A COMPARISON OF GROWTH, DEVELOPMENT, WATER USE, PROTEIN PRODUCTION AND GRAIN YIELD OF WINTER AND SPRING WHEAT IN SASKATCHEWAN

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ABSTRACT

Winter and spring wheat productivity was compared in field trails under a wide range of environments in Saskatchewan. Nine trials were conducted between 1974 and 1979 while nine trials were conducted between 1986 and 1988. In the 1970's, weather conditions were "typical" (moist in June; drier in July) and under these conditions, Sundance HRWW averaged 3211 kg ha^{-1} and Manitou HRSW averaged 2429 kg ha^{-1}. Conditions in 1986, 1987 and 1988 were drier and high levels of early season water and temperature stresses occurred in all years. Under these conditions the approximately 32% yield advantage for winter wheat observed earlier was maintained (Norstar: 1989 kg ha^{-1} vs. Katepwa: 1503 kg ha^{-1}). Greater yield for the winter wheat in these trials was attributed to more efficient water use and a higher production of kernels per unit area of land (i.e., establishment of a higher yield potential). Over all trials, grain protein production was similar for the winter and spring crops (310 kg ha^{-1} for winter wheat vs. 319 kg ha^{-1} for spring wheat), however grain protein concentration was higher for the spring crops (12.3% for winter wheat vs. 15.4% for spring wheat).

INTRODUCTION

Winter wheat is a relatively new crop to most of the Canadian prairies and holds promise for extending crop rotations and soil conservation (Grant et al., 1974). Compared with traditional spring wheat production, "stubbled-in" (Fowler, 1983) winter wheat requires less tillage (Fowler, 1983) and fewer herbicide applications to control weeds (Schwerdtle, 1983). Lower costs of production for winter wheat compared to spring wheat can make winter wheat more profitable to the farmer (Rutherford and Fowler, 1983). It has been observed that fields of winter wheat outyield spring wheat by 20 to 30%, however at the present time, detailed information comparing these two wheat types is lacking. The first objective of this study was, therefore, to evaluate grain yield and protein production of winter and spring wheat cultivars over a wide range of environments in Saskatchewan. Such information is important to properly assess the long-term yield potential and commercial viability of winter wheat crops.

The development of winter wheat crops on the prairies is usually two or more weeks earlier than spring wheat (Grant et al., 1974; Fowler and Entz, 1986; Bauer et al., 1989). Because of its earlier development, it has been suggested (de Jong and Steppuhn, 1983; Fowler and Entz, 1986) that a major advantage of winter wheat over spring wheat is more efficient early season water use. Evaporation of soil water from early spring until full crop ground cover is to a large extent determined by air temperature (Cole and Mathews, 1923; Bauer et al., 1989). In Saskatchewan, water loss during this approximately six week post-melt period can be as high as 60 mm (Gray et al., 1984).

A second advantage resulting from its earlier development is that winter wheat often completes its critical development stages (e.g., floral initiation, flowering) prior to the onset of severe water stress (Grant et al., 1974; Fowler and Entz, 1986). Cooler, wetter conditions, especially during the critical booting to flowering development stages, are known to increase grain yield (Hochman, 1982; Entz and Fowler, 1988) and water use efficiency (de Wit, 1958; Hochman, 1982; Entz and Fowler, 1989). High water stress during this period was also found by French and Schultz (1984), Frank et al. (1987) and Entz and Fowler (1988) to significantly reduce kernel production (i.e., reduce the yield potential).

At the present time, little detailed information comparing growth, development, water use and water use efficiency of winter and spring wheat cultivars is available for the prairie region. Hence, a second objective of this study was to evaluate these factors for winter and spring wheat grown under a wide range of environmental conditions.

MATERIALS AND METHODS

Field experiments were conducted in central Saskatchewan at the following locations: Saskatoon (Bradwell clay loam; Dark Brown Chernozem; Canada Soil Survey Committee, Subcommittee on Soil Classification, 1978); Clair (Yorkton loam; Black Chernozem); Watrous (Weyburn loam, Dark Brown Chernozem); Paddockwood (Paddockwood loam; Dark Grey Chernozem); Hagen (Blaine Lake loam; Black Chernozem); Parkside (Shellbrook loam; Dark Grey Chernozem); Outlook (Asquith fine sandy loam; Dark Brown Chernozem); Elrose (Sceptre clay; Brown Chernozem) and Goodale (Elstow fine sandy loam; Dark Brown Chernozem). These sites covered an area approximately 500 km east to west and 250 km north to south.

