Reprinted from
AGRONOMY JOURNAL, Volume 65
September-October 1973, p. 783-786

# Flue-Cured Tobacco Yield and Oxygen Content of Soil in Lysimeters Flooded for Various Periods[1]

R. B. Campbell[2]

## ABSTRACT

Tobacco (*Nicotiana tabacum* L. var. 'Coker 298') plants grown in lysimeters were flooded for 0, 12, 24, 48, 96, and 120 hours to define more clearly $O_2$-depletion rates in soil and effects of flooding on growth. The $O_2$ content of air entrapped in soil pores was monitored with membrane-covered galvanic-type probes before, during, and after a 96-hour flooding. Oxygen decreased from 16 to less than 4% in the soil atmosphere within 24 hours after flooding. Upon drainage, $O_2$ increased within 48 hours to the original concentration.

Growth and yield differences between the control and 12- and 24-hour flooding treatments were not significant. Flooding for longer than 48 hours significantly reduced yield to less than 40% of that of the unflooded plants. Plants were more susceptible to flood damage at the 12-leaf stage of development than at the 17-leaf stage. Reducing sugars increased from 11.8 to 14.8% and total alkaloids decreased from 1.26 to 0.76% in tobacco leaves flooded for 24 hours.

*Additional index words: Nicotiana tabacum* L., Tobacco quality, Reducing sugars, Alkaloids, Soil oxygen.

FLOODING a soil essentially stops gas exchange between the soil and atmosphere and seriously impedes the flow of $O_2$ to active root surfaces and to microorganisms in the soil.

Although most of the air in soil pores is displaced by water upon flooding, complete displacement is un-

[1] Contribution from the Coastal Plains Soil and Water Conservation Research Center, Southern Region, Agricultural Research Service, USDA, Florence, S. C. 29501, in cooperation with South Carolina Agricultural Experiment Station. Received Feb. 24, 1973.

[2] Soil Scientist. The contributions of P. E. Perritt, former Engineering Technician, and John F. Thornton, deceased, former Director, Coastal Plains Soil and Water Conservation Research Center, Florence, S. C. are acknowledged.

common (3). The amount of entrapped air in a flooded soil depends upon the soil type and manner of wetting. In the laboratory, more than 10% of the total pores of a loamy sand contained air, even though wetting procedures under atmospheric pressure were used to obtain maximum displacement. The length of time required for plant oxygen stress to develop in a flooded soil will depend upon the amount of entrapped air, the respiration rate of plant roots and microorganisms, and the downward diffusion of $O_2$ through the aerial parts of the plant.

Because field tobacco (*Nicotiana tabacum* L.) may be flooded by excessive rainfall, a need exists to determine the degree of recovery for various periods of inundation. Therefore, the objectives of this investigation were to evaluate effects of flooding for different lengths of time and $O_2$-depletion rates on the growth, yield, and quality of 'Coker 298' tobacco.

## MATERIALS AND METHODS

### Lysimeters and Flooding Methods

Lysimeters were made from cylindrical steel tanks 56 cm in diameter by 90 cm deep. The lysimeters were arranged in a trench in two rows with 1.2 m between centers and with their rims 5 cm above the surface of bordering field soil. Soil was filled around the outside of the lysimeters, but the center area between rows was kept open to facilitate adjustment of flow control valves in the water supply system. A 10-cm layer of pebbles topped by a 4-cm layer of sand was placed in the bottom of each lysimeter. The remaining volume was filled with Ap horizon Norfolk loamy sand soil.

Treatments, consisting of flooding for 0, 12, 24, 48, and 96 hours in 1967 and 0, 12, 24, 72, and 120 hours in 1968, were arranged in a randomized block design with four replications. Except for the prescribed periods of flooding, the water-table level was maintained at the 60-cm depth. The level control consisted of a 1.3-cm diameter open pipe connected to inlet water supply pipe line at the base of each lysimeter with the open end terminating at a height of 60 cm below the soil surface. Water was provided for evapotranspiration and for regulation of the water-table level by adjusting an inlet valve connected to the water supply manifold.

Lysimeters were flooded in the middle of June 1967 and 1968 by extending the open pipe outlets 7 cm above the soil surface and by adjusting the inlet valve to give the desired pressure head. All lysimeters were flooded within 16 hours, and a 3-cm layer of water was maintained on the soil surface after flooding. Lysimeters were drained by lowering riser pipe outlets to the original 60-cm level and by readjusting the flow through inlet valves.

