Row spacing effects on plant populations, canopy closure, water use, and grain yields in the Brown soil zone

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Abstract

We compared crop performance at a 20-cm row spacing and at a 30-cm row spacing on a Swinton loam near Swift Current from 1995-98 for seeding directly into untilled wheat stubble and seeding into tilled fallow. The results show that, in the water-limited environment, grain yields and water use efficiencies (WUE) at the 30-cm row spacing were generally lower than at 20-cm spacing. Flax, lentil, and spring wheat had yields and WUE were between 10 and 20% lower at the 30- compared with the 20-cm row spacing. Durum and desi chickpea had yields and WUE about 5 to 10% lower at the 30-cm row spacing. For field pea and kabuli chickpea, yield reductions at the wider row spacing existed primarily when the seed rate was also reduced. Lowest yields with a reduced seed rate combined with wider row spacing occurred for all the pulse crops. The yields of the Brassica oilseeds (canola and mustard) were less affected by row spacing than other crops. For all crops except chickpea, there was a lower plant density at 30- compared with 20-cm row spacing. However, for pulse crops and cereals, since two seed rates were used in this study, we were able to show that the lower yields for the wider row spacing was not due primarily to lower plant densities. We attributed the higher grains yields and WUE at the 20-cm row spacing compared with 30-cm row spacing to more efficient use of water due to quicker exploitation of the soil between the seed row soil and reduced loss of soil water from evaporation in the soil between the rows due to a more quickly closed canopy. Hence, the yield effects of row spacing are primarily related to efficient water use so the yield reductions from widening row spacing appear to be more pronounced in the Brown soil zone than in the Black soil zone. Producers in the Brown and drier parts of the Dark Brown soil zones should consider carefully both the disadvantages and advantages of widening the row spacing on their seeding implement.

Introduction

Conventional row spacings in the Brown soil zone are 17 to 23 cm and many producers are interested in adopting 30-cm row spacing to capitalize on lower draft of the seeding implement, superior residue clearance, and lower seeding implement opener maintenance and capital costs.

Lafond et al. (1997) provided an exhaustive study of row spacing effects on crops in the

Canadian prairies. They concluded that, in wetter areas of the prairies, 30-cm row spacing were provided high yields and that any yield reductions compared with 15 or 20-cm row spacings was compensated by the lower draft and superior residue clearance of the 30-cm row spacing. However, in the studies they report from dryland conditions in the Dark. Brown almost invariably indicate a lower yield for the wider row spacings. For example, Ukrainetz (1990) found that yields of canola (B. napus) and spring wheat were about 10% less with 30- than 20- cm row spacing in a 4-yr study at Scott, Saskatchewan.

Little research has been conducted on row spacing effect on spring crops in the semiarid Brown soil zone. Cutforth and Selles (1992) found that yield and water use of spring wheat was the same in a paired row system (two rows 10 cm part with the centre of the paired rows 50 cm apart) as equal row spacing (rows 25 cm apart). However, they noted that the wide spacing (40 cm) between adjacent paired rows can aggravate water erosion and weed competition compared with equal row spacing. McLeod et al. (1996) found no significant difference in winter wheat yields at 27- and 36-cm row spacing over 11 site-years.

In Mediterranean environments with marked terminal water stress, chickpea has shown increased yield as row spacings decreased from 45 cm or wider to 20 cm or narrower (Beech and Leach 1988; Murray and Auld 1987) while lentil results have shown no difference to row spacings of 15 and 30 cm (Wilson and Teare 1972) to increased yields as row spacing decreased from 0.6 to 0.2 m (Silim et al. 1990). In Manitoba, Ah-Khan and Kiehn (1989) found that lentil yield increased as row spacing was decreased from 30- to 15-cm.

An interaction between row spacing and seed rate is typical. The interaction can be confounded by intense inter-plant competition among the closely spaced plants associated with high seeding rates and/or wide rows which lead to plant die-off. For example, Ukrainetz (1990) found that narrow rows (10 cm) had more than twice the live plant density at the same seeding rates as wide rows (30 cm) and that tripling the seeding rate of spring wheat only increased final plant density by 35%. Nevertheless, in environments with high yield potentials, higher seeding rates generally produce proportionately higher yields at narrower row spacing than at wider spacings compared with low seeding rates (Marshall and Ohm, 1987; Johnson, 1983). In semiarid climates with lower yield potential, the interaction between seeding rate and row spacing is less clear. Yunusa et al. (1993) found no interaction between seeding rate and row spacing on spring wheat yield under conditions of high moisture stress. Also in a semiarid climate, Kemp et al. (1983) found row spacing had no effect at the highest seeding rate, but that narrow row spacings were more productive at the lowest seeding rate.

In the Brown soil zone, several researchers have found that yield of spring wheat grown on stubble is little affected by seeding rate of 22 to 67 kg ha-’ (Pelton 1969; Read and Warder 1982; Dyck, unpublished 1992-94 data). In fact 22 kg ha-’ produced highest yields in extreme drought conditions (Pelton 1969) and wheat yields trended lower at seeding rates of 110 kg ha-’ (Dyck, unpublished data).

For chickpea, Murray and Auld (1987) found that grain increased as seed rate and plant density increased. Silim et al. (1990) found that lentil yield increased up to about 300 plants m-’ after which it decreased while McKenzie et al. (1989) found that maximum lentil grain yields occurred at 400 plants m^{-2}. Both the latter densities are well above those normally recommended for the Canadian prairies. Ali-Kahn and Kiehn (1989) found that highest lentil yields in Manitoba occurred at a plant density of 100 plants m^{-2}. In northeastern Saskatchewan, Townley-Smith and Wright (1994) found that highest field pea yields occurred at a density of about 70 plants m^{-2} with the advantage of denser stands increasing as weed density increased.

Narrow row spacings increase the ability of the wheat to compete with weeds (Solie et al., 1991; O’Donovan 1997).

