Excessive Soil Water Effects at Various Stages of Development on the Growth and Yield of Corn

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Disciplines
Agriculture | Bioresource and Agricultural Engineering | Soil Science | Water Resource Management

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R. S. Kanwar, J. L. Baker, S. Mukhtar

ABSTRACT

The response of corn to naturally fluctuating water tables at five different stages of growth was studied for 3 years. Fifty plots of 15 m x 15 m were established in 1984 on Nicollet soil in an area that is not artificially drained. In the center of each plot, an observation well was installed for water-table measurements. Water-table hydrographs were developed for each plot annually to quantify crop stress factors from excessive wetness (SEW$_{30}$, a summation of days times the height of the water table above 30 cm).

The results of these studies indicate that SEW$_{30}$ values of as low as 40 cm-days in the early part of the growing season can significantly reduce corn yields. Corn yields decreased linearly with the increase in SEW$_{30}$ values and the Stress Day Index (SDI). Lower corn yields resulted from both decreased plant population and poor crop growth due to excessive wetness.

INTRODUCTION

An adequate supply of soil water is essential for plant growth and for transporting plant nutrients to roots, but excess water in the root zone is a problem for most crops. Excess soil water can result in reduced yields in a variety of ways. If it takes longer for soil to dry out in the spring, planting may be delayed. If the seeds are planted in relatively wet soils, the seeds may fail to germinate or may die soon after germination. If waterlogging (when soil pores are filled with water for an appreciable length of time) occurs after germination, the young plants may not survive. High water tables in the field will restrict the growth of roots, rendering plants more susceptible to disease, nutrient deficiency, and drought. Two particular problems could be the deficiency of nitrogen due either to leaching or to denitrification and the development of toxic substances, both caused by lack of oxygen in the soil.

Kanwar et al. (1983, 1984) have reported the results of a field survey designed to assess the extent of crop production losses due to inadequate drainage in a large agricultural watershed of Iowa. The results of this study indicated that inadequate drainage is responsible for average crop production losses equal to 32% of the maximum production potential, and in very poorly drained areas (with excessive soil water conditions), 100% crop production losses are expected in 4 out of 10 years.

The response of crops to drainage in relation to fluctuating water table heights is not well understood (Bouwer, 1974; Belford, 1981; Hiler, 1977). Most of the available research data indicate that crops vary significantly in response to time and duration of flooding. Ritter and Beer (1969) reported reduced corn yields when inundation occurred at the early stages of corn growth. They observed no significant damage to the plants after 96 h of continuous flooding when the corn had reached the silking stage. Joshi and Dastane (1966) found that flooding maize at the preflowering stage reduced the yields and the longer the duration of flooding, the greater was the damage. Alvino and Zerbi (1986) reported that the differences in grain yield between the water regimes they studied were due to the low number of seeds per ear at shallow water-table levels and to the percentage of sterile plants at the deep water-table levels. Several other studies have also indicated that maximum crop damage was observed when flooding occurred at the early stages of growth (Bhan, 1977; Chaudhary et al., 1975; Cannell et al., 1980; Fausey et al., 1985; Zolezzi et al., 1978; Howell et al., 1976; Singh and Ghildyal, 1980; DeBoer and Ritter, 1970). Patwardhan et al. (1986) provide an excellent review on crop response to excessive moisture. These research reports have concluded that the duration of flooding and its timing in relation to the stage of crop development have considerable effect on yield. High water tables during the seedling stage can be fatal, whereas a well developed corn crop is likely to suffer relatively little damage from similar conditions. Purvis and Williamson (1972) reported that plants might be able to survive a flooded environment by increasing the number of their adventitious roots.