Before planting, fertilizer was incorporated into the soil of each lysimeter and into the soil of the border area at the rate of 81, 70, and 201 kg/ha of N, P and K, respectively.

During the first week of May in 1967 and 1968, one tobacco plant was transplanted in each lysimeter and others placed in four rows on each side of the lysimeter installation. Plants were spaced 56 cm apart in rows 1.2 m apart, a population equivalent to 14,880 plants/ha (6,020 plants/acre).

### Field Flooding

Extra rows were planted to study effects of flooding by taking advantage of an intensive or an extended rain should it occur. Such a rainy period could offer an opportunity to compare yields from flooded lysimeters with a flooded field and a well-drained tobacco field. Thus, two areas including four replications were laid out and designated as well-drained and rain-flooded. Each plot consisted of 16 plants, four plants in each of four rows.

### Soil Oxygen Measurements

The oxygen concentration of the soil atmosphere was monitored with galvanic cell oxygen probes, placed 8, 23 and 38 cm deep in the four lysimeters that were flooded for 96 hours in June 1967. The $O_2$-probes, described by Willey (4), consisted of a Au-Ag couple separated from the soil by an $O_2$-permeable plastic membrane. Electrodes were encased in a plastic shell containing KCl, the coupling fluid, and temperature compensation components. Each probe was sealed at the base of a plastic soil-access tube, with the membrane of the probe positioned about 1 mm from the soil. Oxygen measurements were made during 10 to 21 June 1967.

### Plant Growth and Yield Measurements

Plant height, stalk diameter, leaf length and width were measured on June 6, 1967, just before flooding, and again 27 days later. As leaves ripened, they were picked, flue-cured, and then dried to obtain tobacco yields. Stalks and roots of typical plants from each of the flooding treatments were weighed at the end of the harvest season.

In 1968 the total leaf area of each plant was determined just before flooding and again 6 days later to evaluate short-term effects of flooding at the 17-leaf stage of growth. Tobacco harvested in 1968 was flue-cured, weighed, graded, and then dried for leaf yields. Leaves were plucked from stalks as they ripened, a procedure normally used by commercial growers.

## RESULTS

### Soil Oxygen

Oxygen contents at various depths before, during, and after 96 hours of flooding are shown in Fig. 1. Each point shown is the average soil $O_2$ percentage of four or more probe measurements obtained at approximately 1-hour intervals in each of the four lysimeters. Within replicates, the data grouped by 12-hour intervals showed a standard deviation for $O_2$ that ranged from 0.6 to 5.4 with a median of 3.2%. Because flooding progressed upward through the soil, $O_2$ began to decrease at the 38 and 23-cm depths soon after the onset of flooding. Oxygen content remained near zero at these depths for 3 days. However, the 8-cm depth was not flooded completely until 16 hours after flooding began, after which the $O_2$ content at this depth decreased at an average rate of 0.64%/hour for 14 hours. The mean $O_2$ content at the 8-cm depth remained about 4% until drainage. After 4 hours of drainage, $O_2$ began to increase at the 8 and 23-cm depths, and continued to increase for 2 days, when it reached 14%. Oxygen at the 38-cm depth did not change appreciably during this time.

### Tobacco Growth

Figure 2 shows the increase in total plant leaf area that occurred in a 6-day period after the onset of flooding. The control and the 12-hour flooding treat-

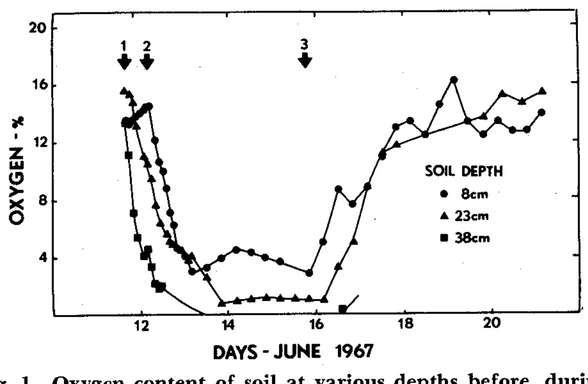


Fig. 1. Oxygen content of soil at various depths before, during, and after a 96-hour flooding period. Arrows 1, 2, and 3 indicate beginning of flooding, completion of flooding, and beginning of drainage, respectively.

