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# EFFECTS OF WITHHOLDING IRRIGATION AFTER TRANSPLANTING TOBACCO

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SUMMARY

**In two successive seasons, irrigation was withheld on a loamy sand for periods of 1–8 weeks from the time tobacco stands were set (one week after transplanting).**

**Observations on soil moisture changes, water usage, evapotranspiration and effect of meteorological conditions are presented and discussed. Evapotranspiration reached a maximum (0·37 in/day) during the period 6–12 weeks from planting and during this period exceeded the evaporation from a meteorological tank.**

**The incidence of blue mould was independent of watering treatment. In the 4–, 6–, and 8–week treatments, time to flowering was increased by approximately one-half of the duration of irrigation restriction, but time to maturity was increased by a lesser amount, due to more rapid leaf growth when watering was resumed. Plant height and leaf number at maturity were positively related to the duration of watering restriction. Depth of root penetration was not increased by withholding irrigation.**

**Data on leaf yield, quality and chemical composition are presented; these favour the withholding of irrigation for 4 weeks during the early life of the crop.**

## I. INTRODUCTION

The irrigation of tobacco is often withheld once the crop is established (set) in the field. It is popularly believed that this may restrict blue mould incidence, assist root growth, conserve limited water supplies, or delay crop maturity.

In the 1958-59 season, a preliminary experiment was conducted at Parada Research Station, on the Mareeba-Dimbulah Irrigation Area in northern Queensland, to investigate the desirability of this practice. The trial was located on a soil classified as Walsh sandy clay loam. Blue mould damage was not severe and the blue mould assessments were statistically inconclusive. Mean yield from the experiment was 1,067 lb tobacco leaf per acre. The highest yield of 1,346 lb was obtained from a treatment in which water was withheld for 6 weeks following an irrigation 1 week after planting. The other treatments included one in which water was withheld for 3 weeks. There was little difference in leaf quality between treatments.

The soil type on which the 1958-59 experiment was conducted has a fairly high available soil moisture level (1·58–2·01 in./ft) and withholding irrigation for 6 weeks during establishment caused no observable restriction of growth. The

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major portion of the Mareeba-Dimbulah tobacco crop is grown on soils with a higher percentage of sand than the soil on which this preliminary experiment was carried out.

This paper discusses more detailed studies carried out on another soil to investigate the effects of withholding irrigation for various periods during establishment on the growth, yield and quality of tobacco leaf.

## II. METHODS

### (a) Location and Cultural Procedures

Experiment 1 represented the first tobacco crop on an area of an Algoma loamy sand at Parada Research Station which was cleared and ploughed in 1955 and left with a cover of native herbs and grasses until January 1960. Experiment 2 was conducted on the same area in the following season.

The soil was fumigated against nematodes with an overall EDB treatment; 0·75 in. spray irrigation was applied 3–5 weeks before planting in experiment 1 and 5·5 weeks before planting in experiment 2. Between the two experiments a cover crop of oats was grown and ploughed in. A complete fertilizer was applied as a single band in the rows just prior to planting. The application rates of the major nutrient elements were, per acre, 13 lb N, 41 lb P and 53 lb K in experiment 1, and 24 lb N, 41 lb P and 100 lb K in experiment 2.

The tobacco variety Hicks was planted by hand on September 13, 1960, and on August 29, 1961; good uniformity of density and early growth was obtained. Standard crop husbandry and insect control techniques were applied throughout the life of the crops.

### (b) Irrigation Layout and Technique

Individual plots consisted of 5 rows 66 ft long with 4-ft inter-row spacing and plants 21 in. apart (6,220 plants per acre). The three middle rows only of each plot were used as datum rows.

Land grading was carried out prior to fertilizing and planting. All furrows were adjusted to a fall not in excess of 1·5 in./ch. During irrigation the furrows were checked at each end to form a basin. The water was applied through 5-in. "Ames" gated pipe set on stands 20 in. above ground level. The flow from each gate was directed into a shallow container to prevent scouring. Flows were measured with a 4·4 gal drum and applications timed accordingly.

All early irrigations were made through V-furrows smoothed with a standard template. The shoulder of the furrow was located 4-6 in. from the plant line. The aim was to use a flow of 0·03 cusecs per furrow, which gave an irrigation time of approximately 5–8 min per furrow depending on the volume required. Broad-based furrows were used for all irrigations after the plants had reached the knee-high stage (18–24 in.) and no further cultivation was possible. These furrows, which were approximately 4 in. deep with a base of 24 in., were smoothed with a standard template. A flow of 0·06 cusecs per furrow, giving an irrigation time of 9–12 min per furrow, was desired.

### (c) Irrigation Treatments

Based on soil moisture deficits, a preplanting spray irrigation of 1·25 in. and a light post-planting spray irrigation of 0·25 in. were applied to all treatments. Subsequent soil moisture determinations indicated that the minimum depth of penetration was 12 in. All treatments were given a light spray irrigation of 0·50 in. 1 week after planting. In experiment 1, 0·70 in. rain fell 14–15 days after planting; no rain fell in the first 4 weeks in experiment 2.

Differential watering treatments were commenced during the third week after transplanting (day 17) and are detailed in Table 1. Four replications were employed in a randomized block arrangement, but it was necessary to discard the data from one block owing to the intrusion of a ridge of a coarser sandy soil.

**TABLE 1**

IRRIGATION TREATMENTS

| Treatment | Irrigation Withheld for Period of | Weekly Irrigations Resumed During |
|---|---|---|
| 1–week | 1 week | Week 3 from planting |
| 2–week | 2 weeks | Week 4 from planting |
| 4–week | 4 weeks | Week 6 from planting |
| 6–week | 6 weeks | Week 8 from planting |
| 8–week | 8 weeks | Week 10 from planting |

### (d) Soil Moisture

Samples for the gravimetric determination of soil moisture were taken at six positions per plot in two representative blocks. The sampling positions were located 4-6 in. from the plant base and as near to the shoulder of the hill as possible. This sampling technique was decided upon after consideration of the results obtained by Allmaras and Gardiner (1956) and of available information on tobacco root distribution. Samples were taken to a depth of at least 2 ft in 4-in. increments using a tube-type sampler (Keefer and Ward 1961).

Similar samples were collected from the trial area for the determination of field capacity. These samples were taken after 1·50 in. had been applied by spray irrigation at planting. This irrigation was completed in the late afternoon and the samples taken early the following morning. Bulk density determinations were also made on the trial area.

The soil had a field capacity of 10·4%, a wilting point of 1·8% and a bulk density of 1·61 g/c.c. in the 0-12 in. horizon. Thus available moisture capacity was 1·66 in./ft, an unexpectedly high value.

