SK-10

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SEEDING ON WIDE ROW SPACINGS

Understanding how to make it work with zero-till...

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INTRODUCTION

The development of Zero-Till or Direct Seeding production systems implies working with standing stubble and surface residues. Residue management and the ability of seeding implements to plant in those conditions are the key to success with these new crop production systems.

Research has shown that higher yields can be obtained with narrow row spacings. However this conflicts with the efforts of getting producers to adopt conservation tillage because it will make Zero-Till more difficult not to mention the increased soil disturbance, cost of seeding equipment and draft requirements. In fact, producers are faced with the dilemma of balancing the use of tall stubble to trap snow with risking lower yields because of the wide row spacings required to seed under those conditions.

Studies were initiated in 1989 at Indian Head to re-evaluate the effects of row spacing, seeding rate and nitrogen fertilizer in spring and winter wheat, barley, durum and flax under zero-till conditions. The purpose was to determine what yield decreases would be observed with 30 cm row spacings, if any, and whether the lower yields could be offset by more favorable economics with wide row spacing due to reduced costs.

Our results have shown that no yield losses were observed by going to 30 cm row spacings, even with flax (Lafond, 1993 and 1994). In the case of durum, we have consistently observed better yields on 30 cm row spacing than 10 or 20 cm. These results conflict with previous results and explanations for the discrepancy between our results and those of other researchers in Saskatchewan has to be addressed. It should be noted that Dr. Byron Irvin at S.I.D.C. in Outlook, SK has repeated the row spacing studies under irrigation and is observing similar results to those from Indian Head.

Examination of the methodology used in the other studies has revealed some confounding effects pertaining to the management of phosphorus fertilizer and plant populations. In some studies the amount of phosphorus was kept constant per row thereby biasing against wide row spacings with the balance being broadcast on the surface. In other studies, the phosphorus fertilizer was broadcast on the surface after seeding in order to avoid confounding the concentration of phosphorus with the seed. In our studies, phosphorus fertilizer was kept constant per area and consequently the amount of phosphorus per row increases as row spacing increases. As well, a zero-till continuous cropping system was used as opposed to conventional fallow or stubble cropping systems.

It is postulated that the row spacing effects observed in the past are a function of P management and plant populations. Proper management of P combined with optimum plant populations can help explain the observed yield decreases at wide row spacing from previous studies.

OBJECTIVES OF STUDY

(1) To examine the interactions of row spacing, seeding rate and seed-placed phosphorus on yield and yield components of spring and winter wheat, barley and durum as well as seedling growth and development, biomass accumulation and P uptake at anthesis.

(2) To determine possible interactions between row spacing, seeding rate and seed-placed phosphorus on grain yield.

(2) to examine the effects of row spacing and seeding rate under conventional fallow cropping conditions in spring wheat and barley.

MATERIALS AND METHODS

Seeding Methods: A small plot seeder equipped with 13 hoe openers on a tool bar spaced 10 cm apart was used for seeding all the experiments. The two outside openers seeded the border rows at a rate of 134 kg ha^{-1} for durum and spring wheat and 108 kg ha^{-1} for barley. The distance between adjacent plots was 25 cm. The 13 openers were in the soil at all times. Row spacing was varied by directing the seed from a rotating cone mechanisms to the desired openers. The ammonium phosphate fertilizer was placed with the seed at the same rate per hectare for the three row spacings; therefore, the ammonimum phosphate fertilizer was three times more concentrated per row at a 30-cm spacing than at a 10-cm spacing. Plots were trimmed to 6.1 m in length at heading time and the border rows were removed just before harvesting. The areas used to calculate yield for the 10-, 20- and 30-cm spacings were 6.81, 6.11 and 5.57 m^2, respectively. The number of rows present for the 10, 20 and 30 cm row spacings are 11, 5 and 3, respectively.

Locations: The test on fallow was only carried out at Indian Head (Indian Head Heavy Clay soil) while the row spacing x seeding rate x phosphorus trial was carried out at Indian Head and Rapid City (Newdale Clay Loam), Manitoba. Winter wheat was only included at the Indian Head site.

Agronomic: A summary of pertinent agronomic information is provided in Tables 1, 2 and 3. The study on stubble pertaining to the effects of row spacing, seeding rate and rate of seed-placed phosphorus used the following treatments:

row spacing: 10,20 and 30 cm
seeding rate: wheat 67, 134 and 201 kg/ha
barley 43, 86 and 129 kg/ha
P_2O_5: 0, 18 and 36 kg/ha NOTE: Mono ammonium phosphate fertilizer was used (12-51-0). Ammonimum nitrate fertilizer was added to the 0 and 18 kg/ha rates to bring them to the same level of N as the 36 kg/ha rate.

Table 1. Summary of chemical weed control practises.

Location	System	Crop	Pre-Seeding			In-Crop		
			Date	**Prod.**	**Rate gai/ ha**	**Date**	**Prod.**	**Rate gai/ ha**
Indian Head	Fallow	SWht	n/a	n/a	na/	June 3, 1993	Bromo and MCPA E	560
		Bly	n/a	n/a	n/a	May 20, 1993	Bromo and MCPA E	560
Indian Head	Stubb.	WWht	Oct 22, 1992	2,4-D	400	May 20, 1993	2,4-D + Dicam ba	544
		SWht	n/a	n/a	n/a	June 1, 1993	Dicam ba + Mecop +MCPA A	400
		Dur	n/a	n/a	n/a	"	"	"
		Bly	n/a	n/a	n/a	"	"	"
Rapid City[1]	Stubb.	SWht	n/a	n/a	n/a	June 11, 1993	2,4-D + Dicam ba	544
		Dur	n/a	n/a	n/a	"	"	"
		Bly	n/a	n/a	n/a	"	"	"

[1] The plots at Rapid City were injured as a result of the in-crop herbicide application. The damage was most severe on spring wheat. The obvious signs were spike twisting, stem breakage and straw shortening. The dry matter values for anthesis and maturity are not reported due to the high level of variability.

Table 2. Summary of seeding and harvest dates, soil test levels for N and P and amount of fertlizer N added.

Location	**Crop**	**Variety**	**Seed. Date**	**Harv. Date**	**Soil Test N kg/ha**	**Soil Test P kg/ha**	**Fert N Added kg/ha**[1]
Indian Head **Stubble**	WWht	Norstar	Sept. 1, 1992	Aug. 27, 1993	46.3	10.1	89.6
	Bar.	Harrington	May 3, 1993	Sept. 3, 1993	44.4	17.7	78.4
	SWht	Laura	May 3, 1993	Sept. 8, 1993	44.4	17.7	78.4
	Dur	Kyle	May 3, 1993	Sept. 8, 1993	44.4	17.7	78.4
Indian Head **Fallow**[2]	SWht	Biggar	Apr. 23, 1993	Sept 7, 1993	n/a	n/a	n/a
	Bly	Harrington	Apr. 23, 1993	Aug 27, 1993	n/a	n/a	n/a
Rapid City **Stubble**	SWHT	Katepwa	May 11, 1993	Sept. 27, 1993	16	32	50
	Dur	Sceptre	May 11, 1993	Sept. 27, 1993	16	32	50
	Bly	Manley	May 12, 1993	Sept. 27, 1993	16	32	50

[1] Fertilizer in the form of ammonium nitrate (34.5-0-0) was broadcast on April 13, 1993 at Indian Head and on May 6 at Rapid City, MB using a Valmar 15′ spreader.

[2] The amount of phosphorus (P_2O_5)placed with the seed was 31.6 kg/ha.

Table 3. Summary of total spring soil moisture recorded for the various sites for different soil depths.

Location	System	Crop	Total Spring Soil Moisture (cm) for different depths.			
			0-30 cm	30-60 cm	60-120 cm	0-120 cm
Indian Head	Stubble	Barley	9.4	7.4	13.5	30.3
		S. Wheat	10.8	9.4	16.3	36.5
		Durum	9.8	11.2	18.1	39.1
		W. Wheat	10.9	8.6	17.2	36.7
	Fallow	S. Wheat	11.0	12.1	18.5	41.6
		Barley	11.0	12.1	18.5	41.6
Rapid City	Stubble	Barley	11.6	9.8	16.7	38.1
		S.Wheat	10.8	8.4	14.1	33.3
		Durum	13.2	7.8	10.4	31.4

Sampling times:

Table 4. Summary of biomass sampling dates for the Indian Head and Rapid City sites.

Location	System	Crop	Seedling Stage	Anthesis	Maturity
Indian Head	Stubble	Winter Wheat	May 19/93	July 2/93	Aug 7/93
		Barley	May 26/93	July 9/93	Aug27/93
		Spring wheat	May 28/93	July14/93	Aug27/93
		Durum	May 31/93	July26/93	Aug27/93
Rapid City	Stubble	Spring Wheat	June 9/93	July29/93	Aug24/93
		Barley	June 9/93	July22/93	Aug24/93
		Durum	June10/93	July29/93	Aug24/93

Experimental Design: The experiment on fallow was set up as a factorial randomized complete block design with four replicates (Part A). The studies pertaining to the interaction of row spacing, seeding rate and seed-placed phosphorus used a factorial randomized complete block design with six replicates(Part B). In the latter case the first three replicates were used for yield and yield component determinations and the last three replicates were use for destructive sampling, in this case for biomass accumulation and seedling growth and development measurements.

