Physiological Characteristics of High-Yielding and High-Protein Wheats in Canadian Prairies: Water Use and Water Use Efficiency

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The moisture condition in the Canadian prairies is often not favourable to wheat growth especially during grain-filling stage (McCaig and Clarke, 1995) because of the limited precipitation, high temperature and high wind speed. Under this environment, new cultivars with both high yield and high protein concentration should have either higher evapotranspiration (ET) or higher water use efficiency (WUE), or both relative to old low- yielding cultivars. Few studies have been done to compare water use among wheat cultivars released at different periods of breeding (Slafer et al., 1993). Research conducted in Australia revealed that new high-yielding cultivars had higher WUE which was attributed to higher grain yield and higher harvest index, while ET did not change (Siddique et al., 1990a) or was even reduced (Siddique et al., 1990b). In a comparative study in the Canadian prairies, Cutforth et al. (1988) found that four wheat cultivars (two common wheat and two durum cultivars), which were different significantly in yield, did not differ in ET. Similarly, McNeal et al. (1971) found no difference in ET among five wheat varieties, which were different in height. The objective of this study was to estimate the differences between old cultivars and new high-yielding and high-protein cultivars in ET and WUE in the Canadian prairies.

MATERIALS AND METHODS

Six Canadian Western Red Spring Wheat (CWRS) (common wheat, *T. aestivum* L.) cultivars (four new high-yielding and high-protein cultivars, AC Barrie, AC Elsa, AC Intrepid and AC Cadillac and two old cultivars, Neepawa and Marquis) and five Canadian Western Amber Durum Wheat (CWAD) (durum wheat, *T. turgidum* L. var *durum*) cultivars (Three new high-yielding and high-protein cultivars, AC Navigator, AC Avonlea and DT 618 (a genotype) and two old ones, Hercules and Kyle) were selected for this study (Table 1) on a Swinton loam soil (Orthic Brown Chernozem) in the experimental farm of Semiarid Prairie Agricultural Research Centre, Agriculture and Agri-Food Canada at Swift Current, Saskatchewan, from 1998 to 2000. Plants were grown on summerfallow with four replications using a randomized complete block design. Each plot was 16-row, 3 m long and 0.23 m apart, with 4-row buffer areas seeded to winter wheat in between plots (no buffer areas in 1999). Seeding dates were April 28 in 1998, May 26 in 1999 and May 9 in 2000. Monoammonium Phosphate and Ammonium Sulphate were broadcasted in the field before seeding with the amounts that would meet the target of 112 kg ha^{-1} available N and 67 kg ha^{-1} available P according to the test of available N (NO_3 and NH_4) and PO_4 from soil samples at 30 cm taken in the end of October of previous year. There were no irrigations except that 48 mm of water was sprinkled on July 16, 1998. The seeding density was 250 seeds m^{-2} which was adjusted according to the germination test before seeding. Neutron tubes were installed within 1d after seeding for each plot. Soil moisture was measured once a week during the growing season to a depth of 120 cm (0-10 and 10-20 cm by gravimetric method for eight randomly sampled cores from each depth and 20-35, 35-55, 55-75, 75-95, and 95-120 cm by neutron probe method for each plot). Upper limit and lower limit for plant extractable water (Ratliff et al. 1983) at different depths were shown in Fig. 2 (Y.W. Jame, personal communication). Daily maximum and minimum air temperature and precipitation were recorded by the weather station of this research centre located 100-200 away from the study sites. The water balance equation was used to calculate ET. Phenological developments were recorded for each plot every 2-3 d using Zadoks-Chang-Konzak scale (Zadoks et al., 1974). Grain yields were determined by harvesting plots (8 central rows in 1999) with a plot combine.

Table 1. Cultivars used in this study.

Genotype	Origin	Year of release	Reference
<u>CWRS</u>			
AC Barrie		SPARC 1994	McCaig, et al., 1996.
AC Cadillac	SPARC	1996	DePauw, et al., 1998
AC Elsa	SPARC	1996	Clarke, et al., 1998
AC Intrepid	SPARC	1997	DePauw, et al., 1999
Neepawa		1969	Campbell, 1970
Marquis		1907	Morrison, 1960
<u>CWAD</u>			
AC Avonlea	SPARC	1997	Clarke et al., 1998
AC Navigator	SPARC	1998	Clarke et al., 2000
DT 618	SPARC		
Kyle			????
Hercules		1969	Leisle, 1970

All dependent variables were analyzed by PROC MIXED procedure of SAS (SAS, 1996) with the REML option for each year and three years combined with genotypes fixed and replications and years random. Means comparisons among cultivars were done by Fisher's protected least significant differences (LSD) based on Student's *t* distribution. Single-degree-of-freedom contrast comparisons using the CONTRAST statement in the PROC MIXED procedure were used to compare variable difference between 'new' and 'old' cultivars and between two wheat classes. Previous observations had shown that AC Barrie performed better than AC Elsa under irrigation or in a wetter and colder environment, but yielded less than AC Elsa under drier environment in Saskatchewan (Saskatchewan Agriculture and Food, 2001). The contrast comparison was also contacted between those two cultivars.