In view of the soil variability referred to previously, samples from each of the plots used for soil moisture determination were retained for mechanical analysis by the improved Bouyoucos hydrometer method (Bouyoucos 1962). For each plot an individual analysis was made on each 4-in. depth to 2 ft. In Table 2 the results are summarized for the 0-12-in. and 12-24-in. depths.

TABLE 2

Mechanical Analysis of the Soil of the Experiment Area

| Depth (in.) | Coarse Sand (%) | Fine Sand (%) | Silt (%) | Clay (%) |
|---|---|---|---|---|
| 0–12 | 59·8 | 28·5 | 5·6 | 6·1 |
| 12–24 | 61·4 | 28·0 | 4·6 | 6·0 |

The amount of water applied to each treatment at each irrigation was based on the soil moisture deficit below field capacity to a 12-in. depth for V-furrow irrigations and to a 16-in. depth for broad-based furrow irrigations.

Soil moisture samples were taken 4 days after each irrigation, and moisture loss was calculated. It was assumed that evapotranspiration dropped to half this figure over the remaining 3 days before the next irrigation; subsequent work confirmed this assumption. In calculating the amount to be applied in each treatment, average lateral penetrations of 18 in. for V-furrows and 36 in. for broad-based furrows were allowed, and an application efficiency of 80% was assumed.

### (e) Meteorological Data

Rainfall was measured in three rain gauges located on the site. The other climatic data used in discussion were recorded at the meteorological enclosure on Parada Research Station, situated approximately 400 yd north of the experimental area.

### (f) Crop Data

"Topping", or inflorescence removal, was conducted twice weekly and applied when five or more florets were open; mean flowering date was calculated by a similar method to that proposed by Christidis and Harrison (1955) for cotton.

Detailed blue mould ratings were made at four stages, using a method similar to one adopted by Pont (1959). Ten plants in the central datum row of each plot were examined, and the percentage infection of each leaf exceeding 9 in. in length was estimated. Since internal stem infection is a serious phase of the disease, the bark at the base of the stalk was raised and the presence or absence of the characteristic internal discoloration noted. These observations were made at 13, 17 and 20 weeks after planting during the first season and at 17 weeks during the second season.

The root distribution of plants in the 1- and 6-week treatments was examined 6 weeks after transplanting and at maturity, using a technique described by Gibson (unpublished Departmental report). This involved sampling the root zone with a 4-in. tube in 4-in. depths and ascertaining the root mass in each sample by washing, drying and weighing (Table 7).

Leaf number data were derived from 10 plants in the central row of each plot. Mean maturity dates were estimated from the weights of cured leaf obtained at each harvest. Cured leaf was graded after bulking, using similar methods to those proposed by E. J. McDonald (unpublished Departmental report).

Samples of leaf were retained after removal of midribs for analysis for chlorine, nitrogen, reducing sugars and total alkaloids. In experiment 1, phosphorus, potassium, nor-nicotine and ash were also determined. Samples from the lower half of the plants comprised 25-30 leaves graded as bright and mahogany lugs (appraisal grades X1B, X2B, X3M). Samples from the top half of the plant comprised 25-30 leaves graded as bright and mahogany leaf (appraisal grades L2B, L3B, L2M, L3M).

## III. RESULTS

### (a) Soil Moisture

The soil moisture changes over the first 10 weeks of each experiment are summarized in Figures 1 and 2 for the 0-12-in. horizon. The changes followed a similar pattern in both experiments, although in the non-irrigated treatments in experiment 2, 50% of the available soil moisture had been lost 2 weeks after planting, whereas in experiment 1, where rain intervened, this level was not reached until 3 weeks after planting.

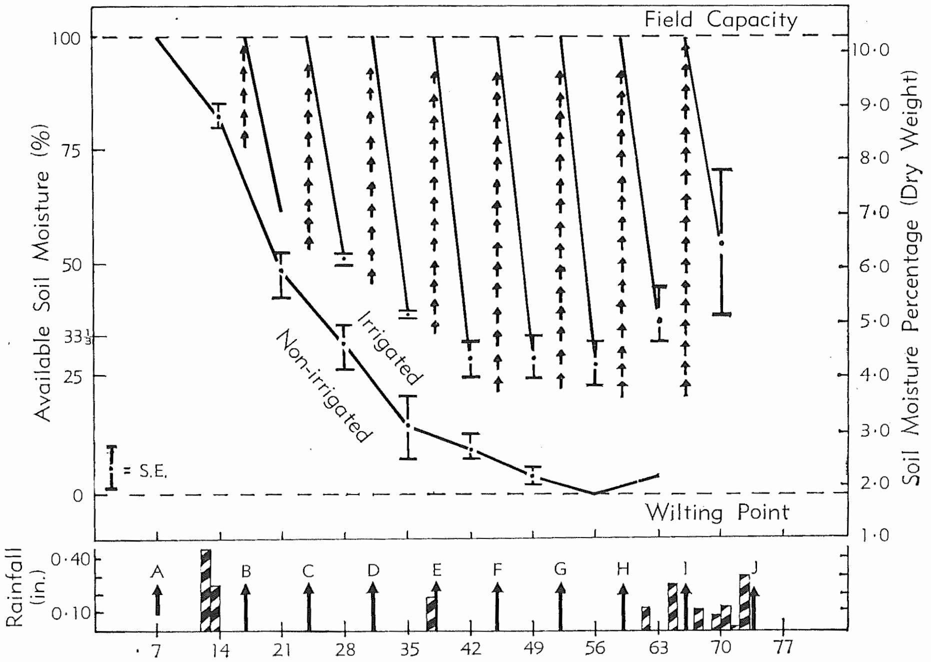


Fig. 1.—Experiment 1: Soil moisture changes, 0–12 in.