Winter wheat cultivars were direct-seeded into standing stubble immediately after harvest of the previous crop ("stubbled-in"; Fowler 1983) in late August or early September at a seeding rate of 75 kg ha^{-1} and a row spacing of 20 cm. The cultivars 'Sundance' (winter wheat) and 'Manitou' (spring wheat) were used in the 1975 to 1979 trials, while 'Norstar' and 'Norwin' winter wheat and 'Katepwa' and 'HY 320' spring wheat were used in the 1986 to 1988 trials. Spring wheat plots were tilled to a 3-4 cm depth immediately prior to seeding using a rotovater followed by a packing implement. Trials at Parkside (1975) and at Clair (1975, 1976, 1977) were seeded on summerfallow. Plot size ranged from 10 to 15 m^{-2}. Phosphate fertilizer (11-51-0 or 11-48-0) was applied with the seed at a rate of 30 kg P_2O_5 ha^{-1}. Ammonium nitrate (34-0-0) fertilizer was broadcast in the early spring at a rate of 100 kg N ha^{-1}. Experimental design was a randomized complete block design with three to four replicates.

Soil water content was measured at regular intervals (approximately once every two weeks) during the growing season for trials conducted between 1986 and 1988. One neutron access tube was located in the centre of each plot. Soil water to 1.3 m was measured using a neutron probe

(Troxler laboratories; Triangle Park, N.C.). Surface soil water (0 to 10 cm) was determined gravimetrically, then multiplied by bulk density values to convert to volumetric basis. Evapotranspiration (ET) was expressed as precipitation plus soil water use and was calculated for each sampling interval and for the entire growing season.

Dry matter accumulation was determined from samples taken approximately every two weeks on 2, 1-m sections of row in each plot. Water use efficiency (WUE) for each increment of dry matter produced was calculated by dividing the increase in dry matter over the time period by the ET during the same period.

Plot area harvested for grain yield determination ranged from 5 to 12 m^{-2}, depending on location. Grain samples were dried (30°C) to 8% water basis before yields were measured. Grain protein concentration was determined by the Udy (1971) dye method. Grain protein yield was calculated as grain yield times protein concentration. A subsample of 250 kernels from each plot was used to determine kernel weight (KWT). Kernel number m^{-2} (KNO) was calculated by dividing grain yield per square metre by KWT.

RESULTS AND DISCUSSION

Climatic Conditions

Monthly pan evaporation and precipitation records for the Clair, Saskatchewan location are shown in Table 1. Average values for the 1970's test years indicate that evaporative demand for water was highest in July while precipitation was highest in May and June. This pattern (i.e., wet in May and June and hot and dry in July) is typical of long-term growing season conditions on the prairies (de Jong and Steppuhn, 1983). Average weather conditions for the 1986, 1987 and 1988 test years were almost completely the reverse. In all three years, the highest evaporation rates and lowest precipitation levels were recorded in May and June (Table 1). Conditions in July (especially precipitation) were much more favourable in comparison to those in May and June.

Grain Yield and Yield Components

Sundance winter wheat and Manitou spring wheat were compared in nine field trials between 1975 and 1979. Under these "typical" Saskatchewan moisture conditions, the winter wheat cultivar significantly ($p \leq 0.05$) outyielded the spring type in all instances (Table 2). Over all trials, Sundance outyielded Manitou by 32% (3211 kg ha^{-1} vs. 2429 kg ha^{-1}). The basis for this higher grain yield was a higher ($p \leq 0.05$) number of kernels per unit area of land and a higher ($p \leq 0.05$) kernel weight for the winter wheat compared to the spring wheat (Table 2). These results indicate that conditions for both kernel production and kernel filling were more favourable for the winter compared to the spring wheat crop.

A second comparison of winter and spring wheat was conducted in Saskatchewan between 1986 and 1988. In these trials, a tall (Norstar) and a semidwarf (Norwin) winter wheat were compared with a tall (Katepwa) and a semidwarf (HY 320) spring wheat type. Norstar (which is very closely related to Sundance) significantly outyielded Katepwa (a close relative of Manitou) in five of the nine trials (Table 3). Over all nine trials, Norstar yielded an average 32% higher than Katepwa (1988 kg ha^{-1} vs. 1503 kg ha^{-1}). These results indicated that the yield advantage observed under "typical" weather conditions was maintained even where the weather conditions favoured the spring wheat type. In the five trials where all four cultivars were tested, grain yields of Norwin and HY 320 (the semidwarfs) never exceeded ($p \leq 0.05$) yields of Katepwa (Table 3). These results indicate that only Norstar showed a consistent yield advantage of the hard red spring cultivar Katepwa in these trials.

Kernel number m^{-2} in these trials were often higher ($p \leq 0.05$) for Norstar compared with the two spring wheat cultivars (Table 3). These results indicate that conditions for kernel production were less favourable for the spring wheats compared with Norstar winter wheat. Air temperature just prior to the development of the terminal spikelet is known to be negatively ($p \leq 0.05$) related to kernel number (Frank et al., 1987) and this may be one reason for lower kernel set in the spring wheat type. Kernel production for Norwin was often lower than for the tall winter wheat type (Table 3). Significantly ($p \leq 0.05$) lower KNO for Norwin (compared with Norstar) under stress growing conditions was previously observed (Entz and Fowler, unpublished data) and is the focus of a separate study.