RESULTS AND DISCUSSION

Weather conditions

The daily maximum and minimum air temperatures and weekly precipitation are presented in Fig. 1. In 1998, the temperature was low in June but high in July and August compared to the means from 1886 to 2000 (Table 2). The precipitation was slightly lower than the average in the growing season (from May to August) and most of the rains fell before July. Plus 48 mm of irrigation on July 16, the total water received from May to August (249 mm) was fairly above the average. In 1999, the temperature was relatively low from May to July, but a little high in August. The total precipitation was high, but mostly distributed in the early season. In 2000, the temperature was normal but the precipitation was high especially in July, while only a little rain fell in August. In general, for the three years of the experiment, total precipitations (including the irrigation in 1998) in the growing season were higher than the average, but close to the mean of 1990s (247 mm) and the precipitation was low in August.

Table 2. Air temperature and precipitation.

	Max. temperature				Min. temperature				Precipitation
Year	May	June	July	Aug.	May	June	July	Aug.	May to Aug.
	------------------------------------ °C ------------------------------------								mm
1998	20.2	19.5	27.0	28.8	5.0	8.5	13.3	13.1	200.9
1999	15.4	19.4	22.7	26.0	4.4	8.9	10.2	11.7	257.2
2000	17.5	19.8	25.3	25.7	4.3	7.9	13.0	11.2	257.6
1886-2000	17.8	22.1	26.0	25.2	4.0	8.7	11.3	10.0	211.7

Soil water dynamics

Although soil water contents in the depths close to soil surface fluctuated during growing seasons, patterns of soil water dynamics were similar among different depths and among different years, *i. e*. high in the early season, continuously depletion, dry during grain filling and very low at maturity (Fig. 2). The soil water content was high in the early season in 1998. It started to reduce remarkably from all soil segments about 37 days after seeding (terminal spikelet stage) and reduced continually. The irrigation during grain filling recharged soil moisture on the surface and slowed down the deletion. By the time of physiological maturity, water contents reached lower limits from the surface to the depth of 75 cm, while the soil still had a little available water left below the depth of 75 cm. The soil water content was also high in the early season in 1999 and started to reduce later than 1998. About 44 days after seeding (boot stage) it started to drop sharply from all the depths. Because of no irrigation and limited precipitation, the depletion of soil water was very fast. About 20 d before maturity, soil water contents from the surface to 75 cm reached lower limits. Obviously crops suffered severer water stress than 1998 during grain filling. Similar to last two years, the soil water moisture was high in the early season in 2000. The moisture in all depths started to deplete at boot stage, while because of the relatively high precipitation before grain filling, the moisture condition during grain filling was better than 1999, and was similar to 1998. The reduction of soil water content in the deep depths in the early seasons indicated that wheat roots already penetrated deeper than 95 cm at or before boot stage. This is different from a previous study in the same area by Campbell, et. al. (1977), who found that Manitou, a spring wheat, did not use soil moisture from the depth deeper than 90 cm before anthesis.

No significant differences in soil water content were found between new and old cultivars in most of the observations at different depths during the growing season for either CWRA or CWAD (data not shown). However, a tendency of lower moisture content under AC Barrie in comparison with AC Elsa could be distinguished about 55 d after seeding at different depths every year (Fig. 3). It seems that AC Barrie used more water than AC Elsa in the reproductive growth phases which could be one of the reasons that the wetter environment is more favourable for the growth of AC Barrie, while AC Elsa outyield AC Barrie under drier environments (Saskatchewan Agriculture and Food, 2001).

It was also noted that the soil water dynamics were different between CWRS and CWAD wheats (Fig. 4). In 1998, CWRS had lower moisture in the early season than CWAD in upper depths. The differences disappeared, however, in the later season indicating more water use for CWAD cultivars. In 1999 and 2000 CWAD had lower soil moisture than CWRS after boot stage. Evidently, CWAD cultivars tended to use more water than CWRS ones in the later part of the growing season.

