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Effect of Different Moisture Stress Levels on Corn Growth in Field Lysimeters

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Abstract
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Keywords
Drainage, Irrigation, Subirrigation, Lysimeters, Corn

Disciplines
Agriculture | Bioresource and Agricultural Engineering

Comments
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N. Ahmad, R. S. Kanwar

ABSTRACT

Experiments were conducted in field lysimeters to investigate the effects of high water table positions (created by subirrigation practice) on corn growth. Various plant growth parameters (plant dry matter, canopy height, and yield) were measured before, during, and after the excessively wet periods. Two regression models were developed to characterize corn yield production as a function of durations of excessively wet periods and water-table positions. Results indicated that subirrigation practices can improve corn growing conditions. Less corn yield reduction occurred when water tables were maintained at 15 cm than when water tables were maintained at the soil surface during the six-leaf stage. **KEYWORDS.** Drainage, Irrigation, Subirrigation, Lysimeters, Corn.

INTRODUCTION

In designing agricultural drainage systems, it is important to know the drainage requirements of crops. Excessive soil-water conditions inhibit air exchange between soil and the atmosphere, resulting in oxygen deficiency. This subsequently inhibits both root respiration and total root volume, as well as water and nutrient transport by plant roots. It also facilitates the formation of toxic compounds in soil and plants. The degree of crop susceptibility to damage by excessive soil-water conditions is dependent upon plant species, plant-development stage, soil and air temperatures, and duration of waterlogging. Considerable variation in excess-water tolerance exists between and within plant species (Gilbert and Chamblee, 1965).

The timing, duration, and amount of soil-water in the root zone during crop growth periods affect final grain yield and the extent of injury to plants. Joshi and Dastane (1966) observed that flooding corn at the preflowering stage reduced yields significantly and that the longer the duration of flooding, the greater was the damage. Mukhtar et al. (1990) concluded that flooded corn was more susceptible to grain yield reduction at the early vegetative stage than at the late vegetative stage. However, Evans and Skaggs (1984) observed that flooded corn was more susceptible to grain yield reduction when flooded at the late vegetative stage. Most other studies concluded that the greatest crop damage and the maximum yield-reduction occurred during the early vegetative stage (Leyshon and Sheared, 1974; Kanwar et al., 1988; Fausey et al., 1985; Bhan, 1977; Chaudhary et al., 1975; Cannell et al., 1980; Mason et al., 1987; Zolezzi et al., 1978; Howell and Hiler, 1974; Ritter and Beer, 1969; Singh and Ghildyal, 1980).

To identify the optimal root environment for improving plant yield, some researchers have attempted to describe the relation between crop yield and excess soil-water conditions. Sieben (1964) introduced the concept of the sum of the water-level exceedance values, known as the “sum of excess water” (SEW30), which relates yield reduction to a high water-table during the growing season. Hiler and Clark (1971) proposed methods for characterizing crop susceptibility (CS) values in controlled situations and in the field. Ravelo et al. (1982) and Hardjoamidjojo et al. (1982) used the stress-day index (SDI) model, introduced by Hiler (1969), to measure the degree of stress caused to plants under excessive soil-water conditions. Williamson and Kriz (1970) used lysimeters to determine that most crops gave maximum yield when the water table was at 30 cm.

To design drainage and subirrigation systems, the designer needs to know which crop stages are sensitive to excessive soil-moisture conditions. An optimal moisture level for a crop may cause a nonsignificant yield response to wetness under given climatic and agronomic conditions. A study that focuses on the range of stress levels, from least to critical, during a crop’s sensitive growth stages can help determine the optimal soil moisture needs of plants. Additionally, it is important to quantify the adverse effects of high water tables in terms of growth rate and yield. Very few studies have quantified the effects of water table position on crop growth. Therefore, the overall objective of this study was to investigate the response of corn to two water-table positions (at the surface and 15 cm below the surface) during the vegetative stage, when corn is most sensitive to excess water. Each water-table position was maintained for four different durations.

MATERIALS AND METHODS

EXPERIMENT SITE

The experiment site for this study was at the Iowa State University Research Center in Ankeny, Iowa. The soils at this site are predominantly Nicollet loam soils in the Clarion-Niccollet-Webster Soil Association. Nicollet soils are characterized as naturally somewhat poorly drained...
TABLE 1. Particle-size distribution, gravel percentage, and soil reaction of Nicollet loam soil (from Charkhabi, 1990)

