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Optimizing Canola Production: Fertilization, Crop Protection, and Genetic Yield Potential

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* This annual report has been prepared by David Przednowek, Chris Unger and Craig Linde on behalf of the following members of the research team including Don Flaten, University of Manitoba, project leader and Chair, as well as Rob Park, Manitoba Agriculture and Food, project agronomist and Vice-Chair. The project was conducted at three sites in 2001 and at two sites in 2002, all in Manitoba. In 2001 and 2002, sites were located near Brandon and were managed by Byron Irvine of Agriculture and Agri-Food Canada. Sites were also established in 2001 and 2002 near Carman and were managed by Rob Park and Alvin Iverson of the University of Manitoba, respectively. A site was established near Dauphin in 2001 alone, and was managed by Jeff Kostuik of the Parkland Crop Diversification Foundation. The site established at Carman in 2003 failed as a result of severe flea beetle pressure, and as such is not discussed in detail in this report. Other collaborators of the project included Rachael Scarth and Gary Martens who acted as the genetic team leaders; Dilantha Fernando who worked with Rob Park as the crop protection team leaders; and John Heard who worked with Don Flaten as the soil fertility team leaders. Finally, a number of other contributors to the project included Rene Van Acker, Weed Scientist; Martin Entz, Cropping Systems Scientist; Charles Grant, Farm Business Management Specialist; Paul Bullock, Agrometeorologist; Cindy Grant, Soil Fertility Scientist; Ramona Mohr, Sustainable Systems Agronomist; John Gavloski, Entomologist; and Keith Watson, Regional Crop Specialist.

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Introduction

Canola production has become increasingly reliant on purchased inputs. Combined with market volatility, canola, which was once perceived as a very profitable crop, has become less appealing to Canadian producers simply because it is now perceived as expensive to grow. Due to rising production costs, the economic risks associated with crop production are also rising due to the unpredictability of growing season conditions and the yield potential associated therein. As a result, crop input management decisions are becoming an even more critical component of crop production.

Modern agricultural technologies, including improved plant genetics, crop protection, and chemical fertilizers, all claim to provide incremental yield benefits that increase crop productivity and profitability. However, these high performance claims are based on field trials that examine such products on an individual basis. Plant stresses are controlled in such a way that only the intended stress in which the product is being tested (fertility, pest, or genetic pressure) is expressed. For example, canola cultivar variety trials are most often evaluated under an intensive soil fertility and crop protection regime, thereby enhancing yield potential and allowing the crop to more readily realize its maximum genetic potential. This experimental method is valid and is the easiest way to investigate the impact of new inputs on crop productivity. However, increasing yield potential by selectively eliminating sources of plant stress, except for the input being tested, and attributing all of the yield increase to that single input may result in exaggerated productivity claims. In reality, yield improvements are achieved by using a combination of crop inputs. However, each input within a package is often priced as if it was individually responsible for the potential yield improvement.

The following report summarizes the results and observations from a series of field trials conducted during the 2001, 2002, and 2003 growing seasons.

Project Objectives and Design

The main objective of this project is to measure the individual and combined effects of low, medium, and high levels of fertilization, crop protection, and genetic yield potential on canola yield, quality, and profitability. Three levels of fertility and pest control were included, namely high, medium, and low. Two levels of genetic potential were used - high and medium. A general description of the input packages is as follows:

Fertilization Packages

Low fertility:	No fertilizer added.
Medium fertility:	Amount of fertilizer added was based on a conservative soil test recommendation with a medium target yield of 35 bu/ac. Macronutrients were soil applied; micronutrients were foliar applied.
High fertility:	Amount of fertilizer added was based on an aggressive recommendation from a soil test recommendation, including "insurance" applications of K, S, and micronutrients. Target yield was 50 bu/ac. Macronutrients were soil applied; micronutrients were foliar applied.

Crop Protection Packages

Low protection:	No herbicides, fungicides, or insecticides applied.
Medium protection:	Fungicide and insecticide applied according to threshold infestations (integrated pest management – IPM). Registered rate of herbicide used without threshold consideration.
High protection:	High rates of all pesticides, including scheduled, preventative application of fungicides and insecticides, and two applications of herbicide

Genetic Potential

Medium Yield Potential: The open pollinated Liberty Link variety SW Flare seeded at 6 lb/ac.

High Yield Potential: The hybrid Liberty Link variety InVigor 2663 seeded at 4 lb/ac. The Manitoba Seed Guide suggests InVigor 2663 yields 30% higher than SW Flare

It should also be noted that pre-seeding burnoff with glyphosate was carried out at the Brandon site in all three years of the trial for all treatments. Details of the crop input packages, as applied at each site, are summarized in Tables 1 and 2.

	Location		
	Brandon	Carman	Dauphin
Environmental Conditions	Good growing conditions throughout season	Good growing conditions early; however, excessive precipitation in late July drowned out two replicates and seriously stressed two replicates	Good growing conditions early; but late season drought and late season infestation of flea beetles from surrounding field reduced grain yields
Fertilization Packages (N-P_2O_5-K_2O-S in lb/ac)			
Low fertility	No Fertilizer added	No Fertilizer added	No Fertilizer added
Medium Fertility	107-32-0-27.5 Boron @ 0.22 L/ac	95-10-0-17	40-35-35-0
High Fertility	159-46-0-27.5 Boron @ 1.7 L/ac Zinc @ 0.22 L/ac	130-30-0-35 Boron @ 3.45 L/ac	100-45-45-10 Zinc @ 0.6 L/ac
Crop Protection Packages			
Low Protection	No Pest Control	No Pest Control	No Pest Control
Medium Protection	Foundation Lite Liberty @ 1.35 L/ac Ronilan @ 0.4 kg/ac	Foundation Lite Liberty @ 1.35 L/ac Malathion @ 0.5 L/ac Ronilan @ 0.4 kg/ac	Foundation Lite Liberty @ 1.35 L/ac Ronilan @ 0.4 kg/ac
High Protection	Helix Extra Liberty/Select/Amigo 2nd Liberty @ 1.1 L/ac Lorsban @ 0.405 L/ac Ronilan @ 0.4 kg/ac	Helix Extra Liberty @ 1.35 L/ac 2nd Liberty @ 1.08 L/ac Ronilan @ 0.4 kg/ac Decis @ 0.06 L/ac	Helix Extra Liberty @ 1.35 L/ac 2nd Liberty @ 1.08 L/ac Ronilan @ 0.4 kg/ac Decis @ 0.06 L/ac
Genetics Packages			
Medium	SW Flare LL	SW Flare LL	SW Flare LL
High	InVigor 2663	InVigor 2663	InVigor 2663

Table 1. Input packages for the 2001 field experiments.

The experiment used an incomplete factorial design, with treatments made up of packages of inputs (Table 3). Treatments 1-8 represent a true factorial design where all combinations of medium and high levels of inputs for genetic potential, fertility, and crop protection are included. Treatment 9 is a "check treatment" with low levels of all inputs; treatments 10 and 11 are "reference treatments" that represent typical checks for fertilization and crop protection inputs, respectively; treatment 12 serves as a measure of the yield advantage for InVigor 2663 vs SW Flare under low input conditions.

	Location		
	Brandon 2002	Carman 2002	Brandon 2003
Environmental Conditions	Very dry conditions in early spring until summer. Germination was poor and weed pressure high	Generally, good growing season conditions except for hot weather during flowering	Good growing conditions during May-June, followed by hot, dry weather during flowering and podding
Fertilization Packages (N-P_2O_5-K_2O-S in lb/ac)			
Low fertility	No Fertilizer added	No Fertilizer added	No Fertilizer added
Medium Fertility	80-25-0-10	35-17-0-12	40-22-0-25
High Fertility	151-45-0-10	109-21-0-36	86-34-18-30
Crop Protection Packages			
Low Protection	No Pest Control	No Pest Control	No Pest Control
Medium Protection	Foundation Lite Liberty @ 1.35 L/ac Ronilan @ 0.2 kg/ac	Foundation Lite Liberty @ 1.35 L/ac Malathion @ 0.5 L/ac Ronilan @ 0.35 kg/ac	Foundation Lite Liberty @ 1.35 L/ac Malathion @ 0.5 L/ac
High Protection	Helix Extra Liberty @ 1.35 L/ac 2nd Liberty @ 1.08 L/ac Lorsban @ 0.405 L/ac Ronilan @ 0.4 kg/ac (split)	Helix Extra Liberty @ 1.35 L/ac 2nd Liberty @ 1.08 L/ac Ronilan @ 0.4 kg/ac (split) Decis @ 0.06 L/ac	Helix Extra Liberty @ 1.35 L/ac 2nd Liberty @ 1.08 L/ac Lorsban @ 0.405 L/ac Malathion @ 0.5 L/ac
Genetics Packages			
Medium	SW Flare LL	SW Flare LL	SW Flare LL
High	InVigor 2663	InVigor 2663	InVigor 2663

Table 2. Input packages for the 2002 and 2003 field experiments.

Treatment	Genetics Level	Fertilization Level	Crop Protection Level	Abbreviation
1	Medium	Medium	Medium	M-M-M
2	Medium	High	Medium	M-H-M
3	Medium	High	High	M-H-H
4	Medium	Medium	High	M-M-H
5	High	Medium	High	H-M-H
6	High	High	High	H-H-H
7	High	Medium	Medium	H-M-M
8	High	High	Medium	H-H-M
9	Medium	Low	Low	M-L-L
10	High	Low	High	H-L-H
11	High	High	Low	H-H-L
12	High	Low	Low	H-L-L

Table 3. Field experiment treatment arrangement.

Field Monitoring and Measurements

System level research requires diligent monitoring and record keeping because interactions among factors can be very complex. Sources of yield response associated with the various combinations of input packages may be attributed to improved growth or protection at a number of crop development stages. The best way to isolate possible sources of yield response is to monitor plant growth and pest levels at these critical periods throughout the season. Following is a brief description of the measurements collected during the growing season in an attempt to accomplish what was just stated. Summaries of measurement means are presented in Appendices A-E.

Pre-planting Measurements

In the spring, prior to seeding, the soil at each site was sampled for soil fertility. Samples were taken at 0-15, 15-60 cm. Twelve to fifteen soil cores were taken from each site. For each depth, a composite of the cores for each depth were used to characterize the site. Samples were air dried at 20-30^oC then ground and mixed thoroughly. Sub-samples were submitted to Norwest Labs, EnviroTest Labs, and AgVise Labs for analysis of N, P, K, S, and micronutrients (B, Cl, Cu, Zn, Mn, Fe) in the top 15 cm and N, S, and Cl to 60 cm. Fertilizer recommendations were requested from all three soil test labs, based on 35 and 50 bu/ac target yields, including any possible micronutrient recommendations based upon midseason foliar application The least expensive recommendation for the 35 bu/ac yield goal was selected as the "medium" fertility treatment and the most expensive recommendation for the 50 bu/ac yield goal was selected as the "high" fertility treatment.

Early Season Measurements

1. Crop Emergence and Plant Density: Crop density counts provide information on germination (seed vigour), as well as plant mortality due to flea beetle and soil-borne pathogens. At all sites, plant counts were conducted at the cotyledon stage (approximately 10 days after planting, except at Brandon in 2002 where the first count was taken 20 days after planting) and the 2-leaf stage (approximately 17 days after planting, except at Brandon in 2002 where the second count was taken 41 days after planting). At Carman and Brandon in 2002, plant counts were also conducted immediately after harvest (stems only). Counting areas were marked so the same area was assessed each time. Starting counts 1 m from each end of the plot, two samples of 1m by 4 rows were counted for each plot. Densities were recorded in plants/square metre.

2. Crop Development: For all three Brandon site years, as well as the Carman site in 2002, plant vigour was monitored by recording crop development using the development scale of Harper and Berkenkamp (Can. J. Plant Sci. 55: 657-658). The first crop development evaluations occurred approximately 10 days after seeding, after which development was monitored weekly.

Mid-Season Measurements

1. Weed Density: To provide information on weed competition and herbicide efficacy, weed counts for all treatments were conducted at pre-spray and post-spray at Brandon and Dauphin in 2001 and at Carman in 2002. At Carman in 2001, only pre-spray weed counts were taken. At Brandon in 2002, no weed densities were recorded; however, due to the poor emergence of the crop, weed pressure was high. Each weed species in 4 X 1/10 square meter quadrates per plot were counted prior to the herbicide application and again post herbicide application and were reported in units of plants/m^2.

2. Midseason Plant Tissue: Plant nutrition was monitored using plant tissue samples at the Brandon 2001 and Carman and Brandon 2002 locations. Plant tissue samples of the newest fully developed leaf were removed from 10 plants for each rep at the late rosette/early bolting stage of development. Samples were taken from treatments #3, 4, 5, 6 and 10.

Late Season Measurements

1. Lodging: Data was collected to determine the severity of lodging, wherever lodging was observed (no lodging at Dauphin in 2001 and Brandon 2002). Plots were rated weekly, beginning at mid flowering. For severity, lodged plants were rated on a scale of 1-5 with 1 being erect and 5 being plants bent to within 30 cm of the soil surface. For extent of lodging (incidence), the % of the plot lodged in 10% increments was rated, disregarding the outside 2 feet of the plot ends and edges as these areas were more likely to stand up due to more light.

2. Harvestability: At Carman in 2001 and 2002 and at Brandon in 2001 and 2002, crop harvestability was measured immediately prior to swathing or pushing. The erect height of the crop was measured by taking the average height of 5 randomly selected plants. Four samples were taken per plot from the edges. The height to the first pod in 4 areas of each plot, as well as the lodged height of the crop (where applicable), were also measured.

Harvesting and Seed Yield Measurements

Treatments were swathed and harvested according to their optimum maturity and dryness levels. All reps for a given treatment were harvested at the same time. The centre two-metre rows were harvested at the Brandon 2001 location, and the entire plot was harvested at both Carman and Dauphin in 2001, at Brandon and Carman in 2002 and at Brandon in 2003.

Post Harvest Measurements

1. Canola Quality: Canola quality analyses included measurements of oil and protein concentration (NIR), glucosinolates (NIR), green kernels, chlorophyll, overall grade, dockage, moisture content, and fatty acid profile.

2. Post Harvest Soil Fertility: At Brandon and Carman in 2002, as well as at Brandon in 2003 (data not presented), each plot was sampled separately in the fall to depths of 0-30, 30-60, 60-90 and 90-120 cm. At Brandon in 2001, soils samples were collected from the 0-15, 15-30, and 30-60 cm depths. Two to four soil cores were taken per replicate; cores for each depth in each plot were combined into a composite sample. Composite samples were air dried at 20-30^oC, then ground and mixed thoroughly; Nitrate-N determination was carried out subsequently.

Entire Season Measurements

1. Environmental Monitoring: At Brandon in 2001 gravimetric soil moisture content was determined for 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths (data not presented). At all sites, except Dauphin in 2001, a weather station collected standard information such as temperature, wind speed, humidity, and precipitation.

2. Economic and crop input information was recorded for all sites; costs of the various inputs were held at 2001 levels. The input, yield, and quality data was also used to generate information for other scenarios (e.g. higher or lower canola/crop prices).

Insect and Disease Monitoring and Thresholds

Field scouting was a necessary part of the "integrated pest management" strategy at the medium crop protection level, but not at the high or low input levels in this experiment. However, to gather quantitative information on the effects of pests on the crop and the interaction between input levels, pest pressure and pest control, all the plots in the experiment were monitored.

Flea beetle monitoring consisted of assessing damage (% defoliation) to canola seedlings on all plots every one or two days during and after emergence until the four leaf stage. For the medium input treatment, insecticide was applied if there was 25% defoliation and flea beetles were present. At Brandon and Carman in 2001, damage did not surpass threshold levels and medium plots were not sprayed. Flea beetle control was not warranted during the early stages of growth at Dauphin; however, a late season infestation of flea beetles from the field surrounding the test plot resulted in all plots being sprayed in early August. At Carman in 2002, flea beetle pressure did not surpass threshold levels early; however, later in the season, flea beetle activity increased but no additional insecticide was applied.

Plots were monitored on a weekly basis for Diamondback moth larvae in July and early August. Populations were visually assessed and the number of larvae per plant recorded. Counts were conducted in a one-foot square area. Medium input treatments were sprayed if there were 100-150 larvae/m^2 (10-15 larvae/ft^2) in immature and flowering fields and 200-300 larvae/m^2 (20-30 larvae/ft^2) in podded canola fields. Lygus bugs were scouted weekly, from just prior to bud formation until seeds within the pod became firm. The economic threshold for the medium crop protection treatment was 10-21 Lygus bugs / 10 sweeps from the end of flowering to early pod development in the upper canopy, and 15-29 Lygus bugs / 10 sweeps in the early pod ripening stage. Scouting for Bertha Armyworm larvae started in mid-July. Scouting continued once a week until harvest. The spray threshold for bertha armyworm was set at 30-35 larvae/meter square based on anticipated yield and the price of canola.

Populations of Diamondback Moth, Bertha Armyworm, and Lygus did not exceed threshold at any location, therefore medium crop protection treatments were not sprayed. High crop protection treatments were sprayed with Lorsban at Brandon in 2001 and 2002 and Decis at Carman in 2002 and Dauphin in 2001.

Shortly after harvest, five canola roots from each plot (25 at Brandon in 2001) were randomly selected, pulled from the soil, and rated for root maggot injury. Ratings were based on a scale of 0 to 5, where 0 indicated no damage and 5 was the highest level of damage (Dosdall et al. 1994).

Plant disease, including sclerotinia and blackleg, were monitored and controlled in the medium protection package, if considered severe. Where disease was present (Brandon in 2001), plants were examined for sclerotinia damage three weeks after flowering, and severity was expressed as percent of the stand infected. A sclerotinia severity scale was used where zero indicated no affected plants, 1 indicated only 1-2% of plants showing symptoms, a rating of 2 indicated 2-15% of plants were affected, and 3 corresponded to 15% or greater plants affected.