For direct cropping systems, wide row spacings (>25 cm) provide better residue clearance through the seeding implement equipped with hoe or knife-type openers than conventional 17 to 23 cm row spacings. Conventional recommendations call for stubble height no taller than the row spacing. However, for maximum water conservation, 30 cm or taller stubble is recommended (McConkey et al. 1994) and Cutforth and McConkey (1997) found that the in-crop microclimate benefits of seeding directly into cereal stubble that was 30 cm tall or taller increased spring wheat yields by 6% compared to seeding into cereal stubble that was 14 to 18 cm tall. Consequently, allowable stubble heights for conventional row spacings could limit potential water conservation and microclimate improvement and thereby limit yield potential for crops seeded directly into stubble.

Wide row spacings lower the initial purchase price of a seeding implement compared to conventional row spacings. In addition, wider row spacings lower seeding implement draft and costs for opener maintenance. These economic advantages of wide row spacings exist for all tillage systems.

Narrow rows provide better support for the swath for windrowed grain, particularly for lower yielding crops more common to drier areas. However, straight combining without windrowing is growing in popularity across the Canadian prairies, especially in the Brown and Dark Brown soil zones. Therefore, the harvest restrictions for wide rows will not be important for many producers.

The objectives of this study were:
1) To determine the difference between 20- and 30-cm row spacings for production of several important crops on direct seeded wheat stubble and tilled fallow.
2) To determine the effect of reducing seed rate at 20- and 30-cm row spacing for several cereal and pulse crops.

Materials and Methods

Two separate experiments were conducted near Swift Current on a Swinton loam from 1995 to 1998: one experiment involving seeding directly into untilled wheat stubble after a glyphosate application and the other involving seeded after a pre-seeding tillage with a cultivator with mounted harrows into tilled fallow. These two divergent management systems represent important production practices in the Brown soil zone. The experiments were moved to new land each year that had been previously at least three years in a tilled wheat-fallow rotation. However, the longer-term cropping history of the land for the two experiments was frequently different. Further, based on availability of suitable land, the stubble and fallow experiment were not always adjacent. Consequently, any comparison between experiments, although statistically possible, is confounded by land location and management history.

Two Versatile/Noble 2000/2200 hoe press drills were used: one at 30.48-cm (referred to as 30-cm) and the other drill at 20.32-cm (referred to as 20-cm) row spacing. We used the Noble direct-seeding “Eagle Beak” opener with the paired-row attachment. This produced two seed rows about 5-cm apart with all fertilizer placed midway between the seed rows and 3 to 5 cm below the level of the seeds. All crops received 9 kg/ha of P as mono-ammonium phosphate. Oilseeds and cereals received supplemental N fertilizer as urea at a rate so that soil N-NO, measured in the fall to the 60-cm depth plus additional N fertilizer totalled 73/kg/ha of actual N.

Eleven crops types were involved in the experiment (Table 1) to represent a number of canopy architectures as well as crops of interest to producers in the area. For the pulse crops (pea, lentil, chickpea) and cereals (durum, wheat), in addition to the 1X seed rate (Table l), a 0.67X seed rate (i.e. 2/3 of the 1X rate) was also used (the 0.67X seed rate included for spring wheat only from 1996 onwards). Assuming equal percentage of emergence of planted seeds, the 0.67X seed rate at a 30-cm row spacing should have equal inter-plant spacing along the row as the 1X rate at 20-cm row spacing.

The two experiments were seeded together. Seeding dates were: April 26- May 2 (rain delay) 1995; May 14 (cereals and oilseeds), May 22 (pulses except kabuli chickpea), and June 3 (kabuli chickpea) 1996; May 5-6 (except kabuli chickpea) and May 15 (kabuli chickpea) 1997; April 27-28 (except kabuli chickpea) and May 13 (kabuli chickpea) 1998.

The experiment was a split-plot factorial randomized complete block with four replicates. The main plot was crop and the row spacing and seed rate were arranged in a randomized factorial design within crop plots. We analysed each crop separately as a complete sub-experiment as we had postulated during experiment design that the response to seed rate and row spacing would differ between crops.

For 1997 and 1998, six additional treatments were added for spring wheat plots in the tilled fallow experiment. These were a 1.67X seeding rate and an extra N fertilizer treatment. The intent was to determine if higher seed rates or greater N supply would change the row spacing effect. Due to space limitations, the extra N treatments only involved the 1X and 1.67X seeding rates. Extra N applied above the regular N addition was 55 kg/ha in 1997 and 50 kg/ha in 1998.

Starting in 1996, we measured crop water use. A few days before seeding we took nine 5-cm diameter soil cores to 1.2 m randomly over the each experiment. These were subdivided into O-O. 15, 0.15-0.30, 0.30-0.60,0.60-0.90, and 0.90-l .2 m depth increments and analysed for bulk density and gravimetric moisture content from which the volume of water near seeding was calculated. Then, as each crop was harvested, similar cores were taken on the seed row and midway between the seed row (one core from each per subplot). Crop water use was defined as the difference between soil water measured just before seeding and that just after harvest plus the precipitation that fell between those sampling times.

Light interception by the crop canopy was measured in 1998 with a LiCor canopy analyser. Two measurements were made per plot on selected crops at the 1X seed rate in both experiments. All measurements were completed between sunrise and 9:00 local time to have low sun angles.

For 1998, lateral root expansion into the inter-row area was monitored for canola, N.L. pea, and wheat, all at 1X seed rate, in the direct-seeded stubble experiment using the metribuzin-treated trench described by Robertson et. al. 1985 and Kivien et al. 1988. Trenches were cut on a line between two 30-cm spaced seed rows running at an angle of 30 degrees to the seed row. Soil along the line was removed by hammering in a 2.5-cm wide rectangular frame to a depth of 15 cm and removing the soil. The trench was immediately tilled with soil mixed with metribuzin at a rate equivalent to 12 kg/ha of metribuzin. The ends of the trench were then staked. The distance between the stake and the furthest plant along the row that was visually injured by the metribuzin (chlorotic and/or stunted) was noted every 3-4 days until June 19 when visual injury symptoms no longer advanced along the seed rows. For these subplots, we also installed aluminium access tubes on and midway between the seed rows. Volumetric soil water was measured every 0.1 m to 1.2 depth using a previously calibrated neutron probe. Because of damage to the plots from the metribuzin, duplicate adjacent subplots were used for grain yields.

