Shallow Water Table Effects on Photosynthesis and Corn Yield

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Abstract

The effect of water-table management practices on leaf photosynthesis and corn yield was investigated under two different field conditions in 1989 and 1990. In one field, water-table depths were maintained at 0.3, 0.6, and 0.9 m in field lysimeters during the growing season. In the other field, average water-table depths of 0.2, 0.3, 0.6, 0.9, and 1.1 m were maintained through subirrigation. Photosynthesis measurements were made regularly during the growing season, and yield data were collected at harvest. In 1989, a relatively dry year, photosynthesis rates were higher at shallow water-table depths than at deep water-table depths. In 1990, a very wet year, photosynthesis rates were not significantly different for water-table depths between 0.3 and 0.9 m, but rates decreased significantly for water-table depths shallower than 0.3 m. Statistical analysis indicates that water-table effects on photosynthesis rates were not consistent. However, effects of various water-table depths on photosynthetic water-use efficiency (PWUE) were highly significant in both dry and wet seasons. Corn yields increased with increasing water-table depths. At water-table depths of 0.2 to 0.3 m, corn yield decreased significantly. In both dry and wet seasons, effects of water-table treatments on grain yield were highly significant and significant relationships were obtained between PWUE values and yield.

Keywords. Water-table management, Corn yield, Photosynthesis.

Introduction

Crop responses to drainage have been reported from several studies (Evans et al., 1990; Kanwar et al., 1988; Kanwar, 1988; Mukhtar et al., 1990). Previous studies, however, have not provided crop parameter(s) besides yield that may be suitable indicator(s) of shallow water-table and drainage effects on crop production. Although yield is generally a suitable indicator, the effect of a given water-table management practice is not known until harvest. Thus, yield assessment has limited usefulness in adjusting management practices during the growing season. A more useful indicator is needed for seasonal evaluation of appropriate water-table management practices for crop production.

Photosynthesis is an important physiological factor limiting crop production. Crop growth and yield responses depend upon the production and partitioning of carbon assimilates. However, dry matter production rates and partitioning patterns can be influenced by a wide variety of environmental stresses such as drought, high temperatures, low irradiance, nutrient deficiency, and airborne pollutants (Treshow, 1970). Under nonstressed conditions, irradiance is the most important environmental factor causing variation in photosynthetic rate in maize (Reed et al., 1976; Hari et al., 1981). Dwyer and Stewart (1986) reported that the dependence of photosynthetic rate on irradiance was nonlinear and could be described by a rectangular hyperbola. Dwyer et al. (1989) reported cultivar differences in photosynthetic rates as a function of plant age, and that late-maturing cultivars had higher photosynthetic rates than early-maturing cultivars at comparable phenological stages.

The maximum rate of leaf photosynthesis is generally represented by measurements on fully expanded upper sunlit leaves near midday. Therefore, the topmost fully expanded leaves (at optimum physiological condition and plant position) are examined. The correlation between net photosynthesis and crop yield have been examined in several studies. Evans (1975) and Elmore (1980) reported no significant correlation between yield and rate of carbon dioxide (CO_2) exchange per unit of leaf area, although Elmore (1980) stated that higher rates of photosynthesis should lead to higher yield. Moss (1976) reported that it was difficult to document if economic yield and photosynthesis were related in any direct way. Results from these studies may have limited application because of single leaf measurements in control environment tests. Individual leaves in a plant community in the field often differ in their net CO_2 assimilation rates depending on irradiation, temperature, water, other climatic factors, leaf age, and development stage (Zelitch, 1982). Zelitch (1982) strongly suggested that crop yield is closely related to the net photosynthetic assimilation of CO_2 throughout an entire season, but that instantaneous measurements of photosynthesis may be misleading. Christy and Porter (1982) found that adverse climatic factors such as clouds, cold, and water limitations generally decreased net photosynthesis of soybeans. They compared yield with the cumulative net photosynthesis for two soybean varieties for two seasons and observed a near unity correlation (r = 0.98) although no correction was made for carbon lost by respiration in the dark and by roots. On a seasonal basis, integrated net CO_2 exchange rate and corn growth

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were closely related in field experiments by Vietor and Musgrave (1979).

The relationships between water-table depths and crop yields have been reported by several investigators. Wesseling (1974) reported that shallow water-table depths reduced oxygen supply to the roots and decreased nutrient uptake and crop growth. Similar results have been reported by Evans and Skaggs (1985), Kanwar (1988), and Carter et al. (1988). Williamson and Kriz (1970) found that optimum water-table depth was a factor of crop species and soil type. Cavazza and Pisa (1988) found the maximum yield of wheat at 1.25 m water-table depth, and shortage of water resulting from a water-table depth of more than 1.25 m reduced crop yield.

Previous studies have indicated that depletion of root zone soil water and crop water stress reduce photosynthesis rates. However, previous studies have not reported the effects of excess soil water, water-table management and/or drainage practices on crop photosynthesis rate. Therefore, this study was conducted by Iowa State University to investigate the effects of water-table management practices (drainage, subirrigation, and controlled drainage) on photosynthesis and corn yield. The specific objective was to determine photosynthesis rate and photosynthetic water-use efficiency at various stages of corn growth, and crop yield under various water-table management practices.