A–J indicate stages at which treatments were irrigated:

| | | | | | |
|---|---|---|---|---|---|
| A | All treatments | E | Control, 2 weeks, 4 weeks | H | ditto |
| B | Control | F | ditto | I | Control, 2 weeks, 4 weeks, 6 weeks, 8 weeks |
| C | Control, 2 weeks | G | Control, 2 weeks, 4 weeks, 6 weeks | | |
| D | ditto | | | J | ditto |

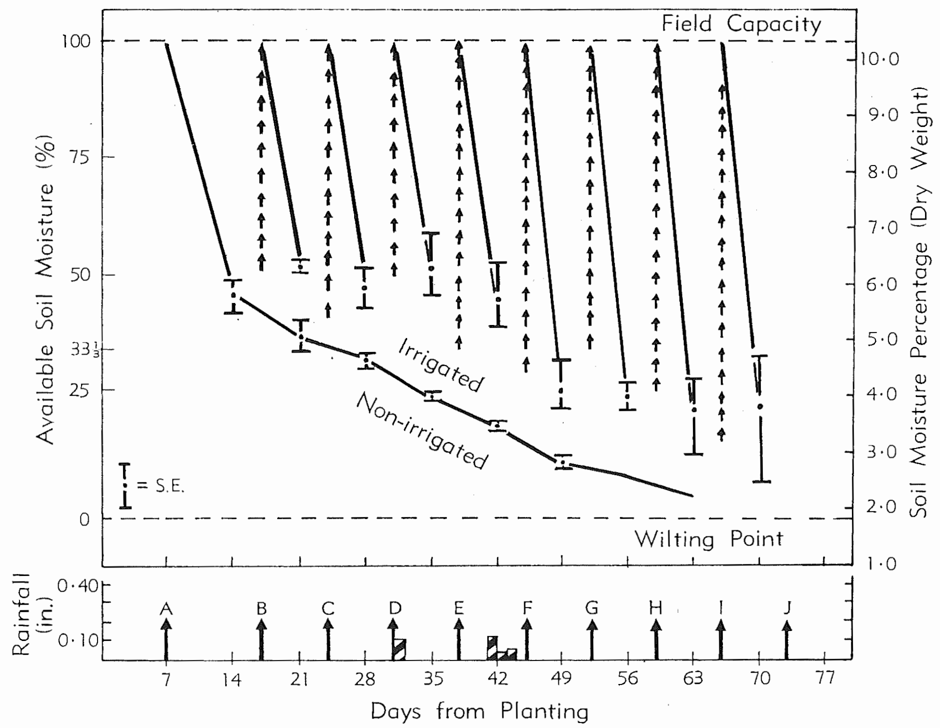


Fig. 2.—Experiment 2: Soil moisture changes, 0–12 in.
(See caption to Fig. 1)

The mean soil moisture levels in the top 12 in. at the end of the drought period are given in Table 3. In neither experiment was there any obvious restriction of growth in the 2-week treatment, in which up to 70% of the available soil moisture in the surface foot has been lost before irrigation was commenced. There was some restriction of growth in the 4-week treatment, in which 75-85% of the available moisture had been lost. In the 6- and 8-week treatments there was a complete cessation of active growth beyond the point where more than 85% of the soil moisture had been lost. After 8 weeks the soil moisture in the remaining delayed irrigation treatment was approaching wilting point.

**TABLE 3**

Mean Soil Moisture Levels at End of Drought Period (0–12 in. Horizon)

| Treatment | Experiment 1 Moisture (%) | Experiment 1 Available Soil Moisture (%) | Experiment 2 Moisture (%) | Experiment 2 Available Soil Moisture (%) |
|---|---|---|---|---|
| 2–week | 5·7 | 45·7 | 5·0 | 31·1 |
| 4–week | 3·2 | 16·7 | 3·9 | 24·6 |
| 6–week | 2·4 | 7·2 | 2·9 | 13·0 |
| 8–week | 2·0 | 2·2 | 2·2 | 4·3 |

From 5 weeks after planting, the irrigated treatments lost two-thirds to three-quarters of their available moisture within 4 days of irrigation during weeks in which no rain fell.

The amount of moisture contributed by the various soil layers was calculated from the soil moisture deficits. The soil moisture extraction pattern for the 0-16-in. depth for both experiments is shown in Table 4. It will be noted that of the water lost by the soil to 16-in., 82% came from the 0-12-in. layer in experiment 1 and 84% in experiment 2.

**TABLE 4**

Soil Moisture Extraction Pattern, 0–16 in.
Percentage of total soil moisture loss 0–16 in.

| Depth (in.) | Experiment 1 | Experiment 2 |
|---|---|---|
| 0–4 | 35·0 | 37·7 |
| 4–8 | 24·0 | 26·7 |
| 8–12 | 23·2 | 20·0 |
| 12–16 | 16·2 | 13·3 |

### (b) Irrigation

In experiment 1, the irrigation totals varied from 24·5 in. for the 1-week treatment to 15·7 in. for the 8-week treatment. The total rainfall for the season (21 weeks) was 12·5 in., and of this 8·5 in. is estimated to have influenced soil moisture in the effective root zone. On this basis, the total water usage varied from 33·0 in. for the 1-week to 24·2 in. for the 8-week treatment.

In experiment 2, the irrigation totals varied from 20·6 in. for the 1-week to 11·6 in. for the 8-week treatment. The total rainfall for the season (20-21 weeks) was 12·3 in., and of this 8·3 in. is estimated to have influenced soil moisture in the effective root zone. Thus the total water usage varied from 28·9 in. for the 1-week to 19·9 in. for the 8-week treatment.

The water usage was thus 4-5 in. higher in experiment 1 than in experiment 2. The rainfall was more evenly distributed in experiment 2 than in experiment 1, so only six light irrigations were given after 12 weeks in experiment 2, compared with seven irrigations during the same period of experiment 1.

### (c) Evapotranspiration

In this paper, the term evapotranspiration (Ea) is used in accordance with the definition of the Soil Science Society of America (Anon. 1956) to denote "that water lost from the land surface by transpiration and evaporation", and does not include moisture percolating beyond the reach of plant roots. In Figure 3, Ea for 7-day and 4-day periods is shown for both irrigated and non-irrigated treatments. The rates recorded in the delayed irrigation treatments reveal that there was a sharp reduction in evapotranspiration rate once the soil moisture dropped below 50% available soil moisture (week 4, experiment 1; week 3, experiment 2).