Plot size was 1.9 m by 6 m. Weed control was accomplished with pre- and post-emergence herbicides combined with hand weeding as required. Two or more flax plots were used as buffer between crop plots that would have different herbicides to minimize risk or spray drift damage. Alleys between the replicates were seeded to spring wheat that was mowed in early July. Yields were measured with a plot combine that harvested the centre 7 rows for the 20-cm row spacing and the centre 5 rows for the 30-cm row spacing. For both row spacings a single guard row was left unharvested on either side of the subplots. For field pea, the plants in one row would grow completely into any space in the adjacent row where there was not a pea plant. This space-filling by plants between adjacent rows was particularly common at the 0.67X seed rate. We became concerned that removing all plants originating in the guard rows before harvest was introducing additional variability. On some plots, we had to remove more plants from the guard row that were invading the plot area to be harvested than there were plants from the next interior rows invading the guard rows while, on about a equal number of plots, there were more plants from the next interior rows invading the guard rows than vice versa. To avoid this potential source of variability, from 1996 onwards, we used flax buffer subplots beside every pea subplot and harvested the entire pea subplot.

Plant densities were measured three to four weeks after seeding for two adjacent l-m row lengths per plot.

Statistical analysis was performed with PROC GLM in SAS. Single degree linear contrasts were used to separate means at the subplot level for the pulse and cereal crops.

Results and Discussion

Weather

Weather was cooler and wetter than normal in 1995, was near-normal in 1997, and drier than normal in July and August of 1996 and 1998 (Table 2).

General agronomic performance

The lowest yielding year was 1998 for the direct-seeded stubble experiment (Table 4) and 1997 for the tilled fallow experiment (Table 5).

Kabuli chickpea failed to establish in 1995, probably because it was seeded into soil that was too cool for the seedling to emerge before being overcome by various microbial infections. The drill metering system caused considerable damage (splitting seeds and cracking the seed coat) to the large kabuli seed that limited total emergence to well below the target of 40 plants m^{-2}. However, due to its high seed rate and associated cost, many growers use lower seed rates and target densities than nominally used in this study. Thus, the results from this study are still useful. Canola failed to establish in 1996, despite re-seeding, due to soil crusting in heavy rains. Poor emergence of N.L. pea in 1995 was attributed to a poor seed lot as similar relative establishment problems were noted for that seed lot regardless of seeding equipment or date. Oriental mustard and C.Q. mustard were added to the experiments in 1996 and 1997, respectively.

There were obvious differences in plant densities and kernel masses among crops reflecting different target densities and inherent seed size. The highest yielding crops were spring wheat, durum, and field pea. For direct seeded stubble the oilseeds had generally the lowest yields while in the fallow experiment, oilseeds and other pulses (excepting field pea) had similar yields. For both experiments field pea usually had the lowest water use to 1.2 while kabuli chickpea and the cereals had among the highest water use.

Row spacing effects on yield and density

To provide an easier comparison across years and crops, we analysed the results as a proportion of the yields and density for the 20-cm row spacing and 1X seed rate (direct-seeded stubble experiment: Tables 6 and 7, tilled fallow experiment: Tables 8 and 9). For brevity, we only present the yield results by year for those crops when there was a significant ($P<0.05$) year by row spacing or year by seed rate interaction. Also for brevity, we only present the density results by year for those crops for which the yield proportion required year by year results.

Direct-seeded Stubble Experiment

For the Brassica oilseeds, plant densities were lower for the 30- than 20-cm spacing but mean grain yields were unaffected by row spacing. In contrast, for flax, there was no significant reduction in plant densities for the 30-cm spacing compared with the 20-cm spacing but grain yields were significantly lower by 9% for the wider row spacing.

The effect of row spacing varied among the pulse crops. For field pea and lentil, there was no effect of row spacing on plant density but lower plant densities were lower for the 0.67X seed rate compared with the 1X rate although the seed rate effect was only statistically significant for S.L. pea and lentil. Yields of N.L. pea were unaffected by row spacing while those of S.L. pea was significantly lower at 30-cm spacing and 0.67X seeding rate than other spacing-seed rate combinations. Lentil yields were 10% lower at 30- compared with 20-cm spacing. For kabuli and desi chickpea there was a larger variation in relative plant densities among the row spacings, seed rates and years than other crops. Generally, chickpea yields increased as plant density increased. For desi type, yields averaged about 7% less at 30- than 20-cm spacing although there was no effect of seed rate on mean yield across years. For kabuli chickpea, there was no significant effect of row spacing but yields were significantly higher at the 1X than the 0.67X seed rate. This effect of seed rate for kabuli was not surprising as plant densities at the 1X rate were already low. For all pulses, the lowest yield treatment was the 30-cm spacing combined with 0.67X seeding rate. This indicates that if using a 30-cm row spacing for pulses, it is important to maintain good plant densities. Morrison et al. (1990) also noted that low seed rates and plant densities also produced the lowest grain yields and increased the relative yield reduction from using 30- than 15-cm row spacing. Their study involved canola in southern Manitoba.

For both wheat and durum, there was a significant reduction in plant densities for the 30-cm spacing or 0.67X seed rate compared with the 20-cm spacing and 1X seed rate. For both cereals, yields were about 10% less for the 30- compared with the 20-cm row spacing.

For the cereals and pulses, yield reductions for the 30-cm spacing relative to the 20-cm spacing occurred when plant densities at the 30-cm row spacing were similar or greater than at the 20-cm row spacing, indicating that the yield reduction due to row spacing was not closely related to the effect of row spacing on plant densities.