| Depth (cm) | Sand (%) | Fl. Silt (%) | Co. Silt (%) | Clay (%) | Gravel* (%) | pH^ | t  
|-----------|----------|--------------|--------------|----------|-------------|------|---
| Ap 0-15   | 29.5     | 11.3         | 33.0         | 26.2     | 0.1         | 5.9  |   
| A1 15-25  | 28.7     | 13.1         | 32.1         | 26.1     | 0.4         | 6.1  |   
| A2 25-46  | 31.5     | 17.2         | 23.2         | 28.1     | 0.2         | 6.6  |   
| AB 46-56  | 34.4     | 10.8         | 27.4         | 27.4     | 1.1         | 7.0  |   
| Bw 56-76  | 38.6     | 9.2          | 24.9         | 27.3     | 2.2         | 7.1  |   
| BC 76-86  | 31.0     | 11.8         | 23.5         | 24.7     | 1.9         | 7.2  |   
| CI 86-102 | 40.1     | 10.8         | 26.8         | 22.3     | 3.0         | 7.7  |   
| CI 102-117| 38.2     | 12.0         | 30.2         | 19.6     | 2.0         | 7.8  |   
| CI 117-135| 39.2     | 11.8         | 29.1         | 19.9     | 2.2         | 8.0  |   
| C2 135-160| 38.6     | 12.6         | 29.0         | 19.8     | 1.5         | 8.1  |   

Gravel: Percentage based on volume.

* pH: 1:1 soil and water ratio.

soils. Some of the physical properties of these soils are given in Table 1. An area 15 m x 40 m was selected for this experiment. Eighteen box-type lysimeters were constructed and installed. Figure 1 shows the topographic map of the site and the layout of the lysimeters.

CONSTRUCTION OF THE LYSIMETERS

Five 6.2 mm-thick PVC plastic sheets (one for each of the four sides of a rectangular box and one for the bottom) were placed together and bolted by using aluminum angle iron to create each of the 24 box-type lysimeters.

Each lysimeter was 229 cm long, 90 cm wide, and 152 cm deep (fig. 2). The corners of the lysimeters were treated with silicone sealant to make them waterproof. Ten centimeters from the bottom of the lysimeter, a 7.6-cm hole was made on one side. An aluminum pipe passed through this hole connected the lysimeter and the water sump. A 10-cm diameter and 220-cm long plastic tile drain with a cap at the end was clamped to the aluminum pipe. The outside of the aluminum pipe was coupled with a 5-cm diameter PVC pipe connecting the water sump to the lysimeter (fig. 2). The water sump was a 183-cm long capped PVC pipe 38 cm in diameter. An adjustable float system was installed in the water sump to control the water level.

LYSIMETER INSTALLATION

The soil profile was excavated in 30-cm layers to a depth of about 150 cm by using a grave-digging machine. Each layer of soil was separated by a plastic sheet and a wooden board. Once the excavation was completed, a lysimeter box (without water sump) was placed in the excavated area, and each soil layer was repacked and compacted inside the lysimeter to match the original vertical soil profile. The water sump then was connected to the lysimeter and to the plastic tile drain. The bottom 30 cm of area around the sump was filled with fine concrete, and the rest of the area to the surface was filled with excavated soil. The same procedure was repeated for the installation of all other lysimeters.

INSTRUMENTATION OF THE LYSIMETERS

To determine the actual position of the water table in the lysimeter, a plastic tube (2.54 cm in diameter and 150 cm long) was installed in the center of the lysimeter. A neutron access tube was installed in each of the lysimeters for determining the soil moisture. To measure moisture tension, two tensiometers were installed in each lysimeter at depths of 30 and 60 cm.

PLANTING

Thirty-six corn seeds (Pioneer 3751) were planted in each lysimeter on 10 May 1990, and then thinned to 18 plants per lysimeter. Three plants were harvested before the beginning of water table treatments. Three plants were harvested after 24 days, when all treatments were over. Twelve plants were kept in each lysimeter until final harvest for grain yield analysis. Fertilizer application rate of 200 kg N (urea), 60 kg P (P2O5), and 60 kg K (K2O) per hectare was applied before sowing on 8 May 1990.

WATER TABLE TREATMENTS

This experiment consisted of nine treatments, each replicated twice. Eight water-table treatments were started at the sixth leaf stage, maintaining water tables at two different positions (either at the surface or 15 cm below the surface). Each water-table position was maintained for four
different durations. The ninth treatment was the control treatment where the water table was maintained at 90 cm.

Durations of water table were selected to apply the same level of stress (Sieben's SEW30 concept) at each of two different water-table positions (0 and 15 cm below the soil surface). Sieben (1964) introduced the concept of SEW30 which quantifies the wet stress by summation of days times water table in the top 30 cm of the soil profile by using the following equation:

\[ \text{SEW30} = (30 - \text{WTD}) \times n \]

where WTD is the daily water table depth on day i, and n is the number of days. Water was raised and maintained in the lysimeters by adjusting the float system in the water sump to a desired position. At the end of the water table treatment, or after any major rain event, water was pumped out of the sump. Table 2 gives the details of these treatments. Because the experimental design was a randomized complete block, all nine treatments were applied to each row (block) of lysimeters and repeated.