The real problem, due to excessive soil-water conditions in the humid regions, is the inadequate aeration of the plant's root system (Carter, 1986; Sojka, 1986; Tondreau et al., 1976; van Schilfgaarde and Williamson, 1965; Wesseling, 1974). Excessive soil water conditions in the root zone are always accompanied by oxygen deficiency, and the roots are injured if continuous waterlogged conditions prevail (Williamson and Kriz, 1970; Bradford and Yang, 1981; and Williamson and van Schilfgaarde, 1965). Most crops respire by gaseous exchange in the root zone, whereby plant roots absorb oxygen from the soil air and release carbon dioxide. In high water table soils, oxygen deficiency severely restricts plant respiration, which directly affects the growth of roots and their ability to absorb nutrients. Oxygen diffuses through air-filled pores about 10,000 times.
faster than through water-filled pores, and consequently, the diffusion rate of oxygen through water is often the limiting factor in root respiration (Clark and Kemper, 1967).

Shallow water tables exist naturally in many agriculturally productive areas of the U.S. Drainage requirements of soils in the high water-table areas are generally unknown. By experience, it has been found that subsurface drains placed at depths of 1 m in humid areas usually give satisfactory results (Tondreau et al., 1976). Van Schilfgaarde and Williamson (1965) found that the maximum yield of soybeans in fine sandy loam with only subsurface watering occurred at a water-table depth of 30 cm, but in their field lysimeter experiments they found that the maximum yield occurred at a water-table depth from 45 to 60 cm. Benz et al. (1982, 1983) have found that the water-table depth for maximum yield of alfalfa was 1.5 m and that irrigation was unnecessary when the water table was maintained at this optimum depth. Williamson and Kriz (1970) reported that the optimum water-table depth was 0.8 m for corn on a loam soil, and Goins et al. (1966) reported optimum water-table depths of 0.8 to 0.9 m for corn on silty clay loam and loam soils.

Several possible drainage requirement criteria have been mentioned in the literature (Bouwer, 1974; Hiler, 1977; and Wesseling, 1974). Most of these design criteria were established on the basis of experiments conducted either in growth chambers or field-type lysimeters where the water table was kept constant for a certain period. In practice, the water table is rarely static. Very little work has been reported where field data on crop response to drainage were collected in areas under naturally fluctuating water table conditions. The purpose of this paper is to report results of a field experiment designed specifically to study the response of corn to naturally fluctuating water table in an undrained area and to develop seasonal crop stress factors from excessive wetness data in relation to corn yields.

METHODS AND MATERIALS

A field experiment was conducted to determine the response of corn to excessive wetness. The experimental site for this study was located at the Iowa State University's Woodruff Farm near Ames, IA. The experimental site was established in the spring of 1984 in an area with slopes of about 0 to 5%. The soils at the experimental site are predominantly Nicolett soils in the Clarion-Niccollet-Webster Soil Association (the Clarion soils are naturally well drained; the Nicolett soils are naturally somewhat poorly to poorly drained; Webster soils are poorly to very poorly drained and occur in slight depressions and nearly level areas). Fig. 1 gives the relationship of parent material, topography, and soils in the Clarion-Niccollet-Webster Soil Association. Fig. 2 shows the topographic features of the experimental area. This area is gently sloping (the slope of the land seems to affect the fluctuations in the water table) and does not have any artificial subsurface drainage system; thus, this

![Fig. 1](image1.png)  
Fig. 1—Soil survey map and parent materials of soils in the Clarion-Niccollet-Webster Soil Association area.

![Fig. 2](image2.png)  
Fig. 2—Topographic map of the experimental site, and layout of the experimental plots. The contour lines are given in meters and the numbers indicate the location of observation wells.
area was considered suitable for conducting excessive moisture stress studies on corn.

Fifty plots of 15 m x 15 m were established. In the center of each plot, an observation well (180 cm long, 3.8 cm diameter plastic pipe with perforated sides and open bottom) was installed after corn planting and necessary fertilizer and pesticide applications. The approximate depth of observation wells was 165 cm from the ground surface. These wells were used to monitor water-table depths during the growing season. Fig. 2 also gives the location of observation wells and layout of the experimental plots.

