Do High-Yield and High-Protein Wheat Cultivars Use More Water?

Wang, H., McCaig, T.N., De Pauw, R. M. and Clarke, J. M.
Semiarid Prairie Agricultural Research Centre, AAFC, Swift Current, SK S9H3X2

Introduction

Some recently developed wheat cultivars have significantly increased yields, while maintaining or even increasing protein content, relative to earlier cultivars. Such cultivars, which meet the demands of the lucrative quality-conscious world markets, have made a substantial contribution to the value of wheat production in western Canada.

In order to understand the physiological basis for these genetic improvements we are conducting a multi-year study. Results of this study could be used by breeders to select new cultivars more efficiently and by producers to improve their soil and crop management. In this report we describe cultivar differences in evapotranspiration (ET) and water use efficiency (WUE) from the experiment in 1998 and 1999 at Swift Current, Saskatchewan.

Materials and methods

Experiment design

Four new (AC Barrie, AC Cadillac, AC Elsa and AC Intrepid) and two old (Marquis and Neepawa) CWRS cultivars and three new (AC Avonlea, AC Navigator and DT 618) and two old (Hercules and Kyle) CWAD cultivars (DT618 is a genotype) were used in this study. Plants were seeded in a randomized complete block design with four replicates on a Swinton loam soil on 28 April, 1998 and 26 May, 1999 at Swift Current. Plots were seeded on fallow with 16-row, 3 m long and 0.23 m apart.

Observations and measurements

Soil water content was determined weekly in the growing season. For depths of 0-10 cm and 10-20 cm, 8 soil samples were taken randomly from each depth and the water content was determined by the gravimetric method; for depths of 20-35 cm, 35-55 cm, 55-75 cm, 75-95 cm and 95-120 cm soil moisture was determined from each plot by the neutron probe method. Field measured field capacity and lower limit (Ratliff et al. 1983) were 8% and 27% for 0-10 cm, 9% and 28% for 10-20 cm, 9.8% and 28.8% for 20-35 cm, 11.6% and 29% for 35-55 cm, 11.8% and 29.2% for 55-75%, 12.2% and 31% for 75-95 cm, and 12.3% and 31% for 95-120 cm, respectively (Y.W. Jame, unpubl. Data). The evapotranspiration per growth phase [Phase I, emergence to flag leaf ligule visible (FLLV); Phase II, FLLV to anthesis complete; and Phase III, anthesis complete to physiological maturity] was calculated by subtracting the volumetric moisture to a depth of 120 cm at the later growth stage from that at the earlier stage plus precipitation during that phase.

Leaf emergence rate and phasic development were observed every 2-3 days for each plot. Leaf area and vegetative aboveground dry matter (leaf, stem and chaff) and harvest index were measured by sampling a 50 cm length of row randomly at terminal spikelet and physiological maturity. Grain yield and protein concentration were determined from harvesting 50 cm length of 4 rows in 1998 and from combining 8
central rows in 1999, respectively.

**Statistical analysis**
All dependent variables were analyzed by PROC MIXED procedure of SAS (SAS, 1996) with the REML option for each year. Mean comparisons among cultivars were done by the calculations of 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 differences between two pre-planned groups of cultivars such as between CWRS and CWAD classes and between new and old cultivars within a class.

**Weather condition**
In 1998, the precipitation from May to August was 201 mm and there was an irrigation (48 mm) on July 16 (one week after anthesis, Fig. 1a). Precipitation plus irrigation was higher than the mean precipitation of 100 years (206 mm), but close to the mean of recent 10 years (245 mm). Most rains fell between head emergence and anthesis.

The mean temperature was lower than the normal before FLLV (from mid May to early June) but was high in July and August and there were six days with maximum temperature =>33 ºC. The precipitation in 1999 (257 mm) was higher than 1998, which fell mostly in the early season (Fig. 1b).

**Results and discussion**

**Soil water content at different depths**
The mean soil water content over all cultivars was high in the early season in 1998(Fig. 2a). It started to reduce remarkably from all soil segments about 28 days after emergence when plants reached terminal spikelet stage and then continually reduced in the whole season except that the irrigation increased moisture for a few days and slowed down the speed of water deletion. By the time of physiological maturity, water contents reached lower limits from the surface to the depth of 55 cm, while the soil still had a little available water left below that depth. It seems that crops experienced heat shock and soil water stress during grain filling.

The soil water content was also high in the early season in 1999 (Fig. 2b) and started to reduce significantly about 39 days after emergence (at FLLV stage) from all different depths. The speed of moisture depletion was higher than 1998 as there was little precipitation after FLLV although the air temperature was not very high. By the time of physiological maturity, soil water contents from the surface to 75 cm reached lower limits. Obviously crops suffered severer water stress than 1998 during grain filling.
Results in these two years showed that wheat roots already penetrated deeper than 95 cm at or before the stage of FLLV which 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.

