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WINTER WHEAT GRAIN YIELD RESPONSE TO WATER AND NITROGEN ON THE NORTH AMERICAN GREAT PLAINS*

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ABSTRACT

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Soil moisture and nitrogen availability and location are the main factors influencing winter wheat yields on the Great Plains. A study was conducted in 1985 and 1986 at five locations with three soil water levels and four nitrogen levels to investigate yield and yield components of winter wheat. Potential yields increased with latitude but rainfed yields were similar at all sites, confirming that moisture stress is the most limiting factor on the Great Plains. Kernels per spike increased with latitude. Optimum fertility rate was about 160 kg of N ha^{-1}. Kernel weight decreased and spike numbers increased as nitrogen was increased. Increased yields from irrigation came mainly through an increased number of spikes. The three components of yield, spike number, kernels per spike and kernel weight, were significantly and positively related to yield but kernel weight and spike number appeared to be the main determinants of final grain yield.

INTRODUCTION

Studies of water and nitrogen effects on spring and winter wheat yields have been conducted with regularity but few, if any, studies have included the effects of water and nitrogen at a diverse array of locations. Water and nitrogen are usually the most limiting factors affecting winter wheat yields on the North American Great Plains and they must be supplemented for maximum yields.

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The maximum response to irrigation depends on the availability of sufficient soil-available nitrogen (Brown, 1971), and the rate of nitrogen fertilization is a function of the soil moisture availability (Bole and Pittman, 1980).

The response to fertilizer nitrogen and to irrigation depends on the level of both soil nitrogen and soil moisture. Little or no yield response to fertilizer nitrogen on some soils is apparently quite common in Europe where high rates of fertilization have been used for some time (Pearman et al., 1977). When available soil nitrogen is combined with fertilizer nitrogen there would appear to be some consensus that maximum yields are attained at about 100–125 kg of N ha^{-1} (Dubetz, 1977; Bole and Dubetz, 1986). This is also consistent with the amount of nitrogen that can be recovered from the crop itself (Krogman and Lutwick, 1964; Daigger et al., 1976; Austin et al., 1977; Sanford and Hairston, 1984). Cox et al. (1985) detected amounts of nitrogen that were higher than usually reported, perhaps because their yields were very high.

Yield response to irrigation will depend on the amount and distribution of precipitation during the growing season. In humid areas, water stress can occur in a rapidly growing crop experiencing a relatively short dry period. In the sub-humid and semi-arid regions, drought stress can become increasingly severe as the season progresses because of longer intervals between precipitation events than in the earlier part of the growing season. Consequently, higher evapotranspiration and reduced precipitation result in a steadily declining soil moisture supply toward the end of the growing season. As a result, irrigation responses in humid regions are variable, and on the eastern edge of the Great Plains irrigation response varies from year to year (Hooker et al., 1983). In most semi-arid regions there will be some moisture stress almost every year so that irrigation consistently increases yields. Quantification of the yield response to irrigation is possible by comparing evapotranspiration or transpiration rates (Doyle and Fischer, 1979).

The effect of nitrogen and water availability on the components of yield may be best described by determining how stress affects the developing sink (Brockelhurst et al., 1978; Sionit et al., 1980; Hooker et al., 1983). Pre-flowering stress will reduce the numbers of tillers and spikelets per head. Early post-flowering stress will result in some spikelet abortion and late-flowering stress will primarily affect kernel size. Brockelhurst et al. (1978) found that kernel size was proportional to the number of endosperm cells except in the case when stress limited the assimilate supply during the cell expansion phase, i.e., late-season stress resulted in reduced kernel size by a reduction in endosperm cell size.

The objective of this study was to evaluate the effects of irrigation on grain yield and its components of winter wheat grown at four soil nitrogen levels at five locations on the Great Plains of North America.

MATERIALS AND METHODS

Grain yield data were obtained for all locations in both years. Kernel weight data were determined at all locations except Mandan in 1986, the number of spikes per square meter was determined at all locations but was not complete for the Tryon or Manhattan locations, and the number of kernels per spike was incomplete for the Tryon location and unavailable for Mandan in 1986. The details of plot size and method of sampling for yield and its components have been presented in detail by Reginato et al. (1988).

Estimated grain yield was calculated as the product of number of spikes m^{-2}, kernels $spike^{-1}$ and kernel weight in mg. The estimated yield was then regressed against actual measured yield. Regression analyses were performed to detect associations among components of grain yield and to assess effects of water and nitrogen on yield and its components.