Water-table depths were measured with a depth gauge three times a week; however, if a rainfall event was greater than 1.25 cm, daily water-table readings were taken for at least the next 5 continuous days. Data on water-table depths were collected during June through November (between planting and harvesting) for 3 years (1984-1986). The average water-table depths were calculated by constructing water-table hydrographs for each plot for the entire growing season. When the water-table receded below the 165 cm depth, the slope of the water-table hydrograph was used to estimate the water table below 165 cm depth. Daily rainfall data were also collected at the experimental site during the study.

All experimental plots were under no-till continuous corn between 1984 and 1986. Planting, harvesting, and chemical application data for this experiment are given in Table 1. Plant population counts were made approximately 3 and 6 weeks after planting and various other plant growth parameters were measured at least four times (every third week) during the growing seasons of 1985 and 1986. These plant growth parameters included plant canopy height, plant knuckle height, and dry-matter weight of plants.

Plant canopy height was measured as the distance from the ground surface to the top bending leaf. Five plants were randomly selected in each plot for such measurements, and the average plant canopy height for each plot was recorded. The same five plants were used to measure the knuckle height. Plant knuckle height was measured as the distance between the ground surface and the top knuckle (the rounded knob at plant stem joint) of the plant. About every 3 weeks, five randomly selected plants were cut at ground level, and dry matter weight of the plants was determined after drying at 140 °F.

At harvest, corn yields were measured from an area 13.5 m x 13.5 m surrounding each of the observation wells by using a combine equipped with a weighing bin. The dashed lines in Fig. 2 indicate the areas included in corn yield measurements. Corn yields were corrected to a uniform moisture content of 15.5% for final analysis. Relative yields were determined by dividing the measured yields by the highest corn yield for each production period. Highest yields were 6664, 5329, and 6742 kg/ha for 1984, 1985, and 1986, respectively.

The seasonal crop stress factors were calculated by using the water table data collected from each of the 50 observation wells. Water-table hydrographs were drawn between the water-table depths and day of the year. The water-table depth data for the days when water-table readings were not taken were interpolated by observing the slope of the hydrograph curves in relation to the rainfall pattern. Then, values quantifying the excessive soil water conditions (SEW 30) were calculated by using the following equation as originally defined by Sieben (1964).

\[
SEW_{30} = \sum_{i=1}^{n} (30 - X_i)
\]

where

- \(X_i\) = the water table depth below the ground surface in cm on day \(i\)
- \(n\) = the number of days in the growing season

Negative numbers inside the summation series were neglected; i.e., for computations only \(X_i\) values smaller than 30 are taken into account, so that the sum is a measure of depth above the 30 cm level (Wesseling, 1974). Larger SEW 30 values generally indicate poor drainage conditions. This concept is used in this paper to quantify excessive soil water conditions.

A statistical analysis systems program (SAS) was used to find the best fitted models between SEW 30 data for each growth stage and for the entire growing season (given as cumulative in Table 3), and relative corn yield for 1984, 1985, and 1986. Three mathematical functions (linear, exponential, and hyperbolic) were used to fit the data. The OLM (general linear model) subroutine of SAS was used for these analyses.

The stress-day index (SDI) concept, was used to quantify the cumulative effect of wetness on corn during the growing season. The stress-day index method was first used to schedule irrigations (Hiler and Clark, 1971; Hiler et al., 1974), but this concept was expanded to characterize drainage requirements of crops by Ravelo et al. (1982) and Hardjoamidjojo et al. (1982). Mathematically, the stress-day index concept has been expressed by Ravelo et al. (1982) and others as:

\[
SDI = \sum_{j=1}^{M} \left( CS_j \times SD_j \right)
\]

where

- \(M\) = the number of growth stages
- \(CS_j\) = the crop susceptibility factor for stage \(j\)
- \(SD_j\) = a stress day factor for stage \(j\).

