | (3.69)** | 11.025 | (.721)** | -1.57 | (.177)** | 119.87** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 3.2** | | 1.3 ns | | 1.5 ns | | |
| DP-None vs Field | | 2.1* | | 0.5 ns | | 1.2 ns | | |
| DP-Wk 8,9 vs Field | | 1.2 ns | | 0.8 ns | | 0.3 ns | | |
| SWP-100 vs SWP-25 | | 0.0 ns | | 0.4 ns | | 0.1 ns | | |
| *Mean Stalk Dry Weight (g)* | | | | | | | | |
| DP-None | 21 | 99.6 | (10.92)** | 16.78 | (2.44)** | -1.59 | (.594)* | 24.90** |
| DP-Wk 8,9 | 17 | 67.2 | (8.92)** | 11.61 | (2.42)** | - | | 23.13** |
| Field | 9 | 65.1 | (9.88)** | 11.03 | (2.85)** | - | | 15.03** |
| SWP-100 | 29 | 82.6 | (8.73)** | 13.90 | (1.90)** | -1.19 | (.481)* | 27.28** |
| SWP-25 | 30 | 90.7 | (7.14)** | 15.59 | (1.43)** | -1.26 | (.387)** | 61.82** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 2.3* | | 1.5 ns | | 2.7** | | |
| DP-None vs Field | | 2.3* | | 1.6 ns | | 2.7** | | |
| DP-Wk 8,9 vs Field | | 0.2 ns | | 0.2 ns | | - | | |
| SWP-100 vs SWP-25 | | 0.7 ns | | 0.7 ns | | 0.1 ns | | |
| *Mean Stalk Fresh Weight (g)* | | | | | | | | |
| DP-None | 21 | 612.7 | (61.06)** | 86.31 | (13.65)** | -11.26 | (3.32)** | 20.06** |
| DP-Wk 8,9 | 16 | 442.0 | (48.25)** | 65.40 | (11.02)** | 6.27 | (2.69)* | 17.76** |
| Field | 9 | 335.5 | (35.98)** | 49.92 | (10.37)** | - | | 23.20** |
| SWP-100 | 29 | 511.6 | (51.81)** | 70.88 | (11.26)** | -8.84 | (2.86)** | 19.88** |
| SWP-25 | 30 | 506.3 | (34.86)** | 74.26 | (6.98)** | -6.82 | (1.89)** | 57.86** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 2.2* | | 1.2 ns | | 1.2 ns | | |
| DP-None vs Field | | 3.6** | | 2.0 ns | | 3.4** | | |
| DP-Wk 8,9 vs Field | | 1.7 ns | | 1.0 ns | | 2.3* | | |
| SWP-100 vs SWP-25 | | 0.1 ns | | 0.3 ns | | 0.6 ns | | |
| *Mean Stalk Dry Wt/Fresh Wt (%)* | | | | | | | | |
| DP-None | 22 | 16.22 | (0.92)** | 0.563 | (.232)* | - | | 5.90* |
| DP-Wk 8,9 | 17 | 15.93 | (1.02)** | 1.014 | (.339)** | - | | 9.00** |
| Field | 9 | 17.99 | (1.62)** | 0.547 | (.464) ns | - | | 1.39 ns |
| SWP-100 | 30 | 17.18 | (1.26)** | 0.327 | (.339) ns | - | | 0.94 ns |
| SWP-25 | 31 | 15.90 | (0.94)** | 0.861 | (.241)** | - | | 12.80** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 0.2 ns | | 1.1 ns | | - | | |
| DP-None vs Field | | 1.1 ns | | 0.3 ns | | - | | |
| DP-Wk 8,9 vs Field | | 1.2 ns | | 0.8 ns | | - | | |
| SWP-100 vs SWP-25 | | 0.8 ns | | 1.3 ns | | - | | |

shown to be the most detrimental stage of growth for drought to occur; the third was related to the field condition (Field) where the tobacco received water as under local field conditions; the fourth was related to the effect of the trigger soil water pressure at -100 kPa (SWP-100) over all treatments; and the fifth was related to the effect of the trigger soil water pressure at -25 kPa (SWP-25) over all treatments. The first three effects are compared among each other and the last two between each other. The remaining effects are not presented since they occurred between DP-None and DP Wk 8-9.

**Table 16. Regression Coefficients and Selected Comparisons of Interest for Selected Treatments for Mean Number of Leaves per Plant, Stalk Diameter, and Internodal Distance**

| | | Intercept | | Linear | | Quadratic | | |
|---|---|---|---|---|---|---|---|---|
| Treatment Regime | df | Beta | (SE) | Beta | (SE) | Beta | (Se) | F-test |
| *Mean Number of Leaves per Plant* | | | | | | | | |
| DP-None | 70 | 19.76 | (.337)** | 1.367 | (.0889)** | -0.146 | (.0172)** | 123.70** |
| DP-Wk | 66 | 19.17 | (.401)** | 1.295 | (.1068)** | -0.121 | (.0206)** | 78.65** |
| Field | 64 | 19.96 | (.367)** | 1.497 | (.0968)** | -0.136 | (.0195)** | 127.55** |
| SWP-100 | 69 | 20.16 | (.312)** | 1.424 | (.0823)** | -0.146 | (.0159)** | 158.33** |
| SWP-25 | 72 | 19.74 | (.323)** | 1.249 | (.0850)** | -0.127 | (.0164)** | 115.24** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 1.1 ns | | 0.5 ns | | 0.9 ns | | |
| DP-None vs Field | | 0.4 ns | | 1.0 ns | | 0.4 ns | | |
| DP-Wk 8,9 vs Field | | 1.4 ns | | 1.4 ns | | 0.5 ns | | |
| SWP-100 vs SWP-25 | | 0.9 ns | | 1.5 ns | | 0.8 ns | | |
| *Mean Stalk Diameter (mm)* | | | | | | | | |
| DP-None | 70 | 24.87 | (1.150)** | 2.317 | (.301)** | -0.242 | (.0582)** | 31.16** |
| DP-Wk 8,9 | 65 | 21.62 | (0.799)** | 2.181 | (.212)** | -0.163 | (.0407)** | 61.50** |
| Field | 62 | 21.78 | (0.769)** | 2.135 | (.202)** | -0.202 | (.0404)** | 59.05** |
| SWP-100 | 69 | 22.59 | (0.745)** | 2.330 | (.197)** | -0.200 | (.0379)** | 79.20** |
| SWP-25 | 72 | 24.03 | (0.870)** | 2.296 | (.229)** | -0.235 | (.0442)** | 53.51** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 2.3* | | 0.4 ns | | 1.1 ns | | |
| DP-None vs Field | | 2.2* | | 0.5 ns | | 0.6 ns | | |
| DP-Wk 8,9 vs Field | | 0.1 ns | | 0.2 ns | | 0.7 ns | | |
| SWP-100 vs SWP-25 | | 1.3 ns | | 0.1 ns | | 0.6 ns | | |
| *Mean Internodal Distance (cm)* | | | | | | | | |
| DP-None | 70 | 4.532 | (.164)** | 0.645 | (.0433)** | -0.053 | (.0084)** | 127.95** |
| DP-Wk 8,9 | 63 | 3.961 | (.149)** | 0.565 | (.0387)** | -0.040 | (.0075)** | 127.00** |
| Field | 60 | 3.912 | (.144)** | 0.563 | (.0368)** | -0.039 | (.0074)** | 136.96** |
| BAR-100 | 69 | 4.265 | (.140)** | 0.610 | (.0369)** | -0.048 | (.0071)** | 159.90** |
| BAR-25 | 72 | 4.333 | (.146)** | 0.614 | (.0384)** | -0.050 | (.0074)** | 150.27** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 2.6* | | 1.4 ns | | 1.2 ns | | |
| DP-None vs Field | | 2.8** | | 1.4 ns | | 1.2 ns | | |
| DP-Wk 8,9 vs Field | | 0.2 ns | | 0.1 ns | | 0.1 ns | | |
| BAR-100 vs SWP-25 | | 0.3 ns | | 0.1 ns | | 0.2 ns | | |