Weather Summary

The weather at Brandon in 2001 was typical of normal weather for the region, providing near-perfect growing conditions for the entire growing season (Table 4). The weather at Carman in 2001 was moderately dry in the spring but provided good growing conditions until late July, when 15 cm of precipitation fell in two days, causing major flooding in the plots and resulting in two replicates being dropped from the canola yield analysis. In Dauphin, drought late in the season restricted crop moisture supply and reduced yields.

In 2002, Carman experienced relatively good growing conditions. Spring moisture conditions were good and crop emergence and development was excellent (Figure 1). July was relatively dry in comparison to June, yet there was adequate precipitation for plant growth and development. The dry July conditions also served to minimize disease pressure. At Brandon, spring growing conditions were poor. May and June were both extremely dry, resulting in poor crop emergence and development. When rains finally materialized in late June, crop development was delayed substantially and did not recover, resulting in extremely high weed pressure. Precipitation was well below normal in Carman and Brandon resulting in additional crop moisture stress in the latter. Average monthly temperatures at both sites did not limit plant growth, although in August, the temperature at both 2002 sites was significantly lower than temperatures experienced at the sites in August 2001.

Conditions at the Brandon site in 2003 were near ideal in May and June, although delayed planting meant that the crop could not take full advantage of the favorable growing conditions. Between mid-June and the end of July, precipitation was well below normal, and temperatures were well above normal, resulting limited disease pressure as well as causing crop moisture stress during the flowering and filling period, thereby reducing yield potential. At the Carman 2003 site, severe flea beetle pressure made it impossible for pesticide-treated plots to coexist with untreated plots, leading to catastrophic losses and severe yield reductions across all treatments.

	Carman-01	Brandon-01	Carman-02	Brandon-02	Brandon-03
May					
Precipitation (mm)	53 (53)	70 (48)	48	0	42
Mean Temperature (ºC)	12.8 (11.9)	12.7 (11.0)	8.2	7.9	7.4
June					
Precipitation (mm)	41 (73)	168 (67)	141	3	65
Mean Temperature (ºC)	16.2 (17.4)	15.2 (16.2)	17.7	17.4	12.9
July					
Precipitation (mm)	193 (69)	31 (72)	49	28	5
Mean Temperature (ºC)	19.8 (20.1)	19 (18.7)	20.3	20.0	25.0
August					
Precipitation (mm)	22 (66)	53 (69)	129	78	28
Mean Temperature (ºC)	19.5 (18.7)	18.9 (17.5)	17.8	17.1	19.8
Growing Season Precip. (mm)	309 (261)	322 (256)	368	109	140

[z] Data in parentheses are 1961-1990 climatic averages (Environment Canada Climate Center, Winnipeg, MB)

Table 4. Weather summary for the Carman and Brandon site years.

Effect of Crop Inputs on Canola Grain Yield

Crop inputs vary in their ability to increase productivity. Genetic potential, which refers to the genetic ability of a crop to produce more seed, is most often greater for hybrid cultivars relative to conventional, open-pollinated cultivars. Fertilization increases yield by providing the crop with the nutrients it needs to achieve its full yield potential. Pesticides enhance crop yield potential by warding off insects and disease, or by limiting or elimination competition with weeds for water and nutrients. Table 5 illustrates the substantial variability in yield response to crop input packages among site years.

		Yield (bu ac^{-1})^{z}					
Treatment	Abbreviation^{y}	Brandon01	Carman01	Dauphin01	Carman02^{x}	Brandon02	Brandon03
1	M-M-M	25.5e	21.4abc	19.5bcd	20.8	6.6cd	15.8bcd
2	M-H-M	33.9cd	31.7a	23.2abc	21.4	8.0cd	18.7abc
3	M-H-H	37.7bcd	29.4ab	22.1abc	20.0	20.0a	21.8ab
4	M-M-H	31.7de	14.7cd	21.3abc	20.1	14.4b	19.6abc
5	H-M-H	39.9bc	23.3abc	22.9abc	20.6	10.9bc	23.2a
6	H-H-H	46.5a	23.9abc	24.3abc	23.5	24.3a	23.4a
7	H-M-M	34.5bcd	20abcd	25.1abc	19.3	5.2d	14.4cd
8	H-H-M	40.5ab	22.2abc	25.4ab	20.0	7.1cd	18.5abc
9	M-L-L	6.1g	8.0d	18.7cd	9.5	0.2e	6.6e
10	H-L-H	17.4f	12.5cd	14.3d	16.0	4.7e	15.6bcd
11	H-H-L	35.2bcd	16.7cd	27.4a	16.0	0.6e	15.5cd
12	H-L-L	7.4g	13.7cd	21.1abc	14.0	0.3e	9.5de
LSD		6.5	13.2	6.6		4.6	6.3

^{z} Means designated by a different letter are significantly different within a given site.

^{y} Genetics-fertility-crop protection level.

^{x} LSD not possible due to unbalanced data.

Table 5. Yield of the various crop input combinations for the site years evaluated in the study.

Independent Comparisons of All Treatments

Independent comparisons among all twelve treatments evaluated the performance of individual input packages. Using pre-determined, single degree of freedom contrasts, cultivar yields were compared under conditions where crop protection *and* fertility levels were low (Ttreatment 12 versus 9) or high (Treatment 3 vs 6). The latter comparison is typical for crop variety research trials, where all crop inputs are utilized at high levels to ensure that the yield potential of each cultivar in the trial is maximized. However, testing cultivars without high levels of other inputs provides some insight into the stress tolerance of both varieties. For example, the complete range of fertility packages was tested using InVigor 2663 with the high crop protection regime alone (Treatments 10, 5, and 6). The complete range of crop protection packages was also tested using InVigor 2663 under the high fertility regime alone (Treatments 11, 8, and 6). The complete range of all possible fertilizer and pesticide packages was not tested with both cultivars due to labour, cost, and space restrictions.

Statistically significant yield differences among the two cultivars were only observed at Brandon in 2001 at the high level of fertility and crop protection (Table 6); InVigor 2663 out-yielded SW Flare by 24% and 22% under high and low input conditions, respectively. Although the relative yield advantage of InVigor 2663 versus SW Flare was similar under both high and low input levels, the absolute yield advantage (i.e. economic incentive) was much greater under the high input conditions (497 kg/ha) than under the low input conditions (73 kg/ha). It is also important to note that the percentage difference in grain yield between InVigor 2663 and SW Flare at the Brandon 2001 location is comparable to the projected yield advantage of InVigor 2663 as described in the 2001 Manitoba Seed Guide (30%).

Site Year	Input Level	SW Flare Yield (kg/ha)	InVigor 2663 Yield (kg/ha)	Relative Yield Advantage of InVigor 2663 (% of SW Flare)	Absolute Yield Advantage of InVigor 2663 (kg/ha)	Pr > F
Brandon 2001	Low	339	412	122%	73	0.64^{ns}
	High	2109	2606	124%	497	0.003**
Carman 2001[z]	Low	447	766	171%	319	0.35^{ns}
	High	1644	1339	81%	-305	0.33^{ns}
Dauphin 2001	Low	748	925	124%	177	0.29^{ns}
	High	1137	1271	112%	134	0.25^{ns}
Carman 2002	Low	535	787	147%	252	0.45^{ns}
	High	1121	1320	118%	199	0.24^{ns}
Brandon 2002	Low	12	17	145%	5	0.62^{ns}
	High	1119	1359	121%	240	0.36^{ns}
Brandon 2003	Low	371	534	144%	164	0.0653^{ns}
	High	1222	1310	107%	88	0.97^{ns}

** comparison significant at P<0.05

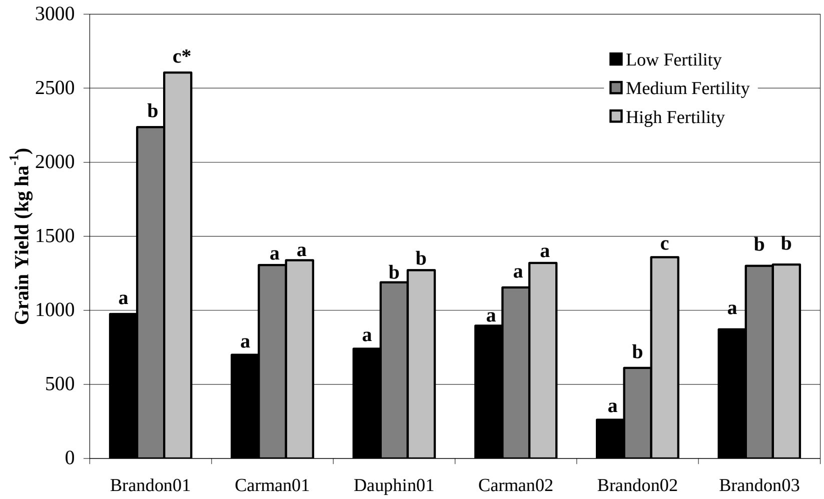
ns – cultivars not significantly different

[z] after flooding, only the best two replicates were harvested and analyzed

Table 6. Independent cultivar comparisons using high and low input packages for grain yield.

At Carman in 2001, InVigor 2663 out-yielded SW Flare under low input conditions, whereas the opposite was true under high input conditions. Significant yield differences were not observed at the Dauphin site, although InVigor 2663 yielded 12% and 24% more than SW Flare at high and low input levels, respectively. At Carman and Brandon in 2002, as well as at Brandon in 2003, although there were no significant yield differences at high and low input levels, the relative yield improvement of InVigor 2663 over SW Flare was generally greater under the low input conditions. However, at Brandon in 2003 the absolute yield advantage of InVigor 2663 was much greater under high input conditions (240 kg/ha) than under low input conditions (5 kg/ha).

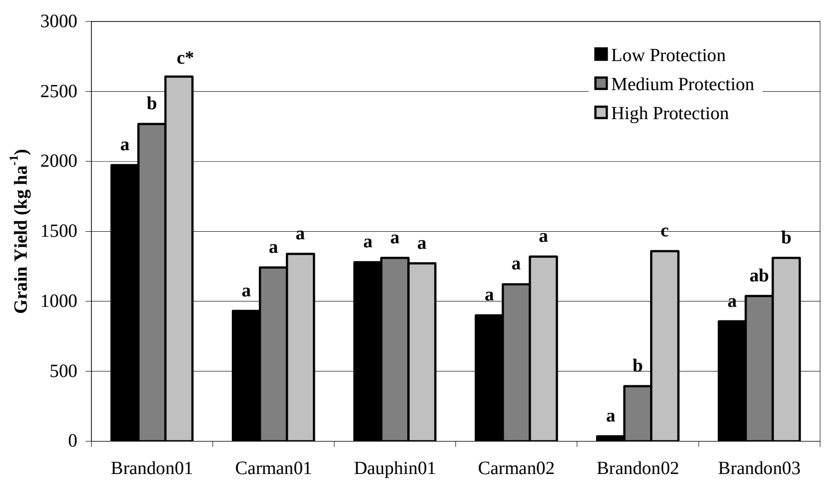
As expected, at the highest level of crop protection, the yield of InVigor 2663 generally increased as fertility level increased (Figure 1), although there were no significant differences among any of the fertility levels at the Carman 2001 and 2002 sites. In 2001 and 2002, crop stress was a feature of the second half of the growing season at Carman, which may have prevented the crop from taking full advantage of the highest fertility level. For all three Brandon site years, as well as the Dauphin site, increasing the fertility level from low to medium significantly increased grain yield, while increasing fertility level from medium to high resulted in significantly higher yields in two of four instances, namely at Brandon in 2001 and 2002 (Figure 2).



* means designated by a different letter are significantly different (*P* <0.05) within a site

Figure 1. Influence of fertility on canola productivity where crop protection level and genetic potential were high.

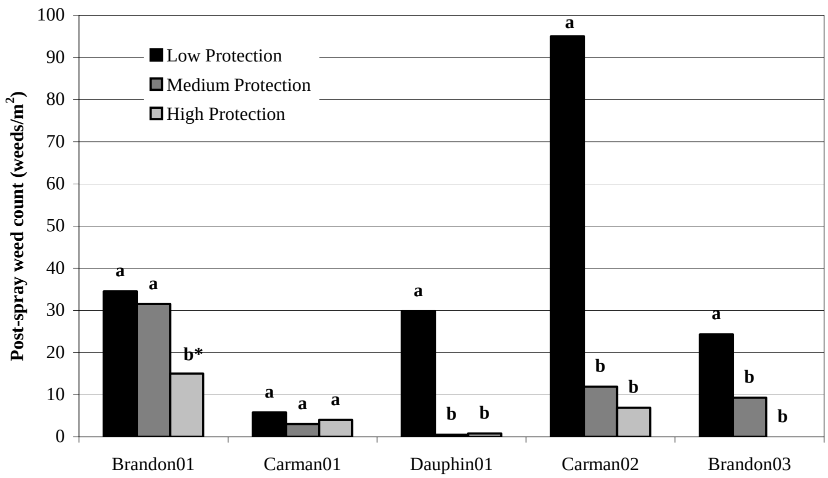
Crop protection level strongly influenced the yield of InVigor 2663 under high fertility conditions for all three Brandon site years, while no significant differences among crop protection treatments were observed at the Carman or Dauphin sites (Figure 3). At Carman in 2001 and 2002, however, there appeared to be a trend towards higher yields as crop protection level increased. At Brandon, the lowest level of crop protection resulted in the lowest yields; in 2002, grain yield was nearly zero under the low pesticide treatments due to the high weed pressure and poor germination of the crop in spring. In 2001, using the medium protection system resulted in 15% more yield than using no pesticides. The high protection management system provided an additional 15% more yield relative to the medium protection system. In 2002, using the medium protection system increased grain yields from near zero to 395 kg/ha which, due to the poor growing conditions, was still very small. However, the high protection system out-yielded the medium protection system by 245%.



* means designated by a different letter are significantly different (*P* <0.05) within a site

Figure 2. Influence of crop protection level on canola productivity where fertility and genetic potential were high.

One of the reasons why crop protection level had a pronounced effect on productivity at the three Brandon sites may be partially attributable to differences in weed pressure post-spraying (Figure 3). Not surprisingly, post-spraying weed pressure was in fact significantly higher for the lowest level of crop protection compared to the highest level of crop protection for all site years with the exception of the Carman-01 site. Although weed density was not quantitatively assessed at Brandon in 2002, weed pressure was noted as being high at the site. To make matters worse, canola germination was poor at the Brandon site in 2002, which further reduced the crop's competitive ability at higher weed densities. Crop protection level also had a significant effect on crop development at the Brandon site in 2002 and 2003 (data not presented - see Appendix E and F), which may have also affected productivity. In the case of the Dauphin 2001 and Carman 2002 sites, adverse growing conditions later in the growing season had a more pronounced effect on productivity, which may help to explain why crop protection level affected canola productivity at these two site years.



* means designated by a different letter are significantly different (P <0.05) within a site

Figure 3. Influence of crop protection level on post-spraying weed density where fertility and genetic potential were high.

Factorial Comparisons for Treatments 1-8

A factorial experiment tests the independent and interactive effects of a given set of treatments, in this case specific levels of three classes of crop inputs. With a factorial set of treatments, more than one factor is present, and all levels of each factor are present in combination with all the levels of the other factors. In this experiment, genetics, fertility, and crop protection were evaluated at medium and high levels, representing a complete 2x2x2 factorial experiment (when treatments 9-12 are not considered). Interactions among crop inputs, for example, occur when one crop input influences another as the magnitude of each is manipulated. If an increase in fertility level results in a much greater yield increase for cultivar A than for cultivar B, there may be a significant interaction between fertility and cultivar, because cultivar A is more responsive to fertilizer than cultivar B. One method of determining which factor(s), whether independently or interactively, are responsible for the greatest variability, or had the greatest influence on a response variable (e.g. grain yield), is to calculate the percent contribution to total variability.

For all three Brandon site years, significant yield differences were observed among treatments (Tables 7 and 8), although the factors responsible for the differences were not necessarily the same from year to year. At Brandon in 2001, all three crop input factors had a significant influence on productivity. Genetic potential had the greatest influence on productivity, accounting for 35% of the total variability, while fertility and crop protection level explained approximately 24% and 15% of yield variability, respectively. There were no significant interactions between factors; all interactions collectively accounted for less than 2% of the total variability in grain yield. In other words, while additional investment in crop protection and soil fertility inputs was providing diminishing marginal returns, genetic potential had a relatively large impact on yield. These results are similar to those observed for the yield difference between cultivars under low and high input conditions, where the absolute value of the genetic response was much greater under high input conditions, even though the genetic response under low and high input conditions was similar in relative terms.

	Brandon01				Carman01				Dauphin01			
Factor	df	% Total Variance	Pr>F	Sig	df	% Total Variance	Pr>F	Sig	df	% Total Variance	Pr>F	Sig
Error	21	26.0%			7	43.2%			21	77.9%		
Genetics	1	34.9%	<0.0001	**	1	2.1%	0.55	ns	1	4.5%	0.10	ns
Fertility	1	23.6%	<0.0001	**	1	27.8%	0.0529	ns	1	3.9%	0.13	ns
Protection	1	14.9%	0.0011	**	1	0.6%	0.76	ns	1	0.2%	0.74	ns
Genetics*Fertility	1	0.1%	0.76	ns	1	17.8%	0.11	ns	1	0.0%	0.86	ns
Genetics*Protection	1	0.1%	0.80	ns	1	7.1%	0.29	ns	1	4.4%	0.11	ns
Fertility*Protection	1	0.1%	0.76	ns	1	0.3%	0.83	ns	1	0.0%	0.86	ns
Genetics*Fertility*Protection	1	0.3%	0.61	ns	1	1.3%	0.64	ns	1	3.7%	0.14	ns

ns - not significant
** signficiant (*P* <0.05)

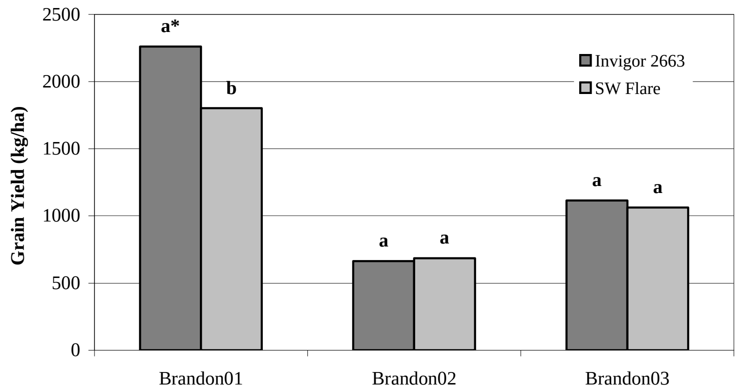
Table 7. Contribution of factors and their interactions to the total variance of canola yield for the factorial portion of the experiment in 2001.