The SEW 30 parameter was used as the SD factor in this study as suggested by Hardjoamidjojo et al. (1982). Hiler and Clark (1971) and Hiler et al. (1974) recognized that other factors such as genotype, soil type, fertility, temperature, etc., could affect the values of CS factors determined experimentally from one year to another.
### TABLE 2. NORMALIZED CROP SUSCEPTIBILITY FACTORS FOR CORN FOR EXCESSIVE SOIL WATER CONDITIONS (EVANS AND SKAGGS, 1984)

<table>
<thead>
<tr>
<th>Growth stage</th>
<th>Days after planting</th>
<th>Mean crop susceptibility factors (CS)</th>
<th>Normalized mean susceptibility factors (NCS)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establishment</td>
<td>18</td>
<td>0.28</td>
<td>0.16</td>
</tr>
<tr>
<td>Early Vegetative</td>
<td>36</td>
<td>0.32</td>
<td>0.18</td>
</tr>
<tr>
<td>Late Vegetative</td>
<td>56</td>
<td>0.65</td>
<td>0.38</td>
</tr>
<tr>
<td>Flowering</td>
<td>76</td>
<td>0.36</td>
<td>0.21</td>
</tr>
<tr>
<td>Yield Formation</td>
<td>100</td>
<td>0.10</td>
<td>0.06</td>
</tr>
</tbody>
</table>

*NCS = CSj / ∑j CSj  

Evans and Skaggs (1984) have suggested a concept of developing normalized crop susceptibility factors (NCS) by using the CS values. They found that this approach statistically eliminated these uncontrollable factors and allowed the

### TABLE 3. RELATIONSHIP BETWEEN CROP STRESS FACTORS (SEW30) AT DIFFERENT GROWTH STAGES OF CORN AND RELATIVE YIELD FOR CORN

<table>
<thead>
<tr>
<th>Year</th>
<th>Days after planting</th>
<th>Growth stage</th>
<th>Type of regression*</th>
<th>Regression equation†</th>
<th>R²-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>20</td>
<td>Establishment</td>
<td>L</td>
<td>Y = 0.82 - 0.0046S1</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Stage 1)</td>
<td>E</td>
<td>Y = -0.1386 - 0.0089S1</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H</td>
<td>Y = 1/(0.908 + 0.0245S1)</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>Early Vegetative</td>
<td>L</td>
<td>Y = 0.62 - 0.0035S2</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Stage 2)</td>
<td>E</td>
<td>Y = -0.42 - 0.0279S2</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H</td>
<td>Y = 1/(1.68 + 0.075S2)</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>Late Vegetative</td>
<td>L</td>
<td>Y = 0.809 - 0.0055S3</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Stage 3)</td>
<td>E</td>
<td>Y = -0.169 - 0.076S3</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>Flowering</td>
<td>L</td>
<td>Y = 0.809 - 0.0055S4</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Stage 4)</td>
<td>E</td>
<td>Y = -0.169 - 0.076S4</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>Yield Formulation</td>
<td>L</td>
<td>Y = 0.809 - 0.0055S5</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Stage 5)</td>
<td>E</td>
<td>Y = -0.169 - 0.076S5</td>
<td>0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H</td>
<td>Y = 1/(0.908 + 0.0245S5)</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>101</td>
<td>Stage 6</td>
<td>L</td>
<td>Y = 0.91 - 0.0005S6</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>thru harvest</td>
<td></td>
<td>E</td>
<td>Y = -0.054 - 0.0008S6</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H</td>
<td>Y = 1/(0.91 + 0.0025S6)</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cumulative</td>
<td>L</td>
<td>Y = 0.91 - 0.0005S6</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(planting thru harvest)</td>
<td>E</td>
<td>Y = -0.038 - 0.0005S6</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>H</td>
<td>Y = 1/(0.853 + 0.0015S6)</td>
<td>0.59</td>
</tr>
</tbody>
</table>

*L = Linear, E = Exponential, H = Hyperbolic  
†Y = measured relative corn yield, S1, S2, S3, S4, and S5 respectively, S6 is the stress day factor for the entire growing season.
analysis to concentrate on the influence of the water stress only. The CS values used in this paper to calculate the SDI were taken from Evans and Skaggs (1984) and are given in Table 2.

