Developing Profitable
Canola Production Strategies
For The Semiarid Prairie

Final Report
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And The Canodev Research Inc.

By

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Executive Summary:

Developing Profitable Canola Production Strategies For Semiarid Prairie

Crop establishment is the key factor for the success of rainfed agriculture. 'Canola Quality Brassica juncea' lines (CQ) always had populations comparable to Argentine canola and superior to Polish canola. Populations of AC-H102 were consistently lower than for Quantum at all 10 site years, indicating a lower seedling vigour for the hybrid. Location and year significantly affected crop establishment. Nitrogen application did not have any influence on the population.

CQ1flowered about 5 days earlier and Maverick about 6 days earlier than Quantum. Days to maturity rankings were AC-H102> CQ1=CQ2≥Quantum> Cutlass>Maverick. Under non-water stress conditions nitrogen can delay maturity, but in the dry and hot semiarid prairie water stress limits that response. Crop development was more influenced by site year than by N.

Average seed yield of Cutlass was about 15 % higher than Quantum. Based on 14 site years data seed yield ranking was Cutlass>CQ1≥Quantum>Maverick; about 32 % difference between highest and lowest yielding genotypes. The CQ2 line and AC-H102 had lowest yield potential. Oil synthesis cost is higher than starch or protein synthesis in plants. Highest and lowest oil content in the present study were in Maverick (43.6 %) and Cutlass (46.9 %), respectively, which may partly explain the yield differences between them. However, converting oil contents to oil yield per unit area maintains ranking for the seed yield, indicating better adaptability of Cutlass to the semiarid prairie. This good yield performance is encouraging for the effort of developing canola quality *Brassica juncea*.

Nitrogen influenced seed yield of Brassica species significantly. Pooled over genotypes common to all 14 site years, seed yield increased by 360 and 480 kg ha^{-1} with application of N at normal risk and high risk. Biomass yield response did not increase with N applied above normal

risk, indicating moisture may be limiting for further increase in biomass. Individual genotype response indicates that Maverick limited its yield response to normal risk levels, while CQ1, Cutlass and Quantum responded to high risk level N application. Thus Cutlass was producing 210 kg more seed yield than Maverick at low risk and that increased to 390 and 590 kg ha^{-1} at normal and high risk N levels.

Maverick, onaverage used 288 mm of water which was 29 mm less than CQ1. Cutlass and Quantum used similar (305 and 306 mm) amounts of water. Nitrogen application increased water use by a small amount (14 to18 mm).Though the amount is small, because it was supporting plant at critical stages, the water use efficiency of the crop improved.

High temperature stress is the second most important abiotic stress, after water, reducing the yield potential in many crops. Brassica spp. is a cool season crop. Our growth chamber work showed that daytime temperature of 35 °C was very harmful to reproductive organs in all three species with its effect more severe at the flowering than at the pod development stage. In the field seeding early can avoid or reduce heat stress. For example, at Swift Current in 1998 in spite of just average water use, compared to all other site years, yields were highest because the temperature during flowering were the lowest. This indicates that canola and mustard are losing yield potential due to high temperature in semiarid prairie in most years.

All crop species have a narrow optimum temperature range and yields decline at temperatures on either side of the optimum range. The three *Brassica* spp. differ in their optimum temperature requirement. For example, we observed *Brassica napus* L. has lower optimum range (close to 20/15 °C day/night temperature) than *B. juncea* or *B. rapa* (close to 28/15 °C day/night temperature). The difference in optimum temperature probably contributed for the better

performance of B. juncea in our field studies. B. rapa was most susceptible to high temperature stress. All species tried to recover by recommencing flowering and pod formation after returning to 20/15 °C from high temperature stress. Therefore all genotypes stressed with mild or severe heat stress produced more reproductive organs than control plants. Producing extra pods as a stress recovery strategy is responsible for the better yield elastic response by canola and mustard to short periods of stress. Pods formed after stress relief were deformed and thus Argentine canola failed to recover after returning to 20/15 °C from 35/15 °C at flowering.

The drought response of mustard or canola was similar. The strategy adopted by mustard or canola was significantly different than wheat or pulses. The Brassica spp. do not use osmotic adjustment to counter water stress effect. However, they have deep root and higher root hydraulic conductivity than many other crops. Therefore if water is available in the profile, canola or mustard will extract it to meet the transpirational demand. If there is no water in soil profile then they try to shed some leaves in an effort to reduce transpiration. From our field studies we can rank pulses, wheat, canola as most to least drought tolerant crops from semiarid prairie perspective. However, canola or mustard can be an good crop to grow on fallow, where extraction of soil moisture at depth can reduce effects of dry periods. We did not sample a wide range of genotypes and there may be great opportunities to improve adaptability of Brassica spp. to the conditions of the semiarid prairie.

Chapter 1

Adaptation of Different Brassica Species to the Semiarid Prairie Environment: Effect of nitrogen Management.

1. Adaptation of Different Brassica Species to the Semiarid Prairie Environment: Effect of nitrogen Management.

Abstract:

Field trials were conducted to study the adaptability of *Brassica juncea* L. to the semiarid prairie with special emphasis on canola quality (CQ) lines. Water and nitrogen are the two major factors affecting productivity in the semiarid prairie. Six genotypes, three from B. Juncea (CQ1, CQ2 and Cutlass), two from B. napus (Quantum, Legacy/AC H102) and one B. rapa (Maverick), were studied over 14 site years during 1996-98 for yield responses to nitrogen application at low, normal and high risk levels. Brassica spp. varied in dry matter accumulation, seed yield , oil yield, water use and water use efficiency. The Oriental mustard, Cutlass, consistently performed better than rest of the genotypes with average yield advantages of 360 kg ha $^{-1}$, indicating the higher yield potential of mustards in semiarid prairie. The harvest index of Cutlass was significantly higher than other genotypes. The present CQ lines were performing similar to *B. napus*, but have the advantages of seedling vigour, less disease and pests, heat and drought tolerance and shatter resistant pods. Nitrogen response and adaptability of Maverick was poor. Water extraction and water use efficiency for seed production increased due to N fertilization in all genotype.

1.2 Introduction

Canola has been established as a profitable crop on the Canadian prairie. Among Brassica species, *Brassica napus* L. (Argentine canola), *B. rapa* L. (Polish canola) and *B. juncea* L.(Oriental mustard) are economically exploited for edible oil purpose. The results of Nuttal et al. (1992), Morrison and McVetty (1993) and Brandt and McGregor (1997) suggest that Argentine canola may fail to express their full yield potential under hot and dry environments of the semiarid prairie. Polish canola, due to its shorter duration and smaller yield potential, can not take advantage of occasional favourable conditions that may occasionally prevail in the region. Mustard is often considered to be better adapted to stressful environments than Polish or Argentine canola (Lewis and Thurling, 1994). However, the strict oil quality standards set by canola council of Canada does not allow to crush mustards for edible oil purpose. Recent breeding efforts have improved oil quality of mustards and a number of canola quality B. juncea L. lines are under development. Very little information is available on the adaptability of canola or mustard crop to the semiarid prairie (brown and dark brown soil zone).

Water is the major factor limiting productivity in the region. Low and unevenly distributed rainfall, high temperature and desiccating wind result in an annual precipitation deficit (ie.potential evapotranspiration minus precipitation) of 250-400 mm yr^{-1}. Annual recharge of the soil profile is not fully assured. In such conditions a crop capable of using soil water more efficiently and effectively has an advantage. Efficient extraction of water from depth is one mechanism of accomplishing above. The three species of Brassica differ in their duration, growth habit and yield potential. Yield and biomass production of Brassica spp. are known to reduce with decreasing water availability (Wright, 1988). Information on the water extraction abilities of three species in the semiarid environment is not available.

Nitrogen fertilization is recognized as the second most important factor, after water, limiting crop yields in the semiarid prairie (Campbell, 1992). Canola is reported to extract about 25 % more N from soil than wheat (Hocking, 1997). The benefit of applied nitrogen depends on water available to the crop. Canola has better response to applied nitrogen when there is adequate supply of water than when there is restricted supply of water (Krogman and Hobbs, 1975; Henry and MacDonald, 1978; Smith et al., 1988). Excessive N early in the season can induce larrge plants that exhaust the limited soil moisture reserve for vegetative growth. Later reproductive growth and yield formation can suffer from lack of water. Such stress induced by excessive N seems to indicate that N fertilizer can lower economic returns. Canola are extremely sensitive for water stress at reproductive stage (Richards and Thurling, 1978). Soil testing laboratories in Western Canada recognize the importance of soil moisture in recommending fertilizer. On the other hand N fertilization may improve better water extraction from the soil by improved rooting characters. Therefore it is necessary to study the effect of N fertilization on water use, biomass accumulation and yield of three Brassica spp. under semiarid conditions. Providing a range of environments, increases the ability to detect differences of the Brassica spp. to the weather of the semiarid prairie.

1.2 Materials and Methods

Field experiments were conducted during summers of 1996 to 1998 at nine different locations ranging from 49° 38' N to 51° 40' N in latitude and 105° 28' to 107° 48' in longitude. Details of locations, cropping history, soil type, seeding time, temperature and moisture content are presented in Table. 1. The locations ranged from dry brown to dark brown regions of Saskatchewan, representing variation in agroclimatic conditions on the semiarid prairie. The soil type ranged from heavy clay to loam, representing the range of soil textures mostly used for crop production in the region. Weather conditions prevailed during the experimentation, April-August precipitation, minimum and maximum temperature are presented in Table 1 and 2.

Adaptability of six genotypes belonging to three Brassica species were studied in this project. Brassica juncea L. (Oriental mustard) was represented by cutlass and two canola quality mustard lines, CQ1 (J-90-4316) and CQ2 (a composite of breeding lines). Argentine canola (Brassica napus L.) was represented by Quantum and AC-H102, while Polish canola (Brassica rapa L.) was represented by Mavarick. CQ2 is an advanced breeding line and each year its composition changed (from pool of elite genotypes to one elite line during 1998). In 1996, instead of AC-H102, Legacy was used as second Argentine canola variety. All genotypes were seeded one inch deep with a plot seeder. Seeds of all genotypes were treated with Vitavax to control seed borne fungal disease. The six Brassica oilseeds are the main plot treatments and three N fertility levels, representing three levels of soil nitrogen management associated with low, normal and high availability of water during growing season are the subplot treatments in a split-plot design. The low N fertility plots received only a small amount of fertilizer N (Table 1.1) in the form of 11-51-0 placed with the seed. The normal and high risk N fertility treatments were calculated based on the fertilizer recommendations from Enviro-Test Labs, Saskatoon, Canada (formerly Plains Innovative Laboratory Services). Locations with low soil Nwere selected to get graded nitrogen levels. Nitrogen was applied in the form of urea-ammonium sulphate blend (40-0-0-6) or mono-ammonium phosphate (11-51-0) either as a mid-row band or broadcast at all sites.

Observations on plant populations, days to flower, days to mature, plant height and above ground biomass accumulation (DM) were recorded on all trials. DM samples were taken from approximately 0.5-1 m^2 sample area. Yield was measured with plot combine, while samples (20 pod $plot^{-1}$) pods were collected randomly from the whole plant for seeds per pod. Seed sample from yield was used for thousand kernel weight (TKW). Pod number per plant was calculated from TKW, number of seeds per pod and yield per plant. Oil content was measured with NMR technique. Soil N and P2O5 content was assessed both in the spring and fall.

Water use was monitored by soil moisture balance method. Soil water was measured by gravimetric method from a single soil core os 2 cm diameter to a depth of 120 cm was taken with a hydraulically powered sampler and divided in to 30 cm increments.. In the spring soil cores were taken in approximately 24 spots, one in each main plot. However, in the fall the moisture was measured in each subplot. In 1997, the Coderre, Eyebrow and Kenaston site could not be sampled in spring. But the profile was approximately at field capacity at seeding and the moisture content was estimated from moisture release curve. Runoff, runon, leaching of water to below 120 cm depth or upward movement of water in to the upper 120 cm of soil was assumed negligible. An access tube for a neutron probe was installed so that soil moisture could be measured during growing season without damaging the crop.

Analysis of variance was conducted on all data individually for each year and effect of genotype or nitrogen levels were assessed. This was necessary to assess comparative performance of canola quality Brassica juncea lines, composition of which was changing each year. After comparing main traits at each site year, data from four common genotypes (CQ1, Cutlass, Quantum and Maverick) were pooled and analyzed as split-split-split-plot analysis was used to account for year, location and genotype effects for nitrogen response. Year was used as a random effect.

1.3 Results and Discussion

1.3.1 General Conditions

Some site years were production on wheat stubble with others being production on fallow, this is included in the site-year effect (Table 1). Climatic conditions during three year of the study indicates wide variation from year to year as well as within year among locations (Table 2). The rainfall amounts and temporal distribution varied between location within and between years while in contrast temperature was similar among locations and major differences were between years. Of the 12 site years for which rainfall data is available, Assiniboia in 1996 was the driest and Eyebrow in 1998 was the wettest location. However, looking at the distribution, Eyebrow in 1998 received large amount of its rainfall in one rainfall event during vegetative growth stage and rest was fairly dry (Fig. 1). Though temperature variation was minimum between locations, seeding dates varied up to 30 days (Table 1). Thus, the flowering period at different site years indicates that different extent of heat stress were experienced by different genotypes at different locations (Fig. 1). In general, cooler May month followed by warmer June and July was the trend except in 1998, which had very warm May and it was followed by very cold June, which was followed by extremely hot July and August (Table 2).

1.3.2 Effect on Growth Parameters

Crop establishment and growth parameters observed in the present trial were influenced by genotype, nitrogen, locations and year (Table 3). Population density was affected by genotype, but not by nitrogen, which was expected since it was either applied as a mid-row band or broadcast at all sites. Polish canola, 'Maverick' had consistently lower population than rest of the genotypes (Table 7). *Brassica juncea* genotypes (Mustards), 'CQ1' and 'Cutlass', on pooled basis had highest population, indicating better seedling vigour than polish canola. In semiarid environment, efficient water use is a key to the success of the crop (Campbell et al., 1993). Better establishment is the first step towards efficient water use (Sojka et al., 1988). The present study reveals that B. juncea is on par with B. napus and better than B. rapa in quick establishment. Second B. napus genotype, 'AC H102', tried during 1997 and 1998 is a hybrid and a better seedling vigour from it was expected. But in both years one of the lowest populations were observed with AC H102. Population densities differed significantly between locations and we can not explain all the variation such as the higher plant density at Eyebrow in 1997.

Crop development rate (flowering and maturity) was different among genotypes and it was influenced by site years and nitrogen levels (Table 3 and 7). Argentine canola, 'Quantum', was about 7 days later in initiating flowering than Maverick, while mustard species were intermediate. Overall, high levels of nitrogen delayed flowering and maturity significantly, but in terms of days, the delay was negligible (less than a day). Further the effect of N application on days to maturity was not consistent across site years (Table 8). Higher nitrogen is reported to delay maturity by increasing leaf area duration in canola, but that occurs only under adequate water supply (Wright et al., 1988). The present study was conducted under semiarid conditions with typical moisture deficit of 250 to 400 mm yr^{-1} (Cutforth et. al., 1993). In addition, due to the high temperature prevailing during the day time, the diurnal stress on these crops were much higher than soil moisture stress (see chapter 3). Maverick matured about 9 days earlier than Quantum, while CQ1 and Cutlass were 1 day later and 2 days earlier than Quantum, respectively. Maturity in B. juncea is defined as 70 % of the seeds having begun to change colour, while that in canola (both B. napus and B. rapa) is only 30%. Using a common definition of maturity would give mustard about two days earlier than reported in this paper.

Plant height and biomass (DM) accumulation pooled over all site years were influenced by nitrogen, location and genotype, but no genotype by nitrogen interaction was noticed (Table 3 and 7). Taller plants were noticed in Brassica juncea (canola quality B. juncea lines were the tallest) , while the shortest plant was B. rapa. Nitrogen application increased plant height and DM, but levels of nitrogen had little effect (Table 7). All twelve site years indicated increase in biomass due to nitrogen application, but only on three occasions using high risk N levels had influence on biomass (Table 10). Moisture availability was again limiting the response at higher N levels. On pooled basis, significantly lower DM than other genotypes was noticed in polish canola (Table 7). Genotypic variation in DM accumulation was noticed only in 4 out of 13 site years, indicating the similarity among genotypes (Table 9).

1.3.3 Effect on Seed Yield and Yield Parameters

Seed yield and yield forming traits were significantly influenced by site years, genotypes and nitrogen levels (Table 4). However, effect of year and its interactions with genotype or nitrogen for yield was not significant, with few exceptions. The interaction between genotypes and site within year were highly significant for most of the yield and yield forming traits, indicating different genotypes were responding to agroclimatic situation prevailed in each site year differently (Table 4). In the semiarid prairie, rainfall events are mostly location specific and therefore site within year and genotype (or nitrogen interaction) were highly significant. On pooled basis, two *Brassica juncea* genotypes, 'CQ1' and 'Cutlass', were out yielding Argentine canola 'Quantum' by 5 and 15 %, respectively (Table 11). Polish canola, 'Maverick', was 14 % lower yielding than Quantum. Mean nitrogen response of four common genotypes was 35 and 47 % with normal and high N application. Next to water, nitrogen fertility is the most important factor limiting crop yield in the semiarid prairie (Campbell, 1992). Brassica spp. uses more N than wheat (Hocking et al., 1998), therefore better yields with increasing nitrogen application were expected. Nitrogen response was observed in all 14 site years, but response to high N was noticed only in 10 of them. Genotype and nitrogen interaction was significant (Table 4). Seed yield of CQ1, Cutlass and Quantum increased with successive increase in N levels (Table 12), but Maverick responded to only normal risk level of N. At low fertility status Cutlass was yielding 210 kg ha^{-1} more than Maverick, but the same difference increased to 390 and 490 kg ha^{-1} at normal and high risk N fertilization. At low N levels difference between two B. juncea genotypes was only 20 kg ha^{-1} and gradually increased to 190 kg ha^{-1} at high N levels, indicating poor N response by CQ1 compared to Cutlass.

Complex interactions between yield forming traits determines yield in Brassica species. Positive effect of environment on one component can have negative impact on others. Canola and mustards are known to produce more number of reproductive organs (RO) than its photosynthetic machinery can sustain (McGregor, 1981). Therefore, RO compete for limited resources. Thus a factor reducing pod number can result in higher number of seeds per pod or thousand kernel weight (TKW). Comparing pooled means of common genotypes reveals that B. juncea genotypes tend to have higher pod number, lower number of seeds per pod and slightly lower TKW, while Argentine canola produces lower number of pods, higher number of seeds per pod and heavier seeds (Table 11). On the contrary, lowest number of pods, seeds per pod and TKW were observed Polish canola. Argentine canola completes vegetative growth and stem elongation and then starts reproductive growth. In contrast, Polish canola initiates reproductive development before stem elongation. Therefore, higher competition between RO and vegetative growth leads to floral abortion and sterility. Nitrogen increased pods per plant and seeds per pod, but lowered

TKW and did not influence harvest index (HI). Extremely high population at Eyebrow in 1997 reduced mean number of branches to 10, but had little effect on number of seeds and TKW.