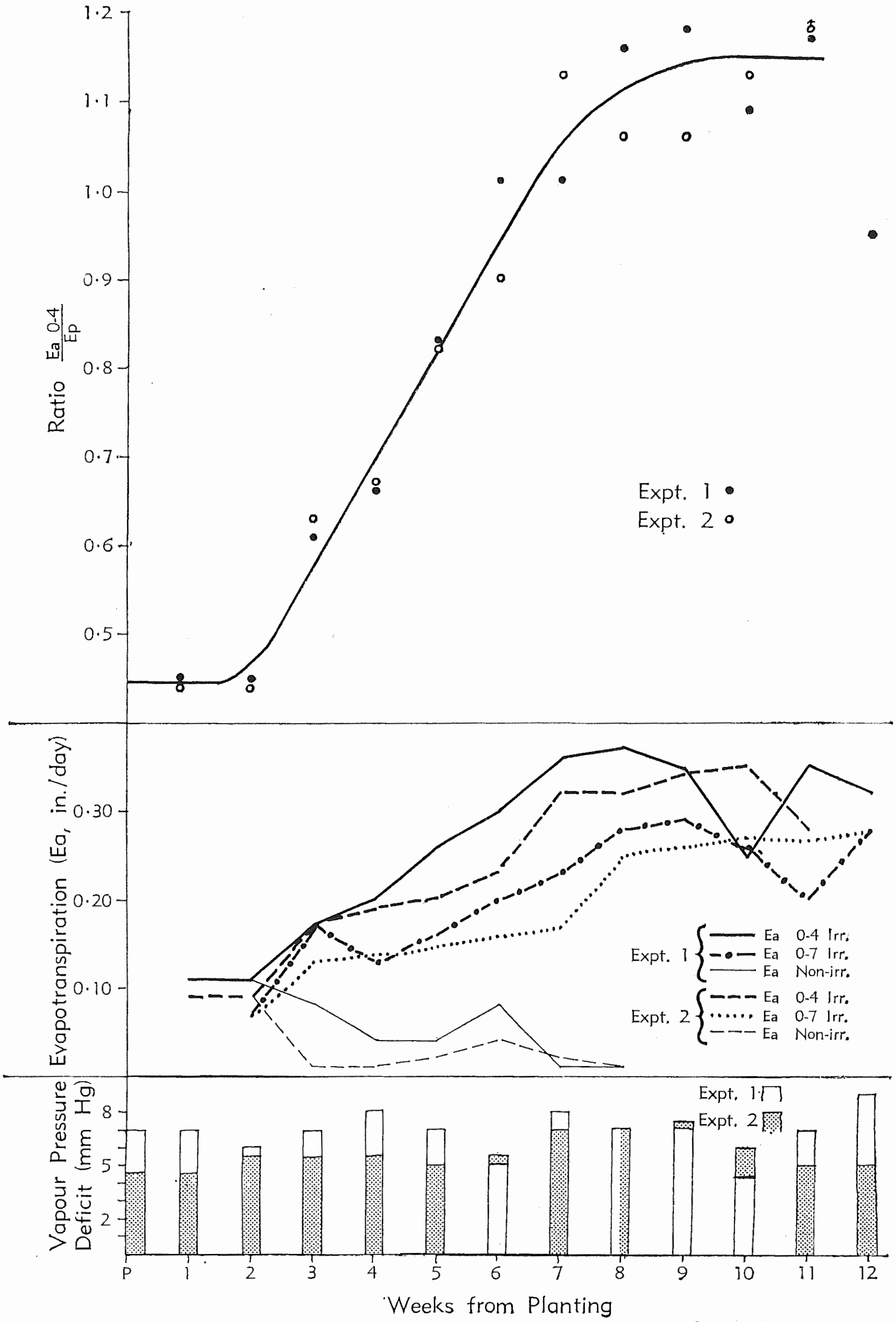


Fig. 3.—Vapour pressure deficits, evapotranspiration (Ea) and Ratio $\frac{\text{Ea } 0\text{–}4}{\text{Ep}}$.

The rates for the irrigated treatments determined for the 4-day period following irrigation may be considered as maximum Ea at the various stages. As these rates are based on soil moisture samples taken in the zone of maximum root concentration, it is highly probable that the average soil moisture deficit over the entire root zone was lower; hence Ea for an irrigated field of tobacco would also be lower. In the irrigated treatments, Ea started to exceed 0·30 in./day during week 6 or week 7 after planting and from this point Ea exceeded standard Australian meteorological tank evaporation (Ep). Maximum Ea recorded in experiment 1 was 0·37 in./day during week 8, while the maximum rate recorded in experiment 2 was 0·35 in./day during week 10. Ep also reached a peak at these times.

### (d) Meteorological Data

The meteorological data confirm the suggestion already made that evaporative conditions were higher in experiment 1 than in experiment 2. The maximum temperatures (Figure 4) were consistently higher in experiment 1 from planting to week 12. The minimum temperatures do not show consistent differences, but were in general also higher in experiment 1. In both seasons, there was a marked

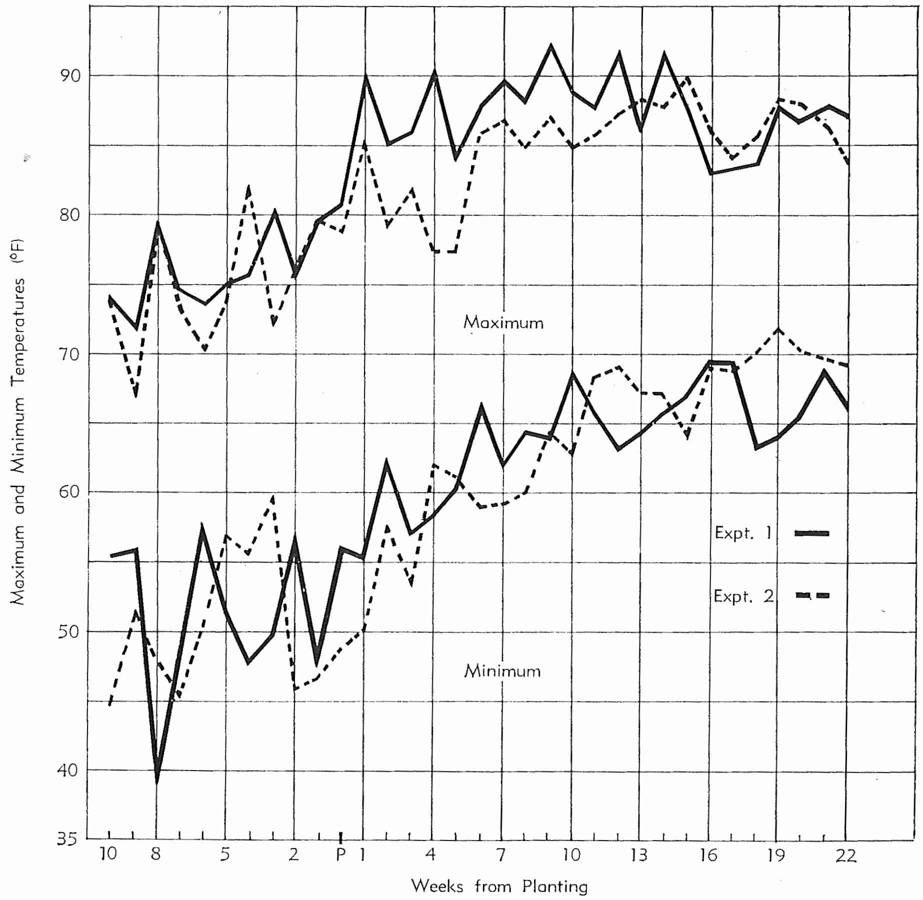


Fig. 4.—Maximum and minimum temperatures—weekly means.

increase in temperature during the growing period. Prior to planting, the maxima ranged from 70 to 80°F and the minima from 45 to 55°F. During weeks 0–8, maxima ranged from 80 to 90° and minima from 55 to 65°, while during the later part of the growing season the maxima ranged from 85 to 90° and the minima from 65 to 70°.

