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Organic and conventional management of mixtures of wheat and spring cereals

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Abstract – Cereal mixtures may provide both organic and conventional producers with a more sustainable approach in reducing weed pressure, crop rotation flexibility, improved yield stability, buffering against pests and diseases, minimizing soil variability and increasing animal feed value. We examined the response of small grain mixtures containing wheat, oats, barley and triticale to varying degrees of natural competition and environmental stress at three locations in central Alberta, Canada. One modern and one heritage hard-red spring wheat cultivar, along with one cultivar each of oats, barley and triticale and eighteen two-way mixtures, were planted on organic and conventional land at seven location-years between 2003 and 2005. Average yields were 30% to 70% lower on organically managed sites. Monocrop barley yielded 43% and 16% higher than the site average at two organic locations. Our results suggest two main conclusions: (1) on conventionally managed land, wheat-barley mixtures exhibited potential for yield maintenance and weed suppression, and; (2) on organically managed land, competition with weeds had a large negative effect on yield (>30%). The 25:75 mixtures of wheat and oats, and all mixtures of Park (a heritage) wheat and Manny barley exhibited yield potential similar to or (up to 1.0 t ha^{-1}) greater than monocrop yield. Manny barley mixtures exhibited weed suppressive capabilities.

1. INTRODUCTION

Mixtures of cereals may be useful for reducing weed pressure (Francis, 1989), increasing yield stability (Francis, 1989; Juskiw et al., 2000a), increasing yield through complementary niche utilization (Juskiw et al., 2000a; Taylor, 1978), increasing crop rotation flexibility (Walton, 1975), pest and disease buffering, minimizing soil variability, and increasing animal feed value (Stoskopf, 1985).

Certified organic agriculture is a relatively new practice in western Canada, with only 1.4% of total cropland in Alberta, Saskatchewan and Manitoba currently registered organic (Statistics Canada, 2002). Organic grain producers on the Canadian Prairies must employ many non-chemical agronomic techniques to remain viable. Crop species and cultivars are chosen not only for yield potential, but also as part of complex crop rotations to control weeds, insects and diseases (Teasdale et al., 2004). The use of small grain mixtures is promising for both conventional and organic growers, albeit for different reasons. Yield advantages of cereal mixtures over sole crops have been reported under both high (Jokinen, 1991; Sobkowicz and Tendziagolska, 2005) and low (Jokinen, 1991) input environments.

A great deal of research has concentrated on the use of cereal mixtures for forage or silage production. To maximize yield and quality, barley and oat are harvested at the soft dough stage, while rye and triticale exhibit peak quality and yield at the boot to milk stage (Juskiw et al., 2000b). This may lead to complementarity in cereal mixtures, as rye and triticale are generally slower growing than barley and oat, and therefore a mixture may be at the optimal stage for all species at harvest. The slower growing species will generally increase feed quality because of their high proportion of leaf biomass compared to the more mature components (Juskiw et al., 2000b). There have also been several studies conducted to test the grain yield potential of cereal mixtures on conventional land (Juskiw et al., 2000a, b), but none to date on organic land.

There are several obstacles to developing successful cereal mixtures, such as differences in height, vigor, lodging resistance, rooting depth, nutrient requirements and maturation rates of the component species (Loomis and Connor, 1992). Many studies have reported height to be a major

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Table I. Planting and harvesting dates, and environmental data for field trials conducted in north-central Alberta from 2003 to 2005.

Year	Location	Planting Date	Harvest Date	Precipitation (mm) May	June	July	Aug	Sept	Total	Average Temperature (°C) May	June	July	Aug	Sept
2003	Edmonton Conventional	May 15	Sept 9	33	59	72	56	15	235	9.1	14.1	17.6	17.4	10.3
2003	Edmonton Organic	May 15	Sept 13											
2004	Edmonton Conventional	May 10	Sept 15	48	27	256	44	39	414	8.5	13.9	16.7	14.6	8.8
2004	Edmonton Organic	May 18	Oct 6											
2004	Certified Organic	May 26	Sept 22	27	24	118	69	42	280	8.4	13.0	16.3	14.0	9.3
2005	Edmonton Conventional	May 10	Sept 8	39	62	60	97	27	285	10.6	14.3	16.4	13.7	8.9
2005	Edmonton Organic	May 27	Oct 4											
	Thirty-year average			45	87	91	69	42	334	11.7	15.5	17.5	16.6	11.3

determining factor in a component's competitive ability in mixture (Valentine, 1982). This doesn't always occur, however, as barley can be more competitive than oats in mixtures, even though the oats are often taller at harvest (Taylor, 1978). Barley is generally a fast-maturing crop while triticale matures quite slowly (Maloney et al., 1999). However, this difference in maturation times may increase yield due to staggered timing of resource requirements (i.e. complementarity) (Sobkowicz and Tendziagolska, 2005). Also, early season vigor has a large impact on the competitiveness of each component (Sobkowicz and Tendziagolska, 2005) and whether a mixture maintains its ratio from planting to harvest. Vigorous allelopathic species may outcompete the other components in the mixture, resulting in almost a monoculture at harvest (Juskiw et al., 2000a). A producer must account for this by using a ratio and seeding rate that maximizes yield while minimizing interspecific competition (Stoskopf, 1985).