1.3.4 Oil Percent and Oil Yield

Genotypes varied in seed oil percent, with Cutlass recording the lowest seed oil per cent, while and Maverick recorded the highest seed oil per cent (Table 5 and 16). Nitrogen application reduced seed oil concentration (Table 17). Oil concentration depends on rate of maturity, which inturn depends on temperature and water stress during maturity. Therefore oil percent varied with year and site within year. However, better seed yield compensated for lower oil percent and Cutlass recorded highest oil yield per hectare (Table 18). Oil yield per ha increased with nitrogen application (Table 19). Oil concentration was highest in 1998 and lowest in 1997 (Table 16). Nitrogen and genotype interaction for oil percent was mainly due to the differences in relative responses and trend was similar in all genotypes (Table 12).

1.3.5 Water Use, Nitrogen Use and Phosphorous Use and Efficiencies

Genotypic variation in water use was very small (Table 15). On a pooled basis Maverick used lowest amount of water (288 mm) while highest was noticed in CQ1 (317 mm) (Table 5,15). Nitrogen application also increased water use by a small amount (19 mm). Available water and evapotranspiration determines the amount of evapotranspiration (ET), therefore site years showed significant influence on ET (Table5, 15). Application of nitrogen affected nitrogen use but did not have any effect on phosphorous uptake. Water use efficiency (WUE) varied due to genotype and Cutlass produced about 20 % more seed yield than Maverick per unit of water used (Table 20, 21). However the same genotypic variation for WUE of DM production was not noticed (Table 20, 23). This indicates that a higher HI was responsible for the better WUE in Cutlass. The interaction between genotype and nitrogen for WUE, shows that difference between Cutlass and other genotypes widened with N application (Table 12). This indicates that application of N improved efficiency of water use in Cutlass, but the effect was smaller in other genotypes (Table 22). Nitrogen use efficiency for both seed yield and DM was negatively affected by N application and genotypic differences were also not apparent.

1.4 Conclusions

Oriental mustard, Cutlass, is better adapted to semiarid conditions than canola genotypes. Present Canola quality Brassica juncea breeding material is comparable to Argentine canola in yield potential, but better seedling vigour, less insect and decease problem, better temperature tolerance and less seed shattering make them a good crop for semiarid prairie. Extensive field observation has not revealed any water extraction advantage with mustard. Canola and mustard needs nitrogen application, however limited water restricts taking advantage oh high dose of nitrogen. Yield advantage of up to 500 kg ha^{-1} can be realized with nitrogen application. N application also improves water use efficiency by 20 %.

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Table 1. Details of experimental sites for Brassica Adaptation Trials during 1996-98.

Site	Location	Soil Type	Cropping History	Seeding Date	Fertilizer Applied Kgha^{-1}		Soil Temp	Soil Moisture (%)	
					N	P_2O_5	(°C)	2.5	5
1996 Trials									
Assiniboia	49°38′ N 105°59′W	Ardill-Valour Clay	Fallow	May 16	4, 45, 73†	19	18.5	4.6	7.7
Stewart Valley	50°36′ N 107°48′W	Sceptre Heavy Clay	Fallow	May 27	4, 39, 67	19	9	7.8	11.2
Swift Current	50°17′ N 107°48′W	Swinton Silt Loam	Fallow	May 23	4, 28, 56	19	9	4.6	7.3
1997 Trials									
Cadillac	49°44′ N 107°44′W	Ardil Clay Loam	Fallow	May 8	5, 56, 84	23	10.7	8.7	16.7
Coderre	50°08′ N 106°23′W	Willows Clay Loam	Fallow	May 19	7, 18, 31	17	-	-	-
Eyebrow	50°48′ N 106°09′W	Wayburn Loam	Wheat Stubble	May 29	0, 18, 31	33	-	-	-
Kenaston	51°30′ N 106°17′W	Wayburn Loam	Wheat Stubble	May 28	0, 22, 34	23	-	-	-
Stewart‡ Valley	50°36′ N 107°48′W	Sceptre Heavy Clay	Fallow	May 15	4, 67, 95	17	14.4	30	38.4
Swift Current	50°17′ N 107°48′W	Swinton Silt Loam	Fallow	May 7	4, 56, 84	17	7	17.9	18.1
1998 Trials									
Cadillac	49°44′ N 107°44′W	Ardil Clay Loam	Fallow	May 8	4, 52, 80	17	17	7	14
Eyebrow	50°48′ N 106°09′W	Weyburn loam	Fallow	May 24	0, 37, 67	34	-	-	-
Mortlach	50°27′ N 106°04′W	Haverhill loam	Wheat Stubble	May 27	0, 39, 78	34	-	-	-
Stewart Valley	50°36′ N 107°48′W	Sceptre Heavy Clay	Fallow	May 12	4, 35, 62	17	15	12	24
Swift Current	50°17′ N 107°48′W	Swinton Silt Loam	Fallow	Apr 28	4, 30, 58	17	14	17	20
Watrous	51°40′ N 105°28′W	Elstow loam	Fallow	May 8	0, 39, 62	34	-	-	-

† Nitrogen fertilizer applied to low, normal and high risk fertilizer treatments , respectively.

‡ Crop failed due to lower population and high weed infestation.

Table 2. Seasonal weather data of the sites during 1996-1998.

Site	Precipitation (mm)					Mean Temperature (°C)					GDD$_5$ (°C)				
	May	June	July	Aug	Total	May	June	July	Aug	Mean	May	June	July	Aug	Total
1996 Trials															
Assiniboia	36	67	47	12	**162**	9	16.6	18.3	19.9	**16**	133	349	412	463	**1357**
Stewart Valley	80	88	54	28	**250**	9	16.5	18.6	19.6	**16.3**	133	347	422	450	**1352**
Swift Current	65	78	23	33	**199**	8	15.9	17.7	19.4	**15.3**	106	326	394	447	**1273**
1997 Trials															
Cadillac	42	109	19	-	-	10.8	16.7	19	-	-	185	350	434	-	-
Coderre	15	68	46	53	**182**	10.8	17.6	19	18.5	**16.8**	178	377	428	418	**1401**
Eyebrow	32	71	27	51	**181**	10.8	17.4	18.9	18.5	**16.5**	186	373	426	418	**1403**
Kenaston	47	70	19	55	**191**	10	17	18.5	18	**16**	157	358	412	402	**1329**
Swift Current	50	70	44	48	**212**	10.2	16.3	18.1	18.7	**15.8**	164	340	401	425	**1330**
1998 Trials															
Cadillac	45	82	58	76	**261**	12	13	20	20	**16.3**	213	250	449	461	**1373**
Eyebrow	79	127	13	59	**278**	13	15	20	21	**17.3**	239	272	436	485	**1432**
Mortlach	72	108	20	59	**259**	13	15	20	21	**17.3**	240	293	463	485	**1481**
Stewart Valley	-	113	37	54	**204**	-	15	21	22	**14.5**	-	312	487	538	**1337**
Swift Current	38	91	33	35	**197**	12.6	14	20.1	20.9	**17**	236	270	455	494	**1455**
Watrous	44	123	36	12	**215**	11.6	13.8	18.6	19.1	**16**	203	264	408	439	**131**

Table 3. Pooled analysis of plant population, growth, development and biomass accumulation by four common genotypes in all 14 site years over three years of experimentation.

Source		Population	Flowering	Maturity	Height	Dry Matter
		m^{-2}	d	d	cm	t/ha
Year†	(Y)	100195^{ns}	382.1^{ns}	40.5^{ns}	27933*	30.8^{ns}
Site (year)†	(S)	399980***	1130.3***	2404.9***	5182***	55*
R (S X Y)	(a)	842	2.1	3.7	188	3.7^{ns}
Genotype	(G)	14614***	923.4***	3158.3***	26388***	21.1***
G X Y		6740**	33.1*	113.9*	378^{ns}	4.5^{ns}
G X S(Y)		1345**	11.1***	44.1***	292***	6.8**
G X R(S X Y)	(b)	675	1.3	2.9***	75	2.7**
Nitrogen	(N)	535^{ns}	4.2***	19.9***	8460***	288.9***
N X Y		179^{ns}	4.3^{ns}	10.5^{ns}	419^{ns}	15.8^{ns}
N X S(Y)		500^{ns}	2***	6.2***	675***	13.9***
N X G		1088^{ns}	0.2^{ns}	1.4^{ns}	35^{ns}	3.2^{ns}
N X G X Y		541^{ns}	0.5^{ns}	1.4^{ns}	24^{ns}	2.2^{ns}
N X G X S(Y)		319^{ns}	0.3^{ns}	0.9**	25^{ns}	2.1^{ns}
Error	(c)	348	0.4	0.6	32	1.9

† Year, Site(Year) and their effects were analysed as random effects.

Table 4. Pooled analysis of yield and yield forming traits of four common genotypes in all 14 site years over three years of experimentation.

Source		Seed yield	Pod Number	Number of Seeds	Thousand Kernel Weight	Harvest Index
		kg ha^{-1}	Plant^{-1}	pod^{-1}	g	t/ha
Year	(Y)	1780394^{ns}	26714^{ns}	14.9^{ns}	11.67**	6023*
Site (year)	(S)	7086400***	8346***	74.5***	1.24***	1166***
R (S X Y)	(a)	211778	647	4.8	0.04	47
Genotype	(G)	3469337***	13421***	2741***	15.7***	341***
G X Y		399930^{ns}	1473^{ns}	43.9*	0.1^{ns}	118^{ns}
G X S(Y)		234860***	998***	14.6***	0.16***	80^{ns}
G X R(S X Y)	(b)	71766	244	4.2	0.02	52
Nitrogen	(N)	1.3e+07***	6142***	125.5***	0.09***	54^{ns}
N X Y		81870^{ns}	249^{ns}	1.8^{ns}	0.05^{ns}	35^{ns}
N X S(Y)		219465***	426***	6.3**	0.03*	43^{ns}
N X G		198014*	346^{ns}	6.4^{ns}	0.02^{ns}	48^{ns}
N X G X Y		66366**	237*	2.6^{ns}	0.02^{ns}	43^{ns}
N X G X S(Y)		25692^{ns}	111^{ns}	2.7*	0.02**	27^{ns}
Error	(c)	21286	89	1.9	0.01	28

Year, Site(Year) and their effects were analysed as random effects.

Table 5. Pooled analysis of oil content, oil yield, water, nitrogen and phosphorus by four common genotypes in all 14 site years over three years of experimentation.

Source		Oil Percent g kg^{-1}	Oil Yield kg ha^{-1}	Water Use mm	Nitrogen Use kg ha^{-1}	Phosphorus Use kg ha^{-1}
Year	(Y)	35464^{ns}	3704439^{ns}	183425^{ns}	1565^{ns}	30993^{ns}
Site (year)	(S)	11341***	1489729***	69290***	21421***	6678**
R (S X Y)	(a)	614	33744	3959	1318	1377***
Genotype	(G)	31074***	381514***	18228***	747^{ns}	143^{ns}
G X Y		5505^{ns}	86478^{ns}	1935^{ns}	679^{ns}	22^{ns}
G X S(Y)		750***	54702***	1221^{ns}	338^{ns}	260^{ns}
G X R(S X Y)	(b)	275	13610	1020	612	453
Nitrogen	(N)	16210***	2127758***	15488***	102152***	111^{ns}
N X Y		519^{ns}	16333^{ns}	345^{ns}	946^{ns}	345^{ns}
N X S(Y)		262**	48326**	384^{ns}	421***	171^{ns}
N X G		319*	32455^{ns}	120^{ns}	86^{ns}	307^{ns}
N X G X Y		81^{ns}	13102*	321^{ns}	80^{ns}	457***
N X G X S(Y)		7472***	5475^{ns}	29902**	44^{ns}	90^{ns}
Error	(c)	65	4405	321	52	202

Year, Site(Year) and their effects were analysed as random effects.

Table 6. Pooled analysis of efficiencies of using water and nitrogen in yield and biomass formation by four common genotypes in all 14 site years of experimentation.

Source		WUE$_{Seed}$ kg hamm^{-1}	WUE$_{DM}$ kg hamm^{-1}	NUE$_{Seed}$ kg kg^{-1}	NUE$_{DM}$ kg kg^{-1}
Year	(Y)	319.4*	1996.5*	515.9^{ns}	15841.7^{ns}
Site (year)	(S)	67.4***	322.2^{ns}	1780.8^{ns}	659611^{ns}
R (S X Y)	(a)	1.5	36.1	367.7	4942.9
Genotype	(G)	16.9***	42.2^{ns}	256.9^{ns}	4178.6^{ns}
G X Y		2.2^{ns}	42^{ns}	408.6^{ns}	4267.4^{ns}
G X S(Y)		2.3**	59.8^{ns}	418.9**	4388.9^{ns}
G X R(S X Y)	(b)	1	36	206.7	3503.3
Nitrogen	(N)	78.8***	2318.9***	4415.7***	94251.7***
N X Y		2.3^{ns}	155.2^{ns}	59.4^{ns}	125.6^{ns}
N X S(Y)		3***	158.1***	416.2***	23023.2***
N X G		1.1*	34^{ns}	1.2^{ns}	127.6^{ns}
N X G X Y		0.3^{ns}	15.1^{ns}	34.5^{ns}	449.8^{ns}
N X G X S(Y)		0.4*	27.2^{ns}	32.8^{ns}	589.2^{ns}
Error	(c)	84.4	23.2	32.5	1151.2

Year, Site(Year) and their effects were analysed as random effects.

Table 7. Effect of site(year), genotype and nitrogen levels on population, growth and development of Brassica species pooled over 14 site years of data during 1996-98.

Source		Population	Flowering	Maturity	Plant Height	Dry Matter
		m^{-2}	d	d	cm	t/ha
1. Site (Year)						
Assiniboia	96	80.8	44.9	83.5	94	-
Stewart Valley	96	110.4	41.6	81.9	86	5.2
Swift Current	96	110.3	40.5	79.3	111	6.2
Cadillac	97	110.6	50.4	84.2	91	4.2
Coderre	97	115.2	54.6	90.4	88	6.8
Eyebrow	97	199.9	39.3	69.7	95	4.9
Kenaston	97	142.4	39.3	72.8	111	7.1
Swift Current	97	138.9	42.9	85.4	107	7.2
Cadillac	98	89.9	45.5	82.4	105	5.7
Eyebrow	98	111.7	39.6	74.5	112	5.7
Mortlach	98	-	37.5	70.9	107	5.9
Stewart Valley	98	135.4	47.1	82.6	118	7.5
Swift Current	98	-	48.5	90.9	131	7.3
Watrous	98	123.5	48.6	84.6	125	7.2
2. Genotype						
CQ-1		124	44.2	84.7	123	6.5
Cutlass		123	42.9	81.3	108	6.4
Quantum		121	48.2	83.7	99	6.4
Maverick		103	41.8	74.8	93	5.6
Lsd (0.05)		6	0.3	0.4	1.9	0.4
3. Nitrogen						
Low		118	44.2	81	98	4.7
Normal		119	44.3	81	109	6.8
High		116	44.4	81.3	110	7.1
Lsd (0.05)		ns	0.1	0.1	1.1	0.3

Table 8. Days to maturity averaged for all genotypes at all locations during 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current				Mean
			1996				
Low	83.3	83.2	80.5				82.3
Normal	85.2	83.8	80.4				83.1
High	86.2	84.5	80.8				83.8
LSD$_{(0..05)}$	0.5	0.44	0.29				0.3
N level	**Cadillac**	**Coderre**	**Eyebrow**	**Kenaston**	**Swift**		**Mean**
			1997				
Low	86.7	90.7	71.7	73.9	87		82.5
Normal	85.5	91.4	70.8	74.2	86.6		82.2
High	85.4	92.4	71.1	75.4	86.2		82.6
LSD$_{(0.05)}$	0.33	0.43	ns	0.92	0.33		ns
Entry	**Cadillac**	**Eyebrow**	**Mortlach**	**Stewart Valley**	**Watrous**	**Swift Current**	**Mean**
				1998			
Low	82.6	76.8	73	83.7	85.9	92.8	82.6
Normal	83.7	75.5	72.3	84.3	86.7	93.2	82.8
High	83.7	75.3	72.6	84.8	87	93.6	83
LSD$_{(0..05)}$	0.09	0.4	0.24	0.2	0.44	0.35	0.13

Table 9. Above-ground biomass averaged for all N fertility levels at all locations during 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current	Mean
	---- 1996 ----			
J90-4316	-	5.2	6.1	5.6
J96 composite	-	6.3	6	6.1
Cutlass	-	5	6.3	5.7
Legacy	-	5.5	6.5	6
Quantum	-	5.8	6.2	6
Maverick	-	5	6.2	5.6
LSD$_{(0..05)}$	-	ns	ns	ns
CV	-	20.3	14.5	14

Entry	Cadillac	Coderre	Eyebrow	Kenaston	Swift	Mean
	---- 1997 ----					
J90-4316	4.3	7.9	5.5	8.7	6.3	6.6
J96 composite	3.7	7.3	4.5	6.1	7.3	5.9
Cutlass	4.1	6.7	4.5	8.1	6.8	6
ACH102	3.8	6.7	5.3	6.9	7.8	6.3
Quantum	3.9	7.2	4.8	6.5	8.6	6.3
Maverick	4.5	5	5	5.2	6.9	5.5
LSD$_{(0.05)}$	ns	0.9	ns	ns	1.2	ns
CV	23	24	26	39	21	27

Entry	Cadillac	Eyebrow	Mortlach	Stewart Valley	Swift Current	Watrous	Mean
	----1998----						
J90-4316	6.1	6	5.7	7.8	7.2	8.2	6.8
J96 composite	4.8	5.4	5.4	7.5	6.9	8.3	6.4
Cutlass	5.9	5.6	6	8.1	8.1	7.9	6.9
ACH102	7	5.6	5.9	7.5	8.7	9.3	7.3
Quantum	5.7	5.7	6.1	7.7	7.3	7.9	6.7
Maverick	5	5.2	6.3	6.3	6.7	4.9	5.7
LSD$_{(0..05)}$	ns	ns	ns	1	ns	1.7	0.6
CV	14.4	18.5	17.8	13.6	26.1	21.7	29.2

Table 10. Effect of nitrogen levels on biomass yield (t ha^{-1}) averaged for all entries during 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current				Mean
			1996				
Low	-	4.66	5.65				5.16
Normal	-	5.61	6.32				5.97
High	-	6.06	6.69				6.37
LSD$_{(0..05)}$	-	0.65	0.53				0.48
N level	**Cadillac**	**Coderre**	**Eyebrow**	**Kenaston**	**Swift**		**Mean**
			1997				
Low	3.25	6.1	2.58	3.53	6.09		4.33
Normal	4.55	6.62	6.14	9.27	7.84		6.75
High	4.53	8.02	6.03	8.18	7.94		6.81
LSD$_{(0.05)}$	0.6	0.97	0.77	1.81	0.93		0.43
Entry	**Cadillac**	**Eyebrow**	**Mortlach**	**Stewart Valley**	**Watrous**	**Swift Current**	**Mean**
			1998				
Low	4.34	3.2	3.23	6.41	6.39	6.13	4.99
Normal	6.42	6.44	6.12	7.93	8.98	7.74	7.23
High	6.38	7.11	8.38	8.11	7.87	8.49	7.73
LSD$_{(0..05)}$	0.49	0.54	0.55	0.6	0.87	1.15	0.29

Table 11. Pooled analysis of growth, development, yield and yield forming parameters over three years of experimentation.