Also under discussion, the second objective has been met by individually examining each of the characteristics and the effect of the nine treatments upon those characteristics. Then the mean of the means for treatment pairs 1 and 2, 3 and 4, 5 and 6, 7 and 8, the mean of treatment 9, and the mean of means for treatments under the different trigger soil water pressures have been ranked (1–5 and 1–2), with the more desirable value having the lowest rank. Rather than test each plant characteristic for its importance, requiring a physiological and economical analysis, all 26 plant characteristics are included as having equal importance. It is from this total of ranks that the overall effects of the different treatments has been determined (table 20). Ranking of means includes characteristics of harvested leaf as well as of growth, which should give a more complete description of the effect of drought than ranking the slopes or intercepts of the regression curves that consider only characteristics of growth. A similar consideration applies to growth over the entire season instead of only characteristic measurements taken at the end of the season. Further, under discussion, are some of the implications of the results.

**Table 17. Regression Coefficients and Selected Comparisons of Interest for Selected Treatments for Mean Leaf Length, Width, and Area per Leaf**

| | | Intercept | | Linear | | Quadratic | | |
|---|---|---|---|---|---|---|---|---|
| Treatment Regime | df | Beta | (SE) | Beta | (SE) | Beta | (Se) | F-test |
| *Mean Leaf Length (cm)* | | | | | | | | |
| DP-None | 70 | 50.68 | (0.998)** | 4.43 | (.263)** | -0.408 | (.0509)** | 156.45** |
| DP-Wk 8,9 | 65 | 47.38 | (0.816)** | 4.07 | (.217)** | -0.354 | (.0416)** | 193.79** |
| Field | 62 | 45.55 | (0.744)** | 3.85 | (.196)** | -0.316 | (.0391)** | 214.77** |
| SWP-100 | 69 | 48.30 | (0.834)** | 4.18 | (.221)** | -0.367 | (.0424)** | 200.93** |
| SWP-25 | 72 | 49.89 | (1.030)** | 4.13 | (.272)** | -0.411 | (.0524)** | 124.90** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 2.6* | | 1.1 ns | | 0.8 ns | | |
| DP-None vs Field | | 4.1** | | 1.8 ns | | 1.4 ns | | |
| DP-Wk 8,9 vs Field | | 1.7 ns | | 0.8 ns | | 0.7 ns | | |
| SWP-100 vs SWP-25 | | 1.2 ns | | 0.1 ns | | 0.7 ns | | |
| *Mean Leaf Width (cm)* | | | | | | | | |
| DP-None | 70 | 24.31 | (.602)** | 1.872 | (.1586)** | -0.205 | (.0307)** | 72.29** |
| DP-Wk 8,9 | 65 | 22.03 | (.473)** | 1.480 | (.1255)** | -0.141 | (.0241)** | 74.11** |
| Field | 62 | 20.97 | (.431)** | 1.435 | (.1132)** | -0.118 | (.0227)** | 88.59** |
| SWP-100 | 69 | 22.75 | (.517)** | 1.680 | (.1365)** | -0.170 | (.0263)** | 80.31** |
| SWP-25 | 72 | 23.56 | (.568)** | 1.692 | (.1496)** | -0.186 | (.0289)** | 66.47** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 3.0** | | 1.9 ns | | 1.6 ns | | |
| DP-None vs Field | | 4.5** | | 2.2* | | 2.3* | | |
| DP-Wk 8,9 vs Field | | 1.7 ns | | 0.3 ns | | 0.7 ns | | |
| SWP-100 vs SWP-25 | | 1.1 ns | | 0.1 ns | | 0.4 ns | | |
| *Mean Leaf Area ($cm^2$)* | | | | | | | | |
| DP-None | 30 | 923.4 | (63.7)** | 59.86 | (15.6)* | -9.547 | (3.83)* | 7.53** |
| DP-Wk 8,9 | 26 | 752.8 | (50.8)** | 39.84 | (15.4)* | - | | 6.71* |
| Field | 19 | 750.6 | (47.8)** | 38.72 | (16.3)* | - | | 5.64* |
| SWP-100 | 37 | 854.5 | (56.0)** | 62.48 | (13.0)** | -9.969 | (3.32)** | 12.28** |
| SWP-25 | 40 | 894.0 | (46.7)** | 61.16 | (10.5)** | -10.201 | (2.79)** | 17.98** |
| *Comparisons of Interest* (\|t\|) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 2.1* | | 0.9 ns | | 2.5* | | |
| DP-None vs Field | | 2.1* | | 0.9 ns | | 2.5* | | |
| DP-Wk 8,9 vs Field | | 0.3 ns | | 0.1 ns | | - | | |
| SWP-100 vs SWP-25 | | 0.5 ns | | 0.1 ns | | 0.1 ns | | |
| *Mean Estimated Leaf Area ($cm^2$,LW*LL*0.62)* | | | | | | | | |
| DP-None | 70 | 834.6 | (37.5)** | 106.76 | (9.87)** | -10.161 | (1.91)** | 63.59** |
| DP-Wk 8,9 | 65 | 700.9 | (25.6)** | 86.68 | (6.78)** | -7.347 | (1.31)** | 90.65** |
| Field | 62 | 636.7 | (23.3)** | 79.96 | (6.12)** | -5.611 | (1.23)** | 99.33** |
| SWP-100 | 69 | 745.4 | (29.3)** | 96.10 | (7.75)** | -8.328 | (1.49)** | 86.56** |
| SWP-25 | 72 | 797.2 | (33.3)** | 96.13 | (8.76)** | -9.920 | (1.69)** | 64.02** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 2.9** | | 0.7 ns | | 1.2 ns | | |
| DP-None vs Field | | 4.4** | | 2.3* | | 2.0* | | |
| DP-Wk 8,9 vs Field | | 1.9 ns | | 0.7 ns | | 1.0 ns | | |
| SWP-100 vs SWP-25 | | 1.2 ns | | 0.1 ns | | 0.7 ns | | |

