Corn Growth as Affected by Excess Soil Water

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Abstract

In a two-year study, corn was subjected to controlled flooding during various physiological stages of growth by using specially constructed isolated field plots to determine how growth and grain yield were affected by excess soil water. Corn was most susceptible to flooding at the early-vegetative stage (36 days after planting) with maximum reductions in plant-canopy height, dry-matter production, and grain yield. Two-year averages of the crop susceptibility (CS) factors calculated from the yield data were 0.64, 0.44, 0.15, and 0.19 for early-vegetative, late-vegetative, flowering, and yield-formation stages of growth, respectively.

The SDI concept was tested by comparing the relative yield-SDI relationships for a nearby area with naturally fluctuating water tables using CS values obtained in this study. The SDI models indicated a linear decrease in the relative yield with increasing wetness (SDI values), but the best-fit regression lines of the yield-SDI data for the undrained area differed considerably between years.

Introduction

Excessive rainfall on poorly drained soils usually results in very high water tables or even temporary flooding. Planting delays, poor crop emergence, and reduced efficiency of farming operations are typical problems resulting from excessive soil wetness. In addition, poor soil aeration may reduce crop growth. Therefore, substantial crop yield losses due to inadequate soil-water drainage may occur (DeBoer and Ritter, 1970; Wesseling, 1974; Kanwar et al., 1984).

The degree of crop damage due to excessive soil wetness varies with plant species and duration and timing of flooding, or high water table conditions, during the growing season. Plant species that most rapidly produce adventitious roots suffer the least injury and have the greatest rate of recovery from flooding or excess soil-water stress (Kramer, 1951; Purvis and Williamson, 1972). Several experiments on crop response to controlled flooding (Joshi and Dastane, 1966; Ritter and Beer, 1969; Luxmoore et al., 1973; Bhan, 1977; Zolezzi et al., 1978) have indicated greater damage to plants and reduction in grain yields with longer periods of flooding. This adverse effect of longer flooding periods may be due to prolonged oxygen deficiency in the root zone.

The timing of excess soil-water conditions relative to plant-growth stage during active crop growth seems to play an important role in reduction of grain yields and the extent of injury to plants. Flooding at the pregermination stage can significantly reduce emergence (Fausey et al., 1985). Most studies conclude that the greatest crop damage and maximum yield reductions occur when soils are excessively wet during early stages of plant growth (Joshi and Dastane, 1966; Leyshon and Sheard, 1974; Howell et al., 1976; Patwardhan et al., 1986; Kanwar et al., 1988).

To provide drainage to avoid excessive wetness, effective drainage system designs are based not only on the evaluation of the soil properties affecting drainage, but also incorporate the drainage requirement criteria for the crops to be grown. Hiler (1969) proposed the stress-day index (SDI) concept as a quantitative means of determining the degree of stress (excess or deficit soil-water stress) imposed on a crop during its growing season. One of the components of SDI is the crop susceptibility (CS) factor that describes the plant susceptibility (or response) to stress and depends upon the species and the stage of development of a given crop. Field and lysimeter experiments have been conducted to determine values for CS factors for various physiological growth stages of corn and soybeans subjected to controlled flooding (Barkle and Schwab, 1984; Evans and Skaggs, 1984). Evans and Skaggs (1984) have suggested a concept of developing normalized crop susceptibility (NCS) factors by using the CS values. They found that this approach statistically eliminates the effects of factors other than flooding stress (e.g., genotype, soil type, fertility, and temperature) on the CS values determined experimentally from one year to another.

Previously, the SDI concept was utilized with soil-water deficits to schedule irrigations (Hiler et al., 1974). In recent years, CS values determined for crops subjected to excess soil-water stress have been used to calculate SDI values for soil water excesses. These indices have been used to predict relative crop yields for evaluating drainage system designs (Hardjoamidjojo et al., 1982; Ravelo et al., 1982; Desmond et al., 1985; Kanwar, 1988).

The purpose of the research reported herein was to assess the response of corn to temporary flooding with the following specific objectives:

1. To conduct experiments on specially constructed, isolated field plots to determine CS and NCS factors for corn subjected to controlled flooding at different physiological stages of growth.
2. To test the SDI concept by comparing the relationship

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between relative yields and SDI values (calculated from water table elevations and determined CS factors) for a nearby undrained area with naturally fluctuating water tables.