Tilled Fallow Experiment

For the Brassica oilseeds, both plant densities and yields trended higher in 1997 for the 30- than the 20-cm row spacing while they both trended lower in 1998. The force on the on-row packing wheels is the sum of the downward force on the moving openers and the weight of the drill. The force from the openers is proportional to the number of openers so should be the same regardless of row spacing but, as row spacing is increased, more of the weight of the drill is carried on each packer. We hypothesize that the higher packing force on the packing wheels on the 30-cm row spacing improved emergence in 1997 for these crops having small seeds, while the higher packing force may have been a detriment in 1998. There was no significant effect of row spacing on plant densities for the Brassica oilseeds across years and, with the exception of 0. mustard for which the 1996-98 yields at 30-cm spacing was less than that at 20-cm spacing, there was no average effect of row spacing on yield.

For flax, both plant density and yield were significantly reduced at the 30-cm row spacing compared with 20-cm spacing.

Field pea yields were significantly lower for the 30-cm spacing than the 20-cm spacing. Plant densities were lower at the 0.67X seed rate than the 1X rate although yields were only statistically reduced by the lower seeding rate for S.L. pea.

Lentil yields showed some large reductions at the wider row spacing in several years. Over all years, plant densities were only affected by seed rate while grain yields were reduced by both the wider row spacing and the lower seed rate.

Desi chickpea yields were lower for the wider row spacing while plant densities was only affected by seed rate. For kabuli chickpea, plant densities actually averaged higher for the wider row spacing although grain yields were lower at 30-cm spacing than expected based on their higher plant densities.

With the exception of kabuli chickpea, the lowest yielding treatment combination was 30-cm row spacing and 0.67X seed rate, often significantly lower than the 20-cm row spacing and 0.67X seed rate.

For both wheat and durum, there was a significant reduction in plant densities for the wider row spacing or lower seeding rate. For spring wheat yields, yields were about 12% less for the 30- compared with the 20-cm row spacing. However, for durum, yields were about 4% less for the 30- compared with the 20-cm row spacing

The extra nitrogen and 1.67X seeding rate treatments for spring wheat in 1997 and 1998 (Table 9) provide more evidence of the row spacing effect on this crop. The results show that there was an about 10% lower yield reduction for with the 30-cm rows for every corresponding fertilizer and/or seed rate. Also there was 10% yield reduction when densities were very similar such as 20-cm spacing with 1X seed rate with regular fertilizer vs 30-cm spacing with 1.67X seed rate with regular fertilizer in 1997 or 1998. Only with the 1.67X seed rate plus extra N fertilizer were the grain yields at 30-cm spacing equivalent to those with 20-cm spacing with 1X seed rate with regular N fertilizer addition.

For the cereals and pulses, yield reductions for the 30-cm spacing relative to the 20-cm spacing occurred when plant densities at the 30-cm row spacing were similar or greater than at the 20-cm row spacing, indicating that the yield reduction due to row spacing was not closely related to the effect of row spacing on plant densities.

Kernel masses

There were frequent effects of both row spacing and seed rate on mean kernel mass for most crops, but, as the differences were small (generally less than 5%) and inconsistent among treatments and years, we will only present the data for kabuli chickpea for which kernel size can greatly affect the market value (Table 10). There was general pattern that kabuli kernel masses increased as overall grain yield increases. In both experiments, considering all three years, mean kernel mass was less at the 0.67X than 1X seed rate. Murray and Auld (1987) also found that kabuli seed mass increased as seed rate increased but, unlike this study, they found that seed mass increased as row spacing decreased. In their study, higher seed mass occurred in narrower row spacing and/or higher seed rate treatments in which the plants were more likely to set one rather than two seeds per pod.

Row Spacing effects on crop canopy

The 1998 measurements of canopy light interception for the two experiments (Table 10 and 11) show there was a general trend, occasionally statistically significant, during the early to mid growing season for less sunlight interception by the canopy at the 30- compared with the 20-cm row spacing. This effect is expected but has important implications to water use efficiency as closing the canopy quickly is possibly the most practical method to maximize the efficient use of water by reducing evaporation from the soil surface (Ritchie 1983). Quicker canopy closure at narrower row spacing also increases the competitiveness of the crop against weeds.

Lateral Root Extension

From about 30 days after planting, the N.L. field pea had greater lateral root expansion than canola or wheat. For field pea and canola it took approximately 3 or 4 days to extend from 10 cm (i.e. filling in the between row area for 20-cm spacing) to 15 cm (i.e. filling in the between row area for 30-cm spacing). However, this same extension took about 10 days for wheat. During this interval between the roots filling the between row area at the 20- and 30-cm spacing, the soil water between the seed row at the 30-cm spacing is subject to evaporative losses without the crop having an opportunity of using that water. Further, evaporative losses between the row would be expected to be higher at the 30- than the 20-cm row spacing since the canopy is often less closed at the wider row spacing.

Water Use

There was no apparent or significant effect of seed rate, row spacing, or their interaction on seeding to harvest water use within crop types for either experiment (data not shown). There was also no significant difference between on row and between row water use for the seeding to harvest period in either experiment. Despite the crop differences in root extension observed in 1998, there was no row spacing effect on water use between the row (Table 13). Water use to mid season was highest on the seed row at 20-cm row spacing for all crops with the difference being significant for canola.

Because water use was unaffected by row spacing or seed rate treatments, changes in grain yields reflected changes in water use efficiency.

Summary and Conclusions

The results of this study show that, in a water-limited environment, the 30-cm row spacing produced lower water use efficiencies and grain yields than the 20-cm spacing. Flax, lentil, and spring wheat had yields that were between 10 and 20% lower at the 30- compared with the 20-cm row spacing. Durum and desi chickpea had yields about 5 to 10% lower at the 30-cm row spacing. For field pea and kabuli chickpea, yield reductions at the wider row spacing existed primarily when the seed rate was also reduced. Lowest yields with the combination of a reduced seed rate and wider row spacing existed for all the pulse crops. The yields of the Brassica oilseeds (canola and mustard) were less affected by row spacing than other crops.