# Results

## Available Soil Water

In order to consider the effect of a period of drought on the amount of soil water that remained, the available soil water content was calculated (table 7). At the end of the period of drought during weeks six and seven (treatments 1 and 2), the top 150 mm were totally depleted of plant available soil water and there were reductions in all other depths, especially the 150-300 mm zone. At the end of the period of drought during weeks eight and nine (treatments 3 and 4), once again the top 150 mm of soil were almost totally depleted

**Table 18. Regression Coefficients and Selected Comparisons of Interest for Selected Treatments for Mean Leaf Dry Weight, Fresh Weight, Dry Weight/Fresh Weight and Leaf Fresh Weight per Unit Area**

| | | Intercept | | Linear | | Quadratic | | |
|---|---|---|---|---|---|---|---|---|
| Treatment Regime | df | Beta | (SE) | Beta | (SE) | Beta | (Se) | F-test |
| *Mean Leaf Dry Weight (g)* | | | | | | | | |
| DP-None | 30 | 8.816 | (.769)** | 0.777 | (.214)** | - | | 13.23** |
| DP-Wk 8,9 | 26 | 7.642 | (.631)** | 0.654 | (.191)** | - | | 11.72** |
| Field | 18 | 7.655 | (.641)** | 0.723 | (.214)** | - | | 11.43** |
| SWP-100 | 37 | 7.645 | (.583)** | 0.822 | (.167)** | - | | 24.48** |
| SWP-25 | 39 | 9.479 | (.692)** | 0.973 | (.155)** | -0.117 | (.041)** | 19.71** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 1.2 ns | | 0.4 ns | | - | | |
| DP-None vs Field | | 1.1 ns | | 0.2 ns | | - | | |
| DP-Wk 8,9 vs Field | | 0.1 ns | | 0.2 ns | | - | | |
| SWP-100 vs SWP-25 | | 2.0* | | 0.7 ns | | 2.9** | | |
| *Mean Leaf Fresh Weight (g)* | | | | | | | | |
| DP-None | 30 | 56.73 | (4.95)** | 4.670 | (1.220)** | -0.610 | (.297)* | 7.424** |
| DP-Wk 8,9 | 26 | 44.48 | (3.22)** | 3.042 | (0.975)** | - | | 9.74** |
| Field | 19 | 41.43 | (2.89)** | 2.818 | (0.985)** | - | | 8.20** |
| SWP-100 | 37 | 51.16 | (3.89)** | 4.604 | (0.899)** | -0.589 | (.231)* | 13.25** |
| SWP-25 | 40 | 53.95 | (3.31)** | 4.496 | (0.741)** | -0.630 | (.198)** | 18.66** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 2.0* | | 1.0 ns | | 2.1* | | |
| DP-None vs Field | | 2.0* | | 1.2 ns | | 2.1* | | |
| DP-Wk 8,9 vs Field | | 2.5* | | 0.2 ns | | - | | |
| SWP-100 vs SWP-25 | | 0.7 ns | | 0.1 ns | | 0.1 ns | | |
| *Mean Leaf Dry Wt/Fresh Wt (%)* | | | | | | | | |
| DP-None | 21 | 15.56 | (.706)** | 0.826 | (.177)** | - | | 21.94** |
| DP-Wk 8,9 | 17 | 15.37 | (.673)** | 0.844 | (.183)** | - | | 21.47** |
| Field | 8 | 15.87 | (.812)** | 0.731 | (.224)* | - | | 10.69* |
| SWP-100 | 29 | 15.91 | (.487)** | 0.824 | (.130)** | - | | 40.32** |
| SWP-25 | 30 | 15.81 | (.498)** | 0.729 | (.128)** | - | | 32.91** |
| *Comparisons of Interest* (\|t\|) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 0.2 ns | | 0.1 ns | | - | | |
| DP-None vs Field | | 0.3 ns | | 0.4 ns | | - | | |
| DP-Wk 8,9 vs Field | | 0.5 ns | | 0.4 ns | | - | | |
| SWP-100 vs SWP-25 | | 0.1 ns | | 0.5 ns | | - | | |
| *Mean Leaf Fresh Wt/Leaf Area (mg/cm²)* | | | | | | | | |
| DP-None | 31 | 59.12 | (1.36)** | 1.089 | (.381)** | - | | 8.17** |
| DP-Wk 8,9 | 26 | 57.46 | (1.28)** | 1.164 | (.387)** | - | | 9.07** |
| Field | 19 | 53.90 | (1.19)** | 1.119 | (.404)* | - | | 7.68* |
| SWP-100 | 38 | 57.47 | (1.01)** | 1.257 | (.290)** | - | | 18.83** |
| SWP-25 | 41 | 58.33 | (1.00)** | 1.125 | (.282)** | - | | 15.92** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| DP-None vs DP-Wk 8,9 | | 0.9 ns | | 0.1 ns | | - | | |
| DP-None vs Field | | 2.8** | | 0.1 ns | | - | | |
| DP-Wk 8,9 vs Field | | 2.0* | | 0.1 ns | | - | | |
| SWP-100 vs SWP-25 | | 0.6 ns | | 0.3 ns | | - | | |

of available soil water and there was a more even depletion of soil water throughout the rest of the profile than in treatments 1 and 2. This suggests a higher $E_t$, increased root activity, or both. The same applied at the end of weeks 10 and 11 (treatments 5 and 6). After each period of drought, the available soil water was 10–40 mm less than the minimum available during irrigation periods, as controlled by SWP-25 or SWP-100. The frequency of irrigation incidents was up to 160% greater for SWP-25, than for SWP-100.