Materials and Methods

Experiments

Experiments were conducted in 1989 and 1990 at research farms of Iowa State University near Ames and in Ankeny. At the Ames site, experiments were conducted in field lysimeters by maintaining three water-table depths of 0.3, 0.6, and 0.9 m during both years. Water-table depth treatments were replicated three times using nine field lysimeters. Water-table elevations were raised to the desired depths on 53 and 52 days after planting in 1989 and 1990, respectively. The elapsed time between planting and treatments allowed corn roots to develop within the 0.9 m soil profile before establishing water-table treatment. Water-table elevations were maintained at treatment depths until harvest dates. Soil moisture contents (by depths) were monitored using a neutron probe. Crop-growth parameters of plant height and photosynthesis were measured weekly during the growing season.

At the Ankeny site, experiments were conducted in a field equipped with a dual-pipe subirrigation system. water-table depths ranged in the subirrigation field from 0.03 to 1.25 m during the growing season in 1990. The average water-table depths at five major locations A, B, C, D, and E (where monitoring devices were installed in the subirrigation field) were 0.2, 0.3, 0.6, 0.9, and 1.1 m, respectively, during the growing season. A maximum water-table depth of 1.25 m was observed at location E in the beginning of the season, and a minimum water-table depth of 0.03 m was observed at location A once during the season due to heavy rainfall. However, specific water-table depths were maintained through subirrigation from 2 July (54 DAP) to 12 September (96 DAP). Plant height and photosynthesis rates were measured at 15-day intervals at the Ankeny site.

Photosynthesis Measurements

Photosynthesis was measured with the LICOR-62001 portable photosynthesis system consisting of a CO_2 analyzer, a system console, and a sensor housing with interchangeable leaf chambers. The CO_2 analyzer is a differential, nondispersive, infrared-type (NDIR) instrument calibrated for measurements of 0-1100 ppm.

The net exchange of CO_2 between a leaf and the atmosphere was measured by enclosing a leaf section in the leaf-chamber and monitoring the exchange rate in CO_2 concentration of the air in the chamber during a short time interval of 10 to 20 s. Area of the leaf section in the chamber was measured. The net photosynthesis rate was calculated based on the rate of change in CO_2, leaf area enclosed, volume of enclosure, and air and leaf temperatures. Details of this measurement system are given in *LI-6200: Technical Reference* (1987).

The photosynthesis measurements were made at the Ames site on 70, 77, 84, and 98 DAP in 1989, and 48, 55, 64, 70, 77, 84, 91, and 98 DAP in 1990. At the 1990 Ankeny site, photosynthesis measurements were made on 34, 48, 64, 77, and 91 DAP. The latest fully developed leaf (generally third or fourth leaf from the top) was used for photosynthesis measurements. Measurements representing normal leaf position and orientation were replicated on five plants per plot.

Site Description

The soils at the Ames site are predominantly Nicollet loam in the Clarion-Nicollet-Webster soil association. Physical properties of the soils are presented by Kanwar (1988). Nine field lysimeters of 3 m × 6 m were installed at this site in 1986. Lysimeters were enclosed using a 0.25-mm thick plastic barrier to a depth of 1.2 m to prevent lateral subsurface water movement among plots. The plastic barrier was placed in a 0.2 m wide × 1.2 m deep trench around the perimeter of each lysimeter. A corrugated, perforated plastic tube (0.1 m dia) was installed at the bottom of the trench inside the plastic barrier. Corrugated plastic pipe (0.46 m dia × 1.35 m deep) was installed as a sump at the corner of each lysimeter. The two ends of the perforated plastic tube were inserted into the sump at 0.15 m from the bottom and trenches back-filled with excavated soil. In 1989, all lysimeters were enclosed with a 0.25 mm thick pvc (polyvinylchloride) flexible liner to a depth of 1.70 m. Each liner encased a square area (9 m × 9 m) with the 3 m × 6 m field lysimeter located in the center to prevent lateral movement of subsurface water. A detailed procedure for the lysimeter installation was presented by Kalita and Kanwar (1990).

A float mechanism was installed in each sump to maintain the desired water level in the lysimeter. An isometric view of the lysimeter with installed sump and float assembly is shown in figure 1. Each lysimeter was connected to the main water-supply tank using a 0.075 m diameter pvc irrigation pipe. The main water-supply tank (1.6 m high and 1.3 m dia) was raised 2.0 m from the soil surface and placed on a concrete floor. Hydraulic head was adequate for free flow of water from the tank to all