RESULTS AND DISCUSSION

Monthly variations in precipitation patterns as observed at the experimental site for the three growing seasons (1984, 1985, and 1986) are shown in Fig. 3. The year 1985 was relatively dry, with total growing season (April through October) rainfall of 44.2 cm; normal is 75 cm. Also during 1985, 70% of the rainfall occurred in August through October. Rainfall in 1984 and 1986 was greater than normal with total growing seasonal rainfall of 90.3 and 92.2 cm, respectively. In 1984, 68% of rain fell in early spring (April, May, and June), whereas in 1986 all months received greater than normal rainfall. Because of excessive wet conditions in May and early June, late planting was done (June 8 to 13). Earlier planting would have caused larger SEW30 values for 1984 and 1986.

The distribution of SEW30 and average water table depth across the experimental area was similar for the years 1984 thru 1986. For example, five plots (numbering 15, 25, 35, 24 and 26 in Fig. 1) gave the highest average SEW30 values during 1984 and some plots exhibited similar behavior in 1985 and 1986, but yielded highest average corn yields in 1985 (as no stress due to wetness occurred until 110 days after planting), this showed that during excessive wet years (1984 and 1986), the high water conditions were the principal factor affecting plant growth and yield. Other experimental plots have also exhibited similar water table response from year to year (except some plots had more damage due to weeds and surface runoff).

Effect of Stress Day Factors at Various Stages of Growth on Yield

Table 3 gives the relationships between the crop stress day factors for excessive soil water conditions, SEW30, for different stages of growth and the measured relative corn yields, RY, for the years 1984 through 1986. Although Evans and Skaggs (1984) used 18, 36, 56, 76 and 100 days after planting for growth stages 1 through 5, respectively, we used 20, 40, 60, 80 and 100 days after planting to represent plant growth stages 1 through 5, respectively, in this statistical analysis (Table 3). In 1984, excessively wet conditions occurred only in the early growing season (within 40 days after planting), and water-table levels were never above 30 cm for the rest of the growing season. In 1985, SEW30 values were not observed until 120 days after planting, whereas in 1986, excessive soil water conditions (giving non-zero SEW30 values) were observed throughout the growing season.

The results of the statistical analysis clearly indicate that for the 1984 data, the best fitting regression models are linear equations with coefficients of determination, R^2, of 0.62 and 0.27 for growth stages 1 and 2, respectively (statistically significant at the 5% level). Thus, the 1984 data (when excessive wet conditions occurred early) show that corn yields are most affected when excessive soil moisture conditions occur during the plant establishment stage; i.e., growth stage 1.

The 1986 results in Table 3 indicate that, the best fitting equations for growth stages 1 and 2 are linear, for stage 3 is exponential, and for stages 4 and 5 are hyperbolic, with R^2-values of 0.85, 0.78, 0.85, 0.94, and 0.76, respectively. This shows that relative corn yields are most affected by the SEW30 values at the flowering stage (stage 4) and least affected at the yield formation stage (stage 5). R^2-values of 0.85 at stages 1 and 3 show that the corn yields will be highly sensitive to the SEW30 values during the establishment and early vegetative stages.

The SEW30 data for stage 6 (day 101 thru harvest) for 1986 were also correlated with the relative corn yield. The best fitting curve for stage 6 was found to be linear with a R^2 value of 0.80 (Table 3). This R^2 value of 0.80 was higher than the R^2 values of stages 2 and 5. This indicates that the excessive wet conditions during stage 6 had more impact on yield than during stages 2 and 5.

