Effect of Soil Surface Submergence and a Water Table on Vegetative Growth and Nutrient Uptake of Corn

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Abstract

Effects of excessive-water stress on corn vegetative growth and nutrient uptake were investigated in environmentally controlled growth chambers. Two excessive-water treatments (soil surface submergence and water table at 15-cm depth) and four excessive-water stress levels (equivalent to 90, 180, 270, and 360 cm-day of stress as defined by SEW_{30} concept) were imposed at 21 days after emergence. Data on plant growth parameters (i.e., height, leaf area, dry matter, and shoot uptake of N, P, and K) were compared for both water-table positions. Corn plants were significantly larger when a water table was imposed at the 15-cm depth than when the surface was submerged at all excessive-water stress levels. Plant nutrient uptake also was greater when a water table was maintained at 15 cm below the surface than when the surface was submerged. Nutrient uptake decreased significantly with increasing stress level for the submerged-surface treatment, but the trend was not consistent for the water-table treatment.

Keywords. Water table, Vegetative growth, Nutrient uptake, Irrigation.

Introduction

Water is one of the most important environmental factors affecting crop growth and yield. Too much or too little water can limit plant growth rates (Scott and Batchelor, 1979). Recently, effects of excessive soil water on plant growth have received renewed attention because of interest in subirrigation and water-table control practices.

Water-table depth is an important parameter in drainage or subirrigation system design (Wesseling, 1974). When water tables are too close to the soil surface, excessive-water stress develops and plant growth is limited. Maintaining a constant water-table depth in an agricultural field for an extended period is difficult. Therefore, most studies examining crop response to high water-table conditions have been conducted using field-type lysimeters (van Schilfgaarde and Williamson, 1965; Hiler and Clark, 1971; Cannell et al., 1980; Mukhtar et al., 1990). In some studies, lysimeters have been equipped with moveable shelters to protect them from undesirable weather, especially from rainfall (Cannell et al., 1980). In other studies (van Schilfgaarde and Williamson, 1961, 1965), lysimeters were placed in growth chambers to control environmental conditions and to reduce the plant growth variability found in field lysimeters.

Many studies have been conducted to determine response of crops to high water-table conditions. A number of these studies have concluded that for corn, the greatest crop damage and yield reduction result when excessive-water stress occurs during early vegetative stages (Joshi and Dastane, 1966; Kanwar et al., 1988; Mukhtar et al., 1990; Singh and Ghildyal, 1980; Chaudhary et al., 1975; Ritter and Beer, 1969) or late vegetative stages of growth (Evans et al., 1990). Sieben (1964) introduced the concept of the sum of the exceedence value in excess soil water, now known as the "Sum of Excess Water" (SEW_{30}), to relate yield reduction to occurrence of a water table within 30 cm of the soil surface. Using Sieben's SEW_{30} concept, an excessive-water stress level can be calculated from height of a water table above the 30-cm depth and number of days the water table remains at that height.

Few studies have been conducted to investigate the effect of different excessive-water stress levels on vegetative growth and nutrient uptake of corn. Therefore, the objectives of this study were to determine the effects of two excessive-water treatments (soil surface submergence and a water table at 15 cm below the soil surface) at four stress levels on corn growth and shoot uptake of nitrogen, phosphorous, and potassium during vegetative growth.

Experimental Procedure

This study was conducted in two controlled-environment growth chambers (Conviron PGW36; 243×243×121 cm). Growth chamber temperatures were programmed to simulate normal mid-Iowa temperatures between 8 May and 29 June. Daily diurnal temperature patterns were based on the 30-year normal maximum and minimum temperatures. Temperatures were ramped between hourly set points. For 14 hours of the 16-hour daylight period, light was provided by 45 incandescent 120 W and 30 fluorescent 115 W light bulbs. During the first hour only incandescent light was supplied and during the last hour only fluorescent light was provided. Relative humidity was maintained at 70%.

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Eighteen plastic containers (40×65×81 cm) were utilized as lysimeters in the growth chambers. A float-controlled valve and water reservoir were used to maintain the water level in the lysimeters. Water level was changed by raising or lowering height of the water reservoir relative to the lysimeters. A plastic tube 0.30-m deep and 2.54-cm in diameter was installed in each lysimeter to measure internal water elevation.

The soil used for this study was Nicollet loam soil from the Clarion-Nicollet-Webster Soil Association. Some of the physical properties of this soil are given in Table 1.