Before and after the treatment, the water table was maintained at 90 cm in all lysimeters. Surface irrigation was applied when the soil water tension reached more than 45 kPa.

**RESULTS**

**GRAIN YIELD**

Grain yield of corn was affected by the duration of subirrigation. Figure 3 gives the relationship between the duration of subirrigation and average grain yield per plant. This figure shows that the effect of surface flooding was much more severe than when the water table was 15 cm below the surface. Figure 3 also indicates that grain yield for the control treatment (when water table was kept at 90 cm depth) was significantly greater (at 5% level) than for high water-table treatments. When the water table was maintained at the surface, grain yield decreased significantly (at 5% level) with the increased duration of subirrigation (6 and 12 days of subirrigation) but no significant difference was found between 6 and 9 days of subirrigation duration. When the water table was maintained 15 cm below the surface, grain yield decreased as the subirrigation duration increased from 6 to 18 days, although differences were not statistically significant (at 5% level). Another interesting observation was that the grain yield increased when subirrigation duration was increased from 6 to 24 days maintaining the water table 15 cm below the surface. Percentage of grain-yield reductions obtained from each of the eight water table treatments in comparison with the control treatment also were calculated. Results indicated that as subirrigation duration increased, grain yield decreased where water table was maintained at the surface. The maximum percentage grain-yield reduction of 51.1% occurred for 12 days of subirrigation maintaining the water-table at the surface and was more severe than the percentage yield reduction of 32.5% for 18 days of subirrigation maintaining the water table 15 cm below the soil surface. The range in percentage yield reduction (51.1 - 27.1 = 24.0%) also was greater for a surface water table than for water table 15 cm below the soil surface (32.5 - 17.6 = 14.9%).

**TABLE 2. Water table treatments**

<table>
<thead>
<tr>
<th>Duration of stress due to excessive wetness (days)</th>
<th>Depth of water table beneath the soil surface (cm)</th>
<th>Daily Stress SEW30 values (cm-day)</th>
<th>Total Stress SEW30 values (cm-day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water table at the soil surface*</td>
<td>3 0 30</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0 0 30</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0 0 30</td>
<td>270</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>0 0 30</td>
<td>360</td>
<td></td>
</tr>
<tr>
<td>Water table at 15 cm below the soil surface</td>
<td>6 15 15</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>15 15 15</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>15 15 15</td>
<td>270</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>15 15 15</td>
<td>360</td>
<td></td>
</tr>
</tbody>
</table>

* Actually water table position was about 3 cm above the surface.

Figure 3-Grain yield as a function of duration of subirrigation and water table position (at the surface and 15 cm below the surface) for the year 1990.
Linear regression models between grain yield and subirrigation duration also were developed (Table 3). These equations show that at both water-table positions, the average grain yield decreased linearly with increased subirrigation duration. The high R² value of 0.99 for the surface water-table model explains more than 99% of the variability. The reason for the lower R² value of 0.47 for the 15-cm-deep water table is a larger variability between subirrigation durations.

**SHOOT DRY MATTER**

The first response of the corn plants to moisture stress was notice in reduced shoot growth. Both water-table positioning had a significant effect on dry matter production, but greater reduction was observed in lysimeters with surface water tables than with those with water-tables 15 cm below the surface. Figure 4 shows the differences between shoot dry matter with the increase in subirrigation duration for both water-table positions. Shoot dry matter decreased significantly between 3, 6, and 12 days of subirrigation. No significant differences were found in shoot dry matter between 6, 12, and 24 days of subirrigation. When the water table was kept at the 15 cm depth, no significant differences were found in shoot dry matter between 6 and 24 days, but significant differences (at 5% level) existed between 6, 12, and 18 days of subirrigation. The percentage decrease in shoot dry matter as affected by the water table position, was also calculated. This percentage reduction was greater for the surface water level (56.2 - 28.5 = 27.7%) in comparison with the water table at 15 cm depth (36.9 - 20.3 = 16.6%).

The percentage of shoot growth reduction (PGR) was calculated for all treatments. These calculations were made by harvesting plants 36 and 60 days after planting. Figure 5 indicates that shoot growth reduction was greater for the surface water-table treatment than when the water table was maintained at 15 cm below the surface. Percentage growth reduction increased with the duration of subirrigation for both water table positions with one exception when water table was maintained at 15 cm depth for 18 days. Table 3 gives the regression models between dry matter at crop harvest time and subirrigation duration.

