The Influence of Simulated Herbicide Drift on Canola (*Brassica napus* L.) and Dry Bean (*Phaseolus vulgaris* L.).

BY

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A Thesis
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The Influence of Simulated Herbicide Drift on Canola (*Brassica napus* L.) and Dry Bean (*Phaseolus vulgaris* L.). Jaret Sawchuk. Supervisor: Dr. Rene Van Acker. University of Manitoba, Winnipeg, Manitoba, Canada

A field experiment was conducted over two years at two sites to determine yield and quality loss in canola and field beans in Manitoba, as a result of simulated herbicide drift of MCPA, glyphosate and thifensulfuron:tribenuron (2:1). Experimental design was a randomized complete block with four replicates. Five dosages of each herbicide, along with an untreated control, were applied in each crop to simulate herbicide drift. In canola, dosages of MCPA ester were 0, 25, 50, 100, 150, and 280 g ai/ha; dosages of glyphosate were 0, 13, 25, 50, 100, and 200 g ai/ha; while dosages of thifensulfuron:tribenuron were 0, 0.01, 0.05, 0.15, 0.5, and 2 g ai/ha. In field beans, dosages of MCPA ester were 0, 50, 100, 280, 560, and 1120 g ai/ha, dosages of glyphosate were 0, 30, 60, 125, 250, and 500 g ai/ha; while dosages of thifensulfuron:tribenuron were 0, 0.3, 1, 3, 6, and 12 g ai/ha. Dosages varied slightly in 2002. A nonionic surfactant (Agral 90) was added at a rate of 1% v/v to the glyphosate and thifensulfuron:tribenuron treatments. Assessments of herbicide effect included visual injury, stand density, shoot biomass, pods per plant, seeds per pod, 1000 seed weight, and grain yield. In general for both crops and all three herbicides, increasing herbicide dosage resulted in decreased final yield, with field beans being surprisingly tolerant to MCPA ester and thifensulfuron:tribenuron. For canola, the most damaging herbicide in terms of effect on yield vs. percent of field rate was thifensulfuron:tribenuron (2:1). The simulated herbicide drift of thifensulfuron:tribenuron (2:1) at a rate of 13 percent of the field rate (15 g ai/ha) caused a 46 percent decrease in yield. A 50 percent yield loss in the canola plots treated with glyphosate occurred at 23 percent of the field rate (440 g ae/ha). A 50 percent yield loss in the canola plots treated with simulated herbicide drift of MCPA occurred at 18 percent of the field rate (280 g ae/ha). For field beans, the most damaging herbicide in terms of effect on yield vs. percent of field rate was glyphosate. A 48 percent yield loss in the bean plots treated with glyphosate occurred at 28 percent of the field rate (440 g ae/ha). The simulated herbicide drift of thifensulfuron:tribenuron (2:1) at a rate of 80 percent of the field rate (15 g ai/ha) caused only a 25 percent decrease in field bean yield. A 25 percent yield loss in the bean plots treated with simulated herbicide drift of MCPA occurred at 400 percent of the field rate (280 g ae/ha).

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1.0 INTRODUCTION:

There are very few good quality days for post-emergent herbicide application in Western Canada. Wind is one of the major factors that may cause herbicide drift. Wind can cause the water droplets that contain a herbicide to stray off their desired target, possibly hit an undesired target and cause a great deal of damage to that undesired target. This unfortunate event is commonly known as herbicide drift. Drift is the movement of a crop protection agent (CPA) from its intended target area in an airflow (Wolf, 2001). Spray drift during herbicide application remains an ongoing economic and environmental concern for farmers on the Prairie Provinces, where Canadian herbicide use is most widespread (Grover et al., 1997). Herbicide drift is also a problem in the United States. For example, in 1974, post-emergence dicamba sprays used on approximately 250,000 hectares of corn resulted in 68 reports of dicamba drift effects on soybeans (Behrens and Lueschen, 1979).

Large-scale farming has lead to an increased use of "custom applicators". The machines used by custom applicators have the ability to cover a large amount of ground in a relatively short time. This is desirable for Manitoba farmers because there are only 6 to 8 suitable post-emergence spraying days in a typical spraying season (Tom Wolf, Personal communication). Therefore, much of the spray application is done in less than ideal environmental conditions. Farmers and custom applicators have to deal with several factors that can influence a spray solution during its journey from the nozzle to its intended target. Some of these factors include wind direction and speed, temperature, relative humidity, temperature inversions, nozzle type, application speed, type of herbicide and use of a surfactant.

Study of the physical drift of herbicides to non-target, desirable vegetation is critical to the understanding of the contamination potential to non-labeled crops as well as the potential economic injury to non-target crops (Banks and Schroeder, 2002). The objectives of this project are to characterize the effect of simulated herbicide drift of MCPA, glyphosate and thifensulfuron:tribenuron (2:1) on the growth and yield of canola and navy beans.

2.0 LITERATURE REVIEW

2.1 INFLUENCES ON HERBICIDE DRIFT:

Most agricultural chemicals used to control pests are applied into the atmosphere as liquid spray droplets (Ellis and Griffin, 2002). Conversion of a liquid into spray droplets and the ultimate fate of the droplets depend on nozzle type, spray pressure, droplet size, environmental conditions, protective shielding, boom height, and spray additives (Ellis and Griffin, 2002).

2.1.1 INFLUENCE OF ENVIRONMENT

Environment plays a major role in the efficiency of herbicides. A strong wind has the potential to cause a great deal of the herbicide to move off target, or drift, thus decreasing its efficiency. The drift can move very far or it may not go far at all. Wall (1994) reports that the volume of herbicide likely to drift during conventional ground application varied from 1.8 to 16.5 % of the total spray volume. Ellis and Griffin (2002) also report that downwind drift from unshielded sprayers ranges from 1 to 16 % depending on the nozzle size and wind velocity. Previous research has shown that at wind speeds of 4.4 meters per second, downwind drift deposits of herbicides applied with a ground sprayer averaged 9.2 % (Eberlein and Guttieri, 1994). An 8001 spray tip applying 50L/ha will lose about 3% drift at a 10km/h wind speed, 7% at 20km/h and 11% at 30km/ha (Wolf, 1999c).

Temperature and relative humidity not only affect how quickly spray droplets evaporate once they are atomized by the nozzle (Wolf, 1999a), but they can also affect uptake and translocation of various herbicides. Several studies confirm that the uptake of glyphosate occurs more readily under high relative humidity conditions. A greenhouse experiment (Adkins et al., 1998) was conducted to test the effects of soil moisture content, light, temperature and relative humidity on the efficacy of glyphosate. The test plants used in the experiment were wild oat (*Avena fatua* L.) and liverseed grass (*Urochloa panicoides*). The results of the experiment showed that the efficacy of 360g acid equivalent per hectare (ae/ha) glyphosate was greatest under well-watered (100% field capacity), warm (30/25°C for *A. fatua* and 35/30°C for *U. panicoides*) and humid (>92/90%) conditions. The efficacy was lowest under water-stressed (29% field capacity), warm (30/25°C for *A. fatua* and 35/30°C for *U. panicoides*) and moderately humid (>65/60%) conditions. In addition, Chase and Appleby (1979) reported that five to six times more ^{14}C-labelled glyphosate was translocated into bermudagrass (*Cynodon dactylon*) at 100% relative humidity than at 40% relative humidity.

2.1.2 TEMPERATURE INVERSIONS

Temperature inversions can cause a considerable amount of spray drift (Wolf, 1999a). Under normal sunny daytime conditions, the atmosphere is unstable (i.e. the air near the ground is much warmer than the air above). Under these conditions, there is considerable turbulence in the atmosphere and adjacent air layers mix readily with each other. Therefore, if the air contains some drift, this drift is quickly dispersed upward and downward, diluting it with clean air and reducing its impact on adjacent crops or fields (Wolf, 1999a). The opposite of an unstable atmosphere is a stable atmosphere. This happens at night, when air near the ground becomes cooler than the air above it. Spraying under inversion conditions can lead to long distance transport of a drift cloud and result in severe drift damage at considerable distances (Wolf, 1999a).

Under inversion conditions, turbulence is suppressed because adjacent air layers cannot mix with each other. In fact, the layers of the atmosphere tend to remain distinct. Any drift in the air therefore remains concentrated and may hang over the treated area for a long time. If wind speed increases, a concentrated spray drift cloud is moved off the treated area and can cause considerable damage at its destination. This can sometimes be difficult to understand because inversions are usually associated with calm conditions and herbicide drift is associated with windy conditions.

2.1.3 DROPLET SIZE

Herbicide drift most commonly occurs with small water particles. Small water droplets are lighter, therefore they move more slowly from the nozzle to the plant. There is more chance for smaller droplets to be displaced by wind and drift (Wolf, 1999a). Large droplets are less prone to drift because they have more momentum, the product of their larger velocity and mass. However, if the small water droplets do not evaporate before they reach the crop canopy they can cause greater damage than expected because their volumetric ratio of chemical: water is very high. A small droplet will be carried almost horizontally in any wind and is most likely to impact on vertical surfaces. It has a much greater chance of getting inside the canopy without being caught because most leaves are near horizontal (Spillman, 1984). However, smaller droplets may not penetrate dense canopies as well as larger droplets (Wolf et al., 1992). Smaller water droplets have a greater ability to adhere to leaf surfaces. This occurs because larger droplets have a greater velocity so they tend to bounce off leaves (Wolf. 1999). Small droplets can stick to plant stems as well as leaves. This is why more damage than one would expect often occurs after herbicide drift. Al-Khatib et al. (1994) found that small and concentrated droplets of thifensulfuron could damage peas more than large and diluted droplets as a result of increased herbicide absorption by plants.

Existing information regarding the effect of droplet size on effectiveness of phenoxy herbicides is conflicting, some studies showing increased efficacy with large droplets and yet other studies show either increased efficacy when small drops were applied or no effect of droplet size on effectiveness of a spray application (Wolf et al., 1992). The variance in results is most likely due to lack of consistent experimental methodology. The variance in results makes it difficult to relate any result to current herbicide use patterns. Previous research on phenoxy herbicide drift does not represent consistent treatments with regard to herbicide formulations, concentrations, or carrier volumes (Wolf et al., 1992).

Upon droplet formation at the nozzle, spray droplets are subjected to gravity and aerodynamic drag (Elliot and Wilson, 1983). Additionally, spray droplets are released with an initial momentum. The distance within which the initial momentum dissipates depends on droplet speed, droplet size, nozzle orientation and operating conditions. For small droplets, the initial momentum dissipates rapidly and has only little effect on the droplet trajectory (Spillman, 1984). However, for large droplets a specific proportion of the trajectory may be governed by the initial momentum. According to Elliot and Wilson (1983), spray droplets > 200 μm emitted from a vertically oriented hydraulic nozzle are likely to be projected into the crop canopy. Whether subsequent droplet movement is dominated by aerodynamic forces or by gravity depends on the sedimentation velocity of the spray droplet and the vertical component of the local wind speed (Knoche, 1994). It is most likely then, that gravity dominates large droplet movement but turbulence dominates small droplet movement.

On the other hand, using MCPA, paraquat and glyphosate, Merritt (1982) found that the activity of all three herbicides was affected by variation of the site of application on individual plants but not by droplet size. All three herbicides were obtained as aqueous concentrate formulations containing no surfactant. They were then diluted with distilled water for application and Agral 90 surfactant was added to give a final concentration of herbicide solution of 1 ml/litre. In these experiments, herbicide concentration had no marked effect on the performance of MCPA or paraquat, while the activity of glyphosate increased as concentration increased. MCPA and glyphosate were less active when applied to the cotyledons than between the veins of foliar leaves, while paraquat was equally effective whether applied to the cotyledons or foliar leaves.

2.1.4 CROP SPECIES SPECIFIC RESPONSES TO DRIFT

A report published by the Agri-Food Research and Development Initiative (ARDI) (Van Acker, 2000) shows the effect of various glyphosate timings and concentrations on canola. The project simulated drift with rates between 1.5% and 25% of the 1/2 litre per acre rate of Roundup Transorb (450 g ae ha^{-1} of glyphosate) for herbicide application. It showed these low rates of glyphosate can influence the yield and flowering dates of peas, canola, flax, and spring wheat. Among these crops, peas were the least sensitive to this herbicide, while flax and wheat were most sensitive. Canola was moderately sensitive.

Ellis and Griffin (2002) conducted a field research trial in Baton Rouge, Louisiana to evaluate the response of soybean (*Glycine max* L. Merrill) and cotton

(*Gossypium hirsutum* L.) to simulated herbicide drift of glyphosate and glufosinate. The rates used represented 12.5, 6.3, 3.2, 1.6 and 0.8% of the usage rates of 1120 g ai ha^{-1} glyphosate on glyphosate resistant soybean. Early post-emergence applications of glyphosate were made at the 2 to 3 trifoliate leaf stage of soybean and a late post-emergence application was made at first flower. Soybean injury and height reduction occurred in most cases for only the two highest rates of the glyphosate with variation noted between years (Ellis and Griffin, 2002). Soybean height was reduced by no more than 11%, regardless of herbicide rate or timing. The soybeans were able to recover rapidly from herbicide injury, and yields were not negatively affected.

Al-Khatib and Peterson (1999) also conducted a field research experiment to evaluate the response of soybean to various herbicides (dicamba, glyphosate, glufosinate and various sulfonylurea herbicides) applied at rates to simulated drift damage. The various herbicides were applied at 1, 3, 10 and 33 % of the recommended use rates. Al-Khatib and Peterson (1999) found soybean yields were not reduced by glyphosate. Applications of all herbicides at rates higher than 33 % of the use rates caused injury symptoms within thirty days after treatment. However, soybean plants had partially or fully recovered by the end of the growing season. Therefore, early-season injury symptoms from herbicide drift are not reliable indicators for soybean yield reduction (Al-Khatib and Peterson, 1999).

The tolerance of broadleaf crops commonly grown in western Canada to sub-lethal herbicide doses has, generally, not been well documented (Wall, 1994). Wall conducted an experiment from 1992 to 1994 in southern Manitoba to investigate the tolerance of buckwheat (*Fagopyrum esculentum* Moench.), canola (*Brassica napus* L.), field pea (*Pisum sativum* L.), lentil (*Lens culinaris* L.), and sunflower (*Helianthus annuus* L.) to sub-lethal doses of 2,4-D amine. In canola he found that by harvest time, there was no apparent difference between 2,4-D dosages and the untreated check plots in any year. He also found that there tended to be a stronger relationship between visual estimates of crop injury and yield than between Leaf Area Index (LAI) and yield.

Dicamba (3,6-dichloro-2-methoxybenzoic acid) spray drift is phytotoxic to a number of broadleaf crops, including potato (*Solanum tuberosum* L.), sugarbeet (*Beta vulgaris* L.), sunflower (*H. annuus*) and soybean (*G. max*) (Wall, 1994). Wall (1994) reported that in similar studies, 56 g ai ha^{-1} of dicamba reduced total potato yield by 18 %. In other studies, dicamba applied at a rate of 1.0 g ai ha^{-1} caused phenoxy-type symptoms in potato, but tuber yields were unaffected (Weidenhamer et al., 1989). MCPA (rate not reported) applied at tuber initiation reduced total potato yield and caused tuber malformations (Wall, 1994). Low rates (not reported) of tribenuron applied at tuber initiation reduced tuber yields and increased the incidence of tuber malformations. However, it is interesting to note that low rates of 2,4-D applied at first bloom increased potato yield (Hemphill et al., 1981). In Minnesota, post-emergence spraying of corn with dicamba has caused a greater number of soybean drift injury incidents than has been caused by post-emergence spraying of corn with 2,4-D (Behrens and Lueschen, 1979). In 1974, post-emergence dicamba sprays used on approximately 250,000 hectares of corn resulted in 68 reports of dicamba drift effects on soybeans, while post-emergence use of 2,4-D on over 800,000 hectares of corn resulted in only seven reports of 2,4-D drift effects on soybeans (Behrens and Lueschen, 1979).

Wall (1994) also studied the tolerance of several crops to simulated thifensulfuron:tribenuron spray drift. Sulfonylurea herbicides are generally highly active on a number of broadleaf species at very low dosages. Wall (1994) determined that rates of thifensulfuron:tribenuron as low as 0.23 g ai ha^{-1}, or 1.5 % of the recommended field rate, severely injured canola, field pea and lentil. Average predicted yield loss was 22 % for canola at the 0.23 g ai ha^{-1} rate. At the same 0.23 g ai ha^{-1} rate, average yield losses were 16 % for sunflower, 20 % for buckwheat, 26 % for lentil and 37 % for field pea.

In a similar experiment, Wall and his colleagues (1995) determined that thifensulfuron and thifensulfuron:tribenuron at rates as low as 0.1 g ai ha^{-1} (0.67 % of recommended field dosages for both products in Manitoba) severely injured canola, delayed flowering, and reduced yield and subsequent seed germination. For both of these herbicides, crop injury increased with dosage. There was a strong linear relationship between %age injury and yield.

Wall (1997) also conducted an experiment to investigate the effect of crop growth stage on canola (*B. napus*) and sunflower (*H. annuus*) tolerance to sublethal dosages of thifensulfuron:tribenuron (2:1). Thifensulfuron:tribenuron at doses of 0, 0.23, 0.45, 0.9, 1.8, and 3.6 g ai ha^{-1} plus a nonionic surfactant at 0.5% v/v were applied to canola and sunflower at the 2 to 3 leaf, 4 to 5 leaf and 6 to 7 leaf stages (Wall, 1997). The crop injury was lowest, and flowering, seed yield, and seed oil content were least affected in low doses of thifensulfuron:tribenuron when applied at the 2 to 3 leaf stage. At the highest dose, there was little practical difference among growth stages since yield of both crops was severely reduced (Wall, 1997).

2.1.5 CHALLENGES OF SIMULATING HERBICIDE DRIFT

Simulated physical drift of aqueous herbicide solutions and the resulting effects on susceptible non-target crops have been reported for many herbicides that are foliarly applied on a variety of crops (Banks and Schroeder, 2002). In all these reports, the carrier volume used remained constant while the herbicide dosage varied. Constant carrier volumes do not accurately reproduce physical drift of herbicides because concentration in the carrier is reduced for each incremental reduction in dosage as compared with using carrier volumes that change proportionally with dosage (Banks and Schroeder, 2002). Therefore, herbicide concentration in the carrier remains constant. Banks and Schroeder (2002) found that few studies attempt to use very low carrier volumes in simulated drift studies, and they found none were using dosage-proportional carrier volumes. This is because it is far more convenient to use only one carrier volume when conducting a simulated drift study than to change carrier volume delivery for each rate being evaluated (Banks and Schroeder, 2002). The additional time needed to calibrate equipment for each dosage, the variable wind conditions during application that can cause very low carrier volumes to drift, and the need for buffer rows between plots to avoid off-plot movement are all reasons to discourage the use of carrier volumes that change with herbicide dosage (Banks and Schroeder, 2002).

A field experiment (Ellis et al., 2002) was conducted to study the influence of carrier volume with herbicide drift rates representing 12.5 and 6.3% of the use rates of 1120 g ai ha^{-1} glyphosate and 420 g ai ha^{-1} of glufosinate. Corn (*Zea mays* L.) and soybean (*G. max*) were exposed to herbicide rates applied in constant carrier volume of 234 L ha^{-1} and in proportional carrier volumes of 30 L ha^{-1} for the 12.5% rate and 15 L ha^{-1} for the 6.3% rate. Averaged across herbicides, corn height reduction 14 days after treatment was greater for the 12.5% rate when applied in proportional 30 L ha^{-1} carrier volume (45%) compared with constant 234 L ha^{-1} carrier volume (28%). When carrier volume was changed from constant to proportional, corn injury 14 days after treatment increase from 33 to 51% for the 12.5% rate and 18 to 38% for the 6.3% rate. When compared with the constant spray volume, corn yield reduction was 1.5 times greater for the 12.5% rate but 4 times greater for the 6.3% rate when spray volume was varied proportionally to the herbicide rates.

2.2 CANOLA AND NAVY BEANS IN MANITOBA:

2.2.1 CANOLA

Rapeseed was introduced as an alternative crop for Manitoba producers during World War II when its oil was used as a lubricant. The crop increased in significance in the early 1970s when research conducted at the University of Manitoba led to the first canola variety with oil suitable for human consumption and meal for livestock feed (Manitoba Agriculture and Food, 2003a). Today, canola has become a major part of the Manitoba agricultural industry. In 1999, Manitoba producers seeded 991,000 hectares of canola, second only in seeded acres to wheat (Manitoba Agriculture and Food, 2003a). This seeded acreage produced 1.78 million tonnes (or 78.5 million bushels) equaling 23.3 % of Canada's total canola cash receipts (Manitoba Agriculture and Food, 2003a). Canola seed, which contains approximately 42 % oil, is also processed locally in Manitoba, where we have two canola processing facilities that have a combined crushing capacity of 28 million bushels per year.

Manitoba is one of the best canola (*B. napus*) producing areas in the entire world. High canola yields can be achieved here because of soils that are high in nutrients and the very favorable climate. Canola does well where extreme heat and moisture limitations are not common. Canola oil is used for the production of consumer goods such as margarine, shortenings and salad oil. Canola is also important in the Canadian livestock industry. Canola meal is used in dairy, beef, swine and poultry rations (Manitoba Agriculture and Food, 2003a).

Canola seed is usually protected with both a fungicide and an insecticide. The fungicide protects the seed from diseases such as damping off, root rot, and seed-borne Blackleg. The insecticide protects the seed from flea beetles. Canola is generally seeded throughout the month of May and it is seeded at a rate of approximately 5 kg ha^{-1}. Canola should be seeded at a depth of 1.25 cm to 3.75 cm when moisture conditions are ideal (Manitoba Agriculture and Food, 2003a). If the soil is dry and moisture can only be reached at a depth of 5 cm or deeper, farmers seed in the 1.25 to 3.75 cm range and wait for rain.

In Canada, there are a large number of canola varieties to choose from. Producers should choose a variety that works best in the unique conditions of their farm. Some variety characteristics to be aware of are blackleg resistance, lodging resistance, crop maturity rating, herbicide tolerance and yield.

In order to achieve a high yield in canola, high nitrogen rates are required. However, a producer must be cautious because high nitrogen rates can often cause problems at harvesting. High nitrogen can cause an increase in lodging and will increase the green seed count at harvest time. It is generally recommended that following a stubble crop, a producer should apply about 70-90 kg ha^{-1} of actual N for their upcoming canola crop (Manitoba Agriculture and Food, 2003a).

Swathing is the most common method of harvesting canola. Canola can be swathed when 30-35 % of the seeds on the main stem turn from green to brown. This is also approximately equal to 30-35 % seed moisture (Manitoba Agriculture and Food, 2003a). This is the proper stage to swath canola because this will reduce the amount of green seeds at harvest. A canola swath is generally ready to combine when the moisture %age has reached 10 % or less and there are minimal green seeds in the swath.

2.2.2 NAVY BEANS

Navy, or field beans (*Phaseolus vulgaris* L.) are becoming more prevalent in Manitoba's Red River Valley. Manitoba farmers began producing field beans in 1963 when 100 acres were harvested (Manitoba Agriculture and Food, 2003b). The industry grew at a respectable rate from the 1960s until the mid-1990s, at which time production had reached approximately 16,200 hectares (Manitoba Agriculture and Food, 2003b). However, Manitoba field bean production has grown more rapidly over the last 5 years from 26,000 hectares in 1996 to 100,400 hectares in 2000 (Manitoba Agriculture and Food, 2003b). As a result of this explosive growth, Manitoba farmers now produce approximately 60 % of Canada's total dry bean crop (73% of navy beans and 47% of coloured beans) (Manitoba Agriculture and Food, 2003b).