There are several mechanisms by which cereal mixtures may affect crop pests and diseases. The quality and quantity of crop residue from both host and non-host crops can influence pathogen growth, sporulation, and survival through the release of fungicidal compounds during residue breakdown (Bailey and Lazarovits, 2003). Mixtures can also decrease pathogen infection on subsequent crops (Vilich, 1993). Similar to wheat cultivar mixtures, researchers have noted that disease mitigation of cereal mixtures is prevented or skewed by the small size of experimental plots (Stoskopf, 1985). Vilich-Meller (1992) reported that wheat-barley mixtures provided greater disease reduction on wheat than did applications of fungicide, illustrating the potential of cereal mixtures for use in organic agriculture.

Conventional production emphasizes high yield as its primary goal (Sobkowicz and Tendziagolska, 2005). Most mixtures yield less than the highest-yielding component in monoculture, but may offer small yield increases over the mean component yield in sole crop (Juskiw et al., 2000a; Maloney et al., 1999; Stoskopf, 1985; Taylor, 1978). Inconsistency of mixture yield advantages is probably due to the similarity between cereal crop species growth habits and requirements for limiting resources (Sobkowicz and Tendziagolska, 2005).

Crop mixtures are used chiefly on subsistence farms with limited resource availability and little new technology (Francis, 1989), making them directly applicable to modern organic farms. Crop mixtures are often employed as a non-chemical means of disease and weed control rather than strictly for yield increase (Fukai, 1993). In a management regime that cannot use broad-spectrum herbicides to control weeds, any competitive advantage that can be employed will aid organic producers (Cousens, 1996). As well, mixtures of grain may be fed directly to organic livestock, or the biomass may be harvested for silage production.

It is unlikely that any mixture, regardless of how beneficial it turns out to be, can be used over such a large area that disease problems become widespread. Every agro-ecosystem has its own crops and cultivars that suit the climate and soils; it is from these that effective mixtures must be developed. Mixture development is a localized mechanism that can be fine-tuned to suit a given farm's soil, topography and crop rotation.

The objectives of the present study were to: (1) determine the potential of various spring cereal mixtures on the northern Canadian prairies under both organic and conventional management, and (2) to establish the competitive abilities of the various cereal mixtures for the development of protocols for growing cereal mixtures on organic farming systems on the western Canadian prairies. We endeavored to identify specific cereal mixtures that could be implemented by producers immediately, and to determine characteristics that could be used to compose effective spring cereal mixtures in the future.

2. MATERIALS AND METHODS

Field trials were conducted at the University of Alberta Edmonton Research Station in Edmonton, Alberta, Canada (53° 34′ N, 113° 31′ W) from 2003 to 2005 and at a certified organic farm near New Norway, Alberta, Canada (52° 52′ N, 112° 56′ W) in 2004 (Tab. I). The soils in Edmonton are classified as Orthic Black Chernozemic, typical of central Alberta, and soils at New Norway were classified as an Eluviated Black Chernozemic (Alberta Agriculture Food and Rural Development, 1995). Soil fertility levels for all fields over all years were determined in the fall prior to the cropping year (Tab. II). The conventional land at the Edmonton Research Station (Edmonton Conventional) had fertilizer added as urea

Table II. Soil nutrient content and physical characters recorded before planting on conventional and organic land in Edmonton, AB and New Norway, AB from 2003 to 2005. N: Nitrate-N only; S: Sulfate-S only; EC: Electrical conductivity; OM: Organic matter content.

Year	Location	Soil Nutrient Analysis (kg ha^{-1})				pH	EC	OM
		N	P	K	S		(dS m^{-1})	(%)
2003	Edmonton Conventional	153	86	>1347	26	6.8	1.09	10.1
2003	Edmonton Organic	72	>135	921	>45	6.6	0.62	9.9
2004	Edmonton Conventional	300	73	817	65	6.0	0.75	12.1
2004	Edmonton Organic	147	113	1114	64	6.3	0.59	10.3
2004	Certified Organic	65	47	730	22	6.5	0.37	5.4
2005	Edmonton Conventional	272	192	1462	>90	7.3	0.99	7.2
2005	Edmonton Organic	199	260	1582	>90	6.1	0.91	10.3

(46-0-0: N-P_2O_5-K_2O) broadcast to give 67–73 kg ha^{-1} total N in 2003; at a rate of 45 kg ha^{-1} N and 20 kg ha^{-1} P, as urea and ammonium phosphate (11-52-0) in the seed row in 2004; and at 28 kg ha^{-1} as ammonium phosphate banded with the seed in 2005. The organic land at the Edmonton Research Station (Edmonton Organic) had compost (comprised of dairy manure, sawdust, wood chips and straw) added at a rate of 50–62 t ha^{-1} each year. The certified organic land in New Norway (Certified Organic) had no external inputs of fertilizer, but the field had plowdown crops containing legumes the previous year. Precipitation during the growing season was sufficient in Edmonton in 2004 and 2005, but there was a mild drought in 2003 in Edmonton (Tab. I).