	Carman02				Brandon02				Brandon03			
Factor	df	% Total Variance	Pr>F	Sig	df	% Total Variance	Pr>F	Sig	df	% Total Variance	Pr>F	Sig
Error	19	94.5%			21	18.9%			21	65.1%		
Genetics	1	0.7%	0.99	ns	1	0.1%	0.75	ns	1	0.8%	0.60	ns
Fertility	1	0.2%	0.70	ns	1	14.9%	0.0002	**	1	5.0%	0.19	ns
Protection	1	0.4%	0.84	ns	1	54.8%	<0.0001	**	1	24.6%	0.006	**
Genetics*Fertility	1	3.5%	0.77	ns	1	2.0%	0.12	ns	1	0.0%	0.91	ns
Genetics*Protection	1	0.0%	0.38	ns	1	0.3%	0.52	ns	1	2.6%	0.34	ns
Fertility*Protection	1	0.7%	0.97	ns	1	7.5%	0.0051	**	1	1.2%	0.51	ns
Genetics*Fertility*Protection	1	0.0%	0.68	ns	1	1.6%	0.17	ns	1	0.6%	0.64	ns

ns - not significant
** significant (*P* <0.05)

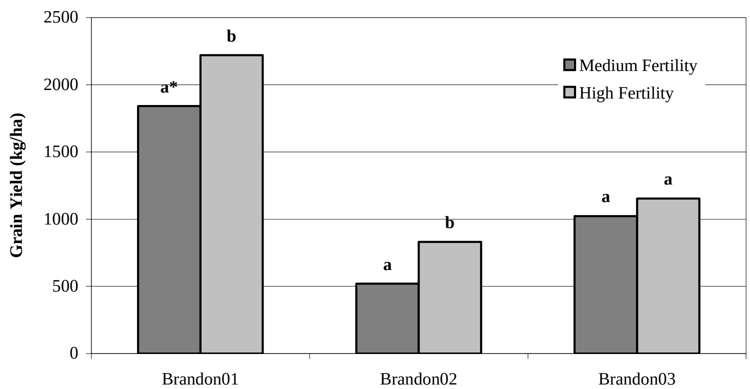
Table 8. Contribution of factors and their interactions to the total variance of canola yield for the factorial portion of the experiment in 2002 and 2003.

The hierarchy of influence on canola yield among factors at the Brandon sites is also illustrated in the overall average yield response to the medium and high levels of inputs (Figure 4-6). Averaged over all medium and high soil fertility and crop protection treatments, yield of InVigor 2663 was 25% higher than the yield of SW Flare at the Brandon 2001 site. Using the high fertility program rather versus the medium fertility program increased yield by an average of 21% at the Brandon 2001 site, while the high crop protection system resulted in 16% greater yield relative to the medium crop protection system at the Brandon 2001 site. The high crop protection level also resulted in significantly higher yields than the medium crop protection level at the Brandon02 and Brandon03 sites.



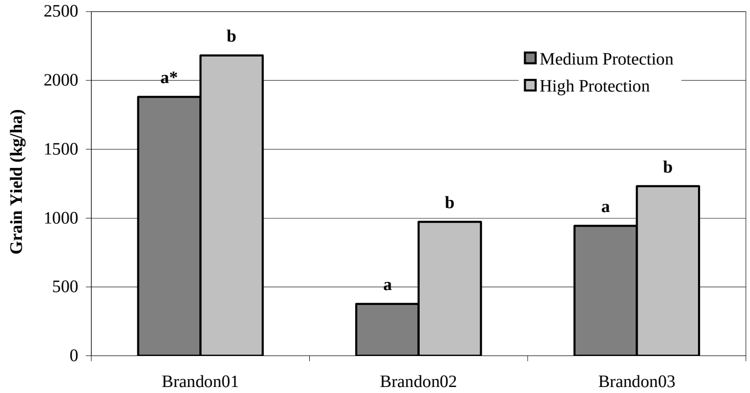
* means designated by a different letter are significantly different (*P* <0.05) within a site

Figure 4. Effect of medium and high genetic potential on yield at the three Brandon site years.



* means designated by a different letter are significantly different (*P* <0.05) within a site

Figure 5. Effect of medium and high fertility levels on yield at the three Brandon site years.



* means designated by a different letter are significantly different ($P < 0.05$) within a site

Figure 6. Effect of medium and high crop protection levels on yield at the three Brandon site years.

Unlike the observations for Brandon in 2001, genetics did not have a significant effect on grain yield at the Brandon site in 2002 (Table 8). Probably due to the cool and dry conditions in the spring, the superior yield potential of InVigor 2663 was not realized; therefore, no yield advantage over SW Flare was observed. Crop protection had the greatest influence on grain yield by far at the Brandon site in 2002, accounting for approximately 55% of the total variability. Fertility also had a significant effect on yield, representing approximately 15% of the total variability. Also of note is the significant interaction between crop protection and fertility (8% of the total yield variability).

At Brandon in 2002, the relative influence among factors on yield is also illustrated in the overall average yield response to the medium and high levels of inputs. Averaged over all medium and high soil fertility and crop protection treatments, there was no advantage of using InVigor 2663 versus SW Flare. Using the high versus medium fertility program increased grain yield by approximately 60%, and using high protection versus medium protection resulted in an extra 159% more yield. However, as mentioned previously, the interaction between crop protection and fertility was significant. This indicates that the response in grain yield to one factor was affected by the level of the other factor.

According to contrasts conducted on the data (Table 9) the yield response to increasing crop protection level from medium to high was significant at both levels of fertility; although, the response to the increased crop protection was greater under high fertility conditions. However, the significant interaction was probably due to the lack of yield response to increasing fertility level under medium crop protection and the large yield response to increasing fertility level when crop protection was high. Weed pressure was high and it was not necessary to increase the fertilizer rate if the high rate of crop protection was not used. However, under the high crop protection treatments, increasing the rate of fertilizer significantly improved yield.

Factor Combinations of Interest	Grain Yield Response (kg ha^{-1})	Significance
High minus medium fertility at medium crop protection	91	ns
High minus medium fertility at high crop protection	531	**
High minus medium crop protection at medium fertility	377	**
High minus medium crop protection at high fertility	817	**

ns - not significant
** significant (P<0.05)

Table 9. Effect of the interaction between fertility and crop protection on the yield of InVigor 2663 and SW Flare at Brandon in 2002.

At Brandon in 2003, the only factor to have a significant influence on productivity was crop protection level, accounting for roughly 25% of total variability (Table 7). The proportion of total variance attributable to error was much at Brandon in 2003 (53.7%) compared to roughly 15% at the Brandon site in 2001 and 2002, reflecting greater heterogeneity among replicates. Genetics and fertility level accounted for less than 6% of variability combined, and no significant interactions were observed. In this instance, greater investment in crop protection resulted in significant productivity gains, while enhancing soil fertility and genetics had relatively little impact on productivity, particularly in the case of the latter since the mean yield of Invigor 2663 and SW Flare was nearly identical.

Proper analysis of the Carman 2001 site was complicated by the fact that only two replicates were available, thereby reducing the robustness of the statistical analysis. Despite the fact that fertility level and the interaction between soil fertility and genetics explain a significant portion of total variability (27.8% and 17.8%, respectively), neither factor was statistically significant within the statistical model ($P < 0.0553$ and $P < 0.1087$, respectively). The overall statistical model itself was not statistically significant ($P < 0.30$), implying that no factor had any significant effect on productivity. However, had four replicates been available for analysis instead of two, treatment effects could have been more effectively assessed.

Reasons for Yield Responses to Crop Input Packages at Each Site

At Carman in 2001, excess soil moisture in early spring caused delays in seeding. Later in the growing season, much of the potential yield increase associated with the fertilizer treatments was lost or obscured due to greater lodging incidence and severity (Appendix B) as well as variable flooding stress caused by excessive rain in July. Greater lodging in conjunction with excess moisture would have increased the likelihood of disease development, further decreasing the potential yield of the high input treatments. Also, although herbicides worked very well, weed densities were very low and unlikely to greatly influence yield potential. Overall yield potential ranged from 31.7 bu/ac (M-H-M) to 8.0 bu/ac (M-L-L), with almost all of Treatments 1-8 yielding above 20 bu/ac.

The Dauphin 2001 site experienced a damp spring, which delayed seeding. Emergence was very good and canola flourished once it was out of the ground, resulting in a very competitive crop. Yield ranged from 27.4 bu/ac (H-H-L) to 14.3 bu/ac (H-L-H), and the gap between the high input and low input packages was much narrower than at the Carman 2001 site. Crop competition may have already suppressed any weeds present when spraying took place, causing the operation to be purely cosmetic with no significant impact on potential yield. The lack of insects early in the season and lack of disease pressure throughout the season eliminated any potential response to insecticide and fungicide. Although weed pressure would have been sufficient to decrease yield (Appendix C), there was no yield response to crop protection, even though herbicide efficacy was high. The lack of response to micronutrients and added nitrogen may be explained by dry conditions late in the season. During this period, lack of water would have been the limiting factor for potential yield; therefore, added nutrients were not utilized. Finally, late season flea beetle pressure from the field surrounding the small plots may have increased the variability within and between blocks enough to weaken treatment effects.

At Brandon in 2001, as mentioned previously, the yield advantage for InVigor 2663 over SW Flare in Brandon 2001 (25%) was similar to the projected yield advantage described in the 2001 Manitoba Seed guide (30%). The low concentration of nutrients in spring soil tests is the probable reason for the substantial fertilizer response to both the medium and high fertility treatments. Overall low and uniform levels of blackleg and sclerotinia (Appendix A) suggest that yield response due to crop protection came from either insect or weed control. Treating canola seed had no influence on canola density or growth and development, opposing the possibility of flea beetle feeding or soil-borne pathogens as sources of yield loss. Post spray measurements of broadleaf weed densities were significantly higher for the less intensive pest control treatments compared to the high intensity pest control treatments and may have lowered the crop's yield potential. Yield ranged from 46.5 bu/ac (H-H-H) to 6.1 bu/ac (M-L-L), demonstrating the strong overall response to crop input intensity; almost all of the medium or high input packaged had yields that exceeded 25 bu/ac.

At Carman in 2002, even though growing conditions were generally good, grain yields remained relatively low and no significant responses to any of the factors were observed. Yield of Treatments 1 to 8 ranged from 19.3 to 23.5 bu/ac, while the poorest yield was exhibited by Treatment 9 (9.5 bu/ac). High daily temperatures during flowering and high levels of mid to late season flea beetle pressure may have reduced the treatment effects, diminishing the overall effect of each factor (Appendix D). Furthermore, because no insecticide was applied to control the late season flush of flea beetles, the effect of any earlier insecticide application probably diminished. The lack of a fertilizer response may be due to the reasons already explained plus the relative sufficiency of nutrients in the soil in early spring; therefore, the additional nutrients supplied by the fertilizer treatments was not utilized by the crop.

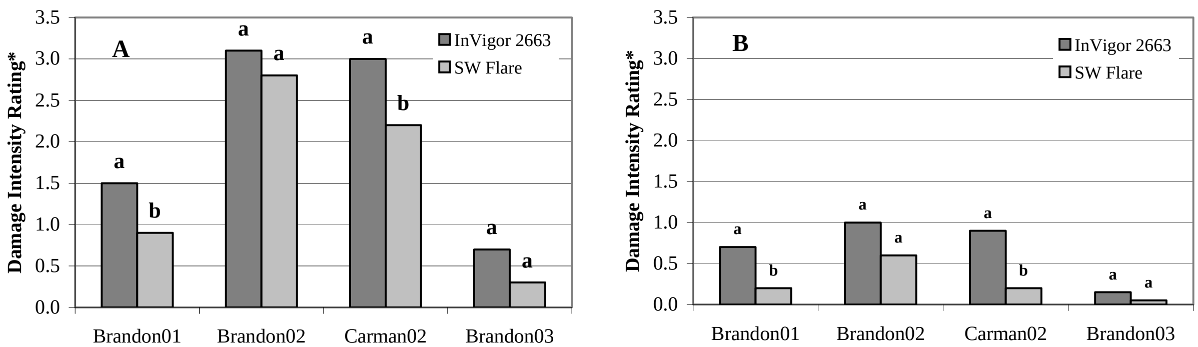
At Brandon in 2002, the low concentration of nutrients in spring soil tests is the probable reason for the substantial fertilizer response to both the medium (11-14 bu/ac) and high (20-24 bu/ac) fertility treatments where crop protection level was high. Yields of Treatments 3-6 were the only ones to exceed 10 bu/ac. The large response to the medium and high crop protection treatments was due to a combination of high weed competition and low crop vigour. Due to the extremely dry conditions in spring, crop germination and emergence was poor, and the crop stand that developed was very weak (Appendix E). Therefore, due to the poor stand, weed proliferation excelled and any herbicide application significantly reduced the weed competition and increased the crop competition. Furthermore, the response in grain yield to crop protection was probably not due to a crop response to fungicide application due to the relatively dry conditions later in the growing season and the lack of disease pressure.

At the Brandon 2003 site, crop protection clearly had a significant impact on canola productivity. Yields ranged from 6.6 bu/ac (M-L-L) to 23.4 bu/ac (H-H-H). As was the case at Brandon in 2002, Treatments 3-6 had the highest yields. Favourable growing conditions early on during the growing season promoted vigorous crop emergence, although the favourable soil moisture conditions also fostered weed competition, particularly broadleaf weeds. Disease pressure was extremely limited later in the growing season due to the dry and hot conditions, lending further support to the notion that the yield differences observed at varying levels of crop protection was attributable to differences in weed pressure. While yield potential was above average prior to the reproductive phase of development, the hot dry weather that occurred during July and August reduced yield potential.

Effect of Crop Inputs on Root Maggot Damage

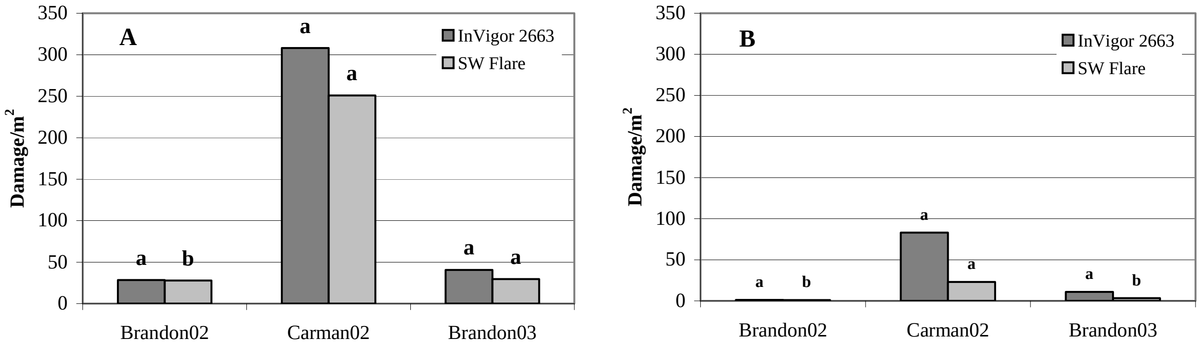
Although root maggots were not specifically targeted with pesticides, there were differences among treatments. Root maggot damage intensity was significantly higher for InVigor 2663 than for SW Flare at two of three sites under low and high inputs (Figure 7). *Delia* spp. favor thicker stems (Dosdall et al. 1995) possibly explaining why there was greater root maggot damage in treatments containing InVigor 2663 than in treatments containing SW Flare. In addition, plant densities for InVigor 2663 tended to be lower than for SW Flare due to a lower seeding rate (4 vs. 6 lb/ac, respectively) and a larger seed size. Root maggots were probably more concentrated on the stems of InVigor 2663, causing more damage. When the post harvest stem density was multiplied by the root maggot damage rating to give an index of root maggot damage, it is evident that although the damage rating was different for the different varieties, the overall plant damage on an area basis was not significantly different (Figure 8). However, there is potentially greater yield and economic risk from root maggot activity when growing InVigor 2663 because the intensity of damage was higher for InVigor 2663 relative to SW Flare.

Root maggot damage also increased at high fertility for InVigor 2663 (Figure 9). This was possibly due to improvement in plant health, growth, and vigour, and the attractiveness of thicker stems due to the increased fertilization. Finally, although there were treatment and factor effects on root maggot damage, root maggots usually cause economic damage in central parts of Alberta, only (Turnock et al, 1992). However, small plot experiments such as these may create an unnaturally high incidence of *Delia* spp. in plots with thickened stems, due to the extraordinary ease of migration from one small plot to another. Therefore, the practical impact of these observations for field scale production of canola is uncertain.



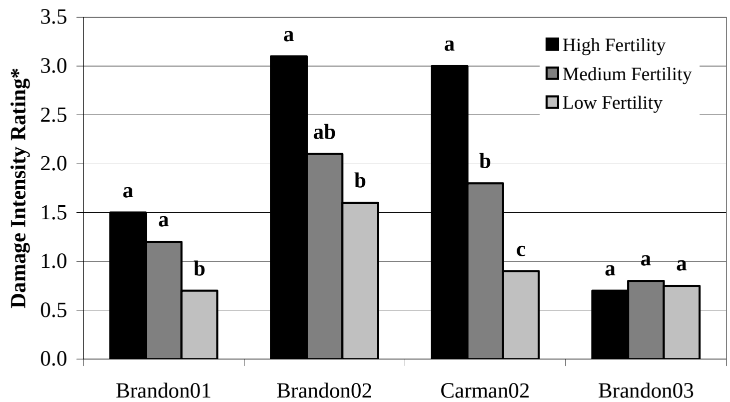
* 0-5 rating system where 0 = no damage and 5 = highest damage. Means designated by a different letter are significantly different (P<0.05) within a given site.