Soil was removed from a field site in 0.20 m layers, to a depth of about 0.80 m. Soil layers were placed in the lysimeters in the same order as they existed at the field site. After each layer was added, the lysimeter was vibrated to settle the soil until the layer occupied approximately the same volume as it had in the field. After all four layers were placed in the lysimeters and settled, the lysimeters were filled with water from the bottom and then drained.

This experiment included eight treatments plus a control. The control had a water table maintained at the 70-cm depth. The eight treatments consisted of two excessive-water treatments, submerged surface (3 cm of water ponded on the surface), and a water table at 15 cm below the soil surface, each at the same four excessive-water stress levels. The same level of excessive-water stress (Sieben's SEW_{30} concept) was applied by maintaining the two different excessive-water treatments for a different number of days. After the specified number of days, water was drained and a water table was maintained at the 70-cm depth for the rest of the experiment. Sieben (1964) used the SEW_{30} concept to quantify the stress due to excessive soil water conditions as:

$$SEW_{30} = \sum_{i=1}^{N} (30 - WTD_i)$$

where WTD is the daily water table depth on day i, and N is the number of days. To calculate stress levels for this experiment, the submerged-surface treatment is assumed to have a water-table depth of 0 cm. SEW_{30} values are expressed in cm-day. Each of the four stress levels for surface submergence and 15-cm water table depth are shown in Table 2.

The experimental design was a randomized complete block design with four replications. Only nine lysimeters could be placed in each growth chamber at the same time. Lysimeters were arranged in the growth chambers so that each received similar light levels. The experimental treatments were repeated four times, twice in each of the two chambers. Each repetition or run was treated as a single replication and was considered to be a block in time for the statistical analysis.

Four small seed furrows (3×3×8 cm) were made in each lysimeter about 10 cm from the walls and 20 cm apart. Sixteen corn (Pioneer3 3751) seeds were planted in each lysimeter, four in each furrow. Seeds were covered with a potting mixture to obtain uniform germination and to avoid crusting. After germination, seedlings were thinned to six plants per lysimeter. Each time the experiment was repeated, each lysimeter received the equivalent of 200, 60, and 60 kg ha^{-1} of N, P, and K, respectively, during the second week after planting. Fertilizers (8.42, 5.50, and 2.33 g of urea, superphosphate, and potassium chloride,

TABLE 1. Particle-size distribution, gravel percentage, and soil reaction of Nicollet loam soil (from Charkhabi, 1990)

Horizon	Depth (cm)	Sand (%)	Fine silt (%)	Coarse silt (%)	Clay (%)	Gravel (%)	pH_w (%)
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	32.5	24.7	1.9	7.2
Cl	86 - 102	40.1	10.8	26.8	22.3	3.0	7.7
Cl	102 - 117	38.2	12.0	30.2	19.6	2.0	7.8
Cl	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

TABLE 2. Stress levels for water-table treatments

Duration of Stress Due to Excessive Water (day)	Depth of Water Table Beneath the Soil (cm)	Daily Stress Levels in SEW_{30} Values (cm-day)	Total Stress Level in SEW_{30} Values (cm-day)
Submerged-surface treatment			
3	0	30	90
6	0	30	180
9	0	30	270
12	0	30	360
Water table at 15 cm below the soil surface			
6	15	15	90
12	15	15	180
18	15	15	270
24	15	15	360

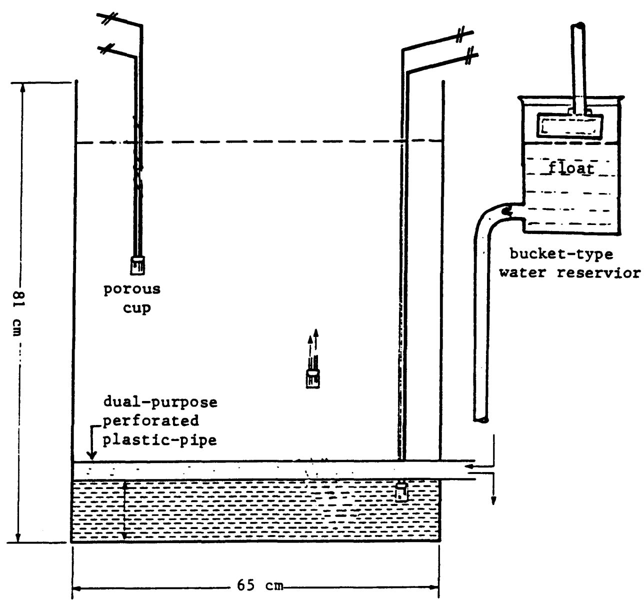

Figure 1–Schematic diagram of the lysimeter (with water table maintenance facility) placed in the growth chamber.

respectively) were dissolved in 500 mL water and were applied uniformly to the soil surface.