For all crops except chickpea, there was a lower plant density at 30- compared with 20-cm row spacing. However, for pulse crops and cereals, since two seed rates were used in this study, we were able to show that the lower yields for the wider row spacing was not due entirely to lower plant densities.

In Saskatchewan, Tompkins and coworkers (Tompkins et al. 1991a, 1991b) attributed the greater grains yields and water use efficiencies at narrower row spacings to reduced inter-plant competition for light, water, and nutrients. However, in our study, this did not appear to be the case as the lower seed rate included for the pulse and cereal crops at the wider row spacing would have effectively reduced such inter-plant competition. Instead, we attributed the generally greater yields at the 20-cm row spacing than at the 30-cm row spacing to quicker exploitation of the soil between the seed row soil and reduced loss of soil water from evaporation in the soil between the rows due to a more quickly closed canopy. Hence, the yield effects of row spacing are primarily related to efficient water use so the yield reductions from widening the row spacing are more pronounced in the Brown soil zone than in the Black soil zone. We hypothesize that the better relative yields for the pulse crops at the recommended seed rate than the reduced seed rate when grown in 30-cm spaced rows was because greater interplant competition at the higher plant densities induced the plants to more aggressively grow into and exploit the light, water, and nutrient resources between the seed rows.

Producers in the Brown and drier parts of the Dark Brown soil zone should consider carefully both the disadvantages and advantages of widening the row spacing on their seeding implement.

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Table 1. Crops used in the experiments.

Crop	Comments	Species	Cultivar	1X seed rate (kg ha-‘)
durum		*Triticum durum*	Kyle	101
wheat	hard red spring wheat	*Triticum aestivum*	Katepwa	67
kabuli	kabuli chickpea	*Cicer kabulicum*	Sanford	213
desi	desi chickpea	*Cicer arietinum*	Cheston	108
C.Q. Mustard	canola-quality oil mustard	*Brassica juncea*	CQ1	7
0. Mustard	oriental mustard	*Brassica juncea*	Cutlass	7
Canola	Argentine canola	*Brassica napus*	Cyclone	9
Flax		*Linum usitatissimum*	Vimy	45
Lentil		*Lens culinaris*	Laird	101
S.L. pea	semi-leafless yellow field pea	*Pisum sativum*	Carneval	174
N.L. pea	normal-leafed yellow field pea	*Pisum sativum*	Grande	174

Table 2. Monthly precipitation and temperatures during the growing season.

Year	May	June	July	August
		Precipitation (mm)		
1995	29.0	101.0	58.0	107.6
1996	65.0	77.7	23.1	32.6
1997	49.9	69.8	43.8	48.0
1998	38.1	90.5	37.0	35.3
L.T.Mean[z]	43.4	72.6	51.6	43.2
		Mean Maximum Temperature (°C)		
1995	16.2	22.7	23.6	23.0
1996	13.0	21.7	24.3	27.3
1997	16.5	22.0	25.1	25.8
1998	20.1	19.5	27.0	28.8
L.T.Mean	17.8	22.1	26.0	25.2
		Mean Minimum Temperature (°C)		
1995	3.3	9.9	11.2	10.3
1996	2.2	10.0	10.9	11.6
1997	3.6	10.7	11.1	11.4
1998	5.0	8.4	13.3	13.1
L.T.Mean	4.0	8.7	11.2	10.0

[z] Long-term mean

Table 3. Plant density (Den) (m^{-2}), water use (WU) (mm), grain yield (Yld) (kg ha^{-1}), and grain kemal mass (kwt) (mg) for 20 cm row spacing and 1X seed rate for the direct-seeded wheat stubble experiment.

	1995			1996				1997				1998			
Crop	Den	Yld	kwt	Den	WU	Yld	kwt	Den	WU	Yld	kwt	Den	WU	Yld	kwt
Durum	76	2529	37.0	133	30	2415	35.8	183	31	2749	34.9	117	21	1533	30.4
Wheat	60	1975	27.6	100	31	2276	28.6	172	30	2869	28.3	127	22	1487	22.4
Kahuli					28	1269	417.9	18	31	1566	488.0	20	27	833	399.4
Desi	31	2215	156.9	31	24	1632	163.1	59	29	2315	176.8	40	21	1407	141
C.Q. Mustard								97	29	1134	2.4	130	22	716	2.2
0.. Mustard				71	29	932	2.0	103	29	1219	2.5	91	21	920	2.8
Canola	62	1173	3.2					67	28	1080	2.8	73	22	885	2.5
Flax	54	1599	6.2	105	29	1332	5.6	237	29	1136	5.6	191	21	1077	5.1
Lentil	49	1533	59.5	68	29	1360	60.6	82	29	1879	63.0	82	21	1334	64.3
S.L. Pea	33	3316	221.1	37	27	1981		55	27	2450	217.0	41	21	1648	202.6
N.L. Pea	14	2040	220.8	47	27	2476	243.6	49	27	2872	244.4	54	21	2735	203.7
LSD	15	446	7.1	16	1	284	10.6	36	1	309	6.9	27	1	252	5.5

Table 4. Plant density (Den) (m^{-2}), water use (WU) (mm), grain yield (Yld) (kg ha^{-1}), and grain kemal mass (kwt) (tng) for 20-m row spacing and 1X seed rate in the tilled fallow experiment.