Trials were seeded into cultivated and harrowed soil that was tilled both in the autumn and in the spring prior to seeding. Organically managed land had an additional tillage operation, immediately before seeding to control weeds. In 2003, the plots were four rows wide (23 cm row spacing) and 4 m long, seeded with a self-propelled, double-disk plot drill (Fabro Enterprises Ltd., Swift Current, SK, Canada), while in 2004 and 2005 plots were six rows wide (23 cm row spacing) and 4 m long, and seeded with a self-propelled, no-till, double-disk plot seeder (Fabro Enterprises Ltd., Swift Current, SK, Canada).

The experiment was grown for three years at the three locations – Edmonton Conventional and Edmonton Organic for three years (2003 to 2005) and for one year (2004) at certified organic location – for a total of seven location-years of data. The seven experimental trials were planted as randomized complete block designs (RCBD) with four blocks. Mixture entries included eighteen two-way cereal mixtures and five monocrop entries of the cultivars used to comprise the mixtures (Tab. III). Mixtures were prepared on a kernel-number basis of pure seed to plant at a standard rate of 300 seeds m^{-2}. One cultivar each of barley, oats and triticale was chosen to combine with two cultivars of hard red spring wheat to form the mixture entries. One wheat cultivar (McKenzie) is a modern, high-yielding cultivar registered in 1997, and the other is a taller, later-maturing cultivar (Park), registered in 1963 but still favored by some organic producers in Alberta. Herbicide was used for weed control on conventional but not on organic land. Herbicide was a commercial formulation of Dyvel (active ingredients MCPA and Dicamba) applied at 1235.5 mL ha^{-1} at the recommended crop (2–4 leaf) and weed (emergence to 3 leaf) stage (Brook, 2006).

2.1. Data collection

Emergence counts were taken before the onset of tillering (1–3 leaf stage) and the plots were scored for early season vigor on a scale of 1 (low vigor) to 5 (high vigor) one month after seeding. At Edmonton Conventional and Edmonton Organic in 2004 and 2005, heading and maturity was recorded when 75% of each species exhibited emerged heads and was physiologically mature, respectively. Weed samples were collected from each plot using 25 cm × 25 cm quadrats when the crop had reached physiological maturity. Height measurements for each species were taken once stem elongation was completed. Lodging ratings were recorded throughout the season, particularly in 2004, when heavy winds and an early snowfall caused widespread lodging. Lodging was rated from 0 (no lodging present) to 9 (plot completely flat). Once the entries were fully mature, but prior to harvest, ten spikes were randomly collected from each species in each plot to determine kernels per spike and kernel weight.

A Wintersteiger plot combine harvested the entire plot for yield, which was determined after each sample was cleaned and dried to 13–14% moisture. Small weed seeds were removed from the harvested grain using a 2 mm sieve and a fan, which also removed chaff. In 2004, plot yields from the certified organic farm in New Norway were infested with wild oats (*Avena fatua* L.) to such a degree that they had to undergo hand cleaning on a sub-sample of 150 g. Final mixture ratios were calculated by separating 100 g samples of plot yield into its respective species in 2003, and through the harvest of randomly chosen 1m-row of plot and subsequent separation in 2004 and 2005. Kernels of different species were separated. Thousand kernel weight was measured for each component. This was used to calculate the relative mixture ratios back to a kernel number basis in the same way the mixtures were originally synthesized.

Table III. Least-square means for early season vigor (ESV), grain yield and weed biomass at the Edmonton Conventional, Edmonton organic, and certified organic locations from 2003 to 2005. [1] Main column entries significantly different from their mid-component average $P < 0.05$ (*) and $P < 0.01$ (**), respectively. [2] * and ** indicate entry weed biomass differs monocrop barley at $P < 0.05$ and $P < 0.01$, respectively. [3] ns = not significant, * = significant at $P < 0.05$, ** = significant at $P < 0.01$.