**Table 19. Regression Coefficients and Selected Comparisons of Interest for Selected Treatments for Mean Stalk Diameter, Leaf Length, Leaf Width, and Leaf Area per Plant by Position**

| | | Intercept | | Linear | | Quadratic | | |
|---|---|---|---|---|---|---|---|---|
| Treatment Regime | df | Beta | (SE) | Beta | (SE) | Beta | (Se) | F-test |
| *Mean Stalk Diameter (mm)* | | | | | | | | |
| Bottom | 47 | 24.60 | (0.888)** | 2.988 | (.242)** | -0.306 | (.0477)** | 82.95** |
| Lower | 43 | 23.59 | (0.986)** | 2.463 | (.250)** | -0.251 | (.0503)** | 53.37** |
| Middle | 41 | 22.20 | (1.400)** | 2.037 | (.423)** | -0.217 | (.0799)** | 13.01** |
| Upper | 34 | 21.79 | (2.150)** | 0.141 | (.470) | - | | 0.09 |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| Bottom vs Lower | | 0.7 ns | | 1.5 ns | | 0.8 ns | | |
| Lower vs Middle | | 0.8 ns | | 0.9 ns | | 0.4 ns | | |
| Middle vs Upper | | 0.2 ns | | 3.0** | | 1.9 ns | | |
| *Mean Leaf Length (cm)* | | | | | | | | |
| Bottom | 54 | 37.39 | (0.843)** | 3.57 | (.210)** | -0.289 | (.548)** | 147.84** |
| Lower | 68 | 53.03 | (0.803)** | 3.94 | (.209)** | -0.431 | (.0432)** | 182.92** |
| Middle | 70 | 51.62 | (1.150)** | 5.03 | (.333)** | -0.474 | (.0619)** | 129.74** |
| Upper | 56 | 36.71 | (1.240)** | 4.81 | (.663)** | -0.334 | (.0945)** | 51.75** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| Bottom vs Lower | | 13.5** | | 1.2 ns | | 2.1* | | |
| Lower vs Middle | | 1.0 ns | | 2.8 ** | | 0.6 ns | | |
| Middle vs Upper | | 8.9** | | 0.3 ns | | 1.3 ns | | |
| *Mean Leaf Width (cm)* | | | | | | | | |
| Bottom | 54 | 19.31 | (.647)** | 1.998 | (.1609)** | -.168 | (.0421)** | 78.13** |
| Lower | 68 | 26.57 | (.627)** | 1.776 | (.1629)** | -.202 | (.0337)** | 60.49** |
| Middle | 70 | 22.45 | (.637)** | 2.112 | (.1845)** | -.187 | (.0344)** | 76.57** |
| Upper | 57 | 14.78 | (.679)** | 1.044 | (.1551)** | - | | 45.35** |
| *Comparisons of Interest* (\|t\|) | | | | | | | | |
| Bottom vs Lower | | 8.1** | | 1.0 ns | | 0.6 ns | | |
| Lower vs Middle | | 4.6** | | 1.4 ns | | 0.3 ns | | |
| Middle vs Upper | | 8.3** | | 4.4** | | 3.8** | | |
| *Mean Estimated Leaf Area (cm²,LW*LL*0.62)* | | | | | | | | |
| Bottom | 54 | 490.7 | (24.2)** | 78.57 | (6.01)** | -4.910 | (1.57)** | 89.11** |
| Lower | 68 | 920.4 | (32.9)** | 104.30 | (8.54)** | -11.220 | (1.77)** | 76.73** |
| Middle | 70 | 787.3 | (37.5)** | 117.25 | (10.86)** | -9.707 | (2.03)** | 70.33** |
| Upper | 57 | 374.4 | (32.7)** | 59.02 | (7.47)** | - | | 62.44** |
| *Comparisons of Interest* (*t*) | | | | | | | | |
| Bottom vs Lower | | 10.3** | | 2.4* | | 2.6** | | |
| Lower vs Middle | | 2.7** | | 0.9 ns | | 0.6 ns | | |
| Middle vs Upper | | 8.2** | | 4.3** | | 3.4** | | |

## Climatical Conditions

The mean daily air temperature rose during weeks four to 11, from 17°C–25°C (figure 1), while the maximum air temperature rose from 27°C–32°C and the minimum or night-time temperature rose from 10°C–18°C. As a result of this air temperature change, the soil temperature (@ 100 mm) began to rise. It was noted that because of the low heat storage capacity of soil ($2.0 \times 10^6$ J/m³ °K for dry soil), drier soil warmed more quickly than soil at field capacity or even waterlogged soil. The mean daily soil temperature rose from 23°C–28°C and the minimum daily soil temperature rose from 16°C–24°C during this same period. It was observed that a swing in plant growth took place approximately two weeks following a swing in climate.

**Table 20. Rank of Treatment Means for Measured Characteristics**

| Characteristics | More Desirable Characteristic | Treatments 1, 2 | 3, 4 | 5, 6 | 7, 8 | 9 | 1, 3, 5, 7 (SWP-25) | 2, 4, 6, 8 (SWP-100) |
|---|---|---|---|---|---|---|---|---|
| Leaf length | Longer | 2[a] | 3 | 4 | 1 | 5 | 2 | 1 |
| Leaf width | Wider | 3 | 4 | 2 | 1 | 5 | 2 | 1 |
| Leaf area | Larger | 2 | 4 | 3 | 1 | 5 | 1 | 2 |
| Leaf dry weight | Heavier | 2.5 | 4 | 2.5 | 1 | 5 | 1 | 2 |
| Leaf dry weight/fresh weight | Larger | 2 | 5 | 4 | 3 | 1 | 1 | 2 |
| Leaf density (bottom) | Larger | 2.5 | 2.5 | 2.5 | 2.5 | 5 | 1 | 2 |
| Leaf density (lower) | Larger | 3 | 4 | 2 | 1 | 5 | 2 | 1 |
| Leaf density (middle) | Larger | 2.5 | 4 | 1 | 2.5 | 5 | 2 | 1 |
| Leaf density (upper) | Larger | 1.5 | 3.5 | 1.5 | 3.5 | 5 | 1 | 2 |
| Crop dry weight | Larger | 2 | 4 | 3 | 1 | 5 | 2 | 1 |
| Leaf cured grade value | Larger | 3 | 3 | 3 | 5 | 1 | 2 | 1 |
| Leaf chemical analysis TN[b] | Lower | 1 | 5 | 3 | 2 | 4 | 1.5 | 1.5 |
| Leaf chemical analysis Starch | Lower | 4 | 2 | 4 | 4 | 1 | 1.5 | 1.5 |
| Leaf chemical analysis RS[b] | Larger | 2 | 4 | 1 | 3 | 5 | 1 | 2 |
| Leaf chemical analysis TA[b] | Larger | 5 | 2 | 4 | 3 | 1 | 1 | 2 |
| Leaf chemical analysis TN/TA[b] | Smaller | 3 | 3 | 3 | 3 | 3 | 1.5 | 1.5 |
| Leaf chemical analysis RS/TA[b] | Larger | 1 | 4 | 2 | 3 | 5 | 1.5 | 1.5 |
| Stalk height | Higher | 2 | 5 | 4 | 1 | 3 | 2 | 1 |
| Stalk diameter | Wider | 3 | 3 | 3 | 1 | 5 | 1 | 2 |
| Stalk dry weight | Heavier | 2 | 3 | 5 | 1 | 4 | 1 | 2 |
| Stalk dry weight/fresh weight | Larger | 5 | 2 | 4 | 3 | 1 | 1 | 2 |
| Internodal distance | Longer | 2 | 4 | 3 | 1 | 5 | 2 | 1 |
| Root depth | Deeper | 1 | 4 | 3 | 2 | 5 | 1 | 2 |
| Root dry weight | Heavier | 1 | 3 | 4 | 2 | 5 | 1 | 2 |
| Root dry/fresh wt | Larger | 4 | 2 | 5 | 3 | 1 | 2 | 1 |
| Number of leaves | More | 5 | 4 | 3 | 2 | 1 | 2 | 1 |
| Mean of all ranks[c] | Smaller | 2.58 | 3.50 | 3.06 | 2.17 | 3.69 | 1.42 | 1.58 |
| SD[d] | | 1.21 | 0.92 | 0.89 | 1.13 | 1.76 | 0.47 | 0.47 |

