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Influence of Nitrogen Fertility on Water Use, Water Stress, and Yield of Winter Wheat in the Central Great Plains

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ABSTRACT

Available water supply and nitrogen fertility are the primary factors limiting dryland winter wheat (*Triticum aestivum* L.) yields in the Central Great Plains. The objective of this field study was to determine how level of nitrogen fertility influences water use, water stress, and yield of winter wheat grown under dryland conditions in the Central Great Plains. The study was conducted during the 1988 growing season on a Platner loam (fine montmorillonitic mesic Aridic Paleustoll) near Akron, Colordao. Nitrogen fertilizer was broadcast as NH_4NO_3 at 0, 28, 56, 84, and 112 kg N ha^{-1}. Canopy temperatures were measured with an infrared thermometer and used to compute the Crop Water Stress Index (CWSI). Evapotranspiration was computed and rooting depth inferred from weekly neutron probe readings of soil water content. Plant height, phytomass, rooting depth, water use, and grain yield increased with increasing N. CWSI was higher in the low N plots through flowering and early grain fill, primarily due to radiative and convective

transfer of heat from the warmer soil surface resulting from less vegetative cover, but also due to lower availability of soil water due to decreased rooting depth. During the dough stage, the lower water demand of the smaller, less vegetative plants from the 0 N treatment resulted in a lower CWSI than observed in the larger plants from the higher N treatments. Grain yield increased with increasing N up through the 84 kg ha^{-1} rate and was linearly correlated with cumulative evapotranspiration.

INTRODUCTION

Available water supply and nitrogen fertility are the primary factors limiting winter wheat yields in the Central Great Plains. These two factors are related in that increased N fertility can stimulate deeper rooting by winter wheat (Brown 1971) making a greater quantity of stored soil water available to the plant, thereby reducing potential water stress. However, a larger phytomass stimulated by increased N availability results in greater transpiration requirements. Thus, if sufficient soil water reserves are not available, greater water stress in high N treatments would also occur. Onken et al. (1989) found that water use efficiency based on final grain yield and cumulative growing season evapotranspiration increased significantly with increased N fertility for winter wheat grown in the Central Great Plains. Heading, flowering, and grainfilling are the most critical growth stages in winter wheat with respect to water requirement (Musick (1963), Singh (1981), Kirkham and Kanemasu (1983)). Musick and Dusek (1980) found that water stress during vegetative growth stages limits leaf and tiller development of winter wheat, while water stress during jointing increases rate of senescence and decreases number of spikelets per head. The objective of this study was to determine how level of nitrogen fertility influences water use, water stress, growth, and yield of winter wheat grown under dryland conditions in the Central Great Plains.

MATERIALS AND METHODS

Winter wheat (*Triticum aestivum* L., var. 'TAM 107') was planted in a Platner loam (fine montmorillonitic mesic Aridic Paleustoll) on 14 September 1987 at a rate of 68 kg ha^{-1} at the Central Great Plains Research Station (40" 9' N, 103" 9' W, 1384 m above m.s.l), 6.4 km east of Akron, CO. Row direction was north-south. The experimental area had been fallowed the previous 11 months following a corn crop. The experimental design was a randomized complete block of five nitrogen fertilizer treatments (0, 28, 56, 84, 112 kg N ha^{-1} broadcast as NH_4NO_3 just prior to planting) replicated four times. Individual plots were 9.1 by 12.2 m.

Soil water was measured weekly at one location in each plot from 21 April 1988 until grain harvest with a neutron probe (Model 3321, Troxler Electronic Lab., Research Triangle Park, NC)[5] at depths of 0.15, 0.46, 0.76, 1.06, 1.37, and 1.68 m. The data were used to calculate evapotranspiration by the water balance method (Rosenberg et al. 1983), and to infer rooting depth from changes in soil water

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5 Trade names are included in the text as convenience to the reader and do not constitute any preferential endorsement by USDA-ARS of these products over other similar products.

content by depth between measurement times following the method of Bauer et al. (1989). Runoff and deep percolation were assumed to be negligible. The neutron probe was calibrated at the beginning of the season against gravimetric soil water data collected at the time of access tube installation. Crop height and growth stage were also measured weekly. Total phytomass was measured at heading and maturity. Final grain yield was sampled on 7 July 1988 from two 29.7 m^2 areas in the center of each plot.

Soil temperature was measured at 51 mm below the soil surface in one replication of the 0, 56, and the 112 N treatments with five copper-constantan thermocouples wired in parallel. The data were logged with a battery-powered data logger (CR21X, Campbell Scientific, Logan, UT) at 1-minute intervals and weekly averages were computed.

