THE EFFECT OF SEED RATE, ROW SPACING AND NITROGEN FERTILITY ON THE PATTERN OF WATER USE BY NO-TILL WINTER WHEAT IN THE SASKATCHEWAN PARKBELT REGION

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ABSTRACT

Increased rate of nitrogen (N) application, high seed rate (SR) and narrow row spacing (RS) increased water use (WU) over the course of the growing season. Most of the increase in WU occurred during the pre-anthesis growth period. High SR exhibited higher WU in the pre-anthesis growth period, but higher WU in the post-anthesis growth period was associated with low SR. Highest grain yield and water use efficiency (WUE) were associated with the combination of high SR and narrow RS. Increased N rate, and high SR also promoted higher levels of grain protein (GP). Differences in yield components and GP were related to the pattern of WU.

INTRODUCTION

Optimum SR of wheat varies with environment and agronomic practice. Soil moisture, N fertility (Fischer et al, 1975) and RS (Tompkins et al, 1990) have been reported to influence optimum SR. Generally, the higher the crop yield potential the higher the optimum SR. In Saskatchewan, optimum SR for spring wheat can range from 20 kg ha^{-1} for spring wheat seeded on stubble in the Brown Soil Zone (Read and Warder, 1982) to 124 kg ha^{-1} on a Black Soil in the Parkbelt region (Wright et al, 1987). This corresponds to a move from a drier to a moister environment. Recent work in the Parkbelt region suggests that optimum SR for winter wheat is higher than for spring wheat (Tompkins et al, 1990).

Crop management affects the pattern of WU. In Texas, Winter and Welch, (1987) found that the use of wide RS was effective in economizing the use of soil water by winter wheat before the boot stage, but total WU was not affected. Similarly, Steiner (1986) reported that the use of wide RS reduced evapotranspiration (ET) in the vegetative period with a greater proportion of WU in the grain filling period. With the use of high SR and narrow RS, increased overall WU included increased partitioning of ET to transpiration (T). Before the crop cover is established, the majority of water loss due to ET is to evaporation (E) and is highly dependent on the crop cover that is present. As the crop cover increases, the T component of ET becomes relatively more important (Ritchie, 1971) resulting in increased WUE when sufficient moisture is available (Ritchie and Burnett, 1971; Fischer and Turner, 1978).

Vegetative growth and WU prior to heading are greater with increased nitrogen fertility (Bond et al, 1971). Ideally this is translated into higher WUE (Campbell et al, 1987; Bole and Pittman, 1980). According to Brown (1971) higher WUE at higher N fertility is associated with a deeper rooting zone and greater extraction of water from throughout the rooting zone.

In Saskatchewan, high dry matter yields are necessary for high grain production (Baker and Gebeyehou, 1982; Entz and Fowler, 1989a). The dry matter yield at anthesis determines the maximum yield potential of the crop and the post-anthesis growth period determines the level of expression of that yield potential (Fowler et al, 1989a). With the growing conditions present in Saskatchewan, dry matter yield is influenced more by evaporation than precipitation (Entz and Fowler, 1988). Part of the yield advantage of winter wheat over spring wheat is due to lower early season water losses to E before the winter wheat crop canopy is established (Entz and Fowler, 1989b). High dry matter at anthesis results in reduced losses to E and increased WUE (Entz and Fowler, 1989a).

High WUE is also associated with a high number of heads m^{-2} (Entz and Fowler, 1989a). Heads m^{-2} can be maximized by high SR and narrow RS (Johnson et al, 1988; Tompkins et al, 1990) and optimum N fertility (Black, 1970).

This study was undertaken to determine the effect of SR, RS and nitrogen fertility on the pattern of WU and WUE of winter wheat grown in the Saskatchewan Parkbelt region. The effect of the treatment variables on the individual yield components and on GP levels were also considered.

MATERIALS AND METHODS

Nine winter wheat trials were established in rapeseed or barley stubble in the Parkbelt region of Saskatchewan over the period 1987 to 1989 (Table 1). Soils ranged from Black to Gray Soils and from medium to light in texture.