Additional analysis consisted of comparing treatment means. Tests of significance were determined using analysis of variance with the error term derived from locations and years. Since there were so many factors involved, the initial analyses entailed scrutinizing the means to determine at what locations nitrogen and irrigation effects were observed. Locations were then grouped according to the degree of response to nitrogen or irrigation or both.

RESULTS AND DISCUSSION

Average full irrigation (W3) and rainfed (W1) yields at each location were plotted against latitude to provide a preliminary examination of location effects and also to examine consistency of irrigation by location and years (Fig. 1). The 1986 rainfed yield at Lubbock was considerably lower than the average for all of the other rainfed estimates and the irrigation response at Tryon in

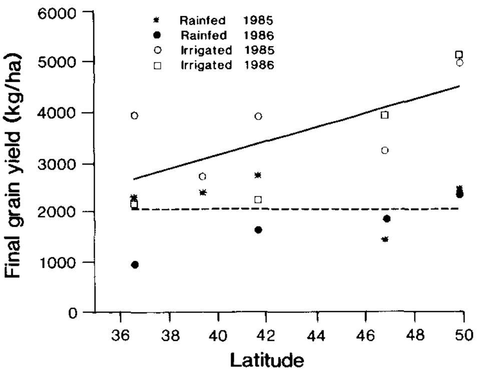

Fig. 1. Final grain yield of winter wheat grown under irrigation or rainfed conditions versus latitude for five locations on the North American Great Plains in 1985 and 1986. Latitudes are: Lubbock, 36° 31′; Manhattan 39° 09′; Tryon, 41° 37′; Mandan, 46° 46′; Lethbridge, 49° 42′.

1986 was virtually non-existent. The broken line in Fig. 1, which is the average of the rainfed yields, indicated that there was no trend among locations for rainfed yields while the solid line suggested that there was an increase in irrigated yield as latitude increased. However, considering the large disparity between irrigated yields in 1986 versus 1985 for both Lubbock and Tryon and considering the non-existent response to irrigation at Manhattan in 1985, one might possibly conclude that there is no latitudinal response for irrigated yield either.

If there is a trend in irrigated yields by latitude it might be due to the fact that air temperature and daylength are confounded in comparisons involving

TABLE 1

Winter wheat yield and its components as affected by cultivar at five locations on the Great Plains in 1985 and 1986

Site	Year	Cultivar	Grain yield (kg ha^{-1})	Spikes m^{-2}	Kernel weight (mg)	Kernels spike^{-1}
Lubbock	1985	Colt	2799	580	30.6	13.4
		TAM 101	3309	531	35.0	13.9
Lubbock	1986	Colt	1088	418	18.0	12.5
		TAM 101	1733	409	25.4	15.0
Manhattan	1985	Colt	2335	511	24.9	16.3
		Brule	2769	682	24.4	15.8
Tryon	1985	Colt	3348	618	26.8	26.5
		Brule	3711	571	26.3	28.1
Tryon	1986	Colt	1919	379	25.7	21.8
		Brule	2042	400	24.8	23.6
Mandan	1985	Colt	2115	341	29.3	26.8
		Norstar	2571	456	29.6	24.0
Mandan	1986	Colt	3200	588	27.6	20.2
		Norstar	2946	482	27.1	22.9
Lethbridge	1985	Colt	3415	402	33.7	24.5
		Norstar	3449	364	33.7	26.9
Lethbridge	1986	Colt	4753	801	32.2	18.8
		Norstar	3447	596	29.7	21.1
$LSD_{0.05}$			294	47	1.5	1.5

different locations. In another paper in this series (Major et al., 1988) we found that the onset of rapid whole-plant biomass began when average air temperature was about 11°C. The date when this occurred was later at the more northerly locations resulting in large daylength differences among sites. The fact that no latitudinal effect was found for rainfed yield suggested that moisture was the most limiting factor at all sites.

The locally adapted cultivar had a higher yield than Colt except at Mandan and Lethbridge in 1986 where Colt outyielded Norstar by 38% (Table 1). The reason for this was that Colt produced a higher number of spikes per unit area than Norstar in 1986. Yields of Colt and Norstar were similar at Mandan and Lethbridge in 1985 in spite of the fact that there was winterkill at Mandan and Lethbridge in 1985 that affected Colt more adversely than Norstar, presum-

TABLE 2

Winter wheat yield and its components as affected by nitrogen at five locations on the Great Plains averaged over 1985 and 1986