Source		Seed yield	Pod Number	Number of Seeds	Thousand Kernel Weight	Harvest Index
		t/ha	plant^{-1}	pod^{-1}	g	
1. Site (Year)						
Assiniboia	96	1.14	31	20.1	2.91	-
Stewart Valley	96	1.61	34	17.9	2.67	0.32
Swift Current	96	1.82	37	19.2	2.51	0.3
Cadillac	97	0.91	23	18.4	2.22	0.22
Coderre	97	0.82	20	20	2.17	0.13
Eyebrow	97	0.73	10	18.3	2.26	0.16
Kenaston	97	0.83	16	19.2	2.21	0.12
Swift Current	97	1.63	33	18.9	2.06	0.24
Cadillac	98	1.32	40	19.1	2.07	0.24
Eyebrow	98	1.26	28	17.7	2.36	0.23
Mortlach	98	0.74	-	16.7	2.47	0.13
Stewart Valley	98	1.82	33	20.3	2.13	0.25
Swift Current	98	1.91	-	20.4	2.37	0.28
Watrous	98	1.64	33	17.1	2.57	0.24
2. Genotype						
CQ-1		1.35	41	14.9	2.22	0.22
Cutlass		1.48	38	16.1	2.38	0.24
Quantum		1.29	31	24.4	2.78	0.21
Maverick		1.12	19	19.8	2.06	0.21
Lsd (0.05)		0.06	3.6	0.5	0.03	0.02
3. Nitrogen						
Low		1.03	26	17.9	2.38	0.23
Normal		1.39	34	19	2.34	0.22
High		1.51	37	19.4	2.36	0.23
Lsd (0.05)		0.03	1.9	0.3	0.01	ns

Table 12. Genotype and nitrogen interaction for 4 common entries pooled over 14 site-years.

Entry	Low	Normal	High
		Biomass (t ha^{-1})	
J90-4316	4.81	7.38	7.27
Cutlass	4.65	7.31	7.29
Quantum	4.84	6.91	7.36
Maverick	4.32	5.74	6.57
LSD$_{(0.05)}$		1.01	
		Yield (t ha^{-1})	
J90-4316	1.09	1.41	1.55
Cutlass	1.11	1.58	1.74
Quantum	0.99	1.37	1.49
Maverick	0.9	1.19	1.25
LSD$_{(0.05)}$		0.09	
		Oil (g kg^{-1})	
J90-4316	449	442	435
Cutlass	443	437	428
Quantum	463	450	439
Maverick	479	469	457
LSD$_{(0.05)}$		4.7	
		Water Use (mm)	
J90-4316	310	320	320
Cutlass	294	307	314
Quantum	295	309	315
Maverick	275	292	295
LSD$_{(0.05)}$		9.4	
		WUE$_{(Seed)}$	
J90-4316	3.69	4.46	4.9
Cutlass	3.91	5.3	5.61
Quantum	3.48	4.73	4.96
Maverick	3.42	4.26	4.44
LSD$_{(0.05)}$		0.33	

LSD (P=0.05) for comparing nitrogen X genotype interaction effect.

Table 13. Seed yields averaged for all N fertility levels at all locations during 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current	Mean
		1996		
J90-4316	1.38	1.81	1.8	1.67
J96 composite	1.15	1.63	1.61	1.46
Cutlass	1.37	1.67	1.89	1.64
Legacy	0.93	1.18	1.62	1.24
Quantum	0.98	1.59	1.85	1.47
Maverick	0.85	1.36	1.73	1.31
LSD$_{(0..05)}$	0.22	0.19	0.12	0.1
CV	15	10.4	7.1	10.4

Entry	Cadillac	Coderre	Eyebrow	Kenaston	Swift Current	Mean
			1997			
J90-4316	0.94	0.95	0.79	1.03	1.41	1
J96 composite	0.64	0.87	0.76	0.69	1.49	0.88
Cutlass	1.05	1.07	0.87	0.87	1.67	1.1
ACH102	0.62	0.39	0.58	0.68	1.24	0.69
Quantum	0.8	0.63	0.64	0.72	1.73	0.9
Maverick	0.87	0.63	0.58	0.69	1.79	0.9
LSD$_{(0.05)}$	0.26	0.12	0.15	0.31	0.12	0.18
CV	13	11	15	16	9	12

Entry	Cadillac	Eyebrow	Mortlach	Stewart Valley	Swift Current	Watrous	Mean
				1998			
J90-4316	1.31	1.24	0.71	1.76	2.16	1.57	1.44
J96 composite	1.17	1.13	0.72	1.67	1.63	1.73	1.32
Cutlass	1.42	1.47	0.86	2.1	2.17	1.94	1.63
ACH102	1.41	1.13	0.77	1.7	2.18	1.87	1.48
Quantum	1.44	1.22	0.84	1.83	1.69	1.97	1.48
Maverick	1.12	1.03	0.66	1.58	1.58	1.06	1.15
LSD$_{(0..05)}$	0.23	0.2	ns	0.2	0.16	0.24	0.1
CV	7	19.4	8.4	8.7	7	14.2	34.4

Table 14. Seed yields averaged for all genotypes at all locations during 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current				Mean
				1996			
Low	0.81	1.23	1.67				1.24
Normal	1.13	1.59	1.77				1.5
High	1.38	1.79	1.81				1.66
$LSD_{(0..05)}$	0.1	0.09	0.07				0.05
N level	Cadillac	Coderre	Eyebrow	Kenaston	Swift		Mean
				1997			
Low	0.64	0.63	0.35	0.39	1.27		0.66
Normal	0.9	0.77	0.8	0.87	1.64		1
High	0.92	0.87	0.97	1.08	1.68		1.1
$LSD_{(0.05)}$	0.07	0.05	0.06	0.11	0.09		0.04
Entry	Cadillac	Eyebrow	Mortlach	Stewart Valley	Watrous	Swift Current	Mean
				1998			
Low	0.92	0.81	0.4	1.54	1.51	1.7	1.14
Normal	1.44	1.37	0.76	1.83	1.73	1.94	1.53
High	1.58	1.47	1.1	1.95	1.87	2.09	1.66
$LSD_{(0..05)}$	0.05	0.11	0.04	0.09	0.14	0.08	0.04

Table. 15. Effect of site(year), genotype and nitrogen levels on oil content, oil yield and use of water, nitrogen and phosphorus by Brassica species pooled over 14 site years of data during 1996-98.

Source		Oil Percent	Oil Yield	Water Use	Nitrogen Use	Phosphorous Use
		g kg^{-1}	kg ha^{-1}	mm	kg ha^{-1}	kg ha^{-1}
1. Site (Year)						
Assiniboia	96	438	496	-	-	-
Stewart Valley	96	446	713	349	71.1	-
Swift Current	96	418	759	304	105.4	-
Cadillac	97	429	389	302	71.5	25.8
Coderre	97	454	370	379	-	-
Eyebrow	97	445	320	264	-	-
Kenaston	97	458	377	382	-	-
Swift Current	97	444	723	317	89.9	22.1
Cadillac	98	472	620	260	87.3	35.6
Eyebrow	98	424	528	238	100.6	66.2
Mortlach	98	468	345	275	48.5	33.4
Stewart Valley	98	462	833	315	104.9	58
Swift Current	98	474	900	306	111.9	32.8
Watrous	98	461	748	272	67.3	34.9
Lsd (0.05)						
2. Genotype						
CQ-1		442	597	317	86.8	37.1
Cutlass		436	642	305	87.9	38.6
Quantum		451	577	306	83.4	37.5
Maverick		469	520	288	81.3	40.1
Lsd (0.05)		3.6	25.5	7.3	ns	ns
3. Nitrogen						
Low		458	467.8	293	52.8	39.2
Normal		449	621.2	307	90.1	38.8
High		440	662.8	311	114.9	36.9
Lsd (0.05)		1.5	12.5	3.5	1.7	ns

Table 16. Seed oil concentration (g kg^{-1}) averaged for all N fertility levels, 1997.

Entry	Assiniboia	Stewart Valley	Swift Current	Mean
		1996		
J90-4316	425	448	411	428
J96 composite	449	458	414	440
Cutlass	432	426	405	421
Legacy	458	458	422	446
Quantum	442	447	411	434
Maverick	425	462	444	453
LSD$_{(0..05)}$	16	12	0.64	11
CV	16	13	0.7	0.7

Entry	Cadillac	Coderre	Eyebrow	Kenaston	Swift Current	Mean
			1997			
J90-4316	425	451	445	438	428	439
J96 composite	427	451	448	458	442	446
Cutlass	408	444	434	445	434	434
ACH102	438	470	470	466	450	460
Quantum	421	459	440	448	441	443
Maverick	462	459	464	488	467	469
LSD$_{(0.05)}$	9	12	20	28	5	10
CV	1.1	1.2	2.9	3.3	1.2	2.1

Entry	Cadillac	Eyebrow	Mortlach	Stewart Valley	Swift Current	Watrous	Mean
				1998			
J90-4316	462	425	446	457	470	457	452
J96 composite	484	431	455	461	476	455	458
Cutlass	460	415	450	451	457	451	447
ACH102	507	454	510	487	501	490	491
Quantum	481	423	486	463	480	457	463
Maverick	486	453	489	476	485	475	477
LSD$_{(0..05)}$	4.2	16.6	10	10.3	15.2	17.3	5.9
CV	1	2.3	1.2	1.3	1.3	3.1	0.9

Table 17. Seed oil concentration (g kg^{-1}) averaged for all entries during 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current	Mean
		1996		
Low	451	454	422	442
Normal	442	450	419	437
High	436	446	413	432
$LSD_{(0..05)}$	4.2	3.3	1.8	1.9

N level	Cadillac	Coderre	Eyebrow	Kenaston	Swift	Mean
			1997			
Low	444	464	464	468	459	459
Normal	428	458	452	462	445	448
High	416	448	436	450	434	435
$LSD_{(0.05)}$	3	3	8	11	3	3

Entry	Cadillac	Eyebrow	Mortlach	Stewart Valley	Watrous	Swift Current	Mean
				1998			
Low	494	435	478	478	479	489	475
Normal	477	435	476	466	455	478	464
High	470	418	465	453	460	469	456
$LSD_{(0..05)}$	2.7	5.9	3.1	3.7	9.1	3.6	1.8

Table 18. Seed oil yield (kg ha^{-1}) averaged for all N fertility levels during 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current	Mean
	------------	------------	1998	------------
J90-4316	588	809	741	713
J96 composite	513	745	666	641
Cutlass	585	710	765	687
Legacy	427	536	681	548
Quantum	430	709	761	633
Maverick	383	625	770	592
LSD$_{(0..05)}$	111	91	65.8	39.6
CV	15.7	10.3	7.2	6.5

Entry	Cadillac	Coderre	Eyebrow	Kenaston	Swift	Mean
	------------	------------	------------	1998	------------	------------
J90-4316	398	428	349	454	599	437
J96 composite	274	392	338	316	657	391
Cutlass	429	472	376	388	720	474
ACH102	270	180	268	317	555	315
Quantum	334	289	283	320	763	396
Maverick	400	291	269	329	837	421
LSD$_{(0.05)}$	111	54	74	NS	68	88
CV	13	12	17	18	10	13

Entry	Cadillac	Eyebrow	Mortlach	Stewart Valley	Swift Current	Watrous	Mean
	------------	------------	------------	1998	------------	------------	------------
J90-4316	601	525	315	801	1012	717	643
J96 composite	564	484	320	766	774	785	596
Cutlass	651	606	383	939	990	867	712
ACH102	712	508	393	821	1092	913	711
Quantum	689	506	409	840	809	892	674
Maverick	538	467	323	752	766	503	532
LSD$_{(0..05)}$	106	82	ns	82	78	90	40
CV	7.5	19.8	8.5	8.8	7.3	13.7	7

Table 19. Seed oil yield averaged for all entries, 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current	Mean
		1996		
Low	364	556	703	541
Normal	499	714	741	651
High	599	798	747	715
LSD$_{(0.05)}$	45	41	31	24

N level	Cadillac	Coderre	Eyebrow	Kenaston	Swift	Mean
			1997			
Low	282	287	158	182	584	302
Normal	377	345	359	392	731	448
High	392	382	423	469	733	475
LSD$_{(0.05)}$	26	24	31	43	54	71

Entry	Cadillac	Eyebrow	Mortlach	Stewart Valley	Watrous	Swift Current	Mean
				1998			
High	450	345	188	731	718	829	543
Normal	684	592	361	849	850	926	710
Low	743	611	511	880	789	978	754
LSD$_{(0.05)}$	28	49	20	42	61	39	18

Table 20. Effect of site(year), genotype and nitrogen levels on the efficiency of using nitrogen and water of Brassica species pooled over 14 site years during 1996-98.

Source		WUE_{Seed}	WUE_{DM}	NUE_{Seed}	NUE_{DM}
		kg hamm^{-1}	kg hamm^{-1}	kg kg^{-1}	kg kg^{-1}
1. Site (Year)					
Assiniboia	96	-	-	-	-
Stewart Valley	96	4.6	15.1	28.4	97.2
Swift Current	96	6	20.5	18.8	63.8
Cadillac	97	3	13.9	15	70.7
Coderre	97	2.2	18.3	-	-
Eyebrow	97	2.7	18.8	-	-
Kenaston	97	2.1	18.4	-	-
Swift Current	97	5.2	22.7	21	91
Cadillac	98	5.2	22	16.9	73.1
Eyebrow	98	5.3	24.1	12	54.7
Mortlach	98	2.7	21.5	24	181.8
Stewart Valley	98	5.8	23.5	17.9	73.9
Swift Current	98	6.2	23.8	17.7	68
Watrous	98	6	26.5	30.1	128.9
Lsd (0.05)					
2. Genotype					
CQ-1		4.4	20.9	19.9	90.4
Cutlass		4.9	21.2	21.7	91
Quantum		4.4	21	22.1	100.7
Maverick		4.1	19.8	18	87.7
Lsd (0.05)		0.2	ns	ns	ns
3. Nitrogen					
Low		3.6	16.1	28.2	28.2
Normal		4.7	22.6	18	18
High		5	23.3	14.5	14.5
Lsd (0.05)		0.1	1	1.4	1.4

Table 21. Water use efficiency in seed production of different Brassica species averaged for all N fertility levels during 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current	Mean
	1996			
J90-4316	-	5.1	5.5	5.3
J96 composite	-	4.2	5.2	4.7
Cutlass	-	4.6	6.5	5.6
Legacy	-	3.6	5.4	4.5
Quantum	-	4.5	6.2	5.4
Maverick	-	4.1	6	5
LSD$_{(0..05)}$		0.7	0.7	0.6
CV		10.8	8.4	7.1

Entry	Cadillac	Coderre	Eyebrow	Kenaston	Swift Current	Mean
	1997					
J90-4316	3.1	2.4	3.1	2.4	4.3	3.1
J96	2.2	2.3	3	1.9	4.4	2.7
Cutlass	3.5	2.9	3.3	2.5	5.3	3.5
ACH102	2	1.1	2.2	1.7	3.7	2.1
Quantum	2.6	1.7	2.4	1.9	5.4	2.8
Maverick	2.9	1.8	2.2	1.8	5.6	2.9
LSD$_{(0.05)}$	0.7	0.3	0.6	ns	0.6	0.3
CV	14.7	10.8	15.7	17.7	9.7	6.9

Entry	Cadillac	Eyebrow	Mortlach	Stewart Valley	Watrous	Swift Current	Mean
	1998						
J90-4316	5.2	5	2.4	5.4	5.5	6.7	5.1
J96 composite	4.2	4.4	2.5	5.1	5.9	5.2	4.6
Cutlass	5.4	6.2	3.1	6.6	6.9	6.8	5.8
ACH102	5.1	4.7	2.4	5.3	6.5	6.6	5.2
Quantum	5.5	5.4	2.9	5.7	6.9	5.5	5.4
Maverick	4.6	4.8	2.4	5.3	4.6	5.9	4.6
LSD$_{(0..05)}$	ns	1	ns	0.7	1.2	0.7	0.4
CV	10.4	18.4	12.4	9.2	13.1	7.3	6

Table 22. Water use efficiency (seed) averaged for all entries during 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current	Mean
	---- 1996 ----			
Low	-	3.6	5.5	4.6
Normal	-	4.5	5.9	5.2
High	-	5	5.9	5.5
LSD$_{(0..05)}$		0.3	0.3	0.2

N level	Cadillac	Coderre	Eyebrow	Kenaston	Swift Current	Mean
	---- 1997 ----					
Low	2.2	1.7	1.3	1.1	4.1	2.1
Normal	3	2	3	2.2	5.1	3.1
High	2.9	2.3	3.1	2.8	5.2	3.4
LSD$_{(0.05)}$	0.2	0.1	0.3	0.3	0.3	0.1

Entry	Cadillac	Eyebrow	Mortlach	Stewart Valley	Watrous	Swift Current	Mean
	---- 1998 ----						
Low	3.5	3.7	1.4	5.1	5.4	5.6	4.2
Normal	5.4	5.6	2.7	5.7	6.7	6.2	5.4
High	5.9	5.9	3.7	6	6	6.6	5.7
LSD$_{(0..05)}$	0.32	0.55	0.2	0.3	0.5	0.26	0.18

Table 23. Water use efficiency in biomass production of different Brassica species averaged for all N fertility levels during 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current	Mean
		1996		
J90-4316	-	14.8	18.4	16.6
J96 composite	-	16.1	19.6	17.8
Cutlass	-	19.9	21.7	17.8
Legacy	-	17	21.8	19.4
Quantum	-	16.5	20.6	18.5
Maverick	-	15.3	21.4	18.3
LSD$_{(0..05)}$		ns	2.4	ns
CV		20.8	16	14.5

Entry	Cadillac	Coderre	Eyebrow	Kenaston	Swift	Mean
			1997			
J90-4316	14.2	20.7	21.5	20.5	19.9	19.1
J96 Composite	12.4	19.3	17.5	17.5	22.2	17.3
Cutlass	13.4	18.6	17.2	21.5	21.8	18.2
Legacy	12.9	18.5	19.8	17.6	23.7	18.5
ACH102	13	19.5	17.9	18.1	27.2	19.2
Maverick	15.2	14.5	18.7	13.7	21.7	16.4
LSD$_{(0.05)}$	ns	3	ns	ns	3.6	1.2
CV	25.8	25.4	26.1	36.3	23	12.8

Entry	Cadillac	Eyebrow	Mortlach	Stewart Valley	Watrous	Swift Current	Mean
				1998			
J90-4316	24.4	24.1	18.9	23.7	29.3	22.4	23.6
J96 composite	17.7	21.2	18.4	23	29.2	21.8	22
Cutlass	22.7	24	21.4	25.5	29.1	25.2	24.7
ACH102	25.3	22.8	18.7	23.4	31.8	26.3	25
Quantum	20.1	23.5	20.8	24	27.1	23.6	23.3
Maverick	20.7	24.7	24.7	21.1	20.3	23.9	22.5
LSD$_{(0..05)}$	ns	ns	ns	ns	ns	ns	ns
CV	15.4	23.2	19.2	14.5	24.3	24.9	8.56

Table 24. Water use efficiency of biomass production averaged for all entries during 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current	Mean
		1996		
Low	-	13.9	18.7	16.3
Normal	-	15.9	21.1	18.5
High	-	17	22	19.5
LSD$_{(0..05)}$		1.9	1.9	1.5

N level	Cadillac	Coderre	Eyebrow	Kenaston	Swift	Mean
				1997		
Low	11.1	16.8	9.9	9.7	19.5	13.4
Normal	14.9	17.5	23.4	23.6	24.2	20.6
High	14.5	21	22.1	21.1	24.5	20.3
LSD$_{(0.05)}$	2	2.8	3	4.5	3.2	1.4

Entry	Cadillac	Eyebrow	Mortlach	Stewart Valley	Watrous	Swift Current	Mean
				1998			
Low	17	15.4	11.7	21.2	23.4	20.4	18.4
Normal	24.1	26.1	21	24.4	32.4	24.5	25.6
High	23.9	28.3	28.9	24.7	27.6	26.7	26.7
LSD$_{(0..05)}$	2.1	3.2	2.4	2	4	3.5	1.2

Table 25. Effect of nitrogen levels on nitrogen use efficiency (kg kg^{-1}) averaged for all entries during 1996-98.