In Figure 5, mean hourly humidity, Ep and rainfall totals have been plotted on a weekly basis. The relative humidity does not show any consistent seasonal differences. The peaks of high humidity correspond with periods of rain. Aqueous vapour pressure deficits, determined on mean hourly humidity and mean hourly temperature (Figure 3), reveal some marked differences between the two seasons. Ep also shows this effect, and was markedly depressed during periods of rain. In both seasons there was a gradual increase in Ep from 2 weeks before planting to 9 weeks after planting, and a gradual decline during the rainy periods of December and January.

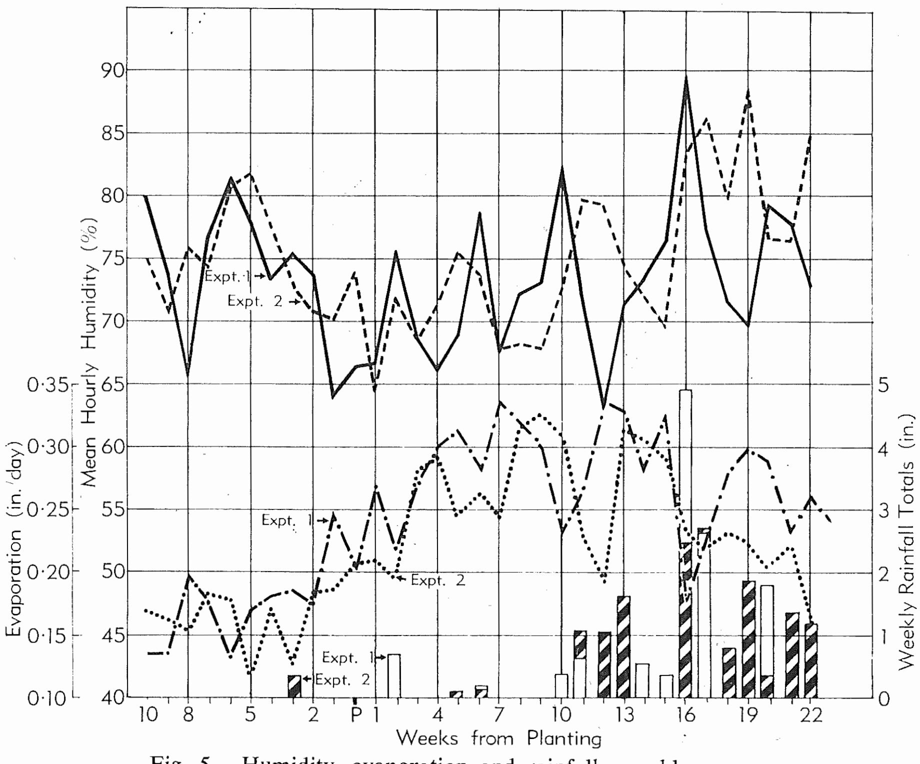


Fig. 5.—Humidity, evaporation and rainfall—weekly means.

## (e) Blue Mould and Insect Attack

In both experiments, blue mould was first noted during the seventh week after transplanting (i.e. prior to the irrigation of the 6- and 8-week treatments). A serious outbreak of leaf mould did not occur in either season, although infection was more severe in experiment 2 than in experiment 1. The detailed leaf ratings indicated that irrigation treatment had no consistent effect on blue mould incidence and its ultimate effects on yield and quality. No consistent association of internal stem infection with treatment occurred in either experiment. Insects did not cause any serious damage in either experiment.

### (f) Crop Growth

During the sixth week after planting, the delayed irrigation treatments appeared to have darker green and more fleshy leaves than the 1- and 2-week treatments. From this stage, the 6- and 8-week treatments made very little growth and the leaves became more erect. Photographs of representative plants of each treatment taken during week 9 are shown in Figure 6.