Unlike results from the 1975 to 1979 trials (Table 2), KWT was not consistently higher for the winter wheat compared with the spring types (Table 3). In fact, in three of the nine trials, KWT was significantly lower for the winter wheats. These results suggest that the basis for higher grain yield of Norstar winter wheat in these trials was due to a higher KNO, not due to the combination of higher KNO and higher KWT. This observation supports other workers (Fischer et al., 1977; French and Schultz, 1984; Shanahan et al., 1984) who found that grain yield of wheat is limited more by KNO than by KWT.

Grain Protein

In general, grain protein yield was similar for winter and spring wheat while grain protein concentration was highest for spring wheat (Tables 2 and 3). For grain protein yield, the only exception to this was at Saskatoon in 1977 where Sundance had a higher ($p \leq 0.05$) grain protein content than Manitou (Table 2), and at Clair (1987), where Norstar produced significantly ($p \leq 0.05$) more kg grain protein ha^{-1} than either Katepwa or HY 320 (Table 3). Greater grain protein production for the winter wheat cultivars in these trials may have been due to greater N uptake. At Watrous in 1986, the significantly ($p \leq 0.05$) lower grain protein yield for Norstar compared to Katepwa was attributed to a stem rust infestation. Norwin was found to be less affected by this pathogen in this trial (Table 3).

For trials conducted in the 1970's, grain protein content was always greatest for the spring wheat type (Table 2). In these years, moisture conditions were favourable and in three of the nine trials the grain protein concentration for the winter wheat was below the minimum standard of 11%. Moisture conditions in the 1980's were much drier and this was reflected in higher grain protein levels (Table 3). Katepwa had a significantly ($p \leq 0.05$) higher protein content than both winter wheat cultivars in all trials except Elrose (1988), where severe drought conditions resulted in very high grain protein concentrations for both wheat types (Table 3). As expected, grain protein content for the HRSW was greater ($p \leq 0.05$) than for HY 320 at five of six trials (Table 3). However, HY 320 had a significantly ($p \leq 0.05$) greater grain protein content than winter wheat in three of six trials while no significant differences were observed at the other three trials (Table 3). These results indicate that HRSW should be expected to have a consistently higher grain protein content than HRWW types, while HY 320 (the prairie spring wheat types - 3M) will have an intermediate grain protein concentration.

Crop Development

Crop development stage was monitored at regular intervals throughout the growing season using the Zadoks growth scale (Zadoks et al., 1974). In wheat, the maximum potential number of spikelets per spike is set by approximately stem elongation (Zadoks 31) (Kirby and Appleyard, 1987). This development stage occurred, on average, on May 28 for winter wheat and on June 13 for spring wheat (Table 4). Therefore, the winter crop was an average 20 days (range 14 to 28 days) earlier than the spring crop for this development stage. By anthesis (Zadoks 65), the total yield potential (i.e., number of kernels per unit area of land) is set (Shanahan et al., 1984). This development stage occurred, on average, on June 24 for winter wheat and on July 7 for spring wheat (Table 4). These results show that the difference in development between winter and spring wheat was reduced from an average of 20 days at stem elongation to an average 13 days (range 7 to 20 days) by anthesis (Table 4), indicating that spring wheat had 7 fewer days in which to establish its yield potential. Rate of plant development is dependant upon temperature (Johnson and Kamemasu, 1983), and faster development rates for the spring crops may have been due to higher air temperatures from June 13 to July 7 compared with the period from May 28 to June 24. Because kernel production is positively correlated with the length of the pre-anthesis period (Frank et al., 1987; Entz and Fowler, 1988), it follows that lower ($p \leq 0.05$) KNO for spring wheat observed in these trials (Table 3) may have been due to its shorter pre-anthesis period. The soft dough development stage (Zadoks 85) was an average 13 days earlier for winter wheat compared to spring wheat, indicating that the difference in development between these two wheat types did not change between anthesis and soft dough stages (Table 4).

Dry Matter Production and Harvest Index

Aerial dry matter accumulation (DM) for these trials is shown in Figure 1. Results indicate that winter wheat crops produced more DM early in the growing season than spring wheat. The only exception was at Elrose in 1988 where very high water and temperature stresses resulted in extremely low productivity for both wheat types.

The most productive time period in terms of conversion of radiant energy into DM occurs during the exponential growth period between onset of tillering and heading (French and Schultz, 1984). In the present study, daily growth rates between early June and early July averaged 10.3 g m^{-2} day^{-1} and 6.9 g m^{-2} day for Norstar and Katepwa, respectively. This indicates greater efficiency for the HRWW over the HRSW during this period. By crop maturity, however, the differences in DM levels had disappeared at some sites (Outlook, 1986; Hagen, 1987; Clair, 1988). At several sites (Clair, 1986; Clair, 1987), HY 320 produced significantly more DM than the two winter wheat types (Figure 1). At Paddockwood and Clair in 1987, Norwin had a significantly lower DM than either HY 320 or Norstar. These results indicate that in some cases, HY 320 produced the highest ($p \leq 0.05$) levels of DM. However in general, Norstar and HY 320 produced higher levels of DM than either Katepwa or Norwin.