		Edmonton Conventional				Edmonton Organic				Certified Organic			
Mixture Components	Mixture Ratio	ESV	Grain Yield $t\ ha^{-1}$	Yield Rank	Weed Biomass[2] gm^{-2}	ESV	Grain Yield[1] $t\ ha^{-1}$	Yield Rank	Weed Biomass[2] $g\ m^{-2}$	ESV	Grain Yield $t\ ha^{-1}$	Yield Rank	Weed Biomass[2] $g\ m^{-2}$
Park (wheat)	Monocrop	3.9[1]	3.99	21	10	2.6	2.45	16	240	4.31	1.37	11	210
McKenzie (wheat)	Monocrop	4.5	3.65	22	10	3	2.6	15	90	2.8	0.75	19	275*
Barley (Manny)	Monocrop	5	4.48	8	5	3.5	4.71	2	90	4	1.55	5	120
Oats (Grizzly)	Monocrop	3.6	4.67	6	5	3.4	4.35	3	120	3.5	1.38	10	160
Triticale (AC Alta)	Monocrop	2.8	4.68	5	0	1.5	2.11	22	440**	4	1.11	16	115
Park-Barley	50:50:00	4.9	4.89*	1	10	3.1	4.23	4	215	4.5	1.61	3	170
Park-Barley	25:75	5	4.73	2	15	3.8	4.23	4	40	4.8*	1.56	4	110
Park-Barley	75:25:00	4.4	4.48	8	10	3	3.51	9	170	4.5	1.44	9	135
McKenzie-Barley	50:50:00	4.8	4.69*	4	5	3	3.95	6	60	4	1.19	15	250
McKenzie-Barley	25:75	4.5	4.44	10	15	3	4.81	1	110	4.5*	1.31	13	240
McKenzie-Barley	75:25:00	4.4	4.16	16	0	2.9	3.31	11	100	3.3	0.98	17	285*
Park-Oats	50:50:00	4.4*	4.31	13	5	3.1	3.35	10	160	4	1.37	11	155
Park-Oats	25:75	3.9	4.45	9	15	3.1	3.62	8	190	4.3	1.71	2	200
Park-Oats	75:25:00	3.9	4.09	17	10	2.9	3.13	13	105	3.8	1.19	15	180
McKenzie-Oats	50:50:00	4.3	4.51	7	5	2.9	3.83	7	345*	3.3	1.48*	7	225
McKenzie-Oats	25:75	4.1	4.72	3	5	2.8	4.07	5	110	3	2.21**	1	125
McKenzie-Oats	75:25:00	4	4.25	15	20	2.2**	3.2	12	155	3	1.2	14	180
Park-Triticale	50:50:00	3.6	4.36	12	5	2.2	2.22	21	240	4	1.46	8	150
Park-Triticale	25:75	3.5	4.41	11	0	1.8	2.44	17	430**	3.8	1.5	6	165
Park-Triticale	75:25:00	3.5	4.01	19	0	3.0*	2.63	14	300	4	1.32	12	240
McKenzie-Triticale	50:50:00	3.6	4	20	5	2.5	2.43	18	315	3.5	0.98	17	270*
McKenzie-Triticale	25:75	3.1	4.26	14	5	2.3	2.36	20	300	3.5	1.19	15	225
McKenzie-Triticale	75:25:00	3.5	4.06	18	0	2.5	2.37	19	240	3	0.9	18	230
Mean		**4**	**4.36**		**5**	**2.8**	**3.3**		**200**	**3.8**	**1.34**		**190**
F-value (entry)[3]		**	**		ns	**	**		*	**	**		ns
SE (entry)		0.35	0.29		6.8	0.32	0.37		127.9	0.35	0.22		70.3
LSD (entry) $P = 0.05$		0.73	0.6		14.1	0.66	0.77		265.3	0.73	0.46		145.8

2.2. Data analysis

For the purposes of examining differences in the seven environments, a preliminary combined analysis of variance over all environments was performed using the MIXED procedure (Littell et al., 2006) of SAS (SAS Institute, 1999); where environment, entry and competition were considered fixed, and replication and replication interactions were considered random. In preliminary analyses, the seven environments differed ($P < 0.01$) for grain yield (data not shown). Mean yield at the Certified Organic Farm was low (1.34 $t\ ha^{-1}$ in 2004), compared to Edmonton Organic (3.36, 3.22, 3.36 $t\ ha^{-1}$ in 2003, 2004 and 2005 respectively) and Edmonton Conventional (3.42, 4.29 and 5.37 $t\ ha^{-1}$ in 2003, 2004 and 2005 respectively). Due to the large differences in location soils and climate (Tabs. I, II), yield potential and management characters, analyses and results for yield and agronomic indices were conducted and are presented by location, combined over years. Thus, analyses of variance for each of the three locations (Edmonton Organic, Edmonton Conventional, and Certified Organic), separately, were performed using the MIXED (Littell et al., 2006) procedure of SAS, where year, replication within year and replication interactions were considered random. Entry was considered fixed. The mid-component average yield of a mixture is the combined average for the monocrop yield of the components in that mixture, weighted according to ratio. Single degree of freedom contrasts, weighted by proportion seeded (e.g. 50:50, 75:25 or 25:75) were conducted to compare mixtures means with mid-component averages for yield and the percent seed composition outcome of the final harvest.