The newest niche markets for Manitoba beans include quick-cooking bean-based foods and other specialty products. All Manitoba beans are grown for human consumption with quality being the number one priority for producers. Manitoba beans are backed by Canada's strict food safety assurance system and the producers' unwavering attention to detail. All Manitoba produced beans are grown and processed to exceed the consumers' expectations of high quality and safety. Manitoban producers strive for excellence in three key quality criteria: size, shape and colour.

In Manitoba, field beans have traditionally been grown as a row crop, in rows spaced 30-36 inches apart. However, producers accustomed to growing cereals, flax and canola are starting to look at field beans as an alternative crop. Many of these producers are only interested in field beans if they can use their existing equipment (air seeders, sprayers and combines) to grow the crop (Manitoba Agriculture and Food, 2003b). Field beans planted with air seeders can be grown in row spacings that range from 12.5 cm all the way to 30 cm, depending on the type of seeder. This is known as solid seeding. A seeding depth of 3-5 cm is optimal.

Field beans in Manitoba are inoculated with a strain of rhizobia (*Rhizobium phaseoli*) before seeding. Field beans generally grow best on fertile soils. It is recommended that nitrogen be applied at a rate of 20-40 kg ha^{-1} (Manitoba Agriculture and Food, 2003b). Beans require approximately 15 kg ha^{-1} of nitrogen from the time of seeding to the time nodules begin to fix nitrogen (Manitoba Agriculture and Food, 2003b). This takes about a month.

When harvesting field beans, there are two different methods, depending on whether the beans were seeded as a row crop or solid seeded. Beans grown in rows are pulled, windrowed and then combined using a pick-up header. The standing beans are "pulled" by cutting the stem just below the soil surface with a fixed blade, rod weeder or rotary disk-type puller (Manitoba Agriculture and Food, 2003b). Beans are ready to be cut or pulled when some of the pods are dry and most have turned yellow. The pulled beans are then left to cure in windrows. Pulling and windrowing can be done in one operation with suitable equipment. At harvest, the windrows are lifted into the combine using a SUND or RAKE UP pick-up (Manitoba Agriculture and Food, 2003b). When beans are pulled before combining, pod height above the ground is not as critical as it is in a solid-seeded system.

Solid-seeded bean production requires a determinant, bush type bean plant. At harvest, these bush-type plants tend to lodge less, resulting in the pods being held higher off the ground (Manitoba Agriculture and Food, 2003b). This allows for a cutter bar (swather or straight-cut header) with lifters to get below the majority of the pods. However, there always remains a certain level of "acceptable" loss. Pods that are below the cutter bar will be missed in the swathing or direct-harvesting operation (Manitoba Agriculture and Food, 2003b). Once the beans have been windrowed, they can be threshed with a combine that is equipped with a regular pick-up header. Harvest losses due to shattering can be higher in solid seeded versus row-crop stands because the equipment used in the solid-seeding method is more aggressive.

2.2.3 HERBICIDE USE PATTERNS IN MANITOBA

The herbicides used in this project are commonly used products in field crop production in Manitoba. A large portion of Manitoba's cereal acreage is sprayed with Buctril M. In fact, 7.9, 10 and 8.4% of spring wheat, barley and oats, respectively, are treated with Buctril M. Almost 16 % of all oilseeds grown in Manitoba are treated with Buctril M (Thomas et al, 1999). One of the components in Buctril M is MCPA ester. Four and a half % of spring wheat and 8.9% of oat fields in Manitoba are treated with MCPA Ester (Thomas et al, 1999). Thirty-eight and a half % of spring wheat, 49.8% of barley and 48.1% of oat fields were sprayed with glyphosate in 1997 (Thomas et al,

1999) during both the pre-emergence or pre-harvest periods. Thirty-eight percent of all oilseeds in Manitoba in 1997 were sprayed with glyphosate. More specifically, 40.3% of all canola acres were sprayed with glyphosate. Weed control technology, such as Roundup Ready™ canola, has increased the amount of glyphosate being sprayed at the normal post-emergence timing. In 2002, 86.4 % of all canola grown in Manitoba was herbicide tolerant (Park, 2003). This is a dramatic change from 1996, when only 14.3 % of the canola acres in Manitoba were seeded to herbicide tolerant varieties. In 2002, of the 86.4 % of the herbicide tolerant varieties, 31.4 % was Roundup Ready. Refine Extra® is also one of the major herbicides sprayed on wheat in Manitoba. Thirty-three and a half percent of spring wheat in 1997 was sprayed with Refine Extra (Thomas et al, 1999). Because all three of these herbicides are so widely used, there is a high probability that incidences of drift will include one of these herbicides.

2.3 HERBICIDE APPLICATION TECHNOLOGIES

Herbicides are applied by a number of different methods and machines. Ground machines range from the very small and simple "bicycle plot sprayer" to the very large and complex self-propelled, high clearance and high-speed sprayer (Grover et al., 1997). Aerial equipment can also be used to apply herbicides to a field. An airplane is commonly used to accomplish this but there are also some instances when a helicopter can be used (Yates et al., 1978). Aerial application of herbicide is unlikely in an agricultural system and is more common in forestry. Time of application ranges from pre-planting to post-harvest (Manitoba Agriculture and Food, 2002).

Regardless of when a herbicide is applied, it is usually applied as a spray solution. The water droplets produced by the nozzles are very small and light, and are therefore subject to drift under windy conditions. There are several methods that can be used to prevent herbicide drift. Increasing droplet size is one method. The time required for droplets of 500 µm diameter to fall from the nozzle height (approximately 50cm for a boom sprayer) to the ground is only 1 to 2 seconds (Maybank et al., 1974). Droplets of smaller diameter possess lower terminal velocities and take longer to hit a target. Droplets of 50 µm or less can evaporate so quickly that they will often disappear just before or soon after impact with the target (Wolf, 1999a).

Increasing carrier volume is an effective way to reduce drift. If travel speed is maintained, a larger nozzle can be used to apply the higher volumes. This results in a coarser, less drift-prone spray. In addition, the spray solution is more dilute at the higher volume. This means that if drift should occur, the water droplets will contain less active ingredient and therefore have less potential to cause damage (Wolf, 1999c).

Another method to reduce herbicide drift is to use low-drift nozzles. These nozzles can be used at conventional pressures and will deliver a less drift-prone spray (Wolf, 1999c). These nozzles are actually low-pressure nozzles but the orifice is slightly larger than in a conventional nozzles and this maintains a standard flow rate at a reduced pressure. Low drift nozzles work effectively between 30 and 60 psi (Wolf, 1999c). Another type of nozzle is called the Turbo Teejet (TT) nozzle. TT nozzles have a turbulence chamber built into the nozzle that mixes the spray solution before it forms a spray pattern, and this creates larger droplets. The TT nozzles maintain good patterns between 15 and 90 psi (Wolf, 1999c). A third type of nozzle tip is called the Venturi nozzle. The venturi design draws air into the nozzle, which mixes with the spray. The resulting droplets are larger and contain air bubbles. These droplets are less drift-prone and explode upon impact with the target to produce smaller, more concentrated droplets and good spray coverage on the target.

2.3.1 INFLUENCE OF SURFACTANTS ON HERBICIDE DRIFT

Some weed species are known as difficult-to-wet species. This means that coarse sprays are not adequately retained on the leaf surface after impact of the water droplet. In order to combat this, surfactants (surface-active agents) are used. In general, surfactants are widely used as spray adjuvants to improve the biological performance of formulations of many different types of foliage applied herbicides (van Toor et al., 1994). They may be included as an ingredient of the primary formulation or they can be tank-mixed at the time of application. Herbicide concentration increases as spray volume decreases, thereby enhancing herbicide efficacy in low spray volumes (Ramsdale and Messersmith, 2002). Conversely, herbicide efficacy generally increases as spray volume increases when adjuvants are applied as a percentage of spray volume (Ramsdale and Messersmith, 2002). Surfactants primarily reduce surface tension, which decreases the stability of the liquid sheet emanating from the nozzle (Wolf, 1999b). The result is a finer spray. However, it is not always clear precisely how surfactants are producing their beneficial effects on herbicidal activity under spray application conditions (van Toor et al., 1994). As phytotoxicity is only the end result, this effect must arise from substantial improvements in the efficiency of one or more of the preceding stages, namely spray atomization, spray retention, target coverage, foliar uptake of active ingredient and for systemic herbicides, also translocation (van Toor et al., 1994).

Type of surfactant can affect the uptake of herbicides. Reichers et al. (1995) found that enhancement of foliar glyphosate uptake in common lambsquarters

(*Chenopodium album*) by cationic amine surfactants is responsible for preferentially increasing glyphosate efficacy when compared to its use with nonionic surfactants. Wall et al. (1995) found that thifensulfuron was more phytotoxic to canola when applied with Merge, a 50% surfactant blend and 50% petroleum hydrocarbon solvents, than with Agral 90, a nonionic spreader and activator, at recommended adjuvant concentrations (1% and 0.2% v/v, respectively). Kudsk and Mathiassen (1993) found that tribenuron activity on canola was significantly enhanced when nonionic nonyl-phenol polyoxyethylene surfactants with ethylene oxide contents of 15 (NP15) and 30 (NP30) were used, as compared to nonionic nonyl-phenol polyoxyethylene surfactants with ethylene oxide contents of 6 (NP6) and 9 (NP9). Retention on difficult-to-wet leaf surfaces is greatly influenced by the dynamic surface tension of the spray solution. Differences in the dynamic surface tensions of the surfactants can be expected to influence retention on the highly water-repellent canola, and therefore explain the improved activity of tribenuron when mixed with NP15 and NP30 (Kudsk and Mathiassen, 1993).

2.4 THE HERBICIDES:

2.4.1 MCPA ESTER

MCPA (2-methyl-4-chlorophenoxyacetic acid) is a systemic herbicide that is absorbed through foliage and roots and is translocated to actively growing areas within the plant (Holly, 1952). Symptoms include bending and twisting of leaves and stems within 2 to 7 days after application, followed by browning and plant death 3 to 4 weeks after application (Manitoba Agriculture and Food, 2002). In the Canadian System of Herbicide Classification, MCPA is classified as a Group 4 herbicide.

2.4.1.1 MECHANISM OF ACTION

The mechanism of action of MCPA is not completely understood but is similar to that of endogenous auxin, indoleacetic acid (IAA) and other auxin type herbicides (WSSA Herbicide Handbook, 1994). The specific cellular or molecular binding site relevant to the action of IAA and the auxin type herbicides has not been identified. Nevertheless, the primary action of these compounds appears to involve cell wall plasticity and nucleic acid metabolism. It is thought that MCPA acidifies the cell wall by stimulating the activity of a membrane bound ATPase proton pump. The reduction in appoplasmic pH induces cell elongation by increasing the activity of enzymes responsible for cell wall loosening. Low concentrations of MCPA also stimulate RNA polymerase , resulting in subsequent increases in RNA , DNA, and protein biosynthesis (WSSA Herbicide Handbook, 1994). Abnormal increases in these processes presumably lead to an uncontrolled cell division and growth, which results in vascular tissue destruction. In contrast, high concentrations of MCPA and other auxin type herbicides inhibit cell division and growth, usually in meristematic regions that accumulate photosynthate assimilates and herbicide from the phloem. MCPA and other auxin type herbicides stimulate ethylene evolution, which may in some cases produce the characteristic epinastic symptoms associated with exposure to these herbicides (WSSA Herbicide Handbook, 1994).

2.4.1.2 SYMPTOMS

There are several symptoms in plants associated with the use of MCPA. The symptoms are typical of the other auxin type herbicides. Symptoms include epinastic bending and twisting of stems and petioles, stems swelling (especially at the nodes) and elongation, and leaf cupping and curling. Leaf shape and venation often appear abnormal. These symptoms are followed by chlorosis at the growing points, growth inhibition, wilting and necrosis (WSSA Herbicide Handbook, 1994). Death of susceptible plants usually occurs within three to five weeks.

2.4.1.3 ABSORPTION

MCPA is readily absorbed into leaves. MCPA esters penetrate cuticles more rapidly than amine formulations. MCPA applied as a salt is protonated in the acidic environment outside the plasmalemma, and readily penetrates the plasmalemma as the protonated acid (WSSA Herbicide Handbook, 1994). Once inside the cell, the more alkaline cytoplasm causes dissociation to produce MCPA anion, which is trapped inside the cell due to its reduced ability to pass through the plasmalemma.

2.4.1.4 TRANSLOCATION

MCPA is among the more mobile phenoxy herbicides. It is transported in plant tissues primarily via the symplastic pathway (including the phloem) and accumulates at the growing points. Translocation rates in tolerant species appear to be slower, perhaps because of the formation of immobile complexes, reduced xylem transport, and anatomical differences among species (WSSA Herbicide Handbook, 1994).

2.4.1.5 METABOLISM

MCPA esters are hydrolyzed rapidly to yield MCPA acid. The 2-methyl group is hydroxylated to form (4-chloro-2-hydroxymethylphenoxy) acetic acid, which can then be conjugated to glucose (WSSA Herbicide Handbook, 1994). Formation of the glucose ester of MCPA has also been reported, as well as conjugates with aspartic acid and perhaps other amino acids. Similar metabolites were identified in callus cells of wheat. After 24 hours, the primary metabolite (49 %) was the glycoside of (4-chloro-2-

hydroxymethylphenoxy) acetic acid with very little unmetabolized MCPA remaining (WSSA Herbicide Handbook, 1994).

2.4.1.6 FACTORS AFFECTING EFFICACY

MCPA can be applied at lower rates (0.28 to 0.45 L/acre) when weeds are small (2 to 4 leaf stage) and actively growing. Higher rates (0.45 to 0.71 L/acre) are needed when weeds are larger, in heavy populations, or growing under stressful environmental conditions (i.e. excessive cold, hot, dry or wet). Lower rates (0.28 to 0.45 L/acre) may be applied in late fall to control winter annual weeds (Manitoba Agriculture and Food, 2002).

When using MCPA, the best weed control occurs when temperatures are about 21°C during the day or 10°C during the night and humidity is above 70 % (Manitoba Agriculture and Food, 2002). MCPA should not be applied if temperatures exceed 27°C. Extremely hard water may reduce performance or cause problems in spraying the product (Manitoba Agriculture and Food, 2002). Rainfall within 2 hours of MCPA ester application will reduce efficacy.

2.4.2 GLYPHOSATE

Glyphosate (*N*-phosphonomethylglycine) is a nonselective, systemic herbicide that moves from treated foliage into roots and kills the entire plant. Visual effects include gradual wilting and yellowing of the plant that advance to complete browning of the above ground growth and deterioration of underground plant parts. Effects may not be visible for 7 to 10 days after application (Manitoba Agriculture and Food, 2002). In the Canadian System of Herbicide Classification, glyphosate is classified as a Group 9 herbicide.

2.4.2.1 MECHANISM OF ACTION

Glyphosate inhibits EPSP (5-enolpyruvoylshikimate 3-phosphate) synthase, which is a key enzyme involved in aromatic amino acid biosynthesis. EPSP synthase (EPSPS) catalyzes the formation of EPSP from phosphoenolpyruvate (PEP) and shikimate 3-phosphate (S3P) (Franz et al, 1997). The EPSPS reaction is the penultimate step in the shikimic acid pathway, which produces the important branch point intermediate, chorismate, from *D*-glucose via erythrose 4-phosphate. Chorismate is required for the biosynthesis of a wide variety of aromatic plant metabolites, including the essential aromatic amino acids (phenylalanine, tyrosine, and tryptophan) as well as tetrahydrofolate, ubiquinone and vitamin K (Franz et al, 1997). Phenylalanine is used in protein synthesis and as a substrate for the phenylpropanoid pathway, which produces numerous secondary plant products such as anthocyanins, lignin, growth promoters, growth inhibitors and phenolics. Tyrosine and tryptophan are also required for protein synthesis. In addition, the plant hormone indoleacetic acid (IAA), is derived from tryptophan and is necessary for cell expansion, maintenance of apical dominance, and many other regulatory processes.

2.4.2.2 SYMPTOMS

Visual effects include gradual wilting and yellowing of the plant, which advance to complete browning of the above ground growth and deterioration of underground plant parts. Effects may not be visible for 7 to 10 days after application.

2.4.2.3 ABSORPTION

When environmental conditions are favorable, glyphosate is rapidly absorbed by plant foliage (Franz et al, 1997). Glyphosate has initial rapid entry into the plant.

However, this rapid entry is followed by a much longer phase of slower uptake. An excellent example of the slower uptake phase is reported in Franz et al. (1997). In one experiment, 34% of glyphosate applied to quackgrass (*Agropyron repens* L.) leaves had penetrated within four hours. However, absorption of the glyphosate reached a maximum of 53% over the next 44 hours. There are several factors that influence the mode and extent of uptake of glyphosate. These factors are plant characteristics (species, growth stage, cuticular properties) environmental conditions (water status, light, and temperature), the concentration of glyphosate and adjuvant(s) used in the formulations and the method of application. De Ruiter and Meinen (1998) report greenhouse and growth chamber experiments that demonstrate lowering soil moisture (water status) can strongly reduce the efficacy of glyphosate in barnyard grass (*Echinochloa crus-galli* L.), cogongrass (*Imperata cylindrical* L.), common milkweed (*Asclepias syriaca* L.), johnsongrass (*Sorghum halepense* L.) and purple nutsedge (*Cyperus rotundus* L.). These studies show a reduced glyphosate efficacy because foliar absorption and translocation are reduced. Adkins and his colleagues (1998) conducted greenhouse experiments to determine the effects of soil moisture content, irradiance, temperature and relative humidity on the efficacy of glyphosate applied to 6 isogenic lines of wild oat (*A. fatua*). The efficacy of 360 g acid equivalent ha^{-1} glyphosate was greatest under well watered (100% of field capacity), warm (30/25 °C day/night) and humid (>92% R.H. day/90% R.H. night) conditions. The efficacy of 360 g acid equivalent ha^{-1} glyphosate was least under severe water stress (29% of field capacity) warm (30/25 °C day/night) and moderately humid (65% R.H. day/60% R.H. night) conditions. The efficacy was not altered by the level of irradiance nor was there a difference in efficacy between isogenic lines.

2.4.2.4 TRANSLOCATION

Usually glyphosate is rapidly translocated in most plants. It is because of this rapid translocation that glyphosate acts primarily as a systemic herbicide. After glyphosate is taken up by plant foliage, it undergoes transport in the aqueous environment between cells, within cell walls, and in the xylem tissue. It is possible that glyphosate can be absorbed by plant roots. However, it is highly unlikely because most soils rapidly inactivate glyphosate. As a result of its ability to penetrate cell membranes, glyphosate readily enters the symplast and is extensively translocated throughout plants via the phloem sieve tubes. Glyphosate can also undergo symplastic cell to cell translocation via the plasmodesmata, which interconnect most cells (Franz et al, 1997).

2.4.2.5 METABOLISM

It is well-documented that glyphosate is very efficacious. This high activity is believed to be due to glyphosate's high water solubility (salts), it's anionic character, a slow mechanism of action, and a lack of significant metabolism (Franz et al, 1997).

2.4.2.6 FACTORS AFFECTING EFFICACY

Glyphosate is available for sale under many product names. Glyphosate is registered for pre-seeding, summer fallow, in crop, pre-harvest, post harvest and shelterbelt weed control in Manitoba. Some products may be more effective under adverse conditions, but that benefit is reduced when applications are made under optimal conditions for activity (Manitoba Agriculture and Food, 2002). Hard or dirty water can reduce glyphosate efficacy. Using clean water at 23 to 45 L per acre of spray solution will provide acceptable weed control in most situations. Use of lower spray solution volumes will reduce control. Control will also be reduced if foliage is heavily covered with dust. Glyphosate is most effective when temperatures are near 20°C and when weeds are actively growing (Manitoba Agriculture and Food, 2002). A frost which kills more than 40 % of the above ground tissue will reduce control. Glyphosate should not be applied if rainfall is forecast at the time of application.

2.4.3 THIFENSULFURON:TRIBENURON (2:1)

Thifensulfuron:tribenuron (2:1) (Refine Extra) is a systemic herbicide that is absorbed through foliage and translocated to growing points within plants. Symptoms include discoloration (yellowing, purpling, reddening) of newest leaves and are visible in 1 to 3 weeks (Manitoba Agriculture and Food, 2002). In the Canadian System of Herbicide Classification, Refine Extra is classified as a Group 2 herbicide. Thifensulfuron's chemical nomenclature is 3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid. Tribenuron's chemical nomenclature is 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)methylamino]carbonyl]amino]sulfonyl]benzoic acid (Wall, 1994).

2.4.3.1 MECHANISM OF ACTION

Thifensulfuron:tribenuron (Refine Extra) inhibits acetolactase synthesis (ALS), also called acetohydroxyacid synthase (AHAS) a key enzyme in the biosynthesis of the branched-chain amino acids isoleucine, leucine and valine (WSSA Herbicide Handbook, 1994). Plant death results from events occurring in response to ALS inhibition, but the actual sequence of phytotoxic processes is not clear.

2.4.3.2 SYMPTOMS

Growth of treated plans is inhibited within a few hours after application. Injury symptoms usually appear one to two weeks later. Susceptible weeds can die 7 to 21 days later. Meristematic areas generally become chlorotic and necrotic, followed by a general foliar chlorosis and necrosis (WSSA Herbicide Handbook, 1994). There are other potential symptoms as a result of thifensulfuron:tribenuron (2:1) application. These others symptoms may include purpling of leaves, leaf death and vein discoloration.

2.4.3.3 ABSORPTION/TRANSLOCATION

Thifensulfuron:tribenuron (2:1) is rapidly absorbed by foliage and roots and translocates extensively in both the xylem and phloem after foliar applications with accumulation in meristematic areas (WSSA Herbicide Handbook, 1994).

2.4.3.4 METABOLISM

The mechanism of metabolism of tribenuron in plants is not known. However, it is known that non-susceptible species metabolize thifensulfuron quickly (WSSA Herbicide Handbook, 1994). For example, soybeans rapidly de-esterify thifensulfuron to the non-phytotoxic thifensulfuron acid. Wheat metabolizes thifensulfuron at a rate sufficient to create a half-life of three to four hours, producing the deesterified free acid as the major metabolite with smaller amounts of the *O*-demethylated sulfonylurea bridge cleavage yielding the thiophene sulfonamide and triazine amine (WSSA Herbicide Handbook, 1994).

2.4.3.5 FACTORS AFFECTING EFFICACY

Thifensulfuron:tribenuron (2:1) should be applied when cereal crops are between the 2 leaf stage and the flag leaf stage. Thifensulfuron:tribenuron (2:1) should be applied to young and actively growing weeds that are less than 10 cm in height or width

(Manitoba Agriculture and Food, 2002). Thifensulfuron:tribenuron (2:1) should not be applied to wheat, barley or oats that are stressed by severe weather conditions (frost, drought or water saturated soil) as crop injury may result (Manitoba Agriculture and Food, 2002). Rainfall within 4 hours of application may reduce control.