The harvest index (HI) is a measure of the conversion efficiency of DM to grain yield (Baker and Gebeyhou, 1982). In the present study, the two winter wheat cultivars had significantly higher HI compared with the spring wheat cultivars at Clair (1986), Clair (1987) and Hagen (1987). With the exception of Watrous, where stem rust resulted in a dramatically lower HI for Norstar (HI=18%), the HI in all other trials was similar for winter and spring wheats (data not shown). These results suggest that with the exception of the rust-infected trial, the conversion of DM to grain for winter wheat was better than or equal to the conversion efficiency for spring wheat. The lack of any consistent superiority in the HI of the semidwarf compared with the tall cultivars, may reflect the stress conditions which occurred in these years. In more favourable environments, semidwarfs often have a significantly better HI than tall wheat types (Pearman et al., 1978; Fischer, 1979).

<u>Crop Water Use</u>

Total growing season water use or evapotranspiration (ET) was similar for winter and spring wheat cultivars in all but three trials. Greater ($p \leq 0.05$) ET for spring wheat at Hagen (1987) and Clair (1986, 1987) (Table 5), was attributed to heavy late season rains, hence greater water availability after the winter crops were harvested.

Bauer et al. (1989) reported that although winter wheat development and growth is initiated two weeks or more earlier than spring wheat, only slight if any ET differences were observed at heading between the two wheat types. Cole and Mathews (1923) reported ET to be more affected by daily weather than by crop type. Results of the present study support these findings as no significant differences in soil water in the 130 cm profile at anthesis were observed for the different wheat cultivars in these trials (data not shown). However, when individual soil depth increments were considered, small but significant ($p \leq 0.05$) differences in soil water content were observed. For example, in several instances, soil water in the 0 to 10 cm depth was significantly greater for spring wheat (Table 6), indicating that the winter crops used more water from shallow depths. Differences in surface soil water use between winter and spring wheats were greatest early in the season.

Differences in water use between winter and spring wheat types were not confined to early development stages. For example, at Outlook and Clair in 1986, significant differences were observed in mid-June and mid-July, respectively (Table 6). In these trials, Norstar used 5 to 7 mm more ($p \leq 0.05$) water than Katepwa and HY 320 in the 30 to 50 cm and 50 to 70 cm soil depths, indicating deeper root activity for Norstar compared with the spring wheat types. Significant differences in soil water content between cultivars was also observed late in the growing season. At Paddockwood (1987), Norwin used less ($p \leq 0.05$) water in the 30 to 50 cm and 50 to 70 cm soil depths compared with Norstar and Katepwa (Table 6). By the August 14 sampling date, both Norwin and HY 320 had used less water at depth than the tall wheat types (Table 6). These results indicate that late-season water use varied more between tall and semidwarf types than between winter and spring wheat types. Inferior rooting by some semidwarf compared with tall wheat types was previously speculated (Hurd 1974).

Water Use Efficiency

Water use efficiency (WUE), calculated as kg grain yield ha^{-1} mm^{-1} ET, was consistently higher for winter than for spring wheat. At six of the nine trials, differences in WUE between Norstar winter wheat and Katepwa spring wheat were significant ($p \leq 0.05$) (Table 5). Differences between the semidwarf winter wheat and the two spring wheats were less dramatic (Table 5). Results of this study indicated that given similar ET levels (or even less in some instances - Table 5), winter wheat used available water more efficiently. One reason for this may be the earlier development of winter wheat compared with spring wheat (Table 4). Earlier development of wheat crops in the prairie region usually means that environmental conditions during the critical booting to flowering stages are cooler and wetter (de Jong and Steppuhn, 1983; Fowler and Entz, 1986). Low air temperatures during this period increase WUE (Hochman, 1982; French and Schultz, 1984).

Efficient production of dry matter (DM), especially prior to flowering (French and Schultz, 1984), is important for yields of dryland wheat (Fischer, 1979). In the present study, large significant ($p \leq 0.05$) differences in the WUE of early increments of DM were observed between winter and spring wheat crops. For example, between May 1 and early June, WUE of DM for winter wheat was 30 to 900% higher than for spring wheat (Table 7). Between May 1 and early July, WUE values for winter wheat were still higher by 20 and 80% (Table 7). Given the importance of pre-anthesis DM to yields of dryland wheat (Woodruff, 1983; Entz and Fowler, 1989), these results indicate a greater yield potential for the winter crop. By crop maturity, differences in WUE between wheat classes had diminished considerably (Table 7).