Experimental design was a split-plot with two replicates. Nitrogen fertility treatments, 0 and 100 kg applied N ha^{-1}, were main plots. Subplots were a factorial of SR: 35 and 140 kg ha^{-1}, and RS: 9 and 36 cm, providing a wide range of treatments for Saskatchewan Parkbelt conditions.

A no-till offset double disk press drill, custom built to enable seeding at various SR and RS combinations was used to seed plots 1.4 m by 7 m in size. All trials were seeded in late August or early September. Seventy-five kg P_2O_5 ha^{-1} from monoammonium phosphate fertilizer was broadcast on each trial after seeding and in early May, the ammonium nitrate fertilizer was broadcast.

In early spring, at anthesis, and immediately prior to harvest soil moisture was measured to a depth of 1 m with a Troxler 3331 depth moisture gauge. Access tubes were placed in the soil in early spring and readings were taken at depths of 20, 40, 60, 80 and 100 cm below the surface. The depth moisture gauge was calibrated by comparing readings with volumetric moisture values measured from drying soil cores. Soil moisture in the top 10 cm was determined gravimetrically and converted to volumetric moisture. The difference between soil moisture measured in the spring and at anthesis plus rainfall during that time period was used as a measure of WU during the pre-anthesis growth period of the crop. Similarly, the difference between soil moisture measured at anthesis and harvest plus rainfall during that time period was used as a measure of WU during the post-anthesis growth period of the crop.

Data collected included dry matter at anthesis (DMa), dry matter at harvest (DMh), head counts at maturity, grain yield, kernel weight and harvest index (HI). Kernels head^{-1} were derived arithmetically from the other yield component measurements. Water use efficiency was determined from the WU and grain yield measurements. Grain protein was calculated from percent N and grain protein yield from percentage GP multiplied by grain yield.

Data for all variables considered were subjected to an analysis of variance (SAS, 1985). Single degree of freedom contrasts were used to distinguish the effects of SR, RS and their interaction (Little and Hills, 1978).

RESULTS AND DISCUSSION

Poor growing conditions prevailed during the study period. Spring, in particular, was uncharacteristically hot and dry in all three years of the study.

Effect of trial and nitrogen fertility. Trial had a significant effect on pre-anthesis, post-anthesis and total WU due to differences in spring moisture and growing season precipitation (Table 2). Total WU ranged from 7.5 cm in the very dry Trial 5 to 20.8 cm in Trial 9. In Trial 1, there was an apparent high level of post-anthesis WU due to a heavy late season rainfall much of which was lost as runoff and which was too late to benefit crop yield.

Total WU was 0.6 cm higher under conditions of higher N fertility (Table 3). The increase in WU with increased N fertility confirms results reported in other studies (Brown, 1971; Bole and Pittman, 1980), and may have been due to increased root weight at higher N fertility (Kmoch et al,1957). However, more water was used under conditions of low N fertility in Trials 4 and 5 resulting in a significant trial by fertility interaction for growing season WU. Both of these trials were subjected to severe moisture stress which resulted in premature leaf senescense. This was particularlly true under conditions of higher fertility where more early season plant growth had occurred. Consequently, in these two trials, conditions of lower N fertility resulted in more sustainable plant growth and increased WU over the course of the growing season.

Trial and N fertility level had a significant influence on DMa and DMh. Better moisture conditions (Table 2) and increased N fertility (Table 3) produced increased dry matter yield.

Trial and the level of nitrogen fertility also significantly influenced grain yield. Trials with better moisture conditions produced higher yields than the very dry trials: yields ranged from 430 kg ha^{-1} in Trial 5 to 2410 kg ha^{-1} in Trial 7 (Table 2). Higher N fertility produced a 270 kg ha^{-1} or 19% increase in grain yield as compared to the check treatment (Table 3).

A significant trial by N fertility interaction for grain yield resulted from the extremely dry growing conditions in Trial 5. In this trial, slightly higher grain yield was associated with low N fertility.

Trial and N fertility both had a significant effect on WUE. As has been reported by Heitholt (1989) higher WUE was associated with better moisture conditions. Severe early season drought resulted in a very low WUE in Trials 1 and 5 (Table 2). Table 3 shows that higher N fertility also resulted in higher WUE as has been reported by Eck (1988).