RESULTS AND DISCUSSION

PART A: Row Spacing x Seeding Rate Effects Under a Conventional Tillage, summerfallow production system in Spring Wheat and Barley.

The objectives of this experiment were to verify whether or not the results obtained under zero-till stubble cropping conditions could be duplicated using conventional till summerfallow conditions. In this case, the plots were seeded on an area used for the increase of breeder seed which consisted of 2 consecutive years of summerfallow.

Spring Wheat:

The results from the analysis of variance are given in Table A1. Row spacing had a significant effect on kernels per meter square plant height and grain yield while seeding rate had an effect on all variables measured except plant height. A row spacing x seeding rate interaction was only observed for plant height.

Table A1. Summary of analysis of variance for the various variables measured for spring wheat (cv Biggar).

Source	Plants m^{-2}	Heads m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Height	1000 Seed Weight	Grain Yield
Spacing (RS)	ns	ns	ns	**	*	ns	**
Seed Rate (SR)	***	*	*	**	ns	**	**
Rep	ns	*	ns	**	ns	**	**
RSxSR	ns	ns	ns	ns	*	ns	ns

The effects of row spacing on the various variables measured are given in Table A2. The number of kernels per meter square increased significantly as row spacing increased and plant height was significantly greater for the 30 cm than either the 10 or 20 cm spacings. In terms of yield, the 20 and 30 cm spacing were similar but significantly greater than the 10 cm spacing. The increase over the 10 cm spacing was on the order of 4.7%. Based on the results of this trial, yields on 30 cm spacings can be more than maintained under summerfallow cropping conditions, even when no crop residues are present.

Table A2. Summary of means for variables measured as a function of row spacing for spring wheat (cv. Biggar). Each value represents the mean of 24 observations.

Row Spacing (cm)	Plants m^{-2}	Heads m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Height (cm)	1000 Seed Wt (g)	Grain Yield kg/ha
10	271	543	25.1	12487	78	42.0	5234
20	249	540	25.2	13153	78	41.8	5481
30	243	572	24.4	13433	80	41.0	5478
s.e	11	22	1.4	48	1	0.3	37
Contrast							
10+20 vs30 cm	ns	ns	ns	**	**	*	**
10vs20 cm	ns	ns	ns	**	ns	ns	**

A summary of the effects of seeding rates is given in Table A3. Increases in seeding rates were followed by increases in the number of plants and heads produced, increases in grain yield and seed weight and a decrease in kernels per meter square and kernels per spike with no differences for plant height. The increase in seed weight is surprising considering that in previous studies the results show no effect in seed weight or a small decrease with seeding rate. The response of yield to seeding rate tended to be flat with the largest increment observed when going from 34 to 67 kg/ha.

In summary, the greatest effect of seeding rate was on the number of plants established and the number of spikes produced which translated into only small differences in yield.

Table A3. Summary of means for variables measured as a function of seeding rate for spring wheat (cv. Biggar). Each value represents the mean of 12 observations.

Seeding Rate kg/ha	Plants m^{-2}	Heads m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Height (cm)	1000 Seed Wt (g)	Grain Yield kg/ha
34	97	474	29.0	13354	79	38.1	5075
67	150	517	27.1	13548	80	40.4	5465
100	231	581	23.2	13040	79	41.9	5448
134	259	519	27.8	13078	78	41.8	5461
168	365	617	21.4	12898	80	42.9	5501
202	427	602	21.0	12228	78	44.6	5437
s.e.	16	31	1.9	214	1	0.5	53

Barley:

The results for the analysis of variance are given in Table A4. Row spacing had no significant effect on the variables measured while seeding rate affected all variables except kernels per meter square and seed weight. No interaction was observed between row spacing and seeding rate.

Table A4. Summary of analysis of variance for the various yield components of spring barley.

Source	Plants m^{-2}	Heads m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Height	1000 Seed Weight	Grain Yield
Spacing (RS)	ns	ns	ns	ns	ns	ns	ns
Seed Rate (SR)	***	**	**	ns	**	ns	*
Rep	ns	*	ns	ns	**	ns	ns
RSxSR	ns	ns	ns	ns	ns	ns	ns

The values measured for the effect of row spacing are given in Table A5. It should be noted that seeding on 30 cm had no effect on yield, even in the yield range of 6000-6300 kg ha^{-1} and this represents the upper range for barley yields for most of Western Canada. This means that the concept of seeding on 30 cm spacing is feasible for most of Western Canada.

Table A5. Summary of means of variables measured as a function of row spacing for barley (cv. Harrington).

Row Spacing (cm)	Plants m^{-2}	Heads m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Height (cm)	1000 Seed Wt (g)	Grain Yield kg/ha
10	170	1082	15.4	15877	80	38.5	6066
20	174	1075	17.0	16658	80	38.3	6335
30	153	1084	15.5	15881	80	38.5	6059
s.e	11	47	0.8	450	1	0.6	123
Contrast							
10+20 vs30 cm	ns	ns	ns	ns	ns	ns	ns
10vs20 cm	ns	ns	ns	ns	ns	ns	ns

Seeding rate had more notic eable effects (Table A6). As seeding rate increased, the number of plants established and heads produced increased along with grain yield but plant height and kernels per spike decreased. This is similar to previous observations reported for barley (Lafond, 1994). The response of yield to seeding rate was more pronounced for barley than spring wheat. Maximum yield was obtained with a seeding rate of approximately 108 kg ha^{-1} which supports the previous observations.

Table A6. Summary of means for variables measured as a function of seeding rate for barley (cv. Harrington). Each value represents the mean of 12 observations.

Seeding Rate (kg/ha)	Plants m^{-2}	Heads m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Height (cm)	1000 Seed Wt (g)	Grain Yield kg/ha
27	83	852	19.0	14461	87	39.0	5587
54	92	901	18.5	15875	82	38.0	6022
81	137	1145	14.8	16344	77	38.6	6252
108	187	1179	14.1	16303	78	39.9	6485
134	215	1156	14.7	16675	77	37.8	6240
161	280	1250	14.4	17174	78	37.1	6336
s.e.	16	67	1.2	637	1	0.8	174

PART B: The effects of row spacing, seeding rate and seed-placed phosphorus in spring and winter wheat, durum and barley under a zero-till cropping system at Indian Head.

In order to ensure clarity in the discussion of the results, each crop will be discussed separately.

Winter Wheat:

A summary of the analysis of variance for the variables measured is given in Table B1.

A row spacing effect was observed on all variables measured while for seeding rate, a significant effect was only observed four of the seven variables measured. A significant P effect was observed for only kernels per meter square and yield.

Only one significant interaction was observed, seeding rate x phosphorus for the number of plants established. The nature of the interaction was such that at the higher seeding rates, the high rate of phosphorus had a larger effect in reducing plant numbers at the higher seeding rates than at the lower seeding rates.

The effects of row spacing are given in Table B2. As row spacing increased, the number of plants established and heads produced decreased while kernels per spike, kernel per meter square, plant height, seed weight and grain yield increased.

The effects of seeding rate are given in Table B3. As seeding rate increased, plant and head numbers increased while kernels per spike, plant height and seed weight decreased.

The effects of phosphorus are given in Table B4. Phosphorus increased kernels per meter square, plant height and yield with no effects on the other variables.

Table B1. Summary of analysis of variance for variables measured for winter wheat.

Source	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha	Dry matter[1] kg/ha			Nutrient content at S2 kg/ha	
								S1	S2	S3	N	P
Spacing RS	**	**	**	**	**	ns	**	ns	**	**	**	**
Rate SR	**	*	**	ns	*	ns	ns	**	ns	ns	ns	ns
P	ns	ns	ns	**	ns	ns	**	*	**	ns	**	**
Rep	**	*	ns	**	**	ns	**	**	**	*	**	**
RSxSR	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
RSxP	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
SRxP	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
RSxSRxP	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1] The sampling times S1, S2 and S3 correspond to seedling, anthesis and maturity, respectively.

Table B2. The effects of row spacing on measured variables in winter wheat.

Row Spacing cm	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
10	254	573	14.9	7714	80	30.4	2344
20	195	435	20.5	8391	81	30.8	2563
30	176	408	24.9	8640	84	31.8	2738
s.e	13	30	1.9	175	1	0.4	45
Contrast							
10+20vs30	**	**	**	**	**	*	**
10vs20	**	**	*	**	ns	ns	ns

Table B3. The effects of Seeding rate on measured variables in winter wheat.