Higher WUE in winter compared to spring wheat may be attributed to a number of different factors. One way to increase WUE is to increase total ET (de Jong and Cameron, 1980). Greater early season ET for the winter wheat (Table 6) may, therefore, have contributed to greater WUE for winter wheat observed in this study. WUE can also be increased by increasing transpiration (T) as a fraction of total ET (Fischer and Turner, 1978); i.e., increasing the proportion of ET that actually passes through the plant. An effective method of achieving higher T/ET ratios is by increasing the percent ground cover, thereby decreasing direct soil water evaporation. Assuming that full ground cover in wheat crops occurs at approximately Zadoks 31 (stem elongation), winter wheat in the present study covered the ground approximately two weeks earlier than spring wheat (Table 4).

Based on observations in this study, it can be concluded that higher WUE for winter wheat compared to spring wheat was due to 1) less direct soil evaporation prior to anthesis, and 2) completion of flowering prior to onset of maximum temperature stress.

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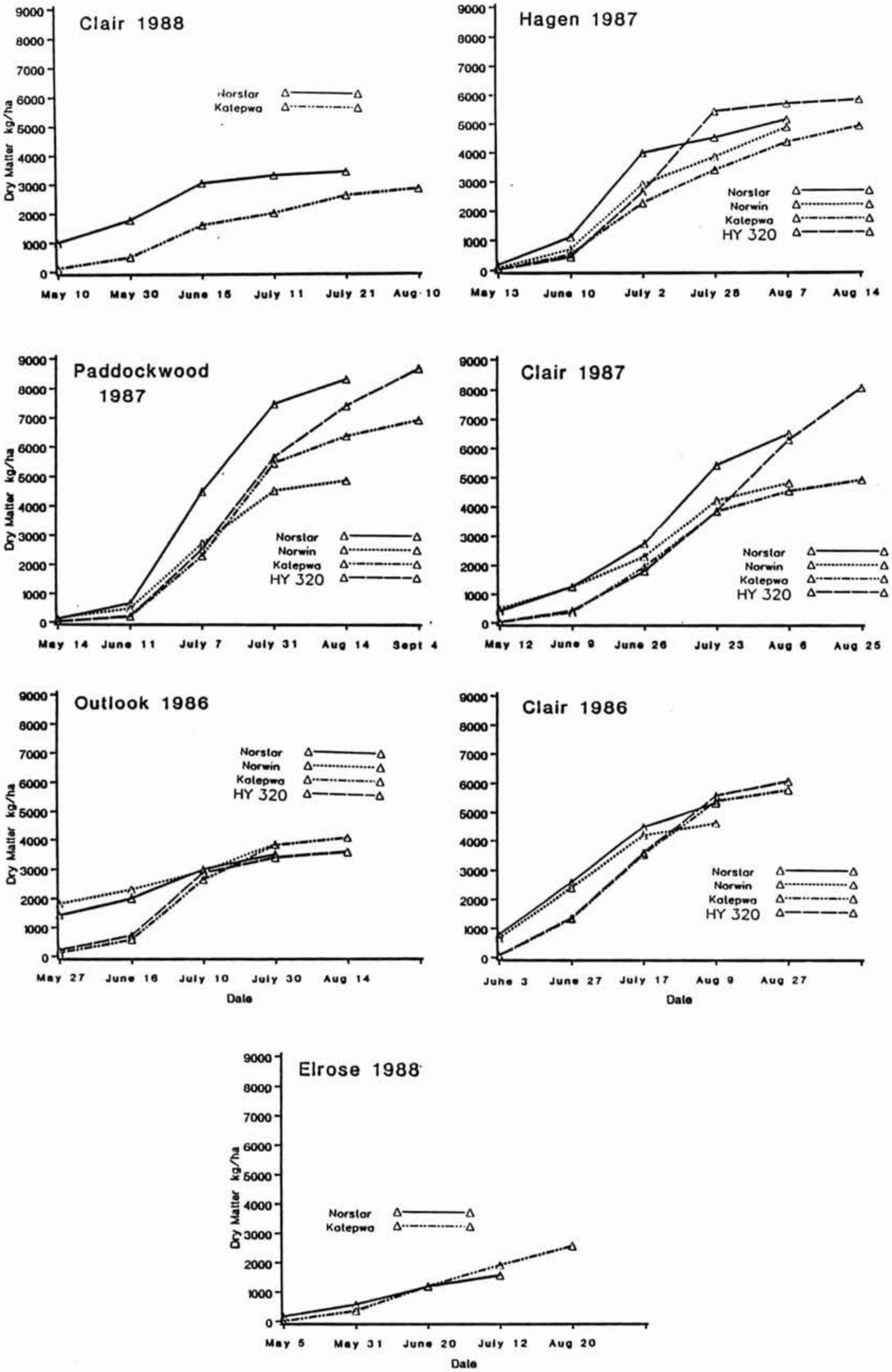

Figure 1. Seasonal dry matter accumulation for winter and spring wheat cultivars in Saskatchewan.