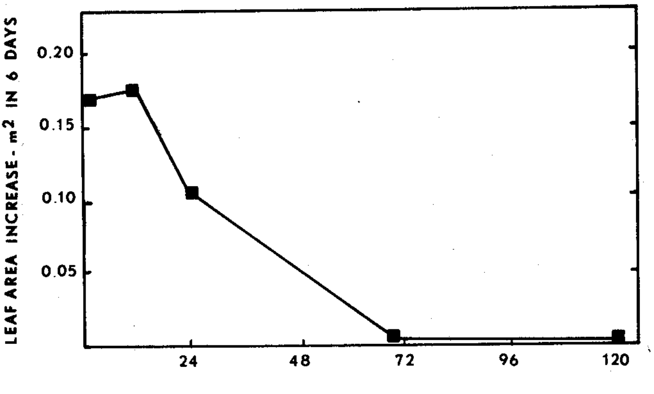


Fig. 2. Leaf area increase within a 6-day interval after flooding for various flooded periods in 1968.

ments had equal leaf area increases. The area increase for the 24-hour treatment was 40% less than the control. Leaf area for the 72 and 120-hour flooding treatments did not change during the 6-day observation period.

In 1967, flooding of any duration reduced plant height, stalk diameter, leaf length, and leaf width; however, only the growth for treatments flooded for 24, 48, and 96 hours were significantly less than the control (Table 1).

Dry leaf, stalk, and root weights for various flooding treatments show that inundation for 24 hours or more severely retarded the tobacco growth rate (Table 2). Dry matter production for the 12 and 24-hour treatments was 12 and 45% below that of the control, respectively. Plants flooded in 1967 and 1968 for 48 hours or more developed a few new, poor-quality leaves on the upper part of the stalk by time of last harvest, but the yields were less than 35% of that of the control plants.

## Dry Leaf Yield

Inundation for longer than 12 hours decreased dry leaf yield in both 1967 and 1968 (Fig. 3). The dry weight yield of the 24-hour treatment was significantly less than those of the control and the 12-hour treatments in 1967, but not in 1968. This difference in yields between years for the same treatment was attributed to stage of plant development at the time of

Table 1. Tobacco growth 27 days after flooding in 1967.

| Flooding duration | Leaves/ plant | Plant height | Stalk diameter | Single leaf Length | Single leaf Width |
|---|---|---|---|---|---|
| hours | | cm | | | |
| 0 | 20 | 183 | 3.6 | 60 | 38 |
| 12 | 19 | 178 | 3.5 | 58 | 35 |
| 24 | 16 | 136 | 2.9 | 52 | 31 |
| 48 | 12 | 90 | 2.7 | 49 | 24 |
| 96 | 11 | 61 | 2.7 | 42 | 22 |
| LSD, P=0.05 | 6 | 18 | 0.2 | 8 | 7 |

Table 2. Yields of leaves, stalks, and roots of flue-cured tobacco at the end of the leaf harvest in 1967 for several periods of flooding.

| Flooding duration | Leaves | Stalks | Roots | Total |
|---|---|---|---|---|
| hours | g/plant | | | |
| 0 | 157 | 108 | 77 | 342 |
| 12 | 136 | 94 | 70 | 300 |
| 24 | 82 | 53 | 51 | 186 |
| 48 | 55 | 34 | 19 | 108 |
| 96 | 49 | 27 | 7 | 83 |

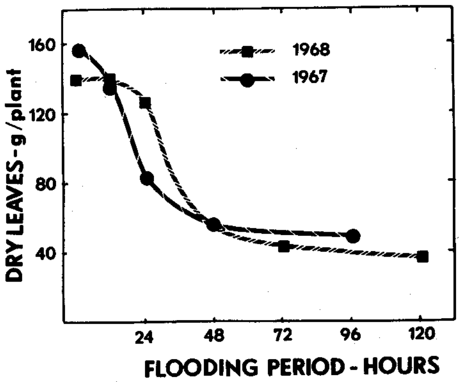


Fig. 3. Dry leaf yield for different periods of flooding.