Seeding Rate kg/ha	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
67	129	411	25.1	8011	84	31.9	2548
134	224	483	18.5	8482	81	30.7	2602
201	272	522	16.7	8252	80	30.4	2495
s.e	13	30	1.9	175	1	0.4	45
Contrast							
67 vs 134+201	**	*	**	ns	**	*	ns
134vs 201	*	ns	ns	ns	ns	ns	ns

Table B4. The effects of seed-placed phosphorus on measured variables in winter wheat.

P_2O_5 kg/ha	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
0	226	461	18.7	7117	80	30.8	2189
18	212	450	20.0	8496	82	31.3	2654
36	186	504	21.5	9131	83	30.9	2802
s.e	13	30	1.9	175	1	0.4	45
Contrast							
0 vs 18+36	ns	ns	ns	**	*	ns	**
18 vs 36	ns	ns	ns	*	ns	ns	*

Spring Wheat:

A summary of the analysis of variance for the variables measured is given in Table B5. Row spacing had a significant effect on all variable except plant numbers, kernels per meter square and grain yield. Seeding rate had a significant effect on all variables while phosphorus only affected kernels per meter square and yield.

A significant row spacing x seeding rate interaction was observed for kernels per meter square and grain yield. The nature of the interaction for kernels per meter square was one of difference in the magnitude of the response rather than changes in rank. In absolute terms, the interaction is not important. The same argument can be used for the interaction of row spacing and seeding rate on grain yield. A row spacing x seeding rate x phosphorus was observed for kernels per spike.

Table B5. Summary of analysis of variance for variables measured for spring wheat.

Source	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha	Dry matter[1] kg/ha			Nutrient content at S2 kg/ha	
								S1	S2	S3	N	P
Spacing RS	ns	**	*	ns	*	**	**	ns	ns	ns	ns	ns
Rate SR	**	**	*	*	**	*	*	**	ns	*	ns	ns
P	ns	ns	ns	**	ns	ns	**	*	**	**	**	**
Rep	ns	ns	ns	*	**	ns	*	ns	**	**	**	**
RSxSR	ns	ns	ns	*	ns	ns	*	ns	ns	*	ns	ns
RSxP	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
SRxP	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns
RSxSRxP	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1] The sampling times S1,S2 and S3 correspond to seedling, anthesis and maturity, respectively.

The effects of row spacing are given in Table B6. As row spacing increased, head numbers decreased and kernels per spike, plant height and seed weight increased.

The effects of seeding rate are given in Table B7. As seeding rate increased, plant and head numbers and yield increased while kernels per spike, plant height and seed weight decreased.

The effects of phosphorus fertilizer is given in Table B8. As the rate of phosphorus increased, kernels per meter square, plant height and yield increased.

Table B6. The effects of row spacing on measured variables in spring wheat.

Row Spacing cm	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
10	233	471	23.2	10380	92	30.4	3155
20	248	408	27.3	10755	92	30.9	3324
30	224	418	26.4	10902	96	31.3	3411
s.e	17	14	1.0	255	1	0.2	78
Contrast							
10+20vs30	ns	ns	ns	ns	**	**	ns
10vs20	ns	**	**	ns	ns	*	ns

Table B7. The effects of Seeding rate on measured variables in spring wheat.

Seeding Rate kg/ha	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
67	143	393	27.2	10393	97	31.2	3247
134	225	411	26.1	10380	91	30.8	3191
201	337	493	23.5	11264	92	30.6	3452
s.e	17	14	1.0	255	1	0.2	78
Contrast							
67 vs 134+201	**	**	*	ns	**	*	ns
134vs 201	**	**	ns	*	ns	ns	*

Table B8. The effects of seed-placed phosphorus on measured variables in spring wheat.

P_2O_5 kg/ha	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
0	240	415	25.0	9938	91	30.8	3060
18	224	438	25.1	10563	94	30.9	3268
36	240	443	26.8	11535	94	30.9	3562
s.e	17	14	1.0	255	1	0.2	78
Contrast							
0 vs 18+36	ns	ns	ns	**	*	ns	**
18 vs 36	ns	ns	ns	**	ns	ns	**

Durum:

A summary of the analysis of variance is given in Table B9. Row spacing had a significant effect on all variables measured except kernels per spike and plant height while seeding rate had a significant effect on all variables. Phosphorus affected all variables except plant numbers, plant height and seed weight. Only one interaction was observed in this experiment, a row spacing x seeding rate x phosphorus for plant numbers.

As row spacing increased, plant and head numbers decreased while seed weight increased with no effect on final grain yield (Table B10). As seeding rate increased, plant and head numbers, kernels per meter square and yield increased while kernels per spike, plant height and seed weight decreased(Table B11). With phosphorus, increasing rates increased head numbers, kernels per meter square and yield but decreased kernels per spike (Table B12).

Table B9. Summary of analysis of variance for variables measured for durum wheat.

Source	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha	Dry matter[1] kg/ha			Nutrient content at S2 kg/ha	
								S1	S2	S3	N	P
Spacing RS	*	**	ns	**	ns	**	**	**	ns	ns	ns	*
Rate SR	**	**	*	**	**	**	**	**	ns	*	ns	ns
P	ns	**	*	**	ns	ns	**	ns	*	ns	ns	**
Rep	ns	ns	ns	**	ns	ns	**	ns	*	ns	**	**
RSxSR	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns
RSxP	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	*
SRxP	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns
RSxSRxP	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1] The sampling times S1,S2 and S3 correspond to seedling stage, anthesis and maturity, respectively.

Table B10. The effects of row spacing on measured variables in durum.

Row Spacing cm	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
10	180	414	25.3	9371	116	41.2	3861
20	167	363	27.9	9901	117	41.0	4061
30	149	333	29.1	9595	117	42.3	4056
s.e	8	14	1.2	106	1	0.2	45
Contrast							
10+20vs30	*	**	ns	ns	ns	**	ns
10vs20	ns	*	ns	**	ns	ns	**

Table B11. The effects of seeding rate on measured variables in durum.

Seeding Rate kg/ha	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
67	98	319	30.1	8874	119	42.1	3737
134	159	395	26.8	10159	117	41.4	4208
201	239	396	25.5	9834	114	41.1	4033
s.e	8	14	1.2	106	1	0.2	45
Contrast							
67 vs 134+201	**	**	**	*	**	**	ns
134vs 201	**	ns	ns	**	**	ns	ns

Table B12. The effects of seed-placed phosphorus on measured variables in durum wheat.

P_2O_5 kg/ha	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
0	160	326	30.1	9130	117	41.6	3799
18	167	374	26.8	9803	118	41.4	4053
36	169	410	25.4	9934	116	41.6	4126
s.e	8	14	1.2	106	1	0.2	45
Contrast							
0 vs 18+36	ns	**	**	**	ns	ns	**
18 vs 36	ns	ns	ns	ns	ns	ns	ns

Barley:

A summary of the analysis of variance is given in TableB13. Row spacing had a significant effect on kernels per meter square and plant height. Seeding rate affected all variables and phosphorus had a significant effect on head numbers, kernels per meter square and yield. A significant row spacing x phosphorus interaction was observed for plant and head numbers and kernel per meter square. A significant seeding rate x phosphorus interaction was also observed for kernels per meter square and yield.

As row spacing increased, plant numbers decreased and plant height increased (Table B14). With increasing seeding rates, plant and head numbers, kernels per meter square and yield increased while kernels per spike, plant height and seed weight decreased (Table B15). With increasing rates of phosphorus, head numbers, kernel per meter square and yield increased (Table B16).

Table B13. Summary of analysis of variance for variables measured for barley.

Source	Plant m^{-2}	Head m^{-2}	Kernel spike^{-1}	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha	Dry matter[1] kg/ha			Nutrient content at S2 kg/ha	
								S1	S2	S3	N	P
Spacing RS	ns	ns	ns	**	*	ns	ns	**	ns	ns	ns	ns
Rate SR	**	**	**	**	**	**	**	**	*	ns	ns	ns
P	ns	**	ns	**	ns	ns	**	ns	*	ns	ns	**
Rep	ns	ns	ns	**	**	ns	**	ns	ns	**	ns	ns
RSxSR	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
RSxP	*	*	ns	*	ns	ns	ns	ns	ns	ns	ns	ns
SRxP	ns	ns	ns	*	ns	ns	*	ns	ns	ns	ns	ns
RSxSRxP	ns	*	*	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1] The sampling times S1, S2 and S3 correspond to seedling stage, anthesis and maturity, respectively.

Table B14. The effects of row spacing on measured variables in barley.

Row Spacing cm	**Plant m^{-2}**	**Head m^{-2}**	**Kernel $spike^{-1}$**	**Kernel m^{-2}**	**Plant Ht. cm**	**1000 Seed Wt. g**	**Grain Yield kg/ha**
10	157	786	16.7	12280	68	37.9	4632
20	159	795	16.8	12923	67	37.0	4757
30	143	753	18.0	12966	70	37.0	4785
s.e	6	27	0.6	159	1	0.4	56
Contrast							
10+20vs30	*	ns	ns	ns	*	ns	ns
10vs20	ns	ns	ns	**	ns	ns	ns

Table B15. The effects of Seeding rate on measured variables in barley.