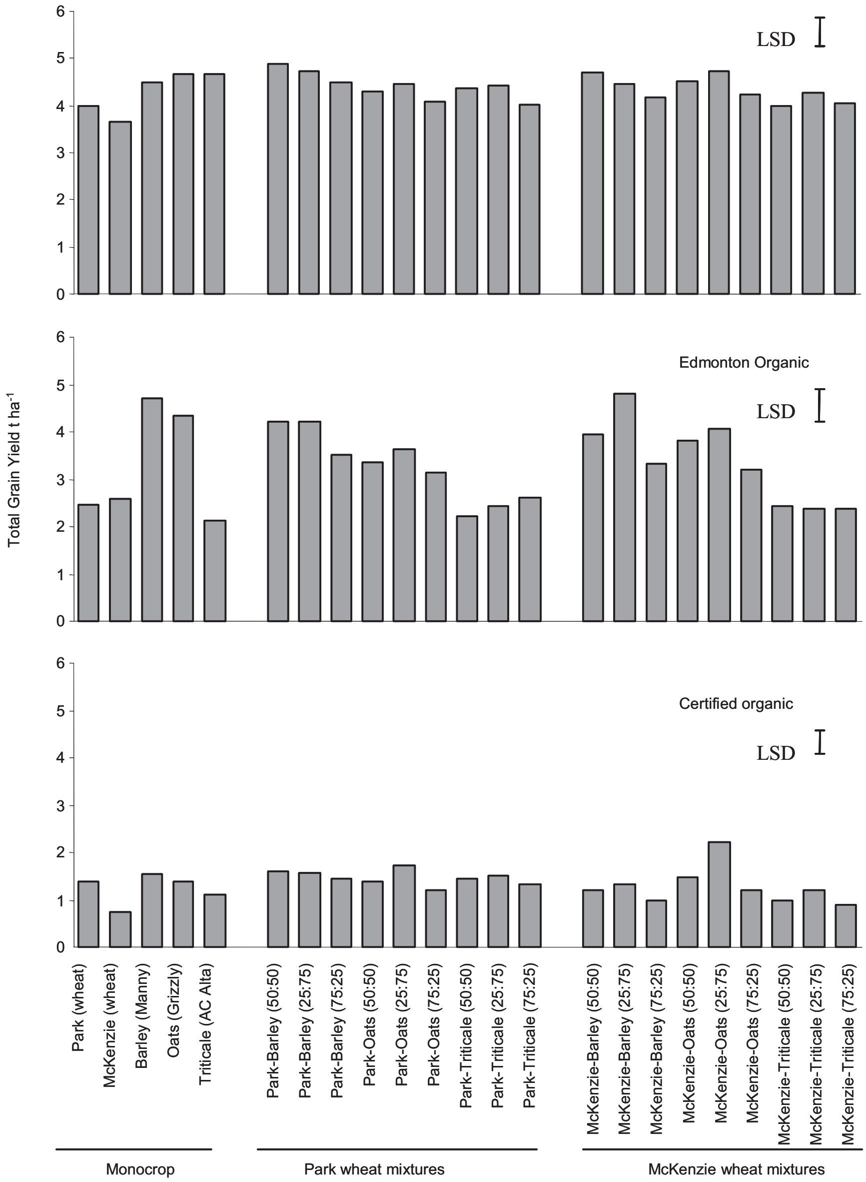

Figure 1. Total grain yield of wheat, barley, oat and triticale cultivars in monocrop and in mixtures of differing ratios at the Edmonton Conventional, Edmonton Organic, and Certified Organic locations from 2003 to 2005.

The final mixture ratios were compared to their originals using the TTEST procedure of SAS. Weed biomass was generally the lowest under barley treatments and barley has been reported to be strongly competitive with weeds (O'Donovan et al., 2000). We therefore conducted single degree of freedom contrasts comparing the weed biomass of all other entries with monocrop barley. Significance levels for total weed biomass were calculated using a square-root transformation to stabilize variance (Steel et al., 1996).

3. RESULTS AND DISCUSSION

In the by-location analyses, the five monocrop and 18 mixtures differed ($P < 0.05$) for early season vigor, grain yield (Tab. III; Fig. 1) and final grain mixture ratio at all three locations (Fig. 2). At Edmonton Conventional, triticale, barley and oat entries yielded more grain than both wheat cultivars (Tab. III, Fig. 1). Under higher weed competition at the Edmonton Organic and Certified Organic locations, Manny barley and Grizzly oat yielded the most grain of all monocrops and AC-Alta triticale and the two wheat cultivars yielded the least. No mixture yielded greater ($P > 0.05$) than its respective mid-component average at Edmonton Organic, but Park wheat:Manny barley (50:50) and McKenzie wheat:Manny barley (50:50) under Edmonton Conventional management and McKenzie wheat:Grizzly oats (50:50 and 25:75) under certified organic management yielded greater than their mid-components. Under low weed competition at Edmonton