Entry	Assiniboia	Stewart Valley	Swift Current	Mean
1996				
Low	-	38.6	19.9	33.6
Normal	-	23.7	18.5	22.1
High	-	19.2	14.4	17.2
LSD$_{(0..05)}$	-	4.6	2.5	4.3

N level	Cadillac	Coderre	Eyebrow	Kenaston	Swift	Mean
1997						
Low	18.4	-	-	-	27.5	22.5
Normal	11.8	-	-	-	16.8	14.4
High	9.3	-	-	-	13.9	11.5
LSD$_{(0.05)}$	2.4	-	-	-	3.1	1.9

Entry	Cadillac	Eyebrow	Mortlach	Stewart Valley	Watrous	Swift Current	Mean
1998							
Low	20.9	10.3	39.3	19.7	44.3	20.3	26.7
Normal	15.6	12.7	14.6	17	24.8	17.5	16.9
High	13.1	10.3	12.5	14.6	17.6	15	14.2
LSD$_{(0..05)}$	1.6	1.4	6.2	0.9	3.9	1.4	2.3

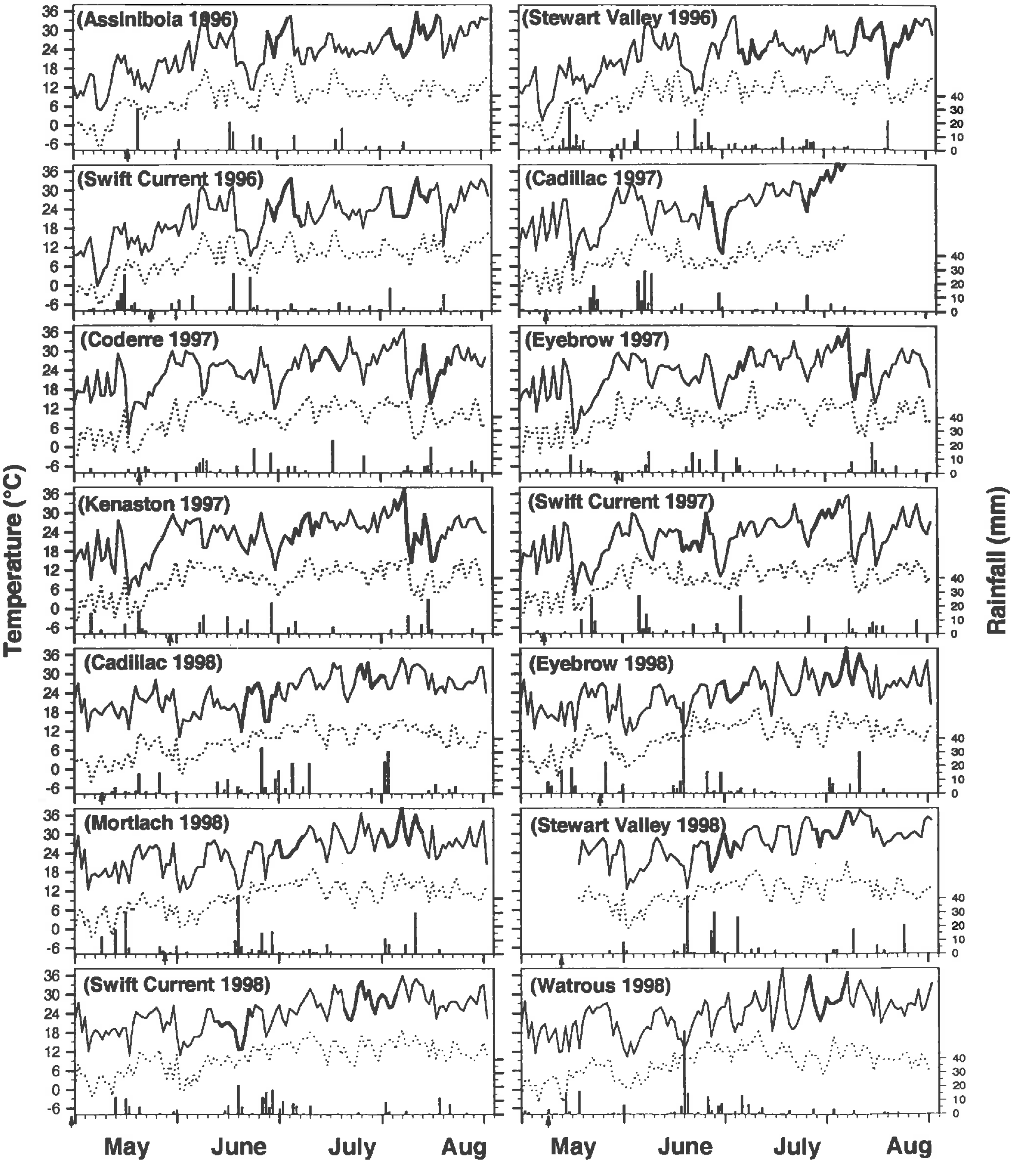

Fig. 1. Weather information of different locations during three years of experimentation. Daily maximum and minimum temperatures are shown with solid and dotted lines. Precipitation received is presented as a vertical bar. Small arrows on horizontal axis indicate seeding dates. Two thick portions on maximum temperature curve are initiation of flowering and days to maturity, respectively.

Chapter 2

Response of Three Brassica Species to Short Periods of High Temperature Stress

2. Response of Three Brassica Species to Short Periods of High Temperature Stress

Abstract:

The effect of high temperature on three oilseed Brassica species were studied in growth chamber studies for two cycles. Species differed in the optimum range of temperature, with *Brassica juncea L.* and *B. rapa L.* having higher optimum range than *B. napus L.* However, a a day/night temperature of 35/15 °C was injurious to reproductive organs. High temperatures at flowering was more injurious than at pod development. Reproductive organs (RO) at different developmental stage were affected by the heat stress. A yield reduction of 88% 'CQ1' to 99% 'Parkland' was noticed on the terminal raceme due to severe heat stress at flowering. Rather than decreased DM, decreased harvest index was responsible for reduction in seed yield. But, pods that have passed certain developmental phase tolerated heat stress and helped in maintaining seed yield of the plant. The yield reduction was followed by reduction in viable pod number (not total pod number), thousand seed weight and seeds per pod. Most of the observations reveal that the reduction in yield in the present study was mainly due to deleterious effect of high temperature on RO. All genotypes tried to recover by continuing flowering after returning to 20/15 °C, as shown by the higher RO on terminal raceme. Argentine canola failed to recover from severe stress at flowering due to formation of abnormal pods. Per plant yield response of canola quality *B. juncea* line 'CQ1' was similar to oriental mustard 'Cutlass' and a daytime temperature of around 28/15 °C at flowering improved yield while it was injurious to quantum (*B. napus L.*).

2.1 Introduction

High temperature stress is one of the most important, but the least studied, abiotic stresses affecting plant productivity around the world (Hall, 1992). Temperature variation in both time and space exists; along with rainfall, temperature decides the adaptation of a plant to a certain locality. A field grown crop is under temperature stress for much of the season (Mahan et al., 1995). The yield losses due to high temperature are large and are often combined with other environmental stresses. Large differences in yields between areas with cooler temperature and warmer temperature or between winter and summer yields, in spite of adaquate supply of water, suggest the magnitude of loss due to high temperature stress (Paulsen, 1994). Warmer temperature also reduces length of growing period, thereby reducing the yield potential. In canola, like many other crops, temperature is the most important factor regulating phenological development (Morrison, et.al., 1989). Direct effect of heat stress on fertility failure and yield loss have been reported in many crops including Argentine canola (Polowick and Sawhney, 1988; Morrison, 1993), broccoli (Heather et. al., 1992), tomato (Baki, 1991), pea (Guilioni et al., 1997), wheat (Wardlaw, 1980, Ferris et al., 1998), cowpea, cotton, rice (Hall, 1992). Direct effect of high temperature stress depends on the crop species and its adaptability. Adapted plants will have either heat avoidance or heat tolerance mechanisms to overcome temperature stress. Transpirational cooling, leaf wilting or rolling to avoid radiation interception, reflecting solar radiation and shading sensitive parts are some of the heat avoidance mechanisms, which maintain sensitive tissue at lower temperature (Hall, 1992). Heat tolerant plants survive the rise in tissue temperature and the mechanisms may be linked to physiology or morphology of the plant. There is need for understanding heat stress and yield relationship for major crops in the semiarid prairie.

Canola is an important oilseed crop in Canada and the area of canola in the Brown and Dark Brown soil zones of Canadian prairies, where it has not bee traditionally grown, is fast increasing. Changing government policy, world grain price, the increasing awareness of farmers of agronomic value of having both broadleaf and cereal crops and the availability of appropriate seeding and harvesting technologies have encouraged farmers in the semiarid prairie to diversify their cropping system. Canola appears to be better suited as an oilseed crop in the semiarid prairie as early maturing dwarf sunflowers have failed (Miller et al., 1998) while safflower failed to mature in some years (report on seeding date). Canola is a cool season crop and is believed to suffer from high temperature stress (Morrison, 1993). Analysis of the relationship between canola seed yield and growing season temperature has indicated negative relationship (Nuttal et.al., 1992; Brandt and McGregor, 1997). The mean temperature in semiarid prairie is increasing (Cutforth; personal communication) and global warming is expected to result in marked increase in events of extreme temperatures. Higher wind speed and water deficit in the region are expected to increase the heat stress experienced by crops. In such dry conditions plant temperature is often higher than the air temperature (Mahan, et. al., 1995). Hence, there is an urgent need for evaluating high temperature stress characteristics of *Brassica* species to determine its future suitability for the semiarid prairie cropping system.

Brassica napus L. (Argentine canola), *B. rapa L.* (Polish canola) and *B. juncea L.*, (mustard) are important oilseed crops in Canada. Argentine canola has a better yield potential, but is considered more susceptible to abiotic stresses. Nuttal (1992) estimated 0.4 t/ha reduction in Argentine canola yield for every 3° C rise in mean monthly temperatures of July and August. Polish canola is also susceptible to heat stress (Brandt and McGregor, 1997). Mustard is reported to be better adapted to semiarid prairie than the other two species (Rakow, 1995). However, in spite of resistance to shattering and blackleg disease, the poor oil quality of *B. juncea L.* Has restricted its markets and thereby production. Recent success in developing new lines of *B. juncea L.* with oil quality similar to canola, has renewed interest of *B. juncea L.* in semiarid prairie. Research on the direct effect of high temperature stress on B. species is limited. Therefore there is need to generate information on heat stress to help determine which B. species is best suited to the semiarid prairie.

Threshold temperature for heat stress has only been studied in Argentine canola without conclusive results. The critical temperature for heat injury has been found to be as low as 25 to 27 °C (Morrison et al., 1989; Morrison 1993), while others claim the critical temperature is 30 to 32 °C (Fan and Stefansson, 1986; Polowick and Sawhney, 1988). Genotype, light and water stress often confound heat stress effects (Hall, 1992; Paulsen, 1994). The long term weather data has revealed that at least 7 days in a year, maximum temperature above 32 °C were experienced in semiarid prairie (McCaig, 1996). Mustard (B. Juncea L.) is proposed as an oilseed crop for the semiarid prairie without information on its temperature responses. Polish canola (B. rapa L.) usually flowers early and escapes heat stress in the field, but under the situation of reseeding later in the growing season, polish canola flowering is more likely during warmer temperatures.

Therefore information on threshold temperatures for heat injury is urgently needed for each Brassica species.

The seed yield of oilseed Brassica plant is determined by number of pods, seeds per pod and seed weight (McGregor, 1981). Number of pods is determined by the initiation of floral bud and is dependent on the plant biomass and the combined stress level at that time (Brandt and McGregor, 1997). Seeds per pod depends on photosynthetic supply during fertilization, while seed weight depends on the continued supply of photosynthates after fertilization until maturity. Thus yield adjustment takes place from seeding to maturity. However, reproductive stage has been identified as the most susceptible stage for temperature stress in most of the crops in which temperature response is studied (Hall, 1992; Paulsen, 1994). A survey has revealed that canola crop grown in Saskatchewan province is suffering from abiotic stresses between flowering and pod formation stage (Brandt and McGregor, 1997). Therefore, understanding the critical stage for heat stress, nature of heat injury and recovering from heat stress will help in the management decisions.

The overall aim of the current study was to determine the most sensitive crop growth stage for high temperature stress in three oilseed Brassica species, variation in critical temperature and to assess whether canola quality *Brassica juncea L.* is a better crop for semiarid prairie because of greater high temperature tolerance perspective. Further, the B. species were evaluated for their ability to recover from heat stress.

2.2 Materials and Methods

Growth chamber experiments were conducted at the Semiarid Prairie Agricultural Research Station, Swift Current, Canada during 1997 and 1998. A canola quality *Brassica juncea L.* genotype, CQ1, was compared with one genotype from each species, namely *Brassica* napus (Quantum), *B. rapa L.* (Parkland) and *B. juncea L.* (Cutlass) for high temperature tolerance. Milk cartoons of 2 L capacity filled with soil (Swinton silt loam) were used for the study. Peat moss was mixed in to the top soil layer to prevent crusting. Several seeds, treated with vitavax, were planted in the milk cartoons and later thinned to one plant per pot at the 2-3 leaf stage. All genotypes used in this trial have different growth and development patterns, therefore, to narrow down the development phase, planting was staggered within a temperature treatment. Plants were watered regularly to avoid water stress. Beginning three weeks after seeding, every alternate week nutrient solution (4.2 g of 20-20-20 dissolved in 1 L water) was used for watering the plants. Aphid infestation was controlled by spraying systemic insecticides. Self incompatibility and failure of pollination (Morrison, 1993) are problems in such studies. Therefore two plants of each genotype were used in each replication and they were treated as one experimental unit. During flowering, both the plants were shaken together to ensure better pollination. Split plot design with temperature as main plot and genotypes as subplot were used for the study. Plants were rearranged within replication until flowering.

Plants were grown in the growth chamber (Model GR96, CENVIRON, Control Environment Ltd., Winnipeg, Canada) at 20/15 °C day night temperature till the high temperature treatments were imposed. The photosythetic flux at the leaf level (about 0.75 m from light source) was 300 μmol m^{-2} sec^{-1}. Temperature in the canopy was monitored at two locations within the growth chamber and it was used to adjust the chamber settings. Two high temperature stress treatments, 28/15 and 35/15 °C, were imposed for one week period in a growth cabinet (Model PGW36, CENVIRON, Control Environment Ltd., Winnipeg, Canada) during flowering or pod formation stage. To optimize the use of high temperature growth cabinets the 28/15 °C plants were seeded 3 weeks before those subjected to 35/15 °C treatment. In spite of the staggered planting, there was a small variation in the developmental stage among treatments and/or replications. Therefore, whenever each experimental unit (2 plants in two separate pot) reached required developmental stage, it was moved to high temperature growth cabinets. The relative humidity (RH) in the first run was not regulated, while in the second run, RH was maintained above 70 %. The high RH and regular watering minimized the water stress during high temperature stress treatments. Temperature and RH control relied on a Viasala sensor (Model HMI-32, Finland) positioned in the lower part of the canopy to sense RH and temperature of growth cabinets. After the stress period, plants were moved back to their respective replications in the growth chamber. During the second run, at late pod filling stage, plants from 35/15 °C temperature treatment were moved to a greenhouse (breakdown of growth chamber necessitated this move) and maintained at 22 °C till maturity.

Growth and yield response of all genotypes to short period of high temperature stress treatment was observed in the present studies. In the first run, plant height, dry matter accumulation (DM), total number of reproductive buds on terminal raceme (POD_T), number of viable pods on terminal raceme (defined as pods with at least one seed) (POD_V), number of sterile reproductive organs (RO) on terminal raceme (aborted flowers, sterile pods) (POD_S) and yield per plant were recorded. The second run was monitored more closely with additional observations like number of flowers opened every two days in 35/15 °C stress at flowering and the development of those flowers. In addition, seeds per pod, thousand seed weight and seed yield was recorded on terminal raceme on at least one plant in each replication.

