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Yield of Flue-Cured Tobacco and Levels of Soil Oxygen in Lysimeters with Different Water Table Depths[1]

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ABSTRACT

Flue-cured tobacco (*Nicotiana tabacum* L.) was grown in lysimeters with static water- table levels at 30, 45, 60, and 90 cm below the soil surface to more clearly define the level at which a favorable balance between soil aeration and water supply is attained. The oxygen and CO_2 content of the soil air was determined periodically at various depths. Water-table treatment effects were evaluated in terms of root and shoot growth, yield, and quality of tobacco.

Dry leaf yields for the 90-, 60-, and 45-cm water-table treatments were all significantly ($P \geqslant 0.05$) greater than that for the 30-cm treatment. Yields for the 60- and 90-cm water-table levels were larger, but not significantly ($P \geqslant 0.05$) larger than the 45-cm treatment. The yield difference between the 60- and 90-cm treatments was not significant ($P \geqslant 0.05$). Roots of tobacco recovered from soil above the 60- and 90-cm water tables weighed only 10% more than roots recovered from soil above the 30-cm water table. Average CO_2 and O_2 gradients in the soil above the water table were nearly equal but of opposite sign. Soil environmental conditions imposed by the 60-cm water-table treatment of this study provided the most favorable balance between aeration and water supply for tobacco.

***Additional key words:* *Nicotiana tabacum* L., Tobacco quality, Soil CO_2, Reducing sugars of tobacco, Alkaloids in tobacco.**

WATER-TABLE levels are affected by rainfall and river and tidal elevations in many tillable sections of the southeastern Coastal Plains. In this region the frequency and the distribution of rainfall are virtually unpredictable. As a result, drought hazards exist for many field crops almost every year. Consequently, the amount of water drained from the soil profile that could have been utilized by plants is an important phase of soil water management in this region. Another significant phase is whether or not water-table levels exist for which a balance between water uptake and soil aeration can be optimized for plant growth. The response of various agricultural crops to static water-table levels in soil has been recently reviewed by Williamson and Kriz (7). They point out that the sensitivity of plants to wet soils partly depends upon plant species. For example, orchardgrass (*Dactylis glomerata* L.) (3), alfalfa (*Medicago sativa* L.) (5), and wheat (*Triticum aestivum* L.) (6) grew best at stabilized water-table levels of 30, 60, and 150 cm, respectively.

Similar data do not appear to be available for flue-cured tobacco (*Nicotiana tabacum* L.), a crop that is known to be sensitive to wet soil conditions.

Experimental data presented describe some of the effects of different static water-table levels on the gaseous composition of soil air, and on the growth, yield, and quality of tobacco of variety 'Coker 298.'

PROCEDURE

Lysimeter Layout and Cultural Methods

Tobacco plants were grown in lysimeters that were constructed from cylindrical steel tanks 56 cm in diameter by 90 or 120 cm deep. The lysimeters were arranged in two rows, 1.2 m apart, center to center, in a trench with their rims projecting 5 cm above the bordering soil surface. A 10-cm layer of rock followed by a 4-cm layer of sand was placed in the base of each lysimeter and was filled with Norfolk loamy sand topsoil to the same level as soil in the surrounding field.

The experimental treatments were constant water-table levels maintained at 30, 45, 60, and 90 cm below the soil surface throughout the growing season. These treatments were arranged in a rondomized block design with four replications. The pressure head that controlled the level of the water table was established by overflow pipes terminating at the desired water-table depth. Water needed for evapotranspiration plus an amount to maintain the pressure head was provided by an adjustment of water flow control valves connected to the water supply.

Small tobacco plants were transplanted into the lysimeters on May 5, 1967 and May 7, 1968. The particular arrangement of the lysimeters permitted a 56-cm space between plants, which resulted in a conventional plant density of 14,880 plants/ha (6,020 plants/acre). A four-row border area was planted on both sides of the lysimeters at the same row spacing as plants in the lysimeters. Prior to planting, a mixed fertilizer was incorporated in the surface soil in each lysimeter at the rate of 81, 70, and 201 kg/ha of N, P, and K, respectively.