**CANOPY HEIGHT**

Figures 6 and 7 show relationships between days after planting and canopy height for different subirrigation durations and water table positions. These figures show that canopy height decreased at both water-table positions in comparison with the control treatment, but the effects were more significant for the surface water-table treatment.

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**TABLE 3. Relationship between subirrigation durations and corn growth parameters (grain yield and shoot dry matter)**

<table>
<thead>
<tr>
<th>Water table position (cm)</th>
<th>Variable</th>
<th>Type of statistical model</th>
<th>Regression equation</th>
<th>R²-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>At the surface</td>
<td>Grain yield</td>
<td>Linear</td>
<td>Yield = 159.45 - 5.39 X</td>
<td>0.99</td>
</tr>
<tr>
<td>15 cm below the surface</td>
<td>Grain yield</td>
<td>Linear</td>
<td>Yield = 162.64 - 1.05 X</td>
<td>0.47</td>
</tr>
<tr>
<td>At the surface</td>
<td>Shoot dry matter</td>
<td>Linear</td>
<td>DM = 98.47 - 3.62 X</td>
<td>0.96</td>
</tr>
<tr>
<td>15 cm below the surface</td>
<td>Shoot dry matter</td>
<td>Polynomial (2-degree)</td>
<td>DM = 127.38 - 5.37 X + 0.16X²</td>
<td>0.76</td>
</tr>
</tbody>
</table>

\[ X = \text{Duration of subirrigation in days.} \]

\[ DM = \text{Shoot dry matter in grams/plant.} \]

\[ Y = \text{Grain yield in grams/plant.} \]

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**Figure 5—Percent shoot growth reduction as a function of duration of subirrigation and water table position (at the surface and 15 cm below the surface) for the year 1990.**

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**Figure 6—Canopy height as a function of days after planting for various subirrigation durations when water table was kept at the surface for year 1990.**

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* 3 PGR = \[ \frac{1 - \text{Growth (treatments)}}{\text{Growth (control)}} \] \times 100.

Growth = \{ shoot dry weight (after treatment – before treatments) \}. 

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**Figure 4—Shoot dry matter as function of duration of subirrigation and water table position (at the surface and 15 cm below the surface) for the year 1990.**

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**Figure 7—Canopy height (cm) as a function of days after planting for various subirrigation durations when water table was kept at the surface for year 1990.**
compare the differences in crop growth due to excess water-stress levels. This study resulted in the following:

- Height, dry matter weight, and grain yield were collected to
- Canopy growth stages. Eighteen lysimeters (229 x 90 x 152 cm)
- Subirrigation practices on corn growth during the early vegetative period than during the late vegetative period
- Grain yields and dry matter concentrations of barley.
- Two regression models were developed, one for each water-table position, to characterize grain yield production as a function of subirrigation duration.

These figures also show a greater spread in canopy heights for all four durations for the surface water-table treatment than for the water table at 15 cm below the surface. The maximum canopy height of 212 cm was observed for the control treatment and the lowest canopy height of 136 cm.

**DISCUSSION**

Corn yields varied in response to both water-table positions (surface and 15 cm below the soil surface) and to durations of subirrigation for each water table position. Yield variations were greater for the surface water table treatment than for the treatment with the water table 15 cm below the soil surface.

Visual observation indicated marked differences in growth parameters (shoot dry matter and canopy height) between the two water-table positions. Growth was nearly halted under longer periods of maintaining water tables at the surface, which was not true when water tables were 15 cm below the soil surface. Grain yields and dry matter were greater after 24 days of subirrigation than after 18 days of subirrigation maintaining water tables 15 cm below the surface. This unexpected result might be because corn is more sensitive to high water tables during the early vegetative period than during the late vegetative period (Kanwar et al., 1988; Mukhtar et al., 1990). These results suggest that corn yield could be increased in poorly drained soils with proper management of subirrigation practice. Therefore, more studies need to be conducted on crop response to subirrigation practices.

**SUMMARY**

A study was conducted to determine the effect of subirrigation practices on corn growth during the early growth stages. Eighteen lysimeters (229 x 90 x 152 cm) were constructed and installed in the field. Data on canopy height, dry matter weight, and grain yield were collected to compare the differences in crop growth due to excess water-stress levels. This study resulted in the following conclusions:

- Both corn yield and plant growth were significantly different (at 5% level) under two water-table positions (water table 15 cm below the surface and at the surface).
- The percentage shoot dry-matter loss, due to excessive wetness, after 110 days of planting was less than the percentage shoot dry-matter loss after 60 days of planting. This indicates that corn plants have the ability to survive after the removal of moisture stress. Nonetheless, stress effects were persistent until harvesting time.
- At harvest, growth parameters (shoot dry matter, canopy height, corn yield) showed significant differences (at 5% level) in growth in relation to excess soil-water conditions.

**REFERENCES**