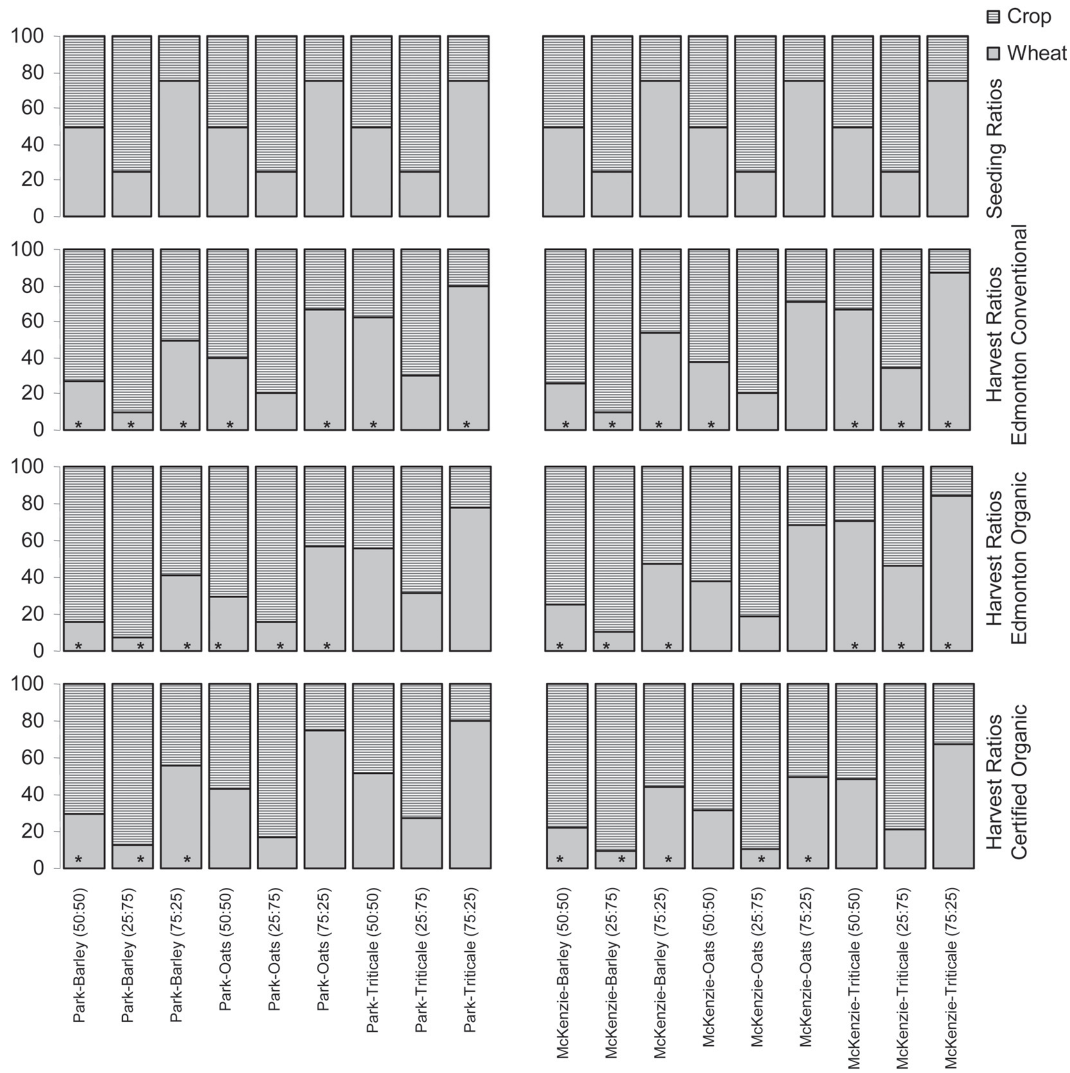

Figure 2. Seeding ratios (top) and harvest ratios at Edmonton Conventional, Edmonton Organic and Certified Organic locations from 2003 to 2005 for wheat-crop mixtures. Bars marked with * indicate significant difference between seeding and harvest ratios ($P < 0.05$) in respective locations.

Conventional, mixture entries yielded similarly; between 4.0 and 4.9 $t\,ha^{-1}$. As weed competition and abiotic stress levels increased under organic management, there were greater yield differences among the mixtures. Mixtures of wheat with barley or oats tended towards yield improvements (Fig. 1) and weed suppressive abilities (Tab. III) over monocrops grown under organic management at the Edmonton Organic and Certified Organic location.

Final grain mixture ratios differed ($P < 0.01$) from the original ratios in all wheat:barley mixtures at all locations (Fig. 2). The barley variety tested here was more competitive than the two wheat cultivars. In environments with high weed competition levels and high abiotic stress (Edmonton Organic and Certified Organic), wheat competed better when mixed with AC-Alta triticale and Grizzly oats than at Edmonton Conventional. In general, a 50:50 mixture of wheat and barley resulted in a 25:75 ratio at harvest, while mixtures seeded as 75:25 resulted in a 50:50 ratio at harvest, and a 25:75 ratio was harvested as a 10:90 ratio (Fig. 2). Conversely, both cultivars of wheat were more competitive than the triticale cultivar examined here. Grizzly oat and the wheat cultivars tested here competed equally with each other. The mean final wheat ratio decreased as environmental stress increased from Edmonton Conventional to Certified Organic, indicating Manny barley and Grizzly oat were more stress tolerant and competitive in general than the two wheat cultivars.