a. The treatment means are ranked, with more desirable represented by a lower number (ranks summed for each column). Information obtained from tables eight to 13.
b. TN = Total Nitrogen; RS = Reducing Sugars; TA = Total Alkaloids.
c. Average ranking (Sum of column / 26 characteristics).
d. Average deviation among the ranks for 26 characteristics.

## Plant Characteristics

*Roots.* Roots serve as a means of collecting and transferring water and nutrients to the leaves by way of the stalk. Roots extend during the season according to the age of the plant, the availability and the need for water and nutrients. As the roots grow they provide increased stability as the plant grows taller and heavier.

All root depths (table 8) were similar with those under treatments 1 and 2, 3 and 4 penetrating more deeply than under other treatments. Within periods of drought, SWP-25 stimulated the deepest roots. Root dry weight was greatest under treatments 1 and 2 and under SWP-25. Even though the root depth under treatments 7 and 8 was moderate, there was a high dry weight, indicating that the mass of roots was extensive but closer to the surface than roots under treatments 1 and 2, 3 and 4.

*Stalks.* A tobacco plant stalk provides the transport of water and nutrients from the roots to the leaves and provides support for the leaves in the form of a canopy to gather sunlight and $CO_2$. The stalk needs to be sufficiently strong to support the leaves and large enough in diameter to enable the transport of sufficient water and nutrients in order to satisfy the needs of the plant.

The tallest stalks (table 9) were found under treatments 7 and 8, the second tallest under treatments 1 and 2, with the shortest under treatments 3 and 4. Within periods of drought the tallest stalks were found under SWP-100. Stalk dry weight was greatest under treatments 1 and 2, with treatments 7 and 8 in second place. Within periods of drought the greatest dry weight was found under SWP-25. Stalk diameter was greatest for treatments 7 and 8 and narrowest for treatment 5 and 6. Within periods of drought, SWP-25 soil gave the broadest diameter. Internodal distance was greatest for treatments 7 and 8 and least for treatment 9, there being a minimal difference between the effects of soil water pressure. Number of leaves per plant had little variation between treatments having 21–23 leaves/ plant. Even under drought conditions, tobacco plants appeared to establish leaves, whether or not they fully developed.

*Leaves.* For leaf length, leaf width, measured and estimated leaf area (table 10), the largest values were found under treatments 7 and 8, the next under treatments 1 and 2, 5 and 6, 3 and 4 with the smallest under treatment 9. Leaf width was similar under most treatments. Treatment effects within periods of drought were similar, although SWP-25 gave slightly larger values. Leaf dry weight follows the above leaf characteristics in order, with the exception that treatments 1 and 2 and 5 and 6 were equal.

*Crop Dry Weight.* If crop dry weight (table 11) under treatments 7 and 8 is considered as the optimum (100%), then the crop dry weight of treatments 1 and 2 was 94%; treatments 5 and 6, 90%; treatments 3 and 4, 82%; and treatment 9 only 78% . Within periods of drought, SWP-25 provided the greatest crop dry weight.

*Stalk Position.* Even though tobacco is grown for its leaves, leaves of each position on the stalk have a specific structure. Structure may be described in several ways, including the subjective concept known in the industry as the “body” of the leaf. Body may be partially quantified by density. Since both leaf weight and leaf area had the same order of largest to the smallest, the densities (table 12) were similar and not significantly different ($P<0.05$). The density varied from position to position, however. For lower leaves, the overall mean of means was 53.4, for lower 56.4, for middle 59.4 and for upper 56.4 mg/cm$^2$. The most desirable flue-cured tobacco is taken from the middle leaf, although all stalk positions are included in a manufacturer’s blend. Within periods of drought, SWP-25 rather than SWP-100 provided more dense leaves, except for lower leaves.

*Grade Value.* For grade value, (table 13) there was a reversal to the general trend. Treatment 9 had the highest grade value and treatments 7 and 8 the lowest. Within periods of drought SWP-100 provided a slightly higher grade value. Grade values of the first year were higher than for other years, for all treatments.

*Chemical Constituents.* Chemical analyses of the cured leaf were available for two out of the three years of the study. Appropriate levels for each of these ingredients were discussed by Gaines et al. (1983). Examining total nitrogen (table 13), it is undesirable to have a high level of nitrogen in the leaf at harvest because accumulation of nitrogen late in the growing season may restrict the level of starch in the leaf as well as prevent the conversion of starch to reducing sugars. As a rule, nitrogen levels in the leaf do not change during curing. An acceptable range for total nitrogen in the cured leaf would be 1.8%–2.2%, with a desirable amount around 2.0%. All nitrogen levels were within acceptable limits except for treatments 1 and 2, which were low. The highest nitrogen level was under treatments 3 and 4. Within periods of drought the effect of trigger soil water pressure was similar.

Starch converts to reducing sugar during curing, so a low level of starch at harvest will inevitably result in a low reducing sugar content. Prior to curing, an acceptable level of starch may be in the range 15%–25%. Following curing the preferred level is 1.5% (Gaines et al. 1983). Starch (table 13) was ample for most treatments, with the exception of treatment 9. Within periods of drought the effect of trigger soil water pressure was similar.

Reducing sugars contribute to the flavor of cured tobacco leaf. They behave conversely with starch both before and after harvest (Gaines et al. 1983) and are converted from starch during curing. Reducing sugars may appropriately vary from 15%–25% with a desirable value around 20% in the cured leaf. All values of reducing sugars (table 13) were very low compared with the desired value. The highest values were under treatments 5 and 6 and the lowest under treatment 9. Within periods of drought, SWP-25 provided a slightly higher level of reducing sugars.