2.5 CONCLUSION

Wind, water volume, surfactant, plant surface, and type of herbicide all influence levels of and impact of herbicide drift. The objectives of this project are to characterize the effect of simulated herbicide drift of MCPA, glyphosate and thifensulfuron:tribenuron (2:1) on the growth and yield of canola and navy beans, and to consider the consistency of the effects of these herbicides on these two crops by conducting the study at two different sites in two different seasons. Currently, the amount of information available describing crop injury as a result of herbicide drift is minimal. This is because simulating herbicide drift is not easy. During an actual herbicide drift situation, the water in the spray solution evaporates as it is moving through the air (Wolf, 1999c). This increases the concentration of the herbicide in the spray droplet. Therefore, this simulated herbicide drift project may more accurately be describing the effects of sub-lethal dosages of MCPA ester, glyphosate and thifensulfuron:tribenuron (2:1) on canola and field beans. The information generated by this study could serve as a guideline for extension specialists and to advise growers on expected yield losses and management options following inadvertent injury to canola and navy beans as a result of herbicide drift.

3.0 MATERIALS AND METHODS

A field study was conducted during the summers of 2001 and 2002 to characterize the effect of simulated herbicide drift of MCPA, glyphosate and thifensulfuron:tribenuron (2:1) on the growth and yield of canola and navy beans. In order to evaluate the consistency of the effects of these products on these crops, the study was conducted at two different sites and in two different seasons.

3.1 FIELD SELECTION

The experiments were conducted at the Carman Research Station, in Carman, Manitoba, and at the Point in Winnipeg, Manitoba in 2001 and 2002. The soil series in Carman in 2001 is a Winkler clay. In Carman in 2002, the soil series is a Hibsin fine sandy loam. The soil series in Winnipeg is a Newdale clay loam. In 2001, the canola experiment in Carman was sown to land that was sown to wheat (*Triticum aestivum*) the previous year. In 2002, the canola in Carman was sown to land that was sown to oats (*Avena sativa*) the previous year. In Winnipeg, for both 2001 and 2002, the canola was sown to land that was summer fallowed the previous year.

In 2001, the field beans in Carman were sown to land that was sown to flax (*Linum usitatissimum*) the previous year. In Winnipeg, the beans were sown to land that was sown to winter wheat (*Triticum aestivum*) the previous year. In 2002, the beans in Carman were sown to land that was oat (*Avena sativa*) fallow the previous year. In Winnipeg, the beans were sown to land that was fallowed the previous year.

The experiments were each a randomized complete block design composed of 20 treatments and 4 replications. Individual plots were 1.8 meters wide and 5 meters long. Between each of the four replications, there was a two-meter alleyway. Land area of each plot for each site year was calculated to be 0.23 acres. An experimental layout diagram can be found in Appendix 7.20.

3.2 AGRONOMIC PRACTICES

Agronomic practices between the two crops differed. For each of the two crops, agronomic practices did not differ between years. Standard fertilizer and seeding rates were used in all site-years (Thomas et al, 1999). Herbicidal weed control in-crop was used when necessary.

3.2.1 CANOLA

In 2001, fertilizer was applied in Carman on May 18 and was incorporated the same day with a cultivator to a depth of 7.5 cm. The fertilizer (23-24-0) was broadcasted at a rate of 200 kg ha^{-1} with a 3-point hitch fertilizer spreader. The canola (cv. 46A65, Proven Seed, Winnipeg, MB, Canada) was seeded in Carman on May 26 with a 3-point hitch double-disc drill. The seeding rate was 6 kg ha^{-1}. This particular variety was chosen because it was a high yielding variety and it is not a genetically modified canola variety. A genetically modified canola variety was not used because of logistic reasons. The University of Manitoba has an extensive conventional canola breeding program and it was thought that a genetically modified canola variety could contaminate the breeder's canola during the time of pollination. If a genetically modified canola was going to be used, a different location would have been needed to ensure adequate separation. In order to combat pests (flea beetles) and seed diseases, the canola was treated with a seed treatment (Helix Xtra, Syngenta, Guelph, ON, Canada). The fungicide active ingredients, difenoconazole, metalaxyl-M, and fludioxonil protect the seed against seed rot, root rot, seedling blight, and damping off. The insecticide active ingredient thiamethoxam provides early season flea beetle protection (Syngenta Canada, 2003).

When the canola reached the 2 to 4 true leaf stage, if it was necessary to apply herbicides for weed control, a tank-mix of ethametsulfuron-methyl (Muster), clopyralid (Lontrel 360) and sethoxydim (Poast Ultra) was used. All herbicides were used at recommended label rates; Muster – 12 g/acre (22 g a.i. ha^{-1}), Lontrel – 0.34L/acre (302 g a.i. ha^{-1}), Poast Ultra – 0.27L/acre (300 g a.i. ha^{-1}). Merge (adjuvant) was used at a rate of 1% v/v. This tank-mix was sprayed on June 14, 2001 with an ATV-mounted sprayer set to apply spray solution at a rate of 110 L ha^{-1} at 275 kpa. However, a strong wind and the immanent chance of rain were not favorable for herbicide application. Environmental conditions were as follows: temperature – 15°C, relative humidity – 92%, wind speed – 24-33 km/h, wind direction – N, and % cloud cover – 100%. It rained approximately 30 minutes after application. Of the herbicides included in this in-crop tank-mix, Poast Ultra has the shortest rainfast period. Rainfall within one hour of application may reduce weed control (Manitoba Agriculture and Food, 2002). Because of the rainfall event approximately 30 minutes after the herbicide application, a re-spray was necessary. The re-spray took place on June 16, 2001. The same herbicides and same herbicide application rates were used as on June 14. The canola was in the three to four leaf stage at the time of the re-spray and environmental conditions were as follows: temperature – 11°C, relative humidity – 79%, wind speed – 19 km/h, wind direction – NNW, and % cloud cover – 10%.

In 2001, the canola (cv. 46A65) was seeded in Winnipeg on May 30. The seeding rate was 6 kg ha^{-1}. The canola seed was treated as per 2001. Fertilizer was applied in

Winnipeg on May 31 and was not incorporated the same day with a cultivator because the plot was seeded already. Fortunately, Winnipeg received a rainfall event later that day and the next morning which helped to move the fertilizer into the soil. The fertilizer (23-24-0) was broadcasted at a rate of 200 kg ha^{-1} with a 3-point hitch fertilizer spreader. For this particular site-year, a herbicide application for general weed control was not necessary because there was very low weed pressure. Rather than applying an in-crop herbicide application, weeds between the plots and in the alleys were hand weeded on July 10, 2001.

In 2002, the same basic procedures were followed as in 2001. In Carman, the canola plots were fertilized on May 11. Fertilizer (23-10-5) was broadcasted with a wheelbarrow type turf-grass fertilizer spreader and was spread at a rate of 200 kg ha^{-1}. The fertilizer was incorporated the same day with a field cultivator to a depth of 7.5 cm. In 2002, canola (cv. 46A65) (seed treated with Helix, Syngenta, Guelph, ON, Canada) was seeded on May 24 at 7 kg ha^{-1} with a 3-point hitch double-disc drill. In Winnipeg, fertilizer (23-10-5) was broadcasted at a rate of 200 kg ha^{-1} using a wheelbarrow type turf-grass fertilizer spreader on May 17 and was incorporated the same day with a field cultivator to a depth of 7.5 cm. The canola (cv. 46A65) was seeded on May 18 with a 3-point hitch double-disc drill.

In 2002, the canola experiment in Carman was sprayed for general weed control on June 20. A tank-mix of Muster (22 g a.i. ha^{-1}), Lontrel (302 g a.i. ha^{-1}), and Poast Ultra (300 g a.i. ha^{-1}), was used. Environmental conditions on June 20 were as follows: temperature – 19°C, relative humidity – 70%, wind speed – 28 km/h, wind direction –

SW, and % cloud cover – 0%. The herbicides used in 2002 came from the same source containers as the herbicides that were used in 2001.

A second herbicide application for green foxtail (*Setaria viridis* L.) was necessary in the canola experiment at Carman on July 11 because of persistant weed pressure. It is suspected that the green foxtail infestation at Carman was Group 1 resistant. As such, clethodim ("Select") and sethoxydim ("Poast Ultra") were used in a tank-mix at a rate of 0.080 L/acre or 47 g a.i. ha^{-1} Select and Poast Ultra at a rate of 0.45 L/acre or 500 g a.i. ha^{-1} and Merge at a rate of 1% v/v. The re-spray of the sethoxydim and the clethodim had a minimal effect on the green foxtail. Seeds from the mature green foxtail plants were collected and tested. They were found to be resistant to Group 1 herbicides (Lyle Friesen, Personal Communication).

The canola experiment in Winnipeg was sprayed for general weed control on June 21, 2002. A tank-mix of Muster (22 g a.i. ha^{-1}),, Lontrel (302 g a.i. ha^{-1}), and Poast Ultra (300 g a.i. ha^{-1}), was used again. Environmental conditions on June 21 were as follows: temperature – 22°C, relative humidity – 63%, wind speed – 9 km/h, wind direction – S, and % cloud cover – 10%.

3.2.2 FIELD BEANS

In 2001 at Carman, the fertilizer (23-24-0) was broadcasted on May 22 at a rate of 200 kg ha^{-1} with a 3-point hitch fertilizer spreader. Trifluralin (Treflan EC) was applied to the bean experiment in Carman on May 24, 2001. Trifluralin was applied at a rate of 0.93L/acre (1103 g a.i. ha^{-1}) with a bicycle plot sprayer set to apply spray solution at a rate of 110 L ha^{-1} at a pressure of 275 kpa. Field conditions were too wet to allow incorporation of either the fertilizer or the trifluralin with a field cultivator, therefore incorporation was done with harrows to a depth of 5cm. In Winnipeg, trifluralin was applied to the bean experiment on May 29 at the 1103 g a.i. ha^{-1} rate with an ATV-mounted sprayer, applying the spray solution at a rate of 110 L ha^{-1} at a pressure of 275 kpa. The trifluralin was incorporated the same day with a field cultivator to a depth of 7.5 cm.

Beans (cv. Envoy, Aggasiz Seed Farms, Homewood, Manitoba, Canada) were seeded in Carman on May 25 with a 3-point hitch double-disc drill at a rate of 53 kg ha^{-1}. The beans were treated with DCT (Diazinon Captan Thiophanate methyl, Norac Concepts Inc., Ottawa, Ontario, Canada). Envoy was chosen as the bean variety because it is a high yielding variety and it is popular in southern Manitoba.

Beans were seeded in Winnipeg on May 30 with a 3-point hitch double-disc drill at a rate of 53 kg ha^{-1}. Fertilizer was applied in Winnipeg on May 31 and was not incorporated the same day with a cultivator because the plot was seeded already. Winnipeg received a rainfall event later that day and the next morning which would have helped to move the fertilizer into the soil. The fertilizer (23-24-0) was broadcasted at a rate of 200 kg ha^{-1} with a 3-point hitch fertilizer spreader. In Winnipeg in 2001, the emerged bean density was low, and therefore a second experiment was seeded (called the late-seeded experiment at Winnipeg). For this second experiment, trifluralin and fertilizer (23-24-0) were applied on June 11, 2001 at the same rates as for the first experiment (now called the early-seeded experiment at Winnipeg). For the late-seeded experiment, the beans were planted on June 12 using the cone attachment on the 3-point hitch double-disc drill. This helped the beans flow through the seeder and helped to increase the resulting stand.

When the beans reached the 2 to 3 trifoliate leaf stage, if it was necessary to spray for weed control, the herbicide bentazon (Basagran) with the adjuvant "Assist" was used. Approximately four days later, sethoxydim (Poast Ultra) was applied. This four-day period allowed the beans to recover from the bentazon application, as is recommended practice (Manitoba Agriculture and Food, 2001). All herbicides were applied at recommended label rates; Basagran – 0.91L/acre (1079 g a.i. ha^{-1}), and Assist – 0.74L ha^{-1} and Poast Ultra – 300 g a.i. ha^{-1} and Merge - 0.74L ha^{-1}. The Basagran was sprayed on June 14, 2001 in Carman with an ATV-mounted sprayer set to apply spray solution at a rate of 110 L ha^{-1} at a pressure of 275 kpa. However, weather conditions were not favorable for herbicide application. Environmental conditions were as follows: temperature – 15°C, relative humidity – 92%, wind speed – 24-33 km/h, wind direction – N, and % cloud cover – 100%. It rained approximately 30 minutes after application. Basagran has a rainfast period of six to eight hours (Manitoba Agriculture and Food, 2002). Because of the rainfall event approximately 30 minutes after the herbicide application, a re-spray was necessary. The re-spray took place on June 16, 2001. A tank mix of bentazon (Basagran), and sethoxydim (Poast Ultra) was used. All herbicides were used at recommended label rates; Basagran – 1079 g a.i. ha^{-1}, and Poast Ultra – 300 g a.i. ha^{-1}. Merge was used at a rate of 0.5% v/v. This is not a registered tank mix but it will work to control grass and broadleaf weeds in beans (Scott Chapman, BASF, personal communication). At the time of the herbicide application, the beans were in the 2 - 3 trifoliate leaf stage and environmental conditions were as follows: temperature – 11°C, relative humidity – 79%, wind speed – 19 km/h, wind direction – NNW, and % cloud cover – 10%.

In Winnipeg, the beans were not sprayed for weed control in either the early or late-seeded experiments because weed pressure was very low. Later in the growing season, Canada thistle (*Cirsium arvense* L.), perennial sow thistle (*Sonchus arvensis*), annual sow thistle (*Sonchus oleraceus* L.) and dandelion (*Taraxacum officinale* Weber in Wiggers) became weed problems. On June 28, these weeds were spot sprayed using glyphosate (10%v/v) applied with a hand-held spray bottle. These weeds were controlled in the late-seeded bean trial in Winnipeg using the same technique on June 29.

In 2002, the same procedures were followed as in 2001. In Carman, the bean experiment was fertilized on June 4. Fertilizer (23-10-5) was broadcasted with a wheelbarrow type turf-grass fertilizer spreader at a rate of 200 kg ha^{-1}. The fertilizer was incorporated the same day with a field cultivator to a depth of 7.5 cm. Trifluralin was applied on June 4 at a rate of 0.93L/acre (1103 g a.i. ha^{-1}), and was incorporated the same day with a field cultivator to a depth of 7.5 cm.

In Winnipeg in 2002, the bean experiment was fertilized on May 29, 2002. Fertilizer (23-10-5) was broadcasted with a wheelbarrow type turf-grass fertilizer spreader at a rate of 200 kg ha^{-1}. The fertilizer was incorporated the same day with a field cultivator to a depth of 7.5 cm. Trifluralin was applied on May 29 at a rate of 1103 g a.i. ha^{-1} and was incorporated the same day with a field cultivator to a depth of 7.5 cm.

In 2002, beans (cv. Envoy) were seeded at 53 kg ha^{-1} using the cone attachment on the 3-point hitch double-disc drill. The beans were seeded in Carman on June 4, 2002 and in Winnipeg on May 30, 2002. In 2002, the beans experiments in Carman and in Winnipeg were not sprayed for general weed control. These experiments were hand-weeded throughout the season.

3.3 HERBICIDE TREATMENT APPLICATION

Constant carrier volumes do not necessarily accurately reproduce physical drift of herbicides because concentration in the carrier is reduced for each incremental reduction in dose (Banks and Schroeder, 2002). In this project, the carrier volume used remained constant while the herbicide dose varied. This is because it is far more convenient to use only one carrier volume when conducting a simulated drift study than to change carrier volume delivery for each herbicide dose being evaluated (Banks and Schroeder, 2002). The additional time needed to calibrate equipment for each dose, the variable wind conditions during application that can cause very low carrier volumes to drift, and the need for buffer rows between plots to avoid off-plot movement are all reasons for not changing carrier volume with herbicide dose (Banks and Schroeder, 2002).

For all site-years, distilled water was used when mixing the herbicide solutions. Because of very low herbicide doses, it was desirable to use distilled water to prevent minerals in the water from tying up the herbicide molecules. All herbicides were applied with a bicycle plot sprayer using standard 80015 flat fan nozzles and application pressure was 275 kpa to produce a spray solution application rate of 110 L ha^{-1}.

Rates chosen to simulate herbicide drift were based on information in the literature, experience of L. Friesen and R. Van Acker and limited tests conducted in growth rooms (data not shown) in order to create a rate range for each herbicide and each crop that could produce a complete dose response. The calculations for determining the proportions of the herbicide rates used in each 2L pop bottle for 2001 are shown in Appendix 7.21. The calculations for 2002 are shown in Appendix 7.22.

In 2001, the herbicide treatments (Table 3.1) were applied to the canola experiment in Carman on June 20. Environmental conditions on June 20 were: temperature – 18.5°C, relative humidity – 55%, wind speed – 4 km/h, wind direction – NNE and percentage cloud cover – 40%. The herbicide treatments were applied to the canola experiment in Winnipeg on June 27. Environmental conditions were as follows: temperature – 17°C, relative humidity – 82%, wind speed – 24 km/h, wind direction – NE and % cloud cover – 75%.

Table 3.1. Herbicide rates used to simulate drift of MCPA ester, glyphosate or thifensulfuron:tribenuron (2:1) on canola in 2001. Registered field rate of each herbicide is also included.

Rate #	MCPA ester (g ae ha^{-1})	Glyphosate (g ae ha^{-1})	Thifensulfuron: tribenuron (2:1) (g ai ha^{-1})
1	0	0	0
2	25	13	0.01
3	50	25	0.05
4	100	50	0.15
5	150	100	0.5
6	280	200	2
Field Rate	280	440	15

In 2002, the herbicide treatments (Table 3.2) were applied to the canola experiment in Carman on June 17. Environmental conditions on June 17 were not recorded. The herbicide treatments were applied to the canola experiment in Winnipeg on June 14. Environmental conditions were as follows: temperature – 22°C, relative humidity – 54%, wind speed – 24 km/h, wind direction – NNE and % cloud cover – 75%.

In 2001, the herbicide treatments (Table 3.3) were applied to the bean experiment in Carman on June 20. Environmental conditions on June 20 were: temperature –

Table 3.2. Herbicide rates used to simulate drift of MCPA ester, glyphosate or thifensulfuron:tribenuron (2:1) on canola in 2002. Registered field rate of each herbicide is also included.

Rate #	MCPA ester (g ae ha^{-1})	Glyphosate (g ae ha^{-1})	Thifensulfuron: tribenuron (2:1) (g ai ha^{-1})
1	0	0	0
2	25	13	0.05
3	50	25	0.15
4	100	50	0.5
5	150	100	0.8
6	280	200	2
Field Rate	280	440	15

18.5°C, relative humidity – 55%, wind speed – 4 km/h, wind direction – NNE and % cloud cover – 40%. The herbicide treatments were applied to the early seeded bean experiment in Winnipeg on June 27. Environmental conditions were as follows: temperature – 17°C, relative humidity – 82%, wind speed – 24 km/h, wind direction – NE and % cloud cover – 75%. The herbicide treatments were applied to the late seeded bean experiment in Winnipeg on June 30. Environmental conditions were as follows:

Table 3.3. Herbicide rates used to simulate drift of MCPA ester, glyphosate or thifensulfuron:tribenuron (2:1) on field beans in 2001. Registered field rate of each herbicide is also included.

Rate #	MCPA ester (g ae ha^{-1})	Glyphosate (g ae ha^{-1})	Thifensulfuron: tribenuron (2:1) (g ai ha^{-1})
1	0	0	0
2	50	30	0.3
3	100	60	1
4	280	125	3
5	560	250	6
6	1120	500	12
Field Rate	280	440	15

temperature – 10°C, relative humidity – 78%, wind speed – 25 km/h, wind direction – N and % cloud cover – 75%.

In 2002, the herbicide treatments (Table 3.4) were applied to the bean experiment in Carman on June 28. Only the glyphosate treatments were applied in Carman in 2002 because the rest of the experiment was lost to flooding. Environmental conditions on June 28 were: temperature – 24°C, relative humidity – 65%, wind speed – 24 km/h, wind direction – SSW and % cloud cover – 20%. The herbicide treatments were applied to the bean experiment in Winnipeg on June 26. Environmental conditions were as follows: temperature – 27°C, relative humidity – 60%, wind speed – 13 km/h, wind direction – W and % cloud cover – 15%.

Table 3.4. Herbicide rates used to simulate drift of MCPA ester, glyphosate or thifensulfuron:tribenuron (2:1) on field beans in 2002. Registered field rate of each herbicide is also included.

Rate #	MCPA ester[a] (g ae ha^{-1})	Glyphosate (g ae ha^{-1})	Thifensulfuron: tribenuron (2:1)[b] (g ai ha^{-1})
1	0	0	0
2	50	30	1
3	100	60	3
4	280	90	6
5	560	125	12
6	1120	250	20
Field Rate	280	440	15

[a] Herbicide not applied to beans in Carman in 2002.
[b] Herbicide not applied to beans in Carman in 2002.

In both 2001 and 2002, the simulated herbicide drift treatments were generally applied at least 24 hours prior to a rainfall event. On June 27, 2001 in Winnipeg, a rainfall event of 25 mm occurred later in the day that the simulated herbicide drift treatments were applied to the canola and early-seeded bean experiment (refer to

Appendix 7.5). On June 18, 2002, there was also a very small rainfall event (0.4mm) 24 hours after the simulated herbicide drift treatments were applied to the canola in Carman (refer to Appendix 7.8).

3.4 DATA COLLECTION

In order to fully understand the effect of simulated herbicide drift of MCPA, glyphosate and thifensulfuron:tribenuron (2:1) on the growth and yield of canola and navy beans, several different measurements were taken throughout the growing season. The measurements were visual injury (scale of 0-100), biomass (g plant^{-1}), density (plants m^{-2}), pods/plant, yield (g ha^{-1}), seeds/pod and thousand kernel weight (g). These measurements were taken in the canola and beans experiments in both 2001 and 2002.

Visual injury ratings were taken approximately two to three weeks after the simulated herbicide drift treatments were applied. Visual injury ratings were based on an efficacy scale ranging from 0 to 100 %, where 0 is equal to no visible symptoms and 100 is complete plant mortality.

Above ground biomass samples were taken approximately 14 to 21 days after treatments were applied. Biomass samples were taken by clipping crop plants at ground level within quadrats set within each plot. For canola in 2001, biomass was collected from within two 0.25 m^2 quadrats per plot. Low coefficients of variation on biomass samples in 2001 meant that in 2002 biomass samples were collected from only one 0.25 m^2 quadrat per plot. In both 2001 and 2002 (in both Carman and Winnipeg), a full m^2 of plant material was taken to measure above ground bean shoot biomass in both Carman and Winnipeg. For both canola and beans, harvested plant material was placed in paper bags and the number of plants harvested per plot was recorded and converted to density

m^{-2}. The paper bags were placed in a drying oven at 80°C for approximately seven days. After the seven days, the bags were removed from the drying oven and the dry plant material was weighed. Dry biomass was calculated on a g $plant^{-1}$ rather than g m^{-2} because stand density was variable among plots.

Just before canola was ready to swath, pods were counted. In 2001, five random plants were selected from each plot and the number of pods on each of those plants were counted. In 2002, 10 random canola plants were selected from each plot and pods were counted on these plants. In 2001 and 2002, five random bean plants were selected from each plot and pods were counted on these five plants. Bean pod counts were done just as beans were beginning to senesce. At this point, the beans are no longer producing new pods.

Harvest methods in 2001 and 2002 were the same for the canola in Winnipeg and Carman. Harvest methods in 2001 and 2002 were the same for the beans in Winnipeg and Carman. In 2001 and 2002, canola in the remainder of the plot (i.e. subtract the area used for biomass sampling from the whole plot area) was hand-swathed using sickles. Canola is considered ready for swathing when approximately 30% of the seeds on the main stem have turned from green to brown (Manitoba Agriculture and Food, 2002). The cut plant material was laid in a swath in order to mature. Each individual canola plot had to be monitored separately for appropriate time for swathing because the various herbicide treatments caused differences in crop maturity (Table 4.8). The plots to which the lowest doses of each herbicide were applied matured faster than the plots to which the higher doses had been applied.