	1995			1996				1997				1998			
Crop	Den	Yld	kwt	Den	Wu	Yld	kwt	Den	WU	Yld	kwt	Den	WU	Yld	kwt
Durum	89	3835	41.7	114	29	2749	36.9	206	35	2847	40.8	164	26	3069	39.4
Wheat	69	2752	30.7	69	28	2838	27.5	193	34	3067	29.7	158	27	3187	30.2
Kabuli				25	32	1679	449.9	10	36	1448	480.0	13	29	1260	407.7
Dcsi	31	1942	146.2	55	23	2809	164.2	43	34	2461	172.0	43	25	2290	154.1
C.Q. Mustard								76	34	1097	2.3	186	26	1893	2.2
0. Mustard				44	30	916	2.2	96	34	1352	2.5	172	25	1669	2.9
Canola	100	1731	3.1					35	33	856	2.6	130	25	1484	2.8
Flax	123	2006	6.0	83	30	1413	6.0	220	33	1366	5.7	343	24	1874	5.6
Lentil	65	1355	49.1	75	28	1885	59.4	77	33	1992	66.5	97	26	1911	65.4
S.L. Pea	40	3628	214.8	34	28	2892	222.1	52	31	2732	221.3	41	23	3542	207.7
N.L. Pea	14	2347	198.5	58	27	3301	251.4	52	31	3359	250.1	57	24	3916	212.0
LSD	20	519	7.7	30	2	313	4.7	29	1	341	4.9	23	2	526	7.9

Table 5. Grain yields for the 20- and 3Ocm row spacings at 0.67X and 1X seed rates as a proportion of 20-cm row spacing at 1X seed rate for the direct-seeded wheat stubble experiment.

		Proportion of 2O-cm rows at 1X				
		30-cm rows		20-cm rows		
Crop	Year	1x	0.67X	1X	0.67X	Significance (P=0.05)
C.Q. Mustard	97-98	1.03a	-	1.00a	-	-
0. Mustard	96-98	1.00a	-	1.00a		-
Canola	95-98	0.98a		1.00a		
S.L.Pea	95-98	0.97a	0.87b	1.00a	0.96a	yr, rs, sr [z]
N.L. Pea	95-98	1.04a	0.95a	1.00a	0.99a	yr
Durum	95-98	0.90a	0.89a	1.00a	1.00a	rs
Lentil	95-98	0.91bc	0.87c	1.00a	0.97ab	yr, rs
Flax	95-98	0.91b		1.00a		rs
Desi	95	0.95a	0.66b	1.00a	0.97a	sr, rs, sr* rs
	96	1.17a	1.24a	1.00a	1.08a	
	97	0.85bc	0.83c	1.00a	0.90b	sr, rs, sr* rs
	98	0.80b	0.84b	1.00a	1.01a	rs
	95-98	0.95ab	0.89b	1.00a	0.99a	yr, rs, yr*rs, yr*sr
Kabuli	96	1.01a	0.78b	1.00a	0.92a	sr
	97	0.90b	0.75a	1.00b	0.87a	sr
	98	1.07a	0.95ab	1.00a	0.82b	sr
	96-98	0.99b	0.84a	1.00b	0.87a	sr, yr*rs
Wheat	95	0.92a		1.00a		-
	96-98	0.89c	0.90bc	1.00a	0.97ab	yr, sr

[z] rs = row spacing, sr = seed rate, yr = year
values in rows not followed by same letter are significantly different (P=0.05)

Table 6. Plant densities for the 20- and 30cm row spacings at 0.67X and 1X seed rates as a proportion of 20-cm row spacing at 1X seed rate for the direct-seeded wheat stubble experiment.

		Proportion of 20-cm rows at 1X				
		30-cm rows		20-cm rows		
Crop	Yr	1x	0.67X	1X	0.67X	Significance (P=0.05)
C. Q. Mustard	97-98	0.68b		1.00a		yr, rs, yr*rs [z]
0. Mustard	96-98	0.85b		1.00a		rs
Canola	95-98	0.88a		1.00a		
S.L. Pea	95-98	0.94ab	0.78c	1.00a	0.82bc	yr, sr, yr*rs
N.L.Pea	95-98	1.00a	0.88a	1.00a	0.80a	
Durum	95-98	0.82b	0.73c	1.00a	0.70c	yr, rs, sr, yr*rs,rs*sr,yr*rs
Lentil	95-98	1.05a	0.75b	1.00a	0.87c	sr
Flax	95-98	0.97a		1.00a		
Desi	95	1.20a	0.54c	1.00ab	0.66bc	sr
	96	1.70a	1.39b	1.00c		sr,rs
	97	0.72bc	0.62c	1.00a	0.77b	sr,rs
	98	1.00a	0.74b	1.00ab	1.04a	
	95-98	1.16b	0.82c	1.00a	0.82c	yr, sr, yr*rs, yr*sr
Kabuli	96	0.71a	0.40c	1.00a	0.58bc	sr
	97	0.63bc	0.40c	1.00a	0.81ab	sr , rs
	98	2.09a	1.18a	1.00a	1.11a	sr
	96-98	1.14b	0.66a	1.00ab	0.83b	yr, sr, yr*rs
Wheat	95	1.19a		1.00a		
	96-98	0.79b	0.59c	1.00a	0.65c	yr, rs, sr, rs*sr, yr*rs

[z] rs = row spacing, sr = seed rate, yr = year
values in rows not followed by same letter are significantly different (P=0.05)

Table 7. Grain yields for the 20- and 30cm row spacings at 0.67X and 1X seed rates as proportion of 20-cm row spacing at 1X seed rate for the tilled fallow experiment.