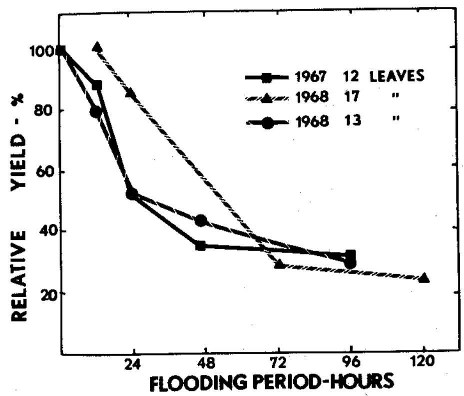


Fig. 4. Relative yield of dry tobacco leaves in relation to length of flooding period.

flooding; plants were flooded at the 12-leaf stage in 1967 and at the 17-leaf stage in 1968. To confirm this observation, a second crop was grown and flooded at the 13-leaf stage. Relative yields for the 1967 crop and both 1968 crops are plotted for various periods of flooding in Fig. 4. Flooding at the 12 to 13-leaf stage damaged plants considerably more than flooding at the 17-leaf stage.

## Cured Leaf Yield, Grade, and Value

Flooding for longer than 24 hours significantly reduced flue-cured yield of tobacco (Table 3). During the period between flooding and harvesting, the lower leaves of the flooded plants appeared yellow and matured earlier than leaves at similar positions on the control plants. Lower leaves of plants flooded 12 hours matured later than those of plants flooded for longer periods.

Grade, as it affects the value of tobacco, is given as grade index[3] and is expressed as price per unit weight. Lower grade index values were associated with longer flooding, but grade index differences between flooding treatments were not significant. Values relative to the control for various flooding periods are presented in Table 3. Relative-yield values for the 12-hour and control treatments were essentially the same, with a 13% decrease for the 24-hour

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

**Table 3. Flue-cured leaf yield and relative value of tobacco grown in lysimeters and flooded for various periods of time; 1968.**

| Flooding period | Cured leaf weight | Grade index | Relative value |
|---|---|---|---|
| hours | g/plant | $/kg | |
| 0 | 167 | 1.23* | 100 |
| 12 | 171 | 1.26 | 105 |
| 24 | 145 | 1.23 | 87 |
| 72 | 51 | 1.15 | 29 |
| 120 | 43 | 1.20 | 25 |
| LSD, P=0.05 | 30 | ns | |

* Based on average prices paid for graded flue-cured tobacco in 1967 and 1968.

**Table 4. Reducing sugars, total alkaloids, and the ratio of reducing sugars to alkaloids of tobacco leaves for different flooding periods in lysimeters.**

| Flooding period | Reducing sugars | Total alkaloids | Sugar to alkaloid ratio |
|---|---|---|---|
| hours | % | | |
| 0 | 11.8 | 1.26 | 12.3 |
| 12 | 15.8 | 0.76 | 22.2 |
| 24 | 14.8 | 0.90 | 16.9 |
| 72 | 6.7 | 0.97 | 6.9 |
| 120 | 5.5 | 0.62 | 8.4 |
| LSD, P=0.05 | 5.2 | 0.42 | 7.9 |

treatment and more than a 72% decrease for the 72 and 120-hour treatments.

Reducing sugars, total alkaloids, and the ratio of sugars to alkaloids are factors used in judging tobacco quality[4] (Table 4). Tobacco grown in soils that are kept wet will usually have a lower alkaloid content and a higher sugar content than tobacco grown in relatively dry soil (1, 2). Plants flooded for 12 and 24 hours had higher reducing sugar contents than the control, but sugar percentages for the 72 and 120-hour treatments were significantly less than that of the control. Flooding for 12 hours reduced total alkaloids of the tobacco. The ratio of reducing sugars to total alkaloids for the 12-hour flooding treatment was substantially higher than either the control or the other flooding treatments.

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

## Field Observations

In June 1968, 13.7 cm of rain fell within 5 days and flooded part of the border. Plants growing in this rain-flooded area lost their turgor or, according to local terminology, "flopped." Similar symptoms were observed in commercial tobacco fields.

The dry leaf yield was significantly higher ($P \geq 0.05$) from the surface-drained area (162 g/plant) than from the rain-flooded area (99 g/plant). Leaf yield from the surface-drained area was similar to the yield of control plants from the lysimeters when the water table was maintained at the 60-cm depth throughout the growing season.

## CONCLUSIONS

Tobacco is usually planted on better drained soils, but even with careful land selection, high intensity rainfall or extended periods of low intensity rain may cause flooding, low $O_2$ levels in soil, and yield loss within certain field areas. Under flooded conditions $O_2$-depletion occurred within a 24-hour period after the onset of flooding, and yields of tobacco were reduced when plants were flooded for periods exceeding 24 hours. Therefore, adequate field drainage should be an important land preparation step of the preplant operation.

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