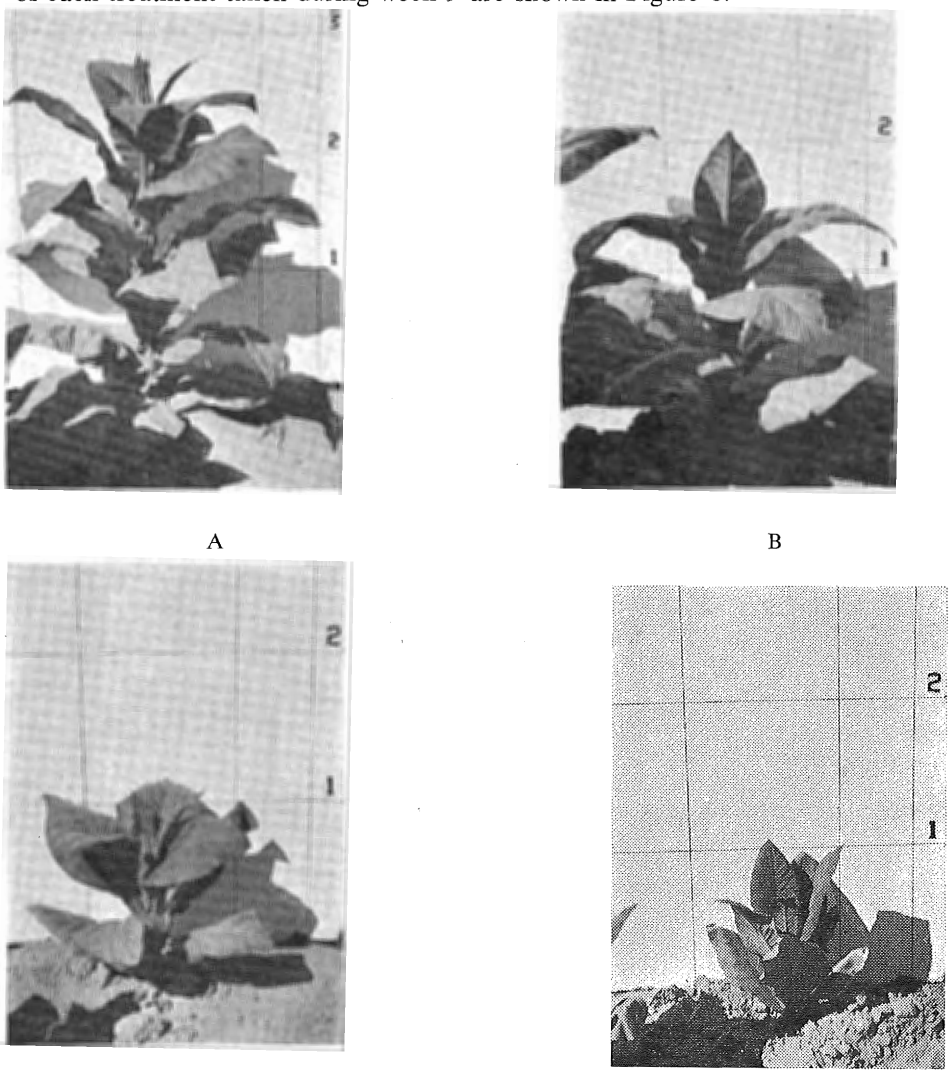


Fig. 6.—Representative plants of each treatment during week 9 from planting. (A) 1- and 2-week treatments; (B) 4-week treatment; (C) 6-week treatment; (D) 8-week treatment.

During week 10 after planting, the remaining delayed irrigation treatment (8-week) showed signs of severe water stress (Figure 7), although no mortality occurred. At this stage a mottling developed on the tips and margins of the lower leaves; in extreme cases this was associated with dead tissue, which dried to a reddish brown colour. The margins of the mottled leaves were rolled towards the abaxial surface. Once irrigation was recommenced the plants in all treatments made rapid growth.


Fig. 7.—Plant and leaves of 8-week treatment during week 10 from planting. Left, 8-week treatment showing upright leaves, rolling of margins and dieback of tips. Right, leaves of 8-week treatment showing mottling of tips and margins.

Growth was slower in experiment 2 than in experiment 1. This could be explained largely on the basis of temperature differences (Figure 4).

There were no significant differences in either year between the 1-week and 2-week treatments in the number of days from transplanting to flowering (Table 5). The 4-, 6-, and 8-week treatments took increasingly longer periods to reach the flowering stage, and these differences were all significant in experiment 1. In experiment 2, however, the difference between the 6-week and 8-week treatments was not statistically significant. Once irrigation was resumed, the late-watered plants flowered more quickly; in the 4-, 6-, and 8-week treatments, time to flowering was increased by approximately one-half of the duration of irrigation restriction. A maximum difference of only 13 days was recorded in time from planting to maturity.

## TABLE 5

DURATION OF GROWTH PERIODS

| Treatment | 1-week | | 2-week | | 4-week | | 6-week | | 8-week | |
|---|---|---|---|---|---|---|---|---|---|---|
| Stage Attained | No. of Days from Planting | Duration (days) | No. of Days from Planting | Duration (days) | No. of Days from Planting | Duration (days) | No. of Days from Planting | Duration (days) | No. of Days from Planting | Duration (days) |
| | | | | | Experiment 1 | | | | | |
| End of drought period .. | 17 | | 24 | | 38 | | 52 | | 66 | |
| 18-in. growth stage .. .. | 46 | 29 | 46 | 22 | 52 | 14 | 63 | 11 | 71 | 5 |
| Mean date of flowering—topping | 74 | 28 | 73 | 27 | 81 | 29 | 90 | 27 | 99 | 28 |
| Mean date of maturity .. | 108 | 34 | 108 | 35 | 112 | 31 | 121 | 31 | 121 | 22 |
| Total .. .. | | 91 | | 84 | | 74 | | 69 | | 55 |
| | | | | | Experiment 2 | | | | | |
| End of drought period .. | 17 | | 24 | | 38 | | 52 | | 66 | |
| 18-in. growth stage .. .. | 52 | 35 | 52 | 28 | 56 | 18 | 66 | 14 | 73 | 7 |
| Mean date of flowering—topping | 71 | 19 | 71 | 19 | 81 | 25 | 92 | 26 | 97 | 24 |
| Mean date of maturity .. | 124 | 53 | 124 | 53 | 118 | 37 | 129 | 37 | 131 | 34 |
| Total .. .. | | 100 | | 100 | | 80 | | 77 | | 65 |

As indicated in Table 6, both mean plant height and number of harvested leaves at maturity were positively correlated with the duration of watering restriction.

**TABLE 6**

MEAN PLANT HEIGHT AND LEAF NUMBER AT MATURITY

| Treatment | Mean Plant Height (in.) | | Leaf Number | |
|---|---|---|---|---|
| | Experiment 1 | Experiment 2 | Experiment 1 | Experiment 2 |
| 1-week .. .. .. .. .. | 52·5 | 44·0 | 25·4 | 22·5 |
| 2-week .. .. .. .. .. | 50·7 | 46·7 | 24·4 | 22·7 |
| 4-week .. .. .. .. .. | 59·3 | 53·1 | 28·3 | 25·4 |
| 6-week .. .. .. .. .. | 59·6 | 60·8 | 30·0 | 28·3 |
| 8-week .. .. .. .. .. | 63·7 | 57·6 | 32·1 | 29·3 |
| Necessary differences for significance 5% | 8·6 | 5·1 | 2·0 | 1·6 |
| Necessary differences for significance 1% | 14·3 | 7·4 | 2·9 | 2·4 |

The pattern of root distribution observed in experiment 1 is shown in Tables 7 and 8. It will be noted that, 6 weeks after planting, the roots of the 1-week plant had penetrated more deeply than those of the 6-week plant. The latter had spread further into the inter-row space; perhaps this was associated with the absence of recent cultivation in this treatment. In the 1-week plant, 65% of the plant roots were within 6 in. of the plant base and 85% were within 12 in. of the surface, while in the 6-week plant, which had not been irrigated for 4 weeks, 62% of the plant roots were within 6 in. of the plant base and 98% of the roots were within 8 in. of the surface. At maturity, the 1-week plant had 61% of the roots within 6 in. of the plant base and 95% in the top 20 in., while the 6-week plant had 62% of the roots within 6 in. of the plant base and 95% in the top 12 in. Similar results were obtained in experiment 2. Thus, withholding irrigation did not increase root penetration.

It might be noted that the soil moisture samples, which were taken within 4–6 in. of the plant base, were from the zone of maximum root concentration.