Seeding Rate kg/ha	**Plant m^{-2}**	**Head m^{-2}**	**Kernel $spike^{-1}$**	**Kernel m^{-2}**	**Plant Ht. cm**	**1000 Seed Wt. g**	**Grain Yield kg/ha**
54	81	644	18.9	11532	73	39.0	4481
108	155	809	16.5	13017	68	37.1	4823
161	223	882	16.2	13620	65	35.8	4869
s.e	6	27	0.6	159	1	0.4	56
Contrast							
54 vs 108+161	**	**	**	**	**	**	**
108vs 161	**	ns	ns	**	*	*	ns

Table B16. The effects of seed-placed phosphorus on measured variables in barley.

P_2O_5 kg/ha	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
0	153	704	18.1	12171	67.8	37.3	4517
18	151	788	17.1	12940	68.3	37.1	4779
36	154	842	16.3	13056	69.5	37.5	4878
s.e	6	27	0.6	159	1	0.4	56
Contrast							
0 vs 18+36	ns	**	ns	**	ns	ns	**
18 vs 36	ns	ns	ns	ns	ns	ns	ns

As mentioned earlier, a number of interactions were identified. The row spacing x P interaction on plant m^{-2} was due to no effect of P with 10 cm spacing, a decrease at 20 cm and an increase at 30 cm (Table B17). In the case of heads per meter square, increasing rates of phosphorus resulted in increasing head numbers on 10 and 20 cm spacings with no difference on the 30 cm row spacing (Table B18). With kernels per meter square, the difference between the 0 P and the high P rate decreased as row spacing increased (Table B19).

In the case of the seeding rate x phosphorus interaction, as seeding rate increased, the response to P decreased for kernels per meter square. At the higher seeding rates, the 0 P rate produced as many kernels as the high rate of P but the opposite was observed at the low sseding rates (Table B20). In the case of yield, the response to P changed as seeding rate increased such that with the high seeding rate, maximum yield was obtained even without the use of P fertilizer (Table B21).

Table B17. The effects of row spacing and phosphorus on the plants m^{-2}.

Row Spacing (cm)	P_2O_5 (kg//ha)[1]		
	0	**18**	**36**
10	153	161	157
20	176	156	144
30	133	136	162

[1] The s.e. of the means=10.

Table B18. The effects of row spacing and phosphorus on the heads m^{-2}.

Row Spacing (cm)	P_2O_5 (kg//ha)[1]		
	0	18	36
10	697	737	926
20	681	889	815
30	734	740	786

[1] The s.e. of the means=10.

Table B19. The effects of row spacing and phosphorus on the kernels m^{-2}.

Row Spacing (cm)	P_2O_5 (kg//ha)[1]		
	0	18	36
10	11342	12593	12904
20	12193	13525	13051
30	12981	12703	13213

[1] The s.e. of the means=10.

Table B20. The effects of seeding rate and phosphorus on kernels m^{-2}.

Seeding Rate (kg/ha)	P_2O_5 (kg//ha)[1]		
	0	18	36
54	10540	12150	11904
108	12335	13286	13430
161	13641	13384	13385

[1] The s.e. of the means=10.

SUMMARY OF PART B:

The most important findings of this study are how seeding rates and row spacings influence the yield response to phosphate fertilizer. The most dramatic example was with barley because of the significant interaction observed with seeding rate (Figure B1). Although no interaction was observed for row spacing, it would appear that as row spacing increases, the response to P decreases which in essence mimics seeding rates because you are in essence concentrating the seed over a smaller area. It is postulated that the concentration of plants over a smaller area is having a large influence on the rhizosphere which in turn is making P more available to the crop. A similar observation can be made also for winter wheat but in this case, row spacing tended to have a larger influence than seeding rate (Figure B1). In the case of durum, the magnitude of the response rather than the nature of the response was more affected by row spacing and seeding rate (Figure B2). Spring wheat showed the least response (Figure B2).

PART C: The effects of row spacing, seeding rate and seed-placed phosphorus in spring and winter wheat, durum and barley under a zero-till cropping system at Rapid City, Manitoba.

BARLEY

The analysis of variance for all variables measured are given in Table C1. Row spacing had a significant main effect on plant numbers while seeding rate significantly affected plant numbers, kernels per spike and kernels per meter square. No effects due to P were observed. Only one significant interaction was observed ie row spacing by phosphorus.

A summary of the variables measured as a function of row spacing are given in Table C2. As row spacing increased, plant numbers decreased. The reduction was on the order of 26% but did not affect the final grain yield. Seeding rates increased plant numbers, kernels per spike, kernels per meter square and yield but reduced kernel weight and plant height (Table C3). Phosphorus only had a significant effect on kernels per spike, the effect being an increase in kernel numbers per spike at the high rate of P (Table C4). The interaction between row spacing and phosphorus for plant numbers is due to the high plant numbers recorded at 10 cm with 0 P (Table C4). At the other spacings, P did not change plant numbers.

Figure B1.