Combining the canola swaths started approximately 14 to 21 days after the last of the plots had been swathed. By doing this, all of the plots could be combined on the same day. The plots were combined with a Wintersteiger (Wintersteiger Nursery Master Elite, Saskatoon, Saskatchewan, Canada) plot combine and the seeds from the swaths were collected in paper bags. These bags were placed in a drying room at 25°C for approximately two weeks. After this drying period, the seeds were screened for dockage. Dockage was removed using a Carter dockage tester, following the method of the Canadian Grain Commission (1991). Crop yield after removal of dockage was expressed as a percentage of the dockage-free untreated control for each site-year.

In 2001 and 2002, the beans were left in the field until the plants had almost totally dried and some of the pods had just started to split open. Two full m^2 were clipped at ground level in each plot. The plant biomass was put into burlap sacks and these sacks were hung in a drying room at 25°C for approximately two weeks. After the two-week drying period, the sacks were placed outside for approximately one day so the beans could imbibe some moisture in order to prevent cracking of the seeds during threshing. To minimize seed damage during threshing, beans should be combined when the seed is at a moisture content of 16-22 % (Manitoba Agriculture and Food, 2002). After the day outside, the beans were threshed using a plot combine and the seeds were collected in paper bags. The paper bags were then taken back to the drying room and left for 2 weeks at 25°C. After drying, the bean seeds were screened for dockage using a Clipper mechanical sieve until only whole seeds and cracked seeds were left. The bean seeds were weighed. Crop yield after removal of dockage was expressed as a percentage of the dockage-free untreated control for each site-year. Dockage dry weight was not recorded.

Table 3.5. Dates for fertilizer application, seeding, herbicide application for general weed control, simulated herbicide drift application, visual injury estimates, biomass sampling, # of pods/plant counted, swathing, threshing, yield measurements, # of pods/plant and thousand kernel weights for canola in 2001 and 2002.

	CAR01[a h]	WPG01[b]	CAR02[c]	WPG02[d]
Fert. Appl.	May 18	May 31	May 11	May 17
Seeding	May 26	May 30	May 24	May 18
Herb. App. 1	June 14	-[e]	June 20	June 21
Herb. App. 2	June 16	-	July 11	-
Trt. Appl.	June 20	June 27	June 17	June 14
Visual	July 1	July 1	July 3	July 3
Biomass	July 4	July 10	July 9	July 4
Pods/Plant 1[f]	August 14	August 16	August 12	August 6
Pods/Plant 2	August 15	August 28	August 23	August 16
Pods/Plant 3	August 27	September 12	August 30	August 26
Pods/Plant 4	September 13	-	-	-
Swathing 1[g]	August 14	August 16	August 13	August 6
Swathing 2	August 15	August 28	August 23	August 16
Swathing 3	August 27	-	August 30	August 26
Swathing 4	September 10	-	-	-
Swathing 5	September 13	-	-	-
Threshing	September 13	September 12	September 16	September 13
Yield	September 27	September 28	September 30	October 1
Seeds/Pod	September 27	September 28	September 30	October 1
TKW	September 27	September 28	September 30	October 1

[a] CAR01 represents the Carman site in 2001.
[b] WPG01 represents the Winnipeg site in 2001.
[c] CAR02 represents the Carman site in 2002.
[d] WPG02 represents the Winnipeg site in 2002.
[e] A dash (-) represents a date when the operation or measurement did not take place.
[f] The dates listed for Pods/Plant 1 represent the first date that pod counts started.
[g] The dates listed for Swathing 1 represent the first date that swathing started.
[h] Variation in dates of activity among years is due to selection of timing on the basis of crop development stage and not a specific number of days after seeding.

Thousand kernel weights (g) of both canola and beans were calculated when the seeds were weighed to determine the final yield. An electronic seed counter was used to count

250 seeds per plot. These 250 seeds were weighed, and the weight was multiplied by 4 to determine thousand kernel weights (TKW).

Table 3.6. Dates for fertilizer application, trifluralin application, seeding, herbicide application for general weed control, simulated herbicide drift application, visual injury estimates, biomass sampling, # of pods/plant counted, hand harvesting, threshing, yield measurements, # of pods/plant and thousand kernel weights for field beans in 2001 and 2002.

	CAR01[a h]	WPG01A[b]	WPG01B[c]	CAR02[d]	WPG02[e]
Fertilizer Appl.	May 22	May 31	June 11	June 4	May 29
Trifluralin Appl.	May 24	May 29	June 11	June 4	May 29
Seeding	May 25	May 30	June 12	June 4	May 30
Herb. App. 1	June 14	June 28	June 29	-[f]	-
Herb. App. 2	June 16	-	-	-	-
Treatment Appl.	June 20	June 27	June 30	June 28	June 26
Visual	July 1	July 13	July 18	July 19	July 16
Biomass	July 5	July 13	July 16	July 19	July 18
Pods/Plant 1[g]	September 14	September 20	September 27	September 12	September 5
Pods/Plant 2	-	-	September 28	September 25	September 19
Cutting	September 27	September 29	September 29	September 27	September 26
Threshing	November 1	November 1	November 1	October 15	October 10
Yield	November 15	November 16	November 17	October 30	October 31
Seeds/Pod	November 15	November 16	November 17	October 30	October 31
TKW	November 15	November 16	November 17	October 30	October 31

[a] CAR01 represents the Carman site in 2001.

[b] WPG01A represents the early-seeded Winnipeg site in 2001.

[c] WPG01B represents the late-seeded Winnipeg site in 2001.

[d] CAR02 represents the Carman site in 2002.

[e] WPG02 represents the Winnipeg site in 2002.

[f] A dash (-) represents a date when the operation or measurement did not take place.

[g] The dates listed for Pods/Plant 1 represent the first date that pod counts started.

[h] Variation in dates of activity among years is due to selection of timing on the basis of crop development stage and not a specific number of days after seeding.

Once the number of seeds per pod, final yield and thousand kernel weights were determined, the number of seeds per pod was calculated. The number of seeds per pod was calculated using the formula

$$((\text{yield}*1000)/\text{TKW}))/((\text{pods/plant})*\text{density})) \tag{3.1}$$

A summary of the timeline of important agronomic dates and dates when measurements were taken in each site-year in the canola experiments are shown in Table 3.5.

A summary of the timeline of important agronomic dates and dates when measurements were taken in each site-year in the bean experiments are shown in Table 3.6.

3.5 STATISTICAL ANALYSIS

For both canola and beans, correlation between measurements taken throughout the field season were determined using (PROC CORR) in SAS (Version 8.2). A correlation between characteristics was noted when the correlation coefficient was greater than 0.5. The correlation analysis was used to suggest strong relationships between variables, not as a measure of statistical significance. Those correlation coefficients between 0.8 and 1.0 were designated as being highly correlated. The correlation coefficients between 0.5 and 0.79 were designated as having a good correlation. The correlation coefficients of 0.49 and below were designated as being weak correlations.

Statistical analysis of the dose-response curves from the field experiments closely followed the procedure outlined by Seefeldt et al. (1995). Data initially were fitted to the log-logistic model

$$y = C + (D - C)/(1 + \exp(b(\ln(x) - \ln(I_{50})))) \tag{3.2}$$

where y = crop yield or shoot dry matter (percentage of untreated control), x = herbicide dosage (g ha^{-1}; a small positive value of 1.0 was assigned to 0 g ha^{-1} dosage to calculate natural logarithms), C = lower limit (asymptote) of the response curve, D = upper limit, b = slope, and I_{50} = dose (g ai ha^{-1} of the herbicide that reduced shoot dry matter by 50%

relative to the untreated control). The exp refers to *e* (the base of the natural logarithms) raised to the specified power, and ln is the natural logarithms. Individual curves were statistically tested systematically for common C and D, common b, and common I_{50} using the lack-of-fit F test at the 0.05 level of significance, as outlined by Seefeldt et al. (1995). Models for individual site-years were then combined when possible.

Data were fitted to the models using a derivative-free non-linear regression procedure (PROC NLIN) in SAS (Version 8.2). Coefficients of determination (R^2) were calculated as described by Kvalseth (1985) using the residual sum of squares value from the SAS output. As outlined by Seefeldt et al. (1995), SAS provides only one residual sum of squares value for the model as a whole, even though parameters for several functions are estimated simultaneously (Friesen et al., 2000). Standard deviations are presented rather than standard errors because the standard errors were too small to be seen on a figure. The standard error of a parameter estimate is a measure of confidence, and if it is large, the parameter is poorly estimated. A parameter estimate can be considered statistically significant at the 0.05 level if the standard error is less than half of the numerical value of the estimate (Koutsoyiannis, 1977).

Models not fitting the log-logistic model were analyzed using a linear model

$$y = mx + B \tag{3.3}$$

where y = crop yield or shoot dry matter (percentage of untreated control), x = the herbicide dose, m = slope, and B = y axis intercept. Data were fitted to the linear model using PROC GLM in SAS (Version 8.2). Data that did not fit either of these models was graphed as treatment means with error bars representing standard deviation.

4.0 RESULTS

4.1 GENERAL RESULTS

All three herbicides were used in the correlation analysis to attempt to draw some general conclusions about how various measured variables were correlated with one another (Table 4.1).

For canola, our results show that the variable RATE (herbicide rate) had a good correlation with the visual injury rating (VIS), biomass expressed as a percent of the untreated control (PBIO) and yield expressed as a percent of the untreated control (PYIELD). This did not hold true for field beans, where RATE did not have a good correlation with any of the other measured variables. The visual injury rating for both canola and beans was highly correlated with PBIO and PYIELD. One of the objectives of this experiment was to produce a scale or index for predicting yield loss due to drift based on visual injury ratings. This may be possible given that yield for both canola and field beans had a good correlation with the visual injury rating.

4.2 CANOLA

It was thought that the results presented for canola in Table 4.1 may be masking the effects of each individual herbicide. Based on visual monitoring of the field experiment throughout the field season, it was determined that glyphosate was the most active of the three herbicides. Therefore, further correlation was done after separating the data for glyphosate from that for MCPA and thifensulfuron:tribenuron (2:1) (Table 4.2). When glyphosate treatments were separated from the other two herbicide treatments, there was a much higher correlation of measured variables. RATE and VIS were highly correlated ($r = 0.93$). RATE and VIS had a good correlation for the MCPA and

Table 4.1. Correlation among measured variables expressed as a percent of untreated control for canola and field beans affected by simulated drift of MCPA, glyphosate or thifensulfuron:tribenuron (2:1). P values occur in parentheses below the correlation coefficients. Site-years have been combined.

Canola	RATE	VIS	PBIO	PPODNO	PYIELD	PSEDSPOD	PTKW
RATE[a]	1.00						
VIS[b]	**0.65**[h]	1.00					
	(<0.0001)						
PBIO[c]	**-0.52**	**-0.68**	1.00				
	(<0.0001)	(<0.0001)					
PPODNO[d]	-0.21	-0.20	0.09	1.00			
	(0.0003)	(0.0008)	(0.1413)				
PYIELD[e]	**-0.63**	**-0.70**	**0.65**	0.21	1.00		
	(<0.0001)	(<0.0001)	(<0.0001)	(0.0004)			
PSEDSPOD[f]	-0.49	-0.48	**0.61**	-0.05	**0.71**	1.00	
	(<0.0001)	(<0.0001)	(<0.0001)	(0.3837)	(<0.0001)		
PTKW[g]	-0.42	-0.17	0.14	0.40	0.27	0.18	1.00
	(<0.0001)	(0.0030)	(0.0172)	(<0.0001)	(<0.0001)	(0.0017)	

Beans	RATE	VIS	PBIO	PPODNO	PYIELD	PSEDSPOD	PTKW
RATE	1.00						
VIS	0.35	1.00					
	(<0.0001)						
PBIO	-0.29	**-0.71**	1.00				
	(<0.0001)	(<0.0001)					
PPODNO	-0.01	-0.10	0.17	1.00			
	(0.8694)	(0.0875)	(0.0020)				
PYIELD	-0.22	**-0.55**	0.47	0.32	1.00		
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)			
PSEDSPOD	-0.10	-0.16	0.06	-0.36	0.38	1.00	
	(0.0861)	(0.0063)	(0.2860)	(<0.0001)	(<0.0001)		
PTKW	-0.26	**-0.63**	**0.56**	0.18	**0.57**	0.07	1.00
	(<0.0001)	(<0.0001)	(<0.0001)	(0.0021)	(<0.0001)	(0.2106)	

[a] RATE represents herbicide rate.

[b] VIS represents visual injury rating.

[c] PBIO represents biomass expressed as a percent of the untreated control.

[d] PPODNO represents number of pods expressed as a percent of the untreated control.

[e] PYIELD represents final yield expressed as a percent of the untreated control.

[f] PSEDSPOD represents number of seeds per pod expressed as a percent of the untreated control.

[g] PTKW represents thousand kernel weight expressed as a percent of the untreated control.

[h] All variables with a correlation coefficient of (+/-) 0.50 or greater have been highlighted in bold. The number of observations used in calculating the majority of correlation coefficients for canola was 288. The minimum number of observations used in calculating any specific correlation coefficient for canola was 282 (due to missing values). The number of observations used in calculating the majority of correlation coefficients for field beans was 312. The minimum number of observations used in calculating any specific correlation coefficient for field beans was 301 (due to missing values).

thifensulfuron:tribenuron (2:1) treatments, but not as high as the glyphosate treatments (r = 0.56). For glyphosate treatments, RATE had a good correlation with PBIO (r = -0.71) and a high correlation with PYIELD (r = -0.81). The correlation between RATE and PBIO for the MCPA and thifensulfuron:tribenuron (2:1) treatments was weak (r = -0.43). There was a good correlation between RATE and PYIELD (r = -0.57), but it was not as high as it was for the glyphosate treatments.

The visual injury ratings and the biomass expressed as a percent of the untreated control had a good correlation for both glyphosate treatments alone (r = -0.77) and for MCPA and thifensulfuron:tribenuron (2:1) treatments combined (r = -0.66). The visual injury ratings and the final yield expressed as a percent of the untreated control were also highly correlated for glyphosate treatments alone (r = -0.88) and had a good correlation for MCPA and thifensulfuron:tribenuron (2:1) treatments combined (r = -0.64). This may be a good indicator that yield loss can be accurately predicted by visual injury ratings taken 14 to 21 days after a herbicide drift situation. Biomass expressed as a percent of the untreated control may also be an accurate predictor of final yield because correlation between PBIO and PYIELD had a correlation coefficient of 0.72 for glyphosate alone and r = 0.62 when MCPA and thifensulfuron:tribenuron (2:1) were combined. In addition to canola yield having a good correlation with herbicide rate, visual injury rating and biomass when all three herbicides were combined, it also had a good correlation (0.71) with the number of seeds per pod expressed as a percent of the untreated control (PSEDSPOD). In contrast, the correlation between PYIELD and PSEDSPOD was much lower for glyphosate treatments alone (r = 0.51) as compared to MCPA and thifensulfuron:tribenuron (2:1) treatments combined (r = 0.80). This shows

Table 4.2. Correlation among measured variables expressed as a percent of untreated control for canola affected by simulated drift of (i) glyphosate or (ii) either MCPA or thifensulfuron:tribenuron (2:1). P values occur in parentheses below the correlation coefficients. Site-years have been combined.

Glyphosate

	RATE	VIS	PBIO	PPODNO	PYIELD	PSEDSPOD	PTKW
RATE[a]	1.00						
VIS[b]	**0.93**[h]	1.00					
	(<0.0001)						
PBIO[c]	**-0.71**	**-0.77**	1.00				
	(<0.0001)	(<0.0001)					
PPODNO[d]	-0.10	-0.02	-0.01	1.00			
	(0.3406)	(0.8295)	(0.9418)				
PYIELD[e]	**-0.81**	**-0.88**	**0.72**	0.11	1.00		
	(<0.0001)	(<0.0001)	(<0.0001)	(0.2884)			
PSEDSPOD[f]	-0.40	-0.46	**0.55**	-0.08	**0.51**	1.00	
	(<0.0001)	(<0.0001)	(<0.0001)	(0.4426)	(<0.0001)		
PTKW[g]	-0.29	-0.21	0.09	0.49	0.27	0.12	1.00
	(0.0043)	(0.0411)	(0.3813)	(<0.0001)	(0.0071)	(0.2262)	

MCPA and thifensulfuron:tribenuron (2:1)

	RATE	VIS	PBIO	PPODNO	PYIELD	PSEDSPOD	PTKW
RATE	1.00						
VIS	**0.56**	1.00					
	(<0.0001)						
PBIO	-0.43	**-0.66**	1.00				
	(<0.0001)	(<0.0001)					
PPODNO	-0.30	-0.27	0.21	1.00			
	(<0.0001)	(0.0002)	(0.0032)				
PYIELD	**-0.57**	**-0.64**	**0.62**	0.28	1.00		
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)			
PSEDSPOD	**-0.53**	**-0.50**	**0.65**	-0.02	**0.80**	1.00	
	(<0.0001)	(<0.0001)	(<0.0001)	(0.8131)	(<0.0001)		
PTKW	-0.49	-0.15	0.19	0.35	0.27	0.22	1.00
	(<0.0001)	(0.0416)	(0.0086)	(<0.0001)	(0.0001)	(0.0020)	

[a] RATE represents herbicide rate.

[b] VIS represents visual injury rating.

[c] PBIO represents biomass expressed as a percent of the untreated control.

[d] PPODNO represents number of pods expressed as a percent of the untreated control.

[e] PYIELD represents final yield expressed as a percent of the untreated control.

[f] PSEDSPOD represents number of seeds per pod expressed as a percent of the untreated control.

[g] PTKW represents thousand kernel weight expressed as a percent of the untreated control.

[h] All variables with a correlation coefficient of (+/-) 0.50 or greater have been highlighted in bold. The number of observations used in calculating each correlation coefficient for glyphosate was 96. The number of observations used in calculating the majority of correlation coefficients for MCPA or thifensulfuron:tribenuron (2:1) was 192. The minimum number of observations used in calculating any specific correlation coefficient for MCPA or thifensulfuron:tribenuron (2:1) was 186 (due to missing values).

that yield in the plots treated with MCPA or thifensulfuron:tribenuron (2:1) was much more influenced by the number of seeds per pod than it was in the glyphosate treated plots. When canola plants have been affected by sub-lethal doses of MCPA or thifensulfuron:tribenuron (2:1) it appears that canola plants compensate by producing more seeds per pod. As a result, yield is not as negatively affected as it would be if the canola was exposed to sub-lethal doses of glyphosate. It also suggests that there is a greater recovery in canola when it is treated with MCPA or thifensulfuron:tribenuron (2:1) compared to when it is treated with glyphosate.

Canola biomass as a function of herbicide dose was modeled using log-logistic models where possible. For MCPA treatments, a log-logistic model fit the data for three out of the four site-years (Figure 4.1). The Carman 2001, Winnipeg 2001 and the Carman 2002 sites all had common C (lower limit of the response curve), D (upper limit of the response curve) and b (slope) (Table 4.3). The I_{50} (g ae ha^{-1} that reduced above ground shoot biomass by 50% relative to the untreated control) values range from approximately 30 to 89 g ae ha^{-1}. This indicates that it may be difficult to determine the exact dose that will cause a 50% reduction in biomass. For one site year (Winnipeg 2002), a log-logistic model could not be fit to the data. A linear model was fit and convergence criteria was met (Table 4.3).

For glyphosate treatments, a log-logistic model fit the data for all four site-years (Figure 4.1). The lower and upper limit of the curve, and the slope were common parameters for all four site-years (Table 4.3). The I_{50} values differed among site-years. For three of the four site-years there was a common I_{50} value (39.4 g ae ha^{-1}) but for Carman 2002 the I_{50} value was double that of the three other site years (87.8 g ae ha^{-1}).

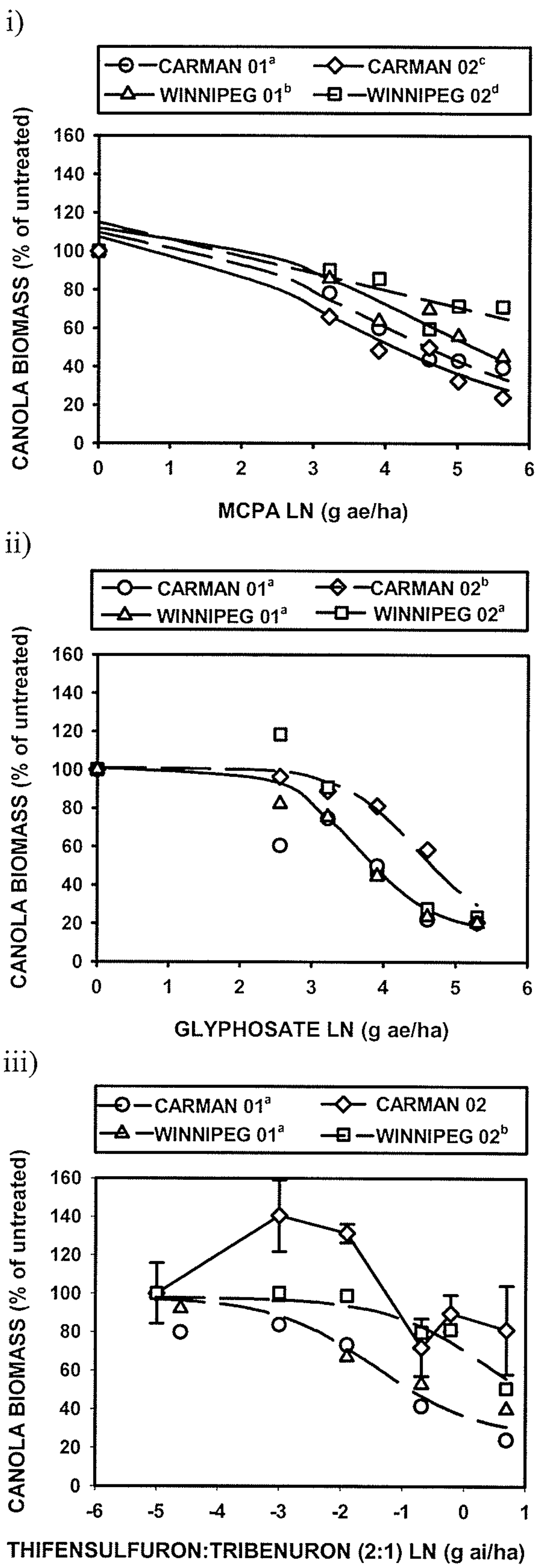

Figure 4.1. Effect of simulated herbicide drift of i) MCPA ester, ii) glyphosate or iii) thifensulfuron:tribenuron (2:1) on canola biomass expressed as a percent of untreated control. Common models in each individual figure (i.e. i), ii) or iii)) are indicated by [a], [b], [c] or [d].

Table 4.3. Parameter estimates for models of the relationship between herbicide dose and canola biomass as affected by simulated drift of either (i) MCPA, (ii) glyphosate or (iii) thifensulfuron:tribenuron (2:1). Values in parentheses are standard deviations. C, D, b, I_{50} and m are model parameters. See Materials and Methods for the models.