Final weed biomass differed ($P < 0.01$) between entries at Edmonton Organic only (Tab. III). Final weed biomass was uniformly high (average = 190 $g\,m^{-2}$) at Certified Organic and uniformly low (average = 5 $g\,m^{-2}$) at Edmonton Conventional. At Edmonton Organic, AC Alta triticale in monocrop and in mixtures generally had the highest final weed biomass,

Table IV. Least-square means for emergence, early season vigor (ESV), days to heading, days to maturity, height and lodging of monocrop varieties grown under Organic (Org) and Conventional (Conv) management in Edmonton in 2004 and 2005.[1] Means with the same letter behind them are not significantly different at $P = 0.05$.[2] Means separation was achieved using single degree of freedom contrasts.

		Emergence (plants m^{-2})[1]		Days to Heading		Days to Maturity		Height (cm)		Lodging (1–9)	
	Cultivar	Conv	Org	Conv	Org	Conv	Org	Conv	Org	Conv	Org
Wheat	Park	212ab[2]	164a	56c	56c	101b	105c	97bc	97bc	2.3b	2.3b
Wheat	McKenzie	218ab	190a	56c	54c	99b	103c	92c	92c	3.6a	3.6a
Barley	Manny	232a	190a	64b	64b	93c	97d	82d	82d	3.6a	3.6a
Oats	Grizzly	247a	172a	68a	66ab	100b	111b	113a	113a	1.2b	1.2b
Triticale	AC Alta	176b	81b	67a	67a	124a	131a	101b	101b	1.0b	1.0b
Mean		**217**	**159**	**62**	**61**	**103**	**109**	**97**	**97**	**2.3**	**2.3**
F-value (entry)		*	**	**	**	**	**	**	**	**	**
SE (entry)		22.1	15.0	0.85	1.5	2.0	2.4	3.2	3.2	0.7	0.7
LSD (entry) $P = 0.05$		45.8	31.1	1.76	3.1	4.1	5.0	6.6	6.6	1.5	1.5

indicating that this variety of triticale was a poor competitor with weeds. The barley monocrop had among the lowest weed biomass levels at all locations (Tab. III), indicating that Manny barley was a strong competitor with weeds, especially on organically managed locations. Although mixtures varied for grain yield, they did not suppress weeds more than their mid-component average ($P > 0.05$) at any location. The barley variety tested here had high early season vigor ratings (Tab. III), high yield (Fig. 1), and low weed biomass levels (Tab. III) at all locations, indicating that it was the most competitive crop planted.

Single degree of freedom contrasts indicated that there were no differences in weed biomass between barley and any other entry at Edmonton Conventional (Tab. III). This was probably due to the uniformly low weed biomass levels. In contrast, at Edmonton Organic, monocrop AC-Alta triticale had the highest weed biomass levels of any entry, significantly ($P < 0.05$) higher than barley (Tab. III). Two mixtures (Park wheat:Triticale 25:75 and McKenzie wheat:Oats 50:50) also had higher ($P < 0.05$) weed biomass than Manny barley (Tab. III). At Certified Organic, monocrop McKenzie had higher ($P < 0.05$) weed levels than Manny barley, and was also the lowest yielding entry (Fig. 1). Two mixtures (McKenzie wheat:Barley 75:25 and McKenzie wheat:Triticale 50:50) also had higher ($P < 0.05$) weed levels than barley (Tab. III). Average weed biomass levels in Park wheat:Barley mixtures at Certified Organic were 138 $g\,m^{-2}$, compared to 258 $g\,m^{-2}$ in McKenzie wheat:Manny barley mixtures.

Monocrop triticale had lower emergence ($P < 0.05$) than all other monocrops at both Edmonton Conventional and Edmonton Organic (Tab. IV). Early season vigor (ESV) was 30% higher at Edmonton Conventional than at Edmonton Organic, with monocrop barley and Park wheat: Manny barley mixtures generally having the highest ESV (Tab. III). Monocrops growing at Edmonton Organic matured an average of 6 days later than monocrops at Edmonton Conventional. Manny barley matured earliest and AC-Alta triticale the latest, regardless of location. Even though it had the lowest emergence and ESV and latest maturity of all crops tested, AC-Alta triticale still had the highest yield under low competition levels at Edmonton Conventional. However, its yield dropped by over half as competition stress increased at the organic locations. This indicates that AC-Alta triticale, despite its drought tolerance and height, has low competitive ability compared to the monocrop and mixture treatments examined in this experiment.