Lysimeters were surface irrigated when excessive-water treatments were not in place. To determine a surface irrigation schedule, transpiration and evaporation from the lysimeters was measured during test runs using gravimetric soil samples. The irrigation schedule was devised to rewet the upper 30 cm of soil to field capacity whenever 50% depletion of available soil water occurred. The values for the field capacity (35%) and the wilting point (13%) on weight basis were obtained from field samples.

Excessive-water treatments were imposed at 26 days after planting (approximately sixth leaf stage of corn and 21 days after emergence). On the same day, two plants out of six were randomly selected and harvested for dry matter and leaf area measurements (data not reported). Average plant height of the four remaining plants was also determined by measuring distance from the soil surface to the tip of the tallest extended leaf. After the initial measurement, plant height was measured every third day for the next twelve days and then every six days for the remainder of the experiment. Plants were harvested at 53 days after planting when plants in control lysimeters began touching the lights in the growth chamber (approximately eleventh leaf stage). Leaves of each plant were removed from the stem to measure leaf area using a leaf-area meter. Then both stem and leaves were put into a paper bag and dried at 60° C until constant weight was achieved for shoot dry matter. Shoot tissue was analyzed for N (Bremner and Mulvaney, 1982), P, and K content (Issac and Kerber, 1971). All plant data is reported on a per plant basis and was averaged over the four plants within a lysimeter before statistical analysis. Means reported in figures are the averages of four replications.

Results and Discussion

Shoot Dry Matter Yield

Figure 2 shows the effect of excessive-water stress on shoot dry matter. Both submergence and 15-cm water-table depth had a significant effect on dry matter production. The submerged-surface treatment, however, caused greater reductions in shoot dry matter than did the water-table treatment. For example, at a stress level of 360-cm day, shoot dry matter of plants with the water table at the 15-cm depth was three times as great as that of plants with the submerged surface. When the surface was submerged, shoot dry matter decreased significantly with each increase in stress level up to the 270-cm-day stress level (nine days of submergence). Increasing stress from the 270-cm-day level to 360-cm-day level (12 days of submergence) did not cause an additional decrease in dry matter. Other researchers have observed similar growth reductions with surface submergence (Bhan, 1977; Joshi and Dastane, 1966; Mason et al., 1987; Oosterhuis et al., 1990). When the water table was at 15 cm below the surface, shoot dry matter decreased as stress level increased up to 180-cm-day level (12 days), but did not decrease significantly as stress levels were further increased.

To analyze the effect of excessive-water stress levels on the shoot dry matter of corn, regression models were developed for both excessive-water treatments (Table 3). Corn shoot dry matter decreased linearly with the increasing stress levels for both treatments, but the slopes were significantly different. This indicates that corn shoot growth of the submerged-surface treatment decreased more with each increase in stress level than did the growth of plants with the water-table treatment.

Leaf Area

The first noticeable effect of excessive-water stress on corn plants was a change in leaf color from light green to purple. This color change was greater for older leaves than for younger leaves. Additionally, at high excessive-water stress levels, leaf tips turned brown, especially for the submerged-surface treatment. Both excessive-water treatments reduced corn leaf area at the lowest stress level (90 cm-day, fig. 3). Reductions in leaf size, both length and width, rather than leaf number, accounted for the reductions in plant leaf area. An increase in the stress level from 90 to 180 cm-day (6 to 12 days) caused an additional reduction in leaf area for the water-table treatment, but increases in stress level above 180 cm-day did not further reduce leaf area. Conversely, for the submerged-surface treatment, each increase in stress level resulted in a further reduction in leaf area.

The greater response of the submerged-surface treatment resulted in a greater slope for the regression of leaf area on stress level as compared with the regression slope for the water-table treatment (Table 3). Truman et al. (1966) found that water tables affected leaf area of sweet corn and observed that leaf area was correlated with plant dry weight at harvest. If unstressed plants are available for

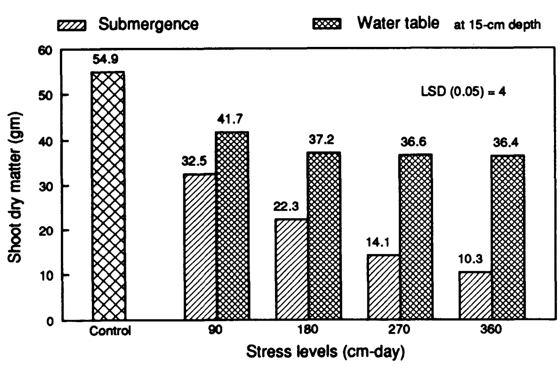

Figure 2–Shoot dry matter as affected by excessive-water stress levels.