## TABLE 7

ROOT DISTRIBUTION AT 6 WEEKS FROM PLANTING
Percentage total root weight

| Depth of | Total | 18–22 in. | 14–18 in. | 10–14 in. | 6–10 in. | 2–6 in. | Plant line | 2–6 in. | 6–10 in. | 10–14 in. | 14–18 in. | 18–22 in. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hill | 2·9 | | | | | 0·9 | 1·1 | 0·9 | | | | |
| 0–4 in. | 32·4 (47·2) .. | | | 0·3 | 0·7 (0·3) | 2·5 (2·4) | 5·9*(38·5)† | 7·1 (4·5) | 12·5 (1·5) | 3·4 | | |
| 4–8 in. | 27·9 (51·0) .. | | | 1·0 (0·2) | 4·5 (4·6) | 2·6 (4·2) | 0·5 (12·6) | 10·5 (9·1) | 7·6 (9·4) | 1·3 (5·3) | (4·9) | (0·7) |
| 8–12 in. | 22·3 (1·8) .. | | | | 0·6 | 4·5 | 7·5 (0·9) | 8·0 (0·7) | 1·8 (0·2) | | | |
| 12–16 in. | 9·6 .. | | | | | 1·5 | 5·5 | 2·7 | | | | |
| 16–20 in. | 4·9 .. | | | | | 0·4 | 2·0 | 2·6 | | | | |
| Distance from plant line | | 18–22 in. | 14–18 in. | 10–14 in. | 6–10 in. | 2–6 in. | Plant line | 2–6 in. | 6–10 in. | 10–14 in. | 14–18 in. | 18–22 in. |
| Total .. .. | | | | 1·3 (0·2) | 5·8 (4·9) | 12·4 (6·6) | 22·5 (52·0) | 31·5 (14·3) | 21·9 (11·1) | 4·7 (5·3) | (4·9) | (0·7) |

* 1-week treatment plant
† 6-week treatment plant

## TABLE 8

ROOT DISTRIBUTION AT MATURITY
Percentage total root weight

| Depth of | Total | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hill | 20·0 (17·9) | | | | | 7·6 (6·4) | 7·2 (8·4) | 5·2 (3·1) | | | | |
| 0–4 in. | 28·5 (47·3) .. | 0·9 (1·9) | 1·5 (2·0) | 1·5 (1·6) | 2·2 (2·6) | 2·4 (4·4) | 8·8*(13·8)† | 4·0 (8·0) | 1·4 (5·1) | 1·6 (3·0) | 2·1 (2·2) | 2·1 (2·7) |
| 4–8 in. | 18·5 (21·1) .. | 0·7 (0·6) | 0·8 (1·3) | 0·9 (1·6) | 1·6 (2·0) | 3·8 (4·5) | 5·0 (2·2) | 2·1 (1·6) | 1·2 (2·4) | 1·9 (2·1) | 0·7 (1·6) | 0·7 (1·2) |
| 8–12 in. | 13·6 (9·0) .. | 0·2 (0·5) | 0·8 (0·3) | 1·2 (0·4) | 1·3 (0·2) | 2·3 (0·7) | 2·4 (4·5) | 1·0 (0·8) | 1·3 (0·4) | 1·0 (0·4) | 1·4 (0·4) | 0·7 (0·4) |
| 12–16 in. | 5·9 (3·0) .. | | | 0·4 | 0·4 (0·1) | 2·7 (0·2) | 0·8 (0·2) | 0·3 (2·1) | 0·5 (0·3) | 0·2 (0·1) | 0·4 | 0·2 |
| 16–20 in. | 8·5 (1·5) .. | 2·6 | 0·3 | 0·7 | 0·7 | 0·7 | 1·5 (0·1) | 0·3 (1·4) | 0·7 | 0·3 | 0·3 | 0·4 |
| 20–24 in. | 4·8 (0·2) .. | | | 0·8 | 0·2 | 0·6 | 1·2 | 0·9 (0·2) | 0·4 | 0·7 | | |
| Distance from plant line | | 18–22 in. | 14–18 in. | 10–14 in. | 6–10 in. | 2–6 in. | Plant line | 2–6in. | 6–10 in. | 10–14 in. | 14–18 in. | 18–22 in. |
| Total .. | .. | 4·4 (3·0) | 3·4 (3·6) | 5·5 (3·6) | 6·4 (4·9) | 20·1 (16·2) | 27·1 (29·2) | 13·8 (17·2) | 5·5 (8·2) | 4·8 (5·6) | 4·9 (4·2) | 4·1 (4·3) |

* 1-week treatment plant
† 6-week treatment plant

### (g) Yield and Quality

Leaf was harvested on 19 occasions in experiment 1 and on 15 occasions in experiment 2. In both seasons the December harvests gave the best cured leaf. November-harvested leaf was trashy and papery, and the February harvests gave very brittle and "boardy" leaf. The overall quality of leaf was not good and most of it exhibited a character described as "flatness". Using a scale of 1 flat–5 good quality, an independent observer gave an average rating of 3 to all treatments in both seasons. Yield and quality are summarized in Table 9.

TABLE 9

Leaf Yield and Quality

| Treatment | | Graded Yield (lb/ac) | | Relative Grade Value | | Acre Index (000's/ac) | |
|---|---|---|---|---|---|---|---|
| | | Expt. 1 | Expt. 2 | Expt. 1 | Expt. 2 | Expt. 1 | Expt. 2 |
| 1–week .. .. .. .. .. | | 1991 | 1591 | 61·6 | 53·4 | 126·0 | 85·4 |
| 2–week .. .. .. .. .. | | 2242 | 1663 | 60·6 | 52·0 | 138·3 | 86·9 |
| 4–week .. .. .. .. .. | | 2207 | 1732 | 63·6 | 58·5 | 142·8 | 101·7 |
| 6–week .. .. .. .. .. | | 1800 | 1333 | 61·4 | 55·1 | 110·1 | 73·3 |
| 8–week .. .. .. .. .. | | 2053 | 1166 | 58·4 | 50·8 | 118·0 | 60·5 |
| Mean .. .. .. .. .. | | 2058 | 1497 | 61·1 | 54·0 | 127·0 | 81·6 |
| Necessary differences for significance | 5% | N.S. | 326 | N.S. | 6·1 | N.S. | 18·7 |
| | 1% | | 474 | | 8·9 | | 27·3 |

In experiment 1, there were no significant yield differences, but there is some indication that the 4-week treatment gave the best overall result in terms of "acre index", which is the product of graded yield and relative grade value.

In experiment 2, the 2- and 4-week treatments significantly outyielded both the 6- and 8-week treatments. The 4-week treatment produced significantly the highest relative grade value and acre index.

### (h) Chemical Analyses

The average chemical composition of leaf from all treatments in both experiments is shown in Table 10. Chloride levels were satisfactory; these were higher in the lugs than in the leaf and also higher in experiment 2. In both experiments, total nitrogen was low and sugar content high; these features are characteristic of "flat" leaf.