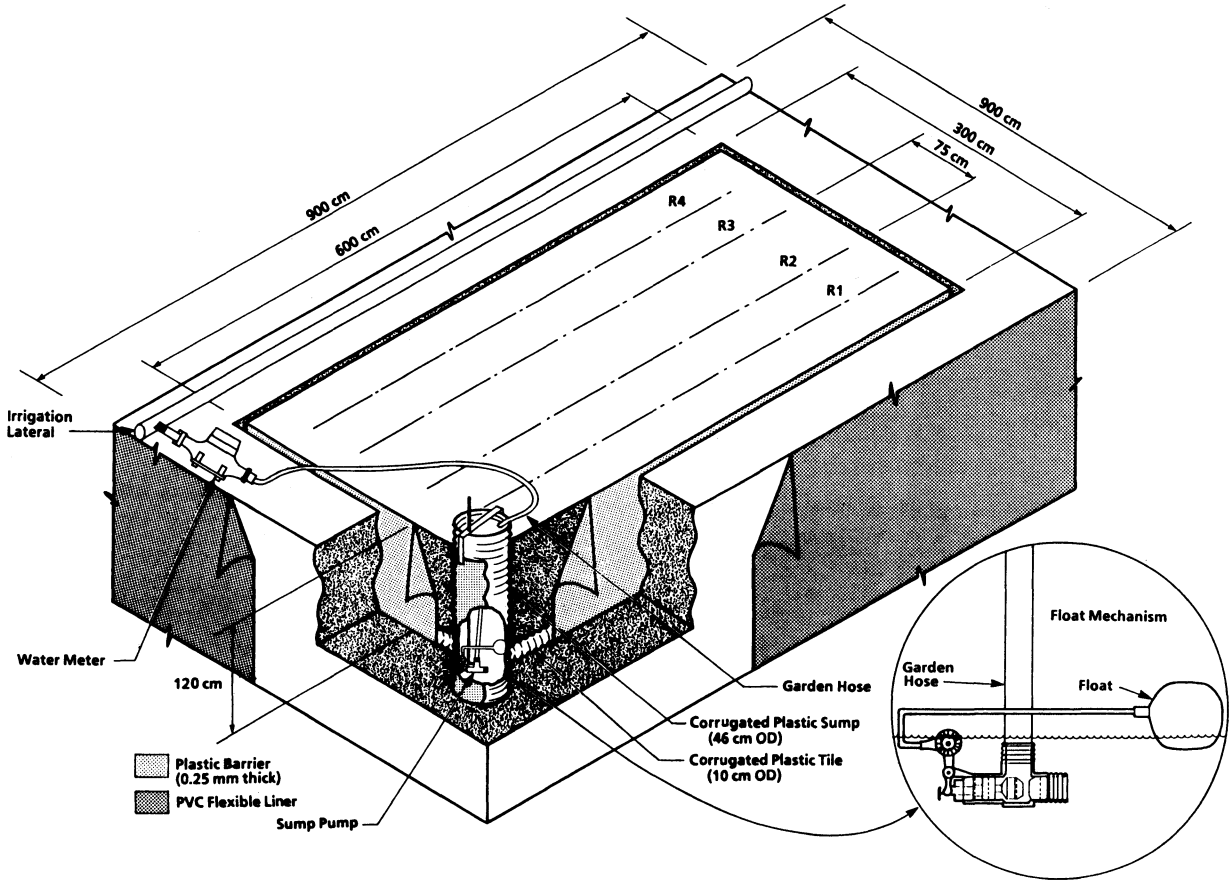

Figure 1–An isometric view of the lysimeter with sump and float assembly.

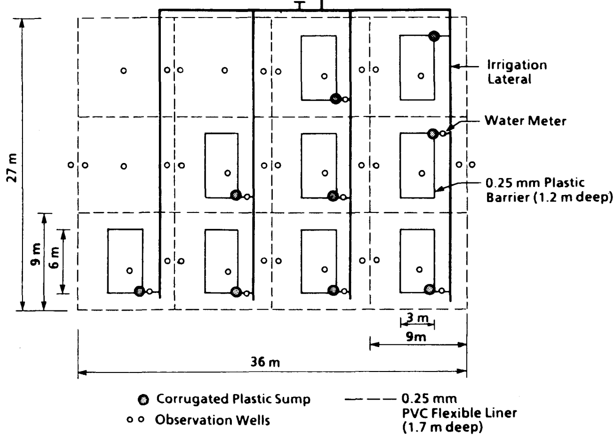

Figure 2–Layout of the experimental plots at the Ames site.

lysimeters. The layout of the experimental area is shown in figure 2.

At the Ankeny site, a dual-pipe subirrigation system was installed in 1988 on a 0.5-ha area with significant natural ground slope of 2.5%. This site is located on Nicollet silt-loam soils and was selected for this study for its relatively large field size (130 m × 40 m). The basic concept of the dual-pipe subirrigation system is illustrated in figure 3. Shallow irrigation pipes were installed at a depth of 0.5 to 0.6 m parallel to and midway between drainage pipes, which were installed at 1.2 m depth. The natural ground slope along the length of the field allowed water tables to be maintained at various depths by controlling the subsurface drainage outflows and by supplying irrigation water through the subirrigation pipes.

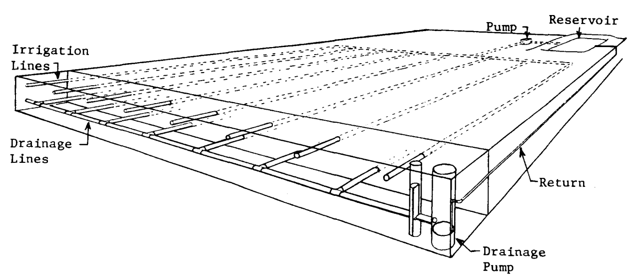

Figure 3–A schematic sketch of the dual-pipe subirrigation system.