**Evapotranspiration**
There were no any differences in total ET among cultivars and between new and old groups in either class in either year. However, the contrast comparison between CWAD and CWRS showed that CWAD was significantly higher ($P \# 0.05$) in 1998 (Fig. 3) and was 5 mm higher in 1999 although it was not significant.

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On the average, there was a higher ET in 1999 than 1998 in Phase I. In this phase, cultivar difference
in ET was significant at the $P \leq 0.10$ level in 1998. Kyle (141 mm) was the highest and followed by DT618 (140 mm), while AC Elsa (123 mm) was the lowest and Marquis (124 mm) was the second lowest (Fig. 4). Although not significant, CWAD had higher ET than CWRS and new CWRS cultivars had higher ET than old ones. Cultivar difference was significant too in 1999 ($P \leq 0.01$). Hercules, AC Avonlea and DT618 were the highest (169 mm), while Neepawa (144 mm) was the lowest and Marquis (146 mm) was the second lowest. CWAD had higher ET than CWRS wheats ($P \leq 0.001$) and new CWRS cultivars were higher than old ones ($P \leq 0.05$) by contrast comparisons.

The larger leaf area of CWAD cultivars in the early growth stage than CWRS could be the reason why they tend to have higher ET in Phase I. This could also be used to explain the difference in ET of Phase I between new and old CWAD cultivars, as new CWRS cultivars had larger leaf area in the early season than old ones.

**Grain yield, protein and vegetative dry matter**

New cultivars yielded an average of 30% and 21% more than the old cultivars in CWRS and CWAD, respectively, and CWAD was 23% higher than CWRS in 1998 (Fig. 5). There was no difference in protein content between new and old cultivars for either wheat classe, while CWRS (15.8%) had higher ($P \leq 0.001$) protein content than CWAD (14.2%). In 1999, the average yield was lower than 1998. New cultivars yielded an average of 7% and 14% more than the old cultivars in CWRS and CWAD, respectively, and CWAD was 9% higher than CWRS. New CWRS cultivars had higher ($P \leq 0.01$) protein content (16.1%) than old ones (15.3%) and CWRS (15.9%) had slightly higher ($P \leq 0.05$) protein content than CWAD (15.4%).

Results indicate that new cultivars had higher yield than old ones under the environment of water deficit during grain filling, but the increase was higher when the yield potential was higher (1998). Similarly, CWAD had higher yield than CWRS in both years but the difference was higher in the year of higher yield potential.

No difference in aboveground vegetative dry matter at physiological maturity was found between new and old CWRS cultivars 1998, but new ones (6.1 t ha$^{-1}$) was slightly higher ($P \leq 0.05$) than old ones (5.3 t ha$^{-1}$) in 1999. For CWAD cultivars, new ones had either lower or no difference from old ones. No differences were found between two classes in vegetative production. It indicates that high grain yield is not necessary accompanied by high vegetative production.

**Water use efficiency**

The mean WUE in 1998 was higher than 1999 which was related to the better soil moisture condition during grain filling in 1998 (Fig. 6). Cultivar difference in WUE was significant in both years. AC Avonlea and AC Navigator were the highest (1.26 g kg$^{-1}$) and the second highest (1.03 g kg$^{-1}$) in 1998 and the second highest (0.93 g kg$^{-1}$) and the highest (1.04 g kg$^{-1}$) in 1999, respectively, while Marquis was always the lowest (0.61 g kg$^{-1}$ in 1998 and 0.67 g kg$^{-1}$ in 1999). New cultivars were significantly higher than old cultivars for both classes in both years and CWAD was higher than CWRS. Those differences were obviously mainly contributed by the differences in grain yield, because the differences in ET were generally small. As the increase of yield is not necessary related to the increase of vegetative production, the improvement of WUE should associate with higher harvest index (HI). Correlation analysis showed that there was a significant linear relationship between WUE and HI in 1998 ($R^2 = 0.59^{**}$) and 1999 ($R^2 = 0.68^{**}$), respectively.
Conclusions

Results of this study showed that both new CWRS and CWAD cultivars had higher WUE than old ones and the total ET was not different significantly. It indicates that, newly developed high-yield and high-protein cultivars do not need more uptake of soil water. However, more study on their response to water stress in the early season is needed because new CWRS cultivars tended to use more water in the early growth stage. CWAD wheats had higher WUE than CWRS ones and they also used more water, especially in the early season. This information is important for the producers.

This study was conducted under the environments of good moisture before anthesis and water stress during grain filling. The results should be interpreted with caution.

References


Key words: wheat, water use efficiency, evapotranspiration, yield, protein.