MCPA Site-year	Parameter Estimates C		D		b		I_{50}[f] (g ae/ha)		Overall model r^2
CAR01[a]	10.9	(27.80)	116.2	(20.67)	0.7	(0.41)	46.7	(6.16)	0.95
WPG01[b]	10.9	(27.80)	116.2	(20.67)	0.7	(0.41)	88.8	(44.90)	
CAR02[c]	10.9	(27.80)	116.2	(20.67)	0.7	(0.41)	29.6	(4.07)	

	Parameter Estimates B		m		r^2
WPG02[d]	114.87	(11.19)	-8.79	(2.66)	0.73

Glyphosate Site-year	Parameter Estimates C		D		b		I_{50} (g ae/ha)		Overall model r^2
CAR01	15.2	(8.64)	101.0	(5.72)	1.9	(0.59)	39.4	(4.34)	0.92
WPG01	15.2	(8.64)	101.0	(5.72)	1.9	(0.59)	39.4	(4.34)	
CAR02	15.2	(8.64)	101.0	(5.72)	1.9	(0.59)	87.8	(20.10)	
WPG02	15.2	(8.64)	101.0	(5.72)	1.9	(0.59)	39.4	(4.34)	

Thifensulfuron:tribenuron (2:1) Site-year	Parameter Estimates C		D		b		I_{50} (g ai/ha)		Overall Model r^2
CAR01	25.6	(10.18)	97.8	(3.82)	1.2	(0.40)	0.2	(0.04)	0.93
WPG01	25.6	(10.18)	97.8	(3.82)	1.2	(0.40)	0.2	(0.04)	
CAR02[e]									
WPG02	25.6	(10.18)	97.8	(3.82)	1.2	(0.40)	1.5	(0.56)	

[a] CAR01 represents the Carman site in 2001.
[b] WPG01 represents the Winnipeg site in 2001.
[c] CAR02 represents the Carman site in 2002.
[d] WPG02 represents the Winnipeg site in 2002. No convergence for sigmoidal model, linear model used.
[e] No significant relationship between herbicide dose and canola biomass. No model fitted to data.
[f] Rate causing 50% reduction in canola biomass.

For thifensulfuron:tribenuron (2:1) treatments, a log-logistic model fit the data for three of the four site-years. The lower limit of the curve, the upper limit of the curve and the slope were common for all three site-years. The I_{50} value for Carman 2001 and Winnipeg 2001 was 0.2 g ai ha^{-1}, while the I_{50} value for Winnipeg 2002 was 1.5 g ai ha^{-1}. For Carman 2002, there was no significant relationship between herbicide dose and canola biomass. Data were not fit to a model for this site-year and only treatment means and standard deviations were presented in Figure 4.1. The log-logistic model described the response of canola biomass to increasing doses of the three herbicides very well, as indicated by the number of site-years for which the model fitted the data and the high r^2 values (Table 4.3).

Canola yield was modeled as a function of herbicide dose using log-logistic models when possible. For the MCPA treatments, a log-logistic model fit the data for three of the four site-years (Table 4.4). The upper and lower limits of the model were common for all three of these site-years. The Winnipeg 2001 site and the Carman 2002 site had a common slope and a common I_{50} value. The Carman 2001 site had a unique slope and a unique I_{50} value. For the Winnipeg 2002 site there was no significant relationship between herbicide dose and canola yield. For this site-year, no model was fitted to the data and only the treatment means and standard deviations were presented for this site-year (Figure 4.2, Table 4.4).

For the glyphosate treatments, a log-logistic model fit the data for all site-years (Table 4.4). The lower limit of the curve, the upper limit of the curve and the slope were common for all 4 site-years. However, the I_{50} values ranged widely among site-years.

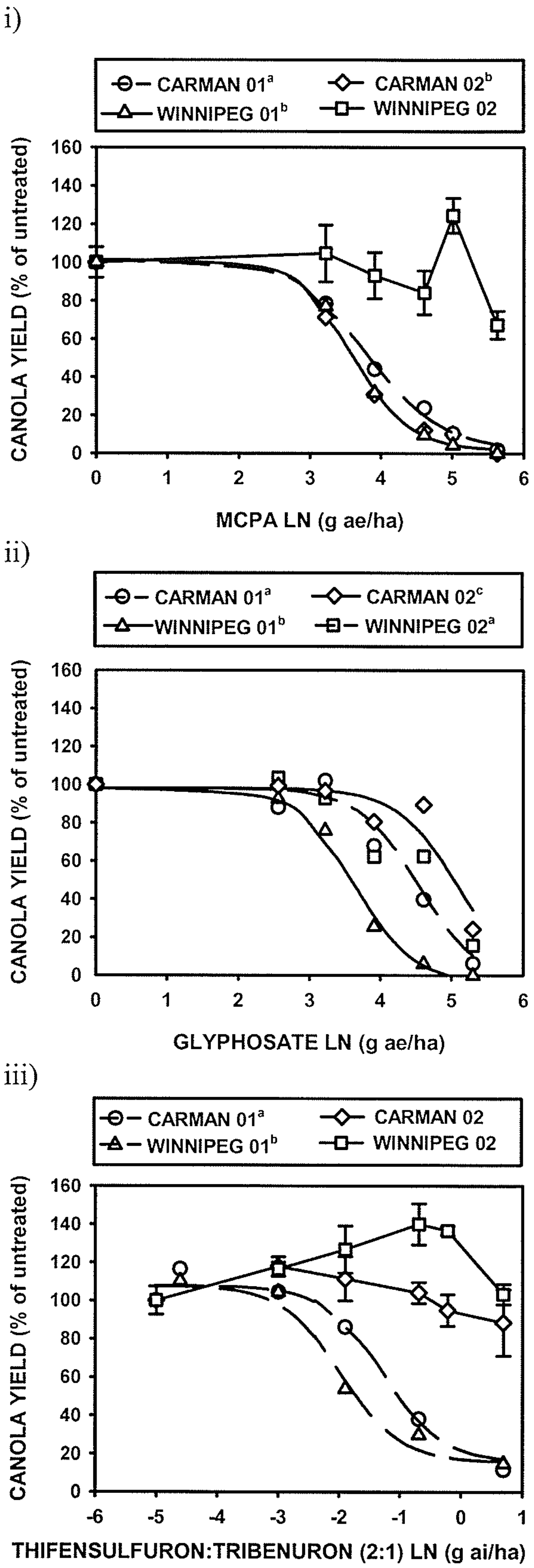

Figure 4.2. Effect of simulated herbicide drift of i) MCPA ester, ii) glyphosate or iii) thifensulfuron:tribenuron (2:1) on canola yield expressed as a percent of untreated control. Common models in each individual figure (i.e. i), ii) or iii)) are indicated by ^{a}, ^{b}, or ^{c}.

Table 4.4. Parameter estimates for models of the relationship between herbicide dose and canola yield as affected by simulated drift of either (i) MCPA, (ii) glyphosate or (iii) thifensulfuron:tribenuron (2:1). Values in parentheses are standard deviations. C, D, b, I_{50} and m are model parameters. See Materials and Methods for the models.

	Parameter Estimates				Overall Model
MCPA Site-year	C	D	b	I_{50}[f] (g ae/ha)	r^2
CAR01	1.5 (1.58)	101.5 (1.82)	1.9 (0.17)	45.5 (2.42)	0.99
WPG01	1.5 (1.58)	101.5 (1.82)	2.5 (0.15)	36.5 (0.91)	
CAR02	1.5 (1.58)	101.5 (1.82)	2.5 (0.15)	36.5 (0.91)	
WPG02[e]					

	Parameter Estimates				Overall model
Glyphosate Site-year	C	D	b	I_{50} (g ae/ha)	r^2
CAR01[a]	-4.5 (9.00)	98.0 (3.32)	2.4 (0.51)	94.5 (8.47)	0.95
WPG01[b]	-4.5 (9.00)	98.0 (3.32)	2.4 (0.51)	38.3 (6.15)	
CAR02[c]	-4.5 (9.00)	98.0 (3.32)	2.4 (0.51)	162.1 (24.98)	
WPG02[d]	-4.5 (9.00)	98.0 (3.32)	2.4 (0.51)	94.5 (8.47)	

	Parameter Estimates				Overall model
Thifensulfuron:tribenuron (2:1) Site-year	C	D	b	I_{50} (g ai/ha)	r^2
CAR01	15.5 (5.35)	107.7 (3.50)	2.0 (0.50)	0.3 (0.05)	0.98
WPG01	15.5 (5.35)	107.7 (3.50)	2.0 (0.50)	0.1 (0.02)	
CAR02[g]					
WPG02[h]					

[a] CAR01 represents the Carman site in 2001.
[b] WPG01 represents the Winnipeg site in 2001.
[c] CAR02 represents the Carman site in 2002.
[d] WPG02 represents the Winnipeg site in 2002. No significant relationship between herbicide dose and canola yield. No model fitted to data.
[e] No significant relationship between herbicide dose and canola yield. No model fitted to data.
[f] Rate causing 50% reduction in canola yield.
[g] No significant relationship between herbicide dose and canola yield. No model fitted to data.
[h] No significant relationship between herbicide dose and canola yield. No model fitted to data.

The Carman 2001 site and the Winnipeg 2002 site had a common I_{50} value of 94.5 g ae ha^{-1}. The Winnipeg 2001 site had an I_{50} value of 38.3 g ae ha^{-1} and the Carman 2002 site had an I_{50} value of 162.1 g ae ha^{-1}. This shows that it may be very difficult to predict the dose that reduces yield by 50 percent at a specific location in a specific year.

For thifensulfuron:tribenuron (2:1) treatments, a log-logistic model fit the data for only two of the four site-years. The Carman 2001 and the Winnipeg 2001 sites had common lower and upper limits of the model and a common slope. The I_{50} value for the Winnipeg 2001 site (0.1 g ai ha^{-1}) was less than half the I_{50} value for the Carman 2001 site (0.3 g ai ha^{-1}). For the Carman 2002 and the Winnipeg 2002 sites there was no significant relationship between herbicide dose and canola yield. For those two site-years, only treatment means and standard deviations were presented (Figure 4.2).

4.3 FIELD BEANS

Correlation of measured variables was run for field bean data just as it was for canola. For beans, herbicide rate (RATE) was weakly correlated with all of the measured variables (Table 4.1). Glyphosate was the most active of the three herbicides based on visual assessments. Data for glyphosate treatments were separated from data for MCPA and thifensulfuron:tribenuron (2:1) treatments and new correlation analyses were run (Table 4.5). For glyphosate treatments alone, the measured variables had a good correlation with herbicide rate (RATE) (Table 4.5). Herbicide rate and the visual injury rating had a correlation coefficient of 0.77. This is much higher than the correlation coefficient of 0.35 (Table 4.1) when all herbicides were grouped. RATE also had a good correlation with the field bean biomass expressed as a percent of the untreated control (PBIO), final yield expressed as a percent of the untreated control (PYIELD), and 1000 kernel weight expressed as a percent of the untreated control (PTKW). For MCPA and thifensulfuron:tribenuron (2:1), herbicide rate was weakly correlated with all of the measured variables (Table 4.5).

For glyphosate treatments, visual injury ratings (VIS) had a good correlation with field bean biomass expressed as a percent of the untreated control (PBIO) in the plots treated with glyphosate alone (r = -0.79) and in the plots treated with MCPA or thifensulfuron:tribenuron (2:1) (r = -0.64). Final bean yield expressed as a percent of the untreated control had a good correlation with the visual injury ratings only in the plots that were treated with glyphosate (r = -0.66). For plots treated with MCPA or thifensulfuron:tribenuron (2:1) there was a weak correlation between final yield expressed as a percent of the untreated control and visual injury ratings (r = -0.36). This is an indicator that field bean yield may be very difficult to predict if the crop has been affected by a sub-lethal dose of either MCPA or thifensulfuron:tribenuron (2:1). This could also mean that the measured variables were not predicting final yield. Estimating final bean yield based on visual injury ratings taken 14 to 21 days after exposure to sub-lethal doses of glyphosate may be relatively more accurate because the correlation coefficient between VIS and PYIELD was -0.66 (Table 4.5). This could be because the bean plants appeared to have recovered better from the simulated herbicide drift of both MCPA and thifensulfuron:tribenuron (2:1). Also, the glyphosate was more efficacious and therefore severely injured many of the bean plants. The glyphosate could have injured them beyond their ability to recover.

For bean plots treated with glyphosate, there was a good correlation between biomass expressed as a percent of the untreated control and yield expressed as a percent

Table 4.5. Correlation among measured variables expressed as a percent of untreated control for field beans affected by simulated drift of (i) glyphosate or (ii) either MCPA or thifensulfuron:tribenuron (2:1). P values occur in parentheses below the correlation coefficients. Site-years have been combined.

Glyphosate

	RATE	VIS	PBIO	PPODNO	PYIELD	PSEDSPOD	PTKW
RATE[a]	1.00						
VIS[b]	**0.77**[h]	1.00					
	(<0.0001)						
PBIO[c]	**-0.50**	**-0.79**	1.00				
	(<0.0001)	(<0.0001)					
PPODNO[d]	-0.42	-0.14	0.22	1.00			
	(<0.0001)	(0.1289)	(0.0168)				
PYIELD[e]	**-0.63**	**-0.66**	**0.54**	0.43	1.00		
	(<0.0001)	(<0.0001)	(<0.0001)	(<0.0001)			
PSEDSPOD[f]	-0.13	-0.18	0.07	-0.23	0.31	1.00	
	(0.1600)	(0.0542)	(0.4429)	(0.0008)	(0.0008)		
PTKW[g]	**-0.69**	**-0.65**	**0.55**	0.29	**0.66**	0.06	1.00
	(<0.0001)	(<0.0001)	(<0.0001)	(0.0063)	(<0.0001)	(0.5151)	

MCPA and thifensulfuron:tribenuron (2:1)

	RATE	VIS	PBIO	PPODNO	PYIELD	PSEDSPOD	PTKW
RATE	1.00						
VIS	0.30	1.00					
	(<0.0001)						
PBIO	-0.24	**-0.64**	1.00				
	(0.0009)	(<0.0001)					
PPODNO	0.13	-0.02	0.12	1.00			
	(0.0785)	(0.7352)	(0.0894)				
PYIELD	-0.17	-0.36	0.39	0.26	1.00		
	(0.0228)	(<0.0001)	(<0.0001)	(0.0003)			
PSEDSPOD	-0.13	-0.10	0.03	-0.42	0.45	1.00	
	(0.0815)	(0.1545)	(0.6660)	(<0.0001)	(<0.0001)		
PTKW	-0.17	**-0.65**	**0.60**	0.07	0.44	0.07	1.00
	(0.0225)	(<0.0001)	(<0.0001)	(0.3456)	(<0.0001)	(0.3120)	

[a] RATE represents herbicide rate, generally.

[b] VIS represents visual injury rating.

[c] PBIO represents biomass expressed as a percent of the untreated control.

[d] PPODNO represents number of pods expressed as a percent of the untreated control.

[e] PYIELD represents final yield expressed as a percent of the untreated control.

[f] PSEDSPOD represents number of seeds per pod expressed as a percent of the untreated control.

[g] PTKW represents thousand kernel weight expressed as a percent of the untreated control.

[h] All variables with a correlation coefficient of (+/-) 0.50 or greater have been highlighted in bold. The number of observations used in calculating the majority of correlation coefficients for glyphosate was 120. The minimum number of observations used in calculating any specific correlation coefficient for glyphosate was 114 (due to missing values). The number of observations used in calculating the majority of correlation coefficients for MCPA or thifensulfuron:tribenuron (2:1) was 192. The minimum number of observations used in calculating any specific correlation coefficient for MCPA or thifensulfuron:tribenuron (2:1) was 186 (due to missing values).

of the untreated control (r = 0.54). This was not true for plots treated with MCPA or thifensulfuron:tribenuron (2:1) (r = 0.39). Although visual injury ratings and biomass had a good correlation in the plots treated with MCPA and thifensulfuron:tribenuron (2:1), yield loss may not be accurately estimated based on biomass because PYIELD and PBIO were not highly correlated (Table 4.5). This could be because the bean plants have the ability to recover from stem and leaf injury early in the growing season and can still produce seed for yield. Visual assessments taken throughout the field season showed that MCPA or thifensulfuron:tribenuron (2:1) did not appear to have caused a great deal of injury.

The high r^2 values (Table 4.6) indicate that the log-logistic model described the response of the field bean biomass to increasing doses of all the three herbicides quite well. For bean biomass, a log-logistic model fit the data for all four site-years for plots treated with MCPA, and two dose-response curves were produced (Figure 4.3, Table 4.6).

The Carman 2001 site (CAR01), the early-seeded Winnipeg 2001 site (WPG01A), the late-seeded Winnipeg 2001 site (WPG01B) and the Winnipeg 2002 site all had common upper (101.3) and lower (35.7) limits of the curve and a common slope (1.2). The I_{50} for the early-seeded Winnipeg 2001 site (48.7 g ae ha^{-1}) was different from the I_{50} value for the others (231.3 g ae ha^{-1}) (Table 4.6).

For glyphosate treatments, a log-logistic model was fit to data for all five site-years. Upper and lower of limits of the curve and slope were common for all five site-years (Table 4.6). Carman 2001 and late-seeded Winnipeg 2001 sites had I_{50} values of 30.9 g ae ha^{-1}. The three remaining site-years had a common I_{50} value of 73.4 g ae ha^{-1}.

Table 4.6. Parameter estimates for models of relationship between herbicide dose and field bean biomass as affected by simulated drift of either (i) MCPA, (ii) glyphosate or (iii) thifensulfuron:tribenuron (2:1). Values in parentheses are standard deviations. C, D, b, I_{50} and m are model parameters. See Materials and Methods for the models.

	Parameter Estimates								
MCPA Site-year	C		D		b		I_{50}[f] (g ae/ha)		Overall Model r^2
CAR01	35.7	(7.60)	101.3	(5.34)	1.2	(0.38)	231.3	(32.66)	0.90
WPG01A	35.7	(7.60)	101.3	(5.34)	1.2	(0.38)	48.7	(13.80)	
WPG01B	35.7	(7.60)	101.3	(5.34)	1.2	(0.38)	231.3	(32.66)	
WPG02	35.7	(7.60)	101.3	(5.34)	1.2	(0.38)	231.3	(32.66)	

	Parameter Estimates								
Glyphosate Site-year	C		D		b		I_{50} (g ae/ha)		Overall Model r^2
CAR01[a]	18.0	(2.92)	101.2	(3.43)	2.9	(0.55)	30.9	(2.57)	0.95
WPG01A[b]	18.0	(2.92)	101.2	(3.43)	2.9	(0.55)	73.4	(4.04)	
WPG01B[c]	18.0	(2.92)	101.2	(3.43)	2.9	(0.55)	30.9	(2.57)	
CAR02[d]	18.0	(2.92)	101.2	(3.43)	2.9	(0.55)	73.4	(4.04)	
WPG02[e]	18.0	(2.92)	101.2	(3.43)	2.9	(0.55)	73.4	(4.04)	

	Parameter Estimates								
Thifensulfuron:tribenuron (2:1) Site-year	C		D		b		I_{50} (g ai/ha)		Overall Model r^2
CAR01	17.3	(4.76)	108.1	(4.44)	1.4	(0.27)	1.7	(0.19)	0.96
WPG01A	17.3	(4.76)	108.1	(4.44)	1.4	(0.27)	4.6	(0.63)	
WPG01B	17.3	(4.76)	108.1	(4.44)	1.4	(0.27)	0.5	(0.09)	
WPG02	17.3	(4.76)	108.1	(4.44)	1.4	(0.27)	1.7	(0.19)	

[a] CAR01 represents the Carman site in 2001.
[b] WPG01A represents the early seeded Winnipeg site in 2001.
[c] WPG01B represents the late seeded Winnipeg site in 2001.
[d] CAR02 represents the Carman site in 2002.
[e] WPG02 represents the Winnipeg site in 2002.
[f] Rate causing 50% reduction in field bean biomass.

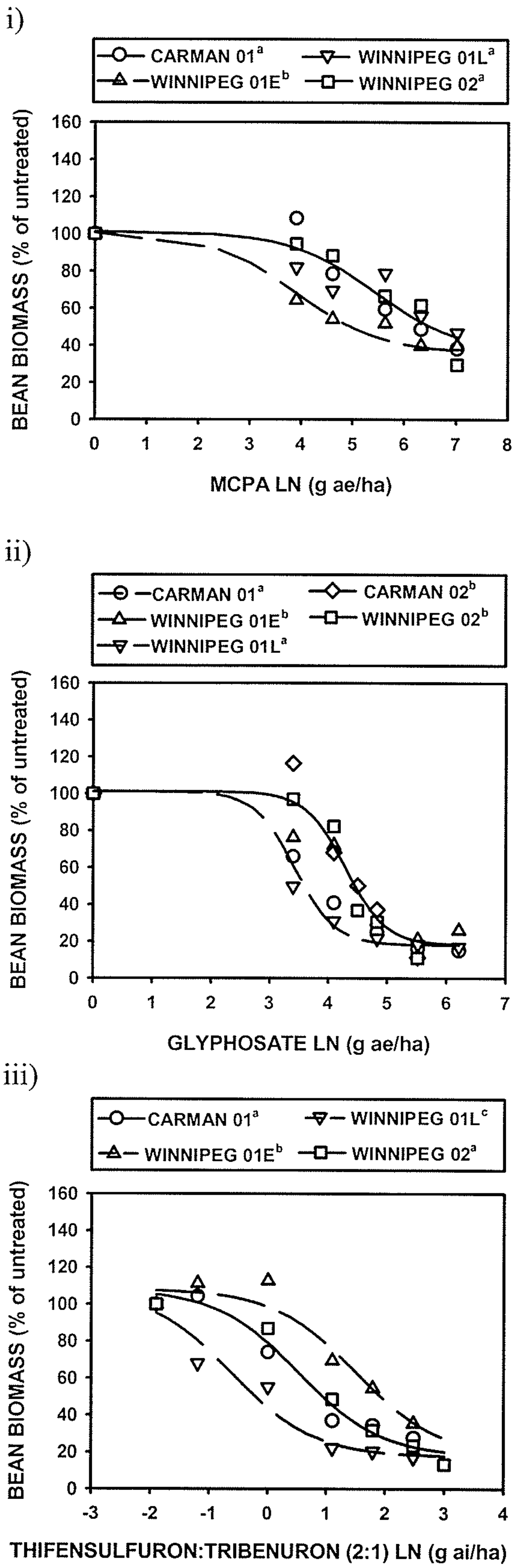

Figure 4.3. Effect of simulated herbicide drift of i) MCPA ester, ii) glyphosate or iii) thifensulfuron:tribenuron (2:1) on field bean biomass expressed as percent of untreated control. Common models in each individual figure (i.e. i), ii) or iii)) are indicated by ^{a}, ^{b}, or ^{c}.

For thifensulfuron:tribenuron (2:1) treatments, a log-logistic model was fit to the data for all four site-years and the models could be used to describe the relationship between herbicide dose and field bean biomass. Models for all site-years had common upper(17.3) and lower (108.1) limits of the curve and slope (1.4). The Carman 2001 site and the Winnipeg 2002 site had a common I_{50} value of 1.7 g ai ha^{-1}. The early-seeded Winnipeg 2001 site had a much higher I_{50} value of 4.6 g ai ha^{-1} while the late-seeded Winnipeg 2001 site had a much lower I_{50} value of 0.5 g ai ha^{-1}.