Stalk diameter, plant height, and number of leaves were determined at prescribed times in 1967 and 1968. In addition, lengths and widths of all leaves on each plant were measured in 1968 to determine total plant leaf area. Leaf area was then calculated from the product of number of leaves $\times$ average leaf length $\times$ average leaf width $\times$ 0.64. The factor 0.64 was determined from the average ratio of leaf area to the product of length $\times$ width of the leaves of plants bordering the lysimeter installation. Suggs et al. (4) reported factors of 0.72 for small leaves and 0.62 for large leaves.

Tobacco leaves were picked from the stalks as they matured. Dry leaf yields were obtained for the various treatments in 1967 and 1968, but in 1968 tobacco was flue-cured and graded before drying. Tobacco leaves for each water-table treatment were analyzed for reducing sugars and total alkaloids. Root weights were determined in 1967 only.

Soil Air Analysis

The O_2 CO_2, and N_2 contents of the soil atmosphere were determined at various heights above the water table in 1968. To sample the soil profile gas exchange chambers were placed in the soil at 15-cm intervals, beginning 5 cm below the soil surface to 10 cm above the water table in two replications in all four treatments. Gas chambers were formed from disks of 24-gauge stainless steel sheeting by pressing them into cylindrical chambers 6.2 cm in diameter by 1 cm deep. The open side of the chamber was covered with 2-mm mesh stainless steel screen to keep soil lumps out of the chamber and to allow exchange of gas between the soil pores and the chamber. A tube, 3.2 mm o.d. by 1.5 mm i.d., which extended 5 cm above the soil surface, was soldered into a hole drilled into the top of each chamber. The upper ends of these tubes were sealed with rubber septa through which hypodermic needles were inserted to obtain gas samples.

Samples of soil air were taken with 1.5-cc capacity gas-tight syringes. Two samples were discarded before the third was transported to the laboratory, where a 1-cc portion of the sample was analyzed. One gas sample was taken from each depth in

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the morning hours for 6 days within an 8-day period beginning May 28, 1968. Although only one sample was obtained, several samples could be taken successively from the 30-cc capacity gas reservoirs without altering the composition of gases in the sample. With similar equipment Yamaguchi et al. (8) have shown that six 1-cc samples could be obtained from gas reservoirs, 3 cc in volume with a 2.5-cm flared base, without appreciably altering the composition of gas taken at various depths in columns of sand.

The components of the soil gas were separated and measured by gas chromatography. Carbon dioxide was separated from the remaining soil gases on a 60- × 0.6-cm silica gel column maintained at 100 C inside the oven of the gas chromatograph. A 180- × 0.6-cm molecular sieve column connected in series with the silica gel column, situated outside the chromatograph oven, separated O_2 + A, N_2 and CH_4 at 23 C. Since A and O_2 were not separated, using these operating conditions, the A content of the gas samples was taken to be the same as air at ambient temperature. Tests at this laboratory have shown that the A content of gas samples taken from soil in which the CO_2 concentration was as high as 18% was essentially the same as A content of air. The water vapor content of samples was assumed to be saturated at time of injection into the chromatograph because these gas samples were taken from pores of moist soil.

Soil Characteristics

The mechanical composition of the Norfolk loamy sand topsoil used in the study was 83.2% sand, 16.6% silt, and 0.2% of <0.002 mm clay. The average water content of soil cores were 31.1, 15.7, 12.4, 11.2, 9.1, 8.0, and 6.3% volume basis, corresponding to matric suction values of 1, 3, 6, 10, 30, 60, and 100 centibars, respectively. The largest change in water content per unit matric suction occurred in the 1 to 6 centibar range. In field soils of the area, a matric suction of 10, rather than 30, centibars is often observed as the suction approximating field capacity. Water content and air-filled porosity data presented in Table 1 were obtained from a lysimeter during low evaporation conditions and with a constant water-table level 60 cm below the soil surface. The air-filled porosity of this soil increased from 10.8% at a depth of 52.5 cm from the surface to 23.6% at a point 7.5 cm below the soil surface.