MATERIALS AND METHODS

EXPERIMENTAL SITE

The experimental site was located on land owned by Iowa State University within 2 km of Ames. The soil was a Nicollet loam (Aquic Hapludoll). Soils from the Nicollet series are characterized as somewhat poorly drained with seasonally high water tables. The surface slopes range from 1 to 3%. The experimental area was under no-till continuous corn production from 1986 through 1988, and flooding experiments were conducted during the 1987 and 1988 growing seasons.

Twelve experimental plots, each 3.0 m wide by 6.0 m long, were established during 1986. Figure 1 shows the topographic map of the site and layout of the plots (plots 7 and 11 were not included in this study). Four rows of corn (Pioneer 3475)*, 0.75 m apart (fig. 2) with an average 0.2 m plant-to-plant spacing were planted in each plot. At the same time, the areas between the plots were planted to avoid an island effect. Twenty days after planting, fertilizer (175-45-100, kg/ha/yr N-P-K, respectively) was dribble-banded on the surface of each plot with a hand applicator. Weeds were controlled before planting and during the growing season on each plot by hand hoeing.

CONSTRUCTION OF ISOLATED FIELD PLOTS

The experimental plots for flooding and control treatments were specially constructed to allow control of water table elevations and creation of flooding above the soil surface. A typical isolated field plot with a cutaway view of the special features is shown in figure 2. A 0.2-m wide and 1.2-m deep trench around the perimeter of each plot was made using a Ditch Witch trencher, and the bottom of the trench was finished manually with a "tile trench crumber". After the trench was dug, the plot was

*Trade name is included for the benefit of the reader and does not imply endorsement or preferential treatment of the product by Iowa State University.

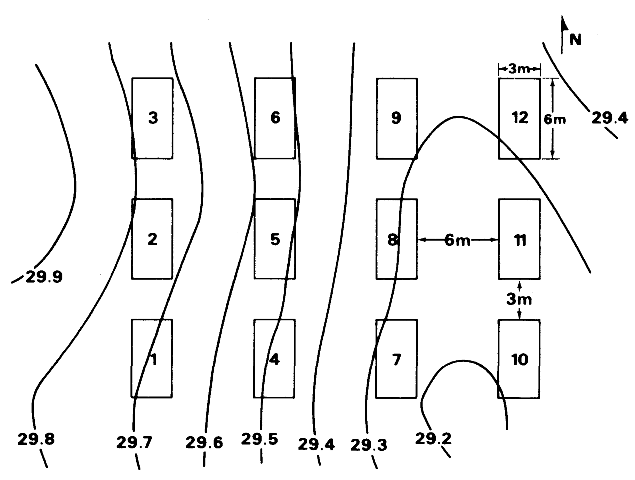

Figure 1–Topographic map (m elevations) and plot layout at the experimental site.

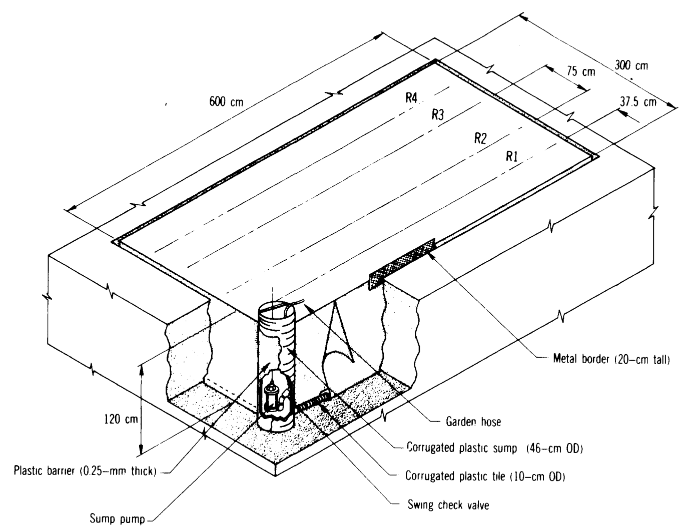

Figure 2–Isolated field plot with a cutaway view of the special features.

completely surrounded by a plastic barrier (0.25-mm thick, polyethylene sheet) which extended from the soil surface to the bottom of the trench. The purpose of this plastic barrier was to isolate the experimental plot from its surroundings and to minimize any lateral seepage during flooding. A corrugated and perforated plastic tube (100-mm OD) was installed at the bottom of the trench on the inside of the plastic barrier.