Figure 7. Root maggot damage intensity rating for InVigor 2663 and SW Flare grown under high (A) and low (B) input levels.



Means designated by a different letter are significantly different (P<0.05) within a given site.

Figure 8. Root maggot damage/m^2 for InVigor 2663 and SW Flare grown under high (A) and low (B) input levels.



* 0-5 rating system where 0 = no damage and 5 = highest damage. Means designated by a different letter are significantly different (*P* <0.05) within a given site.

Figure 9. Root maggot damage intensity ratings for InVigor 2663 grown under high, medium and low fertility.

Effect of Crop Inputs on Economics

Crop input economics is an important consideration in crop management decisions, since using inputs to increase and/or protect yield is only feasible if it translates into greater net income. The potential to increase profitability by intensifying crop input usage is at the same time accompanied by increased yield and market risk (Zentner et al. 2002b). Yield risk is a result of the inherent variability in growing conditions typical of the Prairies, including events such as drought, flooding, hail damage, and pest infestation. As demonstrated by 1991-2000 Manitoba Crop Insurance Corporation (MCIC) yield data for the insurance risk areas in which the Brandon, Carman, and Dauphin sites are located (risk areas 4, 9, and 12, respectively), significant yield variability among years and among sites within a given year is evident (Figure 10). The 1991-2000 average canola yield in Manitoba was 27.5 bu/ac, with a range of 22.0-30.6 bu/ac and a standard deviation of 2.9 bu/ac (Manitoba Agriculture 2002). If a given set of crop management practices or a cash crop is to be sustainable, there must consistently be reasonable assurance of productivity stability.

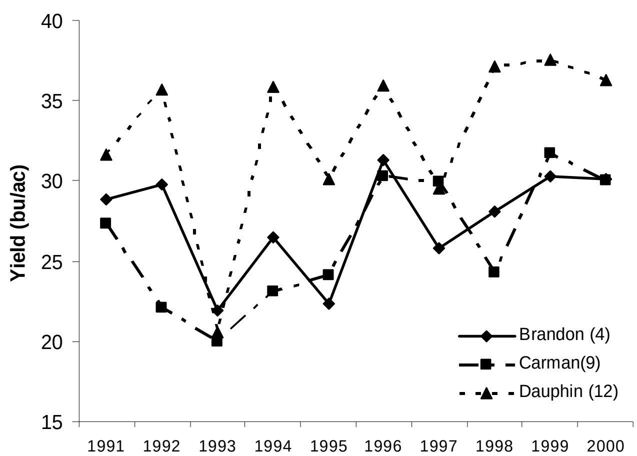


Figure 10. 1991-00 average canola yield in MCIC Risk Areas 4 (Brandon), 9(Carman), and 12 (Dauphin).

Just as important as yield risk is market risk, which arises as a result of swings in commodity prices, as well as changes in the value of crop inputs. For example, the 1991-2000 mean canola farm-gate price received by Manitoba producers (unadjusted for inflation) was $7.02 per bushel, or $309 per tonne (Manitoba Agriculture 2002). The standard deviation was $1.40 per bushel ($61.84/T), with a minimum price of $5.22 per bushel in the 1999-00 crop year and a maximum price of $8.73 per bushel in the 1995-96 crop year. Clearly, producers are exposed to significant market risk in any circumstance, although risk increases as more money is invested in crop inputs. Productivity must be maintained and increased if the producer is to pay for the additional costs associated with heavier investment in crop inputs, or if the producer is to absorb the impact of low canola prices on gross returns. Net returns become more sensitive to changes in commodity prices, since as commodity prices fall, a greater proportion of crop income (gross returns) is required to cover costs, resulting in smaller net returns. In the short term, producers choose crop management practices that result in the highest net returns (i.e. the producer is able to cover variable costs), while in the long term, producers must consider fixed costs as well as the sustainability of crop management practices.

The variability in net returns among the site years illustrates the substantial variability in growing conditions (Table 10 and 11). As expected, the ranking of net returns varied considerably across site years due to substantial variability in growing conditions and the resultant yield response. The Brandon

2001 site provided the best overall net return; variability among replicates was low as demonstrated by low standard deviation. Net returns ranged from $57/ac (H-H-H) to -$54/ac (H-L-H), with the most intensive crop input packages generally yielding the best net returns. At Dauphin in 2001, net returns ranged from -$75/ac (M-H-H) to $76/ac (H-L-L). Given the narrow yield range among treatments, net returns were generally the best in the least input intensive treatments.

		Brandon01		Dauphin01	
Treatment	Abbreviation[z]	Net Return[y]	SD	Net Return	SD
1	M-M-M	-13cd	21	-23cd	53
2	M-H-M	10bc	22	-33cde	28
3	M-H-H	-6c	48	-75e	41
4	M-M-H	-12cd	19	-44de	26
5	H-M-H	46ab	14	-34de	26
6	H-H-H	57a	32	-60de	23
7	H-M-M	47ab	37	13bc	29
8	H-H-M	53ab	19	-21cd	25
9	M-L-L	-33cd	13	64a	33
10	H-L-H	-54d	16	-64de	26
11	H-H-L	74a	56	51ab	26
12	H-L-L	-28cd	43	76a	38
LSD		45		46	

[z] Genetics-fertility-crop protection level.
[y] Means designated by a different letter are significantly different.

Table 10. Average net returns ($/ac) for the various crop input combinations at the Brandon and Dauphin 2001 site years.

Net returns were negative for all Carman02 treatments; M-M-M and M-L-L broke even while H-L-L produced a net return of $27/ac. Given the lack of yield response to increased crop input usage, the most input intensive treatments tended to be the least profitable. Given the very poor yield response at the Brandon site in 2002, net returns were all very negative; the least intensive treatments tended to have much higher net returns than input intensive treatments given the minimal investment in inputs in the former and the very poor yields of the latter.

		Carman02[y]		Brandon02		Brandon03	
Treatment	Abbreviation[z]	Net Return	SD	Net Return[x]	SD	Net Return[x]	SD
1	M-M-M	0	62	-115cd	23	-28ab	35
2	M-H-M	-30	36	-138cde	41	-40abcd	40
3	M-H-H	-80	7	-108bc	14	-84d	43
4	M-M-H	-44	19	-115cd	16	-68bcd	28
5	H-M-H	-40	41	-138cde	39	-42abcd	21
6	H-H-H	-55	17	-77ab	13	-73cd	40
7	H-M-M	-14	16	-128cde	16	-41abcd	11
8	H-H-M	-44	32	-148e	23	-44abcd	40
9	M-L-L	0	45	-74a	2	-29abc	20
10	H-L-H	-53	34	-143de	29	-65bcd	12
11	H-H-L	-14	25	-147e	2	-34abc	33
12	H-L-L	27	56	-78ab	1	-13a	26
LSD				32		44	

[z] Genetics-fertility-crop protection level.
[y] LSD analysis not possible due to unbalanced data.
[x] Means designated bya different letter are significantly different.

Table 11. Average net returns ($/ac) for the various crop input combinations at the Carman 2002, Brandon 2002, and Brandon 2003 site years.

In most cases, the addition of each level of crop input provided additional yield benefit; however, in some cases the added cost of each input was greater than the yield benefit, thereby eroding margin. For example, at the Brandon 2001 site, pest pressure was low, and the yield increase from investment in crop protection was less than that from investment in improved genetics or soil fertility. Therefore, the most profitable treatment was Treatment 11, with high genetic potential, high fertility and no pesticides. For canola priced at $5.50/bu, the three most profitable treatments included high genetic yield potential and the top two treatments also included high fertility. As expected, the probability of a net loss occurring as a result of investing in crop inputs diminished as canola prices increased (Table 12).

At Brandon in 2002, the yield response to crop inputs was poor and insufficient to account for the costs associated with each input, resulting in extremely poor net returns in general even when canola was valued at $8.50/bu. Net returns were well below breakeven levels; Treatment 6 (H-H-H) had the best net return at $8.50/bu (-$41/ac), followed by Treatment 9 (M-L-L) and 12 (H-L-L), due to minimal investment in crop inputs. The same trend was observed at the Brandon 2003 site, as net returns were negative for all treatments. The yield response to increased crop input levels was better than in 2002 but was nowhere near the high yield potential exhibited at the 2001 site. Net returns were negative for all treatments when the price of canola was $6/bu or $8/bu, while net returns ranged between from -$19/ac to $28/ac. Net returns were poorest for Treatments 3, 6, and 10, which all contained the most intensive crop protection package and medium or high fertilizer treatments. In general, treatments that created the greatest net returns were the least input intensive. However, in practical terms, the variability of net returns among treatments was much smaller than the variability exhibited at the Brandon 2001 and 2002 sites.

		Brandon01		Brandon02		Brandon03	
Treatment	Abbreviation[z]	Low Prices[y]	High Prices	Low Prices	High Prices	Low Prices	High Prices
1	M-M-M	-51de	26def	-125bc	-105bcd	-52abc	-4a
2	M-H-M	-41cd	61bcd	-150cd	-126cde	-68bcde	-12a
3	M-H-H	-62de	51cd	-138bcd	-78ab	-117g	-51a
4	M-M-H	-59de	36de	-136bcd	-93bc	-97efg	-38a
5	H-M-H	-14abc	106ab	-155d	-122cde	-77cdef	-7a
6	H-H-H	-13abc	127a	-114b	-41a	-108fg	-38a
7	H-M-M	-5ab	99abc	-136bcd	-121cde	-63bcde	-20a
8	H-H-M	-8abc	114ab	-159d	-137de	-72bcde	-17a
9	M-L-L	-42cd	-24f	-74a	-74ab	-39ab	-19a
10	H-L-H	-80e	-28f	-150d	-136de	-89defg	-42a
11	H-H-L	21a	127a	-148cd	-147e	-57abcd	-11a
12	H-L-L	-39bcd	-17ef	-78a	-77ab	-28a	1a
LSD		36	55	25	39	35	ns

[z] Genetics-fertility-crop protection level.

[y] Means designated by a different letter are significantly different.

Table 12. Net returns for the various crop input combinations at the Brandon site for low and high canola prices in 2001, 2002 and 2003.

Although significant differences in productivity may not be observed at a given location, the situation may be very different with respect to net returns, which ultimately determines whether the perceived or realized yield benefits of a given crop management tool will cover the additional costs associated with it. This phenomenon is evident when net returns are analyzed statistically and variance is partitioned among the various components of the experiment (Tables 13 and 14); the Carman 2001 site was excluded from the analysis due to the high variability among replicates with respect to net returns. For example, at the Brandon 2001 site, genetics, fertility, and crop protection level all had a significant impact on canola productivity, representing 73.5% of total variance. However, with respect to net returns, only genetics had a significant impact on net returns at the Brandon 2001 site. Increasing fertility and crop protection level may have had a significant impact on productivity, but the increased costs associated with higher yields eroded net returns. The cost of improved genetics in this experiment in general was only marginally more expensive ($4.50/ac), but translated into a significantly higher yield, making for a very cost-effective crop management decision in this instance.

In the case of Dauphin in 2001, no crop input had a significant impact on yield; net returns at the medium levels of fertility and crop protection (-$22/ac and -$16/ac, respectively) were significantly higher than at high levels of fertility and crop protection (-$47/ac and -$53/ac, respectively). The three crop input types represented 41.7% of the total variance for net return, compared to only 8.6% for yield.

		Brandon01			Dauphin01		
Factor	df	% Total Variance	Pr>F	Sig	% Total Variance	Pr>F	Sig
Error	24	42.4%			56.5%		
Genetics	1	54.0%	<0.0001		6.1%	0.12	ns
Fertility	1	2.3%	0.27		11.1%	0.0401	**
Protection	1	0.2%	0.77		24.5%	0.0036	**
Genetics*Fertility	1	0.2%	0.76		0.4%	0.68	ns
Genetics*Protection	1	0.4%	0.66		0.5%	0.67	ns
Fertility*Protection	1	0.2%	0.76		0.2%	0.79	ns
Genetics*Fertility*Protection	1	0.5%	0.61		0.9%	0.55	ns

ns - not significant
** signficiant (*P* <0.05)

Table 13. Contribution of factors and their interactions to the total variance of canola net returns ($7/bu) for the factorial portion of the experiment at the Dauphin and Brandon sites in 2001.

As at the Dauphin 2001 site, net returns at the Carman 2002 site at the medium levels of fertility and crop protection (-$24/ac and -$22/ac, respectively) were significantly higher than at high levels of fertility and crop protection (-$52/ac and -$55/ac, respectively), and represented almost 35% of the total variance. Failure to realize the additional yield potential expected with more intensive crop input use resulted in significant loss of profitability. Whereas fertility and crop protection had a significant impact on canola yield at the Brandon 2002 site, only crop protection had a significant impact on net returns. In this instance however, net returns at the high level of crop protection (-$110/ac) were significantly greater than at the medium level of crop protection (-$132/ac). A significant interaction was also observed between fertility and crop protection level at the Brandon 2002 site. At the medium level of crop protection, there was no significant in net returns between medium and high levels of fertility (-$121/ac and -$142/ac, respectively). However, at the high level of crop protection, significant differences in net returns among medium (-$92/ac) and high (-$126/ac) fertility levels were observed, since higher levels of fertility and crop protection did not translate into enough yield benefit to be as profitable as where medium levels of fertility and crop protection were employed. Interestingly, this interaction accounted for the greatest proportion of variance among the crop input combinations.

At the Brandon 2003 site, only crop protection had a significant impact on net returns, accounting for almost 17% of total variance. As was the case in other instances where more intensive crop input use failed to translate into significant yield differences, net returns where the high crop protection level was employed were significantly lower than at the medium crop protection level.

Factor	Carman02 df	% Total Variance	Pr>F	Sig	Brandon02 df	% Total Variance	Pr>F	Sig	Brandon03 df	% Total Variance	Pr>F	Sig
Error	22	61.5%			24	52.3%			24	72.0%		
Genetics	1	0.1%	0.88	ns	1	0.5%	0.63	ns	1	0.5%	0.69	ns
Fertility	1	13.3%	0.04	**	1	13.9%	0.49	ns	1	5.0%	0.21	ns
Protection	1	21.4%	0.0112	**	1	13.9%	0.0184	**	1	16.6%	0.0270	**
Genetics*Fertility	1	0.2%	0.78	ns	1	5.6%	0.12	ns	1	0.0%	0.91	ns
Genetics*Protection	1	3.1%	0.31	ns	1	1.6%	0.40	ns	1	3.9%	0.27	ns
Fertility*Protection	1	0.0%	0.97	ns	1	20.7%	0.0051	**	1	1.3%	0.51	ns
Genetics*Fertility*Protection	1	0.5%	0.68	ns	1	4.3%	0.17	ns	1	0.7%	0.64	ns

ns - not significant
** signficiant (*P* <0.05)

Table 14. Contribution of factors and their interactions to the total variance of canola net returns ($7/bu) for the factorial portion of the experiment at the 2002 and 2003 sites.

As mentioned previously, most agronomic research data is generated from single input experiments where all other inputs are applied at optimum levels. This approach to evaluating an input's contribution to yield overestimates the net value of that input within a whole cropping system, especially if a large number of inputs are required to create that response (e.g., if a superior variety and comprehensive pest control are required to create opportunities for large fertilizer responses in canola). This is demonstrated for the Brandon 2001, 2002, and 2003 site years (Tables 15-17).

The middle rows of the three tables illustrate the typical approach to calculating the effect of genetic, fertilizer, and crop protection treatments in single input experiments where other inputs are managed at high levels. These effects are calculated by subtracting yield means for corresponding treatments of high and low inputs for cultivar, fertilizer, and crop protection, respectively, with all other inputs maintained at maximum levels (e.g. Treatment 6-3, 6-10 & 6-11, respectively). When individual yield benefits are calculated in this way and are then added together, the "theoretical" yield benefit is derived. At Brandon in 2001, 2002, and 2003, the theoretical yield benefit was 122%, 238%, and 103%, respectively of the real yield benefit. The artificially high theoretical yield benefit translated into an expected margin that was $66/ac higher than the real margin achieved at Brandon in 2001 when all inputs were utilized. In 2002 and 2003, the expected yield benefit translated into an expected margin that was $169/ac and $13/ac higher, respectively than the real margin achieved when all inputs were utilized. In addition, not only was the expected margin significantly greater than the real margin in two of three instances, but under actual conditions significant economic losses occurred.