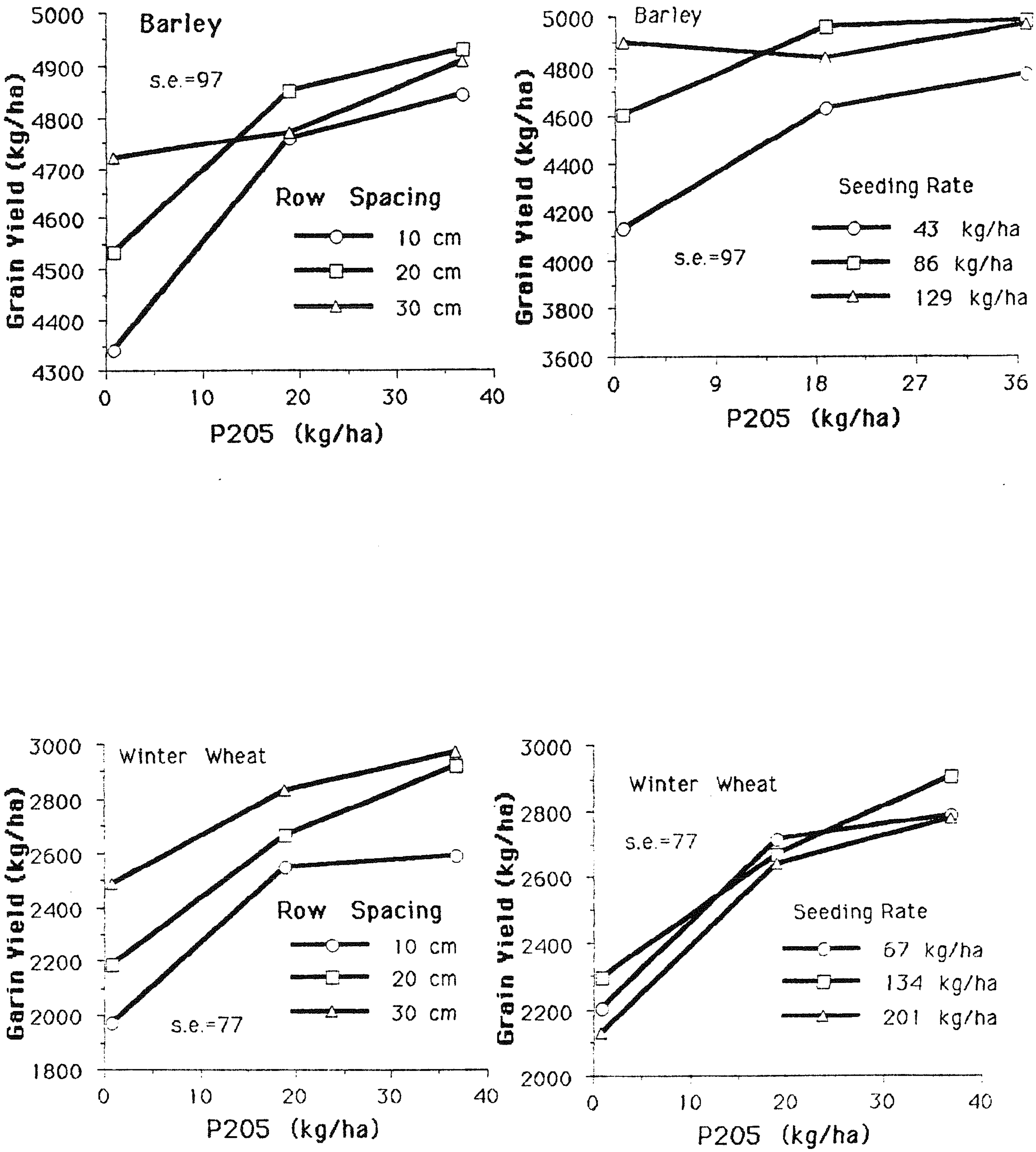
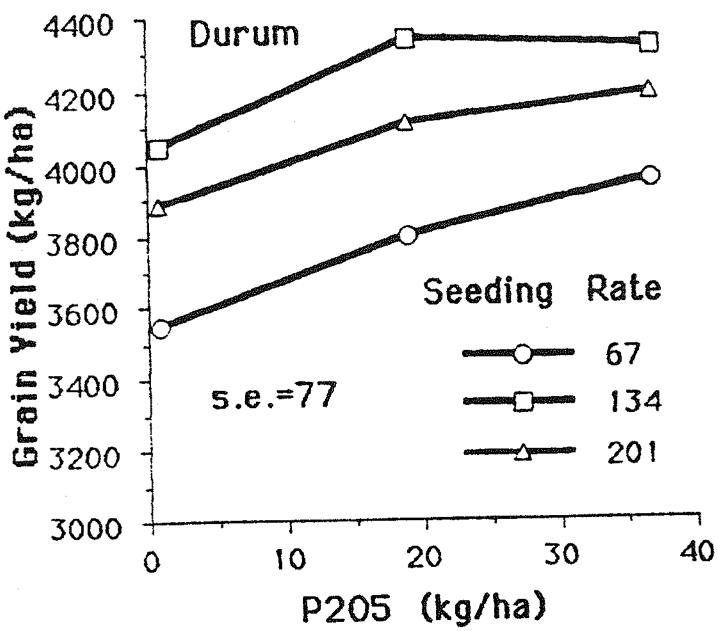
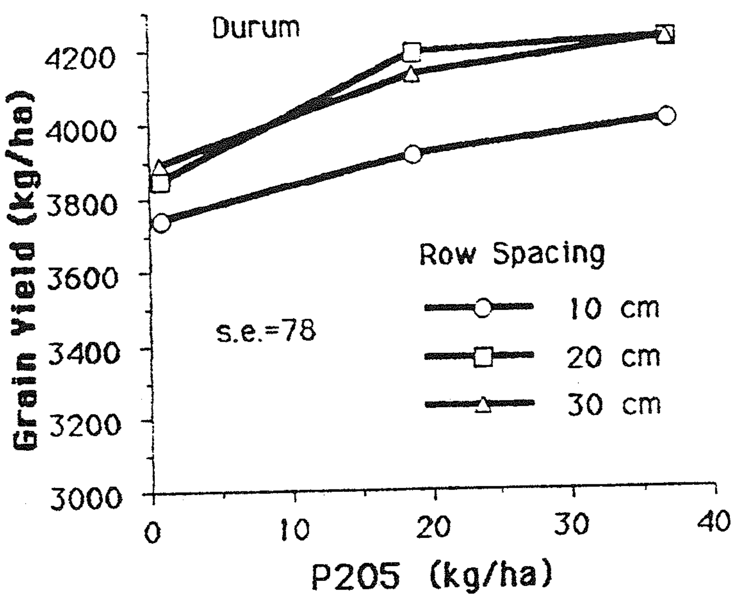
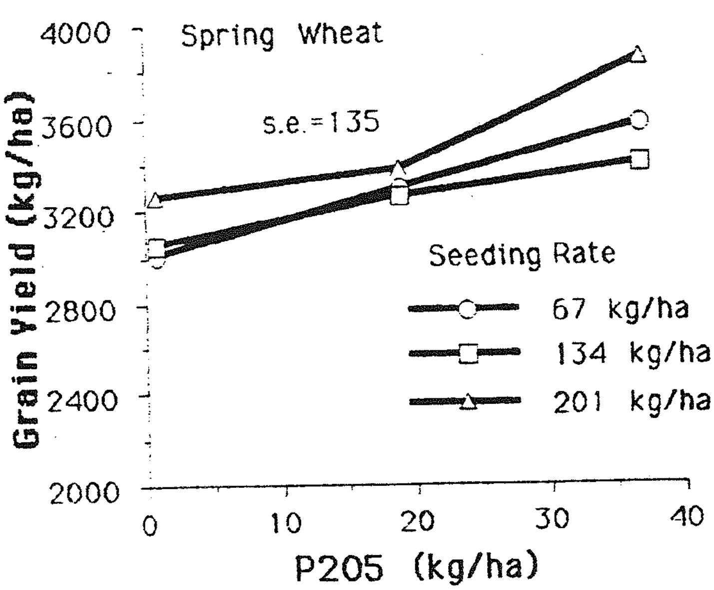

Barley
s.e.=97
Row Spacing
10 cm
20 cm
30 cm
Grain Yield (kg/ha)
P205 (kg/ha)
5000
4900
4800
4700
4600
4500
4400
4300
0
10
20
30
40
Barley
Seeding Rate
43 kg/ha
86 kg/ha
129 kg/ha
s.e.=97
Grain Yield (kg/ha)
P205 (kg/ha)
5000
4800
4600
4400
4200
4000
3800
3600
0
9
18
27
36
Winter Wheat
Row Spacing
10 cm
20 cm
30 cm
s.e.=77
Garin Yield (kg/ha)
P205 (kg/ha)
3000
2800
2600
2400
2200
2000
1800
0
10
20
30
40
Winter Wheat
s.e.=77
Seeding Rate
67 kg/ha
134 kg/ha
201 kg/ha
Grain Yield (kg/ha)
P205 (kg/ha)
3000
2800
2600
2400
2200
2000
0
10
20
30
40

Figure B2.


Durum
Grain Yield (kg/ha)
4400
4200
4000
3800
3600
3400
3200
3000
0
10
20
30
40
P205 (kg/ha)
Seeding Rate
67
134
201
s.e.=77


Durum
Grain Yield (kg/ha)
4200
4000
3800
3600
3400
3200
3000
0
10
20
30
40
P205 (kg/ha)
Row Spacing
10 cm
20 cm
30 cm
s.e.=78


Spring Wheat
Grain Yield (kg/ha)
4000
3600
3200
2800
2400
2000
0
10
20
30
40
P205 (kg/ha)
s.e.=135
Seeding Rate
67 kg/ha
134 kg/ha
201 kg/ha

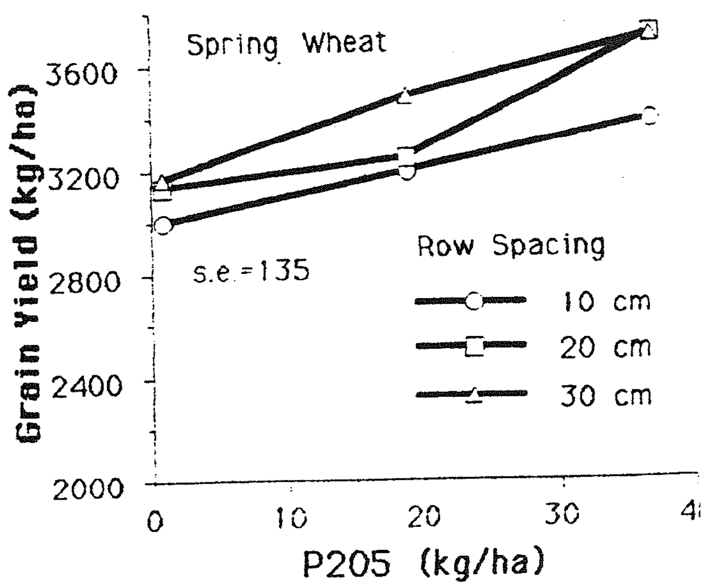

Spring Wheat
Grain Yield (kg/ha)
3600
3200
2800
2400
2000
0
10
20
30
P205 (kg/ha)
Row Spacing
10 cm
20 cm
30 cm
s.e.=135

Table C1. Summary of analysis of variance for variables measured for barley.

Source	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha	Dry matter[1] kg/ha			Nutrient content at S2 kg/ha	
								S1	S2	S3	N	P
Spacing RS	**	ns	ns	ns	ns	ns	ns	ns	-	-	-	-
Rate SR	**	ns	*	**	ns	ns	**	**	-	-	-	-
P	ns	ns	ns	ns	ns	ns	ns	*	-	-	-	-
Rep	ns	**	**	ns	**	ns	**	ns	-	-	-	-
RSxSR	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-
RSxP	*	ns	ns	ns	ns	ns	ns	ns	-	-	-	-
SRxP	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-
RSxSRxP	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-

[1] The sampling times S1,S2 and S3 correspond to seedling stage, anthesis and maturity, respectively.

Table C2. The effects of row spacing on measured variables in barley.

Row Spacing cm	**Plant m^{-2}**	**Head m^{-2}**	**Kernel $spike^{-1}$**	**Kernel m^{-2}**	**Plant Ht. cm**	**1000 Seed Wt. g**	**Grain Yield kg/ha**
10	155	567	13.3	7176	78	40.9	3022
20	128	536	15.2	7640	79	41.4	3162
30	114	540	14.8	7645	81	41.6	3170
s.e	6	22	0.8	219	0.9	0.2	77
Contrast							
10+20vs30	**	ns	ns	ns	ns	ns	ns
10vs20	**	ns	ns	ns	ns	ns	ns

Table C3. The effects of Seeding rate on measured variables in barley.