Site	N rate ($kg\ ha^{-1}$)	Grain yield ($kg\ ha^{-1}$)	Spikes m^{-2}	Kernel weight (mg)	Kernels $spike^{-1}$
Lubbock	60	2961	539	33.7	13.4
(1985)	100	2990	544	32.9	13.1
	160	3143	554	30.5	14.4
	240	3142	580	31.3	13.8
Manhattan	60	2585	624	26.7	15.7
(1985)	100	2578	530	26.5	15.8
	160	2707	614	25.1	15.8
	240	2338	692	20.3	16.8
Tryon	60	3339	578	28.1	27.5
(1985)	100	3611		26.5	
	160	3668	612	26.2	27.1
	240	3502		25.2	
Mandan	60	1832	336	30.9	22.8
(1985-86)	100	2592	436	30.2	25.8
	160	3162	535	28.8	26.7
	240	3246	561	28.0	26.2
Lethbridge	60	3750	460	31.5	22.2
(1985-86)	100	3838	504	32.6	23.4
	160	3781	477	32.4	21.6
	240	3696	506	32.8	23.2
$LSD_{0.05}$		936	70	2.1	2.9

ably due to Norstar's better cold hardiness. This suggested that in years without any winterkill, such as 1986, Colt is capable of outyielding Norstar. The reason may be related to Norstar being tall whereas Colt is a semi-dwarf cultivar.

At the three southern locations Brule or TAM-101, the locally adapted cultivars, were superior to Colt; they produced consistently higher yields (Table 1). The yield advantage was not the result of an advantage in any one component of yield but varied depending on the site and year. The yield superiority of the locally adapted cultivar was consistent across nitrogen and irrigation treatments.

Nitrogen effects were observed at all locations and were most pronounced at Mandan and Tryon, but only a limited response was observed at Lubbock, Manhattan and Lethbridge (Table 2). Extreme lodging at the high nitrogen level decreased yields at Manhattan. Yield tended to increase up to 160 kg N ha^{-1} and then decreased at 240 kg N ha^{-1} except at Mandan. There was no observable effect of nitrogen on the number of kernels per spike. A consistent trend observed in the yield components was that kernel weight decreased and spike numbers increased with increased nitrogen. Final spike number would have been determined by heading so it is possible that increased nitrogen fertility resulted in more heads being initiated than could be filled, and as a result, kernel weight was lower.

TABLE 3

Winter wheat yield and its components as affected by irrigation at five locations on the Great Plains averaged over 1985 and 1986

Site	Irrigation treatment	Grain yield (kg ha^{-1})	Spikes m^{-2}	Kernel weight (mg)	Kernels spike^{-1}
Lubbock	W1	2204	515	31.6	11.9
(1985)	W2	3284	577	32.9	13.3
	W3	3690	570	31.9	15.8
Tryon	W1	2961	526	26.2	27.0
(1985)	W2	3693		26.8	
	W3	3934	664	26.5	27.6
Mandan	W1	1953	356	27.1	26.1
(1985)	W2	2407	417	30.1	25.5
	W3	2669	423	31.1	24.7
Lethbridge	W1	2540	420	28.8	20.2
(1985-86)	W2	3893	518	33.0	23.6
	W3	4865	526	35.2	24.1
$LSD_{0.05}$		936	70	2.1	2.9

Water effects on grain yield were apparent even though winter wheat avoids moisture stress by growing in the coolest part of the season. The most obvious effects of irrigation were observed at Lubbock, Tryon, Mandan and Lethbridge with an advantage to each successive level of irrigation (Table 3). There was no effect of irrigation at Manhattan. The yield increase came about largely as a consequence of more spikes being produced with relatively little change in kernel weight. This suggested that some moisture stress must have occurred prior to heading and growth adjustments had already been made by late seed filling. As a result only slight reductions in final seed weight were measured. If moisture stress increased rapidly during late grain filling, a reduction would be expected in final seed weight. However, this was not the case.

Selected comparisons of yield of Colt at water treatments W1 and W3 were

TABLE 4

Colt winter wheat yield and its components as affected by selected irrigation and nitrogen treatments at five locations on the Great Plains averaged over 1985 and 1986