Yield Source or Response	Yield (bu/ac)	Revenue ($/ac)	Cost* ($/ac)	Margin ($/ac)
Base Yield (Treatment 9)	6.1	$42.36	$75.45	($33.09)
Genetic Response (Treatment 6-3)	8.9	$62.10	($0.30)	$62.40
Crop Protection Response (Treatment 6-11)	11.3	$78.97	$96.20	($17.23)
Fertilizer Response (Treatment 6-10)	29.1	$203.68	$92.77	$110.91
Theoretical Increase From All Inputs	49.3	$344.75	$188.67	$156.08
Real Increase From All Inputs (Treatment 6-9)	40.5	$283.28	$193.47	$89.81
Theoretical Overall Total	55.3	$387.11	$264.12	$122.99
Real Overall Total (Treatment 6)	46.5	$325.64	$268.92	$56.72

*Costs for base yield include SW Flare seed, preseeding glyphosate, machinery, fuel, repairs, and other basic costs

Table 15. Benefit of canola crop inputs when yield responses are added together individually or as a real system at Brandon in 2001 (canola priced at $7/bu)

Yield Source or Response	Yield (bu/ac)	Revenue ($/ac)	Cost* ($/ac)	Margin ($/ac)
Base Yield (Treatment 9)	0.2	$1.49	$75.45	($73.96)
Genetic Response (Treatment 6-3)	4.3	$30.05	($0.30)	$30.35
Crop Protection Response (Treatment 6-11)	23.6	$165.44	$95.45	$69.99
Fertilizer Response (Treatment 6-10)	19.6	$137.28	$71.91	$65.37
Theoretical Increase From All Inputs	47.5	$332.77	$167.06	$165.71
Real Increase From All Inputs (Treatment 6-9)	24.0	$168.35	$171.86	($3.51)
Theoretical Overall Total	47.8	$334.26	$242.51	$91.75
Real Overall Total (Treatment 6)	24.3	$169.84	$247.31	($77.47)

*Costs for base yield include SW Flare seed, preseeding glyphosate, machinery, fuel, repairs, and other basic costs

Table 16. Benefit of canola crop inputs when yield responses are added together individually or as a real system at Brandon in 2002 (canola priced at $7/bu)

Yield Source or Response	Yield (bu/ac)	Revenue ($/ac)	Cost* ($/ac)	Margin ($/ac)
Base Yield (Treatment 9)	6.6	$46.31	$75.45	($29.14)
Genetic Response (Treatment 6-3)	1.6	$11.30	($0.30)	$11.60
Crop Protection Response (Treatment 6-11)	7.9	$55.49	$94.21	($38.72)
Fertilizer Response (Treatment 6-10)	7.8	$54.76	$58.13	($3.36)
Theoretical Increase From All Inputs	17.3	$121.55	$152.04	($30.49)
Real Increase From All Inputs (Treatment 6-9)	16.8	$117.34	$160.84	($43.50)
Theoretical Overall Total	23.9	$167.86	$227.49	($59.62)
Real Overall Total (Treatment 6)	23.4	$163.65	$236.29	($72.64)

*Costs for base yield include SW Flare seed, preseeding glyphosate, machinery, fuel, repairs, and other basic costs

Table 17. Benefit of canola crop inputs when yield responses are added together individually or as a real system at Brandon in 2003 (canola priced at $7/bu)

However, even with overestimated margins, using more inputs was still more profitable than using low inputs at the Brandon 2001 site (Table 18). The low input crop yielded 6 bu/ac; at moderate fertility, with other inputs at moderate levels, yield was 25 bu/ac; with fertility and inputs both at high levels, yield was 47 bu/ac. Assuming a canola price of $7 per bushel, the margin increased from -$33/ac to -$12/ac when moving from low to medium inputs, and increased another $69/ac when high levels of inputs were used.

This trend reversed at the Carman and Dauphin locations in 2001, with margins declining as input levels increased. Furthermore, if the two badly flooded replicates at Carman had been included in the analysis, the negative margins at Carman would have been much worse. At Carman in 2002, net returns were comparable at the low and medium input level, but net returns decreased substantially when moving from medium to high input levels. At Brandon in 2002, where poor crop emergence and lack of precipitation limited yield potential, all levels of inputs resulted in losses, with the losses being greatest under medium inputs, due primarily to the high weed pressure where pesticide use was less intensive. The low investment in crop inputs at low input levels minimized economic losses, resulting in comparable margins relative to the high input level. As at Brandon in 2002, economic losses occurred across all three levels of crop inputs at the Brandon 2003 site, with the low input scenario yielding the least negative net return.

Location		Yield (bu/ac)	Revenue ($/ac)	Cost ($/ac)	Margin ($/ac)	Environmental Factors Affecting Grain Yield and Economics
Brandon01	Low Inputs	6.1	$42.36	$75.45	($33.09)	Good growing season conditions
	Medium Inputs	25.5	$178.44	$191.06	($12.62)	
	High Inputs	46.5	$325.64	$268.92	$56.72	
Carman01	Low Inputs	8.0	$55.79	$66.50	($10.71)	Good growing conditions early; however, excessive precipitation in late July drowned out two replicates and seriously reduced yields
	Medium Inputs	21.3	$149.26	$171.96	($22.70)	
	High Inputs	23.9	$167.32	$248.30	($80.98)	
Dauphin01	Low Inputs	13.3	$93.40	$66.50	$26.90	Good growing conditions early; however, late season drought, along with late season flea beetle infestation seriously reduced yields
	Medium Inputs	18.0	$125.71	$159.08	($33.37)	
	High Inputs	22.7	$158.79	$229.91	($71.12)	
Carman02	Low Inputs	9.6	$66.86	$66.50	$0.36	Good growing season conditions
	Medium Inputs	20.8	$145.69	$145.16	$0.53	
	High Inputs	23.6	$164.91	$219.27	($54.36)	
Brandon02	Low Inputs	0.2	$1.49	$75.45	($73.96)	Very dry conditions in spring. Germination was poor and weed pressure extremely high
	Medium Inputs	6.7	$46.55	$161.18	($114.63)	
	High Inputs	24.3	$169.84	$247.31	($77.47)	
Brandon03	Low Inputs	6.6	$46.31	$75.45	($29.14)	Good growing conditions in May and June, followed by hot, dry weather in July and August that reduced yields
	Medium Inputs	18.6	$110.66	$170.47	($59.81)	
	High Inputs	23.4	$163.65	$236.29	($72.64)	
Average for All Sites	Low Inputs	7.3	$51.04	$70.98	($19.94)	
	Medium Inputs	18.5	$126.05	$166.48	($40.43)	
	High Inputs	27.4	$191.69	$241.67	($49.97)	

Table 18. Yield and economic returns from low, medium, and high crop input packages for all site years (canola priced @ $7/bu).

The net returns at Carman in 2001 and 2002, Dauphin in 2001, and Brandon in 2002 and 2003 highlight the importance of selecting reasonable yield goals, optimizing inputs to match that yield potential, and scouting fields using pest thresholds rather than using blanket applications of pesticides. The profitability levels exhibited at these sites also demonstrates the substantial financial risk associated with increasing the intensity of crop input use, especially when confronting yield risk factors such as the weather. Sub-optimal weather such as drought or flooding cannot be predicted. Besides the aforementioned factors, the use of crop insurance to protect at least a portion of yield potential is advised, particularly where crop input use is intense.

As has already been alluded to, not only do returns on investment rely on yield improvements, but they also rely heavily on the price of canola. Therefore, not only are the economic risks and rewards of inputs dependent on a yield response but they are also dependent on market conditions. If canola prices are low, the risk on an investment increases while potential reward declines. Table 19 summarizes the net margin for four site years of production trials where plot conditions were representative of typical field conditions (Brandon 2001, Brandon 2002, Carman 2002, Brandon 2003) for canola priced at $5.50, $7.00, and $8.50 per bushel for all treatments included in the experiment. This table combines the economic risks (minimum margins) associated with crop production inputs (production and market risks) with potential maximum rewards (maximum margin).

Generally, in comparing the high input package (#6) with the medium input package (#1) and the low input package (#9), an interesting observation emerges, namely that mean net returns across the four sites years are comparable for all three treatments. The limited risk associated with Treatment 9 was expected because of the minimal use of inputs, thereby keeping variable costs at a minimum. However, the productivity of Treatment 9 is also extremely variable, as evident by the poor yields recorded across all four site years evaluated. Riskiness in the short term may be low based on the criteria established in Table 18, but over the long term, Treatment 9 is not a viable cropping option, particularly assuming recurrent pest pressure and the amplified effect it has in situations where crop input use is low.

Furthermore, if a producer making use of crop insurance was to employ this strategy over the long term, his or her long term average yield would quickly collapse, resulting in a low level of protection against yield loss.

In comparing the medium and high input use packages, it is evident that the upside on profitability is much higher with Treatment 6, since the maximum margin is over $80/ac greater than the maximum margin of Treatment 1. The median net return for Treatment 6 is also much higher relative to Treatment 1, while the poorest net return is comparable among the two treatments. In considering the parameters below in the context of this study, the most crop input intensive treatment appears to be a viable crop management option.

Net Margin	Treatment Package											
	1	2	3	4	5	6	7	8	9	10	11	12
	M-M-M	M-H-M	M-H-H	M-M-H	H-M-H	H-H-H	H-M-M	H-H-M	M-L-L	H-L-H	H-H-L	H-L-L
Mean	(38)	(48)	(68)	(58)	(42)	(35)	(33)	(45)	(34)	(79)	(30)	(22)
Median	(20)	(24)	(43)	(44)	(19)	4	6	(24)	(27)	(68)	3	(21)
Maximum	42	61	51	36	106	126	99	114	19	(20)	127	55
Minimum	(125)	(150)	(138)	(136)	(155)	(114)	(136)	(159)	(74)	(150)	(148)	(78)

* Sites include Brandon 2001, Brandon 2002, Carman 2002, and Brandon 2003

Table 19. Summary of net returns for four site years of production trials for canola priced at $5.50, $7.00, and $8.50 per bushel.*

In many situations, producers try to save money by reducing one (or more) input while keeping every other input at a high level. Therefore, it is important to evaluate the potential risks/rewards under situations where a certain input is reduced. With respect to genetics, it is evident that the potential risk or minimum margin of using InVigor 2663 instead of SW Flare at low inputs (Ttreatment #9 vs 12) was not significantly different; however at high inputs (Treatment #3 vs 6), by increasing the genetic potential of the crop, the potential loss declined by approximately $33/ac. In both scenarios, by increasing the genetic potential of the crop, the potential maximum margin increased $36/ac under low inputs and $75/ac under high inputs. Given the minimal additional cost associated with Invigor 2663 relative to SW Flare in this study, investment in genetics is recommended.

With respect to fertility, when comparing the minimum margins of growing InVigor 2663 under low (H-L-H), medium (H-M-H), and high (H-H-H) fertility levels, net returns on average were poorest with the highest fertility level, while the potential losses for the medium and high fertility levels were comparable. The potential maximum returns of the high and medium fertility levels were much greater relative to the low fertility treatment, while the greatest net losses occurred with at the low and medium fertility levels. In summary, investment in at least a medium level of fertility is advised, particularly in instances where inherent soil fertility is poor. In this regard, soil testing is definitely an important part of crop management planning and should not be overlooked. Investment in the highest level of fertility clearly comes with risk, although in relative terms in this study it also provided the greatest reward.

Comparing the margins of growing InVigor 2663 under low (H-H-L), medium (H-H-M), and high (H-H-H) crop protection levels provides an idea of the relative risk associated with each level of crop protection. In this study, the mean net returns among the three treatments were comparable, although the greatest mean net loss occurred where the medium crop protection level was employed. The same trend occurred with respect to the median net return. Interestingly, the maximum net loss was much lower for Treatment 6, while maximum net losses were comparable among Treatment 8 and 11. However, if the herbicide application in the medium crop protection treatment would have been based on threshold levels (as the insecticide and fungicide application were), there would have been more potential to reduce the minimum margin where weed pressures were not greater than threshold levels, making it a more profitable crop management practice.

The comparisons between the high, medium, and low input treatments, as well as the comparisons between the genetic, fertility, and crop protection levels all indicate that the potential savings of reducing one input, while maintaining the maximum level of the other inputs is significantly outweighed by the potential losses and the loss in potential returns. The reason for this is that by cutting rates of one input, it effectively reduces the yield potential of the crop; thus, reducing the potential return on investment for those inputs kept at a maximum level.

Multiple Site Year Analysis

In order for a set of crop management practices to be sustainable, it is worthwhile to measure the variability of parameters such as yield, gross returns, and net returns among a series of diverse environments. In this regard, analysis of variance (ANOVA) was carried out on yield and economic data from the three Brandon site years based on a split-plot design using Proc GLM, with treatment as the main plot and site year as the sub-plot, allowing for more effective evaluation of the interactions between site years and various crop input combinations. ANOVA was also carried out on the factorial component of the experiment in order to assess the influence of crop input components on profitability at various combinations of medium and high levels of crop inputs. Effects in both datasets were considered significant at $P < 0.05$. Crop input costs were held at 2001 levels. The farm-gate canola price used in the analysis was $7.00/bu, which is equivalent to the 1991-2000 average canola price received by Manitoba farmers (Manitoba Agriculture 2000). The sensitivity of net returns to changes in canola price was evaluated by modifying the farm-gate price +/- 1 SD as suggested by Zentner et al. (2002a), which translated approximately into a range +/- $1.50/bu.

Average per acre production costs (Figure 11) at Brandon ranged from $76 per acre (M-L-L) to $251 per acre for treatments 3 and 6 (M-H-H and H-H-H, respectively). The range of production costs translated into a large range in breakeven yields (i.e. the yield required to result in a net return of $0/ac, where canola was priced at $7.00/bu), ranging from 11.4 bu/ac to 35.9 bu/ac (Table 20). The relative yield variability among treatments (i.e. stability across environments), as measured by coefficient of variation (CV), was generally lower for the high crop protection package relative to the medium crop protection package. Not surprisingly, treatments utilizing the least intensive crop protection package had the highest CV, reflecting the importance of proper crop protection in this experiment in managing pest pressure to achieve yield potential. An interaction between genetics and crop protection/fertility was observed as well; while there was no significant difference in the yield of SW Flare versus Invigor 2663 at low levels of fertility and crop protection, Invigor 2663 significantly out-yielded SW Flare at high levels of fertility and crop protection. This interaction was described previously for the Brandon 2001 site.

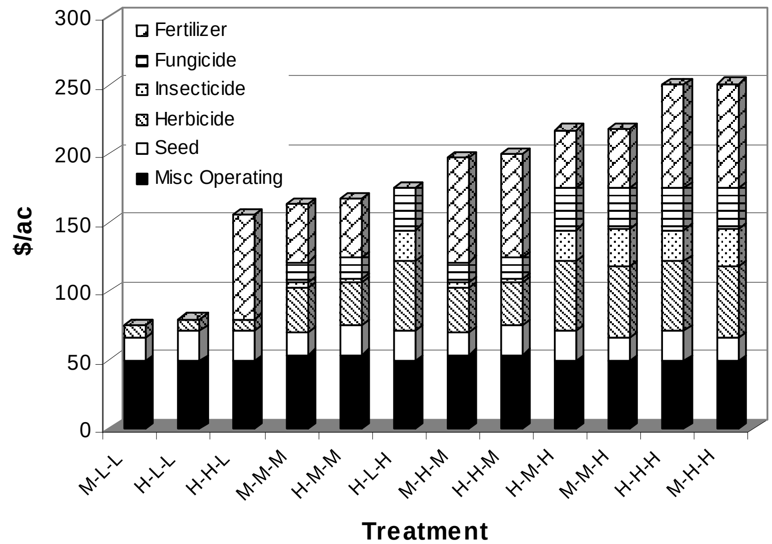


Figure 11. Effect of crop input package on average per acre production cost at the Brandon site.

Treatment	Abbreviation[z]	Cost ac^{-1}	Breakeven Yield ($bu\ ac^{-1}$)[y]	Yield ($bu\ ac^{-1}$)	Yield CV
1	M-M-M	164	23.4	16.0	55
2	M-H-M	197	28.1	20.2	59
3	M-H-H	251	35.9	26.5	36
4	M-M-H	218	31.1	21.9	37
5	H-M-H	218	31.1	24.7	52
6	H-H-H	251	35.8	31.4	38
7	H-M-M	167	23.9	18.0	73
8	H-H-M	201	28.6	22.0	68
9	M-L-L	76	10.8	4.3	82
10	H-L-H	175	25.0	12.6	52
11	H-H-L	156	22.2	17.1	91
12	H-L-L	80	11.4	5.7	97
LSD				8.8	

[z] Genetics-fertility-crop protection level.
[y] Assuming canola price of $7.00 bu^{-1}

Table 20. Effect of crop input package on average per acre production cost, breakeven yield, and average yield across the Brandon 2001-2003 site years.

Despite the large differences in yields (and therefore gross returns) among treatments, the range of net returns tended to be much narrower (Table 21), while ranking was tied strongly to canola price level. Wide variation in net returns among site years for individual treatments was also observed. At the base price of $7/bu, net returns ranged from -$31/ac (H-H-H) to -$87/ac (M-L-L). The ranking of treatments changed considerably when the canola price was $5.50/bu; net returns ranged from -$48/ac (H-L-L) to -$106/ac (H-L-H) while the ranking of H-H-H slipped to first to sixth. Not surprisingly, when the price of canola was $8.50/bu, Treatment 6 (H-H-H) was by far the most profitable ($16/ac), followed by Treatment 5 (H-M-H) at -$8/ac. Treatments 9-12, which were generally some of the most profitable when canola was priced at $5.50/bu and $7.00/bu, became the least profitable when canola was priced at $8.50/bu. There was very little difference among net returns for treatments 1-4 and 7-8, which all contained either medium or high levels of fertility and crop protection.

Treatment	Abbreviation[z]	Net Returns $5.50/bu	$7.00/bu	$8.50/bu
1	M-M-M	-76	-52	-28
2	M-H-M	-56	-56	-26
3	M-H-H	-106	-66	-26
4	M-M-H	-98	-65	-32
5	H-M-H	-82	-45	-8
6	H-H-H	-78	-31	16
7	H-M-M	-68	-41	-14
8	H-H-M	-79	-46	-13
9	M-L-L	-52	-45	-39
10	H-L-H	-106	-87	-69
11	H-H-L	-61	-36	-10
12	H-L-L	-48	-40	-31
LSD		ns	ns	ns

[z] Genetics-fertility-crop protection level.

[y] Means designated by a different letter are statistically different.

Table 21. Effect of crop input package on per acre net returns across the Brandon site years.

Within the factorial component of the experiment, fertility and crop protection had a significant impact on yield; impacts on net returns varied at different canola price levels but no statistically significant differences were observed. The yield of Invigor 2663 was 2.9 bu/ac higher (14%) than the yield of SW Flare, although the difference was not statistically significant. The high level of fertility resulted in a yield increase of 4.9 bu/ac (24%) over the medium fertility level. The greatest absolute yield impact was attributable to crop protection level, as the yield at the high protection level was 7 bu/ac (37%) greater than the yield at the medium protection level. Interactions among input types were not observed.

Treatment		Yield (bu/ac)	Net Return ($/ac) $5.50/bu	$7.00/bu	$8.50/bu
Genetics					
	Medium	21.1	-91	-60	-28
	High	24.0	-77	-41	-5
Fertility					
	Medium	20.1	-81	-51	-20
	High	25.0	-87	-50	-12
Crop Protection					
	Medium	19.1	-77	-49	-20
	High	26.1	-91	-52	-12
ANOVA		Pr>F			
Fertility (F)		0.0433	0.96	0.55	0.65
Crop Protection (P)		0.0038	0.84	0.22	0.67
F*P		0.74	0.70	0.69	0.71
Genetics (G)		0.22	0.19	0.19	0.20
F*G		0.84	0.82	0.81	0.82
P*G		0.69	0.55	0.51	0.57
F*P*G		0.81	0.78	0.77	0.78

Table 22. Effect of various combinations of medium and high genetics, fertility, and crop protection packages on canola yield and net returns at the Brandon 2001-2003 sites combined. Effects are considered significant at *P* < 0.05.