The field bean yield data was much more difficult to model than was the field bean biomass data. For MCPA treatments, a log-logistic model could not fit the data for any of the four site-years (Table 4.7). A linear model was fit to the data for the Carman 2001 site and the early-seeded Winnipeg 2001 site (Figure 4.4). The linear model for these two site-years had a common y-intercept of 113.8 and a common slope of -6.7 (Table 4.7).

For the late-seeded Winnipeg 2001 site and the Winnipeg 2002 site there was no significant relationship between herbicide dose and final bean yield. No model was fit to the data and only treatment means and standard deviations were presented in Figure 4.4.

For glyphosate treatments, a log-logistic model was fit to the data for four out of the five site-years. For the Carman 2001 site, the early-seeded Winnipeg 2001 site, the late-seeded Winnipeg 2001 site and the Carman 2002 site there were common upper (101.3) and lower (13.1) limits for the model (Table 4.7). The Carman 2001 site and the late-seeded Winnipeg 2001 site had a common slope (2.5) and a common I_{50} (67.82 g ae ha^{-1}). For the early-seeded Winnipeg 2001 site, the slope was 5.9 and the I_{50} value was

Table 4.7. Parameter estimates for models of relationship between herbicide dose and canola yield as affected by simulated drift of either (i) MCPA, (ii) glyphosate or (iii) thifensulfuron:tribenuron (2:1). Values in parentheses are standard deviations. C, D, b, I_{50} and m are model parameters. See Materials and Methods for the models.

MCPA Site-year	Parameter Estimates b	 M	 r^2
CAR01[i]	113.8 (6.34)	-6.7 (1.23)	0.75
WPG01A[j]	113.8 (6.34)	-6.7 (1.23)	
WPG01B[g]			
WPG02			

Glyphosate Site-year	Parameter Estimates C	 D	 b	 I_{50}[f] (g ae/ha)	Overall Model R^2
CAR01[a]	13.1 (2.67)	101.3 (2.39)	2.5 (0.26)	67.8 (3.12)	0.99
WPG01A[b]	13.1 (2.67)	101.3 (2.39)	5.9 (4.62)	125.1 (5.30)	
WPG01B[c]	13.1 (2.67)	101.3 (2.39)	2.5 (0.26)	67.8 (3.12)	
CAR02[d]	13.1 (2.67)	101.3 (2.39)	1.3 (0.23)	43.3 (6.03)	
WPG02[e]					

Thifensulfuron:tribenuron (2:1) Site-year	Parameter Estimates C	 D	 b	 I_{50} (g ai/ha)	Overall Model r^2
CAR01	-17.3 (20.65)	105.3 (4.08)	1.4 (0.41)	12.8 (4.10)	0.95
WPG01B	-17.3 (20.65)	105.3 (4.08)	0.6 (0.11)	12.8 (4.10)	
WPG01A[h]					
WPG02					

[a] CAR01 represents the Carman site in 2001.
[b] WPG01A represents the early seeded Winnipeg site in 2001.
[c] WPG01B represents the late seeded Winnipeg site in 2001.
[d] CAR02 represents the Carman site in 2002.
[e] WPG02 represents the Winnipeg site in 2002. No significant relationship between herbicide dose and field bean yield. No model fitted to data.
[f] Rate causing 50% reduction in field bean yield.
[g] No significant relationship between herbicide dose and field bean yield. No model fitted to data.
[h] No significant relationship between herbicide dose and field bean yield. No model fitted to data.
[i] No convergence for sigmoidal model, linear model used.
[j] No convergence for sigmoidal model, linear model used.

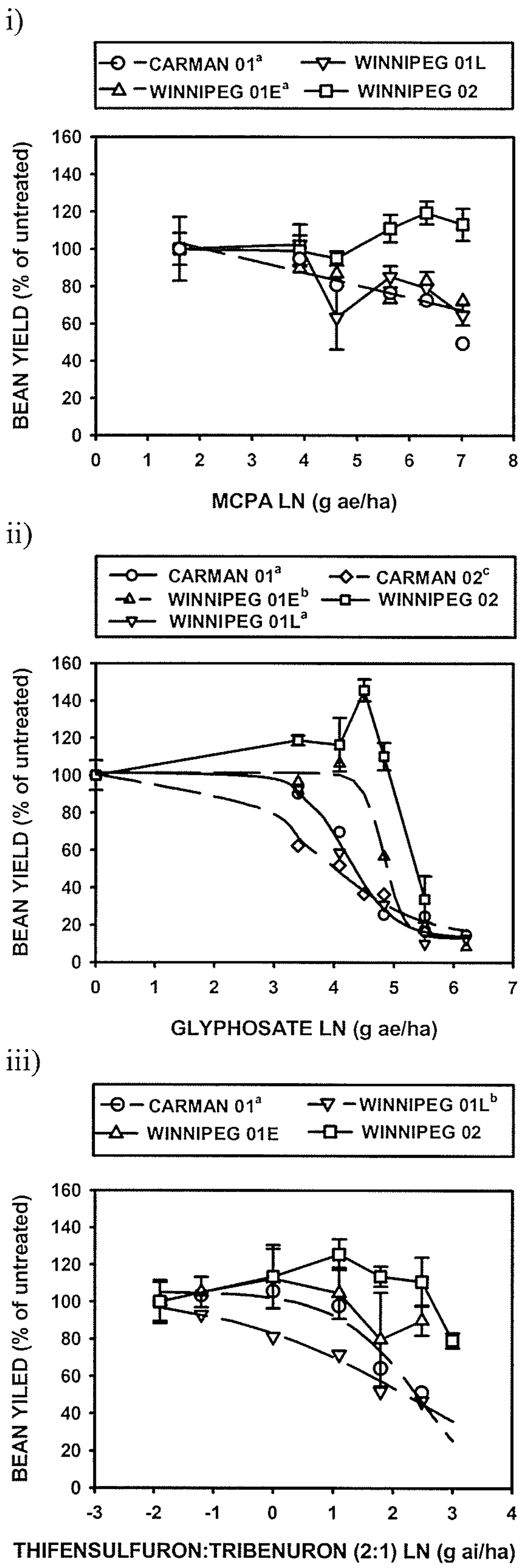

Figure 4.4. Effect of simulated herbicide drift of i) MCPA ester, ii) glyphosate or iii) thifensulfuron:tribenuron (2:1) on field bean yield expressed as a percent of untreated control. Common models in each individual figure (i.e. i), ii) or iii)) are indicated by ^{a}, ^{b}, or

125.1 g ae ha^{-1} while for the Carman 2002 site, the slope was 1.3 and the I_{50} value was 43.3 g ae ha^{-1} (Table 4.7).

For the thifensulfuron:tribenuron (2:1) treatments, a log-logistic model could be fit to the data for only two of the four site-years in order to describe the relationship between herbicide dose and final bean yield. The models for the Carman 2001 site and the late-seeded Winnipeg 2001 site had common upper (105.3) and lower (-17.3) limits and a common I_{50} value (12.8 g ai ha^{-1}). However, the slope of these models differed. The Carman 2001 site had a slope of 1.4 and the late-seeded Winnipeg 2001 plot had a slope of 0.6 (Table 4.7). It appears as though the thifensulfuron:tribenuron (2:1) in Carman 2001 had very little effect at the small doses and the herbicide was more active at the higher doses than it was in the late-seeded Winnipeg 2001 site. This could be because the weather was warm throughout the growing season and the plants were actively growing at a steady rate, therefore the herbicide was taken in at a steady rate and the results show an almost linear dose response. In the Carman 2001 site, the weather was colder and the bean plants may not have been actively growing, therefore low doses of the herbicide had a minimal effect. Higher doses of the thifensulfuron: tribenuron (2:1) may have translocated into the bean leaves faster because there was more herbicide present in the higher doses. For the early-seeded Winnipeg 2001 site and the Winnipeg 2002 site there was no significant relationship between herbicide dose and final bean yield. For these site-years, a model was not fit to the data and only treatment means and standard deviations were presented in Figure 4.4.

Yield loss in the field bean experiments due to simulated drift of glyphosate was not as great as might have been expected given the effect of glyphosate on field bean biomass. This may be due to the good correlation ($r = 0.66$) between final yield expressed as a percent of the untreated control and 1000 kernel weight expressed as a percent of the untreated control in the plots treated with glyphosate. This result suggests that some of the yield obtained from the field bean plots treated with glyphosate can be attributed to an increase in 1000 kernel weight. This was not the case in the plots treated with MCPA and thifensulfuron:tribenuron (2:1), where yield was not highly correlated with any of the other variables.

4.4 EFFECT OF SIMULATED HERBICIDE DRIFT ON CROP MATURITY

4.4.1 CANOLA

For all three herbicides, increasing dose resulted in delays in canola maturity (Table 4.8). For MCPA treatments, the greatest delay in canola maturity was seen at the Carman 2001 site (30 days). At the highest MCPA dose, (280 g ae ha^{-1}), canola maturity was delayed 17 to 30 days. For glyphosate treatments there was a similar effect. At the highest glyphosate dose (200 g ae ha^{-1}) canola maturity was delayed by 29 days at the Carman 2001 site. The delay in maturity in the plots treated with glyphosate ranged from 17 to 29 days. For thifensulfuron:tribenuron (2:1) treatments, the result was similar to that seen with either MCPA or glyphosate. The highest dose of thifensulfuron:tribenuron (2:1) (2 g ai ha^{-1}) resulted in a 26 day delay in canola maturity at the Carman 2001 site. The delay in canola maturity in plots treated with thifensulfuron:tribenuron (2:1), ranged from 17 to 26 days.

The delay in maturity was greatest at the Carman 2001 site (Table 4.8). It is unclear why the response at this site-year was different versus the other three site-years.

There was no rainfall event within 24 hours of the herbicide treatment (Appendix 7.2). However, the Carman 2001 site was the only site that had been sprayed for general weed control two times. The canola was sprayed with ethametsulfuron-methyl (Muster), clopyralid (Lontrel 360) and sethoxydim (Poast Ultra) on June 14, 2001. It rained approximately 30 minutes after the herbicide application so it was likely that the herbicide solution was washed off the leaves. The second herbicide application of the same tank-mix occurred on June 16, 2001. Perhaps a herbicide application of registered field rates 2 days apart may have caused a greater maturity delay response.

4.4.2 FIELD BEANS

Increasing the doses of all three herbicides delayed maturity in field beans slightly (data not shown). Field beans were harvested on the same day, regardless of small differences in maturity among herbicide treatments. Harvest time was determined to be appropriate when an acceptable balance was achieved between when the plots which had the highest rates of MCPA, glyphosate and thifensulfuron:tribenuron (2:1) began to senesce and pods would no longer be formed (longest delay in maturity) and the pods on the plants of the untreated checks began to split (no delay in field bean maturity). The untreated controls were on the verge of the pods beginning to split and shelling out seeds. At the highest rates of all three herbicides, the beans had just finished turning from a green color to a brown color associated with ripening. The delay in maturity would have been 14 days or less at the highest herbicide doses.

4.5 WEATHER DATA

The results presented in Figure 4.1 to Figure 4.4 indicate that canola and field beans responded differently to simulated herbicide drift in 2001 than they did in 2002.

Table 4.8. The influence of simulated herbicide drift of either MCPA, glyphosate or thifensulfuron:tribenuron (2:1) on days to maturity for canola as compared to untreated check.

MCPA Dosage (g ae/ha)	CAR01[a]	WPG01[b]	CAR02[c]	WPG02[d]
0	0	0	0	0
25	1	0	0	0
50	1	0	0	0
100	13	0	0	0
150	30	12	10	10
280	30	-[e]	17	20

Glyphosate Dosage (g ae/ha)	CAR01	WPG01	CAR02	WPG02
0	0	0	0	0
13	1	0	0	0
25	1	0	0	0
50	1	0	0	0
100	12	12	10	10
200	29	-[e]	17	20

Thifensulfuron: Tribenuron Dosage (g ai/ha)	CAR01	WPG01	CAR02	WPG02
0	0	0	0	0
0.01	1	0	-[f]	-[f]
0.05	1	0	0	0
0.15	1	0	0	0
0.5	12	12	10	10
0.8	-[g]	-[g]	10	10
2	26	12	17	20

[a] CAR01 represents the Carman site in 2001.
[b] WPG01 represents the Winnipeg site in 2001.
[c] CAR02 represents the Carman site in 2002.
[d] WPG02 represents the Winnipeg site in 2002.
[e] Plots not harvested due to absence of pods.
[f] Herbicide rate not used in 2002.
[g] Herbicide rate not used in 2001.

This was true for both biomass and yield for both crops. Generally, a log-logistic model could be fit to the data from sites in 2001 but not in 2002 because there tended to be a greater response of crop biomass and yield to herbicide treatment in 2001 versus 2002. In 2002, field bean biomass data was the only data to which a log-logistic model could be fit for all site-years and all three herbicides.

There were greater differences in response between years than between sites. Because year seemed to have such a profound effect on the response of biomass and yield of canola and field beans to simulated herbicide drift, we suspected that weather was causing the difference. Weather data for Carman and Winnipeg in 2001 and 2002 was summarized on a monthly basis. This data can be found in Appendices 7.1 through 7.12. Summaries of the monthly weather data show that weather was not very different between years. Weather data was further summarized to show average mean temperature, average maximum temperature, average minimum temperature and average minimum relative humidity 7 days prior, 4 days prior, 4 days after and 7 days after the simulated herbicide drift treatment application (Appendix 7.13 to Appendix 7.19). Al-Khatib and Peterson (1999) found that herbicide injury symptoms on soybean were much more severe in 1998 than 1997 due to higher temperatures during and after herbicide application in 1998 as compared to 1997. The greater injury symptoms under warm weather conditions were not surprising since high temperatures increase herbicide diffusion rate through the cuticle and cell membranes (Al-Khatib and Peterson, 1999). Relative humidity affects herbicide uptake and performance by delaying the evaporation of individual spray droplets from leaf surfaces (Manitoba Agriculture and Food, 1991). Minimum percent relative humidity (% RH) was used because it shows extremes in

%RH. If the minimum relative humidity was always high, it was assumed that this period was suitable for herbicide translocation. On a humid day, there is very little evaporation and thus more time for herbicide droplets to penetrate leaf waxes (Manitoba Agriculture and Food, 1991). Examination of the weather summaries around the time of simulated herbicide drift application suggested that weather was not sufficiently extraordinary during any particular period such that it would be the cause for the differences in response between 2001 and 2002.

4.6 DISCUSSION

In general, canola above ground biomass decreased as MCPA dose increased. Canola biomass response for the plots treated with MCPA fit a log-logistic model for three of four site-years, (Figure 4.1). At the registered field rate of MCPA, canola biomass was reduced to between 20 and 80% of the biomass of the untreated control. This large variation in biomass loss may make it difficult to predict canola yield when canola has been exposed to a low dose of MCPA early in the growing season. Canola yield for the plots treated with MCPA fit a log-logistic model for 3 of the four site-years (Figure 4.2). These three site-years (Carman 2001, Winnipeg 2001 and Carman 2002) showed very similar results. At the highest MCPA dose, canola yield was reduced to approximately 0% of the yield of the untreated check in these site-years. The Winnipeg 2002 site-year was much different than the other three site-years. The MCPA seemed to have much less of an effect in this site-year. Canola yield dropped to only 70% of the yield of the untreated check at the highest MCPA dose (280 g ae ha^{-1}) (Figure 4.2).

For the canola plants treated with simulated herbicide drift of glyphosate, canola biomass was reduced to approximately 20 % of the biomass of the untreated control for all 4 site-years (Figure 4.1). It required little effort to fit a log-logistic model to the canola yield data from plots treated with glyphosate, and it may, therefore be relatively easy to predict canola injury as a result of glyphosate drift. At the highest simulated herbicide drift dose of glyphosate (200 g ai ha^{-1}), canola yield was reduced to between 0 and 30% of the yield of the untreated check.

Canola plants treated with simulated herbicide drift of thifensulfuron:tribenuron (2:1) produced data that was difficult to fit to a model to. A log-logistic model fit the canola biomass data for three of four site-years (Figure 4.1), while a log-logistic model fit canola yield data for only two of the four site-years. Canola yield loss in 2001 was much greater than it was in 2002. In 2001, canola yield of the plants treated with the highest dose of simulated herbicide drift of thifensulfuron:tribenuron (2:1) (2 g ai ha^{-1}) equaled approximately 15 to 20 % of the yield of the untreated check (Figure 4.2). Canola yield in 2002 was reduced to only 90% of the yield of the untreated check in Carman, and canola yield was actually 103% of the yield of the untreated check in Winnipeg at the highest dose of thifensulfuron:tribenuron (2:1) (2 g ai ha^{-1}) (Figure 4.2). A similar effect of year was found by Ellis and Griffin (2002) when they simulated herbicide drift of glyphosate on soybean. They found that the glyphosate rates of 140 and 70 g ae ha^{-1} in 1998 produced injury symptoms at least 7 times greater than the injury from the same rates in 1999. However, the yield of the soybeans was not affected differently between years.

A log-logistic model fit the data for field bean biomass for all three herbicides used for simulated herbicide drift and for all site-years. At the highest dose of MCPA, field bean biomass was reduced to between 30 and 50% of the biomass of the untreated check (Figure 4.3). Based on the good fit of the log-logistic model to field bean biomass data, it would intuitively make sense that field bean yield would be easy to predict when beans were affected by simulated herbicide drift of MCPA. However, this was not true. At the highest dose of simulated herbicide drift of MCPA, field bean yield ranged from 50 to 120% of the yield of the untreated check. A linear model could be fit to the field bean yield data for only two of four site-years.

A log-logistic model could be fit to the field bean biomass data for all five site-years for field beans treated with glyphosate. At the highest simulated herbicide dose for glyphosate, field bean biomass was reduced to between 20 and 30% of the biomass of the untreated control (Figure 4.3). Field bean yield data was more difficult to fit a log-logistic model because of the large variations in yield at similar herbicide rates. However, at the highest glyphosate dose, field bean yield was reduced to between 10 and 20% of the bean yield of the untreated control for all site-years (Figure 4.4).

A log-logistic model fit the biomass data for all site-years for field beans treated with simulated herbicide drift of thifensulfuron: tribenuron (2:1). However, three separate models were fit for four site-years of biomass data (Figure 4.3). At the highest dose of thifensulfuron:tribenuron (2:1), bean biomass was reduced to between 18 and 30% of the bean biomass of the untreated control. It was difficult to fit a log-logistic model to field bean yield data for beans treated thifensulfuron:tribenuron (2:1). Individual log-logistic models were fitted to data for the two sites in 2001 and no model could be fit to the data from 2002 (Figure 4.4). Field bean yield would be very difficult to predict after drift from thifensulfuron:tribenuron (2:1) because even at the highest simulated herbicide drift dose, field bean yield was only reduced to a range of between 50 and 90% of the yield of the untreated check. This means that there could be almost no yield loss or, in contrast, yield loss could be as high as 50 %.

It can be difficult to estimate yield based on low herbicide dosages applied early in the growing season because there is a great deal of time for plants to recover, thus minimizing the effect of the herbicide. As herbicide rate increases, visual injury rating becomes more consistent (Table 4.9). Standard deviations of the visual injury ratings decreased as herbicide dose increased. For both canola and field beans, visual injury estimates were much more accurate at the highest herbicide doses. At the lowest herbicide doses, standard deviations were quite high.

Glyphosate was the most efficacious of the three herbicides in our experiments. Glyphosate has an initial rapid entry into the plant. It is because of this rapid translocation that glyphosate acts primarily as a systemic herbicide. After glyphosate is taken up by plant foliage, it undergoes transport in the aqueous environment between cells, within cell walls, and in the xylem tissue. It is possible that glyphosate can be absorbed by plant roots. However, this is highly unlikely because most soils rapidly inactivate glyphosate. As a result of its ability to penetrate cell membranes, glyphosate readily enters the symplast and is extensively translocated throughout plants via the phloem sieve tubes. As well as transport in the phloem, glyphosate can also undergo symplastic cell to cell translocation via the plasmodesmata, which interconnect most cells (Franz et al, 1997). Translocation rates of MCPA in tolerant species appear to be slower, perhaps because of the formation of immobile complexes, reduced xylem transport, and anatomical differences among species (WSSA Herbicide Handbook, 1994). It is also known that non-susceptible species metabolize thifensulfuron quickly (WSSA Herbicide

Table 4.9 Visual injury rating (% injury) on canola and field beans (taken 14 to 21 DAT) for simulated herbicide drift doses of MCPA, glyphosate or thifensulfuron:tribenuron (2:1) over all site-years. Standard deviations are presented in parentheses.

Canola

	MCPA			Glyphosate		Thifensulfuron: tribenuron (2:1)		
Rate[b]	Visual	Injury	Rate	Visual	Injury	Rate	Visual	Injury
0	0	-[a]	0	0	-	0	0	-
25	30.9	(24.09)	13	4.4	(6.55)	0.01	1.25	(2.31)
50	53.4	(16.71)	25	8.1	(8.92)	0.05	2.2	(4.46)
100	68.8	(12.71)	50	30.9	(16.66)	0.15	19.1	(20.83)
150	74.1	(10.68)	100	68.4	(16.9)	0.5	62.5	(7.96)
280	82.5	(5.48)	200	93.8	(2.24)	0.8	71.3	(5.82)
						2	77.8	(5.15)

Beans

	MCPA			Glyphosate		Thifensulfuron: tribenuron (2:1)		
Rate	Visual	Injury	Rate	Visual	Injury	Rate	Visual	Injury
0	0	-	0	0	-	0	0	-
50	1.25	(3.42)	30	17.5	(20.36)	0.3	3.3	(4.44)
100	17.5	(21.91)	60	40.8	(22.90)	1	21.3	(17.75)
280	20.6	(18.70)	90	58.8	(6.41)	3	49.4	(19.14)
560	33.1	(18.34)	125	68.3	(11.73)	6	63.4	(11.36)
1120	66.9	(13.28)	250	87.0	(8.80)	12	77.8	(6.32)
			500	92.5	(4.52)	20	88.8	(2.50)

[a] No standard deviation for a visual injury rating of 0.

[b] Rate for MCPA and glyphosate are in g ae ha^{-1}, rate for thifensulfuron:tribenuron (2:1) are in g ai ha^{-1}

Handbook, 1994). For example, soybeans rapidly de-esterify thifensulfuron to the non-phytotoxic thifensulfuron acid. This may be why glyphosate was more efficacious than MCPA or thifensulfuron:tribenuron (2:1), especially on field beans. Field beans may be much more tolerant to herbicide drift of the three herbicides we tested than we initially suspected.

Canola was much more sensitive than the field beans to all three herbicides used to simulate herbicide drift. Wall (1996) studied the effect of sublethal doses of 2,4-D on buckwheat, canola, field pea, lentil and sunflower. He found that at 151.2 g ai ha^{-1} (24% of the registered field rate), predicted yield losses were 43 % for buckwheat, 16 to 52 % for canola, 20 to 57 % for lentil and 93 to 100 % for sunflower. Field pea yields were unaffected. In this experiment, at 50 g ae ha^{-1} of MCPA (18 % of the field rate), canola yield loss, averaged over all site-years, was 50 %.

Wall (1994) also studied the tolerance of buckwheat, canola, field pea, lentil and sunflower to simulated drift of 2:1 mixtures of thifensulfuron:tribenuron. Predicted yield losses at 0.17 g ai ha^{-1}, averaged over two years, were 16 % for sunflower, 20 % for buckwheat, 22 % for canola, 26 % for lentil and 37 % for field pea. In another study, Wall (1995) found that rates of thifensulfuron:tribenuron (2:1) as low as 0.1 g ai ha^{-1} severely injured canola, delayed flowering, and reduced yield and subsequent seed germination. The herbicides tested in this experiment appeared to have less of an effect on yield than many of the experiments in the literature suggest. At the thifensulfuron:tribenuron rate of 0.15 g ai ha^{-1}, yield loss was only 6 % (averaged across all site-years), as compared to the experiment by Wall (1994) which had canola yield losses of 22 % at the 0.17 g ai ha^{-1} rate.