A 0.9-m wide ditch was dug inside the plastic barrier to a depth of 1.35 m with a backhoe to install a 1.5-m tall corrugated plastic pipe (0.46-m ODX 3.2-mm wall) at the corner of the plot as a sump. At 150 mm from the bottom of the sump, two holes were drilled at right angles to each other, and the corner ends of the tile line were inserted horizontally about 150 mm into the sump. The bottom of the sump was located 1.35 m below the soil surface, and the top of the sump was 150 mm above the soil surface. The tile line was "blinded" with topsoil by using hand shovels. The trench and the excavation around the sump were backfilled and tamped. On the outside of the trench, 200-mm tall galvanized sheet metal borders were inserted 80 to 100 mm into the soil to prevent leakage of ponded water during flooding.

A sump pump, with its inlet connected to a garden hose (16-mm OD) and a swing check-valve assembly, was used to control the elevation of the water table in each plot. When flooding was desired, the pump was raised to the top of the sump, and water was added to the sump through the garden hose. Water from the sump moved into the tile line causing flooding of the plot by subirrigation. The height of the sump pump was adjusted until ponding on the plot surface was observed. To maintain the water table at 0.9 m below the soil surface during unflooded periods, the pump was lowered into the sump, and its height adjusted according to the water table elevation measured in an observation well (1.5-m long, 38-mm OD, plastic pipe with perforated sides and open bottom) installed in the center of the plot. The heights of the sump pump was adjusted if observation well readings varied more than ± 100 mm from 0.9 m. A continuous supply of water was maintained to the sump from a 1893-L plastic water-storage tank. The excess

TABLE 1. Treatments and flooding sequence

Stage of growth*	Plots†	Flooding times (DAP‡) Started	Ended
Early vegetative	1,12	36	46
Late vegetative	2,4	56	66
Flowering	6,10	76	86
Yield formation	3,5	100	110
Control	8,9	---§	---

*Stage of growth determined by days after planting per Doorenbos and Kassam (1979).

†Plots = plots assigned to corresponding treatments.

‡DAP = days after planting.

§Not flooded, water table maintained at 0.9 cm.

water that drained out of the plot and discharged into the sump from the tile line was pumped back to the tank through the same hose used to supply water to the sump. This was accomplished by reversing the direction of the flow with the swing check valve.

Excess Wetness Treatments to Determine CS Factors

Table 1 gives the various treatments and flooding times for early-vegetative, late-vegetative, flowering, and yield-formation stages of growth. Each flooding was for a 10-day period. The other treatment was a "control" treatment in which the water table was maintained at about 0.9 m below the soil surface throughout the growing season. The water tables on the flooding treatment plots were also maintained at 0.9 m when not being flooded. Five treatments, replicated twice, were assigned to 10 experimental plots. A complete randomized design was used for comparing the treatment effects on plant canopy height, dry matter weight, grain yield, and CS and NCS factors. The GLM (general linear model) procedure of the SAS program was used for the statistical analysis.

Measurements of Plant-Growth Parameters

Plant canopy heights and dry-matter weights were determined 36, 56, 76, 100, and 125 days after planting. Plant canopy height was measured as the distance from the ground surface to the top flag leaf (even after tasseling). Four plants were randomly selected at the early-vegetative growth stage (36 days after planting), and their average canopy height was recorded throughout the growing season for each plot. Four randomly selected plants were cut at ground level in each plot and average dry matter weight per plant was determined after drying to a constant weight at 60° C. At maturity, corn grain yields were measured from 10 consecutive plants hand harvested from the middle of the second row (fig. 2) of each plot. Grain yields were corrected to a moisture content of 15.5%.

Stress-Day Index (SDI) Model

Crop susceptibility (CS) factors for four stages of growth were computed from the equation,

$$CS_i = (Y - Y_i)/Y \tag{1}$$

where Y = the yield for the control treatment without flooding stress, and Y_i = yield for the flooding treatment at growth stage i.

Normalized crop susceptibility (NCS) factors for the four growth stages were computed from the equation,

$$NCS_i = CS_i / (\sum_{i=1}^{M} CS_i) \tag{2}$$

where M = 4, the number of growth stages i for which measurements were made in this study.