Analysis of variance, using GLM procedure (SAS Institute Inc., Cary, NC), was conducted to assess the effect of treatments on the growth characteristics measured. Outliers from the data were removed by using JMP software (Mahalanobis analysis). Means of the two plants in each experimental unit were used in the statistical analysis. For pooled analysis of plant height, DM and seed yield, split-split-plot design with years (runs) as main plots, genotypes as subplot and temperatures as sub-sub-plot was used. The growth characteristics from each run were analysed as split plod design. If Genotype X Temperature interactions occurred, separate analysis were performed to assess the effect of temperature on each genotype.

2.3 Results and Discussion

Temperature treatments influenced growth of all genotypes (Table 1, 2). Plant height increased with increased daytime temperature, although exceptions were noticed. Higher temperature at flowering was more effective in increasing plant height than at pod formation.

Though increasing temperature to 28/15 °C increased plant height over the control, most of the significant height increases were noticed with temperature of 35/15 °C (Table 2). In general plants were significantly taller and accumulated more dry matter (DM) in 1998 compared to 1997. In the 1998 trial, relative humidity was always maintained above 70 % to minimise water stress effect confounding temperature effect. Our observations of stomatal conductivity and water potential (data not presented) in the 1998 trial indicated that changes due to imposed high temperature stress was much lower than the seasonal variation generally seen in the field. Lower water stress in 1998 maintained net photosynthesis (data not presented) to accumulate DM similar to control plants. Lower RH in the 1997 trial might have imposed water stress (as seen by visible wilting during midday). Heat stress combined with water stress is reported to aggravate the temperature effect by increasing the tissue temperature (Mahan. et. al., 1995) and affect photosynthesis and DM (Richards and Thurling, 1978; Hall, 1992; Mahan. et. al., 1995; Al-Khatib and Paulsen, 1999). Therefore, heat stress caused greater reduction in DM in 1997 and than in 1998. Significant DM reduction due to heat stress in comparison to control temperatures were noticed with 35/15 °C imposed at flowering. Plant height response of Brassica juncea L. genotypes, CQ1 and Cutlass, to 35/15 °C imposed at flowering was higher than other genotypes (Table 2). However, the plant height response was accampanied by decreasing DM, indicating long and slender plants were produced at higher temperature. The same 35/15 °C imposed at later stage had lower response.

The flowering pattern of *Brassica* spp was affected by high temperature stress. Severe stress of 35/15 °C during flowering, progressively reduced the number of flowers opened during the stress (Fig. 1). Thus number of flowers opened between 4th and 6th day of the stress period was only 27 % of that during the first two days of stress in Quantum, lower than Cutlass and CQ1. Similar heat induced floral bud suppression has been noticed in cowpea (Patel and Hall, 1990) and pea (Guilioni, 1997). *B. napus L.* produces fewer pods and branches than *B. rapa L.* (McGregor, 1981) and is less responsive to favorable conditions that may prevail later in the season (Brandt and McGregor, 1997). In addition, *B. napus L.* showed response after imposition of high temperatures earlier than other Brassica spp. Floral bud suppression due to high temperature was least in CQ1 compared to the other genotypes, indicating lower sensitivity of flowering to 35/15 °C stress in CQ1. In addition CQ1 had more floral buds than other genotypes, which is considered a trait of heat stress tolerance in many crops (Hall, 1992; Paulsen, 1994).

The differences noted for the terminal raceme showed a significant effect of one week of high temperature on seed yield and yield forming traits (Table 3). Seed yield of the terminal raceme of all genotypes was reduced at 35/15 °C stress at flowering, while it increased with 28/15 °C in Cutlass, CQ1 and Parkland. This indicates that the optimum daytime temperature for cutlass, CQ1 and parkland cultivar was closer to 28 °C than to 20 °C or 35 °C. In contrast, the decrease in seed yield at 28/15 °C at flowering in Quantum, though it was statistically non-significant, indicated that the optimum for Quantum is lower than 28 °C. All genotypes typically have a narrow optimum temperature range and either side of that optimum range reduces plant yield (Mahan, et.al., 1995). The terminal raceme yield indicates that Argentine canola appears to have optimum temperature range cooler than other two species. Polowick and Sawhney (1988) also observed pod sterility and abortion at 32 °C in Argentine canola. Our results do not fully agree with the findings of Morrison (1993) who reported complete sterile flowers in Argentine canola ('Delta' and 'Westar') at 27/17 °C. The differences in the results are probably related to the water stress and/or genotypes. Genotypic difference in temperature response in Brassica spp. (Morrison, 1993) or in other crops is reported (Hall, 1992). In the second run of present study, water stress was minimized and the plants maintained their stomatal conductance during the temperature stress period similar to the prestress period. Measurement of leaf and air temperature with photosynthesis unit, indicated that the leaf temperature during the stress period was at least 2 °C cooler than air temperature (data not presented).

Reproductive growth and pod formation was sensitive to heat stress in the present study. High temperature stress did not reduce total number of reproductive parts (Fig. 2). Studies on B. napus indicated that under normal conditions a plant differentiates more flower primordia than its photosynthetic capacity can support (Tayo and Morgan, 1975; McGregor, 1981). Therefore, only early formed floral primordia develop into flowers, become pollinated and produce viable pods, while the primordia formed later may not develop into flowers or pods. McGregor (1981) reported that the injury to the reproductive growth early in the flowering period is compensated by producing more branches and/or more flowers on the inflorescence and/or more seeds per pod and/or seed weight. One week of high temperature stress in the present study obstructed some part of the early formed floral primordia from developing into viable pods. Therefore, most of the genotypes recommenced their reproductive growth (visual observation supported this) and produced more floral structures than control plants. This contrasts to pea for which a set number of developing pods is essential before heat stress initiates RO abortion (Guilioni, 1997). In addition the yield from terminal raceme mainly varied due to increasing fraction of non-viable pods (Fig. 2). These results support the argument that reproductive growth was affected mainly due to direct effect of high temperature and not due to lack of supply of photosynthates. The hormonal imbalance created due to high temperature often affects development of floral parts (Hall, 1992). Non-synchrony of floral development or physical or chemical barriers restrict fertilisation (Fan and Stefansson, 1886; Polowick and Sawhney, 1987; Morrison, 1993). Similar observations have been made in wheat (Wardlaw et al., 1980).

The method of stressing during flowering or pod development stage adopted in this study revealed significant differences among the genotypes used in this study. Most of the heat stress work on canola have used continuous stress after particular developmental stage (Morrison, 1993; Morrison et.al, 1989). The method of stressing only 7 days represents a typical field situation in the semiarid prairie where prolonged periods of high temperature is unlikely. A short period of extreme temperature at a sensitive stage can be as critical to the crop yield as a mild temperature stress over a longer period (Howarth, 1996). Flowering in canola, depending on prevailing stress levels, ranges from 15 to 20 days (McGregor, 1981). Therefore, the stress treatment in the present study never exceeded half of the flowering on the terminal raceme. But the yield reduction on the terminal raceme due to 35/15 °C stress at flowering ranged between 88 % in CQ1 to 99% in Parkland (Table 3). The same heat stress at pod formation stage reduced yield by 42 % in Cultass to 74 % in Parkland. The visual monitoring of flowers opened in 35/15 °C revealed that those flowers did not produce any flowers. In addition the flowers which were fertilised at 20/15

°C and then moved to 35/15 °C at flowering, failed to produce viable pods. Thus, the results of this study reveal that not only reproductive parts at anthesis were affected by heat stress, but also smaller pods and floral buds were also affected by heat stress. Fertilised flowers which passed certain developmental stage escaped from heat injury. In peas, similar observations have been made (Guilioni, 1997). The catastrophic yield reduction due to extreme temperature stress, as observed in the present study, is the direct effect of temperature.

In the present study, the flowers opened in the normal temperature after moving back from high temperature stress (35/15 °C) at flowering produced abnormal pods in Quantum, which were plump and short (2-2.5 cm). Similar abnormal pods were noticed by Morrison (1993) and they attributed it to failure of fertilization due to high temperature, leading to parthenocarpy. But, in our study these abnormal pods were invariably formed after stress relief and were more common in Quantum plants stressed at flowering and not in plants stressed at pod formation (which produced many flowers during the stress period). Also it was not common in Maverick and was never seen in *B. juncea L.* genotypes. Further all genotypes in the present study produced viable pods after the 35/15 °C stress at flowering. This indicates the abnormal pods might have been produced by some other physiological response. Another possible hypothesis is that the Quantum plant during the stress period continued its photosynthesis and accumulated most of the photosynthates in (in spite of additional loss due to increased respiration) temporary storage organs (stem and leaf). When temperature stress was relieved, most of the stored photosynthate must have rushed to pods, the growth of which was still recovering, leading to bulged, short pods. Closer observation of abnormal pods revealed that number of seeds in the abnormal pod were similar to normal pod, but due to lack of space they were squished together. This hypothesis is supported by reduced frequency of such abnormal pods in Quantum plants which were stressed at pod formation. At this stage, the already formed pods acted as sink to absorb the extra flush of photosynthate after stress relief. The senescence of most of the leaves by Quantum after returning to control temperatures might have contributed to the photosynthate flush. In *B. juncea L.* senescence of leaf was slower and so less photosythates were retranslocated to pods as suggested by lack of abnormal pods.

Terminal raceme yield variation due to high temperature was closely followed by variations in number of viable pods (PN_{main}), thousand kernel weight (TKW_{main}) and seeds per pod (SPP_{main}) on the terminal raceme (Table 3). However, the major contribution was from PN_{main}. The role of pods in establishing yield potential in canola has been reported (McGregor, 1981; Brandt and McGregor, 1997; Morrison, 1993). PN_{main} increased with 28/15 °C temperature at flowering in all genotypes. However, there was no response when the same 28/15 °C temperature was imposed at pod development stage. The response with more severe stress (35/15 °C) was quite different from milder stress (28/15 °C), wherein the stress at flowering (most reproductive parts were flowering or younger) reduced PN_{main} drastically, while the same stress at pod formation (wider range of reproductive parts from pod formation to bud stage) accounted for the same or higher PN_{main} than control. The reduction in PN_{main} at flowering is in accordance to Morrison (1993), who proposed that the sensitive stage for heat stress is between late bud to early seed development. But higher or same PN_{main} in heat stress at pod formation cannot be explained from the above. All genotypes in 35/15 °C had fertile pods at the tip portion of terminal raceme (abnormal pods in Quantum were counted as viable pods), which otherwise would have been sterile. This observation defends the theory that canola uses the later formed extra pods for yield formation in the event of failure of earlier formed pods due to stress (McGregor, 1981). Severe heat stress at flowering reduced SPP_{main}, but was not consistent in all genotypes. The possibility of more seeds in the pods produced after stress was relieved might have confounded this observation. The reduction in TKW_{main} due to severe heat stress of 35/15 °C was observed in the present study, which was also observed in Argentine canola by Morrison (1993).

Seed yields of all Brassica genotypes investigated in this study responded to temperature stress, while significant temperature X genotype interaction (p=0.01) indicated the variation among species (Table 1 and 4). Seed yield response by each genotype to temperature stress was similar in both years (Table 1). Seed yields were higher in the second run (Table 4). Lower stress levels and better DM accumulation likely explain difference between runs. Seed yield per plant followed a trend similar to that of terminal raceme in both runs (Table 2). Observation of harvest index indicated that yield response was mainly due partitioning of DM into seeds (Table 1). *B.*

rapa L. (Parkland) was the most sensitive species in which yield reduction due to heat stress was up to 93% of the optimum temperature. In *B. napus L.* (Quantum) yield reduction due to heat stress was up to 60%, which was similar to *B. juncea L.* genotypes. Canola quality *B. juncea L.* (CQ1), which responded similar to Cutlass at most temperatures, was more sensitive to severe heat stress at flowering. This genotype had different response to severe heat stress including increased plant height (data not shown) and continued flowering during the stress (Fig. 1) when others have reduced flowering.

2.4 Conclusions

Cultivars of all three Brassica species were severely affected by to midday temperature of 35/15 °C. The damage to the yield forming traits was more severe when the stress occurred during flowering than during pod formation. Heat stress imposed at pod formation indicated that many of the floral structures had passed a sensitive stage and so matured into productive pods. However, we could not ascertain from our observations in the present study what developmental stages of floral structure are susceptible to heat stress. Among the species, *B. rapa L.* was most susceptible while *B. napus L.* and *B. juncea L.* very close to each other in heat stress response. Canola quality *B. juncea L.* did not establish any superiority over either Cutlass or Quantum. More research in the field and in controlled environment is required to identify the critical temperature, reproductive stage and genotypic variation.

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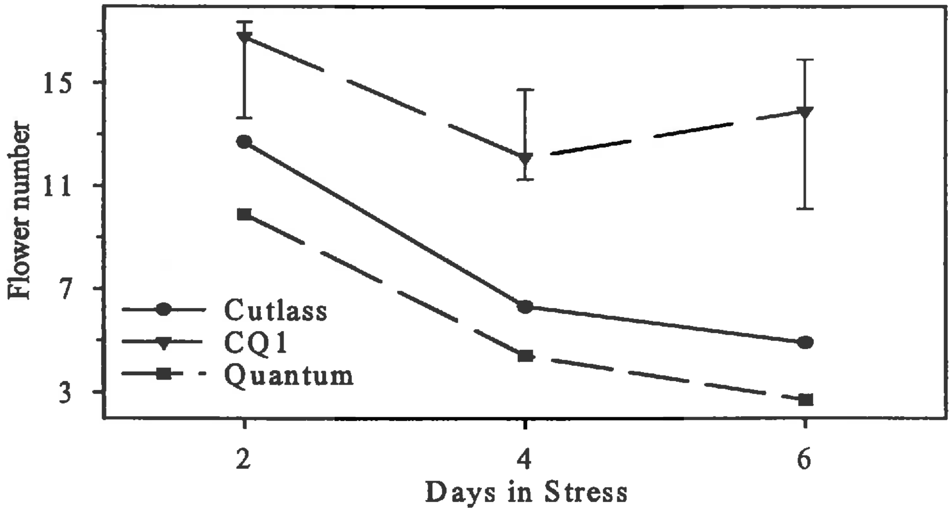

Fig.1. Effect of 35/15 °C temperature stress at flowering on the rate of flower production on the terminal raceme of Argentine canola and Brassica juncea. Vertical bars are LSD (P=0.05) values for comparing genotypes.

Table 1. Analysis of variance of plant height, dry matter and seed yield during 1997 and 1998.

Source	df	Plant Height (cm)	Dry Matter (g pl^{-1})	Seed Yield (g pl^{-1})
Year (Y)	1	3871.1*	1597***	58***
Temperature (T)	4	6342.5***	99***	60***
Y X T	4	1245.5***	95**	1^{ns}
Genotype (G)	3	4170.5***	151***	127***
G X Y	3	95.4^{ns}	42*	13***
G X T	12	345.0*	14^{ns}	4*
G X T X Y	12	601.8***	21^{ns}	4**
Residual	90	173.7	11.3	1.6

+, *, **, *** Represent F-Test significance at 0.10, 0.05, 0.01 and 0.001 levels, respectively.

Table 2. Effect of high temperature stress on the plant height, number of branches and biomass yield of different Brassica species.

Temperature °C	Stage	Plant Height		Dry Matter		Harvest Index	
		1997	1998	1997	1998	1997	1998
		---------------- Canola Quality 1 (Brassica juncea L.) -------------------					
20/15	(Control)	98	128	17.7	23.9	0.42	0.33
28/15	Flowering	131	130	18.0	22.6	0.38	0.42
28/15	Pod	101	131	16.1	22.3	0.38	0.38
35/15	Flowering	154	161	12.8	17.9	0.25	0.19
35/15	Pod	139	128	17.0	19.2	0.34	0.35
		***	*	ns	*	***	**
LSD (0.05)†		19.4	21.2		4.14	0.05	0.10
		----------------------- Cutlass (Brassica juncea L.) ----------------------					
20/15	(Control)	105	107	17.5	23.0	0.35	0.31
28/15	Flowering	116	135	18.4	22.7	0.36	0.38
28/15	Pod	100	116	17.1	20.6	0.37	0.33
35/15	Flowering	121	160	9.7	24.3	0.27	0.20
35/15	Pod	130	117	18.6	17.6	0.31	0.27
		ns	*	***	+	*	ns
LSD (0.05)			28.1	3.32	4.22	0.07	
		-------------------- Quantum (Brassica napus) ------------------					
20/15	(Control)	104	127	19.6	27.2	0.36	0.35
28/15	Flowering	132	128	23.3	25.6	0.28	0.32
28/15	Pod	93	143	13.5	28.8	0.33	0.28
35/15	Flowering	145	130	14.5	28.0	0.18	0.20
35/15	Pod	135	139	19.6	27.6	0.26	0.31
		**	ns	*	ns	***	*
LSD (0.05)		24.8		6.12		0.07	0.08
		-------------------------- (Brassica rapa)†† -------------------------					
20/15	(Control)	67	88	20.8	26.5	0.16	0.14
28/15	Flowering	119	105	20.7	21.7	0.17	0.36
28/15	Pod	105	110	20.5	27.2	0.15	0.04
35/15	Flowering	114	132	10.7	22.5	0.09	0.02
35/15	Pod	121	118	19.4	23.0	0.07	0.06
		***	*	*	ns	ns	***
LSD (0.05)		16.0	23.7	7.29			0.05

+, *, **, *** Represent F-Test significance at 0.10, 0.05, 0.01 and 0.001 levels, respectively.

† LSD (0.10) was used when F-Test was significant at P=0.10.

†† Maverick in 1997 and Parkland in 1998 were used, respectively.

Table 3. Effect of high temperature stress on the seed yield and yield forming traits of main shoot (raceme) of different Brassica species.

Temperature °C	Stage	Seed Yield g	Pod Number	TKW g	Seeds Pod^{-1}
		---------------------- Canola Quality Brassica juncea 1 ------------------			
20/15	(Control)	0.88	34	3.16	8.3
28/15	Flowering	1.87	68	2.92	9.6
28/15	Pod	0.83	36	3.11	7.5
35/15	Flowering	0.23	12	2.24	6.0
35/15	Pod	0.96	61	2.46	6.2
		**	***	+	ns
LSD (0.05)†		0.70	16	0.80	
		------------------------ Cutlass (Brassica juncea) ------------------------			
20/15	(Control)	0.52	16	3.57	9.4
28/15	Flowering	1.73	50	3.34	10.4
28/15	Pod	0.53	23	3.92	5.4
35/15	Flowering	0.10	13	1.54	4.4
35/15	Pod	1.01	39	2.24	11.8
		***	***	**	*
LSD (0.05)		0.33	12	1.11	4.43
		---------------------- Quantum (Brassica napus) --------------------			
20/15	(Control)	1.66	32	4.29	11.42
28/15	Flowering	1.22	43	3.37	9.79
28/15	Pod	0.85	28	4.45	7.14
35/15	Flowering	0.09	14	2.10	2.81
35/15	Pod	0.87	32	2.56	8.82
		**	***	***	*
LSD (0.05)		0.73	8	0.90	4.51
		--------------------------- Parkland (Brassica rapa L.) ------------------			
20/15	(Control)	0.31	32	2.97	-
28/15	Flowering	0.82	46	2.27	-
28/15	Pod	0.05	13	2.83	-
35/15	Flowering	0.01	3	1.03	-
35/15	Pod	0.21	46	1.16	-
		**	*	ns	
LSD (0.05)		0.23	30		

+, *, **, *** Represent F-Test significance at 0.10, 0.05, 0.01 and 0.001 levels, respectively.