TABLE 3. Relationship between SEW_{30} values and corn shoot dry matter and leaf area

Water Table Position (cm)	Variable	Type of Statistical Model	Regression Equation	N	R^2
At the surface	Dry matter	Linear	$DM = 42.15 - 0.018\ X$	4	0.72
15 cm below the surface		Linear	$DM = 38.53 - 0.083\ X$	4	0.96
At the surface	Leaf area	Linear	$LA = 5299.34 - 2.89\ X$	4	0.79
15 cm below the surface		Linear	$LA = 5327.56 - 9.48\ X$	4	0.98

X = SEW_{30} values
DM = shoot dry matter
LA = Leaf area

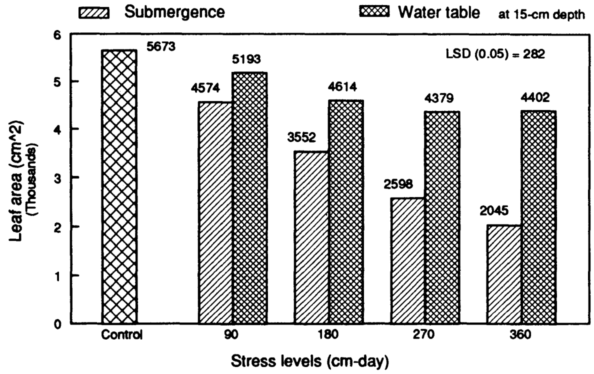

Figure 3–Leaf area as affected by excessive-water stress levels.

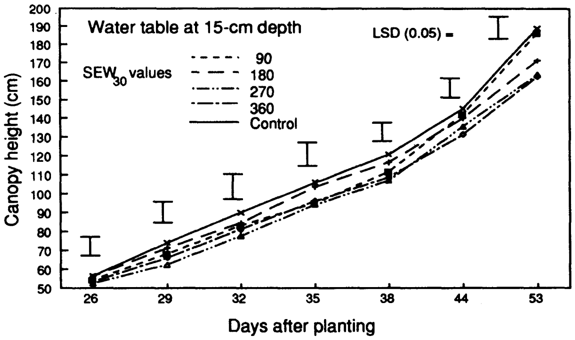

Figure 5–Canopy height as a function of days after planting for four stress levels under water table at 15-cm depth.

comparison, measurements of leaf growth rate may be a non-destructive method of monitoring the level of excessive-water stress experienced by corn plants during vegetative growth. It is possible that leaf color of actively growing leaves could also be used as an indicator of excessive-water stress.

Plant Height

Six days after excessive-water treatments were imposed (32 days after planting), plants exposed to the submerged-surface treatment were significantly shorter than control plants (fig. 4). At 35 days after planting (nine days after treatment began), the 90- and 180-cm-day stress level plants (three and six days of submerged surface, respectively) resumed height increases because the excessive-water stress had been removed. At 53 days after planting, there was no significant difference in plant height between the control plants and plants receiving the 90-cm-day stress level for the submerged-surface treatment. Plants exposed to all four stress levels of the submerged-surface treatment began to increase in height after the stress was removed, but only plants exposed to the 90-cm-day stress level were as tall as the control at 53 days after planting. Had the experiment continued, plants exposed to the other stress levels may have recovered by the onset of silking as suggested by Williamson and Kriz (1970).

The reduction in plant height caused by the water-table treatment (fig. 5) was not as great as it was for the submerged-surface treatment. Plant height continued to increase at nearly the same rate for all four stress levels when a water table was maintained at the 15-cm depth. Control plants and plants receiving the 90-cm-day stress level (six days of stress) were taller at 53 days after planting than plants exposed to the other stress levels, but they were not significantly different at the earlier dates. Plant height could also be used to monitor excessive-water stress. Because plant height was measured from the soil surface to tip of the tallest extended leaf in this experiment, leaf growth influences plant height. Thus, measurements of leaf length may be a more sensitive indicator of excessive-water stress than plant height.