The SDI concept proposed by Hiler (1969) can be expressed as

$$SDI = \sum_{i=1}^{M} (CS_i * SD_i) \tag{3}$$

where SD_i equals a stress-day factor for growth stage i. The SD factor is a measure of the degree of stress caused by excessive soil water conditions. Hardjoamidjojo et al. (1982) suggested the use of the quantity called the SEW_{30} (Sum of Excess Water, defined by Sieben, 1964) as the SD factor. This SEW_{30} parameter, used to quantify the stress caused by fluctuating water tables, can be calculated by using the equation,

$$SEW_{30} = \sum_{i=1}^{N} (30 - X_i) \tag{4}$$

where X_i is the water table depth below the soil surface on day i, and N is the number of days in the growing season. For SEW_{30} calculations, only water elevations (X_i values) above the 30-cm depth are considered, and the negative values inside the summation are neglected.

The SDI models were developed for predicting relative corn yields (ratios of the measured yields to the highest yield for a given year). The CS values used in the models were determined from the isolated field plots during the 1987 and 1988 growing seasons. The SEW_{30} and yield data for the 1984 and 1986 growing seasons were obtained from a field study conducted by Kanwar et al. (1988) near the experimental site on an undrained area with fluctuating water tables.

Other Measurements

Rainfall data for the 1987 and 1988 growing seasons were collected from two 100-mm diameter rain gages installed 25 m apart in the middle of the experimental area. The daily air temperature data for the 1987 and 1988 growing seasons were obtained from the nearby meteorological station located at the Iowa State University Agronomy and Agricultural Engineering Research Center.

Results and Discussion

Rainfall and Temperatures

Monthly rainfall data for the 1987 and 1988 growing seasons at the experimental site are presented in figure 3. Except for September, the 1988 growing season was dryer than that of 1987. Total rainfall for April through September in 1988 was only 470 mm, which is less than the 600 mm normally received in the Ames area for that same period. For both growing seasons, most of the rain fell during July and August (i.e., 64% of 720 mm in 1987 and 50% of 470 mm in 1988).

The maximum air temperatures for the 1988 growing

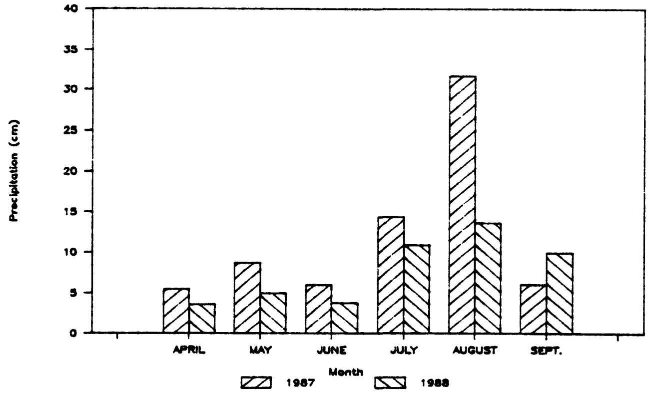

Figure 3. Monthly rainfall pattern for the 1987 and 1988 growing seasons.

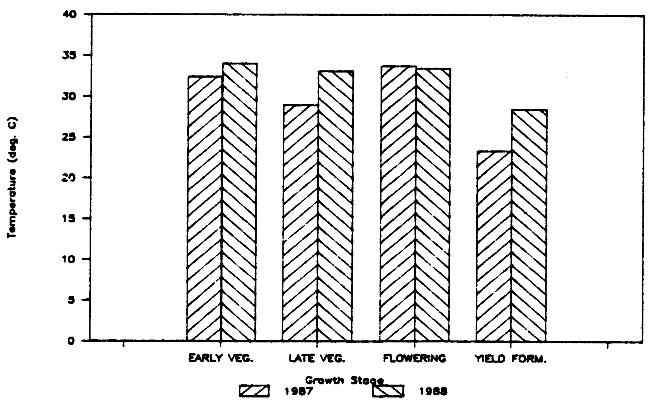

Figure 4. Average maximum temperatures during flooding at various growth stages in 1987 and 1988.

season were higher than those for 1987. Figure 4 shows the average maximum air temperatures during the 10-day flooding periods for the various growth stages in 1987 and 1988. These temperatures were 2, 4, and 5° C higher for 1988 at the early-vegetative, late-vegetative, and yield-formation stages, respectively.