† LSD (0.10) was used when F-Test was significant at P=0.10.

Table 4. Effect of high temperature stress on the seed yield (plant^{-1}) of different Brassica species.

Temperature °C	Stage	CQ1	Cutlass	Quantum	Polish†† Canola	Mean
				1997		
20/15	(Control)	7.39	6.01	6.98	3.08	5.86
28/15	Flowering	6.86	6.64	6.64	3.50	5.91
28/15	Pod	5.99	6.26	4.48	2.99	4.93
35/15	Flowering	3.27	2.68	2.68	1.04	2.42
35/15	Pod	5.77	5.70	5.09	1.30	4.47
		*	***	*	+	***
LSD (0.05)†		1.73	0.94	2.41	1.61	0.73
				1998		
20/15	(Control)	7.63	6.76	9.60	3.89	7.02
28/15	Flowering	8.73	7.94	7.67	5.84	7.79
28/15	Pod	8.37	6.93	8.35	1.23	6.22
35/15	Flowering	3.39	5.25	6.30	0.38	4.16
35/15	Pod	6.79	6.08	8.65	1.50	5.74
		*	+	+	**	**
LSD (0.05)		2.13	1.47	1.90	1.81	1.28
				Mean		
20/15	(Control)	7.51	6.46	7.97	3.50	6.36
28/15	Flowering	7.79	7.29	7.15	3.98	6.78
28/15	Pod	7.18	6.60	6.42	2.11	5.58
35/15	Flowering	3.23	3.96	4.49	0.74	3.18
35/15	Pod	6.28	5.24	6.87	1.40	4.95
		***	**	**	***	***
LSD (0.05)		1.51	1.34	1.62	1.30	0.64

+, *, **, *** Represent F-Test significance at 0.10, 0.05, 0.01 and 0.001 levels, respectively.

† LSD (0.10) was used when F-Test was significant at P=0.10.

†† Maverick in 1997 and Parkland in 1998 were used, respectively.

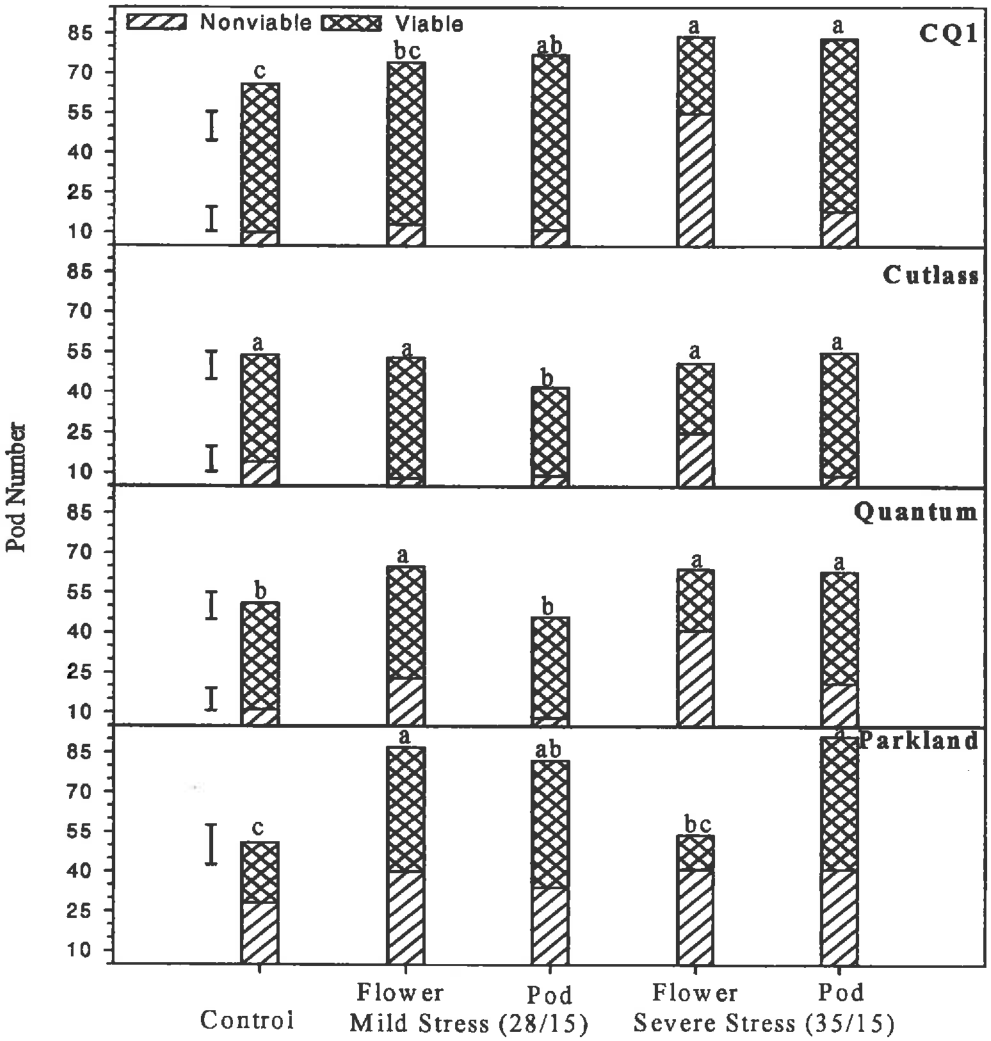

Fig. 2. Effect of the temperature on the number of viable, nonviable and total pods in different Brassica species during the first run of the trial. Same letters on the top of each bar indicates absence of statistical differences (P=0.05) among temperature treatments within the genotype for total pod number. Vertical bars are LSD values (P=0.05) for comparison of viable and non viable pod numbers.

Chapter 3

Drought Adaptation of Alternative Crops on The Canadian Semiarid Prairie

3. Drought Adaptation of Alternative Crops on The Canadian Semiarid Prairie

Abstract:

Water relations of recently introduced field pea, chickpea, canola and mustard were compared to spring wheat for production under semiarid Canadian prairie conditions. The trials under irrigated and dryland conditions revealed differences among crops for drought tolerance. There were more similarity between pulses or between Brassica species than between pulse and cereal, pulse and Brassica or Brassica and cereal. Crops have different strategies to overcome water stress. Wheat always appeared to experience more stress and responded with greater osmotic adjustment, while osmotic adjustment was lower in the other crops. Canola or mustard did not use a strategy of great osmotic adjustment, but its deep and explorative root system combined with higher hydraulic conductivity was able to nullify environmental stress wet soil conditions. Pulses appear to use tissue elasticity and tissue capacitance to buffer higher stress or lower tissue water conditions. Based on our study pulses are well adapted to the semiarid situation.

3.1 Introduction

A number of alternative crops have been introduced in the traditionally wheat based cropping system of the Canadian semiarid prairie. Many producers are reducing fallow frequency. Because water is the major limiting factor for crop production in the semiarid prairie, and seeding on stubble forces producers to often seed into incompletely recharged soil profiles, this increases dependence of crops on growing season precipitation. In order to reduce the risk of extended rotations there is need for identifying crops that tolerate water stress as well or better than traditional cereal crops.

Drought tolerance of plants is determined by a large number of physiological and morphological traits. The potential value of a trait depends on the crop and the nature of drought (i.e., intermittent vs. terminal drought) (Ludlow and Muchow, 1990). Drought tolerance traits involve either conserving tissue water content or maintaining the productivity under range of tissue water content in a water-limiting conditions. Plants should maintain turgor potential in their growing parts to ensure better growth under water stress condition. Sensitive stomata (Ludlow and Muchow, 1990) and osmotic adjustment (Morgan, 1984) are the two important strategies adapted by plants to maintain positive turgor. Leaf water potential is an indicator of water stress experienced by a plant (Turner, 1981). Another strategy is to complete the life cycle before a severe water stress prevails in the field. Plants may adopt any one or a combinations of the above strategies. A series of control environment and field studies were conducted to evaluate different alternative crops for their drought adaptation.

3.2 Materials and Methods

Field experiments were conducted in the Brown soil zone (Swinton Clay Loam) at the Semiarid Prairie Agricultural Research Center, Swift Current between 1996 to 1998. The trials can be classified as dates of seeding test, Irrigation test, rainfed test and Drought test. An irrigated plot, where moisture regime was maintained above 50 % of available water, and a drought plot, where no precipitation was allowed after June second week, and rainfed plot with no regulation of water were established on fallow on close-by blocks. Effect of dates of seeding were studied in another trial, where early and late seeded crops were monitored for water use characters. In 1998, to include one more Brassica species for water relation observations, the seeding date trial was used. All field experiments were seeded between mid April to mid May. Recommended management practices were used for all the crops. Complete experimental details are provided in respective chapters. Over all 11 crops/species were grown in above trials, but for the sake of monitoring water relations only Argentine canola (Cyclone), desi chickpea (Cheston) and field pea (Grande) (few additional crops/cultivars were tried in other years) were compared with wheat (Katepwa) in all years. Four replications were used in most of the trials except in drought trial, where the replications were restricted to two.

In controlled environment experiments, physiological response of alternative crops to regulated water supply was studied. Indoor studies were conduced at the greenhouses of the Department of Plant Science, University of Manitoba, Winnipeg. Large pots of 0.55 m height and 0.20 m diameter were used for green house studies. Approximately 19.5 kg soil (Clay Loam) was filled in each pots. One 0.75 m long PVC tube (0.04 m outer diameter) perforated along the lower 0.40 m length was inserted in the centre for watering. In 1996, a trial was conducted to compare drought tolerance of canola, mustard and annual pulses, while the 1997 trials concentrated on only Brassica species. The pots were watered to 75 % of field capacity and around 50 DAS (early flowering) on half of the replications drought cycle was imposed until the first cultivar/line reached permanent wilting point. Then they were rehydrated to 75 % of FC. Relative water content and osmotic potential observations were made during the experimentation.

Leaf water potential was measured in the field as the negative of the hydrostatic pressure required to bring the xylem sap to the cut end of the petiole (Turner, 1981) using a Scholander type pressure bomb (Model 1002, PMS Instrument Company, Corvallis, Oregan, USA). A top most, fully expanded leaf (a small twig in chickpea) was used for the observation. Osmotic potential of leaf tissue was measured by psychrometric method (Turner, 1981). The leaf material was frozen to disrupt the cell membrane, there by eliminating turgor potential of the cell. At a later date the frozen syringes were thawed for about 30 min and the sap was expressed by using similar force on the syringe plunger for all samples. A filter paper disc (0.5 cm) was saturated with the expressed sap. Care was taken to retain a similar amount of sap on the paper disk for all the samples (Approximately 7-10 µL). Osmotic potential of the discs was recorded with Wescor Vapour Pressure Osmometer (Model Wescor 5500XR, Logan, Utah, USA). The osmometer was calibrated with standard salt solutions of known osmotic potential. Contamination of the thermocouple was checked every 12-15 samples by running standard salt solutions. No effort was made to account the dilution effect of apoplastic water. Means of two samples from the same leaf were used for statistical comparisons. Turgor potential was calculated by subtracting osmotic potential from the leaf water potential. One leaf from each plot was used for the observations.

$$\Psi_T=\Psi_w-\Psi_\pi \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Normally, both predawn and midday water relations observations were taken. The strategy of taking observations changed during all three years. In 1996 only three days predawn and midday observations were recorded (not reported here), while that was extended to weekly observations for major part of the 1997 season. However, in 1998 more intense observation of every alternate day for 17 days during vegetative stage was made. In addition, diurnal variation in leaf water relations were observed twice, once early in the stress cycle and once late in the stress cycle, during 1998. Lack of sampling material restricted inclusion of drought studies on most of the observation days. In addition one day diurnal observation on seeding date test was made to assess the effect of seeding date on water relations.

Relative water content (RWC) on all observation days was simultaneously made on leaf sample similar to the sample used for leaf water relations. A small piece or few leaflets of samples were sealed in a zip lock bag in the field. Later the sample were moved to labaratory and after recording fresh weight (FW), floated overnight on distilled water. Turgid weight (TW) was recorded in the morning. Samples were dried at 70 °C for at least 24 hours before dry weight (DW) was recorded. RWC was calculated as follows.

$$RWC = \frac{FW-DW}{TW-DW} X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Relative water content was used to convert Ψ_π to osmotic potential at full turgor ($\Psi_{\pi100}$). The differences among genotypes in Ψ_π at full turgor during various stages of growing season indicates the differences in osmotic regulation due to active solute accumulation (Entz, 1988).

Data from different trials and from different dates were analysed separately by using analysis of variance procedure (GLM procedure, SAS Institute Inc., Cary, NC) and protected F-test was used for mean comparison. The statistical design was a randomised complete block design (RCBD). Diurnal observations on seeding date trial were analysed as split plot analysis with dates of seeding as main plots. Regression analysis of Ψ and RWC was made using data from all three years and from three trials on moisture regime.

3.3 Results and Discussion

Leaf water potential (Ψ) prevailed during 1997 and 1998 field season are presented in Fig. 1, 2 and 3. The predawn Ψ in 1997 decreased gradually with season, indicating reducing water supply and/or increasing precipitation deficit (Fig.1). In 1998 rainfall amount of 35 mm received during the observation period helped in maintaining stress levels low. There were significant differences among crops for predawn Ψ in both years. Observation for short period during vegetative phase indicates that Cyclone and Cutlass were maintaining higher predawn Ψ than wheat and were closely followed by Cheston and Grande. Grande lowered its Ψ during 17 days of observation period significantly more than Cheston. Observation for longer period of time during the season of 1997 indicates that Cheston lowered its Ψ much slower than other crops. Predawn Ψ is an indicator of the ability of soil to supply water to meet demand by the plant (Richter, 1997). However, plant growth (demand for the water) and their root system also contribute for the variation. In addition, non-stress Ψ for different crop species may be different (Salisbury and Ross, 1991).

Mid-day Ψ observations separate the crop types distinctly (Fig. 2). Similar midday Ψ values have been reported for Brassica spp. (Ashraf and Mehmood, 1989; Wright, et al., 1996) and in Wheat (Entz, et al., 1990), little information is available on pulses. Diurnal stress lowered Ψ more in wheat than in pulses and Brassica spp. were in the middle (Fig. 2 and 3). There was no significant difference in midday Ψ between Cutlass and Cyclone, while Cheston was always under lower stress than Grande, though significance was occasionally noticed. Ashraf and Mehmood (1989) and Wright (1996) rarely observed differences in Ψ between B. juncea and B. napus. Turner (1997) reported lower stress in lupin (a pulse) than wheat. In the present study, rainfed and irrigated trials similar Ψ values at midday. Our objective was to maintain soil moisture above 50 % of available water in irrigated trial. When fraction of transpirable water (FCTW) of sand drops below 0.40, Ψ starts declining in canola (Mogensen, 1997). But, in hot, dry , windy conditions of semiarid prairie where precipitation deficit is high, FCTW of around 50 % was not enough to meet the water requirements of the crops. Further, compared to sand, plants grown in loamy soil have to have to exert more energy to extract water from soil. In addition, the increased plant size under irrigated conditions (biomass was higher under irrigated conditions) might have increased transpiration to nullify irrigation effect on Ψ. Role of plant size on plant water relations has been reported in many crops (Blum and Sullivan, 1997).

Seasonal osmotic adjustment varied among genotypes (Fig. 4). Osmotic adjustment is a strategy adopted by plants to maintain their turgor under water stress conditions so that growth and metabolic processes can continue, may be at slower pace (Morgan, 1984). In the present study wheat always had lower leaf osmotic potential at full turgor ($\Psi_{\pi 100}$) than other crops. Further, except in rainfed trial in 1998, no gradual decrease in $\Psi_{\pi 100}$ during the observation period was recorded. Stress levels (as noticed from Ψ) were lower in the present investigation than the numbers reported in the literature. Therefore, osmotic adjustment was not seen most of the times. In addition, Brassica spp. are considered poor osmotic adjusting crops (Good and Maclagan, 1993; Jensen, et al., 1996). Pulse crops in the present study were less stressed and water use rate was lower (CWU vs DAS graph in Root Section). Water use per plant during the imposed stress in the green house indicated that water use by pulses were much lower than canola and mustard, while wheat with much lower water use was showing better osmotic adjustment than other crops (Data not presented). In some pulses like cowpea, it has been reported that they rely more on minimizing water loss by mechanisms like stomatal regulation, while osmotic adjustment is of minor importance McCree and Richardson (1987). Therefore the two pulses used in our study were more conservative in using limited water, thereby experiencing lower stress which did not induce osmotic adjustment.

Seasonal turgor potential (Ψ_p) indicated significant differences among crops (Fig. 5, 6 and 7). Observation of predawn Ψ_p for a short period, early in the season revealed that wheat, in spite of lower Ψ was maintaining higher turgor potential than other crops (Fig. 5; 1998). Better osmotic adjustment, similar to wheat in the present study, is proposed to help in maintaining Ψ_p in many crops (Morgon, 1984; McCree and Richardson, 1987; Turner, 1997). Brassica spp. along with field pea, due to lower $\Psi_{\pi 100}$,were having lower turgor than wheat. However, midday observations on the same 1998 trials changed turgor responses (Fig. 6). Better $\Psi_{\pi 100}$ in wheat was not enough to maintain positive turgor all the time, especially under rainfed conditions. The turgor loss was also seen in Cyclone and Cutlass. However, two pulses, Grande and Cheston, were able to maintain positive turgor mainly due smaller diurnal change in turgor (Fig. 7).

Season long observation in 1997 showed sightly different trend in predawn Ψ_p(Fig. 5). Wheat, in spite of better $\Psi_{\pi 100}$, was not able to maintain better turgor potential than pulses (especially chickpea). The predawn Ψ_p showed a declining trend in all crops with the exception of chickpea. Midday Ψ_p was lowest in wheat and it was often negative indicating loss of turgor. In other crops turgor declined slowly, much slower in pulses than in cyclone. Again in pulses, field pea had lower midday Ψ_p than chickpea. Surprisingly, turgor was lost more often in irrigated trial than in rainfed trial (Fig. 6). Higher DM in irrigated trial may be partially responsible for the turgor loss. Closer observation reveals that most of the change in midday Ψ_p is due to diurnal variation (Fig. 7). For example the change in Ψ_p due reduced soil moisture supply (predawn Ψ_p) in wheat was only about -0.4 MPa (Fig. 5; 1997), while the same change due to hot, dry and windy environment (Diurnal Ψ_p) was ranging from -0.3 to -1.5 MPa (Fig. 7; 1997).