Canopy temperatures were measured with a hand-held infrared thermometer (IRT) with a field of view of 3° and an 8- to 14-micron waveband (Model 112 Agritherm, Everest Interscience, Fullerton, CA). Measurements were made two to three times a week between 1300 and 1400 MDT when the sun was unobscured by clouds. Data were recorded with a portable data logger (Polycorder, Model 516B, Omnidata International, Logan, UT). The IRT was calibrated before and after each daily measurement period using a blackbody reference. The IRT was hand-held at approximately 1.5 m above the soil surface. Six instantaneous measurements were made from both the SE and SW corners of each plot to insure that no soil surface was viewed. Air temperature and vapor pressure deficit were measured at a height of 1.5 m before and after each measurement period with an Assman-type psychrometer (Model 5230, WeatherMeasure, Sacramento, CA) in an open area adjacent to the plots. The twelve canopy temperature measurements per plot were averaged and used with the average air temperature and vapor pressure deficit to calculate one Crop Water Stress Index value (CWSI) per plot. CWSI was calculated following the method given by Idso et al. (1981) with the baseline equations for winter wheat given by Idso (1982).

RESULTS AND DISCUSSION

Large reductions in CWSI occurred in response to large precipitation events prior to jointing and heading (Fig. 1). Small precipitation events during heading and flowering maintained CWSI at less than 0.3. CWSI increased from 0.3 to 0.7 through late grainfilling due to low precipitation.

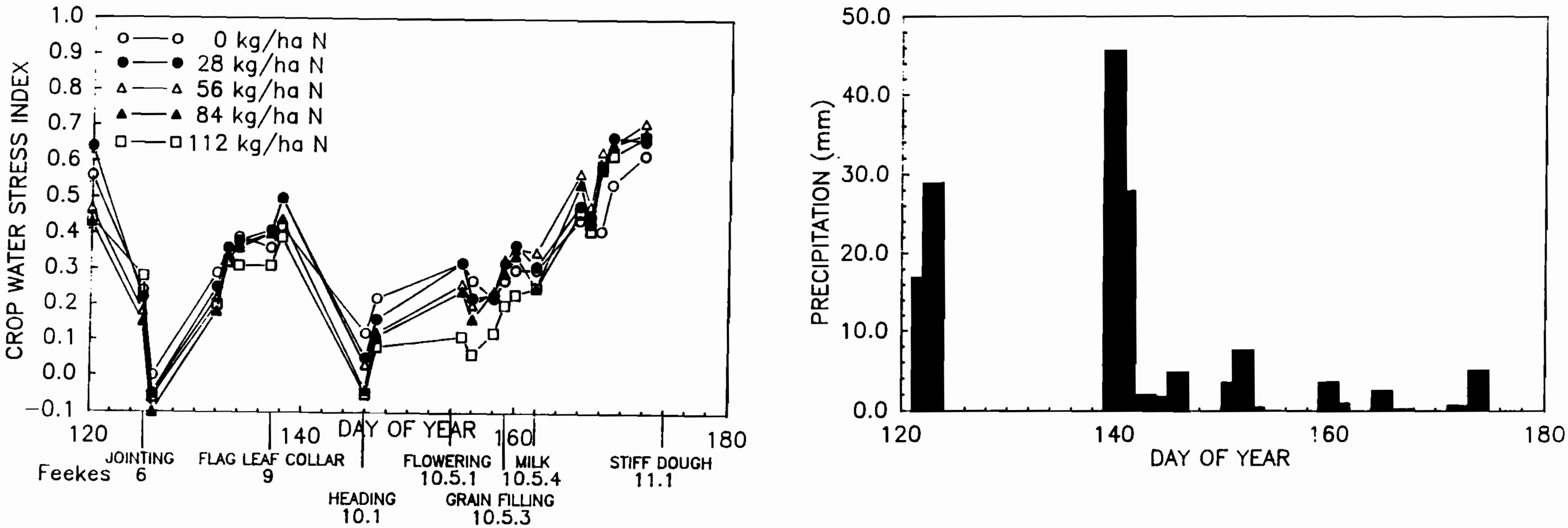

Figure 1. Crop Water Stress Index of winter wheat in 1988 as influenced by five N fertilizer treatments, and 1988 growing season precipitation.

Higher N rates tended to reduce the measured CWSI value, with the effects changing with growth stage (Fig. 2). From jointing through beginning grain fill, the low N treatments showed higher levels of water stress than the high N treatments. This can be explained by several factors. Throughout the growing season the low N treatments resulted in smaller plants with less leaf area, as noted in visual observations of the plots, and in the measurements of plant height and total phytomass (Table 1). This resulted in more of the incoming solar radiation penetrating to the soil surface. Morgan (1988) similarly noted increased leaf area and phytomass development in spring wheat due to a 100 kg ha^{-1} N application which resulted in approximately 30% greater interception of incoming photosynthetically active radiation (PAR).