**TABLE 10**

AVERAGE COMPOSITION OF CURED LEAF

Percentage dry weight basis

| — | Lugs | | Leaf | |
|---|---|---|---|---|
| | Experiment 1 | Experiment 2 | Experiment 1 | Experiment 2 |
| Chloride .. .. .. .. | 0·69 | 0·84 | 0·52 | 0·60 |
| Total nitrogen .. .. .. | 1·15 | 1·28 | 1·11 | 1·23 |
| Reducing sugars .. .. | 24·10 | 22·70 | 24·00 | 28·10 |
| Total alkaloids .. .. .. | 1·12 | 1·24 | 1·26 | 1·11 |

In experiment 1, there were no significant treatment differences in chloride levels or in grades; in the lug grades the 8-week treatment had a significantly higher percentage of nitrogen than the 4- and 2-week treatments. There were no obvious differences in reducing sugars in the leaf grades of the various treatments, but in the lug grades there was an indication that the sugars were lower and the total alkaloids higher in the 6- and 8- week treatments.

The phosphorus levels (Table 11) were rather low, but were significantly higher in the earlier watered treatments in both lug and leaf positions. The potassium levels were satisfactory, particularly in the leaf grades of the 8-week treatment and the lug grades of all treatments.

**TABLE 11**

COMPOSITION OF CURED LEAF, EXPERIMENT 1

Percentage dry weight basis

| Treatment | Phosphorus (% $P_2O_5$) | | Potassium (% K) | |
|---|---|---|---|---|
| | Lugs | Leaf | Lugs | Leaf |
| 1–week .. .. .. .. .. | 0·71 | 0·60 | 2·47 | 2·00 |
| 2–week .. .. .. .. .. | 0·67 | 0·57 | 2·43 | 1·89 |
| 4–week .. .. .. .. .. | 0·68 | 0·48 | 2·51 | 2·17 |
| 6–week .. .. .. .. .. | 0·49 | 0·36 | 2·31 | 2·09 |
| 8–week .. .. .. .. .. | 0·46 | 0·42 | 2·47 | 2·37 |
| Mean .. .. .. .. .. | 0·60 | 0·49 | 2·44 | 2·10 |
| Necessary differences for significance 5% | 0·11 | 0·08 | N.S. | 0·36 |
| Necessary differences for significance 1% | 0·15 | 0·12 | | 0·50 |

## IV. DISCUSSION

### (a) Moisture Use

Estimates of water use during successive stages of development have been published for France, Germany, Morocco, North Carolina, Florida and Canada (Goodall 1958). The rates shown in Figure 3, which reach maxima of 0·37 and 0·35 in./day in experiments 1 and 2 respectively, are in most cases higher than those quoted by Goodall, but this is not unexpected in view of climatic differences and sampling technique. It will be recalled that moisture changes were estimated from the zone of maximum root concentration. In North Carolina and Canada, maximum figures of 0·17 in./day have been estimated. In Morocco a maximum rate of 0·24 in./day has been measured, while in Florida 0·25 in./day has been recorded during the eighth week after planting (Myers and Clark 1958). In this last case the authors stated that "water use may be as much as 0·35 inches on a windy day, accompanied by high temperature and low humidity". Awtramani (1959) in India found that the highest daily water requirement for Hookah tobacco was 0·39 in.

### (b) Crop Development

There appears to be little in the literature dealing with the relationships of soil moisture and flowering of tobacco. Since withholding irrigation restricts growth, and growth is resumed under different climatic conditions, the effects recorded may not be due to moisture alone.

Coolhaas (1955) found that continuous high temperature and humidity each retarded flower formation in tobacco, and that day temperature influenced the number of leaves per plant. He found that the time to floral initiation and leaf number were directly related to length of illumination. Other workers (e.g. Steinberg and Tso 1958) have observed similar trends. At the latitude of Parada Research Station, the day length increases from approximately 11·8 hr on September 1 to 13·1 hr on December 22, and day temperatures increase over the same period.

### (c) Nutritional Considerations

It will be noted that the average yield per acre was approximately 600 lb lower in experiment 2; this occurred in spite of the fact that almost twice as much nitrogen and potassium was applied in the basal fertilizer application as in experiment 1. On sandy soils such as this, however, differences in basal fertilizer application can be cancelled by subsequent leaching.

The mottling of the lower leaves observed in the restricted watering treatments is of interest. Several workers (e.g. Darkis *et al.* 1936: Lovett 1952) described similar symptoms and suggested that they result from a deficiency of potassium possible in association with a deficiency of magnesium and calcium aggravated by dry soil conditions. On the other hand, the 1-, 2-, and 4-week treatments developed heavy puckered leaves. It is suggested that this could have been caused by a build-up of nitrogen at some stage and a resulting imbalance of potash and nitrogen. The 6- and 8-week treatments were not affected to the same extent and appeared to have thinner, narrower leaves than the other treatments.

A conclusion drawn from most experiments in which the effect of water supply on quality has been studied is that total carbohydrate level increases and total nitrogen and nicotine levels decrease with increased water supply (Goodall 1958). On this basis, it could be concluded that the chemical analyses (Table 10) indicate an abundant or even excessive water supply during the main growing period. The trend to low nitrogen and high sugars, however, may possibly be corrected by manipulation of fertilizer during the growing period.

### (d) Irrigation Practice

A number of investigators (Goodall 1958) have found that the rate of use and irrigation need changes during development. Bennett *et al.* (1956) separated three growth stages: stand "set" to knee high, knee-high to flowering, and flowering to maturity. Many investigators have reported that the crop can recover from a period of moisture stress during the first stage provided adequate moisture is available during the remainder of the growing period. Taylor and Slater (1955) stated that "tobacco transplants are resistant to moisture stress for relatively long periods of moisture deficiency but when enough water is once supplied to initiate rapid vegetative growth, a continuance of water at low tensions is required to develop the crop properly".

The evidence from these experiments supports these statements. No advantage from withholding irrigation for more than 2-4 weeks once the stand is set was recorded, but there appeared to be some disadvantage in promoting rapid growth during the first growth stage.

On the basis of these studies, the following irrigation schedule is recommended for tobacco being grown on this or similar soil types:—

(1) At planting 1-1·5 in., followed by 0-0·7 in. 5-7 days later.

(2) Irrigation then withheld for a period of 3-4 weeks.

(3) An irrigation of 1-1·5 in. then given, and thereafter regular irrigations at no greater than weekly intervals. In periods of dry windy weather irrigation at more frequent intervals may be beneficial.

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