The number of heads m^{-2}, kernels $head^{-1}$ and kernel weight were generally higher in the trials with more favourable moisture conditions (Table 2). All three yield components were severely reduced in Trial 5 reflecting the impact of moisture stress throughout the growing season. In Trial 9, moisture stress later in the growing season reduced kernel weight and kernels $head^{-1}$. None of the yield components were significantly affected by the level of N fertility (Table 3).

Harvest index also was affected by trial (Table 2), but not by the level of N fertiltiy (Table 3). Generally, drier trials had a lower harvest index than trials with more favourable moisture conditions.

Trial conditions and N fertility both affected GP. Higher GP levels were associated with the drier trials (Table 2) and with higher N fertility (Table 3). In spring wheat high protein concentration in the grain is typically associated with moisture stress (Campbell et al, 1977). Very high protein levels, such as the 18% GP in Trial 5 occur when grain yield is restricted (Henry et al, 1986). Generally, N assimilation is maximized in the pre-anthesis growth period, and carbohydrate assimilation is maximized in the post-anthesis growth period (Fowler et al, 1989) so low post-anthesis WU resulting from moisture stress would be expected to produce high GP.

Protein yield was influenced by the same variables that affected grain yield and GP. Trials that had very low grain yields due to moisture stress had a lower protein yield despite the higher GP (Table 2). Increased N rate also increased protein yield (Table 3). This would be expected as increased N fertility typically promotes both grain yield and GP. Fowler and co-workers (1989b), reported similar trends for protein yield and GP of winter wheat and fall rye produced in Saskatchewan.

<u>Effect of seed rate and row spacing</u>. Seed rate had a significant effect on WU during both growth periods (Table 4). The high SR treatment produced higher WU in the pre-anthesis growth period, but the low SR treatment produced higher WU in the post-anthesis period. Over the entire growing season, higher WU was associated with the high SR treatment.

The use of narrow RS produced increased WU during the pre-anthesis growth period (p=0.07) and for the total growing season. In Texas, Winter and Welch (1987) also found that wide-row systems were effective in economizing soil WU before the boot stage. This would leave more water for the later growth stages, particularly at low seed rates. In contrast to the Texas study, however, total growing season WU was reduced with use of wide RS in this study.

The use of high SR also produced higher DMa and DMh (Table 4). Row spacing did not affect Dma, but the use of narrow RS did produce higher DMh.

Both SR and RS significantly influenced grain yield (Table 4). As reported in a previous paper (Tompkins et al, 1990), highest grain yield was associated with the use of high SR and narrow RS.

The relationship between dry matter production, grain production and the pattern of WU by plants grown at different SR is of interest. With the use of high SR DMa was 40% higher than with the use of low SR. Harvest dry matter and grain yield were also higher with the use of high SR, but only 11% higher than when low SR was used. Therefore, the response to increased SR for DMa was greater than for DMh or for grain yield. This relates to the pattern of water use in the pre-anthesis and post-anthesis growth periods. Prior to anthesis, more water was used by plants grown at high SR. Under the dry conditions present in this study, more water was used by plants grown at the low SR in the period after anthesis, because there was more water still available. Consequently, with the use of high SR the much higher rate of dry matter production prior to anthesis was not sustained. These results support the observation of Fischer and co-workers (1975) that dry matter production is maximized at a higher SR than is grain production. Nevertheless the use of high SR still produced higher grain yield compared to the low SR treatment. This supports the idea that DMa determines the maximum yield potential of the crop and the post-anthesis growth determines the level of expression of that yield potential (Fowler et al, 1989a).

The use of narrow RS also produced higher DMh as well as higher grain yield, and resulted in higher WU. Better ground cover is associated with the use of narrow rather than wide RS (Tompkins, 1989). This may have resulted in increased T relative to E (Fischer and Turner, 1978).