Table 1. Effect of nitrogen fertility on depth of lowest root penetration (estimated by depth of water extraction), plant height, total phytomass, grain yield, test weight, heads ha^{-1}, and cumulative evapotranspiration (CET) of winter wheat.

			Phytomass		Grain			
N-Treatment kg ha^{-1}	Root Depth m	Plant Height m	At Harvest kg ha^{-1}	At Heading kg ha^{-1}	Grain Yield[1] kg ha^{-1}	Test Weight kg m^{-3}	Heads[2] $acre^{-1}$	CET mm
0	1.14	0.51	5376	6403	1824	724.6	2.11	285
28	1.22	0.52	6988	8072	2134	704.0	2.36	299
56	1.52	0.54	8084	9449	2692	687.3	2.86	328
84	1.52	0.56	9560	10307	2833	673.1	3.16	327
112	1.45	0.55	8303	9046	2397	675.7	2.84	329
LSD[3]	0.36	0.06	2152	2149	873	15.6	0.60	44

[1] *Grain yield was at 12% moisture.*
[2] *Million heads per acre.*
[3] *Differences between values within a column greater than the reported LSD are significantly different at* $\alpha = 0.05$.

In the present study this increased interception of PAR significantly decreased soil temperatures (Fig. 3). This increased thermal energy in the low N treatments was transferred convectively and radiatively to the overlying canopy. Using non-water-stressed baselines for partial canopies as suggested by Hatfield et al. (1985) instead of the non-water-stressed baseline for full canopies used in this study might have eliminated these differences. However, the lower CWSI values in the higher N treatments could in part be due to the greater rooting depth and greater available water supply to these plants (Table 1).

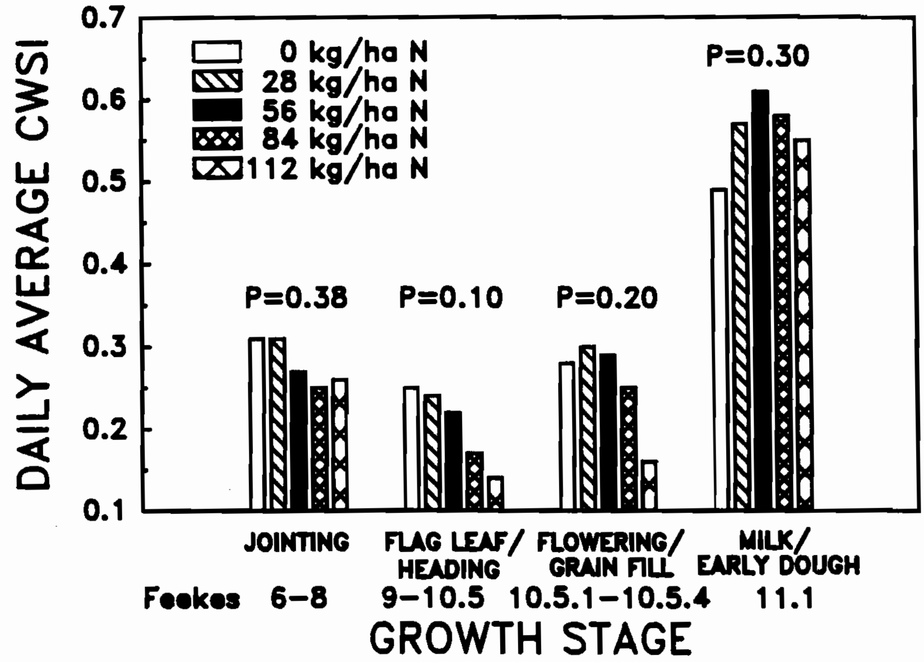

Figure 2. Daily average Crop Water Stress Index (CWSI) of winter wheat as influenced by five N fertilizer treatments. (P=probability for rejecting the null hypothesis).