Total alkaloids (nicotine) are an important constituent in tobacco, giving tobacco the properties for which it is known (Gaines et al. 1983). Alkaloids interact with nitrogen and increase with nitrogen content. It is established that total alkaloids should be 2.14%–3.37%, preferably around 2.95%. Like nitrogen, alkaloid levels generally do not change during curing. Alkaloids under all treatments (table 13) were close to acceptable levels, with treatment 9 being slightly in excess. Within periods of drought, SWP-25 provided a slightly higher level of total alkaloids.

Of greater concern, however, is the ratio of nitrogen to alkaloids. The ratio of total nitrogen to total alkaloids should be 0.7–1.0, but preferably less than 1.0. Values were similarly low for all treatments, implying that for the nitrogen levels received, the alkaloid levels were too high, especially for treatment 9. Within periods of drought, the effect of trigger soil water pressure was similar.

Tobacco flavor is dependent on a balance between alkaloids and sugar (Gaines et al. 1983). A measure of this balance is in the ratio of reducing sugars to total alkaloids. A suitable ratio is 6.0–10.0, preferably closer to 10. The ratio (table 13) was low for all treatments, implying a low level of reducing sugars, a high level of alkaloids, or both. Within periods of drought the effect of trigger soil water pressure was similar.

## Discussion

### Regression growth curves

*Climatic Conditions.* Except under extreme cases, it is assumed that a tobacco plant will grow during the growing season with the prescribed treatments merely modifying that growth pattern. Of interest are the characteristics which take precedence when drought is introduced during the growing season. Tobacco has a natural behavior pattern. Wild tobacco prefers to grow in the shade of other plants rather than in full sunlight. It is mildly sensitive to a combination of light intensity and day length, but cannot normally distinguish between the two (Raper 1988). Assuming that light intensity is coupled with air temperature for a particular time of year, a steady increase is preferable throughout the growing season. Even though flowering is almost day neutral, premature flowering later in the season may be encouraged by a few cool short days during the seedling stage, prior to transplanting (Kasperbauer 1988). Since tobacco is naturally a shade plant, when growing in open fields its photosynthetic process is quite often saturated. Consequently a few cooler days have less chance of seriously affecting normal growth, although this may vary from variety to variety.

*Roots.* Roots (figure 4) of DP-Wk 8,9 and Field, continued to grow deeper beyond week 13 after those of DP-None had ceased to grow deeper. Roots of Field were less developed at the beginning of the season and continued to grow even until harvest time as also observed by a separate rhizotron study (Maw 1989). Rapid root growth for DP-None, as represented by dry weight, occurred before week 11 and was prior to the occurrence of maximum dry leaf weight (figure 6), emphasizing the need for root development to enable bountiful leaf development. More root depth and weight was apparent using SWP-25 than using SWP-100.

*Stalks.* Mean stalk height, dry weight, diameter, internodal distance, and the number of leaves (figures 4 and 5) were mostly described by quadratic trends for most treatment effects. The most rapid growth early in the season took place for stalk length and dry weight. Since the trends were similar for each measured characteristic, a variation in water availability during the prescribed periods had a minimal effect. This behavior was different from that of the roots; neither should this behavior be confused with the effects of long-term drought or deficiencies in nutrients not covered in this study.

*Leaves.* Mean leaf length and width (figure 6) were described by a quadratic trend for all effects. There was an increase during the season, with a peak occurring about weeks 14–16. The trends (table 17) were not different from each other, with the exception of DP-None and Field ($P<0.05$). The high F value for leaf length suggests a close fit of the quadratic trend to the mean values.

Mean measured leaf area (figure 6) was described by a quadratic trend, with the exception of DP-Wk 8,9 and Field, that continued to increase after the others had reached a maximum by week 14. Estimated mean leaf area (not shown), using an equation developed by Maw and Mullinix (1992) based on leaf length and leaf width, was described by a quadratic trend for all effects with a greater closeness of fit than for measured leaf area. DP-None and Field were the only treatments whose effects were significantly different ($P<0.05$) from each other. Mean leaf dry weight (figure 6) was not well described by either a quadratic or linear trend, especially early in the season; however, with the exception of SWP-25, a linear trend has been chosen. The comparisons of interest were not significant ($P<0.05$).

*Stalk position.* Across treatments, mean leaf length, leaf width, estimated leaf area, and stalk diameter (figure 7) were described by a quadratic trend for bottom, lower, and middle positions of leaves on the stalk. The upper position was described by a linear curve in the case of leaf width, leaf area, and stalk. Comparing trends of interest (table 19), there was a significant difference between the bottom and lower positions of leaf length ($P<0.05$ ) and leaf area ($P<0.01$), and between the middle and upper ($P<0.01$) for leaf width and leaf area. Closeness of fit of the curves to the means are all quite high, especially leaf length. In order of maximum length, the sequence was bottom, upper, lower, and middle for leaf length; upper, bottom, middle, and lower for both leaf width and estimated leaf area.

*Solids Content.* Dry weight/fresh weight for roots, stalk, and leaves (tables 14, 15, and 18) was a linear relationship. Comparisons of interest were not significantly different with the exception of DP-none vs Field for roots. The linear curve for leaf was a closer fit than for roots or stalk.

## Detrimental Drought Periods

*Ranking of effect means.* Examining the mean of all ranks (table 20), it is concluded that of the drought periods considered, the most detrimental drought occurred during weeks eight and nine after transplanting (treatments 3 and 4), followed by weeks 10 and 11 (treatments 5 and 6,) and then weeks six and seven (treatments 1 and 2). The benefits of no drought is shown under treatments seven and eight. The field condition (treatment nine) was least desirable of all. Variations occurred among treatments and certain characteristics. Drought under weeks six and seven (treatments 1 and 2) produced the most favorable total nitrogen, reducing sugars/ total alkaloids, root depth ,and root dry weight. Drought under weeks 10 and 11 (treatments 5 and 6) produced the most favorable leaf density and reducing sugars. Tobacco grown under field conditions (treatment 9) had the most favorable grade index, total alkaloids, and starch content. When water was optimally maintained throughout the season (treatments 7 and 8), tobacco had favorable leaf and stalk growth, but less favorable leaf chemical analyses. Drought during weeks eight and nine (treatments 3 and 4) appeared to increase the alkaloid content and slightly lower the reducing sugar content of the tobacco leaf, corresponding to results reported by Pappenfus (1987). Within drought treatments, SWP-25 (treatments 1, 3, 5, and 7) was more favorable than SWP-100 (treatments 2, 4, 6, and 8) trigger soil water pressure.

*Interaction of trigger soil water pressure with drought period.* For there to be no interaction between the two main effects of drought period and trigger soil water pressure, the Standard Deviation (SD) of the first four and the last two columns (table 20) would be zero (i.e., having the same rank). As shown, however, the SD for all columns is other than zero, indicating some interaction between the main effects.