RESULTS AND DISCUSSION

Composition of Soil Gas

The percentages of O_2 and CO_2, shown in Fig. 1, show that O_2 decreased, whereas CO_2 increased almost linearly with depth within the limits of depths sampled above each water-table level. Considering the gas composition of the soil atmosphere for all water-table levels of this study, the O_2 content decreased and CO_2 content increased as the depth of the water table below the soil surface increased. The largest absolute CO_2 and O_2 concentration gradients found between two adjacent sampling depths were associated with the shallow (30-cm) water-table level and the smallest absolute concentration gradients with the deepest (90-cm) water-table level. Average gradients expressed as change in O_2 percent were —0.60, —0.40, —0.32, and —0.21, and the change in percent for CO_2 were 0.69, 0.41, 0.32, and 0.22 for 30-, 45-, 60-, and 90-cm water-table treatments, respectively.

The sums of $O_2 + CO_2$, given in Table 2, at various depths in the soil above the water table varied approximately ± 2% from the normal concentration of O_2 in air. This sum was slightly greater at the 23-cm depth than for other depths for each water-table treatment, indicating that CO_2 accumulated and diluted N_2 in the soil atmosphere. Below the 23-cm depth $O_2 + CO_2$ decreased slightly with depth to the water table, indicating that O_2 decreased without a corresponding increase in CO_2. As a consequence, N_2 increased at these lower depths.

Root Distribution

In the absence of a water table in a deep uniform soil, Hall et al. (2) found that flue-cured tobacco developed a deep root system. In the presence of various water-table levels, the total dry root weight recovered from lysimeters was only 10% greater for the 90-cm water-table level than the 30-cm treatment; the character of root systems for these two treatments, however, was visibly different. A large tap root developed in the 90-cm treatment in contrast to a much smaller tap root and numerous fibrous roots distributed throughout the soil of the 30-cm water-table treatment. The distribution of roots within the lysimeters, represented by block diagrams in Fig. 2, shows that the largest percentage of roots for all treatments occurred in the surface 10-cm layer of soil. Root weight decreased with depth, with relatively more roots found in lower depths of the deeper water-table treatments. Very few roots were found within the 10-cm layer just above the water table in all treatments. Root environmental effects of various water-table levels were indicated by both the size and distribution of roots in soil contained in the lysimeters.

Plant Appearance and Growth

Leaves of tobacco plants, growing in the lysimeters with a 30-cm water table, became chlorotic within 4

Table 1. Water content and air-filled porosity of soil in a lysimeter with a water table 60 cm from the surface.

Sample depth	Volumetric water content*	Air filled porosity
cm	%	%
7.5	16.0	23.6
22.5	19.5	20.1
37.5	24.0	15.6
52.5	28.8	10.8

* Bulk density = 1.60g/cc, assumed particle density = 2.65g/cc.

Table 2. Percent $O_2 + CO_2$ in the soil gas at different depths below the soil surface for different water-table treatments.

Sample depth	Water-table depths - cm			
	30	45	60	90
	% $O_2 + CO_2$			
8	21.0	20.9	20.9	21.0
23	23.0	22.3	22.1	21.1
38		20.9	18.8	19.6
53			20.2	20.2
81				17.3

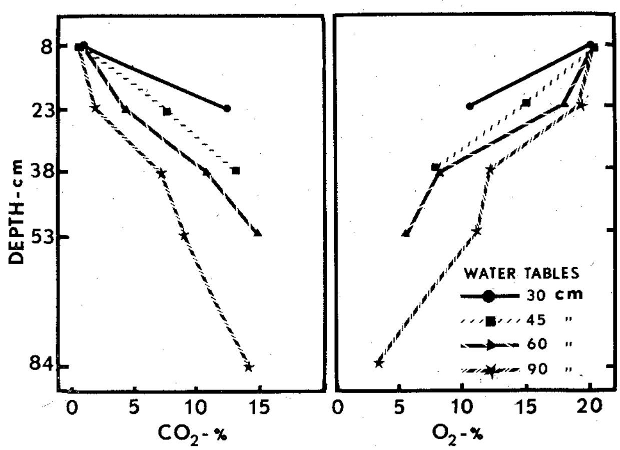

Fig. 1. Percentages of O_2 and CO_2 shown in relation to depth in soil for various static water-table levels.