The sensitivity of selected crop input packages to changes in canola price can also be illustrated graphically (Figure 12); the upper range of canola price was extended to +2 SD ($10.00/bu) in order to show the point at which the price breakeven would be reached for the medium crop input package. As discussed previously, the high input package is most sensitive to changes in canola price, as the range of net returns between $5.50/bu and $10/bu ranged from -$78/ac to $63/ac, with a simple net return breakeven (i.e. mean cost per ac divided by mean yield) of $7.99/bu. Data for M-H-H shows the substantial difference in net returns at the high crop input level among the two cultivars, and once again demonstrates that the minimal additional cost of upgrading the genetics package from SW Flare to Invigor 2663 resulted in a dramatic difference in net returns.

The range of net returns over the same price range for M-M-M was -$106/ac to $14/ac, with a breakeven price of $10.24/bu. Given the poor overall productivity of M-L-L, the price of canola would, theoretically, need to be $17.59 in order to reach the net return breakeven. Although the results point to the high input package as being the least risky in the context of this study, there is clearly substantial risk of dramatic production losses with the medium and high input packages (particularly fertility and crop protection) in case of crop failure. Though this risk can be partially managed through the use of crop insurance, the most sensible crop management strategy is clearly based on the farmer taking a proactive role in evaluating soil fertility and pest pressure and in turn making sensible crop input decisions.

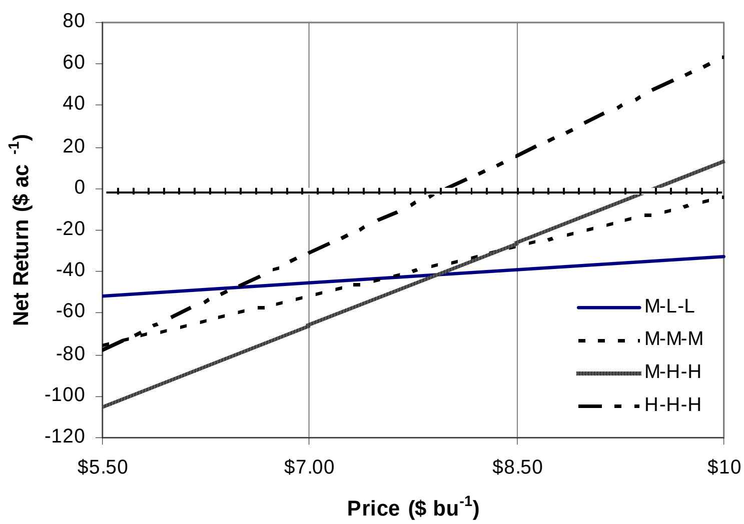


Figure 12. Sensitivity of low, medium, and high crop protection/fertility packages (medium level of genetics) to changes in canola price.

Up until this point, the sensitivity of net returns to changes in market price has been addressed. However, relative profitability is clearly influenced by changes in the prices of crop inputs. For example, the western Canada farm input price index (base year 1992) for seed, fertilizer, and pesticide in 2000 was 155.6, 131.4, and 121.0, respectively (Saskatchewan Agriculture and Food 2002) (Figure 13). From year to year, the price of farm inputs may change substantially, both influencing overall profitability as well impacting crop management practices that are sensitive to those respective changes.

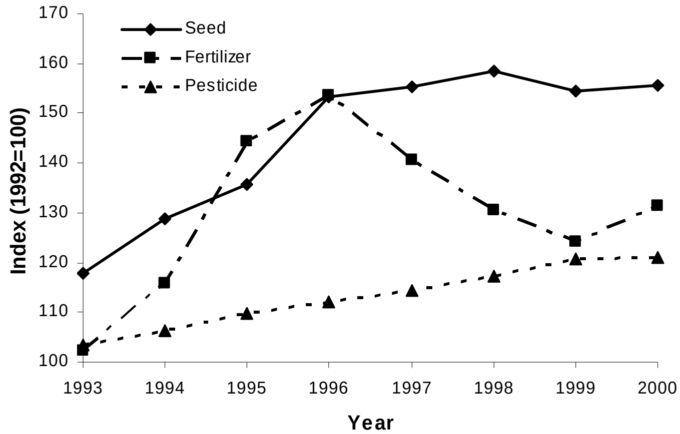


Figure 13. Western Canada farm input price index (1992=100) for selected crop inputs.

In this regard, the sensitivity of net returns of selected crop input packages to changes in crop input prices was addressed by evaluating returns over a range of +/- 50% of the base price as proposed by Zentner et al. (2002a), maintaining the price of canola constant at the base price (Figure 14). As expected, the high input package (H-H-H) was most sensitive to changes in the price of crop protection and fertilizer. When pesticide price was modified, the high input package was by far the most profitable when prices were reduced to 50% of the base level, while at the 150% price level, net returns for the medium and high crop input packages were comparable. Even the low input crop protection package was slightly sensitive to pesticide price changes, since the cost of glyphosate application prior to planting was included in the cost analysis for all treatment combinations.

When the medium and high fertility packages were compared, the same trend existed, although differences in profitability were greatly reduced, particularly when fertilizer prices were 50% of base levels. Altering seed price had little impact on net returns, while modifying the price of all three inputs at once had a pronounced effect on profitability. When input prices were 50% of the base level, the net returns of the low, medium, and high input packages were -$33/ac, $3/ac, and $69/ac, respectively. Conversely, rankings changed considerably as expected at when prices were 150% of the base level. The low input package generated the lowest net loss, while net returns of the medium and high crop input packages were -$107 and -$132, respectively. The results demonstrate the lack of long-term economic sustainability of both the medium and high crop input packages. Despite the potential for additional technological gains in the future, input-intensive cropping practices are particularly sensitive to changes in both crop market price and input prices.

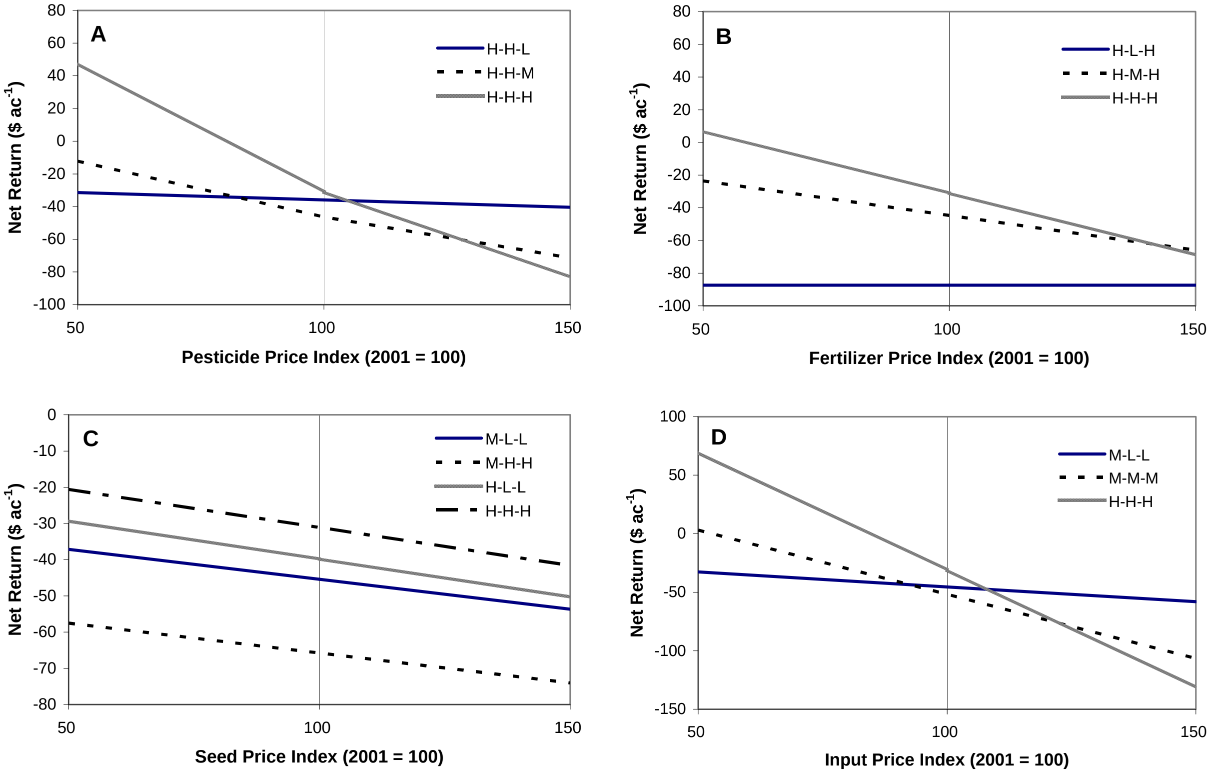


Figure 14. Effect of changes in pesticide (A), fertilizer (B), and seed (C) costs on net returns of select crop input packages at the Brandon site, as well as effect of change in cost of all three inputs (D) on net returns.

As discussed previously, in single input experiments, the effect of genetic, fertilizer, and crop protection treatments on productivity is often overstated since at the same time other inputs are utilized at high levels, thereby assisting in maximizing the productivity gains of the treatment under investigation. When the individual Brandon site years were averaged to represent the stability of productivity and profitability across diverse environments (Table 23), the theoretical yield increase attributable to the three crop input types (38 bu/ac) was 140% of the real yield benefit (27.1 bu/ac). However, given the variability in treatment effects across site years, combined with the additional cost associated with high crop input use, the theoretical yield increase translated into a margin of $97/ac, which was $82.74 higher than the real margin achieved when all inputs were utilized. The theoretical canola yield where genetics, fertility, and crop protection were utilized at high levels was 42.3 bu/ac, or 135% of the yield of Treatment 6 (H-H-H). Whereas the margin would be expected to be $52/ac at a yield of 42.3 bu/ac, under actual field conditions H-H-H translated into an average net loss of $31/ac.

Yield Source or Response	Yield (bu/ac)	Revenue ($/ac)	Cost* ($/ac)	Margin ($/ac)
Base Yield (Treatment 9)	4.3	$30.05	$75.45	-$45.40
Genetic Response (Treatment 6-3)	4.9	$34.48	-$0.30	$34.78
Crop Protection Response (Treatment 6-11)	14.3	$99.97	$95.29	$4.68
Fertilizer Response (Treatment 6-10)	18.8	$131.91	$74.27	$57.64
Theoretical Increase From All Inputs	38.0	$266.36	$169.26	$97.10
Real Increase From All Inputs (Treatment 6-9)	27.1	$189.65	$175.39	$14.26
Theoretical Overall Total	42.3	$296.41	$244.71	$51.71
Real Overall Total (Treatment 6)	31.4	$219.71	$250.84	-$31.13

*Costs for base yield include SW Flare seed, preseeding glyphosate, machinery, fuel, repairs, and other basic costs

Table 23. Contribution of factors and their interactions to the total variance of canola net returns ($7/bu) for the factorial portion of the experiment across the Brandon site years.

While net returns were negative at all three levels of crop inputs across the Brandon site years, the high input treatment was the least costly (Table 24) when canola was priced at $7/bu). Based on the results of this experiment, and from a producer standpoint, low input use was a poor strategy given very poor productivity (particularly in two of three site years). The situation where crop inputs were applied at medium levels was the most costly, since yield was only 12.6 bu/ac higher than the low input treatment, and the additional production cost was almost $100/ac higher. Where high inputs were utilized, cost exceeded revenue but net returns were not as adversely affected relative to low and medium crop[input level treatments.

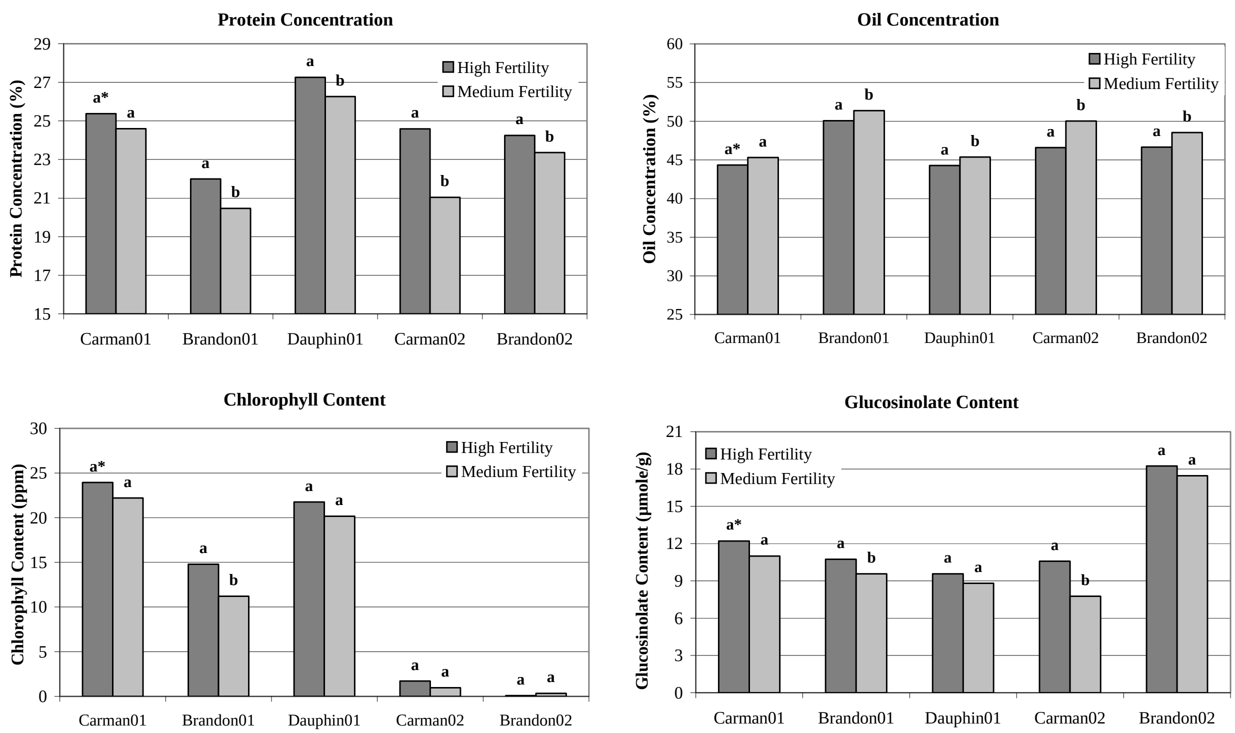
Location		Yield (bu/ac)	Revenue ($/ac)	Cost ($/ac)	Margin ($/ac)
Brandon Average	Low Inputs	4.3	$30.05	$75.45	($45.40)
	Medium Inputs	16.9	$111.88	$174.24	($62.35)
	High Inputs	31.4	$219.71	$250.84	($31.13)

Table 24. Yield and economic returns from low, medium, and high crop input packages averaged across the Brandon site years (canola priced @ $7/bu).

Effect of Crop Inputs on Oilseed Quality

Increasing canola yield without maintaining quality is counter-productive, since income is reliant on both canola yield and grade. Reducing crop input levels when thresholds or soil tests permit improve profit margin only if quality is maintained. Dockage and green seed count are combined to determine the grade and price of canola under the current grading system. However, oil content, glucosinolates, chlorophyll, and protein concentration, though not currently used to determine grade, are valuable indicators of processing and end-use quality. In general terms, the oil content is positively correlated with processing quality. Glucosinolates are sulphur-containing compounds that are undesirable in oil because of the inhibition of hydrogenation, also known as “catalyst poisoning,” in the manufacture of margarines and shortenings (Mag 1990). Glucosinolates also reduce the nutritional value of canola meal for feeding purposes (Sørensen 1990). High chlorophyll concentration is undesirable because chlorophyll adversely affects the hydrogenation of oil during processing and increases the refining costs due to the necessity of bleaching during processing (Mag 1990).

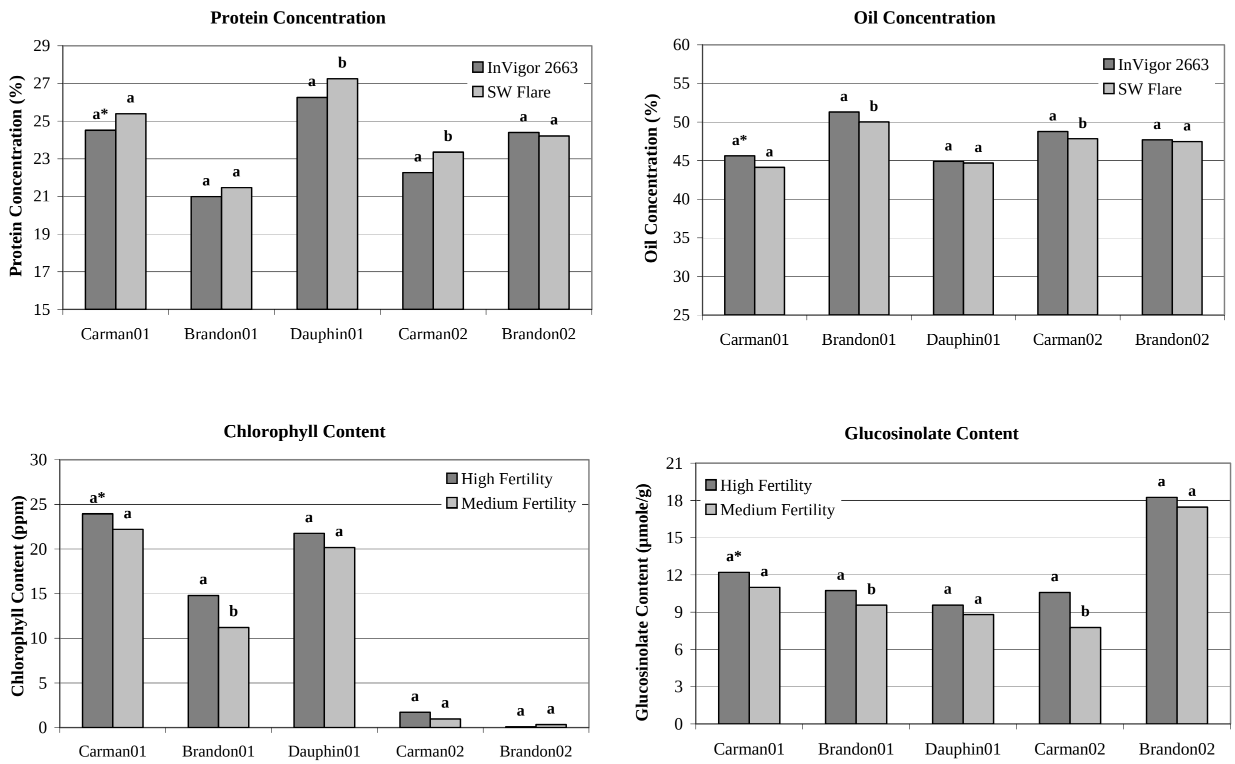
Significant treatment effects were observed for most grain quality parameters at Brandon and Dauphin in 2001 as well as at Carman and Brandon in 2002 (Appendices A-E). At Carman in 2001, significant differences were observed only for glucosinolate content. Within the factorial portion of the experiment, crop protection had a minimal effect on canola quality, whereas fertility had the most consistent effect on protein concentration and oil concentration. At four of the five sites, as expected, canola grown under the high level of fertility had the highest protein concentration and the lowest oil concentration (Figure 15). At two sites, Brandon in 2001 and Carman in 2002, canola grown at the high fertility level also contained higher levels of glucosinolates than canola grown under the medium fertility level; however, the level of glucosinolates under both fertility levels was quite low. Finally, at Brandon in 2001, the canola grown at high fertility contained more chlorophyll than grain under the medium fertility level.