Nutrient Uptake

Excessive-water stress reduced shoot uptake of N, P, and K (figs. 6, 7, and 8). In general, shoot concentrations of N, P, and K did not vary among treatments. Therefore, treatment differences in nutrient uptake were correlated to dry matter differences. The submerged-surface treatment reduced N and K uptake more than the water-table treatment did. When the surface was submerged, N uptake decreased as stress level increased up to 270 cm-day (fig. 6). There was no difference in N uptake between the 270- and 360-cm-day stress levels for the submerged-surface treatment. N uptake for the water-table treatment at 180-cm-day stress level was significantly less than the control, but uptake did not decrease further with increasing stress. Phosphorus uptake of both the submerged-surface and water-table treatments were significantly less than the control at the 180-cm-day stress level, but did not decrease further at higher stress levels (fig. 7). Potassium uptake for the submerged-surface treatment was less than the control at the 90- and 180-cm-day stress levels (fig. 8). Increasing the stress level to 360 cm-day decreased potassium uptake further. For the water-table treatment, the 90-cm-day stress

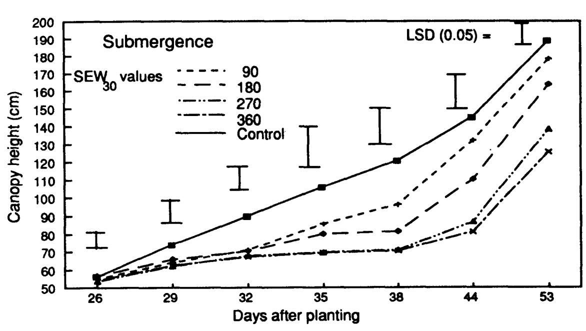

Figure 4–Canopy height as a function of days after planting for four stress levels under submergence conditions.

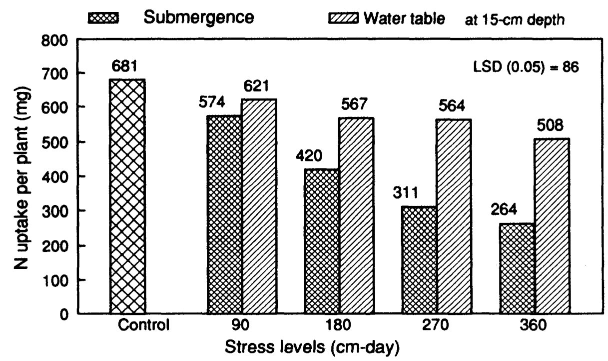

Figure 6–Nitrogen uptake as affected by excessive-water stress levels.

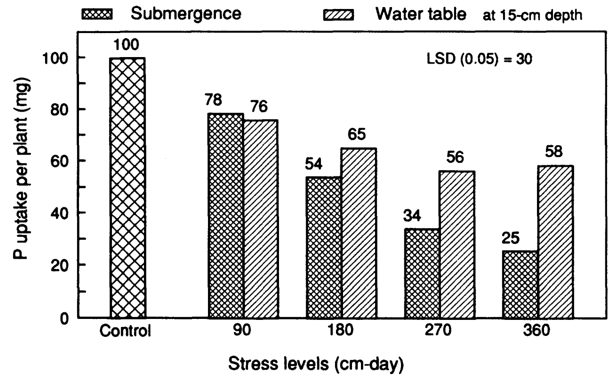

Figure 7–Phosphorous uptake as affected by excessive-water stress levels.

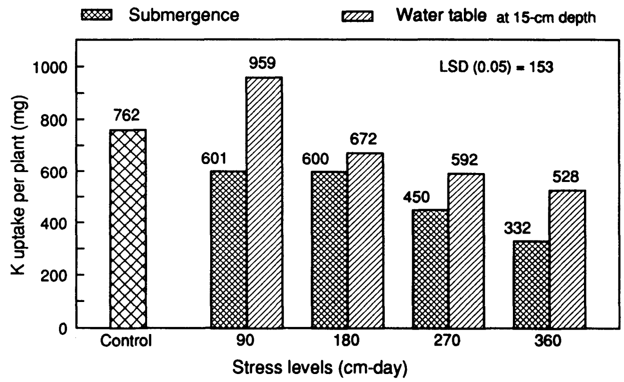

Figure 8–Potassium uptake as affected by excessive-water stress levels.

level increased K uptake. The 270- and 360-cm-day stress levels, however, reduced K uptake relative to the control.

Summary

Corn vegetative growth and shoot uptake of N, P, and K from 26 to 53 days after planting (leaf stages 6 to 11) was reduced by two excessive-water treatments, surface submergence and water table at the 15-cm depth. The submerged-surface treatment reduced growth and nutrient uptake more than the water-table treatment did at the same stress levels. In general, increasing the stress level further reduced shoot growth and uptake for the submerged-surface treatment. Increasing the stress level above 90 cm-day (duration greater than six days), however, did not cause consistent decreases in growth and uptake for the water-table treatment. If a suitable control is available for comparison, non-destructive measurements of leaf growth may provide a method for monitoring excessive-water stress during vegetative growth.

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