Fig. 3—Relationship between relative corn yield and stress day factors for the years 1984 (Fig. 3a) and 1986 (Fig. 3b).
Effect of Stress Day Factors and Stress Day Index on Yield

The relative corn yields, RY, and the corresponding cumulative crop stress day factors, SEW$_{30}$, for the years 1984 and 1986 are plotted in Fig. 4. These figures show that relative corn yields ranged from 0.50 to 0.91 in 1984 and 0.75 to 1.00 in 1986 even at zero values of SEW$_{30}$. This could have been due to several factors. In some of these plots water-table depths were below 120 cm for more than 60 days continuously causing dry conditions both in 1984 and 1986. Also, damage due to runoff water was observed in plots 1, 11, 21, and 31 (these plots gave SEW$_{30}$ values of zero in 1984). Although these data show considerable scatter, there is a strong relationship between corn yields and crop stress day factors. The best fitting linear equations for 1984 and 1986 are also shown in Fig. 4 with coefficients of determination, R$_2$, of 0.60 and 0.85, respectively. For 1984 and 1986, although R$_2$ values are not very high, linear models are highly significant (at the 5% level), indicating that corn yields decrease with an increase in SEW$_{30}$ values.

Wesseling (1974) reported that, at SEW$_{30}$ values of 100 to 200 cm-days, there is a decrease in yield of cereal crops. But the data shown in Fig. 4 for the year 1984 indicate that even SEW$_{30}$ values as low as 40 cm-days in the early growing season can significantly reduce corn yields. For 1985, the data indicate that corn yields were not adversely affected by the increase in SEW$_{30}$ values. The regression model for 1985 data with R$_2$ value of 0.23 (statistically significant at the 5% level), in fact, suggests that corn yields may increase with the increase in SEW$_{30}$ values, which is contrary to 1984 and 1986 findings. This is because a drought occurred in 1985, and excessive wet conditions did not occur until September and October, which, in turn, did not have much adverse effect on crop yields (although there might have been some subirrigation effect during these and previous months, which resulted in better yields).

Stress Day Index, SDI, is a factor of practical significance that could be used in the design of drainage systems, indicating the amount of stress that plants can tolerate without any reduction in crop yields. Relative corn yields were related to the SDI by the best fitted linear equations of RY = 0.81 - 0.0228 SDI and RY = 0.90 - 0.0036 SDI for 1984 and 1986, respectively (Fig. 5). These relationships between RY and SDI are well defined and statistically highly significant. Data in 1984 show a more rapid decrease of RY with the increase of SDI primarily because excessively wet conditions in 1984 occurred only during stages 1 and 2, for which NCS values used were 0.16 and 0.18, respectively.

Relative yields are also plotted as a function of the average water table depths for 1984 and 1986 in Fig. 6. Each data point in Fig. 6 corresponds to one average water-table depth for the entire season for one experimental plot. Fig. 6 shows that maximum potential corn yield was obtained if the average water-table depth remained at the 67 cm depth for 1984 and at the 107 cm depth for 1986, even when fluctuating water tables depths of 30 cm were reached periodically. Also, Fig. 6 gives best fit curves between relative corn yields and average annual water table depths for 1984 and 1986.

Effect of Stress Day Factors on Plant Growth Parameters

Plant Population: Plant population (PP) and the corresponding stress day factors for 1986 are plotted in Fig. 7. The wide range in plant population was due to the fact that the poor germination rate resulted in lower plant population in five out of eight plots giving zero SEW$_{30}$ values. Data for 1986 suggested that maximum plant population was obtained at SEW$_{30}$ of 500-cm-days. Plant population data for 1985 are not shown in Fig. 7 because they did not give a statistically significant correlation. Data for 1985 gave an equation of PP = 53.25 + 0.17 SEW$_{30}$ with R$_2$ value of 0.07; this was because 1985 was a dry year and in most experimental plots shallow water tables were not observed until the latter part of the growing season (i.e., September and October). Plant population data for 1986 indicate that

![Graphs showing relationship between relative corn yield and stress day index for 1984 and 1986.](image-url)
excessively wet conditions had significant impact on the survival of young plants. Fig. 7 clearly indicates that increased values of SEW30 significantly decreased the plant population in very wet plots under fluctuating water table conditions. A linear regression model was fitted to the 1986 data giving an equation of \( PP = 47.7 - 0.0052 \text{SEW}_{30} \) with an \( R^2 \) value of 0.33.