Evapotranspiration

The total water use in the growing season (ET) was not different significantly among cultivars in 1998 (Table 3), while the difference between highest (Kyle) and the lowest (AC Elsa) was 28 mm. Also, CWAD was significantly higher than CWRS and AC Elsa was lower than AC Barrie ($P < 0.05$) by contrast comparison. In 1999, the cultivar difference again was not significant and no difference between two wheat classes. Similar to 1998, however, AC Elsa and AC Cadillac were slightly lower than other cultivars. The cultivar difference was significant in 2000 ($P < 0.05$). For CWRS, AC Elsa was the lowest, followed by AC Cadillac. For CWAD, Kyle was the highest and was significantly higher than Hercules. Similar to 1998, CWAD was significantly higher than CWRS and AC Elsa was lower than AC Barrie ($P < 0.05$). Combined analysis over three years showed that the cultivar difference in total water use was significant ($P < 0.001$) and the G × E interaction was not significant, which means the cultivar difference in total water use were relatively consistent. AC Elsa had the lowest ET and was significantly lower than all other cultivars except AC Cadillac. AC Cadillac was the second lowest and was significantly lower than all other cultivars except two old CWRS cultivars. The genotype difference was smaller among CWAD cultivars. Kyle was the highest, followed by AC Navigator. DT 618 was the lowest and was significantly lower than Kyle. The contrast comparison showed that CWAD wheats were generally higher than CWRS wheats in ET ($P < 0.01$). Although the genotype difference in ET is relatively small as compared to the total water use in a growing season, the consistent genotype difference over three years indicated that genotype difference in ET exits, such as AC Elsa is lower than AC Barrie and CWRSs are lower than CWADs. However, new cultivars as a group is not distinguished significantly from old cultivars for either wheat class in ET.

Water use efficiency

There were significant ($P < 0.001$) genotype differences in WUE in each year and new cultivars were consistently higher ($P < 0.001$) than old ones by contrast comparison for both classes (Table 3). CWAD cultivars had significantly higher WUE in 1998 ($P < 0.001$) and 1999 ($P < 0.01$), but lower ($P < 0.01$) in 2000 than CWRS ones by contrast comparisons. On the average over three years, CWAD was slightly ($P < 0.08$) higher than CWRS. AC Elsa had significantly ($P < 0.01$) and slightly ($P = 0.06$) higher WUE than AC Barrie in 1999 and 2000, respectively, but no difference was found in 1998 and on three-years average.

Obviously, results of this study revealed that new high-yielding, high-protein CWRS and CWAD cultivars in the Canadian Prairies had significantly higher WUE than old ones, which is mainly attributed to higher harvest index and/or higher total dry matter production (Wang et al.). Also, there are cultivar differences in ET. These information are important for breeders and producers.

Table 3. Total water use (ET) and water use efficiency (WUE).

		ET				WUE			
Class	Cultivar	1998	1999	2000	Mean	1998	1999	2000	Mean
		--------------	mm	--------------		---------	$g\ kg^{-1}$	----------	
CWRS	New								
	AC Barrie	377.6	340.8	403.6	374.0	1.18	0.82	0.99	1.00
	AC Cadillac	368.8	325.1	400.8	364.9	1.16	0.91	1.04	1.04
	AC Elsa	356.5	327.1	396.6	360.1	1.16	0.91	1.05	1.04
	AC Intrepid	377.7	340.3	411.8	376.6	1.05	0.89	1.02	0.99
	Old								
	Neepawa	373.2	328.4	407.2	369.6	1.00	0.90	0.97	0.96
	Marquis	369.4	337.9	404.6	370.6	0.82	0.67	0.77	0.75
	Mean	370.5	333.3	404.7	369.3	1.06	0.85	1.00	0.80
	New vs. Old	0.42	0.77	0.76	0.75	***	***	***	***
CWAD	New								
	AC Avonlea	375.0	342.2	412.0	376.4	1.27	0.93	0.92	1.04
	AC Navigator	380.2	337.0	412.9	376.7	1.22	1.04	1.14	1.13
	DT 618	377.3	333.2	405.7	372.1	1.28	0.81	0.96	1.02
	Old								
	Kyle	384.0	340.2	415.5	379.9	1.11	0.84	0.88	0.94
	Hercules	380.1	338.7	402.8	373.9	1.03	0.85	0.89	0.92
	Mean	379.3	338.3	409.8	375.8	1.18	0.89	0.96	1.01
	New vs. Old	0.42	0.77	0.76	0.75	***	***	***	***
Genotype (G)	0.18	0.70	*	***	***	***	***	***	
Year (E)		-	-	-	***	-	-	-	0.17
G × E		-	-	-	0.99	-	-	-	*
LSD (0.05)		17.6	20.8	10.6	6.4	0.13	0.06	0.07	0.11
CWRS vs. CWAD		*	0.26	*	**	***	**	**	0.08

*, **, *** Significant at the 0.05, 0.01, and 0.001 levels of probability, respectively. Other probabilities given.