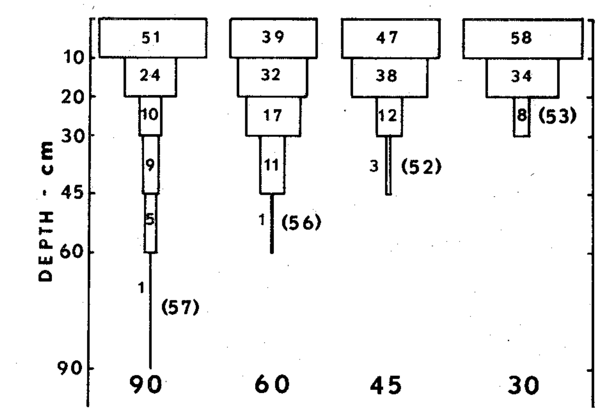

Fig. 2. Distribution of roots at various depths in lysimeters with water tables at 90, 60, 45, and 30 cm below the soil surface. Numbers in blocks indicate percentage of roots found in the layer indicated. Numbers in brackets give the total dry weight of root material expressed in grams per plant.

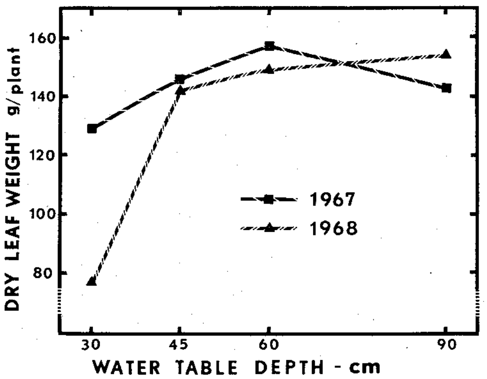

Fig. 3. Tobacco dry leaf yield produced in lysimeters with various static water-table levels.

Table 3. Tobacco growth measurements made 6/14/68, 38 days after transplanting, for various water-table treatments.

Water table level	Leaf width	Leaf length	Stalk diameter	Plant height	Plant leaf area
cm	cm	cm	cm	cm	m^2
30	28.1	45.0	2.54	64	0.80
45	32.2	50.0	2.65	67	1.18
60	34.2	51.5	2.78	75	1.27
90	34.7	51.5	2.73	70	1.18
LSD (P = 0.05)	4.1	3.8	ns	ns	0.18

weeks after transplanting, and remained slightly chlorotic throughout the growing season both years. Leaves of the plants growing at the 45-cm water-table level appeared slightly chlorotic within 6 weeks after transplanting, but recovered as the season progressed.

Plant measurements made 38 days after transplanting in 1968 are presented in Table 3. Leaf area, length, and width were significantly smaller for the 30-cm treatment than those for the 45-, 60-, and 90-cm treatments. Although stalk diameter and plant height measurements showed lower values for the 30- and 45-cm water-table levels than for the 60- and 90-cm treatments, these differences were not significant at $P \geqslant 0.05$. The largest value in four out of five measurements was associated with the 60-cm treatment; differences in growth between the 45-, 60-, and the 90-cm treatments, however, were not significant.

Ratios of the 30- to the 60-cm plant measurements for stalk diameter, average leaf length, average leaf width, plant height, and total leaf area were 91, 87, 86, and 63%, respectively. Leaf area was the most sensitive growth indicator.

Dry Leaf Yield

Tobacco dry leaf yield data for 1967 and 1968 are shown in Fig. 3. In 1967 the maximum dry leaf yield was harvested from the 60-cm water-table depth; this yield, however, was not significantly different from the 45- and 90-cm treatments, but was significantly different from the 30-cm treatment. In 1968, however, the highest yield was associated with the 90-cm water-table treatment and the dry leaf yields from 45-, 60-, and 90-cm water-table treatments were all significantly different from the 30-cm depth. Yields were increased slightly under stabilized water-table conditions ranging in depth from 45 to 90 cm.

The dry leaf yield for the 30-cm water-table treatment was 129 g per plant in 1967, as compared to 77 g per plant in 1968, a difference of 52 g. This difference is approximately equal to twice the magnitude of the $LSD_{P=0.05}$ and, therefore, appears to be too large to be explained on the basis of experimental error alone. The June rainfall in 1967 was very different from that in June 1968.