Site	Treatment	Grain yield ($kg\ ha^{-1}$)	Spikes m^{-2}	Kernel weight (mg)	Kernels $spike^{-1}$
Lubbock	W1 60N	2029	543	32.8	10.5
(1985)	W1 160N	2055	506	27.8	13.0
	W3 60N	2917	552	32.5	14.8
	W3 160N	3909	676	29.8	18.0
Manhattan	W1 60N	2109	562	28.5	16.0
(1985)	W1 160N	2307		27.1	14.5
	W3 60N	2510		28.1	16.0
	W3 160N	2712	614	24.5	16.5
Tryon	W1 60N	2638	529	27.0	26.3
(1985)	W1 160N	2955	599	27.1	26.0
	W3 60N	3561	693	29.5	26.0
	W3 160N	3849	651	25.6	27.8
Mandan	W1 60N	1074	262	29.8	26.3
(1985)	W1 160N	2064	307	27.3	28.5
	W3 60N	1161	241	30.6	21.5
	W3 160N	3092	408	30.9	26.0
Lethbridge	W1 60N	2544	372	29.2	16.0
(1985-86)	W1 160N	2414	360	28.9	17.0
	W3 60N	5242	503	35.8	23.5
	W3 160N	5745	462	37.2	20.0
$LSD_{0.05}$		936	70	2.1	2.9

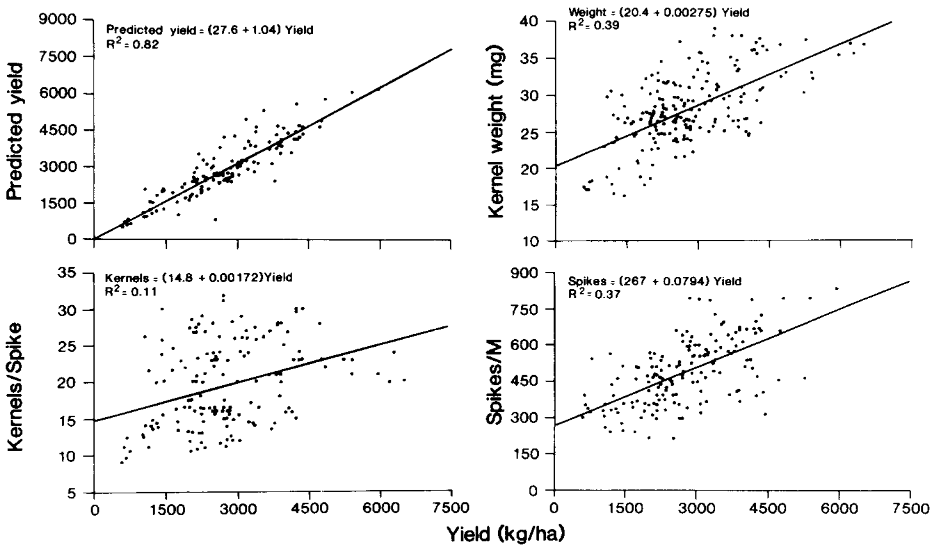

Fig. 2. Grain yield components and yield predicted from components of winter wheat grown at different soil nitrogen and soil water levels at five locations on the North American Great Plains in 1985 and 1986.

of interest because they demonstrated the typical yield that would be expected at each location and allowed logical comparisons of the interaction of nitrogen and irrigation (Table 4). Yield of treatment W3 represented the potential yield and the ratio of this with rainfed yield would represent a measure of the degree of crop water stress. There was a response to nitrogen in the absence of irrigation and a response to irrigation in the absence of added nitrogen but the highest yields were consistently associated with the 160 kg N ha^{-1} level at the highest irrigation level, W3. The response to nitrogen was consistent among water treatments and vice versa in that the highest yield was obtained at the 160 kg N ha^{-1} for all three irrigation treatments. The W3 treatment also produced the highest yield regardless of the nitrogen treatment.

Considering the extremes in environment that were encountered in this study, a very high association (R^2=0.79) was observed between yield and yield predicted from the three components of yield (Fig. 2). This was the result of associations between two of the three components and yield. Kernel weight and spikes per unit area were positively associated with final yield, having coefficients of determination of 0.36 and 0.35 respectively. Kernels per spike were significantly associated with yield but the R^2 was only 0.13. The product of these three, however, was an excellent predictor of yield.

SUMMARY

All edaphic and climatic variables influenced yield of winter wheat. Utilizing the components of yield allowed some conclusions with respect to the influence

of these factors on availability and partitioning of photosynthate throughout the life cycle and at different locations. High N fertility allows the winter wheat crop to produce increased numbers of kernels per spike and spikes per unit area but at the highest N level the sink appeared to be too large as reflected in low final seed weight. Moisture stress was apparent by heading as evidenced by reduced numbers of spikes in the rainfed versus irrigated treatments. This supported the contention that stress on the Great Plains is a gradual phenomenon to which the winter wheat crop must adjust. The maximum yield response for winter wheat was observed at the 160 kg N ha^{-1} and full irrigation treatment.

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