TABLE 1. Mean photosynthesis and PWUE values and their statistical significance for Ames site in 1989 and 1990 and Ankeny site in 1990

		Mean Photosymthesis Rate μ mol m $^{-2}$ s $^{-1}$						Mean PWUE μ mol CO_2 / mol H_2O					
		Water Table Depth (m)						Water Table Depth (m)					
Site	DAP	1.1	0.9	0.6	0.3	0.2	LSD*	1.1	0.9	0.6	0.3	0.2	LSD*
Ames	70		36.0	34.8	36.6		10.2		69.4	53.2	35.2		12.5
1989	77		25.7	24.7	31.0		10.6		96.9	97.5	87.8		8.5
	84		29.5	30.6	31.5		11.6		81.7	59.9	47.7		11.3
	98		29.7	32.4	34.9		3.9		96.9	89.9	81.0		6.8
Ames	48		40.6	27.2	29.3		18.9		13.7	16.8	12.5		5.9
1990	55		27.2	34.7	36.2		7.1		23.7	27.0	24.0		4.8
	64		34.7	49.5	40.1		5.2		56.5	52.1	31.5		10.7
	70		53.0	50.0	50.9		11.0		81.0	66.1	62.9		13.6
	77		46.3	45.6	44.0		9.4		110.4	100.9	83.9		11.4
	84		31.5	28.6	30.3		12.2		95.9	89.0	99.1		10.7
	91		30.9	30.0	34.8		16.7		108.9	79.9	75.8		14.2
	98		25.9	36.0	28.2		7.2		63.7	62.2	42.7		9.1
Ankeny	34	34.3	33.9	21.4	17.8	4.9	12.6	44.1	36.3	31.7	23.3	9.3	12.3
1990	48	94.7	86.0	83.7	70.7	37.5	10.3	73.6	67.7	58.2	46.2	39.8	14.3
	64	43.9	45.3	42.4	38.0	20.2	11.2	35.3	34.4	34.7	29.6	27.4	10.9
	77	30.9	26.0	31.1	29.2	17.0	5.4	99.8	93.3	92.6	83.0	61.8	13.5
	91	31.1	23.6	27.2	19.4	10.3	6.9	83.9	83.4	83.7	61.5	56.7	16.2

* Least significant difference at P0.05 level.

Cultural Management

Corn 'Pioneer 3379' was planted at both sites on 23 May 1989 and 8 May 1990. Harvesting dates were 31 October 1989 and 16 October 1990 at both sites. The plant density was 6.7 plants m $^{-2}$ and row spacing was 0.75 m. Urea nitrogen fertilizer was applied at planting at the rate of 200 kg-N ha $^{-1}$ in both fields, both years. Atrazine and Lasso herbicides were applied at the rate of 2.2 kg ha $^{-1}$ in 1989 and 1990 at the Ames site and in 1989 at the Ankeny site.

Results and Discussion

Photosynthesis Rates

Photosynthesis rates as a function of time and water-table depth for the Ames and Ankeny sites are shown in Table 1. The photosynthesis rates at the Ames site during August 1989 were higher for the 0.3 m treatment depth than for the 0.6 and 0.9 m depths. The rainfall data during the growing seasons of 1989 and 1990 were collected at both sites within 100 m from the experimental fields. The 1989 season was relatively dry with May to October rainfall of 456 mm. In this dry season, the 0.3 m shallow water-table depth supplied more water to the plant-root system than did 0.6 and 0.9 m water-table depths. Good and Bell (1980) reported that photosynthesis rate is enhanced by providing adequate water supply that prevents stress. This may explain why higher photosynthetic rates were observed under shallow water-table conditions in 1989.

Irradiance (photosynthetically active radiation) effects on photosynthesis rates were evaluated in the relationship presented in figure 4. A best-fit hyperbolic mathematical relationship was determined that accounted for 57% of the variance. Similar results have been reported by Dwyer and Stewart (1986) for water deficit conditions.

The 1990 season was very wet in comparison with the previous season. Rainfall between May and October 1990 was 822 and 775 mm for the Ames and Ankeny sites, respectively. At the Ames site, excess drainage water was continuously pumped (particularly after every major rainfall event) from the sumps to maintain the water tables at 0.9 m depth. Photosynthesis rates for all water table depths increased with time until the middle of July (70 days after planting) and thereafter decreased with small variations between water-table depths. The 1989 data (DAP 70, 77, 84, and 91) also showed a declining trend for August. Because of excessively wet conditions in 1990, soil water contents in the root zone remained near field capacity during most of the growing season. Therefore, water-table treatments had little effect on profile water distribution by depth and no clear relationship was observed between photosynthesis rate and water-table depth.

At the Ankeny site, water-table depths during the 1990 growing season fluctuated from 0.03 to 1.25 m due to the combined effects of field slope and subirrigation practice. Table 1 shows that photosynthesis rates for five DAP at

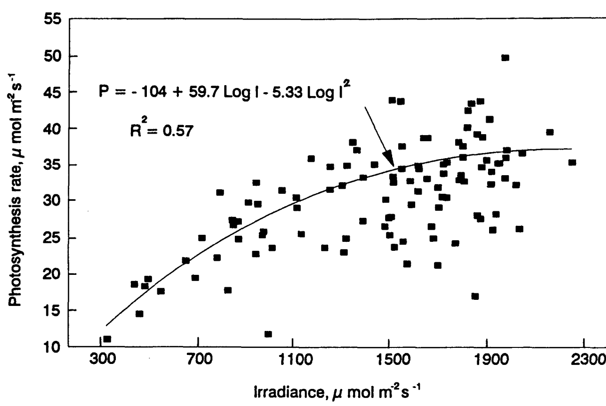

Figure 4–Relationship between irradiance and leaf photosynthesis of corn at the 1989-90 Ames site and the 1990 Ankeny site.