Effect of Controlled Flooding on Plant-Growth Parameters and Grain Yield

Average plant heights and dry-matter weights measured 125 days after planting are given in Table 2. It should be noted that no plant mortality due to flooding was observed for any of the treatments. Plant canopy heights for some treatments were statistically different (at the 5% level) in 1987, but no statistical differences in the canopy heights for any treatments were observed in 1988. In 1987, the greatest reduction in the canopy height due to flooding occurred at the early-vegetative and flowering stages when the canopy heights were significantly lower than those from the control treatment. In addition, canopy heights for the early-vegetative treatment were significantly lower than those for the rest of the treatments.

The statistical analysis of the two-year averages of the canopy heights for all treatments showed that canopy heights for the control and yield-formation treatments were significantly greater than those for the early- and late-vegetative treatments, with the greatest reduction for the early-vegetative stage.

The flooding effect on plant dry-matter production was statistically significant for some treatments for each of the two years. For both years, the greatest reduction in the dry-matter weights occurred when the corn was flooded at the early-vegetative stage of growth. The two-year averages of the plant dry-matter weights for all treatments were similar except for the early-vegetative treatment for which plant dry-matter weights were significantly lower than those for the rest of the treatments.

Table 2 also shows that average canopy heights and dry matter weights for corn in 1988 were significantly lower than those in 1987. This may be due to variations in weather conditions when low rainfall (especially in the early part of the 1988 growing season) and higher temperatures during flooding at three of four growth stages in 1988, further depressed the growth parameters.

Flooding, irrespective of the growth stages of the crop, reduced grain yield (Table 2). Flooding at the early-vegetative stage reduced yields most, followed by flooding at the late-vegetative stage. Statistically, yield for the control treatment in 1987 was significantly greater than for the rest of the treatments, but in 1988, yield for the control treatment was significantly greater than the early- and late-vegetative stages only. Two-year average yields for all treatments (Table 2) also indicate that significantly lower yields resulted from flooding at the two vegetative stages as compared with flooding at the flowering and yield-formation stages, which were statistically similar to the yield from the control treatment.

The grain yield in 1988 was significantly lower than 1987. This is in line with the more pronounced depression in the plant growth parameters (plant-canopy heights and

TABLE 2. Effect of excessive soil water on canopy height, dry-matter weight, and grain yield of corn

Treatment	Canopy height (cm)			Dry-matter weight (g/plant)			Grain yield (kg/ha)		
	1987	1988	mean	1987	1988	mean	1987	1988	mean
Control	248a*	203a	226a	352a	186ab	269a	12184a	9258a	10721a
Early vegetative	185c	177a	181c	199b	77c	138b	4965d	2815c	3890c
Late vegetative	235ab	174a	205b	385a	124bc	255a	8264c	4156bc	6210b
Flowering	223b	211a	217ab	313a	228a	271a	9530b	8605ab	9068a
Yield formation	238ab	214a	226a	312a	199ab	256a	10140b	7324abc	8732a
Average/yr	226a†	196b		312a	163b		9017a	6432b	

*Averages followed by different letters (columns) are different at 5% level.

†Averages followed by different letters (row) are different at 5% level.

TABLE 3. Crop susceptibility (CS) and normalized crop susceptibility (NCS) factors for corn subjected to controlled flooding at Iowa and North Carolina (NC)

Stage of growth	CS(Iowa*)			CS(NC†)	NCS (Iowa)			NCS(NC)
	1987	1988	mean		1987	1988	mean	
Control	0.00	0.00	0.00a‡	0.00	0.00	0.00	0.00a	0.00
Early vegetative	0.59	0.69	0.64c	0.32	0.45	0.45	0.45b	0.22
Late vegetative	0.32	0.55	0.44bc	0.65	0.25	0.36	0.31b	0.45
Flowering	0.22	0.07	0.15a	0.36	0.17	0.05	0.11a	0.25
Yield formation	0.17	0.21	0.19ab	0.10	0.13	0.14	0.14a	0.07

*Average CS and NCS values computed from the yield data of isolated field plots.