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REFERENCES

Campbell, A.B. 1970. Neepawa hard red spring wheat. Can. J. Plant Sci. 50:752-753.

Campbell, C.A., Cameron, D.R., Nicholaichuk, W. and Davidson, H.R. 1977. Effects of fertilizer N and soil moisture on growth, N content, and moisture use by spring wheat. Can. J. Soil Sci. 57: 289-310.

Clarke, J.M., DePauw, R.M., McCaig, T.N., Fernandez, M.R., Knox, R.E., and McLeod, J.G. 1998. AC Elsa hard red spring wheat. Can. J. Plant Sci. 77:661-663.

Clarke, J.M., McLeod, J.G., DePauw, R.M., Marchylo, B.A., McCaig, T.N., Knox, R.E., Fernandex, M.R., and Ames, N. 2000. AC Navigator durum wheat. Can. J. Plant Sci.80 (in press).

Clarke, J.M., McLeod, J.G., McCaig, T.N., DePauw, R.M., Knox, R.E. and Fernandez, M.R. 1998. Registration of 'AC Avonlea' durum wheat. Crop Sci. 39:880-81.

DePauw, R.M., Clarke, J.M., Knox, R.E., Fernandez, M.R., McCaig, T.N., and McLeod, J.G. 1999. AC Intrepid hard red spring wheat. Can. J. Plant Sci. 79:375-378.

DePauw, R.M., Thomas, J. B., Knox, R.E., Clarke, J.M., Fernandez, M.R., McCaig, T.N., and McLeod, J.G. 1998. AC Cadillac hard red spring wheat. Can. J. Plant Sci. 78:459-462.

Cutforth, H.W., C.A. Campbel, Y.W. Jame, J.M. Clarke, and R.M. DePauw. 1988. Growth characteristics, yield components and rate of grain development of two high-yielding wheats, HY320 and DT367, compared to two standard cultivars, Neepawa and Wakooma. Can. J. Plant Sci. 68: 915-928.

Leisle, D. 1970. Hercules, a new durum wheat. Can. J. Plant Sci. 50:118-119.

McCaig, T.N. and Clarke, J.M. 1995. Breeding durum wheat in western Canada: Historical trends in yield and related variables. Can. J. Plant Sci. 75:55-60.

McCaig, T.N., DePauw, R.M., Clarke, J.M., McLeod, J.G., Fernandez, M.R., and Knox, R.E. 1996. AC Barrie hard red spring wheat. Can J. Plant Sci. 76: 337-339.

McNeal, F.H., Berg, M.A., P.L. Brown, and C.F. McGuire. 1971. Productivity and quality response of five spring wheat genotypes *Triticum Aestivum* L., to nitrogen fertilizer. Agron. J. 63: 908-910.

Morrison, J.W. 1960. Marquis wheat - a triumph of scientific endeavour. Agric. History 34: 182-188.

Ratliff, L.F., Ritchie, J.T. and Cassel, D.K. 1983. Field-measured limits of soil water availability as related to laboratory-measured properties. Soil Sci. Soc. Am. 47: 770-775.

SAS Institute Inc. 1996. SAS/STAT Software- Changes and Enhancements through Release 6.11. SAS Institute Inc. Cary, NC, USA.

Saskatchewan Agriculture and Food. 2001. Varieties of grain crops, 2001. 2001 Saskatchewan Seed Guide.

Siddique, K.H.M., Belford, R.K., and Tennant, D. 1990a. Root:shoot ratios of old and modern, tall and semidwarf wheats in Mediterranean environment. Plant Soil 121: 89-98.

Siddique, K.H.M., Tennant, D., Perry, M.W., and Belfort, R.K. 1990b. Water use and water use efficiency of old and modern wheat cultivars in a Mediterranean-type environment. Aust. J. Agric. Res. 41:431-447.

Slafer, G.A., Satorre, E.H., and Andrade, F.H., 1993. Increases in grain yield in bread wheat from breeding and associated physiological changes. In: Slafer, G.A. (Ed.), Genetic Improvement of Field Crops. Marcel Dekker, New York, pp. 168.

Zadoks, J.C., Chang, T.T . and Konzak, C.F. 1974. A decimal code for the growth stages of cereals. Weed Research 14:415-421.