Ankeny site increased as water-table depths increased and were extremely low at a location where water table was nearly at the surface at one time during the growing season. This finding documents the effects of high water table on photosynthesis rates in a field crop. High water tables restrict oxygen supply to roots and soil microorganisms. Root growth and survival require metabolic energy that is generated in aerobic conditions, but in absence of oxygen, this energy is significantly reduced (Cannell and Jackson, 1981). Therefore, crop physiological activities and photosynthesis rate may decline significantly.

Least significant difference (LSD) values of treatment means for photosynthesis and PWUE are presented in Table 1. The effect of water-table depth on photosynthesis was not statistically significant on DAP 70, 78, and 84 for the Ames 1989 site. At the 1990 Ames site, photosynthesis rates were not statistically significant for treatments on DAP 48, 70, 77, 84, and 91. The overall crop growth at the 1990 Ankeny site was poor because of poor germination and weed damage associated with the effects of an error in herbicide application. Photosynthesis rates with 0.2 m water-table depths were significantly different from those with 0.3, 0.6, 0.9, and 1.1 m water-table depths.

Comparison of photosynthesis rates for 1989 and 1990 at the Ames site on DAP 70, 77, 84, and 98 shows that photosynthesis rates were higher in 1990 than in 1989. For a water-table depth of 0.3 m, photosynthesis rates in a relatively dry season varied from 31 to 37 μ mol m^{-2} s^{-1}, and in an extremely wet growing season from 28 to 51 μ mol m^{-2} s^{-1}. The maximum photosynthesis rate at a 1989 water-table depth of 0.9 m was only 36 μ mol m^{-2} s^{-1}. In 1990, it was as high as 53 μ mol m^{-2} s^{-1} at similar plant age. In a relatively dry year like 1989, plants at shallow water-table depths were neither restricted to water supply nor subjected to excessively wet conditions, and hence they showed relatively higher rates of photosynthesis than did plants at deeper water-table depths. In fact, the 1989 data show a positive subirrigation effect on photosynthesis. In a very wet year like 1990, the soil profile was near field capacity because of continuous rainfall between May and October, and the water-table elevation had little influence on water supply to the plants. Thus, photosynthesis rates for plants at shallow water-table depths were almost equal to those at deep water-table depths. Therefore, the effect of water-table depth on photosynthesis rates in a wet season was not conclusive.

A best-fit stepwise regression model ($R^2 = 0.66$) was obtained that related photosynthesis rates to water-table depth, days after planting, and photosynthetically active radiation. The equation and the P-level of the partial regression coefficients with standard error (SE) values are given below:

$$P = 24.8 + 13.0\,(WTD) - 0.40\,(DAP) + 0.02\,(PAR)$$

$$\text{P-level} = (0.001) \quad (0.0168) \quad (0.0001) \quad (0.0001)$$

$$SE = \pm 8.76 \quad \pm 0.06 \quad \pm 0.09 \quad \pm 0.003 \qquad (1)$$

where

P = photosynthesis rate (μ mol m^{-2} s^{-1}),
WTD = water-table depth (m),
DAP = days after planting, and
PAR = photosynthetically active radiation (μ mol m^{-2} s^{-1}).

The numbers in parenthesis below the partial regression coefficients in equation 1 represent the probability that the partial regression coefficients are equal to zero. These values indicate that by using each of these variables in the model, there is no more than a 1.68% probability of accepting the null hypothesis. The null hypothesis states that the partial regression coefficients are equal to zero. Details of the "stepwise regression method" and statistical indices are given elsewhere (Rawlings, 1988).

Photosynthetic Water-Use Efficiency

Photosynthetic water-use efficiency (PWUE) indicates the rate of leaf CO_2 assimilation relative to water vapor flux and is obtained by dividing photosynthesis rate by stomatal conductance (Ritchie et al., 1990). The portable photosynthesis system was used to simultaneously measure both leaf stomatal conductance values and the photosynthesis rates. The relation between water-table depth and PWUE at the 1989 and 1990 Ames site and at the 1990 Ankeny site are presented in Table 1. Photosynthetic water-use efficiency values increased as water-table depths increased. Increase in leaf age also increased PWUE. At the 1989 Ames site, however, PWUE values on DAP 77 were greater than those on DAP 84 and 98. Because of the overcast weather on day 77, the stomatal conductance was very low. Photosynthesis rates were also low but the stomatal conductance decreased to a greater extent than photosynthesis. Thus, PWUE values were high compared with clear day values on DAP 84 and 98. Similar effects on PWUE were reported by Ritchie et al. (1990) under moisture-deficit conditions. They also found that PWUE values decreased with the increase in relative leaf-water content. The LSD values indicate that PWUE values at Ames site in 1989 were significantly different at all three water-table depths on DAP 70, 84, and 98. The plants at shallow water-table depths possibly had higher relative leaf-water contents and thus low PWUE values.

Photosynthetic water-use efficiency values at the Ames site in 1990 show similar results. These values increased with leaf age for all three water-table treatments up to DAP 84, and then decreased for DAP 91 and 98. Although PWUE values increased with increasing water-table depths, the relationship was not clear on DAP 48, 55, and 84. The LSD values show that PWUE values for 0.3 m water-table treatment were significantly different from those for 0.9 m water-table treatment on DAP 64, 70, 77, 91, and 98.

At the Ankeny site, 1990, PWUE values were higher for increasing water-table depths for all days of measurements. The plants with a water-table depth of 0.2 m showed significantly low PWUE values. The LSD values show that PWUE values at shallow water-table depths (0.2 to 0.3 m) were significantly different from those at water-table depths of 0.9 to 1.1 m on all days except on DAP 64.