†Average CS and NCS values computed from the yield data of lysimeters (Evans et al., 1986).

‡Averages in columns followed by different letters are different at 5% level.

dry-matter weights) resulting from drier weather and higher temperatures.

Crop Susceptibility (CS) and Normalized Crop Susceptibility (NCS) Factors

The CS and NCS factors determined for the various growth stages of corn during the 1987 and 1988 growing seasons are shown in Table 3. For comparison, values for those factors determined by Evans et al. (1986), over a three-year study in North Carolina using field lysimeters, are also given. The CS and NCS data for the two-year study in Iowa show that corn was statistically more susceptible to flooding at the two vegetative stages of development than at the flowering and yield-formation stages (one exception was the statistically similar CS values for the late-vegetative and yield-formation stages). Further, maximum two-year average CS and NCS values occurred for the early-vegetative stage at 0.64 and 0.45, respectively. The North Carolina data indicate that corn was most susceptible to flooding at the late-vegetative stage, with CS and NCS values of 0.65 and 0.45, respectively.

Stress-Day Index (SDI) Model

Figure 5 shows the relationship between the measured relative yield (RY) and stress-day index (SDI) for corn grown on a nearby undrained area in 1984 and 1986 (because of dry conditions, corn was not stressed with high

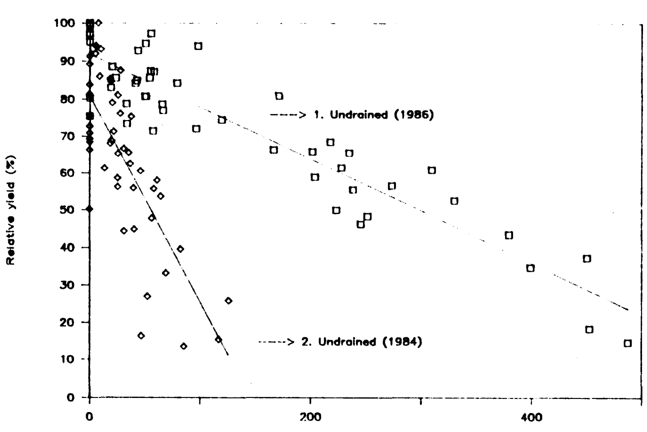

Figure 5–Relationship between relative yield and stress-day index for corn.

water tables in the undrained area in 1985, 1987, and 1988). Stress-day indices were calculated by using CS factors determined at the experimental site. The data gave the best-fit linear regression equations of RY = 91.9 - 0.14 SDI, with $R^2 = 0.86$ (n = 50), and RY = 80.9 - 0.55 SDI, with $R^2 = 0.60$ (n = 50), for 1986 (line 1) and 1984 (line 2), respectively.

Despite the scatter in the 1984 data ($R^2 = 0.60$, meaning that the linear model could describe only 60% of the variation in the relative yield), the relationship between measured RY and SDI was statistically significant (at the 1% level). The 1984 data show a more rapid decrease in the relative corn yield with an increase in SDI (a zero relative yield was predicted for a SDI value of only 147 cm- day from the regression equation).

The slopes of the best-fit linear regression lines (lines 1 and 2) for 1984 and 1986 data were significantly different (at the 1% level)). This may be because corn was subjected to excessive soil moisture stress with a timing and duration different between the two years, although the SDI model is expected to account for this. Use of the normalized (NCS) values did not help; the regression lines still had significantly different (at the 1% level) slopes. Factors other than the direct effect of wetness, e.g., nitrogen availability as affected by denitrification and nitrogen mineralization, may be important in explaining year-to-year variability.

Conclusions

1. Temporary flooding of corn at the vegetative stages of development resulted in poor crop growth (plant-canopy height and dry-matter production).

2. Flooding corn, irrespective of the physiological stage of development, reduced grain yields, but corn was more susceptible to flooding at the early- (CS = 0.64, NCS = 0.45) and late- (CS = 0.44, NCS = 0.31) vegetative growth stages.

3. The SDI models developed between measured relative yields and the stress-day index indicated a linear decrease in the relative yields with increasing soil wetness (SDIs).

4. The lack of a good agreement between the slopes of best-fit regression lines of the relative yield versus SDI data for two different years for the nearby undrained area indicate there are factors other than wetness that are affecting corn yield which the SDI model does not take into account.

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