* means designated by a different letter are significantly different (P<0.05) within a site, only

Figure 15. The impact of fertility on end-use quality of canola in 2001 and 2002

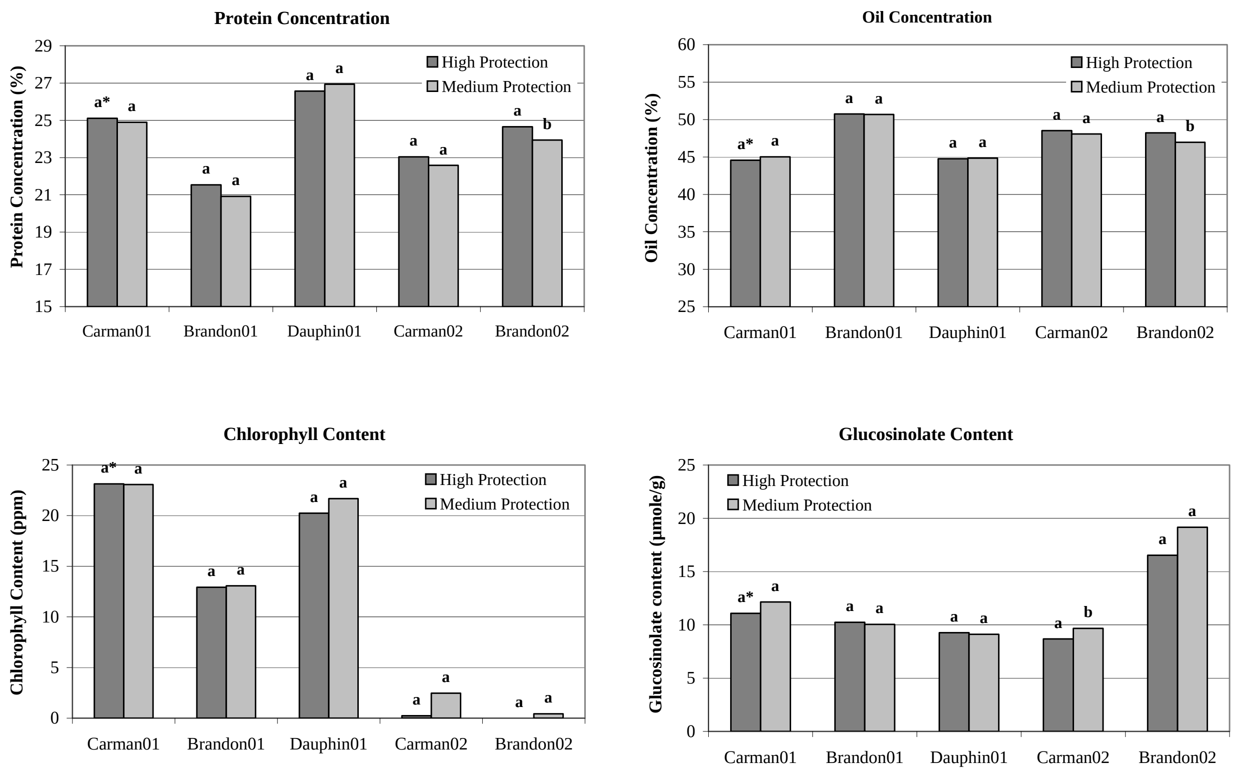
Genetics had an inconsistent effect on the protein concentration and oil concentration (Figure 16). At four sites, InVigor 2663 had a lower protein concentration than SW Flare; however, differences were significant at only two sites. At all sites, InVigor 2663 had a higher oil concentration than SW Flare; differences were significant at only two sites. The glucosinolate content of InVigor 2663 was significantly lower than that of SW Flare at four of five sites. Finally, at four sites, InVigor contained more chlorophyll than SW Flare; however, differences were statistically significant for Carman01 and Brandon01. Furthermore, at Brandon in 2001, there was a significant interaction between fertility and genetics (data not presented). At this site, InVigor 2663 contained higher concentrations of chlorophyll than SW Flare only under high fertility levels. Conversely, fertility only affected the chlorophyll content of grain for InVigor 2663.



* means designated by a different letter are significantly different (P<0.05) within a site, only

Figure 16. The impact of genetics on end-use quality of canola in 2001 and 2002

Crop protection had very little effect on the overall quality of grain (Figure 17). The protein content of grain was generally not affected by crop protection at all sites except for Brandon in 2002, where the concentration of protein was higher when crop protection was high compared to medium. However, at Brandon in 2002, for grain protein content, there was also a significant interaction between fertility and crop protection because the high level of crop protection increased the protein content of grain under the medium fertility level, only (data not presented). The oil content of grain was generally unaffected by crop protection at all sites except for Brandon in 2002, where the oil content was higher under high protection compared to the medium protection treatments. The glucosinolate content of grain was affected by crop protection at Carman in 2002, where the medium protection treatments had higher concentrations of glucosinolates; however, the glucosinolate content in grain remained relatively low under both levels. At Brandon in 2002, for grain glucosinolate content, there was also a significant interaction between crop protection and genetics (data not presented) because crop protection reduced the glucosinolate content of grain only under the high genetic level. Furthermore, increasing the genetic level increased the glucosinolate content of grain under medium crop protection but decreased it under high crop protection. Crop protection had no effect on the chlorophyll content of grain at all sites.



* means designated by a different letter are significantly different (P<0.05) within a site, only

Figure 17. The impact of crop protection on end-use quality of canola in 2001 and 2002

<u>Effect of Crop Inputs on Fall Soil Nitrate</u>

Water-soluble nitrate was measured on fall soil samples from each plot at Brandon in 2001 (to 60 cm) and at Carman and Brandon in 2002 (to 120 cm). Treatment effects and means for fall nitrate are summarized in the appendices. It is apparent from the analysis of all treatments that genetics had no statistically significant effect on the concentration of nitrate in soil after harvest. For example, at all three sites, even at Brandon in 2001, where InVigor 2663 significantly out-yielded SW Flare, there were no significant differences between fall nitrate concentrations where InVigor 2663 and SW Flare were grown under high (Treatment 6 vs 3) and medium (Treatment 5 vs 4) fertility conditions at high crop protection. However, although there were no statistically significant differences between varieties, in five of the six comparisons, the nitrate concentration under InVigor 2663 was lower than under SW Flare, indicating that the hybrid variety may be a more aggressive consumer of fertilizer and soil nitrate, but because of the variability in the measurement of soil nitrate and the lack of a genetic yield response at two sites, these differences were not statistically different. For InVigor 2663, the fertilization treatments had no effect on the concentration of soil nitrate at Carman.

At the Brandon sites, however, as expected, the low fertility treatment (H-L-H) contained less nitrate than both the medium (H-M-H) and high (H-H-H) fertility treatments. Furthermore, at these two sites, there was no difference in the concentration of nitrate between the medium and high fertility treatments.

Finally, crop protection had no effect on fall nitrate for InVigor 2663 at Brandon in 2002. However, at Brandon in 2001, the medium protection treatment (H-H-M) had a higher concentration of nitrate than both the high (H-H-H) and low (H-H-L) protection treatments, although the absolute difference in nitrate concentration between treatments was not large. At Carman in 2002, their was no difference in fall nitrate concentration between the high and med protection treatments for InVigor 2663; however, the low protection treatment contained significantly less nitrate than the medium and high protection treatments, indicating the weed growth under no crop protection may have depleted the soil of nitrate.

Summary and Conclusions

Canola yield at Brandon in 2001 responded to genetic potential and fertility more than to crop protection. The factorial analysis also demonstrated that no significant interactions between factors occurred. At Brandon in 2002, grain yield responded to fertility and crop protection. These two factors also interacted and demonstrated that the yield response to fertility was dependent on the level of crop protection. At Dauphin and Carman in 2001, poor growing conditions overshadowed treatment effects by reducing the yield potential. At Carman in 2002, yield did not respond to any crop input factor, possibly due to a late season infestation of flea beetles and high temperatures during flowering. Therefore, at these three sites, the difference between medium and high levels of inputs was not significant. Crop protection level was the only factor to significantly influence yield at the Brandon03 site, due most likely to differences in weed pressure among treatments. Also, at all sites, yield responses to genetics appeared to be stable and generally did not interact with fertility or crop protection.

Although root maggots do not play a large role in affecting yields in Manitoba, under small plot conditions, the improvement in plant growth due to improved fertility levels increased the damage caused by root maggots. Improved genetics combined with lower seeding rates increased the intensity of damage caused by root maggots. However, on an area basis, with crop density accounted for, it appears that root maggot damage on an area basis does not increase due to improved genetics.

End use quality, although it does not affect the grade of canola, was also affected by the crop input levels. Very few interactions between factors were observed, and as expected, protein concentration tended to increase and grain oil concentration tended to decrease with as fertility level increased.

Due to the variability in soil nitrate, very few trends were observed in response to the inputs for the concentration of fall soil nitrate. However, although there were few statistical differences in the data, it appeared that InVigor 2663 may be a more aggressive consumer of soil and fertilizer nitrate than SW Flare.

The economic analysis suggests a strong interaction between yield benefit and input cost, with the increased income from using more often insufficient to cover the added cost associated with the crop input. As a result, the potential for negative margins diminishes as canola price increases. Furthermore, although input costs were independent and additive, input responses were interdependent and not additive. The real economic value of crop inputs within the complete cropping system was significantly lower than the sum of the apparent individual responses to inputs measured in the traditional fashion. The comparisons between the high, medium, and low input treatments, as well as the comparisons between the genetic, fertility, and crop protection levels all indicate that the potential savings of reducing one input, while maintaining the maximum level of the other inputs is significantly outweighed by the potential losses in returns. Cutting rates of one input effectively reduces yield potential, thereby reducing the potential return on investment for those inputs kept at a high level.

When the three Brandon site years were considered as a separate dataset, all three crop input types had a significant effect on productivity. Interactions between site year and genetics/crop protection level were also observed, demonstrating the inconsistent impact of these crop inputs across site years. Altering the price of canola and the price of crop inputs from base levels revealed the sensitivity of net returns of high and medium crop input packages to such changes, suggesting such crop management practices are not sustainable in the long term without either further technological improvements that lead to increased productivity, or a risk management vehicle that reduces exposure to price risk.

The success of a knowledge-based system is fully reliant on soil testing and crop scouting, as well as comprehensive understanding on how genetic yield potential can be fully exploited under high yielding conditions. Crop management decisions must be made in a methodical manner in order to eliminate unnecessary costs and maximize productivity and profitability. This study describes three years of data and provides a glimpse of the potential importance and impact of how canola producers can use crop scouting, soil testing, and inputs to improve economic sustainability in the short and long term.

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Appendix A. Summary of results for OCP trial at Brandon, 2001.

Measurement		1	2	3	4	5	6	7	8	9	10	11	12	LSD (P <0.05)
		Treatment												
Crop Density (plants/m^2)	10 DAP[z]	21.8	21.8	20.7	24.7	9.8	8.0	10.0	7.1	31.3	13.5	12.2	15.2	6.2
	17 DAP	21.4	29.5	25.8	28.8	16.3	11.0	17.2	11.7	30.4	16.7	18.2	17.9	10.5
Crop Development	11-Jul	3.25	3.45	3.48	3.68	3.88	3.25	3.40	3.23	3.45	3.45	3.23	3.18	ns
	17-Jul	4.13	4.25	4.18	4.20	4.23	4.18	4.18	4.20	4.18	4.15	4.23	3.90	ns
	20-Jul	4.28	4.33	4.30	4.30	4.30	4.30	4.28	4.30	4.30	4.30	4.28	4.28	ns
	24-Jul	5.10	5.10	5.10	5.10	5.10	5.13	5.10	5.10	5.10	5.10	5.10	4.93	ns
	1-Aug	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	ns
	8-Aug	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	ns
Pre-spray Weed Density (plants/m^2)	Grasses	18.3	6.8	10.3	15.5	7.5	18.8	11.5	8.8	10.0	7.5	8.3	5.8	ns
	Broadleaf	4.8	7.0	5.5	6.0	4.3	4.0	10.8	6.3	11.8	8.0	11.8	7.3	ns
	Total	23.0	13.8	15.8	21.5	11.8	22.8	22.3	15.0	21.8	15.5	20.0	13.0	ns
Post-spray Weed Density (plants/m^2)	Grasses	22.5	22.0	13.5	7.5	10.5	10.0	19.0	20.0	14.0	2.0	18.5	12.5	ns
	Broadleaf	5.0	10.0	6.0	1.5	1.5	5.0	8.0	11.5	14.5	3.0	16.0	8.5	8.0
	Total	27.5	32.0	19.5	9.0	12.0	15.0	27.0	31.5	28.5	5.0	34.5	21.0	
Lodging	Incidence (% of plot)	0.0	0.0	7.5	6.3	0.0	0.0	7.5	7.5	0.0	0.0	7.5	0.0	ns
	Severity Rating	1.0	1.0	1.3	1.3	1.0	1.0	1.5	1.3	1.0	1.3	1.3	1.0	ns
	Crop Height (cm)	101.4	109.3	102.2	98.1	109.3	111.7	107.6	115.8	87.0	93.1	105.9	93.3	ns
Disease	Blackleg	0.3	0.5	1.4	0.3	0.8	0.5	0.5	0.5	0.0	0.0	0.0	0.3	ns
	Sclerotinia	1.3	1.0	1.0	1.0	0.9	0.8	0.8	0.8	0.5	0.4	1.0	0.8	ns
Root Maggot Damage	Rating (0-5)	0.55	0.74	0.92	0.75	1.18	1.48	0.94	1.18	0.19	0.73	1.05	0.73	0.50
Grain Yield (kg/ha)		1428	1897	2109	1773	2237	2606	1933	2268	339	976	1974	412	316
Grain Quality	Protein Content (%)	20.8	21.5	22.6	20.9	20.5	22.1	19.6	21.8	18.3	19.3	21.3	16.5	1.3
	Oil Content (%)	50.0	49.8	49.3	51.0	52.0	50.7	52.5	50.4	52.1	53.4	50.5	54.1	1.3
	Chlorophyll (ppm)	11.2	11.6	12.3	10.3	11.5	17.6	11.8	17.7	5.5	6.9	16.6	5.2	4.0
	Glucosinolates (µmoles/g)	12.0	12.5	13.6	13.1	6.6	7.6	6.5	9.2	11.9	3.5	8.2	5.9	1.9
Fall Nitrate (kg/ha to 60 cm)[y]		12.7	13.2	16.4	13.9	16.1	14.5	11.9	19.3	8.1	10.1	12.6	7.5	4.2

ns - treatments are not significantly different.

[z] days after planting

[y] assuming a soil bulk density of 1.33 g cm^3

Appendix B. Summary of results for OCP trial at Carman, 2001.

Measurement		Treatment 1	2	3	4	5	6	7	8	9	10	11	12	LSD (P <0.05)[y]
Crop Density (plants/m^2)	14 DAP[z]	124.3	99.8	144.0	142.3	73.0	64.5	73.0	70.0	103.0	36.0	82.5	69.0	*
	21 DAP	133.0	109.5	149.3	158.3	83.8	71.8	75.0	73.7	163.7	68.0	82.5	75.0	*
Weed Density		1.3	1.3	2.8	3.3	3.3	4.0	3.3	3.0	7.3	6.5	5.8	6.0	ns
Lodging (Aug 1)	Severity Rating	3.8	3.0	3.0	2.5	2.5	3.0	2.3	2.0	2.3	1.0	3.8	2.0	ns
	Incidence (% of plot)	67.5	57.5	47.5	40.0	30.0	55.0	27.5	10.0	192.8	20.7	60.3	25.0	ns
Lodging (Aug 7)	Severity Rating	4.3	4.0	3.5	3.0	2.5	3.8	2.5	2.3	18.3	25.7	4.0	2.0	ns
	Incidence (% of plot)	75.0	67.5	67.5	45.0	35.0	60.0	35.0	26.7	43.5	25.0	60.3	25.0	ns
Lodging (Aug 17)	Severity Rating	4.8	5.0	4.8	3.5	3.3	4.8	3.5	4.0	1.8	2.3	4.8	2.0	*
	Incidence (% of plot)	85.0	90.0	90.0	52.5	40.0	80.0	42.5	50.0	25.3	1.7	62.8	25.0	*
Harvestability	Crop Height (cm)	62.0	94.0	100.8	57.3	76.3	70.0	78.8	96.7	46.5	36.7	39.5	58.5	ns
	Height to 1st Pod (cm)	44.1	60.8	60.5	38.6	48.6	50.1	52.5	68.0	24.3	50.7	28.8	40.3	ns
	Lodged Height (cm)	29.4	38.4	39.8	31.6	38.0	31.8	41.3	45.3	38.9	27.3	16.8	52.0	ns
Grain Yield (kg/ha)		1195	1773	1644	821	1306	1339	1120	1242	447	700	931	766	*
Grain Quality	Protein Content (%)	25.3	26.1	25.0	25.2	25.8	26.3	24.3	25.5	23.7	25.6	23.9	20.1	ns
	Oil Content (%)	44.0	43.8	44.7	43.0	42.8	42.5	45.5	42.8	45.9	42.6	45.6	49.2	ns
	Chlorophyll (ppm)	19.9	21.5	20.5	14.6	23.9	29.7	26.4	22.3	17.4	15.8	22.6	8.0	ns
	Glucosinolates (µmoles/g)	13.2	14.7	13.3	11.6	10.1	10.7	9.7	10.7	9.2	10.1	8.4	6.3	*

ns - treatments are not significantly different.