		Proportion of 20-cm rows at 1X				
		3 O-cm rows		20-cm rows		
Crop	Yr	1x	0.67X	1X	0.67X	Significance (P=0.05)
S.L. Pea	95-98	0.97a	0.88b	1.00a	0.97a	yr, rs, sr, rs*sr [z]
N.L.Pea	95-98	0.93ab	0.91b	1.00a	0.97ab	yr, rs
Durum	95-98	0.97ab	0.96b	1.00ab	1.02a	rs
Flax	95-98	0.83b		1.00a		rs
Desi	95-98	0.89c	0.86c	1.00a	0.95b	yr, rs, rs*sr
Kabuli	96	1.02a	0.91a	1.00a	0.94a	
	97	0.63b	0.3 lc	1.00a	0.58b	sr, rs
	98	1.19a	1.21a	1 .00a	0.39b	sr, rs, sr*rs
	96-98	0.95a	0.81b	1.00a	0.63c	yr, sr, rs*sr, yr*rs, yr*sr
Lentil	95	0.76b	0.69b	1.00a	0.98a	rs
	96	0.93a	0.88a	1.00a	0.93a	
	97	0.88b	0.87b	1.00a	0.81b	sr, sr*rs
	98	0.92b	0.93b	1.00a	1.00a	
	95-98	0.87c	0.84c	1.00a	0.93b	yr, sr, rs, yr*rs
Canola	95	0.87a		1.00a		
	97	1.34a		1.00a		
	98	0.84b		1.00a		rs
	95-98	1.02a		1.00a		yr, yr*rs
0. Mustard	96	0.64b		1.00a		rs
	97	1.00a		1.00a		
	98	0.87b		1.00a		rs
	96-98	0.84b		1.00a		yr, rs, yr*rs
C. Q. Mustard	97	1.14a		1.00a		
	98	0.82b		1.00a		rs
	97-98	0.98a		1.00a		yr, yr*rs
wheat	95	0.96a		1.00a		
	96-98	0.88c	0.83c	1 .00a	0.95b	rs, sr

[z] rs = row spacing, sr = seed rate, yr = year

values in rows not followed by same letter are significantly different (P=0.05)

Table 8. Plant densities for the 20- and 30cm row spacings at 0.67X and 1X seed rates as a proportion of 20-cm row spacing at 1X seed rate for the tilled fallow experiment.

		Proportion of 20-cm rows at 1X				
		3 O-cm rows		20-cm rows		
Crop	Yr	1x	0.67X	1X	0.67X	Significance (P=0.05)
S.L. Pea	95-98	0.94b	0.68a	1.00b	0.74a	yr, sr, yr*rs[z]
N.L. Pea	95-98	0.83b	0.66c	1.00a	0.87b	yr, rs, sr
Durum	95-98	0.94a	0.72b	1.00a	0.69b	yr, sr, yr*rs
Flax	95-98	0.68b		1.00a		yr, rs, yr*rs
Desi	95-98	1.02a	0.83b	1.00a	0.89c	sr
Kabuli	96	1.11a	0.72a	1.00a	0.63a	
	97	0.67a	0.30b	1.00a	0.93b	rs
	98	2.52a	1.79a	1.00b	0.51b	sr, rs,
	96-98	1.43a	0.94cb	1.00b	0.69c	yr, rs, sr, yr*rs
Lentil	95	0.84a	0.54b	1.00a	0.62b	sr
	96	0.84ab	0.74bc	1.00a	0.63c	sr
	97	0.89ab	0.81bc	1.00a	0.72c	sr, sr*rs
	98	1.04a	0.77b	1.00a	0.78b	sr
	95-98	0.90b	0.72c	1.00a	0.68a	yr, sr, rs*sr
Canola	95	1.13a		1.00a		
	97	1.68a		1.00a		
	98	0.47b		1.00a		rs
	95-98	1.10a		1.00a		yr, yr*rs
0. Mustard	96	0.84a		1.00a		- `
	97	1.24a		1.00a		
	98	0.47b		1.00a		rs
	96-98	0.85a		1.00a		yr, yr*rs
C. Q. Mustard	97	1.30a		1.00a		
	98	0.59b		1.00a		rs
	97-98	0.95a		1.00a		yr, yr*rs
Wheat	95	1.01a		1.00a		
	96-98	0.94a	0.66b	1.00a	0.80c	yr, sr, rs, yr*sr

[z] rs = row spacing, sr = seed rate, yr = year
values in rows not followed by same letter are significantly different (P=0.05)

Table 9. Plant density (Den) (m^{-2}) and grain yield (Yld) (kg ha") for spring wheat with extra and regular N fertilizer at 0.67X, 1X, and 1.67X seeding rates for the tilled fallow experiment.

Row Spacing	N Fertilizer	Seed Rate	Den	Yld	Den	Yld
20	extra	1.67X	302	3325	217	3445
	extra	1x	175	3134	133	3455
	regular	1.67X	247	3020	240	3008
	regular	1x	193	3068	158	3187
	regular	0.67X	138	2848	107	3073
30	extra	1.67X	193	2902	168	3104
	extra	1x	149	2926	77	2619
	regular	1.67X	203	2681	152	273 1
	regular	1x	148	2655	122	2619
	regular	0.67X	105	2505	96	2668
	Contrasts					
	extra vs regular		ns[z]	**	**	***
	20 regular vs 30 extra		***	***	***	***
	20 regular vs 20 extra		***	ns	***	ns
	20 regular 1X vs 30 extra 1X		**	ns	***	ns
	20 regular 1X vs 30 regular 1.67X		ns	**	ns	***
	20 regular 1X vs 30 extra 1.67X		ns	ns	ns	ns

[z] ns = not significant, ** = P < 0.01, *** = P<0.001

Table 10. Seed masses (mg) of kabuli chickpea for 20- and 30-cm row spacings at the 1X and 0.67X seeding rates for the tilled fallow and direct seeded wheat stubble experiments.

	3 O-cm rows		20-cm rows		
Year	1x	0.67X	1x	0.67X	Significance (P=0.05)
Direct-Seeded Wheat Stubble Experiment					
96	431a	427ab	418b	420ab	rs
97	482ab	469b	488a	486a	-
98	381b	393ab	399a	395ab	-
96-98	431a	430a	435a	433a	sr, yr*rs
Tilled Fallow Experiment					
96	450a	451a	450a	450a	-
97	470ab	458b	480a	466ab	sr, sr*rs
98	420a	413a	408a	339b	-
96-98	445a	439a	446a	414b	sr. vr*rs

Table 11. Proportion of sunlight reaching the soil surface for 20- and 30-cm row spacings at 1X seed rate at four times after seeding for several crops for the tilled fallow experiment.