**Plant Canopy and Knuckle Heights:** The relationships between the plant canopy and knuckle heights, and the corresponding SEW30 values for 1986 are shown in Fig. 8. The SEW30 values used in Fig. 8 for 1986 were calculated up to September 11, because plant canopy and knuckle heights, and dry matter weight data shown in Fig 8 were collected on September 11. The relations given in Fig. 8 clearly indicate a decrease in plant canopy and knuckle heights with an increase in SEW30 values. Slow and poor plant growth (thin plant stems, yellow leaves, shorter plant heights) and fewer plants per hectare were observed in plots where water tables were within 30 cm of the surface for many days during the early part of the growing season. Fig. 8 shows a very strong correlation between plant canopy and knuckle heights, and SEW30 values. Linear regression functions developed for relative plant canopy height (CAN) and relative knuckle height (KNUC) as a function of SEW30 values for 1986 are given as:

\[
\text{CAN} = 0.96 - 0.00030 \text{SEW}_{30} \quad (R^2 = 0.74) \\
\text{KNUC} = 0.95 - 0.00032 \text{SEW}_{30} \quad (R^2 = 0.68)
\]

**Plant Dry Matter Weight:** The effect of excessive soil moisture conditions on the relatively dry-matter weight (DMW) of plants is also presented in Fig. 8. The data shown in this figure are from 1986 and indicate that dry-matter accumulation is likely to decrease with the increase in SEW30 values. Similar response has been reported by van Schilfgaarde and Williamson (1965) in their studies conducted with the use of growth chambers. The following regression equation was obtained relating the relative dry-matter weight of plants (DMW) and SEW30 values (only for 1986 data).

\[
\text{DMW} = 0.83 - 0.00073 \text{SEW}_{30} \quad (R^2 = 0.78)
\]

**Grain Moisture Content:** Fig. 9 shows relationships between the moisture content of grain at harvest in percent (GM) and SEW30 values for 1984 and 1986. The linear functions developed for the data shown in Fig. 9,
Fig. 8—Relationship between relative plant canopy height, relative plant knuckle height, relative dry matter weight and stress day factor for the year 1986.

are:

\[ GM = 21.24 + 0.00446 \text{ SEW}_{30}, \quad R^2 = 0.36 \]  
(Year 1984)

\[ GM = 22.3 + 0.0038 \text{ SEW}_{30}, \quad R^2 = 0.66 \]  
(Year 1986)

These relations show that grain moisture content increased with the increase in the SEW\textsubscript{30} values, indicating delayed drying of corn under excessively wet conditions.

**SUMMARY**

Lack of information on crop response to drainage under naturally fluctuating water-table conditions prompted this study. Thus an experimental site was selected in an undrained area having naturally well drained to very poorly drained soils. This area is gently sloping up to a slope of about 5% and was considered suitable for studying the effects of excessive wetness at various stages of corn growth.

Field data on water table depths, plant height, dry matter weight, and crop yield were collected from 50, 15 m x 15 m plots during the growing seasons of 1984, 1985, and 1986. Water-table data were used to develop crop stress factors from excessive wetness (SEW\textsubscript{30} and SDI).

A statistical analysis computer program (SAS) was used to determine the effects of wetness at different stages of growth on corn yield. Data for 1984 indicate that, if excessive wet soil conditions occurred in the early part of the growing season, excessive wet conditions during the plant establishment stage (stage 1) will cause the maximum-reduction in corn yields. Data for 1986 show that, if excessive wet condition occur during the entire growing season, corn yields are most affected by the wet conditions at the flowering stage (stage 4).

Data on plant-growth parameters for 1985 indicate that plant population, canopy and knuckle height, and dry matter production decrease linearly with the increase in SEW\textsubscript{30} values. Grain moisture content at harvest seems to increase with the increase in wetness. The data on grain yield showed that corn yields decreased linearly with the increase in crop stress factors due to wetness. Poor conditions for plant growth in excessively wet areas resulted in poor corn yields.

Fig. 9—Relationship between grain moisture content at harvest and stress day factor for the years 1984 (Fig. 9a) and 1986 (Fig. 9b).
References