Table 1. Total monthly pan evaporation and precipitation for Clair, Saskatchewan in the 1970's (n=5) and 1980's (n=3). (Source of evaporation data: Wynard Environment Canada Station).

Month	Pan evaporation (mm) 1975 to 1979	Pan evaporation (mm) 1986 to 1988	Precipitation (mm) 1975 to 1979	Precipitation (mm) 1986 to 1988
May	203	236	68	47
June	220	265	68	39
July	235	230	49	70
August	191	162	39	70
	849	893	224	226

Table 2. Grain yield, grain protein yield, grain protein concentration, kernels m^{-2} and kernel weight for winter and spring wheat cultivars in Saskatchewan: 1975 to 1979.

Location	Cultivar	Grain yield ($kg\ ha^{-1}$)	Grain protein yield ($kg\ ha^{-1}$)	Grain protein concentration (%)	Kernel number per m^2	Kernel weight (mg)
Clair 1975	Sundance	3201 a†	246.2	7.7 b	8358 a	38.3 a
	Manitou	2386 b	298.7	12.5 a	7387 b	32.3 b
Parkside 1975	Sundance	3095 a	261.5	8.4 b	7936 a	39.0 a
	Manitou	2011 b	222.4	11.1 a	7007 b	28.7 b
Clair 1976	Sundance	3297 a	383.2	11.6 b	9783 a	33.7 a
	Manitou	2616 b	379.6	14.4 a	9244 b	28.3 b
Saskatoon 1976	Sundance	3644 a	531.1	14.5 b	10323	35.3 a
	Manitou	3094 b	528.8	17.1 a	9891	31.3 b
Clair 1977	Sundance	3604 a	368.0	10.0 b	8581	42.0 a
	Manitou	3069 b	409.0	13.3 a	8948	34.3 b
Saskatoon 1977	Sundance	2860 a	433.5 a	15.4 b	7730 a	37.0 a
	Manitou	2074 b	338.7 b	16.6 a	7078 b	29.3 b
Clair 1978	Sundance	3470 a	389.4	11.4 b	9830 a	35.3 a
	Manitou	2308 b	328.3	14.3 a	6994 b	33.0 b
Saskatoon 1978	Sundance	2042 a	302.7	14.9 b	6188 a	33.0 a
	Manitou	1526 b	268.9	17.6 a	5208 b	29.3 b
Clair 1979	Sundance	3689 a	504.4	13.7 b	11179 a	33.0
	Manitou	2779 b	472.0	17.0 a	8879 b	31.3

† values in a column not followed by the same letter are significantly ($p \leq 0.05$) different according to the LSD.

Table 3. Grain yield, grain protein yield, grain protein concentration, kernels m^{-2} and kernel weight for winter and spring wheat cultivars in Saskatchewan: 1986 to 1988.

		1986				1987			1988	
		Clair	Outlook	Goodale	Watrous	Clair	Hagen	Paddockwood	Clair	Elrose
Grain yield ($kg\ ha^{-1}$)	Norstar	2723 a†	1496	1323 a	1414	3277 a	2569 a	3460 a	1443 a	195
	Norwin	1994 b	1868	-	1760	1820 b	1962 ab	2347 b	-	-
	Katepwa	2122 ab	1425	1042 b	1414	1835 b	1820 b	2301 b	1050 b	523
	HY 320	2031 ab	1465	-	1431	2326 b	1900 ab	3114 ab	-	-
Grain protein yield ($kg\ ha^{-1}$)	Norstar	358.4	214.1	195.1	190.6 b	432.8 a	378.7 a	426.5 a	194.1	11.2
	Norwin	266.3	252.4	-	231.2 ab	247.6 b	269.6 b	319.7 b	-	-
	Katepwa	362.7	233.4	192.9	254.1 a	298.6 b	322.4 ab	361.2 ab	183.7	116.8
	HY 320	318.8	219.5	-	237.6 ab	335.2 b	296.8 ab	419.7 a	-	-
Grain protein conc. (%)	Norstar	11.6 b	12.6 b	12.9 b	11.9 c	13.3 b	14.7 c	12.3 c	13.1	17.3
	Norwin	11.8 b	11.9 b	-	11.5 c	13.6 b	13.7 c	13.6 b	-	-
	Katepwa	14.9 a	14.4 a	16.2 a	15.7 a	16.3 a	17.7 a	15.6 a	16.3	17.2
	HY 320	12.3 b	13.4 ab	-	14.5 b	14.5 b	16.1 b	13.5 b	-	-
Kernel no. per m^2	Norstar	8614 a	5475 ab	5496 a	6691 a	9387 a	7483 a	9147 a	5214 a	760 b
	Norwin	6558 a	6748 a	-	5920 ab	5851 b	6090 ab	6693 b	-	-
	Katepwa	6600 a	5015 b	3554 b	5406 b	7012 b	5934 ab	7018 b	3201 b	2029 a
	HY 320	5363 b	4422 b	-	3962 c	6658 b	4310 b	8043 ab	-	-
Kernel weight (mg)	Norstar	31.1 b	27.1 b	24.3 b	21.5 c	34.4 a	34.5 b	37.7 ab	27.7 b	25.4
	Norwin	30.3 b	27.8 b	-	29.7 a	30.9 b	32.3 c	35.1 bc	-	-
	Katepwa	31.7 b	28.6 b	29.3 a	26.0 b	26.1 c	30.5 d	32.9 c	32.0 a	26.0
	HY 320	42.3 a	33.0 a	-	26.2 b	34.9 a	44.2 a	38.8 a	-	-