	26 days after seeding		43 days after seeding		50 days after seeding		62 days after seeding	
Crop	20-cm	30-cm	20-cm	3 O-cm	20-cm	30-cm	20-cm	30-cm
Durum	0.93	0.93	0.40	0.53	0.32	0.35	0.26	0.24
Wheat	0.95	0.93	0.39 a[z]	0.54 b	0.26	0.43	0.16	0.23
Canola	0.88	0.90	0.36	0.33	0.17	0.21	0.07	0.07
Flax	0.94	0.98	0.55 a	0.65 b	0.45 a	0.57 b	0.20 a	0.29 b
O. Mustard	0.72	0.79	0.16 a	0.22 b	0.13	0.14	0.08	0.08
Desi	0.94	0.96	0.75	0.77	0.59	0.65	0.19	0.28
Lentil	0.94	0.89	0.44	0.47	0.32	0.32	0.10	0.11
N.L. Pea	0.86	0.87	0.32	0.53	0.21	0.36	0.07	0.16

[z] means within days not followed by the same letter are significantly different (P=0.05)

Table 12. Proportion of sunlight reaching the soil surface for 20- and 30-cm row spacings at 1X seed rate at five times after seeding for several crops for the direct-seeded wheat stubble experiment.

	22 days after seeding		31 days after seeding		42 days after seeding		48 days after seeding		58 days after seeding	
Cron	20-cm	3 O-cm	20-cm	3 O-cm	20-cm	3 O-cm	20-cm	30-cm	20-cm	30-cm
Durum	0.94	0.91	0.80	0.86	0.72	0.65	0.45	0.54	0.32	0.32
Wheat	0.93	0.91	0.83	0.86	0.66	0.71	0.43	0.43	0.3 1	0.33
Canola	0.91	0.93	0.81	0.84	0.49	0.43	0.29 a[z]	0.39 b	0.19	0.25
Flax	0.89	0.95	0.87	0.87	0.67	0.70	0.68	0.60	0.36	0.42
O. Mustard	0.90 a	0.96 b	0.82	0.82	0.34	0.50	0.35	0.39	0.18	0.22
Desi	0.96	0.91	0.88	0.87	0.76	0.80	0.59	0.65	0.47	0.49
Lentil	0.92	0.90	0.84	0.85	0.72	0.74	0.51	0.48	0.31	0.3 1
N.L. Pea	0.90	0.96	0.80	0.85	0.64	0.63	0.48	0.49	0.26	0.3 1

[z] means within days not followed by the same letter are significantly different.(P=0.05)

Table 13. Water use (cm) on the seed row and midway between the seed rows from early and mid growing season for the 20- and 30-cm row spacings at 1X seed rate for on the row and between the row in 1998 for three crops on the direct-seeded wheat stubble experiment.

	20-cm		30-cm	
Crop	On row	Between row	On row	Between row
	April 30 to June 23 1998			
Canola	**8.4a** [z]	**7.6ab**	**7.3b**	**7.8ab**
N.L.Pea	8.0	7.9	7.1	7.6
Wheat	9.5	7.9	7.4	7.8

[z] means within days not followed by the same letter are significantly different.(P=0.05)

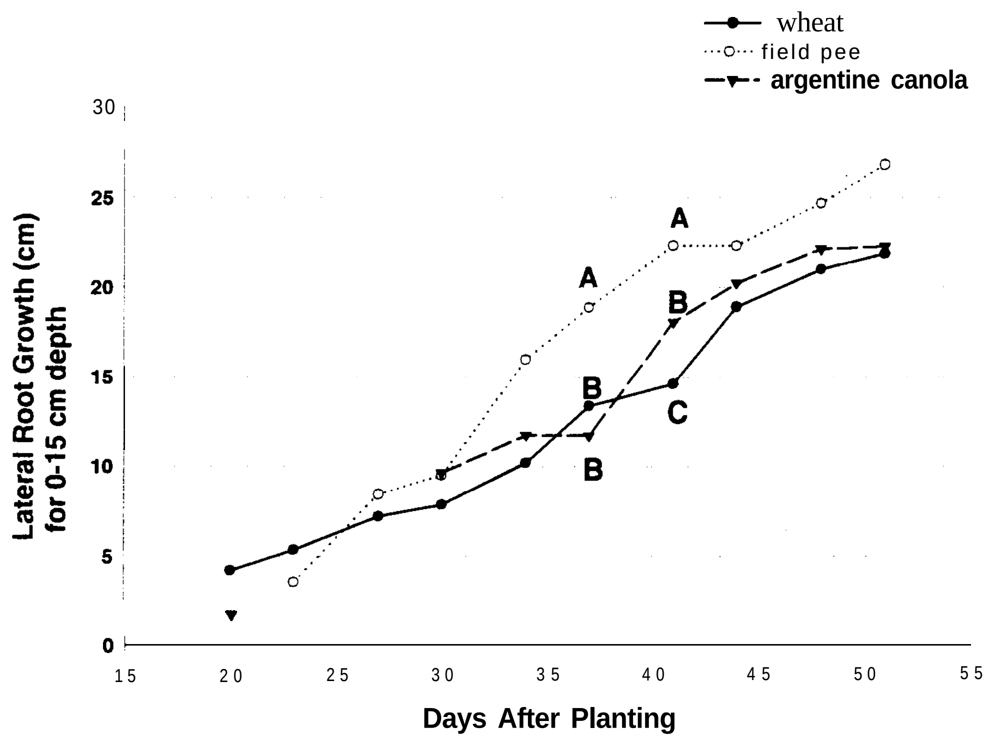

Figure 1. Lateral root expansion for N.L. field pea, canola, and wheat in 1998 in the direct-seeded wheat stubble experiment.