In mid-June 1967 a single rain of 4.88 cm fell as compared to 13.7 cm of rain, which fell within 5 days in mid-June 1968. Within this 5-day period four separate rains of 2.67, 4.70, 2.29, and 3.05 cm fell within 3 of the 5 days. Leaves on some of the plants growing in the 30-cm water-table lysimeter became flaccid or "flopped," indicating that flooding occurred for a period long enough to have resulted in a lower yield in 1968 than in 1967.

Yield and Quality of Flue Cured Tobacco

Flue-cured tobacco yield data are given in Table 4. The cured yield for the 30-cm treatment was significantly less than all other treatments, being only 50% of the yield for the 90-cm treatment. The cured leaf yield was highest for the 90-cm treatment; differences between yields, however, for the 45-, 60-, and 90-cm treatments were not significant at $P \geqslant 0.05$.

The average value of graded tobacco is usually different each year, depending upon buyer requirements and quality grown. The grade index, given in Table 4, column 3, is an index of tobacco quality, based upon grading standards that include color, physical properties, and average prices paid for various grades in previous years[3]. Based upon these quality standards, shallow water-table levels reduced quality; however, the reduction was not significant at $P \geqslant 0.05$.

The grade index multiplied by cured leaf yield represents the tobacco crop index as given in Table 4, column 4. The crop index for the 30-cm treatment was 54% of that for the 90-cm treatment. Differences between the 45- and 60-cm treatments were not significantly different from the crop index obtained in the 90-cm treatment. These data indicate that cured yield had a greater effect on the crop index than grade for the various water-table treatments.

[3] Grade index for flue-cured tobacco was based on average price paid for various grades in 1967 and through September 11, 1968, as issued by the School of Agriculture and Life Science, North Carolina State University, Raleigh, N. C.

Table 4. Flue-cured leaf yield and value of tobacco grown in 1968 in lysimeters at various water-table levels.

Water table level	Cured weight	Grade index	Crop index	Relative value
cm	kg/ha	$/kg	$/ha	%
30	1,305	1.23*	1,605	46
45	2,360	1.24	2,926	84
60	2,435	1.23	2,995	86
90	2,626	1.32	3,466	100
LSD (P = 0.05)	324	ns		

* Based upon average prices paid for graded flue-cured tobacco in 1966 and 1967.

Table 5. Reducing sugars and total alkaloids of tobacco grown in soil with different static water tables (see footnote 4).

Water table	1967 Reducing sugars	1967 Total alkaloids	1967 S/A ratio	1968 Reducing sugars	1968 Total alkaloids	1968 S/A ratio
cm	%	%		%	%	
30	12.4	0.45	27.6	16.0	1.01	22.9
45	13.6	0.50	27.2	15.8	0.92	22.3
60	15.5	0.66	23.5	11.8	1.26	12.3
90	12.8	1.33	9.6	14.8	1.35	13.4
None	--	--	--	7.5	2.61	3.7
LSD (P=0.05)	1.6	0.18	12.7	3.6	0.62	9.2

Chemical Composition of Cured Tobacco[4]

Reducing sugars in tobacco increased slightly with increasing water-table depths, Table 5, but the most significant aspect was that sugars in leaves of plants grown in the lysimeters were much higher than sugars in leaves grown in the absence of a water table.

The total alkaloid content of tobacco, given in Table 5, increased as the depth to the water table increased. Field tobacco, grown in the absence of a water table, had about 2.6 times the alkaloid content as lysimeter-grown tobacco. According to Currin et al. (1), "A wet season tends to reduce the alkaloid content in tobacco, whereas a dry season has the opposite effect."

The presence of high water tables accents the magnitude of the ratio between reducing sugars and total alkaloids, referred to as the S/A ratio in Table 5. Root environmental conditions imposed by water tables had a pronounced effect in increasing the reducing sugars and decreasing total alkaloids in tobacco.

[4] Chemical analyses were made through the courtesy of Dr. T. E. Smith, Brown and Williamson Tobacco Corp., Louisville, Ky.

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