Observing the first four columns, treatments 5 and 6, having the smallest SD, had the closest ranking, suggesting the least differential between trigger soil water pressures. For the other pairs of treatments, there were larger SDs, implying that the ranks were more different with different levels of trigger soil water pressure. Nevertheless, using Cochran's F test (Steel and Torrie 1960), the test of SDs was nonsignificant, suggesting that even though there was some deviation as a result of the trigger soil water pressure, that deviation was not appreciable. Observing the last two columns, there was more variation among the treatments with SWP-25 than with SWP-100. Once again, however, Cochran's F test showed that the SDs were nonsignificant, implying no appreciable interaction.

*Stages of growth.* The severity of a drought period was directly related to the potential growth and development of the tobacco during that period, as nurtured by climatic conditions. Weeks eight and nine coincided with the late budding and early flowering stage of tobacco growth (table 5) and with the time when tobacco had the potential of tripling internodal distance in three weeks and doubling stalk diameter in three weeks (figure 5). This rapid growth was most evident by week 11 from the mass of leaf on the stalk (figure 6).

*Estimating tobacco plant water needs.* In order to estimate the water use of tobacco in this study, certain assumptions have been made. First of all, it has been assumed that a negligible amount of water is consumed by a tobacco plant in order to satisfy metabolic activity and plant structure in comparison with evapotranspiration (Salisbury and Ross 1978). Secondly, it has been assumed that no water was lost through deep drainage. Thirdly, it has been assumed that any water in the soil prior to week six (less or equal to 77 mm, table 4) and thus available to the plant after week 6 would be a small amount compared with that added after week six. Consequently, based on those assumptions, water applied to the tobacco plants under the various treatments has been considered as equivalent to the soil water used by the tobacco plants under those treatments.

As a result of this study, the need for water by tobacco plants after week six may be estimated as the amount of water applied to tobacco growing in the plots under a drought-free condition. This has been calculated as the average water applied (mm) each week to treatments 1, 3, 5, and 7, except on the weeks when drought was imposed. These treatments all used SWP-25, found to be the most beneficial trigger soil water pressure. The water applied during one additional week following any two-week period of drought was also eliminated, since the water applied during this week was considered to make up for the previous two weeks. The remaining weekly average application of water has been plotted in figure 3, using a line smoothing technique (Mosteller and Tukey 1977). Considering the assumptions made, it is suggested here that figure 3 may be considered as representing the evapotranspiration and thus the water needs of a healthy crop of flue-cured tobacco (variety 'NC 2326') at the site of the project.

Results of the study suggest that it is inappropriate to predict crop water use beyond week 16 because the state of the crop beyond that week is dependent on stage of maturity and stage of harvest of the crop. The water use curve in figure 3 compares favorably with a curve reported by Harrison and Witty (1971), except for maintaining a slightly higher level after the mid-season peak. Such differences may be attributed to their research having been conducted on different tobacco varieties and at a different geographical location.

*Estimating irrigation needs* Even though the treatment of field condition of tobacco (treatment 9) produced less than that under no drought conditions (treatments 7 and 8) the tobacco under the field condition appeared turgid during the growing season. It may be concluded from this study that even though a tobacco crop may appear healthy, it may not have sufficient soil water to satisfy its potential as a crop. Furthermore, it may be concluded that using visible signs of tobacco plant water stress, such as wilting, as an indication of when the addition of soil water is required may be to the detriment of the crop because the effect of the water stress may not be completely overcome. Therefore, it is desirable to use a means of determining the water needs of tobacco, other than by visual observations. It is preferable to use a means of detecting soil water deficit before the plant experiences that deficit.

During the study, gypsum resistance blocks were used to monitor soil moisture in each plot and act as a trigger for irrigation. As a result of the study, another method was developed using only climatic data. The measured evapotranspiration ($E_t$) for tobacco (figure 3 and table 21) was compared with open-pan evaporation ($E_p$) (table 22), measured during the growing seasons at a weather station close to the site of the study. During the rapid growth phase of the tobacco crop, weeks nine to 12, $E_t/E_p$ ratio was 0.93 or above and even for weeks 13–15 was 0.9 or above. This ratio, or crop factor, was similar to, and in some weeks slightly higher than, ratios reported by Papenfus (1987).

The derived information may be used in two ways: either as a rough estimate of irrigation, by considering crop water use to be equivalent to open pan evaporation during the rapid growth phase of the crop; or as a closer estimate, by incorporating the crop factor in calculations. For the rough estimate, the difference between open pan evaporation and rainfall 0 (mean evaporation deficit) would give the amount of irrigation needed for the crop. For a closer estimate, the difference between open pan evaporation × crop factor and rainfall would give a mean plant water deficit or the amount of irrigation needed for the crop. This is illustrated in table 22. Mean evaporation deficit is usually positive during the tobacco growing season for the region in which the project was conducted, and an unusually low level of rainfall occurred during weeks eight to 10, compared with a 29-year average (figure 2). In fact, for both 1986 and 1987 the month of April was within the 10 driest years and for 1986 May was within the 10 driest years even over the last 70 years.

As an example of how tobacco may not receive water to enable it to reach potential production, the field condition, treatment 9, was only given 283 mm of irrigation (table 3). Total rainfall for the season was 371 mm (table 22), or 240 mm after the subtraction of weeks one to five and week 20, which occurred during root establishment and after the last priming. The farmer, however, provided only 43 mm of supplemental irrigation and this was applied during weeks 13, 14, or 15 in different years. The crop could have used an additional 88 mm when treatment 9 is compared with treatments 7 and 8.

**Table 21. Evapotranspiration ($E_t$) (calculated by assuming treatment plot irrigation equaled $E_t$), and Ratios ($E_t/E_p$) for Tobacco Growing Under No-Drought Conditions**

| | Weeks after Transplanting | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Evapotranspiration ($E_t$)(mm) | 9 | 20 | 34 | 45 | 49 | 45 | 45 | 44 | 43 | 44 | 43 |
| Open pan evaporation ($E_p$)(mm) | 48 | 37 | 45 | 48 | 45 | 44 | 43 | 49 | 44 | 48 | 52 |
| $E_t/E_p$ (Crop Factor) | 0.19 | 0.54 | 0.75 | 0.93 | 1.1 | 1.0 | 1.1 | 0.9 | 1.0 | 0.9 | 0.8 |
| $E_t/E_p$ (Papenfus 1987) | 0.40 | 0.65 | 0.90 | 1.0 | 1.0 | 1.0 | 1.0 | 0.8 | 0.7 | 0.6 | |