The interaction between SR and RS also had a significant effect on WUE (Table 4). The use of narrow RS and high SR (9-140) resulted in a higher WUE than the other treatments. The wide RS treatments used less soil water than the narrow RS treatments, but also had reduced grain yield. Under the dry conditions that prevailed at most of the trials the increased intra-row competition imposed by the combination of high SR and wide RS (36-140) resulted in a low WUE relative to that of the 9-140 treatment.

The use of high SR and narrow RS produced an increased number of heads m^{-2} (Table 4). This yield component was primarily responsible for the higher grain yield associated with the use of high SR and narrow RS. However, the use of high SR and narrow RS also resulted in greater WU, thus increasing moisture stress and lowering kernels $head^{-1}$. The better distribution of plants with the use of narrow RS resulted in a much higher number of heads m^{-2} for the 9-140 treatment relative to the 36-140 treatment and more than compensated for the reduced kernels $head^{-1}$. Though WU was higher for this treatment, the better distribution of plants together with the high plant density should have resulted in less loss of moisture to weeds (Van der Vorst et al, 1983), increased ET (Johnson et al, 1981), and greater partitioning of ET to T (Steiner, 1986) resulting in the observed higher WUE, a more efficient conversion of moisture into grain yield.

Seed rate also had a significant effect on GP accounting for 88% of the variability in GP due to SR and RS combination. Higher GP was produced with the use of high SR (Table 4). Darroch (1988) reported that 90% of the total plant N is accumulated by anthesis. Spiertz and Vos (1985) reported that 50% to 80% of the N used by the grain is derived from vegetative organs. Nitrogen assimilation is maximized in the pre-anthesis growth period, and carbohydrate assimilation is maximized in the post-anthesis growth period (Fowler et al, 1989b). In this study, plants grown with high SR used more soil moisture in the pre-anthesis growth period, and produced greater dry matter accumulation by anthesis. This would result in greater N uptake, which was translated into higher GP as the N was partitioned. This also left less water for post-anthesis carbohydrate assimilation, thus increasing protein concentration of the grain. The relationship between SR and GP observed in this study was therefore a product of available moisture and should not be extrapolated to situations where more favourable moisture conditions exist, particularly later in the growing season. However, with moisture conditions similar to this study GP concentration may be increased with the use of higher SR.

Grain protein was not affected by RS in this study. While the use of narrow RS also resulted in higher WU in the pre-anthesis period, the difference between pre-anthesis and post-anthesis moisture uptake and dry matter accumulation was much greater for SR than for RS.

The use of high SR produced higher protein yield (Table 4) as the use of high SR produced both higher grain yield and higher GP concentration.

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Table 1. Summary of soil characteristics, preceeding crop and environmental conditions.

			Soil		
Trial	Year	Previous crop[1]	Soil Association[2]	Texture[2]	Environmental conditions[3]
1. Melfort	1986-87	Durum wheat	Melfort	SiCL	Poor
2. Aylsham	1987-88	Rapeseed	Carrot River	SiCL	Poor
3. Carrot River	1987-88	Summerfallow	Carrot River	SL	Average
4. Carrot River	1987-88	Barley	Carrot River	SL	Average
5. Melfort	1987-88	Barley	Melfort	SiCL	Poor
6. Melfort	1987-88	Rapeseed	Melfort	SiCL	Poor
7. Melfort	1987-88	Rapeseed	Melfort	SiCL	Average
8. Carrot River	1988-89	Rapeseed	Carrot River	SL	Poor
9. Melfort	1988-89	Barley	Melfort	SiCL	Poor

[1] Durum wheat (*Triticum durum* L.), Rapeseed (*Brassica campestris* L.), Barley (*Hordeum vulgare* L.).

[2] Soil Survey (1975). L-Loam, Si-Silty, C-Clay, S-Sandy.

[3] Average-no extended dry periods. Heat or wind stress, or both, may have been yield reducing factors.

Poor-periodic drought combined with heat or wind stress, or both.

Table 2 Effect of trial on grain yield, and yield components, dry matter yield at anthesis and harvest, harvest index, water use and water use efficiency (mean of four seed rate and row spacing combinations and two levels of nitrogen fertility, 1987 to 1989).