Diurnal trend in Ψ and relative water content (RWC) was made on two days in 1998, one coinciding with the lower water stress and the other with the higher water stress, in both irrigated and rainfed trials. Different crops used in this study responded in different way to diurnal stress (Fig. 8). In beginning of the observation period (June 8th;lower stress day) Brassica species had least response to diurnal stress. At this period moisture was available in the soil profile and canola and mustard were able to replenish water that was lost due to transpiration. Indoor studies have revealed that as long as water is available in the soil profile Brassica spp. will use water more than pulses or wheat (data not presented). Better hydraulic conductivity of canola and mustard root systems aids in better water extraction (chapter on root system). Diurnal trend in stress levels was seen in wheat on the first observation day and two pulses showed slight decrease in Ψ during day time. However, 17 days later (on June 25th ; Higher stress day) diurnal trend was noticed in all crops at both moisture levels. Canola and mustard were experiencing higher stress than pulses, indicating lowering of available water in the soil profile. All soils will have a critical fraction of available water (RASW) above which plant can obtain water at rates sufficient to meet all transpiration demand, however if the moisture level goes below RASW plant starts experiencing stress (Mogensen, 1997). Diurnal effect on relative water content was less pronounced (Fig. 8).

Relationship between Ψ and RWC of wheat and pulses are presented in Fig. 9. The energy status of water and content of water had significantly different relation in the two crops presented. Wheat crops preferred to maintain its RWC high and when it drops slightly there is a big drop in Ψ. On the contrary, pulses have a wide range of RWC and the slope indicates that a large change in RWC is required to bring a small change in Ψ. Similar relation has been noticed between Rhododendron and sunflower (Kramer and Boyer, 1995). They attributed this to the bulk modulus of elasticity. Similar to their finding, pulses in our studies have elastic cell wall and whenever some water is lost they reduce their cell size and buffer major change in Ψ. On the other hand wheat has rigid cell wall and when a small change in RWC occurs, it results in big change in Ψ. The elasticity and tissue capacitance relationship might be playing a major role in the lower diurnal or seasonal stress experienced by pulses (Jones, 1992). The tissue elasticity buffers against drastic change in Ψ while capacitance buffers against change in RWC. These traits might be responsible for the success of pulses in semiarid prairie, where they use less water, experiance less stress, yet produce good seed yield.

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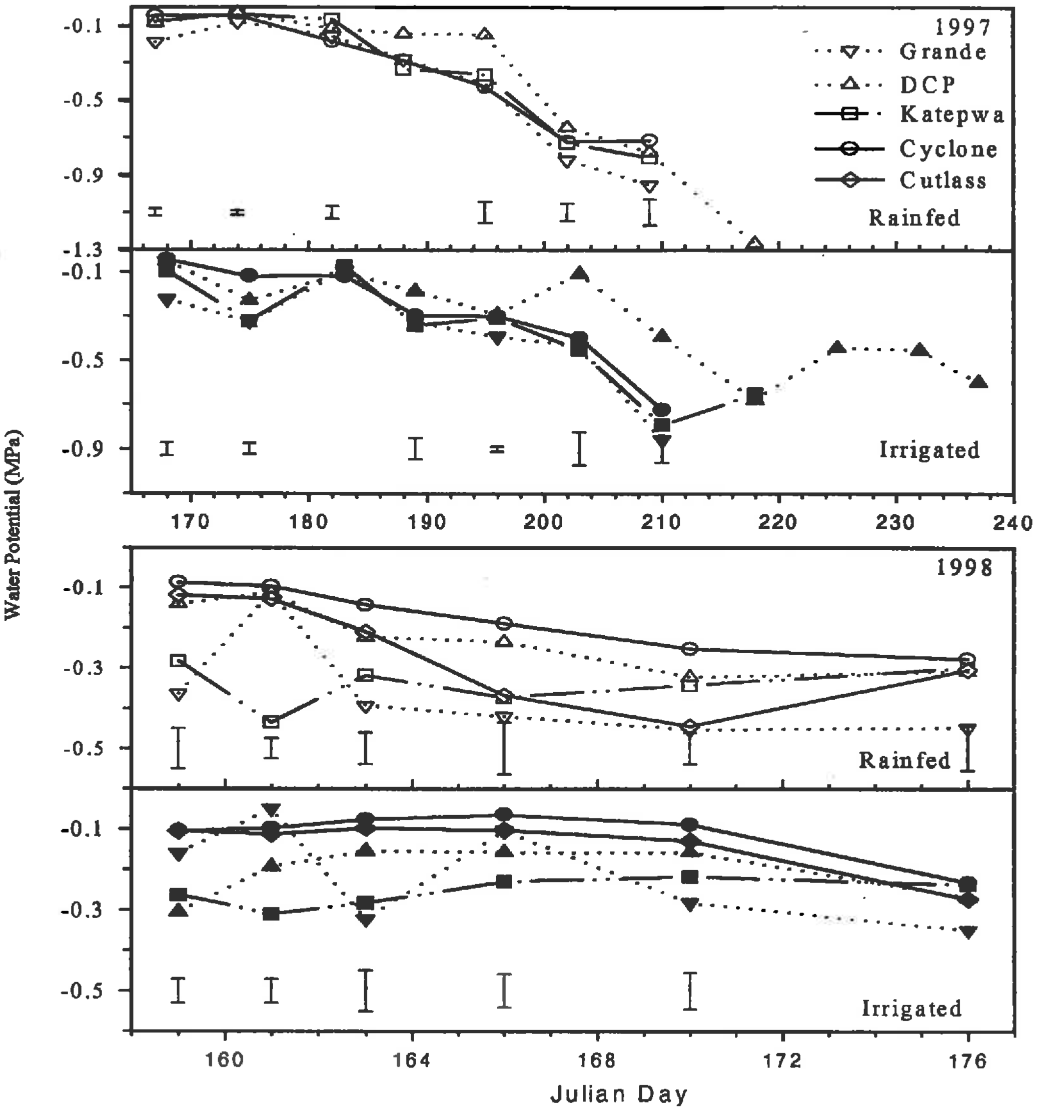

Fig. 1. Predawn leaf water potential of different crop species at Swift Current during 1997 and 1998 seasons. Solid and open symbols represent irrigated and rainfed field conditions, respectively. Vertical bars are LSD values (p=0.05; p=0.10 if plus sign accompanies vertical bar) for comparing genotypes.

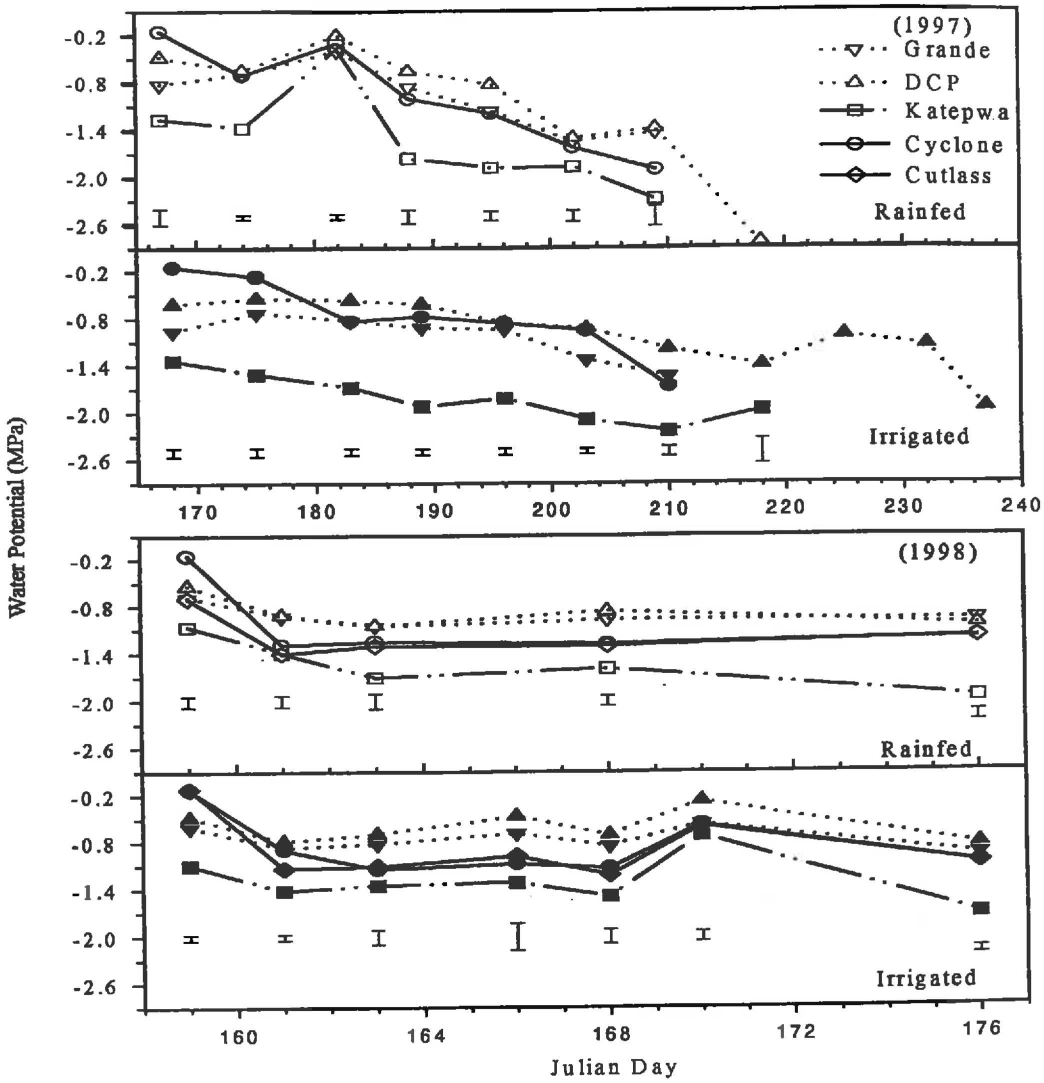

Fig. 2. Midday leaf water potential of different crop species at Swift Current during 1997 and 1998 seasons. Solid and open symbols represent irrigated and rainfed field conditions, respectively. Vertical bars are LSD values (p=0.05; p=0.10 if plus sign accompanies vertical bar) for comparing genotypes.

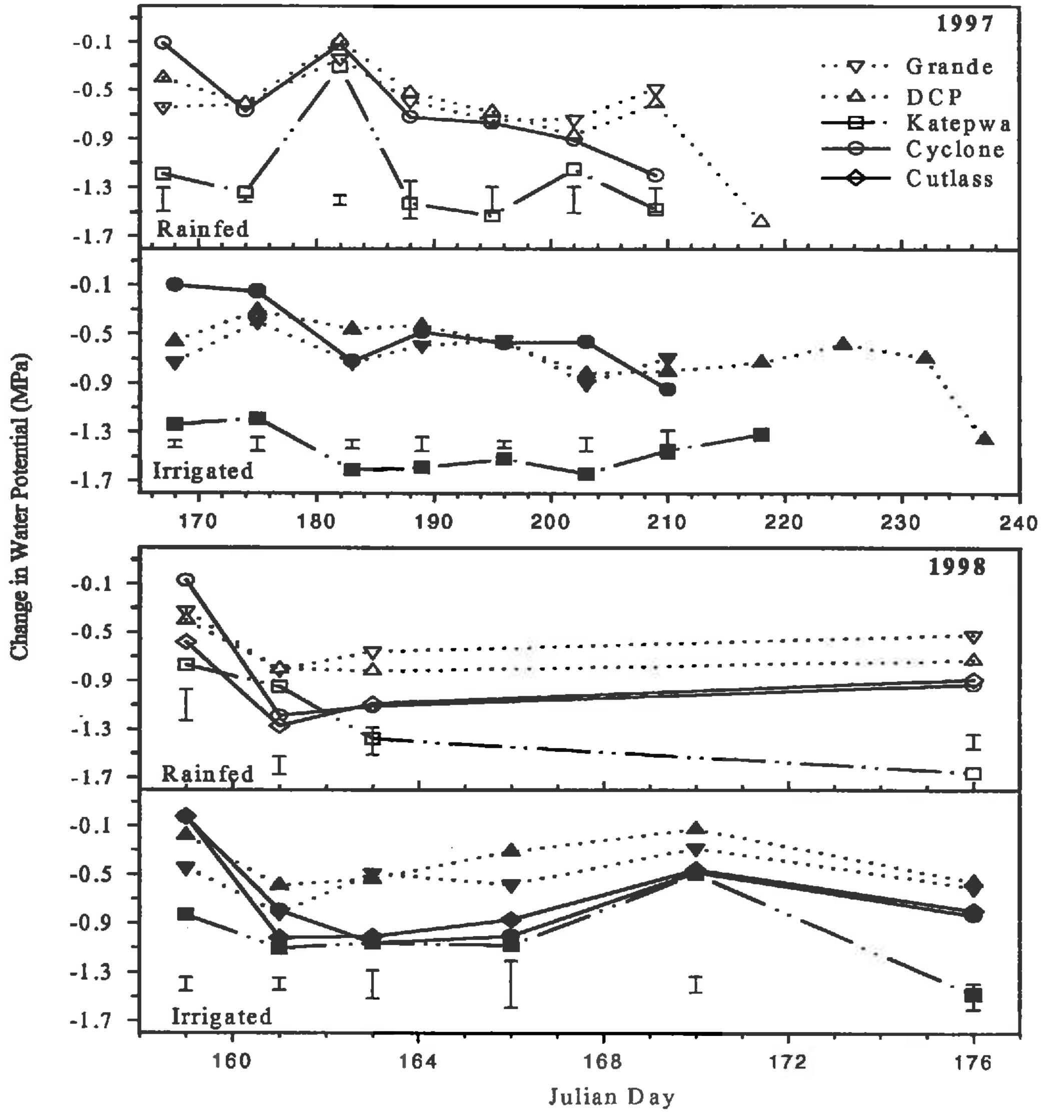

Fig. 3. Diurnal change in the leaf water potential of different crop species at Swift Current during 1997 and 1998 seasons. Solid and open symbols represent irrigated and rainfed field conditions, respectively. Vertical bars are LSD values (p=0.05; p=0.10 if plus sign accompanies vertical bar) for comparing genotypes.

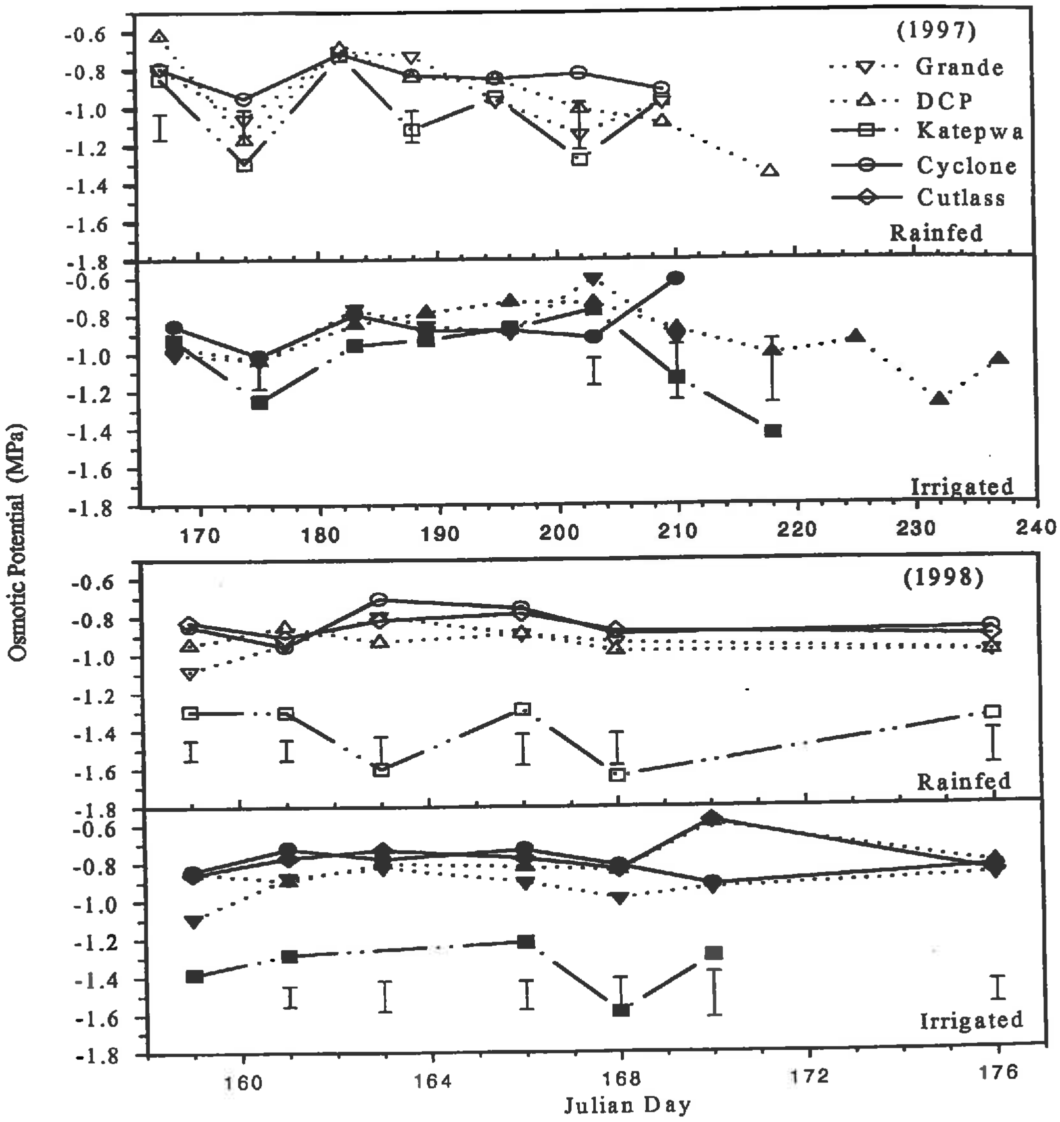

Fig. 4. Midday leaf osmotic potential at full turgor of different crop species at Swift Current during 1997 and 1998 seasons. Solid and open symbols represent irrigated and rainfed field conditions, respectively. Vertical bars are LSD values (p=0.05; p=0.10 if plus sign accompanies vertical bar) for comparing genotypes.