A best-fit stepwise regression model ($R^2 = 0.71$) relating PWUE values to water-table depth, days after planting, and photosynthetically active radiation and the P-levels for the partial regression coefficients are given below:

$$P = -\ 29.3 + 15.0\,(\mathrm{WTD}) + 0.95\,(\mathrm{DAP}) + 0.015\,(\mathrm{PAR})$$

P-level = 0.0001   0.001   0.0001   0.0001

SE = ± 4.27   ± 0.03   ± 0.04   ± 0.001   (2)

where PWUE is in the unit of μ mol CO_2 (mol $H_2O)^{-1}$. The units for WTD, DAP, and PAR are the same as given in equation 1. The probability levels mentioned below each of the partial regression coefficients in equation 2 indicate that all the variables used in equation 1 are highly significant in the model.

Yield Relationships with Water-table Depths, Photosynthesis Rates, and PWUE

Water-table treatments had significant effects on corn yields both in 1989 and 1990. Corn yield increased significantly with increasing water-table depths from 0.3 to 0.9 m. Average corn yields in the lysimeter plots at the 1989 Ames site were 5480, 6970, and 8320 kg ha^{-1} for water-table depths of 0.3, 0.6, and 0.9 m, respectively, with a LSD value of 295 kg ha^{-1} for treatment means. Average corn yields at the 1990 Ames site were 7680, 8670, and 9920 kg ha^{-1} for 0.3, 0.6, and 0.9 m water-table depths, respectively, with a LSD value of 175 kg ha^{-1}. The LSD values indicate that corn yields were significantly different at 0.3, 0.6, and 0.9 m water-table depths at the Ames site for both years. Corn yields in 1989 were less than those in 1990. In 1989, top soil in the lysimeter area was disturbed by a trencher while installing pvc barrier around each lysimeter plot. Surface soil was also dry at the time of planting in 1989 and seed germination was poor that resulted in lower yields in 1989. A shallow water-table depth of 0.3 m reduced oxygen supply to plant roots in the growing season, and corn yield decreased significantly. Wesseling (1974) reported similar results.

At the Ankeny site, average corn yields were 11 430, 7640, 7610, 3500 and 2300 kg ha^{-1} for water-table depths of 1.1, 0.9, 0.6, 0.3, and 0.2 m, respectively, with a LSD value of 110 kg ha^{-1}. Corn yields at 0.3 and 0.2 m water-table depths were reduced significantly. Shallow water-table depths of 0.3 and 0.2 m during the growing season were harmful to crop roots in a very wet year. Crop stress developed because of oxygen deficiency in the root zone, and yield decreased. Corn yields were not statistically different at 0.9 and 0.6 m water-table depths. In a wet year like 1990, a water-table depth of 1.1 m could probably maintain adequate oxygen in the root zone and therefore, the highest corn yield was obtained at this water-table depth. Relationships between photosynthesis and yield for the dry season (1989) at the Ames site, and for the wet season (1990) at the Ankeny site are presented in figures 5 and 6, respectively. Both figures show that corn yield increased with increasing water-table depths. However, data for the dry season (fig. 5) show a reverse trend for increased yield associated with reduced photosynthesis rates. The data for the Ames site in 1990 show no distinct trend of photosynthesis rate with water-table depths, and therefore, photosynthesis and yield relationship was not clear. With the exception on DAP 34 and 48 at the Ankeny site in 1990, photosynthesis rate and corn yield did not show any distinct trend between 0.6 to 1.1 m water-table depths. However, for the 0.2 m water-table depth, both yield and photosynthesis rate decreased significantly (fig. 6). The photosynthesis data at an early growth stage (DAP 34 and 48) indicated that corn yield increased with photosynthesis rates. On DAP 48 and 64, the photosynthesis rates from plants at 0.6 and 0.9 m water-table depths were similar, and differences in yield were not significant. Statistical analysis indicated low correlation between yield and photosynthesis (Pearson correlation coefficient = 0.25). However, a best-fit regression model ($R^2 = 0.64$) was obtained that relates yield to water-table depth (0.2 to 1.1 m) and photosynthesis rate. The equation and the P-levels of the partial regression coefficients are given below:

$$Y = 1{,}547 + 11{,}920\,(\mathrm{WTD}) - 4{,}200\,(\mathrm{WTD})^2 + 16.1\,(P)$$

P-level = 0.0103   0.0001   0.0128   0.0536

SE = ± 596   ± 21.3   ± 0.17   ± 6.87   (3)

where Y is yield in kg ha^{-1}, WTD and P are same as given in equation 1. The P-level of the partial regression coefficients indicate that WTD is the most significant

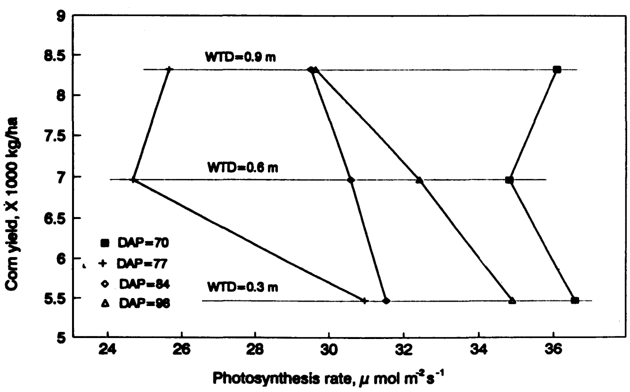

Figure 5–Relationship between photosynthesis rate and corn yield, 1989 Ames site.