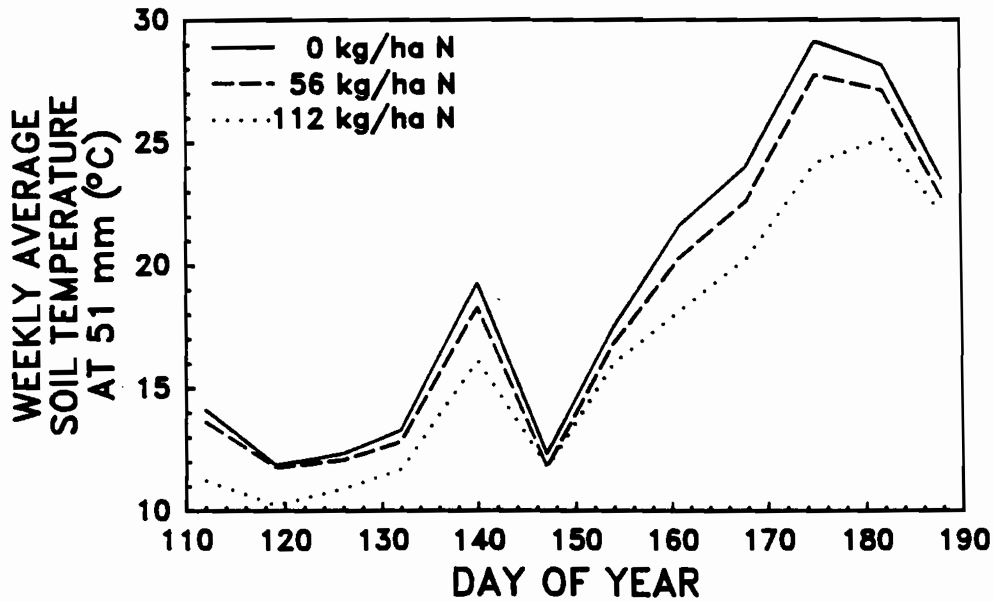

Figure 3. Weekly average soil temperature at 51 mm under a winter wheat canopy as influenced by three N fertilizer treatments.

During the dough stage of development, the 0 N treatment showed lower CWSI levels than the higher N treatments, even though soil temperature in this treatment was still higher than the other treatments. These smaller plants probably had a lower demand for water than the larger plants in the high N treatments. The extra available water from the increased rooting depth of the high N treatments was gone by this time resulting in plants under increased water stress. The higher test weights in the 0 N treatment could in part be a consequence of this lower level of water stress during the late grainfilling stage.

Grain yield increased with increasing N up through the 84 kg ha^{-1} rate (Table 1). Grain yield was linearly correlated with cumulative evapotranspiration (Fig. 4). This relationship is similar to one reported by Halvorson and Kresge (1982) for winter wheat growing in the Northern Great Plains. The slightly greater negative offset found in the current study is consistent with the somewhat higher evaporative demand in the Central Great Plains.

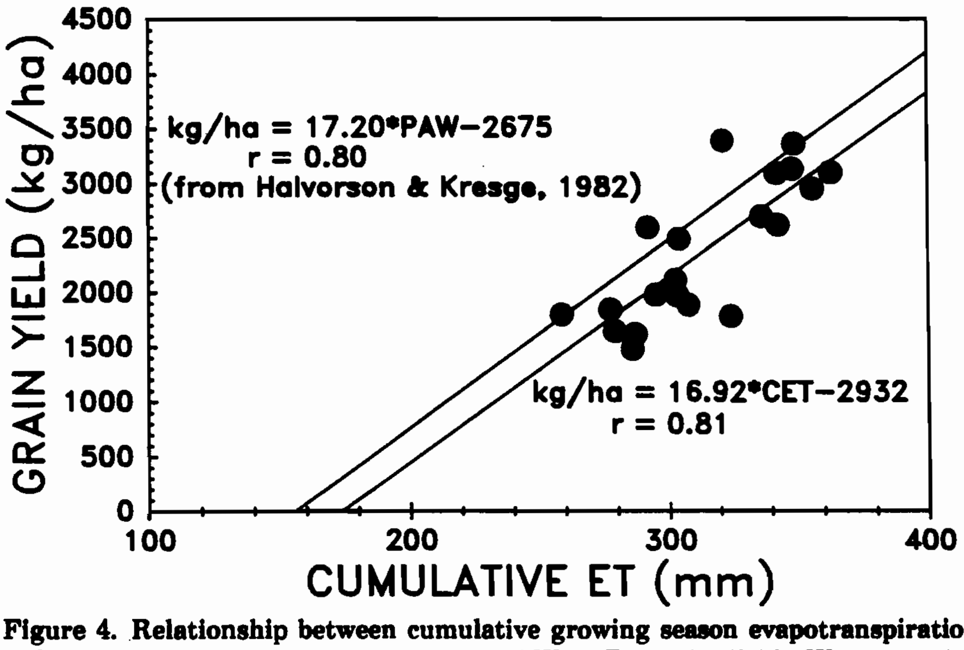

Figure 4. Relationship between cumulative growing season evapotranspiration (CET) and winter wheat grain yield. (PAW = Plant Available Water, mm).

SUMMARY AND CONCLUSIONS

Increased levels of N fertility stimulate both phytomass and root growth. The increased phytomass intercepts more incoming PAR, conferring a higher water requirement on the plant system while at the same time making more soil water available through the deeper root system. This gives the potential for greater yields when adequate or moderately limited water is available. But under conditions of severe water stress during the latter part of the growing season, the larger plant developed during the vegetative growth period may experience increased levels of water stress resulting in lower yields than plants fertilized at a lower N level.

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