Seeding Rate kg/ha	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
54	87	527	12.6	6316	79.7	42.6	2792
108	133	539	16.0	7887	80.7	41.3	3261
161	177	579	14.6	8258	77.9	40.0	3301
s.e	6	22	0.8	219	0.9	0.2	77
Contrast							
54 vs 108+161	**	ns	**	**	ns	**	**
108vs 161	**	ns	ns	ns	*	**	ns

Table C4. The effects of seed-placed phosphorus on measured variables in barley.

P_2O_5 kg/ha	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
0	137	546	14.6	7752	80	41.4	3194
18	137	575	13.2	7270	80	41.4	3108
36	124	523	15.5	7439	78	41.1	3053
s.e	6	22	0.8	219	0.9	0.2	77
Contrast							
0 vs 18+36	ns	ns	ns	ns	ns	ns	ns
18 vs 36	ns	ns	*	ns	ns	ns	ns

Table C5. The effects of row spacing and seed-placed phosphorus on plants m^{-2} in barley. (Interaction significant at $p<0.05$).

Row Spacing (cm)	P_2O_5 (kg/ha)		
	0	**18**	**36**
10	14.4	12.3	13.3
20	14.7	13.8	17.1
30	14.9	13.4	16.0

SPRING WHEAT

A summary of the analysis of variance for the study is given in Table C6. Some of the main effects were significant but no significant interactions were observed.

The effects of row spacing are given in Table C7. Plant numbers decreased as row spacing increased but the number of heads produced were similar. Kernels per area was greater as row spacing increased as a result of more kernels per spike. The end result was a slightly better yield on 30 cm spacing than 10 cm on the order of 7%.

The effects of seeding rates are given in Table C8. As seeding rate increased, plant numbers, kernels per area, seed weight and yield increased but not significantly so for head numbers. The greatest yield increase was from 53 to 107 kg/ha.

The effects of seed-placed phosphorus are given in Table C9. The overall observation was that seed-placed phosphorus did not affect the variables measured. The high rate of P tended to decrease plant numbers but only on the order of 6% which was not significant.

Table C6. Summary of analysis of variance for variables measured for spring wheat.

Source	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha	Dry matter[1] kg/ha			Nutrient content at S2 kg/ha	
								S1	S2	S3	N	P
Spacing RS	ns	ns	ns	**	ns	ns	*	*	-	-	-	-
Rate SR	**	ns	ns	**	ns	**	**	**	-	-	-	-
P	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-
Rep	*	ns	ns	**	ns	ns	**	ns	-	-	-	-
RSxSR	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-
RSxP	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-
SRxP	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-
RSxSRxP	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-

[1] The sampling times S1,S2 and S3 correspond to seedling stage, anthesis and maturity, respectively.

Table C7. The effects of row spacing on measured variables in spring wheat.

Row Spacing cm	**Plant m^{-2}**	**Head m^{-2}**	**Kernel $spike^{-1}$**	**Kernel m^{-2}**	**Plant Ht. cm**	**1000 Seed Wt. g**	**Grain Yield kg/ha**
10	271	453	13.4	5723	93	26.2	1500
20	265	439	14.4	5989	93	25.9	1551
30	236	446	15.1	6200	94	25.9	1607
s.e	12	22	0.9	100	1.0	0.2	26.3
Contrast							
10+20vs30	*	ns	ns	**	ns	ns	*
10vs20	ns	ns	ns	ns	ns	ns	ns

Table C8. The effects of seeding rate on measured variables in spring wheat.

Seeding Rate kg/ha	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
67	148	424	14.4	5609	95	25.5	1428
134	275	444	14.8	6145	94	25.9	1590
202	349	470	13.8	6158	92	26.6	1639
s.e	12	22	0.9	100	1.0	0.2	26.3
Contrast							
67 vs 134+202	**	ns	ns	**	ns	**	**
134vs202	**	ns	ns	ns	ns	**	ns

Table C9. The effects of seed-placed phosphorus on measured variables in spring wheat.

P_2O_5 kg/ha	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
0	265	438	14.6	5874	95	25.8	1516
18	258	478	13.5	6028	93	26.1	1573
36	249	423	14.8	6011	93	26.1	1569
s.e	12	22	0.9	100	1.0	0.2	26.3
Contrast							
0 vs 18+36	ns	ns	ns	ns	ns	ns	ns
18 vs 36	ns	ns	ns	ns	ns	ns	ns

DURUM

The analysis of variance for the variables measured are given in Table C10. A number of main effects were observed but only one significant interaction, row spacing by P for kernels per spike.

The effects of row spacing are given in Table C11. As row spacing increased, plant numbers and head numbers decreased but the number of kernels per spike increased with no effect on grain yield.

The effects of seeding rates are given in Table C12. As the rate increased plant numbers and head numbers increased but kernels per spike, kernels per area, plant height and yield decreased.

The effects of seed-placed phosphorus are given in Table C13. P increased head numbers but decreased kernels per spike with no effect on the other variables. The high rate of P reduced the number of plants established.

The interaction between row spacing and P for kernels per spike is due to the higher numbers for the 20 cm spacing at 0 P with no differences for the other rates or spacing.

Table C10. Summary of analysis of variance for variables measured for durum.

Source	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha	Dry matter[1] kg/ha			Nutrient content at S2 kg/ha	
								S1	S2	S3	N	P
Spacing RS	*	ns	*	ns	ns	ns	ns	ns	-	-	-	-
Rate SR	**	**	**	**	**	**	**	**	-	-	-	-
P	*	*	*	ns	ns	ns	ns	ns	-	-	-	-
Rep	ns	ns	*	ns	**	ns	ns	ns	-	-	-	-
RSxSR	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-
RSxP	*	ns	*	ns	ns	ns	ns	ns	-	-	-	-
SRxP	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-
RSxSRxP	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-	-

[1] The sampling times S1, S2 and S3 correspond to seedling stage, anthesis and maturity, respectively.

Table C11. The effects of row spacing on measured variables in durum.

Row Spacing cm	**Plant m^{-2}**	**Head m^{-2}**	**Kernel $spike^{-1}$**	**Kernel m^{-2}**	**Plant Ht. cm**	**1000 Seed Wt. g**	**Grain Yield kg/ha**
10	287	442	9.9	4216	88	54.2	2287
20	261	401	11.4	4255	88	53.8	2294
30	246	411	11.0	4334	89	53.9	2340
s.e	11	13	0.4	88	1	0.3	52
Contrast							
10+20vs30	*	ns	ns	ns	ns	ns	ns
10vs20	ns	*	*	ns	ns	ns	ns

Table C12. The effects of Seeding rate on measured variables in durum.

Seeding Rate kg/ha	**Plant m^{-2}**	**Head m^{-2}**	**Kernel $spike^{-1}$**	**Kernel m^{-2}**	**Plant Ht. cm**	**1000 Seed Wt. g**	**Grain Yield kg/ha**
67	149	362	12.9	4499	92	55.8	2510
134	261	428	10.1	4181	88	53.9	2254
202	384	464	9.4	4127	86	52.3	2157
s.e	11	13	0.4	88	1	0.3	52
Contrast							
67 vs 134+202	**	**	**	**	**	**	**
134vs202	**	ns	ns	ns	ns	**	ns

Table C13. The effects of seed-placed phosphorus on measured variables in durum.

P_2O_5 kg/ha	Plant m^{-2}	Head m^{-2}	Kernel $spike^{-1}$	Kernel m^{-2}	Plant Ht. cm	1000 Seed Wt. g	Grain Yield kg/ha
0	263	391	11.8	4338	89	54.4	2348
18	285	439	9.9	4154	89	54.4	2251
36	245	425	10.7	4317	88	54.0	2321
s.e	6	2	0.8	219	0.9	0.2	77
Contrast							
0 vs 18+36	ns	*	**	ns	ns	ns	ns
18 vs 36	*	ns	ns	ns	ns	ns	ns

SUMMARY OF PART C.

The yields recorded at Rapid City were lower than those recorded at Indian Head. Nonetheless, row spacing did not reduce yields. In the case of spring wheat, the yields were found to be 7% higher for 30 cm than 10 cm. The interesting observations regarding P at Indian Head in barley were not found at this location. The results do support the concept that wider row spacings (23-30cm) can be used successfully under zero-till without having to suffer yield losses. The lack of any P response is more than likely a function of the low yields or else the high levels of residual phosphorus observed at that site. The producer has been using rates of 39 kg/ha of P_2O_5 per year for a minimum of the last 15 years.

Part D. The effects of row spacing, seeding rates and seed-placed phosphorus on plant development, number of seminal roots produced dry matter accumulation and total N and P uptake at anthesis in spring wheat, barley and durum at Indian Head and Rapid City (MB).

Another important component of this study was to look at the effects of row spacing, seeding rates and seed-placed P on other plant characteristics. The discussion will deal with each crop specifically.