* - significant differences among treatments P<0.05.

[z] days after planting

[y] Where at least one pair of treatments are significantly different (*), LSD can not be calculated due to unbalanced data (missing data points).

Appendix C. Summary of results for OCP trial at Dauphin, 2001.

Measurement		Treatment 1	2	3	4	5	6	7	8	9	10	11	12	LSD (P <0.05)
Crop Density (plants/m^2)	14 DAP[z]	115.5	100.0	109.5	97.5	92.5	79.0	88.8	75.5	111.3	84.3	81.5	98.0	ns
	22 DAP	196.3	174.5	171.0	173.3	130.8	115.0	108.3	105.5	163.3	112.5	124.3	118.8	44.3
Pre-spray Weed Density (plants/m^2)	Broadleaf	34.8	23.8	24.8	18.3	47.5	26.3	14.0	25.5	25.8	29.5	54.0	23.8	ns
	Grasses	26.0	20.3	14.5	12.3	17.0	20.0	14.3	19.0	15.3	21.0	21.8	28.3	11.9
	Total	60.8	44.0	39.3	30.5	64.5	46.3	28.3	44.5	41.0	50.5	75.8	52.0	ns
Post-spray Weed Density (plants/m^2)	Broadleaf	0.5	0.0	0.8	2.3	0.5	0.5	0.0	0.5	20.0	0.8	19.3	28.3	11.0
	Grasses	1.3	0.3	0.3	0.0	0.5	0.3	0.3	0.0	11.0	0.0	10.5	23.3	6.4
	Total	1.8	0.3	1.0	2.3	1.0	0.8	0.3	0.5	31.0	0.8	29.8	51.5	14.5
Efficacy (% control)	Total	97.1	99.4	97.7	96.0	99.4	98.2	99.5	97.9	29.3	98.6	54.1	17.5	17.9
	Broadleaf	95.5	100.0	97.6	94.2	99.7	98.5	100.0	96.1	35.6	98.1	38.9	22.2	23.1
	Grasses	98.1	98.2	98.6	100.0	98.3	96.9	98.3	100.0	26.6	100.0	41.1	24.0	25.3
Grain Yield (kg/ha)		1006	1189	1137	1107	1189	1271	1287	1310	747	741	1279	924	223
Grain Quality	Protein Content (%)	26.9	28.0	27.8	26.2	26.0	26.3	25.9	26.9	26.3	24.9	27.4	24.7	1.3
	Oil Content (%)	45.4	44.0	44.1	45.2	44.9	44.8	45.9	44.1	45.3	45.5	43.8	47.3	1.7
	Chlorophyll (ppm)	18.8	22.4	20.8	18.4	21.1	20.7	22.3	23.2	18.4	22.7	26.1	25.4	ns
	Glucosinolates (µmoles/g)	9.1	10.1	11.2	9.5	8.6	7.8	8.1	9.3	12.8	7.0	9.1	8.6	2.8

* - significant differences among treatments P<0.05.

ns - treatments are not significantly different.

[z] days after planting

Appendix D. Summary of results for OCP trial at Carman, 2002.

Measurement		Treatment 1	2	3	4	5	6	7	8	9	10	11	12	LSD (P <0.05)
Crop Density (plants/m^2)	10 DAP[z]	137.4	104.0	103.8	121.2	111.3	104.2	106.0	91.7	149.7	100.9	92.7	113.0	30.6
	17 DAP	192.8	155.9	151.4	190.8	136.0	127.4	120.4	100.6	200.3	143.4	114.5	122.0	33.2
	Post Harvest	136.4	115.4	117.7	153.2	106.4	102.3	92.1	83.5	107.0	89.2	95.4	90.4	37.3
Crop Development	31-May	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	ns
	7-Jun	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	ns
	14-Jun	2.38	2.40	2.35	2.38	2.40	2.38	2.40	2.38	2.33	2.33	2.38	2.35	ns
	21-Jun	2.48	2.55	2.53	2.48	2.50	2.53	2.48	2.53	2.48	2.45	2.53	2.48	ns
	28-Jun	3.00	3.10	3.03	3.03	3.08	3.13	3.10	3.10	2.75	2.95	3.00	2.88	ns
	5-Jul	4.10	4.10	4.10	4.10	4.10	4.10	4.10	4.10	3.70	4.10	4.10	3.70	0.27
	12-Jul	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	4.30	ns
	19-Jul	4.33	4.35	4.40	4.40	4.38	4.40	4.38	4.30	4.30	4.38	4.30	4.30	0.04
	26-Jul	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40	ns
	2-Aug	5.20	5.20	5.20	5.25	5.23	5.20	5.18	5.20	5.18	5.20	5.23	5.20	ns
	9-Aug	5.33	5.38	5.40	5.40	5.38	5.28	5.33	5.33	5.35	5.40	5.38	5.35	0.07
Pre-spray Weed Density (plants/m^2)	Grasses	35.6	22.5	45.6	25.0	24.4	15.6	34.4	40.0	23.1	13.1	45.6	20.0	ns
	Broadleaf	23.1	21.3	28.8	32.5	10.0	38.1	28.8	13.8	28.1	30.0	24.4	10.6	ns
	Total	58.8	43.8	74.4	57.5	34.4	53.8	63.1	53.8	51.3	43.1	70.0	30.6	ns
Post-spray Weed Density (plants/m^2)	Grasses	3.1	9.4	11.9	8.1	0.6	0.6	46.3	7.5	90.0	1.9	59.4	38.8	44.1
	Broadleaf	4.4	8.8	5.0	3.1	1.3	6.3	9.4	4.4	82.5	3.1	35.6	34.4	39.4
	Total	7.5	18.1	16.9	11.3	1.9	6.9	55.6	11.9	172.5	5.0	95.0	73.1	68.1
Lodging - Aug 2	Incidence (% of plot)	21.3	7.5	8.8	12.5	0.0	0.0	0.0	0.0	35.0	0.0	5.0	5.0	ns
	Severity Rating	1.8	1.5	1.8	1.3	1.0	1.0	1.0	1.0	1.8	1.0	1.5	1.3	ns
Lodging - Aug 9	Incidence (% of plot)	27.5	30.0	27.5	18.8	0.0	0.0	1.3	25.0	22.5	22.5	36.3	0.0	ns
	Severity Rating	1.8	1.8	2.8	1.8	1.0	1.0	1.3	1.3	1.5	1.3	2.0	1.0	ns
Harvestability	Crop Height (cm)	89.0	88.2	86.8	87.7	86.5	99.6	96.5	92.7	75.1	80.6	98.4	89.1	10.3
	Height to 1st Pod (cm)	51.8	53.4	53.9	51.1	56.5	61.4	61.9	60.9	44.7	52.6	63.8	55.4	7.5
	Lodged Height (cm)	68.8	74.9	54.4	54.9	57.5	83.9	85.3	63.7	64.5	71.6	61.3	81.7	ns
Root Maggot Damage	Rating (0-5)	1.2	2.2	2.2	1.3	1.8	3.0	2.2	2.7	0.2	0.9	3.2	0.9	0.68
	Damage/m^2	166.0	259.8	251.0	206.7	187.3	307.7	201.5	224.5	23.2	75.7	295.3	83.0	105.8
Flea Beetle Damage (% defoliation)		36.6	34.4	25.6	24.4	13.1	12.5	38.8	33.8	56.6	18.8	41.3	52.5	13.9
Grain Yield (kg/ha)		1166	1202	1121	1128	1154	1320	1082	1122	535	896	900	787	na
Grain Quality	Protein Content (%)	21.3	24.6	25.6	21.9	20.5	24.2	20.5	23.9	18.6	19.4	22.1	18.4	1.3
	Oil Content (%)	49.5	46.5	46.1	49.3	51.1	47.6	50.2	46.2	50.2	52.2	47.5	51.7	1.6
	Chlorophyll (ppm)	0.0	0.0	0.0	0.0	0.0	0.9	3.9	6.0	0.0	0.0	8.2	0.6	ns
	Glucosinolates (μmoles/g)	10.0	12.2	12.0	9.1	5.2	8.4	6.7	9.7	11.0	3.3	9.5	4.0	1.9
Fall Nitrate (kg/ha to 120 cm)[y]		49.8	50.9	55.6	36.1	33.1	48.2	31.1	59.7	12.9	39.5	23.3	21.2	26.2

na - LSD can not be calculated due to unbalanced data (missing data points).

ns - treatments are not significantly different.

* - significant differences among treatments P<0.05.

[z] days after planting

[y] assuming a soil bulk density of 1.33 g cm^3

Appendix E. Summary of results for OCP trial at Brandon, 2002.

Measurement		Treatment 1	2	3	4	5	6	7	8	9	10	11	12	LSD (P <0.05)
Crop Density (plants/m^2)	20 DAP[z]	28.8	33.2	66.0	69.0	35.0	34.9	37.2	36.1	59.6	44.5	20.8	38.0	19.1
	41 DAP	20.2	24.6	51.9	60.4	30.6	20.4	27.7	22.4	35.8	31.1	12.9	19.2	14.4
	Post Harvest	8.6	7.8	9.9	9.8	7.2	8.8	6.5	9.1	1.1	6.5	3.1	1.5	2.8
Crop Development	5-Jun	1.28	1.00	1.28	1.00	1.00	1.28	1.00	1.00	1.00	1.03	1.28	1.28	ns
	11-Jun	2.15	2.10	2.18	2.15	2.15	2.18	2.10	2.10	2.13	2.18	2.10	2.10	0.06
	20-Jun	2.23	2.25	2.33	2.33	2.35	2.35	2.23	2.23	2.28	2.33	2.25	2.28	ns
	3-Jul	2.95	3.10	3.15	3.23	3.15	3.20	2.78	2.78	2.70	3.00	2.83	2.87	ns
	8-Jul	3.65	3.43	4.18	4.18	4.15	4.18	3.60	3.65	-	4.15	3.43	3.20	na
	18-Jul	4.28	4.28	4.30	4.30	4.28	4.30	4.28	4.25	-	4.25	4.27	4.20	ns
	24-Jul	4.30	4.30	4.30	4.33	4.30	4.30	4.30	4.30	-	4.30	4.30	4.30	ns
	31-Jul	4.70	4.53	4.88	4.55	4.70	4.68	5.05	4.65	-	4.95	5.10	5.10	ns
	22-Aug	5.35	5.25	5.38	5.35	5.33	5.28	5.30	5.28	-	5.40	5.30	5.40	ns
	30-Aug	5.40	5.35	5.43	5.45	5.40	5.38	5.40	5.38	-	5.47	5.40	5.50	ns
Harvestability	Crop Height (cm)	90.0	86.3	85.0	83.8	88.8	98.4	84.1	80.6	-	79.2	66.3	68.8	na
	Height to 1st Pod (cm)	60.0	50.4	50.3	50.6	52.2	56.3	47.8	49.7	-	43.8	102.5	47.5	na
Root Maggot Damage	Rating (0-5)	2.9	2.8	2.8	2.5	2.1	3.1	2.4	2.6	0.6	1.6	2.3	1.0	na
	Damage/m^2	25.2	22.1	27.8	24.1	15.5	28.4	14.5	24.7	0.9	10.5	7.2	1.0	na
Grain Yield (kg/ha)		373	449	1119	803	612	1359	290	394	12	261	35	17	262
Grain Quality	Protein Content (%)	22.5	24.7	25.2	24.5	23.7	25.2	22.8	25.8	24.1	20.0	23.0	20.8	1.5
	Oil Content (%)	47.8	46.3	47.6	48.2	49.5	47.6	48.7	45.1	45.2	51.8	39.9	47.6	2.5
	Chlorophyll (ppm)	1.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.0	2.1	3.3	ns
	Glucosinolates (µmoles/g)	16.7	17.9	18.1	18.6	14.9	14.6	19.7	22.4	20.6	10.2	21.9	12.6	3.3
Fall Nitrate (kg/ha to 120 cm)[y]		28.3	63.2	60.4	49.0	32.1	49.7	21.7	66.5	14.5	18.9	47.8	19.1	22.9

na - LSD can not be calculated due to unbalanced data (missing data points).

ns - treatments are not significantly different.

* - significant differences among treatments P<0.05.

[z] days after planting

[y] assuming a soil bulk density of 1.33 g cm^3

Appendix F. Summary of results for OCP trial at Brandon, 2003.

Measurement		Treatment 1	2	3	4	5	6	7	8	9	10	11	12	LSD (P <0.05)
Crop Density ($plants/m^2$)	17 DAP[z]	81.9	71.2	72.8	87.9	70.9	53.0	60.1	47.5	65.4	65.1	51.1	68.9	18.2
	Post Harvest	74.0	66.1	95.6	68.4	66.6	45.4	41.6	38.4	51.6	56.8	48.1	53.3	11.4
Crop Development	27-May	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	ns
	3-Jun	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	ns
	24-Jun	2.58	2.58	2.68	2.70	2.70	2.73	2.55	2.60	2.53	2.68	2.60	2.55	0.09
	8-Jul	3.15	3.15	3.23	3.30	3.23	3.20	3.10	3.10	3.00	3.23	3.10	3.13	0.10
	16-Jul	4.20	4.15	4.20	4.20	4.20	4.20	4.10	4.10	3.70	4.20	4.10	4.10	0.19
	23-Jul	4.35	4.33	4.33	4.33	4.38	4.33	4.30	4.33	4.20	4.38	4.25	4.28	0.07
	29-Jul	5.15	4.98	5.15	5.15	5.18	5.15	5.00	4.80	4.55	5.15	4.95	5.00	0.31
	5-Aug	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	ns
	14-Aug	5.4	5.4	5.4	5.4	5.4	5.3	5.3	5.4	5.3	5.3	5.4	5.4	ns
Pre-spray Weed Density ($plants/m^2$)	Grasses	1.0	2.8	1.5	4.8	2.3	2.5	15.5	4.3	1.0	1.8	4.3	7.0	ns
	Broadleaf	21.0	20.8	15.5	24.3	19.8	26.0	18.5	22.5	32.3	23.3	9.5	19.0	14.5
	Total	22.0	23.5	17.0	29.0	22.0	28.5	34.0	26.8	33.3	25.0	13.8	26.0	ns
Post-spray Weed Density ($plants/m^2$)	Grasses	0.3	3.5	0.0	0.0	0.3	0.0	1.8	2.8	6.3	0.8	11.8	10.5	7.7
	Broadleaf	3.8	3.8	0.5	1.5	0.3	0.0	2.8	6.5	30.8	6.5	12.5	22.0	9.6
	Total	4.0	7.3	0.5	1.5	0.5	0.0	4.5	9.3	37.0	7.3	24.3	32.5	9.8
Lodging	Incidence (% of plot)	10.0	10.0	7.5	10.0	0.0	2.5	5.0	7.5	7.5	0.0	12.5	7.5	ns
	Severity Rating	1.8	1.8	1.8	1.5	1.0	1.3	1.3	1.8	1.8	1.0	2.0	1.8	ns
Harvestability	Crop Height (cm)	88.5	89.8	95.6	94.1	105.2	105.4	101.4	103.8	88.3	101.3	101.1	98.3	6.9
	Height to 1st Pod (cm)	51.5	50.6	56.9	57.6	65.4	67.3	62.9	62.9	55.6	62.6	62.4	62.3	4.8
Root Maggot Damage	Rating	0.3	1.1	0.4	0.3	0.8	0.7	0.6	1.0	0.1	0.8	0.6	0.2	ns
	$Damage/m^2$	20.8	90.0	29.6	25.9	56.7	40.7	33.9	54.2	3.3	47.5	30.3	10.8	46.8
Flea Beetle Damage (% defoliation)	Cotyledon 7 DAP	3.5	1.4	1.8	2.0	1.7	1.2	3.0	6.6	6.8	1.6	7.8	5.5	3.6
	Cotyledon 14 DAP	21.0	21.9	4.8	6.2	4.4	7.2	3.7	39.0	38.9	9.4	4.2	39.1	6.4
	Leaf 14 DAP	16.5	22.9	0.8	2.1	0.4	1.9	2.7	31.8	38.3	2.2	33.6	31.4	6.5
Grain Yield (kg/ha)		886	1045	1222	1098	1300	1310	809	1038	371	871	866	534	333
Grain Quality	Protein Content (%)	23.5	26.0	25.5	24.4	24.0	25.7	25.9	26.5	22.2	22.1	26.8	20.1	
	Oil Content (%)	45.1	42.6	43.6	44.9	45.4	44.2	42.4	42.7	46.5	47.2	41.9	47.1	
	Chlorophyll (ppm)							not determined						
	Glucosinolates (μmoles/g)	15.0	17.3	17.7	15.5	11.7	10.6	13.5	10.5	18.2	11.4	12.5	12.8	

na - LSD can not be calculated due to unbalanced data (missing data points).
ns - treatments are not significantly different.
* - significant differences among treatments P<0.05.
[z] days after planting