	Trial								
Variable	1	2	3	4	5	6	7	8	9
Water use (cm)									
Pre-anthesis	5.2e[1]	9.4c	8.2d	6.0e	4.9e	7.8d	11.0b	14.2a	10.5bc
Post-anthesis	12.2e	3.6ef	6.0d	9.3bc	2.7f	4.7e	8.7c	6.2d	10.3b
Total	17.4b	13.0de	14.3cd	15.3c	7.5f	12.4e	19.8a	20.4a	20.8a
Dry matter yield (kg ha^{-1})									
Anthesis	-	2260ab	2760a	1240cd	840d	1530c	2180b	-	-
Harvest	2130d	4450ab	4410b	4280bc	1450d	4350bc	5280a	4020bc	3550c
Grain yield (kg ha^{-1})	880d	1480c	1970b	1800bc	430e	1470c	2410a	1770bc	1520c
WUE (kg/cm)	51c	113ab	131a	120ab	59c	123ab	122ab	87bc	74c
Yield components									
Heads m^{-2}	-	-	236abc	172cd	165d	195cd	251ab	245ab	266a
Kernel weight (mg)	28.8c	27.1d	31.0b	33.6a	28.8c	29.4c	31.2b	27.1d	26.7de
Kernels $head^{-1}$	-	-	29ab	34a	12c	28ab	35a	30ab	23b
Harvest index	0.42ab	0.33c	0.45a	0.42ab	0.30c	0.34bc	0.46a	0.45a	0.43a
Grain protein (%)	-	10.2c	12.8b	13.2b	18.0a	14.2b	13.6b	13.2b	13.7b
Protein yield (kg ha^{-1})	-	154c	252b	242b	57d	207bc	319a	235b	212bc

[1] Within a row, means followed by the same letter are not significantly different at p=0.05 (LSD).

Table 3 Effect of nitrogen fertility on grain yield, yield components, dry matter yield at anthesis and harvest, harvest index, grain protein, protein yield, water use and water use efficiency.

	Applied Nitrogen (kg N ha^{-1})	
Variable	0	100
Water use (cm)		
Pre-anthesis	8.8a[1]	8.9a
Post-anthesis	6.8a	7.2a
Total	15.6b	16.2a
Dry matter yield (kg ha^{-1})		
Anthesis	1600b	2040a
Harvest	3450b	4070a
Grain yield (kg ha^{-1})	1390b	1660a
WUE (kg cm^{-1})	92b	101a
Yield components		
Heads m^{-2}	211a	229a
Kernel weight (mg)	28.9a	28.9a
Kernels $head^{-1}$	27a	27a
Harvest index	.40a	.40a
Grain protein (%)	12.7b	14.1a
Protein yield (kg ha^{-1})	187b	239a

[1] Within a row means followed by the same letter are not significantly different at p=0.05 (F-test).

Table 4 Effect of seed rate and row spacing combination on grain yield, yield components, dry matter yield at anthesis and harvest, harvest index, grain protein, protein yield, water use and water use efficiency.

	Seed Rate Row Spacing Combination			
Variable	9-35	36-35	9-140	36-140
Water use (cm)				
Pre-anthesis[1]	8.6	8.1	9.6	9.0
Post-anthesis[1]	7.3	7.2	6.8	6.9
Total[1 2]	15.9	15.3	16.4	16.0
Dry matter yield (kg ha^{-1})				
Anthesis[1]	1460	1620	2190	2110
Harvest[1 2]	3650	3460	4060	3850
Grain yield (kg ha^{-1})[1 2]	1490	1390	1680	1520
WUE (kg cm^{-1})[3]	94	94	103	93
Yield components				
Heads m^{-2}[1 2 3]	209	172	295	205
Kernel weight (mg)	29.2	28.8	28.9	28.7
Kernels $head^{-1}$[1 2]	28	31	21	28
Harvest index	.40	.40	.39	.40
Grain protein (%)[1]	12.9	13.2	14.0	13.7
Protein yield (kg ha^{-1})[1]	201	195	237	217

[1] Seed rate differences significnat at p=0.05 (F-test).

[2] Row spacing differences significant at p=0.05 (F-test).

[3] SR x RS interaction significant at p=0.05 (F-test).