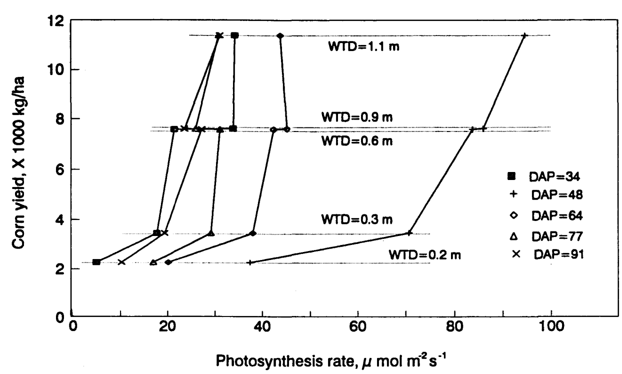

Figure 6–Relationship between photosynthesis rate and corn yield, 1990 Ankeny site.

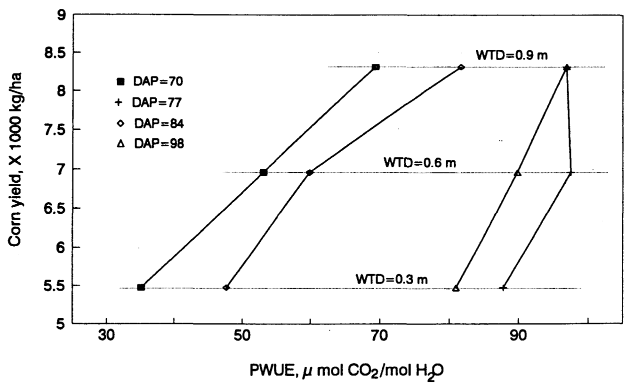

Figure 7–Relationship between photosynthetic water-use efficiency and corn yield, 1989 Ames site.

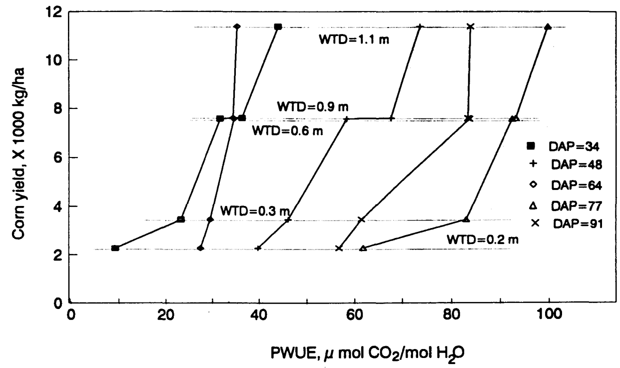

Figure 8–Relationship between photosynthetic water-use efficiency and corn yield, 1990 Ankeny site.

parameter in the model, but photosynthesis rate is not highly significant in yield prediction.

Significant positive relationships were determined between PWUE and yield for both dry and wet seasons (Pearson correlation coefficient = 0.67, P value = 0.03). The relationship between yield and PWUE on four different days of measurements at the Ames site, 1989, is shown in figure 7. The PWUE data on DAP 70 and 98 indicate relationship to be linear between crop yield and PWUE values for the dry season of 1989 (fig. 7). Similar relationship between PWUE and yield was observed from data in 1990 at the Ames site. The increased yield with increasing PWUE values for the Ankeny site, 1990, is shown in figure 8. At the Ames site, increased yield was associated with increased PWUE values for all days of measurement, and the average relation between corn yield and PWUE was only slightly nonlinear. Thus, in all cases, a positive relationship was observed between PWUE and yield. A positive relationship was not established between yield and photosynthesis rate. This finding indicates that PWUE can be useful when combined with data on water-table depth to project corn yield. A best-fit regression model (R^2 = 0.82) was obtained that relates yield as a function of water-table depth (0.2 to 1.1 m) and PWUE values, and is given by the following equation:

$$\begin{aligned} Y &= 68 + 6{,}450\,(\text{WTD}) - 6{,}000\,(\text{WTD})^2 + 83.8\,(\text{PWUE}) \\ \text{P-level} &= 0.0004 \quad 0.0001 \quad 0.0096 \quad 0.02 \\ \text{SE} &= \pm 9.5 \quad \pm 10.2 \quad \pm 0.17 \quad \pm 3.5 \end{aligned} \qquad (4)$$

where Y is yield expressed in kg ha^{-1}, WTD and PWUE are the same as in equation 2. The P-levels of the partial regression coefficients indicate that all the variable used in equation 4 were highly significant in the model. Equation 4 that quantifies yield as a function of PWUE and water-table depths is a more consistent relationship than equation 3 that quantifies yield based on photosynthesis rates.