Our results suggest two main conclusions: (1) on conventionally managed land, wheat barley mixtures exhibited potential for yield maintenance and weed suppression, and; (2) on organically managed, competition with weeds had a large negative effect on yield (>30%). The 25:75 mixtures of wheat and oats, and all mixtures of Park (a heritage) wheat and barley exhibited yield potential similar to or (up to 1.0 $t\,ha^{-1}$) greater than monocrop yields. Barley mixtures exhibited weed suppressive capabilities.

Manny barley was the most competitive treatment evaluated in this study, exhibiting high early season vigor, emergence, yield, and low weed biomass. Studies report plant height at maturity to be positively associated with competitive ability (O'Donovan et al., 2000). These findings are not in general agreement with the results of the present study. Manny barley was the shortest crop we evaluated, but was the most competitive with both weeds and other cereals in mixture. This suggests that plant characters other than height at maturity play important roles in a plant's competitive ability. Manny barley also exhibited the greatest early season vigor, and was almost twice as tall as AC-Alta triticale one month after planting due to earlier initiation of stem elongation, thereby competing strongly with weeds for light, space, moisture and nutrients (Sobkowicz and Tendziagolska, 2005).

AC Alta triticale had poor emergence and very poor early season vigor, and was the least competitive crop in this study. This was not anticipated, as triticale was originally bred as a drought tolerant, competitive crop for use in marginal areas. Current Canadian research on triticale focuses on its potential as an animal feed and fodder crop under conventional management (Ross et al., 2004). This suggests the need for location-specific evaluation within highly competitive or organic environments, as recommendations based on results from conventional, high-input trials alone may be misleading.

Grizzly oat was more competitive than wheat cultivars tested in this study, significantly outcompeting wheat in mixture about half the time, while wheat never significantly outcompeted oats in mixture. The wheat cultivars, Park and McKenzie, also differed in competitive ability between environments. The heritage cultivar Park yielded more grain than the modern cultivar McKenzie under low stress conditions at Edmonton Conventional and under extreme stress at Certified Organic. Overall, the study suggests that Manny barley is more competitive than Grizzly oat, followed by wheat cultivars and AC Alta triticale. This is similar to comparisons made in the literature, which rate barley and oats as the most competitive, followed by wheat (Mason and Spaner, 2006).

Cereal mixtures may prove a valuable tool for organic producers wishing to capitalize on the inherent competitive ability of certain crops (e.g. barley), while still garnering price premiums for high-value crops (e.g. wheat). Many organic producers have their own on-farm means of cleaning weed seeds from their crops to allow for direct marketing to consumers; it would not be difficult for them to adjust their methods to allow for separation of grain crops from each other. Due to its low competitive ability, AC-Alta triticale would not be recommended for use on organic farms. Although we did not evaluate the competitive ability of rye (*Secale cereale*), other studies suggest that it may be a more competitive and higher yielding choice (Creamer et al., 1996). Depending on how much the producer requires of each crop, one of the Park:Barley mixtures may allow for yield maintenance under high abiotic (e.g. drought) and biotic (e.g. competition) stress. Such a mixture may simultaneously serve to provide barley as organic animal feed and wheat for sale into the premium organic flour market. Park wheat and oats may be an alternative choice based on our present results.

When choosing cultivars for use in mixtures on organic land, it is important to consider their individual characteristics. Park wheat and Manny barley combine well as a mixture. Even though the Manny barley had higher early season vigor and serves to compete to the extent of yielding greater grain percentage in the final mixture ratio, the wheat is taller and following stem elongation has access to sunlight at the top of the crop canopy. Using a shorter wheat cultivar with a taller barley cultivar may not be as complementary. This also applies to mixtures of oats and wheat. In the present trial, the Grizzly oat was taller than either wheat cultivar, which may have allowed oats to compete better than wheat in mixtures. Producers can formulate different species mixtures until they discover a combination and ratio that works best for their farming operation (Finckh et al., 2000).

Despite the fact that three of the top four entries on conventional land were Wheat:Barley mixtures, it is unlikely that conventional Canadian grain producers will adopt cereal mixtures. At the present time, low herbicide prices preclude the need for alternate weed control methods. Until chemical prices rise or weed resistance to herbicides becomes a bigger issue than it is at present, conventional producers will continue to use herbicides as their main, and often only, weed control method.

4. CONCLUSION

Organic and conventional management should be considered separately when recommending cereal mixtures. On conventionally managed land, wheat barley mixtures exhibited potential for yield maintenance and weed suppression. If conventional producers are concerned about weed competition causing yield loss and the development of herbicide resistance in weed populations, these mixtures may be considered. On organic land, competition with weeds had a large negative effect on yield, and thus both weed suppression and high yield may be considered when choosing a species mixture. The two 25:75 mixtures of wheat and oats and mixtures of Park wheat and barley exhibited high yield potential and barley mixtures exhibited weed suppressive capabilities. However, further studies are needed to determine which specific cultivars commonly used on the Canadian prairies have good mixing ability and will consistently provide above average yield potential when combined.

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