A report published by the Agri-Food Research and Development Initiative (ARDI) (Van Acker, 2000) shows the effect of various glyphosate timings and concentrations on canola. The project simulated drift with rates between 1.5% and 25% of the 1/2 litre per acre rate of Roundup Transorb (450 g ae ha^{-1} of glyphosate). It showed these low rates of glyphosate could influence the yield and flowering dates of field peas, canola, flax, and spring wheat. Among these crops, peas was the least sensitive to this herbicide, while flax and wheat were most sensitive. Canola was moderately sensitive.

Ellis and Griffin (2002) conducted a field research trial to evaluate the response of soybean and cotton (*Gossypium hirsutum* L.) to simulated herbicide drift of glyphosate and glufosinate. The rates used represented 12.5, 6.3, 3.2, 1.6 and 0.8% of the usage rates of 1120 g ae ha^{-1} glyphosate. Early post-emergence applications of glyphosate were made at the 2 to 3 trifoliate leaf stage of soybean and a late post-emergence application was made at first flower. Soybean injury and height reduction occurred in most cases for only the two highest rates of glyphosate (140 and 70 g ae ha^{-1}, respectively) with variation noted between years (Ellis and Griffin, 2002). In our experiments, we found that almost every rate of simulated herbicide drift of glyphosate produced some visual injury on field beans. Ellis and Griffin (2002) found that at 14 DAT, glyphosate applied early at 140 and 70 g ae ha^{-1} in 1998 injured soybean 35 to 9%, respectively. This injury was at least seven times greater than that for the same rates in 1999. However, there was no explanation for the variation between years. Soybean height was reduced by no more than 11%, regardless of herbicide rate or timing. The soybeans were able to recover rapidly from herbicide injury, and yields were not negatively affected. We also found that field beans were able to recover from injury of all three herbicides. At a rate of 60 g ae ha^{-1} of glyphosate (450 g ae ha^{-1}) in our experiment, there was a resulting 19 % yield loss for field beans.

There was a high correlation between visual injury and yield for certain crops/herbicide combinations. Canola yield was highly correlated with the visual injury rating for glyphosate and field bean yield had a good correlation with the visual injury rating for glyphosate ($r = -0.88$ and $r = -0.66$, respectively) (Table 4.2 and Table 4.5). This is because glyphosate is very effective as a non-selective herbicide. The majority of plants are susceptible to glyphosate. However, there was a very weak correlation between field bean yield and the visual injury rating for MCPA or thifensulfuron:tribenuron (2:1) ($r = -0.36$) (Table 4.5). This is because during the growing season the field beans were able to compensate for the damage in above-ground biomass by producing heavier seeds. The correlation between yield and thousand kernel weight was $r = 0.44$, and the correlation between the visual injury rating and the thousand kernel weight was $r = -0.65$ (Table 4.5).

Yield and visual injury ratings were not always well correlated because it appears as though both canola and field beans were able to compensate to various degrees for the damage caused by the simulated herbicide drift. In the canola plots treated with the simulated herbicide drift of glyphosate, correlation between yield and number of seeds per pod was $r = 0.51$ (Table 4.2). In the canola plots treated with MCPA or thifensulfuron:tribenuron (2:1), the correlation between yield and number of seeds per pod was $r = 0.80$ (Table 4.2). This indicates that when canola is injured by sublethal doses of herbicide, it attempts to compensate by producing more seeds per pod. In the field bean plots treated with glyphosate, correlation between yield and number of seeds per pod was weak (r = 0.31) (Table 4.5) but the correlation between yield and thousand kernel weight was much higher (r = 0.66). In the field bean plots treated with simulated herbicide drift of MCPA or thifensulfuron:tribenuron (2:1), yield was not well correlated with either number of seeds per pod (r = 0.45) or thousand kernel weight (r – 0.44) (Table 4.5). This indicates that when field beans are injured by sublethal doses of glyphosate, they compensate by producing heavier seeds.

The effect of each herbicide on seed quality is an issue that has not been discussed in this thesis. This is because no quality measurements were taken. Sub-samples of both the canola and field beans from 2001 and 2002 were taken and could be analyzed at a future date. Wall (1994) found that simulated thifensulfuron:tribenuron (2:1) drift reduced seed oil content of canola and sunflower. He also found that in one year of his experiment canola, field pea and lentil seed germination was reduced following exposure to simulated herbicide drift.

After examination of the weather summaries (Appendix 7.13 to 7.19), it appears as though weather was not responsible for the differences in biomass and yield response to herbicides between years. Also, we used the same herbicide source for both years and the same equipment and protocols. Crop development stage at time of application would be another variable that could cause year-to-year differences. As plants get older, their tolerance to herbicides increases. Again, in our experiments this should not have been a factor because the herbicides were applied at the same crop development stages in each year. In our experiments, the only difference in protocol between years was the application of herbicide for general weed control. In Carman in 2001, the herbicide application was done after the simulated herbicide drift treatments had been applied. In Carman in 2002, the herbicide application was done before the simulated herbicide drift treatments had been applied. Perhaps the herbicide application for weed control caused the crops to slow their metabolism, therefore causing them to not take up the herbicide as quickly. This appears to be true for the canola plots treated with

Table 4.10 The influence of herbicide drift of either MCPA, glyphosate or thifensulfuron:tribenuron (2:1) expressed as a percent of field rate on canola yield (% of untreated) and percent yield loss.

Canola

MCPA Rate (g ae/ha)	% of Field Rate	% Yield Loss	Yield (g/ha) (% of untreated)
0	0	0	100
25	9	17	83
50	18	50	50
100	36	68	32
150	54	63	37
280	100	83	17

Glyphosate Rate (g ae/ha)	% of Field Rate	% Yield Loss	Yield (g/ha) (% of untreated)
0	0	0	100
13	3	4	96
25	6	8	92
50	11	41	59
100	23	51	49
200	45	88	12

Thifensulfuron:tribenuron (2:1) Rate (g ai/ha)	% of Field Rate	% Yield Loss	Yield (g/ha) (% of untreated)
0	0	0	100
0.01	0.07	-13[a]	113
0.05	0.3	-11[b]	111
0.15	1	6	94
0.5	3	22	78
0.8	5	-16[c]	116
2	13	46	54

[a] 2001 data only.

[b] Negative percent yield loss indicates a yield increase

[c] 2002 data only.

thifensulfuron:tribenuron (2:1) (Figure 4.2 and Figure 4.3) where no model could be fit to either the canola biomass or canola yield data for the Carman 2002 site.

For canola, the most damaging herbicide in terms of effect on yield vs. percent of field rate was thifensulfuron:tribenuron (2:1). The simulated herbicide drift of thifensulfuron:tribenuron (2:1) at a rate of 13 % of the field rate caused a 46 % decrease in yield (Table 4.10). A 50 % yield loss in the canola plots treated with simulated herbicide drift of MCPA occurred at 18 % of the field rate (Table 4.10). A 50 % yield loss in the canola plots treated with glyphosate occurred at 23 % of the field rate (Table 4.10). One hundred percent yield loss was never achieved in the experiments but yield loss in the canola plots treated with the simulated herbicide drift of glyphosate did approach 100 %. An 88 % yield loss was achieved with a glyphosate dose approximately equal to 45 % of the field rate. An 83 % yield loss resulted from simulated herbicide drift of MCPA equal to 100 % of the field rate. Thifensulfuron:tribenuron (2:1) is known to be very active on canola therefore, the herbicide doses chosen to simulate herbicide drift were very low. However, in this experiment the canola proved to be more tolerant than expected. Wall (1994) found a 22 % reduction in canola yield after application of a simulated herbicide drift dose of thifensulfuron:tribenuron (2:1) of 0.17 g ai ha^{-1}. Only a 46 % yield loss resulted from a simulated herbicide drift of thifensulfuron:tribenuron (2:1) equal to 13 % of the field rate.

For field beans, the most damaging herbicide in terms of effect on yield vs. percent of field rate was glyphosate. The simulated herbicide drift of thifensulfuron:tribenuron (2:1) at a rate of 80 % of the field rate caused only a 25 % decrease in field bean yield (Table 4.11). A 25 % yield loss in the bean plots treated with simulated herbicide drift of MCPA occurred at 400 % of the field rate (Table 4.11). A 48 % yield loss in the bean plots treated with glyphosate occurred at 28 % of the field rate (Table 4.11). One hundred percent yield loss was never achieved in our experiments but the field bean plots treated with the simulated herbicide drift of glyphosate came close.

Table 4.11 The influence of herbicide drift of either MCPA, glyphosate or thifensulfuron:tribenuron (2:1) expressed as a percent of field rate on field bean yield (% of untreated) and percent yield loss.

Beans

MCPA Rate (g ae/ha)	% of Field Rate	% Yield Loss	Yield (g/ha) (% of untreated)
0	0	0	100
50	18	4	96
100	36	19	81
280	100	14	86
560	200	11	89
1120	400	25	75

Glyphosate Rate (g ae/ha)	% of Field Rate	% Yield Loss	Yield (g/ha) (% of untreated)
0	0	0	100
30	7	8	92
60	14	19	81
90	20	9	91
125	28	48	52
250	57	79	21
500	114	88	12

Thifensulfuron:tribenuron (2:1) Rate (g ai/ha)	% of Field Rate	% Yield Loss	Yield (g/ha) (% of untreated)
0	0	0	100
0.3	2	-1[a]	101
1	7	-3[b]	103
3	20	0	100
6	40	23	77
12	80	25	75
20	133	21[c]	79

[a] 2001 data only.

[b] Negative percent yield loss indicates a yield increase

[c] 2002 data only.

An 88 % yield loss was achieved with a glyphosate dose approximately equal to 114 % of the field rate. This means that as a proportion of field rate, glyphosate has the greatest effect on field bean yield loss. The next greatest effect on field bean yield came from thifensulfuron:tribenuron (2:1), where a thifensulfuron:tribenuron (2:1) dose equal to 80 % of the field rate caused a 25 % yield loss. In contrast, it took a simulated herbicide drift dose of 400 % of the field rate of MCPA to cause a 25 % yield loss in beans.

4.6.1 CONCLUSIONS

What are the practical implications of the results from our experiments? We see that changes in crop yield resulting from herbicide drift early in the field season may be very difficult to predict. Al-Khatib and Peterson (1999) found the same result when simulating herbicide drift on soybeans. They found that soybean plants recovered rapidly from the simulated herbicide drift injury symptoms found early in the field season. Therefore, such injury symptoms are not reliable indicators for yield reduction especially when they are minor (Al-Khatib and Peterson, 1999). Symptoms that usually are worrisome to growers, such as mottled chlorosis and leaf stunting, crinkling, and discoloration caused by sulfonylureas; cupping of terminal leaf, crinkling and leaf stunting caused by dicamba; chlorosis of the upper leaves caused by glyphosate; and chlorotic and necrotic spots caused by glufosinate, occur at rates much lower than required to reduce yield (Al-Khatib and Peterson, 1999).

We had hoped to produce a scale or index that could be used by farmers, custom applicators and insurance claim adjusters that would help them settle any claims resulting from herbicide drift of MCPA, glyphosate or thifensulfuron:tribenuron (2:1) on canola and field beans. If a scale or index was to be produced, it would relate visual injury to final yield. Visual injury (10-14 days after treatment) and herbicide rate showed a good correlation but herbicide rate and final yield did not. A scale or index would require consistency between visual injury and yield and this was not the result in our experiments. Therefore, a scale based on our results would not be reliably predictive because of the large variations in yield response to herbicide rate (for the three herbicides we tested) between years for both canola and field beans. However, our results may be useful for showing the range in yield losses that could occur. Weed scientists will have to provide more site-years of data to obtain an accurate representation of what may happen in the field. This study was conducted over two years, and two consecutive years can have very different conditions and therefore produce variable results.

Although both canola and field bean appear to be more tolerant to MCPA, glyphosate and thifensulfuron:tribenuron (2:1) than was previously thought, this does not mean that these crops are safe from the potential effects of herbicide drift. Extreme caution and care must still be exercised when applying herbicides around these crops. A herbicide drift complaint is something nobody wants to deal with because it conveys a feeling of negligence toward one or more of the parties involved. The information produced from our experiments will show farmers that low herbicide rates that can cause injury symptoms but may not negatively affect yield. This is especially true for field beans, where rates used to simulate the herbicide drift often exceeded label rates of the herbicides and there was only a small effect on yield even though injury symptoms were present. However, farmers should still take as many precautions as possible to reduce the chance of herbicide drift. Depending on the environmental conditions, sublethal doses of a herbicide could have a very minimal effect, or in contrast, they could have a very large effect on yield loss. In our experiments, there were many instances where very high doses were used to simulate herbicide drift and yield was only minimally affected. Canola was much more sensitive than field beans to the three herbicides used to simulate herbicide drift, but it too was more tolerant than expected.

5.0 GENERAL DISCUSSION

5.1 PROTOCOL

Experiments on herbicide drift, or the effect of sublethal herbicide dose on crops can be challenging to carry out and interpret. The first challenge in these experiments was to choose which herbicides and crops we would use. In order to determine which crops to use in the experiment, we looked at historical records for crops grown in Manitoba. Canola acreage in Manitoba is high and canola is the second most economically significant crop in the province, second only to wheat. Field bean production in Manitoba is steadily increasing because field beans have a much better economic return than the majority of traditional crops. Field beans can also be solid seeded, therefore farmers can use much of the same equipment that they would normally use during the seeding and harvest operations. It can be a very attractive crop to grow with high economic return and relatively low investment in new machinery.

One of the challenges associated with doing a project on herbicide drift is choosing an appropriate experimental design in order to produce reliable data while still keeping the experiments logistically simple. Plot size must be large enough to realistically represent what may happen in a real herbicide drift situation in the field. Plot layout is also important. Plots should be far enough away from one another to eliminate, or at the very least reduce as much as possible, cross contamination of the various herbicides or various herbicide rates. It is important to remember in an outdoor experiment that weather conditions may not always be cooperative. Wind is one of the environmental elements that cannot be controlled. Just as it may be in a real field situation, the crop or weeds may be at the appropriate development stage for herbicide application but the wind may be too strong. In an instance such as this, it is important to have wind-boards to reduce the herbicide drift across plots. The herbicide application may be done in less than ideal conditions in this instance, but it may be necessary to spray because of other time constraints.

The herbicide treatments should be mixed in the laboratory one to two hours prior to spraying. Proper mixing of the herbicides is another very critical step in simulated herbicide drift experiments. Because very low doses of the herbicides are being used, measuring the low doses can be difficult. It is important to be careful so that the proper amount of product is mixed with water.

The canola was swathed by hand using sickles. When swathing, at least five or six inches of stubble should be left standing for the swath to sit on. This aids in drying the swath. The five or six inches of stubble will also keep the swath off the ground to eliminate disease problems (mildew) and problems after harvest. In addition, if the swath is too low to the ground, the combine header picks up large amounts of soil. During threshing, this soil is broken down to the size of the canola seeds. The soil comes through the combine with the seeds. This can cause difficulty when processing the seed samples for yield and thousand kernel weight because there can be large amounts of soil in the sample. It is then very difficult to separate the seeds from the soil because as mentioned previously the soil has been reduced to the same size as the canola seed. Therefore, the only way to separate the seed from the soil is to wash the soil out of every sample and place the clean samples back in a drying room to eliminate all excess moisture. The same problems can occur during field bean harvesting if when hand harvesting the soil attached to the roots of the plants is not shaken off before the plants are placed in the burlap sacks.

In our experiments, a Wintersteiger plot combine was used to thresh the canola and the field beans. Swaths, in the case of the canola, and the whole field bean plants inside the burlap sacks, in the case of the field beans, were run through the combine and the seeds were caught in paper bags.

5.2 LACK OF WORK ON HERBICIDE DRIFT

Dr. Tom Wolf, a researcher for Agriculture and Agri-Food Canada has done extensive work on application technology in order to reduce herbicide drift. Dr. Wolf studies the impact on drift of factors such as application speed, application pressure, new application methods and new nozzle technology. However, in Canada there has not been much work done on crop injury and potential yield and/or quality loss as a result of herbicide drift. Dr. David Wall, a researcher with Agriculture and Agri-Food Canada, has done some work on the tolerance of buckwheat, canola, field pea, lentil, and sunflower to simulated thifensulfuron:tribenuron (2:1) spray drift and sublethal doses of 2,4-D. Extensive amounts of research on herbicide drift or the effect of sublethal herbicide dose on crop yield has not been done. The results from such experiments may be difficult to interpret because there are so many variables that influence efficacy from sublethal herbicide doses. Generally, herbicide drift experiments should be done outside in an attempt to re-create what happens in the field. As such, weather plays a major factor in the final outcome of the experiment. Heat, relative humidity and moisture levels may influence herbicide efficacy. Warm and humid conditions will cause rapid plant growth, causing herbicides to be rapidly taken up by plants. However, in the case of sublethal herbicide doses, the plant may be able to metabolize the low herbicide dose quickly and minimal crop injury may result. Under cooler and drier conditions the opposite may occur.

Another reason for the lack of experimentation on herbicide drift is the issue of changing carrier volumes for each different herbicide rate used in the experiment. In a real herbicide drift situation in the field, as spray droplets travel through the air to a target, water in the spray droplets evaporates. By the time the drift solution reaches a target there is a much higher concentration of herbicide in the solution than there was when the solution left the nozzle. In our experiment we used a default assumption, that for example, if 10 % of a spray solution was prone to drift and moved off target, then the concentration of the herbicide reaching the nontarget plants was approximately 10 % of the rate being sprayed. However, in actual drift situations the concentration of the herbicide would be much higher at the droplet's final destination (Wolf, 1999a). For this reason, carrier volumes should, in theory, be altered to more accurately reflect what is happening in a field herbicide drift situation. Ellis et al. (2002) suggested that constant spray volume may underestimate the yield reduction expected for sensitive crops exposed to glyphosate or glufosinate. It is far more convenient to use only one carrier volume when conducting a simulated drift study than to change carrier volume delivery for each rate being evaluated. The additional time needed to calibrate equipment for each dose, the variable wind conditions during application that can cause very low carrier volumes to drift, and the need for buffer rows between plots to avoid off plot movement are all reasons which discourage researchers from changing carrier volumes with herbicide dose.

However, the information produced by this experiment is still relevant to weed scientists and extension people, even though carrier volumes were not changed. Our experiments provide information about the tolerance of canola and field beans to sublethal doses of several herbicides. This information has been available in limited quantities for canola and it does not exist for field bean. While altering carrier volumes may more accurately reflect what is happening to the herbicide solution during the dose transfer process, it may be less of a factor than year or weather. In our experiments, carrier volumes remained unchanged but the crop response to the herbicides varied greatly among years. Weather summaries should indicate why there was such a difference in efficacy between years, but that did not happen in our experiments. Other factors such as soil fertility levels would influence the growth of the plants. If the plants were stressed because of lack of nutrients, they would not be actively growing and would not be taking in the herbicide that was applied. This did not appear to be the case in this experiment because the untreated controls were always healthy and showed no signs of nutrient, or any other type of stress. Since year-to-year variation in response was so great, it may be necessary to have sufficient site-years to determine more accurately what may happen in a field situation. If more site-years are needed, then it would be necessary to design the experiment so it was logistically easy to carry out. This would mean that the simpler single carrier volume method is better because more site-years of data could be produced. When year or weather seem to be the variables contributing to the major differences in herbicide efficacy, the simpler method may be the best.

In our experiments, top-up surfactants were added to the spray solution rather than changing carrier volumes. Surfactant was added because some of the doses used were extremely low. For example, the lowest dose of thifensulfuron:tribenuron (2:1) in 2001 on canola was 0.01 g ai ha^{-1}. This dose is equivalent to 0.07% of the recommended field rate of Refine Extra. Surfactant was added to this herbicide solution to ensure that the herbicide would enter the plant. Surfactants can aid a spray solution's ability to adhere to leaves, reduce surface tension of the spray droplet, resist evaporation and increase cuticle penetration (Wolf et al., 1999). The benefits of using a surfactant in a sublethal dose experiment may outweigh the benefits of changing carrier volumes.

5.3 HERBICIDE DRIFT A PROBLEM IN THE FUTURE?

Herbicide drift may become more of a problem in western Canada because many crops are being developed to have a genetic resistance to herbicides. For example, a popular herbicide tank-mix option on canola in Manitoba was Muster (ethametsulfuron-methyl), Lontrel 360 (clopyralid) and Poast (sethoxydim) or Muster, Lontrel 360 and Select (clethodim) for weed control. If this tank-mix was to drift into a neighboring canola crop, there would be no damage because canola is naturally tolerant to all three of these herbicides. With genetic herbicide resistance, if a farmer is spraying Liberty (glufosinate ammonium) on his or her InVigor canola in adverse conditions and the herbicide solution drifts into a neighboring Roundup Ready canola field, crop damage will most definitely occur.

However, there are many application technologies being developed to reduce the incidence of herbicide drift. Many new field sprayers have specially designed wind curtains attached to the booms so that farmers can spray in stronger wind conditions without the fear of the herbicide solution moving off target and damaging neighboring crops or plants. New nozzle technologies are also being developed to reduce herbicide drift. Nozzles such as the Venturi nozzle create a vacuum which draws air into a mixing chamber. The spray droplets that leave the nozzle are very large and contain air bubbles. This spray is less prone to drift and can be used at higher than average pressures (Wolf, 1999a). Smaller droplets have been shown to be more easily retained by target plants (Wolf et al. 1992). In some studies, small droplets were more phytotoxic than large droplets when applied at the same herbicide dose and carrier volume (Wolf et al. 1992). With venturi nozzles, because the large droplets are infused with air bubbles they explode into smaller droplets upon impact with a target plant and provide good coverage.

Other methods of reducing drift from herbicide applications are being developed where the herbicide solution is electrically charged with 40,000 volts (Melroe's ESP sprayer). The ground and the plants on the ground have an overall negative charge therefore, if the herbicide solution is positively charged it may adhere to the plants better and even be attracted to the plants thus reducing the potential for herbicide drift (Wolf, 1999c). The attractive force is fairly weak and is only effective at manipulating small droplets. Also, the attractive force only becomes a factor when droplets are already very near their target (Wolf, 1999c).

Crops are not the only plant species susceptible to herbicide drift. Marrs et al. (1993) reported that there is an increasing need to protect natural vegetation from the potential effects of herbicide drift. One way to protect sensitive sites is to surround them with a no-spray buffer zone. Earlier estimates of buffer zone size based on bioassay experiments with established perennials suggested zones needed to be 6 to 10 meters wide (Marrs et al. 1993). However, for many natural and semi-natural species no measurements had been made of the effects of drift at the regeneration stage, when seedlings are establishing. In the latter case, buffer zones may need to be wider.

In summary, controlling or reducing herbicide drift is the responsibility of the applicator. A general knowledge of the factors that influence herbicide drift would be an asset to anyone who is applying herbicides. Common sense should be used when applying herbicides. The herbicide should not be applied in adverse weather conditions. However, if time constraints mean it is necessary to apply the herbicide solution in windy weather, the applicator must take all the necessary precautions to reduce the chance that the herbicide solution will move off target. Some of these precautions include adding surfactant to the spray solution to help the solution stick to the plants, using wind curtains on the field sprayer or using other drift reducing technologies such as low-drift nozzles. If none of these technologies are available, the herbicide applicator can reduce ground speed or decrease the spray solution pressure; both of which can also help to reduce the chance of herbicide drift.