† values in a column not followed by the same letter are significantly ($p \leq 0.05$) different according to the LSD.

Table 4. Date of tillering, stem elongation, anthesis, soft dough and mature development stages for Norstar winter wheat and Katepwa spring wheat.

		Crop Development Stage				
Location	Cultivar	Begin of tillering (Zadok 21)	Stem elongation (Zadok 31)	Anthesis (Zadok 65)	Soft dough (Zadok 85)	Maturity (Zadok 91-96)
Clair 1986	Norstar	May 15*	May 31*	June 27	July 17	Aug. 9
	Katepwa	June 4	June 10	July 11	Aug. 3*	Aug. 27
Outlook 1986	Norstar	May 15*	May 27	June 20	July 16	July 30
	Katepwa	June 2	June 9*	July 3*	July 25	Aug. 14
Goodale 1986	Norstar	May 14	May 24	June 21*	-	Aug. 1
	Katepwa	May 28*	-	-	-	Aug. 14
Clair 1987	Norstar	May 14	May 22	June 26	July 23	Aug. 6
	Katepwa	May 31	June 12	July 3*	Aug. 6	Aug. 25
Hagen 1987	Norstar	May 13	May 25	June 27	July 21	Aug. 7
	Katepwa	June 1	June 11*	July 7*	Aug. 7	Aug. 26
Paddockwood 1987	Norstar	May 13	June 4*	July 1*	July 31	Aug. 24
	Katepwa	June 10	June 20	July 13	Aug. 14	Sept. 4
Clair 1988	Norstar	May 10	May 30	June 15	July 11	July 21
	Katepwa	May 30	June 15	July 5*	July 21	Aug. 10
Mean	Norstar	May 13	May 28	June 24	July 20	Aug. 5
	Katepwa	June 2	June 13	July 7	Aug. 2	Aug. 22

*Indicates that the date was estimated from the closest sampling date.

Table 5. Growing season crop water use, water use efficiency (WUE) of grain yield and WUE of grain protein yield for winter and spring wheat cultivars in Saskatchewan.

	Cultivar	1986 Clair	1986 Outlook	1986 Goodale	1986 Watrous	1987 Clair	1987 Hagen	1987 Paddockwood	1988 Clair	1988 Elrose
Crop water use (mm)	Norstar	241 b†	193	254	228	188 b	232 b	318	197	75
	Norwin	237 b	205	-	235	165 b	230 b	295	-	-
	Katepwa	294 a	201	267	233	251 a	272 a	333	205	116
	HY 320	292 a	203	-	239	269 a	279 a	338	-	-
WUE of grain yield (kg ha^{-1} mm^{-1} ET)	Norstar	11.3 a	7.9	5.3 a	6.1	17.0 a	11.1 a	10.8 a	8.3 a	2.6
	Norwin	8.5 a	9.2	-	7.4	11.2 b	8.5 ab	7.9 b	-	-
	Katepwa	7.5 b	7.1	3.9 b	6.2	7.3 c	7.5 b	6.9 b	5.0 b	4.5
	HY 320	7.8 b	7.2	-	6.1	8.6 bc	6.5 b	9.1 ab	-	-
WUE of grain protein yield (kg ha^{-1} mm^{-1} ET)	Norstar	1.49	1.14	0.78	0.82 b	2.25 a	1.64 a	1.34 a	1.14	0.19
	Norwin	1.13	1.25	-	0.97 b	1.52 b	1.17 ab	1.09 b	-	-
	Katepwa	1.24	1.17	0.72	1.12 a	1.19 b	1.33 ab	1.08 b	0.88	1.01
	Hy 320	1.09	1.08	-	1.02 ab	1.24 b	1.02 b	1.24 a	-	-

† values in a column not followed by the same letter are significantly ($p \leq 0.05$) different according to the LSD.

Table 6 Total soil water amount in individual soil increments for winter and spring wheat cultivars in Saskatchewan. (Note: Soil water values shown only where significant ($p \leq 0.05$) differences between cultivars were observed).