**Table 22. Rainfall and Open Pan Evaporation for Weeks 1–20 after Transplanting (mm)**

| | Weeks after Transplanting | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Rainfall (mm) | | | | | | | | | | | | | | | | | | | | |
| 1st Year | 0 | 4 | 0 | 2 | 0 | 0 | 26 | 4 | 0 | 31 | 43 | 49 | 0 | 7 | 11 | 1 | 22 | 37 | 19 | 60 |
| 2nd Year | 47 | 0 | 5 | 0 | 0 | 16 | 77 | 26 | 0 | 0 | 9 | 25 | 39 | 3 | 12 | 3 | 17 | 4 | 25 | 90 |
| 3rd Year | 0 | 3 | 6 | 67 | 93 | 4 | 16 | 0 | 32 | 0 | 21 | 0 | 30 | 14 | 4 | 69 | 20 | 2 | 0 | 14 |
| Mean | 16 | 2 | 4 | 23 | 31 | 7 | 40 | 10 | 11 | 10 | 24 | 25 | 23 | 8 | 9 | 24 | 20 | 14 | 15 | 55 |
| | | | | | | | | | | | | | | | | | | | | total mean = 371 |
| Open pan evaporation (mm) | | | | | | | | | | | | | | | | | | | | |
| 1st Year | 41 | 43 | 43 | 46 | 60 | 53 | 46 | 42 | 48 | 39 | 44 | 46 | 53 | 49 | 56 | 59 | 42 | 49 | 40 | 34 |
| 2nd Year | 26 | 33 | 36 | 44 | 49 | 44 | 32 | 43 | 49 | 47 | 45 | 28 | 37 | 41 | 41 | 57 | 55 | 39 | 48 | 43 |
| 3rd Year | 37 | 40 | 34 | 37 | 7 | 47 | 34 | 49 | 46 | 48 | 72 | 54 | 57 | 42 | 48 | 41 | 48 | 45 | 46 | 45 |
| Mean | 35 | 39 | 38 | 42 | 39 | 48 | 37 | 45 | 48 | 45 | 44 | 43 | 49 | 44 | 48 | 52 | 48 | 44 | 45 | 41 |
| | | | | | | | | | | | | | | | | | | | | total mean = 874 |
| Mean Evaporation Deficit (mm) | | | | | | | | | | | | | | | | | | | | |
| | 19 | 37 | 34 | 19 | 8 | 41 | -3 | 35 | 37 | 35 | 20 | 18 | 26 | 36 | 39 | 28 | 28 | 30 | 30 | -14 |
| | | | | | | | | | | | | | | | | | | | | total = 503 |
| Mean Open Pan Evaporation × Crop Factor (mm) | | | | | | | | | | | | | | | | | | | | |
| | | | | | | 9 | 20 | 34 | 48 | 50 | 44 | 47 | 44 | 44 | 43 | 42 | | | | |
| Mean Plant Water Deficit (mm) | | | | | | | | | | | | | | | | | | | | |
| | | | | | | 2 | -20 | 24 | 37 | 40 | 20 | 22 | 21 | 36 | 34 | 18 | | | | |

*Comparing seasonal tobacco crop water use with crop dry weight.* There was a direct relationship between the average cumulative water applied for pairs of treatments over the growing seasons (table 3) and the mean of means of crop dry weight (table 11). Treatments 7 and 8 received the most water, with treatments 1 and 2, 5 and 6, treatments 3 and 4, and treatment 9 following in order. This order is also found to compare directly with the order of preferred treatments (table 20).

## Conclusions

1. In an effort to understand further the response of a tobacco crop to the imposition of periods of drought during the growing season, flue-cured tobacco ('NC-2326') was grown under cultural practices recommended by the Cooperative Extension Service, with the exception of water availability. Tobacco was grown in plots isolated from each other by 120 cm concrete barriers, within the boundaries of a high-rise shelter. Soil water was monitored daily with gypsum resistance blocks. Except during periods of

drought, superimposed on the irrigation schedule, the soil water in each plot was depleted by the tobacco to a trigger soil water pressure of either -25 kPa or -100 kPa and then replenished by irrigation to a field capacity. Three drought periods, a no-drought condition, a field condition, and two trigger levels of soil water pressure were combined into nine treatments.

2. Rapid increases in the growth of leaf width, leaf length, leaf area, leaf weight, and stalk height occurred, in the absence of drought, during weeks six to 11 after transplanting, with dimensions reaching a maximum during week 15. Root depth continued to develop throughout the season, but with a spurt of growth just prior to and during leaf weight accumulation. Such growth was retarded by drought according to the period of occurrence.

3. By measuring and ranking characteristics of the tobacco plants over those drought periods considered, a drought during weeks eight and nine proved to be the most detrimental, weeks 10 and 11 the second most detrimental, followed by weeks six and seven. Tobacco grown under simulated field conditions was least productive of all. Of the two, a -25 kPa trigger soil water pressure encouraged greater production, compared with a -100 kPa trigger soil water pressure.

4. The severity of a drought period was directly related to the potential growth and development of the tobacco during that period, nurtured by climatic conditions. Weeks eight and nine following transplanting were critical to the tobacco plant because of climatic conditions that occurred prior to and during that time, and because of the age of the tobacco plants at that time, being in the late budding to early flowering stage. Evapotranspiration was at a seasonally high level during weeks eight and nine after transplanting.

5. Deviations among the ranks for the characteristics measured show that tobacco did not respond uniformly across all measurements to the various treatments imposed. This indicates that under restricted conditions of growth scarce resources will be used by the plant to promote some characteristics at the expense of others.

6. By the end of the drought period, soil water deficits occurred in the upper 300 mm for the period of drought during weeks six and seven, and occurred to a certain extent throughout the entire 600 mm profile for the period of drought during weeks eight and nine and almost completely during weeks 10 and 11.

7. A deficit of soil water encouraged tobacco root development. Root development was a precursor for bountiful leaf production. Stalks were less affected by water availability than were roots. Neither were the number of leaves severely influenced by water availability. A high F value for leaf length suggests a close fit of a quadratic trend to the mean values.

8. There was a direct relationship between the average cumulative water applied for pairs of treatments over the growing seasons, the mean of means of crop dry weight,and the ranking of measured plant characteristics.

9. Even though tobacco under the field condition treatment appeared healthy and turgid, it did not reach its production potential. This would imply that visual observations are

not necessarily a true indicator of the productivity of a crop. It was deduced from this study that an indication of soil water deficit, before it becomes apparent in the crop, can be of benefit to timely irrigation.

10. The ratio of open pan evaporation to calculated actual evapotranspiration was above 0.93 during weeks nine to 12 after transplanting. This crop factor, in conjunction with open pan evaporation, may be used as an indication of the water needs of flue-cured tobacco.

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