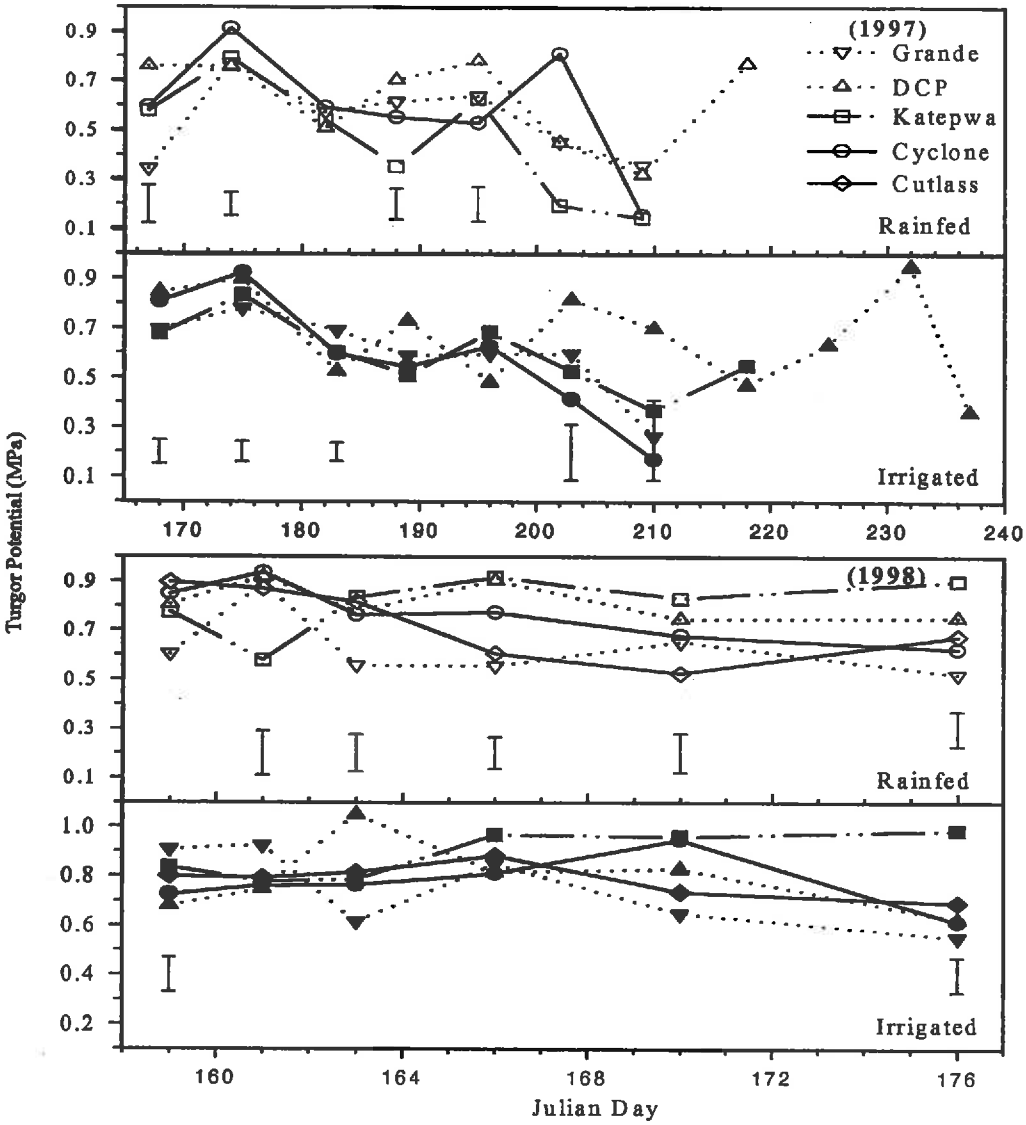

Fig. 5. Predawn leaf turgor potential of different crop species at Swift Current during 1997 and 1998 seasons. Solid and open symbols represent irrigated and rainfed field conditions, respectively. Vertical bars are LSD values (p=0.05; p=0.10 if plus sign accompanies vertical bar) for comparing genotypes.

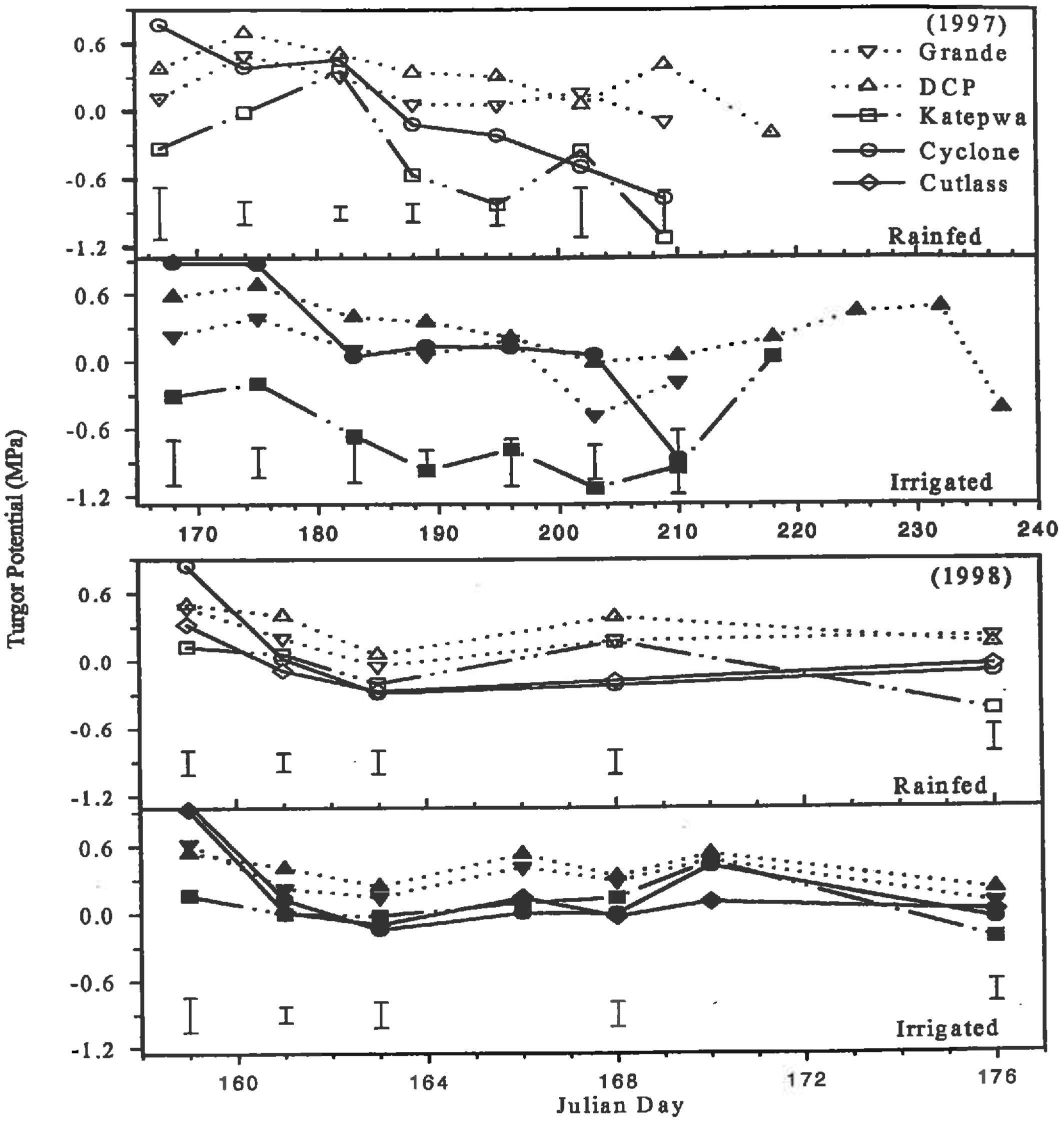

Fig. 6. Midday leaf turgor potential of different crop species at Swift Current during 1997 and 1998 seasons. Solid and open symbols represent irrigated and rainfed field conditions, respectively. Vertical bars are LSD values (p=0.05; p=0.10 if plus sign accompanies vertical bar) for comparing genotypes.

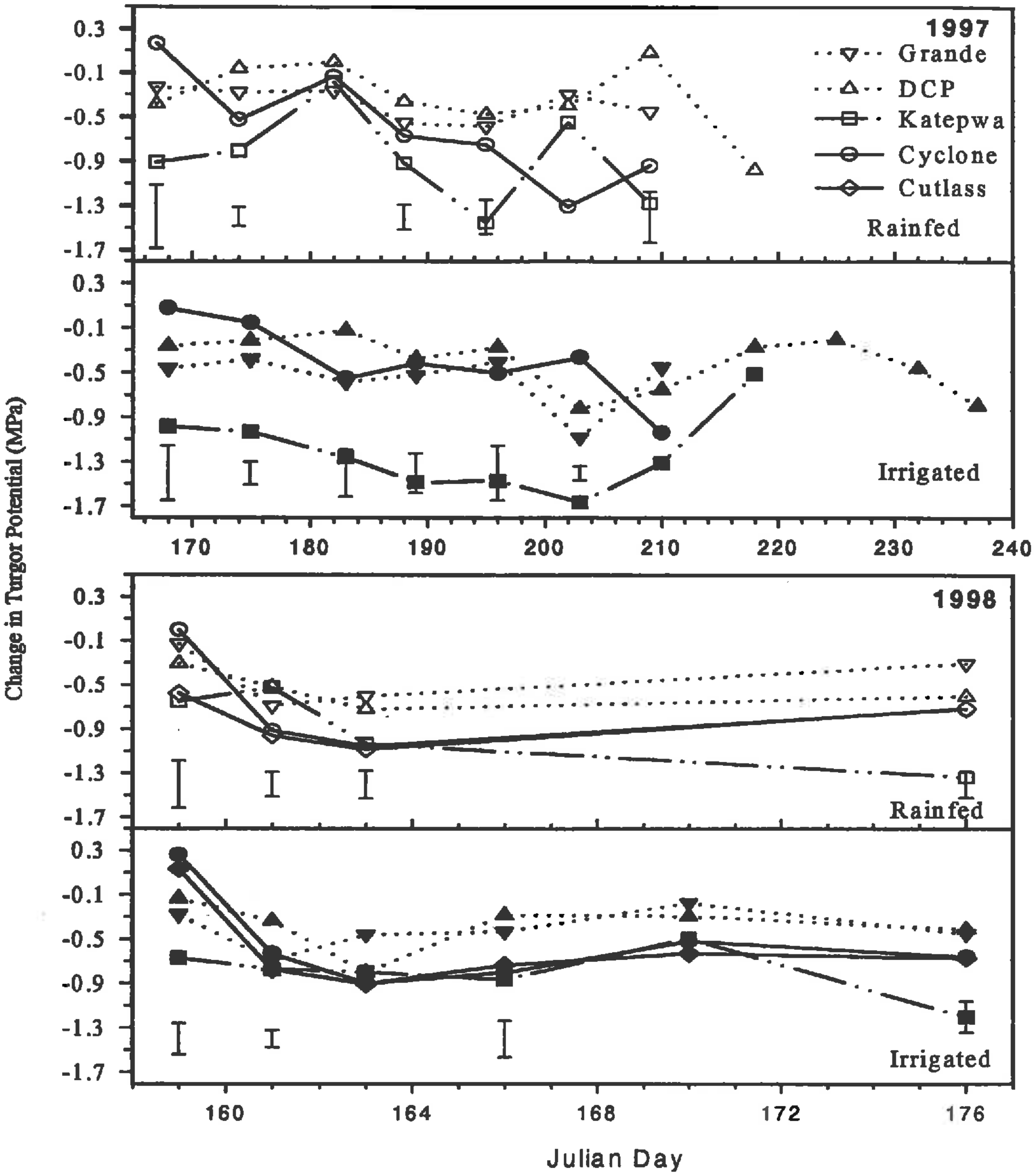

Fig .7. Diurnal change in the leaf turgor potential of different crop species at Swift Current during 1997 and 1998 seasons. Solid and open symbols represent irrigated and rainfed field conditions, respectively. Vertical bars are LSD values (p=0.05; p=0.10 if plus sign accompanies vertical bar) for comparing genotypes.

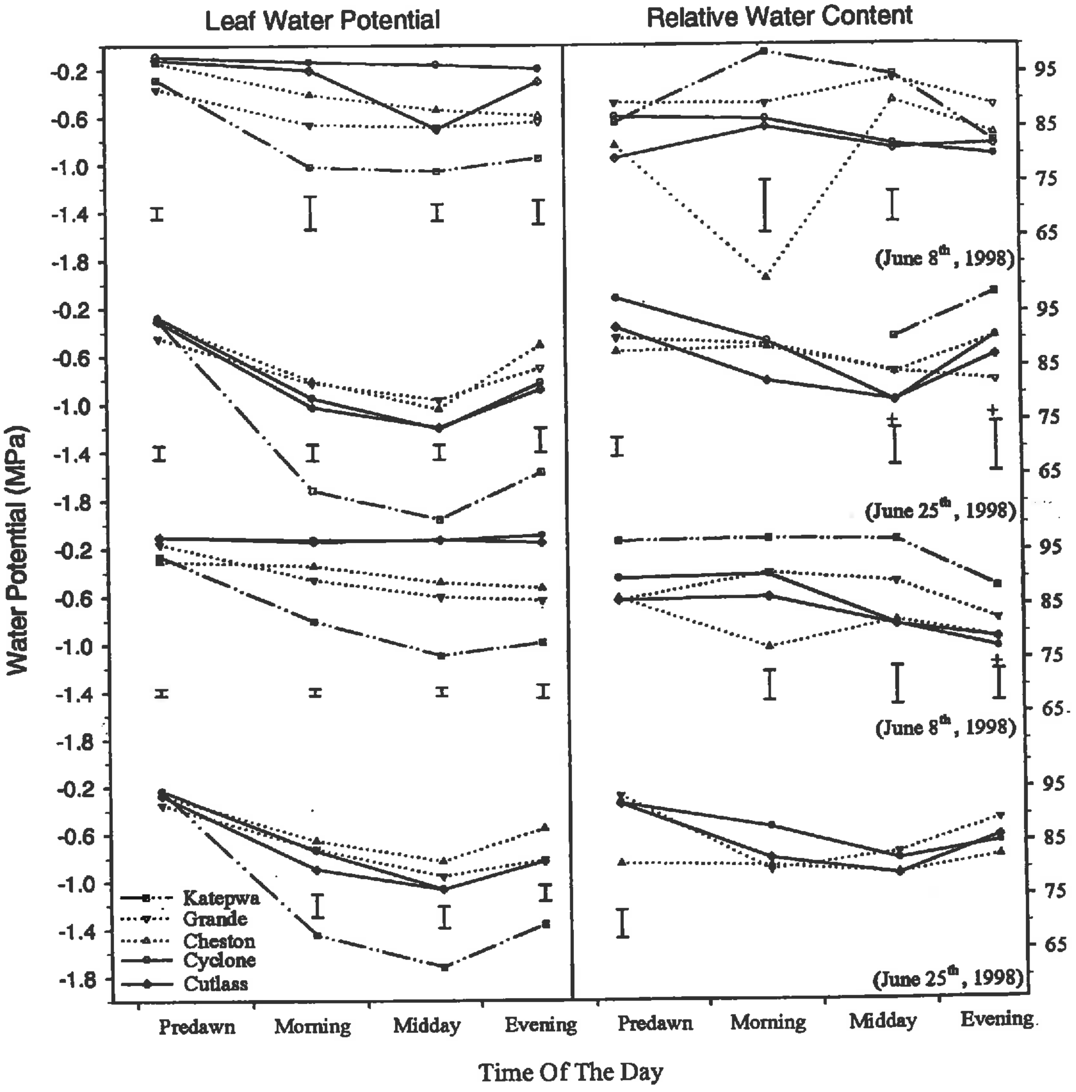

Fig. 8. Diurnal variation in Leaf Water Potential and Relative Water Content of different crop species on two dates at Swift Current in 1998. Filled symbols represent irrigated trial and open symbol represents rainfed trial. Vertical bars are LSD values (p=0.05; p=0.10 if plus sign accompanies vertical bar) for comparing genotypes within the perticular period of the day.

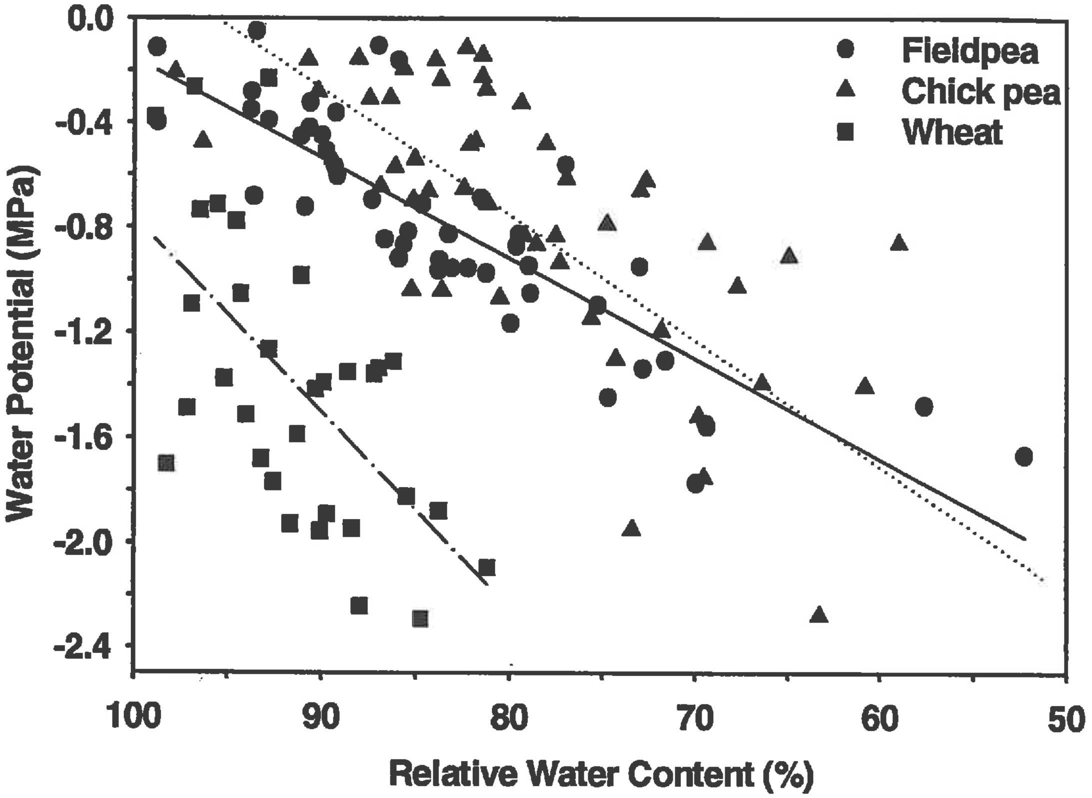

Fig. 9. Relationship between leaf water potential and relative leaf water content of wheat and pulse crops during 1997 and 1998 at Swift Current.