		May 18	June 3	June 27			July 17		
		0-10 cm	10-30 cm	0-10 cm	10-30 cm	30-50 cm	0-10 cm	10-30 cm	30-50 cm
Clair 1986	Norstar	2.83 b*	1.79 b	1.23 b	1.39 b	1.48 bc	2.98 b	1.86 b	1.31 c
	Norwin	2.80 b	1.82 b	1.20 b	1.40 b	1.52 b	2.90 b	2.07 ab	1.48 b
	Katepwa	3.02 a	2.34 a	1.60 a	1.72 a	1.84 ab	3.20 a	2.12 a	1.71 ab
	HY 320	3.00 a	2.31 a	1.61 a	1.91 a	1.95 a	3.17 a	2.29 a	1.86 a
		May 13	May 27		June 16				
		0-10 cm	10-30 cm	30-50 cm	0-10 cm	10-30 cm	30-50 cm	50-70 cm	
Outlook 1986	Norstar	2.13 b	1.54 b	1.68 c	1.37 b	1.25 c	1.40 b	1.25 c	
	Norwin	2.10 b	1.48 b	1.81 bc	1.35 b	1.23 c	1.46 b	1.53 bc	
	Katepwa	2.26 a	1.97 a	2.15 a	1.61 a	1.77 ab	1.98 a	1.70 ab	
	HY 320	2.25 a	1.94 a	1.99 ab	1.57 a	1.51 bc	1.72 ab	1.93 a	
		June 19							
		30-50 cm							
Goodale 1986	Norstar	1.26 b							
	Katepwa	1.50 a							
		June 2							
		0-10 cm	10-30 cm						
Watrous 1986	Norstar	1.94 b	2.42 b						
	Norwin	1.90 b	2.23 b						
	Katepwa	2.40 a	2.99 a						
	HY 320	2.46 a	2.84 a						
		May 12	June 9						
		0-10 cm	0-10 cm	10-30 cm					
Clair 1987	Norstar	2.37 b	1.33 b	4.06 b					
	Norwin	1.88 c	1.34 b	3.22 c					
	Katepwa	2.60 ab	1.77 a	4.43 b					
	HY 320	2.65 a	1.67 a	4.53 ab					
		May 13							
		0-10 cm							
Hagen 1987	Norstar	1.84 c							
	Norwin	1.87 bc							
	Katepwa	2.01 ab							
	HY 320	2.03 a							
		July 31	August 14						
		30-50 cm	50-70 cm						
Paddockwood 1987	Norstar	2.98 c	3.02 c						
	Norwin	4.55 a	3.90 a						
	Katepwa	3.89 b	3.13 bc						
	HY 320	3.63 b	3.79 a						
		May 30							
		0-10 cm	10-30 cm						
Clair 1988	Norstar	1.16 b	3.47 b						
	Katepwa	1.76 a	4.53 a						

* values in a column not followed by the same letter are significantly ($p \leq 0.05$) different according to the LSD.

Table 7. Efficiency of evapotranspiration (ET) water used to produce above-ground dry matter (DM) for winter and spring wheat in Saskatchewan.

		Water use efficiency of DM ($kg\ DM\ ha^{-1}\ mm^{-1}\ ET$)			
		Cultivar			
Location	Time† Period	Norstar	Norwin	Katepwa	HY 320
Clair 1986	M1-JN3	11.2 a‡	9.5 a	0.8 b	1.0 b
	M1-JN27	22.1 a	19.0 ab	11.5 c	12.4 c
	M1-HARVEST	22.0	19.7	21.4	21.9
Outlook 1986	M1-M27	22.0 a	26.1 a	1.8 b	3.4 b
	M1-JN16	20.5 a	22.6 a	7.3 b	7.6 b
	M1-HARVEST	21.6	22.3	20.3	17.6
Goodale 1986	M1-JN19	26.6 a	-	8.1 b	-
	M1-HARVEST	14.8 a	-	6.2 b	-
Clair 1987	M1-JN9	12.5 a	9.6 a	6.3 b	8.5 ab
	M1-JN26	21.8	20.9	17.1	15.6
	M1-HARVEST	34.7 a	29.3 a	19.7 b	28.1 a
Hagen 1987	M1-JN10	18.5 a	19.7 a	12.3 b	10.5 b
	M1-JL2	32.7 a	24.6 b	18.1 b	20.4 b
	M1-HARVEST	22.1	21.1	20.3	19.9
Paddockwood 1987	M1-JN14	8.5	5.2	5.1	5.3
	M1-JL7	25.3 a	15.3 b	14.3 b	16.5 b
	M1-HARVEST	26.3	16.5	20.8	25.7
Clair 1988	M1-M30	19.4 a	-	3.3 b	-
	M1-JN15	18.0	-	15.9	-
	M1-HARVEST	17.4	-	13.8	-

† M-May; JN-June; JL-July. ‡ Values in a row not followed by the same letter are significantly ($p \leq 0.05$) different according to the LSD.