BARLEY

Indian Head

The analysis of variance for the plant development characteristics are given in Table D1 while the ones for dry matter, N and P accumulation were given previously in Table B13. No interactions were observed. Significant effects due to row spacing and seeding rate were found for dry matter accumulation in the seedling stage as well as at anthesis for row spacing. A P effect was observed for dry matter at anthesis and for P content at anthesis.

Table D1. Results from analysis of variance for barley.

Source	df	Main Stem Haun Stage	# of Seminal Roots
Spacing (RS)	2	ns	ns
Seeding Rate (SR)	2	ns	ns
Phosphorus (P)	2	**	*
Rep	2	ns	ns
RS*SR	4	ns	ns
RS*P	4	ns	ns
SR*P	4	ns	ns
RS*SR*P	8	ns	ns

Table D2. The effects of row spacing on plant development and dry matter and N and P accumulation for barley.

Row Spacing (cm)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
10	3.0	4.9	155	3330	8733	75	8.9
20	3.1	4.9	109	3157	8978	73	8.8
30	3.1	4.6	101	3120	8414	73	8.4
se	0.1	0.2	10.4	145	463	3	0.4
Contrast							
10 and 20 vs 30	ns	ns	*	ns	ns	ns	ns
10 vs 20	ns	ns	**	ns	ns	ns	ns

Table D3. The effects of seeding rate on plant development and dry matter and N and P accumulation for barley.

Seeding Rate (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
54	3.1	4.8	79	2871	9354	74	8.4
108	3.1	4.8	126	3240	8357	73	8.8
161	3.0	4.7	160	3396	8414	74	9.0
se	0.1	0.2	10.4	145	463	3	0.4
Contrast							
54 and 108vs161	ns	ns	**	*	ns	ns	ns
108vs161	ns	ns	*	ns	ns	ns	ns

Table D4. The effects of seed-placed phosphorus on plant development and dry matter and N and P accumulation for barley.

Seed-Placed P2O5 (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
0	2.8	4.7	111	2664	8275	70	7.4
18	3.2	4.9	125	3103	8659	71	8.3
36	3.2	4.8	128	3740	9190	79	10.5
se	0.1	0.2	10.4	145	463	3.2	0.4
Contrast							
0 vs 18 and 36	**	ns	ns	**	ns	ns	**
18 vs 36	ns	ns	ns	**	ns	ns	**

Rapid City

A summary of the analysis of variance for plant development is given in Table D5 and for the dry matter results in Table C1. Row spacing had a significant effect on on the number of seminal roots produced (Table D6) but not on Haun stage or dry matter accumulation in the seedling stage. The number of seminal roots produced were slighlty lower for the 30 cm spacing. Seeding rate had a significant effect on dry matter only (Table D7). As the seeding rate increased, seedling dry matter increased because of more plants being produced. Seed-placed P had an effect on plant development and seedling dry matter (Table D8). As P increased Haun stage values increased and seedling dry matter increased.

Table D5. Results from analysis of variance for barley.

Source	df	Main Stem Haun Stage	# of Seminal Roots
Spacing (RS)	2	ns	**
Seeding Rate (SR)	2	ns	ns
Phosphorus (P)	2	*	ns
Rep	2	ns	**
RS*SR	4	*	ns
RS*P	4	ns	ns
SR*P	4	ns	ns
RS*SR*P	8	ns	ns

Table D6. The effects of row spacing on plant development and dry matter and N and P accumulation for barley.

Row Spacing (cm)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
10	3.7	5.1	206	-	-	-	-
20	3.8	5.1	186	-	-	-	-
30	3.7	4.7	206	-	-	-	-
se	0.1	0.2	15	-	-	-	-
Contrast				-	-	-	-
10 and 20 vs 30	ns	**	ns	-	-	-	-
10 vs 20	ns	ns	ns	-	-	-	-

Table D7. The effects of seeding rate on plant development and dry matter and N and P accumulation for barley.

Seeding Rate (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
54	3.8	5.0	118	-	-	-	-
108	3.7	5.0	191	-	-	-	-
161	3.7	4.8	290	-	-	-	-
se	0.1	0.2	15	-	-	-	-
Contrast				-	-	-	-
54 and 108vs161	ns	ns	**	-	-	-	-
108vs161	ns	ns	**	-	-	-	-

Table D8. The effects of seed-placed phosphorus on plant development and dry matter and N and P accumulation for barley.

Seed-Placed P2O5 (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
0	3.6	4.9	169	-	-	-	-
18	3.7	5.0	202	-	-	-	-
36	3.8	5.0	228	-	-	-	-
se	0.1	0.2	15	-	-	-	-
Contrast				-	-	-	-
0 vs 18 and 36	**	ns	*	-	-	-	-
18 vs 36	ns	ns	ns	-	-	-	-

SPRING WHEAT

Indian Head

The analysis of variance for plant characteristics are given in Table D9 while for the biomass accumulation results in Table B5. Row Spacing had no effect on seedling development or biomass accumulation (Table D10). Seeding rates had a significant effect on growth at the seedling stage and at maturity (Table D11). As seeding rates increased, seedling dry weight increased but dry weight decreased at maturity. Seed-placed P increased dry matter at all stages, N and P accumulation and even plant development (Table D12).

Table D9. Results from analysis of variance for Spring wheat.

Source	df	Main Stem Haun Stage	# of Seminal Roots
Spacing (RS)	2	ns	ns
Seeding Rate (SR)	2	ns	ns
Phosphorus (P)	2	**	ns
Rep	2	ns	ns
RS*SR	4	ns	ns
RS*P	4	ns	ns
SR*P	4	ns	ns
RS*SR*P	8	ns	ns

Table D10. The effects of row spacing on plant development and dry matter and N and P accumulation for spring wheat.

Row Spacing (cm)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
10	2.3	3.8	161	3811	8089	68	7.3
20	2.3	4.0	138	3502	7469	66	67
30	2.3	4.0	142	3525	7544	67	69
se	0.1	0.2	8.3	130	294	6	0.3
Contrast							
10 and 20 vs 30	ns	ns	ns	ns	ns	ns	ns
10 vs 20	ns	ns	ns	ns	ns	ns	ns

Table D11. The effects of seeding rate on plant development and dry matter and N and P accumulation for spring wheat.

Seeding Rate (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
67	2.3	4.0	87	3447	8382	67	7.1
134	2.2	3.9	142	3668	7612	67	7.0
201	2.3	3.8	214	3724	7107	66	6.9
se	0.1	0.2	8.3	130	294	6	0.3
Contrast							
67 and 134vs201	ns	ns	**	ns	**	ns	ns
134vs201	ns	ns	**	ns	ns	ns	ns

Table D12. The effects of seed-placed phosphorus on plant development and dry matter and N and P accumulation for spring wheat.

Seed-Placed P2O5 (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
0	2.2	3.9	127	2950	6559	58	5.6
18	2.3	4.0	152	3778	8018	69	7.2
36	2.4	3.9	163	4111	8525	74	8.2
se	0.1	0.2	8.3	130	294	6	0.3
Contrast							
0 vs 18 and 36	**	ns	**	**	**	**	**
18 vs 36	ns	ns	ns	ns	ns	ns	**

RAPID CITY

The analysis of variance for seedling characteristics is given in Table D13 and for dry matter accumulation in Table C6. Plant development and seedling dry weight was affected by row spacing (Table D14). As row spacing increased, there was a slight decrease in plant development and seedling dry weight. As seeding rate increased, plant development decreased and seedling dry weight increased (Table D15). As seed-placed P increased, the number of seminal roots produced and seedling dry weight increased (Table D16).

Table D13. Results from analysis of variance for Spring wheat.

Source	df	Main Stem Haun Stage	# of Seminal Roots
Spacing (RS)	2	ns	ns
Seeding Rate (SR)	2	*	ns
Phosphorus (P)	2	ns	**
Rep	2	*	ns
RS*SR	4	ns	ns
RS*P	4	ns	ns
SR*P	4	ns	ns
RS*SR*P	8	ns	ns

Table D14. The effects of row spacing on plant development and dry matter and N and P accumulation for spring wheat.

Row Spacing (cm)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
10	3.1	4.3	258	-	-	-	-
20	3.1	4.4	221	-	-	-	-
30	3.0	4.3	214	-	-	-	-
se	0.1	0.2	13	-	-	-	-
Contrast							
10 and 20 vs 30	*	ns	ns	-	-	-	-
10 vs 20	ns	ns	*	-	-	-	-

Table D15. The effects of seeding rate on plant development and dry matter and N and P accumulation for spring wheat.

Seeding Rate (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
67	3.2	4.3	148	-	-	-	-
134	3.1	4.4	230	-	-	-	-
201	3.0	4.3	315	-	-	-	-
se	0.1	0.2	13	-	-	-	-
Contrast							
67 and 134vs201	**	ns	**	-	-	-	-
134vs201	ns	ns	**	-	-	-	-

Table D16. The effects of seed-placed phosphorus on plant development and dry matter and N and P accumulation for spring wheat.