Conclusions

Shallow water-table depths increased photosynthesis rates in a dry season. However, in a wet season, depth of water table ranging from 0.3 to 1.1 m did not seem to affect the photosynthesis rates. At very shallow water-table depths (less than 0.2 m), photosynthesis rates decreased significantly. Photosynthesis rates were affected by irradiance, and a hyperbolic relationship was determined. Photosynthesis rates were higher for the wet season than for the dry season. The effect of water-table depths on PWUE were highly significant both in the dry and wet seasons. Photosynthetic water-use efficiency values were higher for the wet season than for the dry season, and these values were higher on plants at deeper water-table depths. The effects of water-table treatments on corn yield were highly significant. Corn yields significantly increased as water-table depths increased from 0.3 to 0.9 m in 1989 and from 0.2 to 1.1 m in 1990. A shallow water-table depth of 0.2 to 0.3 m significantly reduced corn yield in the wet season. The relationships between photosynthesis rates and yield varied for dry and wet seasons and were not conclusive. However, positive relationships were obtained between PWUE values and yield under various water-table treatments for both dry and wet seasons. Photosynthetic water-use efficiency, when combined with data on water-table depths, has potential as a physiologically based indicator for predicting corn yield under various water-table management practices.

References

Cannell, R. Q. and M. B. Jackson. 1981. Alleviating aeration stresses. In *Modifying the Root Environment to Reduce Crop Stress*, eds. G. F. Arkin and H. M. Taylor. St. Joseph, MI: ASAE.

Carter, C. E., R. L. Bengtson and J. S. Rogers. 1988. Drainage needs as indicated by high water tables. *Transactions of the ASAE* 31(5):1410-1415.

Cavazza L. and P. R. Pisa. 1988. Effect of water-table depth and waterlogging on crop yield. *Agr. Water Management* 14:29-34.

Christy, A. L. and C. A. Porter. 1982. Canopy photosynthesis and yield in soybean. In *Photosynthesis–Applications to Food and Agriculture*, ed. Govindjee. New York: Academic Press.

Dwyer, L. M. and D. W. Stewart. 1986. Effects of leaf age and position on net photosynthesis rates in maize (*Zea Mays*, L.). *Agric. For. Meteorol.* 37:29-46.

Dwyer, L. M., D. W. Stewart, D. Balchin, L. Houwing, C. J. Marur and R. I. Hamilton. 1989. Photosynthetic rates of six maize cultivars during development. *Agron. J.* 81:597-602.

Elmore, C. D. 1980. The paradox of no correlation between leaf photosynthetic rates and crop yields. In *Predicting Photosynthesis for Ecosystem Models*, eds. J. D. Hesketh and J. W. Jones, Vol. II:155-167. Boca Raton, FL: CRC Press.

Evans, L. T. 1975. The physiological basis of crop yield. In *Crop Physiology*, 327-335. Cambridge, UK: Cambridge University Press.

Evans, R. O. and R. W. Skaggs. 1985. Agricultural water management for Coastal Plain soils. AG. 355. North Carolina Agricultural Extension Service.

Evans, R. O., R. W. Skaggs and R. E. Sneed. 1990. Normalized crop susceptibility factors for corn and soybean to excess water stress. *Transactions of the ASAE* 33(4):1153-1161.

Good, N. E. and D. H. Bell. 1980. Photosynthesis, Plant productivity, and crop yield. In *Biology of Crop Productivity*, ed. P. S. Carlson, 3-51. New York: Academic Press.

Hari, P., E. Hallman, R. Sulminess and E. Vappavuori. 1981. Evaluation of factors controlling net photosynthetic rate in Scots pine seedlings under field conditions without water stress. *Oecologia* 48:186-189.

Kalita, P. K. and R. S. Kanwar. 1990. Pesticide mobility as affected by water-table management practices. ASAE Paper No. 90-2089. St. Joseph, MI: ASAE.

Kanwar, R. S. 1988. Stress-day factor and stress-day index as indicators of drainage needs of soils. *Transactions of the ASAE* 31(5):1423-1429.

Kanwar, R. S., J. L. Baker and S. Mukhtar. 1988. Growth and yield of corn as affected by excess soil water at various stages of development. *Transactions of the ASAE* 31(1):133-141.

Moss, D. N. 1976. Studies on increasing photosynthesis in crop plants. In *Carbon Dioxide Metabolism and Plant Productivity*, eds. R. H. Burris and C. C. Black, 31-41. Baltimore, MD: University Park Press.

Mukhtar, S., J. L. Baker and R. S. Kanwar. 1990. Corn growth as affected by excess soil water. *Transactions of the ASAE* 33(2):437-442.

Rawlings, J. O. 1988. *Applied Regression Analysis: A Research Tool*. Pacific Grove, CA: Wadsworth & Brooks/Cole Advanced Books & Software.

Reed, K., E. Hamerly, B. Dinger and P. Jarvis. 1976. An analytic model for field measurement of photosynthesis. *J. Appl. Ecol.* 13:925-942.

Ritchie, S. W., H. T. Nguyen and A. S. Holaday. 1990. Leaf water content and gas-exchange parameters of two wheat genotypes differing in drought resistance. *Crop Sci.* 30:105-111.

Treshow, M. 1970. *Environment and Plant Response*. New York: McGraw-Hill.

Vietor, D. M. and R. B. Musgrave. 1979. Photosynthetic selection of *Zea Mays*, L. III. The relationship between CO_2 exchange and dry matter accumulation of two hybrids. *Crop Sci.* 19:70-75.

Wesseling, J. 1974. Crop growth in wet soils. In *Drainage for Agriculture*, ed. J. van Schilfgaard, 7-37. Madison, WI: ASA.

Williamson, R. E. and G. J. Kriz. 1970. Response of agricultural crops to flooding, depth of water table and soil gaseous composition. *Transactions of the ASAE* 13(2):216-220.

Zelitch, I. 1982. The close relationship between net photosynthesis and crop yield. *BioScience* 32(10):796-802.