Seed-Placed P2O5 (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
0	3.0	4.1	207	-	-	-	-
18	3.1	4.4	239	-	-	-	-
36	3.1	4.5	246	-	-	-	-
se	0.1	0.2	13	-	-	-	-
Contrast							
0 vs 18 and 36	ns	**	*	-	-	-	-
18 vs 36	ns	ns	ns	-	-	-	-

DURUM

Indian Head

The summary of the analysis of variance for seedling characteristics is given in Table D17 while for the biomass accumulations in Table B9. As row spacing increased, ssedling dry weight decreased and P uptake decreased (Table D18). As seeding rate increased, seedling dry weight increased but decreased at anthesis (Table D19). As seed-placed P increased, dry matter in the seedling stage and at maturity increased with no differences at anthesis. N and P accumulation were not affected (Table D20).

Table D17. Results from analysis of variance for durum wheat.

Source	df	Main Stem Haun Stage	# of Seminal Roots
Spacing (RS)	2	ns	ns
Seeding Rate (SR)	2	*	ns
Phosphorus (P)	2	ns	ns
Rep	2	ns	ns
RS*SR	4	ns	ns
RS*P	4	*	ns
SR*P	4	ns	ns
RS*SR*P	8	ns	ns

Table D18. The effects of row spacing on plant development and dry matter and N and P accumulation for durum wheat.

Row Spacing (cm)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
10	2.9	4.3	221	8278	10511	130	16.2
20	2.8	4.3	188	7961	9403	120	14.6
30	2.8	4.5	179	7219	10251	112	13.3
se	0.1	0.2	7	384	389	8	0.8
Contrast							
10 and 20 vs 30	ns	ns	**	ns	ns	ns	*
10 vs 20	ns	ns	**	ns	*	ns	ns

Table D19. The effects of seeding rate on plant development and dry matter and N and P accumulation for durum wheat.

Seeding Rate (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
67	2.8	4.2	116	7943	10944	127	15.3
134	2.7	4.4	199	7655	9509	115	14.1
201	2.8	4.5	274	7859	9712	120	14.6
se	0.1	0.2	7	384	389	8	0.8
Contrast							
67 and 134vs201	ns	ns	**	ns	**	ns	ns
134vs201	*	ns	**	ns	ns	ns	ns

Table D20. The effects of seed-placed phosphorus on plant development and dry matter and N and P accumulation for durum wheat.

Seed-Placed P2O5 (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
0	2.7	4.4	184	7240	9333	117	13.0
18	2.8	4.5	206	7577	10575	113	14.1
36	2.9	4.2	199	8640	10258	132	16.9
se	0.1	0.2	7	384	389	8	0.8
Contrast							
0 vs 18 and 36	ns	ns	*	ns	*	ns	ns
18 vs 36	ns	ns	ns	ns	ns	ns	ns

Rapid City

The analysis of variance for seedling characteristics is given in Table D21 and for dry matter accumulation in Table C10. Row spacing had a significant effect only on the number of seminal roots produced (Table D22). As row spacing increased, the number of seminal roots produced decreased slightly. As seeding rate increased, dry matter production in the seedling stage increased (Table D23). Seed-placed P had no significant effect on seedling growth and development (Table D24).

Table D21. Results from analysis of variance for durum wheat.

Source	df	Main Stem Haun Stage	# of Seminal Roots
Spacing (RS)	2	ns	**
Seeding Rate (SR)	2	ns	ns
Phosphorus (P)	2	ns	ns
Rep	2	**	**
RS*SR	4	ns	ns
RS*P	4	ns	ns
SR*P	4	ns	ns
RS*SR*P	8	ns	ns

Table D22. The effects of row spacing on plant development and dry matter and N and P accumulation for durum wheat.

Row Spacing (cm)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
10	3.7	5.1	228	-	-	-	-
20	3.8	5.1	250	-	-	-	-
30	3.7	4.7	221	-	-	-	-
se	0.1	0.2	13	-	-	-	-
Contrast							
10 and 20 vs 30	ns	**	ns	-	-	-	-
10 vs 20	ns	ns	ns	-	-	-	-

Table D23. The effects of seeding rate on plant development and dry matter and N and P accumulation for durum wheat.

Seeding Rate (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
67	3.8	5.0	131	-	-	-	-
134	3.7	5.0	241	-	-	-	-
201	3.7	4.8	326	-	-	-	-
se	0.1	0.2	13	-	-	-	-
Contrast							
67 and 134vs201	ns	ns	**	-	-	-	-
134vs201	ns	ns	**	-	-	-	-

Table D24. The effects of seed-placed phosphorus on plant development and dry matter and N and P accumulation for durum wheat.

Seed-Placed P2O5 (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
0	3.6	4.9	224	-	-	-	-
18	3.7	5.0	241	-	-	-	-
36	3.8	5.0	233	-	-	-	-
se	0.1	0.2	13	-	-	-	-
Contrast							
0 vs 18 and 36	ns	ns	ns	-	-	-	-
18 vs 36	ns	ns	ns	-	-	-	-

WINTER WHEAT

The analysis of variance for seedling characteristics is given in Table D25 and for growth characteristics in Table B1. As row spacing increased, the number of seminal roots decreased somewhat, as well as dry matter at anthesis and maturity (Table D26). As seeding rate increased, on seedling dry matter production increased with no effects on the other characters (Table D27). As seed-placed P increased, dry matter production in the seedling stage and at anthesis increased as well as N and P uptake (Table D28).

Table D25. Results from analysis of variance for winter wheat.

Source	df	Main Stem Haun Stage	# of Seminal Roots
Spacing (RS)	2	ns	*
Seeding Rate (SR)	2	ns	ns
Phosphorus (P)	2	ns	ns
Rep	2	ns	ns
RS*SR	4	ns	ns
RS*P	4	ns	ns
SR*P	4	ns	ns
RS*SR*P	8	ns	ns

Table D26. The effects of row spacing on plant development and dry matter and N and P accumulation for winter wheat.

Row Spacing (cm)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
10	4.0	4.4	296	3311	8056	52	4.5
20	4.0	4.3	287	2268	5981	37	2.9
30	4.0	4.0	276	2184	5723	35	3.1
se	0.1	0.1	18	205	279	3.3	0.3
Contrast							
10 and 20 vs 30	ns	*	ns	*	**	*	ns
10 vs 20	ns	ns	ns	**	**	**	**

Table D27. The effects of seeding rate on plant development and dry matter and N and P accumulation for winter wheat.

Seeding Rate (kg/ha)	Main Stem Haun	# of semina l roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
67	4.1	4.1	203	2538	6410	42	3.5
134	4.0	4.3	305	2550	6720	41	3.4
201	3.8	4.3	350	2675	6630	42	3.5
se	0.1	0.1	18	205	279	3.3	0.3
Contrast							
67 and 134vs201	ns	ns	**	ns	ns	ns	ns
134vs201	ns	ns	ns	ns	ns	ns	ns

Table D28. The effects of seed-placed phosphorus on plant development and dry matter and N and P accumulation for winter wheat.

Seed-Placed P2O5 (kg/ha)	Main Stem Haun	# of seminal roots	Dry Matter (kg/ha)			Nutrient Content at anthesis (kg/ha)	
			Seed-ling	Anthesis	Maturity	N	P
0	3.9	4.3	247	2054	6195	33	2.6
18	4.1	4.2	303	2707	6743	42	3.5
36	4.0	4.2	307	3001	6822	49	4.3
se	0.1	0.1	18	205	279	3.3	0.3
Contrast							
0 vs 18 and 36	ns	ns	*	**	ns	*	**
18 vs 36	ns	ns	ns	ns	ns	ns	ns

SUMMARY OF PART D.

Of interest in this section was the effects of row spacing, seeding rate and seed-placed P on seedling growth and development in a number of cereal crops.

Seedling development was affected by row spacing in only one of seven situations, spring wheat at Rapid City in which case the seedlings growing on 30 cm spacing were 0.1 Haun units behind the other spacings. This means that crowding seedlings in a tight band does not adversely affect their development. Other effects of row spacing were on seminal roots (three of seven cases) where the numbers produced were slightly lower on 30 cm spacings. This indicates the importance of fertlizer placement when going to wider row spacings. Dry matter production tended to be lower as spacings increased in the seedling stage which is a function of less seedlings emerging than effects of interplant competition as indicated by the lower plant populations with 30 cm spacings. These differences disappeared at later growth stages.

Seeding rates had a significant effect on plant development in only one situation (spring wheat at Rapid City). We can therefore conclude that increasing seeding rates has only negigible effects in altering the rate of plant development. Seeding rates did not influence the number of seminal roots produced. Dry matter production in the seedling stage increased with seeding rates due to more plants being established. These differences were also reflected at the other growth stages. No effects were observed on N and P uptake.

Seed-placed P significantly increased seedling development in spring wheat and barley but not winter wheat or durum. Dry matter production tended to be increased as well as N and P content.

E. LITERATURE CITED

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