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7.0 Appendices

Appendix 7.1. Summary of monthly weather data for May 2001 in Carman.

Julian Day	Date	Max T C	Min T C	Mean T C	Max RH %	Min RH %	Precipitation mm
121	01-May-01	17.10	8.20	12.60	103.10	59.17	7.60
122	02-May-01	17.00	5.60	11.30	92.80	42.24	0.00
123	03-May-01	16.10	0.40	8.20	103.90	39.47	0.00
124	04-May-01	20.90	2.60	11.80	100.40	24.32	0.00
125	05-May-01	20.50	3.40	11.90	105.00	23.80	1.60
126	06-May-01	14.00	7.60	10.80	105.20	95.70	0.00
127	07-May-01	9.40	4.70	7.10	101.90	88.10	3.80
128	08-May-01	16.10	2.50	9.30	100.50	37.51	1.20
129	09-May-01	21.40	5.00	13.20	105.40	53.73	7.40
130	10-May-01	10.50	3.40	7.00	96.40	60.97	0.00
131	11-May-01	16.70	-0.30	8.20	104.30	47.44	0.00
132	12-May-01	22.10	5.10	13.60	100.00	41.22	0.20
133	13-May-01	25.60	10.60	18.10	96.00	45.68	0.00
134	14-May-01	28.20	14.80	21.50	96.70	53.16	0.00
135	15-May-01	20.00	11.60	15.80	104.80	60.15	9.00
136	16-May-01	24.60	9.40	17.00	99.20	33.05	2.80
137	17-May-01	22.30	9.50	15.90	98.50	31.50	1.00
138	18-May-01	26.00	7.60	16.80	96.50	26.57	0.00
139	19-May-01	23.20	12.50	17.90	87.50	22.94	0.20
140	20-May-01	17.70	7.80	12.80	97.50	28.37	0.60
141	21-May-01	10.50	6.80	8.70	90.40	68.02	0.00
142	22-May-01	8.10	4.10	6.10	105.50	59.79	5.80
143	23-May-01	8.40	4.60	6.50	103.40	86.50	5.40
144	24-May-01	14.50	5.00	9.80	105.30	68.60	0.20
145	25-May-01	20.30	6.20	13.20	102.40	51.95	0.00
146	26-May-01	23.80	9.80	16.80	95.30	54.33	0.00
147	27-May-01	21.40	12.40	16.70	102.30	66.61	2.20
148	28-May-01	20.50	10.20	15.40	103.90	57.51	0.00
149	29-May-01	22.50	7.50	15.00	102.80	25.72	0.00
150	30-May-01	18.00	8.80	13.40	98.40	56.47	0.20
151	31-May-01	24.00	7.40	15.70	103.00	38.88	3.40
							Total
	Mean	18.75	6.93	12.84	100.27	49.98	52.60

Appendix 7.2. Summary of monthly weather data for June 2001 in Carman.

Julian Day	Date	Max T C	Min T C	Mean T C	Max RH %	Min RH %	Precipitation Mm
152	01-Jun-01	17.00	7.60	12.30	100.00	60.03	0.00
153	02-Jun-01	19.00	7.20	13.10	102.10	49.19	0.00
154	03-Jun-01	20.50	5.70	13.10	102.40	29.43	0.00
155	04-Jun-01	22.80	2.90	12.80	96.20	28.16	0.00
156	05-Jun-01	19.20	6.40	12.80	96.80	46.15	0.00
157	06-Jun-01	19.20	11.10	15.20	97.70	67.91	0.20
158	07-Jun-01	24.90	9.90	17.40	102.50	38.73	0.00
159	08-Jun-01	28.00	9.70	18.90	96.30	29.12	0.00
160	09-Jun-01	29.60	10.20	19.90	87.80	27.94	0.00
161	10-Jun-01	29.80	15.90	22.90	83.70	31.25	0.00
162	11-Jun-01	25.60	11.80	16.70	99.50	30.16	2.40
163	12-Jun-01	22.40	11.10	16.70	90.90	38.86	0.20
164	13-Jun-01	18.00	11.50	14.70	102.40	82.00	3.60
165[b]	14-Jun-01	15.40	12.20	13.80	104.20	89.40	14.80
166	15-Jun-01	15.60	9.20	12.40	103.40	73.90	5.40
167[c]	16-Jun-01	18.10	6.40	12.30	101.30	54.07	0.00
168	17-Jun-01	20.90	4.20	12.50	104.10	42.55	0.00
169	18-Jun-01	16.00	10.10	13.00	100.70	85.00	4.00
170	19-Jun-01	19.50	9.40	14.50	100.90	55.84	0.00
171[a]	20-Jun-01	19.90	6.50	13.20	104.30	47.46	0.00
172	21-Jun-01	24.20	6.70	15.40	103.90	39.23	0.00
173	22-Jun-01	25.60	10.40	18.00	95.80	44.04	0.00
174	23-Jun-01	32.20	14.60	23.40	93.60	42.58	0.00
175	24-Jun-01	31.40	15.30	23.30	96.90	51.15	0.00
176	25-Jun-01	26.70	16.90	21.80	103.80	84.20	6.00
177	26-Jun-01	21.90	14.50	18.20	101.70	67.19	0.00
178	27-Jun-01	18.90	13.40	16.10	103.70	86.00	2.00
179	28-Jun-01	24.50	15.20	19.80	105.30	86.60	2.40
180	29-Jun-01	27.70	13.90	20.80	105.00	46.89	0.00
181	30-Jun-01	16.90	6.60	11.80	101.80	57.88	0.20
							total
	Mean	22.38	10.22	16.23	99.62	53.76	41.20

[a] Herbicide drift treatments applied to canola and beans.

[b] Herbicide application for general weed control in canola and beans. Rain 30 minutes after application.

[c] Second herbicide application for general weed control in canola and beans.

Appendix 7.3. Summary of monthly weather data for July 2001 in Carman.

Julian Day	Date	Max T C	Min T C	Mean T C	Max RH %	Min RH %	Precipitation mm
182	01-Jul-01	19.00	4.10	11.50	101.50	41.90	0.00
183	02-Jul-01	23.90	12.10	18.00	97.30	66.20	0.20
184	03-Jul-01	25.40	12.70	19.10	94.70	46.90	1.80
185	04-Jul-01	20.90	8.80	14.90	98.90	44.24	0.00
186	05-Jul-01	23.90	4.90	14.40	103.20	46.84	0.00
187	06-Jul-01	27.30	14.00	20.60	98.00	44.53	2.20
188	07-Jul-01	29.10	13.00	21.10	94.50	37.95	0.00
189	08-Jul-01	31.80	12.20	22.00	98.00	38.79	0.00
190	09-Jul-01	28.80	15.00	21.90	96.90	42.63	0.00
191	10-Jul-01	23.92	12.39	18.16	99.40	52.41	0.00
192	11-Jul-01	24.32	11.17	17.75	100.20	50.81	0.00
193	12-Jul-01	26.56	9.92	18.24	103.20	46.13	0.69
194	13-Jul-01	27.93	18.20	23.07	103.10	56.39	8.70
195	14-Jul-01	25.26	18.34	21.80	104.30	81.10	1.35
196	15-Jul-01	27.15	18.10	22.63	105.60	73.90	0.00
197	16-Jul-01	23.09	17.95	20.52	104.40	95.90	12.51
198	17-Jul-01	29.22	15.51	22.37	105.10	70.60	0.67
199	18-Jul-01	28.88	17.38	23.13	105.50	76.90	0.00
200	19-Jul-01	30.01	15.35	22.68	105.30	60.30	0.00
201	20-Jul-01	29.82	19.53	24.68	103.80	57.93	0.00
202	21-Jul-01	30.43	17.08	23.76	105.10	59.27	19.65
203	22-Jul-01	29.39	16.34	22.87	104.40	64.38	0.67
204	23-Jul-01	22.13	12.78	17.46	99.30	72.20	0.00
205	24-Jul-01	23.37	9.85	16.61	103.00	53.20	0.00
206	25-Jul-01	24.37	10.36	17.37	103.00	59.56	0.00
207	26-Jul-01	23.66	15.87	19.77	105.00	79.50	92.50
208	27-Jul-01	21.10	14.78	17.94	105.40	88.60	48.38
209	28-Jul-01	25.74	13.64	19.69	106.30	71.20	0.00
210	29-Jul-01	24.39	14.79	19.59	103.70	86.10	0.00
211	30-Jul-01	29.10	12.36	20.73	102.70	48.06	0.00
212	31-Jul-01	22.05	17.68	19.87	103.20	79.40	3.18
							total
	Mean	25.87	13.75	19.81	102.06	61.09	192.51

Appendix 7.4. Summary of monthly weather data for May 2001 in Winnipeg.

Julian Day	Date	Max T C	Min T C	Mean T C	Max RH %	Min RH %	Precipitation mm
121	5 1	16.46	8.58	13.08	[a]		4.32
122	5 2	15.92	7.21	11.32			0.00
123	5 3	17.90	1.17	9.49			0.00
124	5 4	21.80	4.07	13.57			0.00
125	5 5	20.98	7.87	13.69			4.06
126	5 6	16.94	8.65	11.91			33.78
127	5 7	9.68	3.40	6.81			8.89
128	5 8	16.22	2.60	8.28			0.00
129	5 9	21.22	7.06	13.58			4.83
130	5 10	13.15	4.85	8.68			0.00
131	5 11	17.42	2.30	10.68			0.00
132	5 12	24.16	7.29	15.84			0.00
133	5 13	25.14	11.53	18.39			0.51
134	5 14	25.75	15.87	19.35			0.00
135	5 15	22.21	12.63	16.87			8.64
136	5 16	25.45	10.45	17.77			5.59
137	5 17	23.72	10.88	16.32			14.73
138	5 18	26.41	10.18	18.75			0.00
139	5 19	23.50	14.66	18.73			0.00
140	5 20	17.71	11.23	14.64			1.52
141	5 21	11.93	7.03	8.92			0.00
142	5 22	7.91	3.16	5.62			10.16
143	5 23	8.45	4.53	6.21			5.08
144	5 24	17.13	5.39	10.43			0.00
145	5 25	20.35	8.23	15.11			0.00
146	5 26	26.34	10.48	18.78			0.00
147	5 27	21.88	15.00	17.32			0.76
148	5 28	20.47	10.87	16.15			0.00
149	5 29	23.39	7.95	16.21			0.00
150	5 30	19.45	9.25	14.71			0.00
151	5 31	24.08	10.24	15.20			4.83
	Mean	19.45548	8.213226	13.62613	0	0	107.70
30 Year Avg.	Mean	19.2	4.8	12.0			58.8

[a] Relative humidity data not available due to sensor malfunction.

Appendix 7.5. Summary of monthly weather data for June 2001 in Winnipeg.

Julian Day	Date	Max T C	Min T C	Mean T C	Max RH %	Min RH %	Precipitation mm
152	6 1	17.50	8.19	12.70	[c]		3.30
153	6 2	17.57	8.44	13.00			0.00
154	6 3	21.06	5.10	14.18			0.00
155	6 4	24.53	5.51	15.92			0.00
156	6 5	22.28	8.40	16.33			0.00
157	6 6	20.25	12.82	16.20			0.00
158	6 7	25.04	13.32	18.25			0.00
159	6 8	26.47	11.14	18.44			2.79
160	6 9	29.89	11.99	21.54			0.00
161	6 10	30.52	17.16	23.29			0.00
162	6 11	26.71	15.28	20.77			1.78
163	6 12	22.66	10.86	17.31			0.00
164	6 13	17.55	13.09	15.16			3.30
165	6 14	16.34	12.82	14.36			31.75
166	6 15	15.82	10.01	12.46			4.06
167	6 16	17.06	8.47	12.43			0.00
168	6 17	23.35	5.87	15.41			0.00
169	6 18	18.53	11.67	15.02			2.29
170	6 19	19.96	9.13	14.70			0.00
171	6 20	22.79	8.61	15.44			0.00
172	6 21	26.64	7.96	18.15			0.00
173	6 22	26.06	13.44	20.56			0.00
174	6 23	31.12	16.04	23.57			1.27
175	6 24	33.01	17.00	24.72			0.00
176	6 25	28.43	19.16	22.96			10.67
177	6 26	24.43	16.32	19.88			0.00
178[a]	6 27	19.29	13.30	16.12			25.15
179	6 28	28.84	16.86	21.66			6.10
180	6 29	28.17	18.14	23.14			0.00
181[b]	6 30	20.17	9.56	13.24			0.00
	Mean	23.40133	11.85533	17.56367	0	0	92.46
30 Year Avg.	Mean	23.3	10.7	17.0			89.5

[a] Herbicide drift treatments applied to canola and early seeded field beans.
[b] Herbicide drift treatments applied to late seeded field beans.
[c] Relative humidity data not available due to sensor malfunction.

Appendix 7.6. Summary of monthly weather data for July 2001 in Winnipeg.

Julian Day	Date	Max T C	Min T C	Mean T C	Max RH %	Min RH %	Precipitation mm
182	7 1	21.82	7.48	14.90	[a]		0.00
183	7 2	24.28	12.85	17.48			2.79
184	7 3	25.34	14.43	19.40			9.91
185	7 4	20.87	11.75	16.28			0.00
186	7 5	25.52	9.00	17.98			0.00
187	7 6	26.47	15.41	21.49			4.06
188	7 7	29.49	15.32	22.28			0.00
189	7 8	32.08	16.47	24.39			0.00
190	7 9	29.32	18.51	26.41			0.00
192	7 11	27.54	17.84	24.14			0.00
193	7 12	30.08	13.67	22.34			0.00
194	7 13	30.38	19.62	24.37			7.37
195	7 14	25.68	19.37	22.09			5.08
196	7 15	28.80	18.90	23.61			0.25
197	7 16	24.51	19.66	21.71			43.43
198	7 17	29.41	18.48	23.60			0.00
199	7 18	30.73	19.20	24.20			10.92
200	7 19	31.96	18.17	24.87			0.25
201	7 20	30.10	22.17	25.91			0.00
202	7 21	33.10	20.64	25.75			0.00
203	7 22	30.21	20.11	25.01			0.00
204	7 23	23.43	14.32	19.90			0.76
205	7 24	25.47	11.63	18.27			0.00
206	7 25	27.17	12.34	20.27			0.00
207	7 26	24.36	16.95	19.23			6.35
208	7 27	21.82	16.04	17.20			81.30
209	7 28	26.19	16.10	20.29			0.00
210	7 29	24.47	15.80	20.74			0.00
211	7 30	30.94	15.64	23.16			0.00
212	7 31	25.06	19.51	21.76			6.86
	Mean	26.34194	15.72194	20.93645	0	0	179.33
30 Year Avg.	Mean	25.8	13.3	19.5			70.6

[a] Relative humidity data not available due to sensor malfunction.

Appendix 7.7. Summary of monthly weather data for May 2002 in Carman.

Julian Day	Date	Max T C	Min T C	Mean T C	Max RH %	Min RH %	Precipitation Mm
121	1-May-02	3.599	-4.601	-0.50	103	38.51	0.8
122	2-May-02	8.44	-5.633	1.40	89.3	37.35	0
123	3-May-02	23.16	0.07	11.62	94.7	27.56	1.8
124	4-May-02	10.51	-1.795	4.36	82	25.54	0
125	5-May-02	5.128	-2.8	1.16	101.6	52.04	0
126	6-May-02	7.89	-2.741	2.57	85.9	36.36	0
127	7-May-02	10.01	-7.41	1.30	98.8	27.79	0
128	8-May-02	5.495	0.022	2.76	106.6	46.29	10.2
129	9-May-02	4.402	-1.29	1.56	106.7	56.1	10.4
130	10-May-02	15.43	-4.188	5.62	100.1	42.82	0
131	11-May-02	15.8	0.96	8.38	101.1	52.31	4.6
132	12-May-02	17.78	4	10.89	101.6	42.14	0
133	13-May-02	14.44	3.364	8.90	97.9	38.87	0
134	14-May-02	21.42	2.672	12.05	99	32.01	0
135	15-May-02	15.15	0.473	7.81	102.2	59.79	1
136	16-May-02	7.38	-2.678	2.35	92.2	53.83	0
137	17-May-02	10.76	-2.442	4.16	95.9	25.21	0
138	18-May-02	12.5	-2.742	4.88	87.7	27.12	0
139	19-May-02	14.97	-1.312	6.83	78.1	27.68	0
140	20-May-02	19.05	-1.815	8.62	87.7	18.78	0
141	21-May-02	25.84	0.039	12.94	75.9	22.13	0
142	22-May-02	19.42	1.182	10.30	106.1	46.47	4.2
143	23-May-02	6.69	-1.389	2.65	105.8	63.73	0
144	24-May-02	15.29	-3.176	6.06	102.3	31.64	0.2
145	25-May-02	18.12	3.669	10.89	87.5	32.5	0.4
146	26-May-02	20.52	2.282	11.40	89.4	18.85	0
147	27-May-02	28.05	0.705	14.38	74.9	14.02	0
148	28-May-02	28.64	11.78	20.21	101.4	33.99	6
149	29-May-02	25.09	9.58	17.34	103.5	45.75	0.2
150	30-May-02	28.68	9.87	19.28	98.6	32.44	1.6
151	31-May-02	30.74	10.74	20.74	87.9	13.57	0
	Mean	15.8191613	0.49664516	8.15790323	95.0129	36.2319	41.4

Appendix 7.8. Summary of monthly weather data for June 2002 in Carman.

Julian Day	Date	Max T C	Min T C	Mean T C	Max RH %	Min RH %	Precipitation Mm
152	1-Jun-02	21.51	7.49	14.50	93.6	28.23	0
153	2-Jun-02	18.8	4.608	11.70	95.8	35.65	0
154	3-Jun-02	18.88	10	14.44	80.1	36.38	0
155	4-Jun-02	21.43	10.47	15.95	86.1	36.62	0
156	5-Jun-02	25.29	8.06	16.68	91	32.56	1.6
157	6-Jun-02	30.54	11.93	21.24	99	22.29	2.4
158	7-Jun-02	25.25	10.37	17.81	77.3	18.84	0
159	8-Jun-02	21.41	5.06	13.24	102.4	47.82	1.8
160	9-Jun-02	12.99	10.04	11.52	105.3	97.7	36.4
161	10-Jun-02	11.39	9.9	10.65	105.8	103.6	76.2
162	11-Jun-02	20.05	10.13	15.09	105.6	58.13	0.2
163	12-Jun-02	16.48	10.12	13.30	102	70.4	0.6
164	13-Jun-02	20.49	10.74	15.62	105.1	67.61	8.2
165	14-Jun-02	21.13	10.27	15.70	100.1	39.89	0
166	15-Jun-02	24.07	7.77	15.92	102.2	35.71	0
167	16-Jun-02	22.12	9.28	15.70	104	51.51	0
168[a]	17-Jun-02	25.64	12.24	18.94	104	44.79	0
169	18-Jun-02	23.1	15.07	19.09	103.4	77.4	0.4
170	19-Jun-02	19.96	13.2	16.58	104.8	64.48	2.8
171[c]	20-Jun-02	25.28	9.13	17.21	99.6	38.06	0
172	21-Jun-02	26.17	11.33	18.75	99.3	37.84	0
173	22-Jun-02	22.14	15.32	18.73	105.1	89.8	6
174	23-Jun-02	25.38	14.23	19.81	106.4	74.3	0.4
175	24-Jun-02	26.47	17.52	22.00	104	70.6	4
176	25-Jun-02	25.58	17	21.29	104.8	64.13	0
177	26-Jun-02	29.43	16.61	23.02	99.8	49.6	0
178	27-Jun-02	30.77	18.01	24.39	100.1	47.85	0
179[b]	28-Jun-02	32.28	17.52	24.90	99.8	52.69	0
180	29-Jun-02	34.04	19.26	26.65	99.2	54.72	0
181	30-Jun-02	28.27	15.47	21.87	95	38.91	0
	Mean	23.54467	11.93827	17.74147	99.35667	52.937	141

[a] Herbicide drift treatments applied to canola.
[b] Herbicide drift treatments applied to field beans.
[c] Herbicide application for general weed control in canola.

Appendix 7.9. Summary of monthly weather data for July 2002 in Carman.

Julian Day	Date	Max T C	Min T C	Mean T C	Max RH %	Min RH %	Precipitation mm
182	1-Jul-02	26.36	13.09	19.725	101.6	41.24	0.4
183	2-Jul-02	26.84	11.62	19.23	94.7	25.75	0
184	3-Jul-02	22.62	10.01	16.315	97.6	50.84	0
185	4-Jul-02	17.29	9.23	13.26	103.7	77.3	12.6
186	5-Jul-02	30.98	15.35	23.165	99.3	68.73	0.4
187	6-Jul-02	24.93	13.58	19.255	101.5	41.47	0
188	7-Jul-02	25.96	11.82	18.89	104.9	67.34	4.6
189	8-Jul-02	25.7	14.68	20.19	105.5	61.57	0
190	9-Jul-02	23.89	13.22	18.555	98.2	73.2	0.8
191	10-Jul-02	24.67	13.7	19.185	100.7	53.15	0
192	11-Jul-02	25.56	10.94	18.25	103.6	49.25	0
193	12-Jul-02	27.83	11.34	19.585	104.4	58.49	0
194	13-Jul-02	31	15.03	23.015	102.9	49.46	0
195	14-Jul-02	31.76	16.69	24.225	102	48.95	0
196	15-Jul-02	33.78	19.06	26.42	101.5	52.58	0
197	16-Jul-02	28.71	16.23	22.47	103.8	51.67	0
198	17-Jul-02	25.74	14.68	20.21	104.1	65.3	0
199	18-Jul-02	29.6	12.2	20.9	105.6	39.22	0
200	19-Jul-02	30.45	15.43	22.94	104.4	67.69	0
201	20-Jul-02	29.96	18.12	24.04	105	76.3	3.4
202	21-Jul-02	27.54	15.58	21.56	104.5	38.65	0
203	22-Jul-02	20.92	9.76	15.34	100.5	52.72	0
204	23-Jul-02	23.88	7.31	15.595	103.6	47.39	0
205	24-Jul-02	22.5	10.77	16.635	104.3	75.3	0
206	25-Jul-02	27.22	11.08	19.15	105.8	58.81	2.8
207	26-Jul-02	32.71	11.99	22.35	103.8	50.5	0
208	27-Jul-02	30.46	17.99	24.225	100.7	61.71	5.4
209	28-Jul-02	27.84	14.78	21.31	99.3	50.52	1.6
210	29-Jul-02	27.75	14.61	21.18	98.8	44.8	0.2
211	30-Jul-02	26.1	14.43	20.265	101.3	30.42	0.6
212	31-Jul-02	27.93	14.05	20.99	104.8	58.2	16.6
	Mean	27.0477419	13.4958065	20.2717742	102.3355	54.4684	49.4

Appendix 7.10. Summary of monthly weather data for May 2002 in Winnipeg.

Julian Day	Date	Max T C	Min T C	Mean T C	Max RH %	Min RH %	Precipitation mm
121	5 1	4.6	-3.05	0.54	96.40	31.66	1.02
122	5 2	7.91	-3.18	2.03	88.10	39.77	0
123	5 3	20.22	0.85	10.13	70.50	23.65	0.25
124	5 4	9.41	-1.21	4.03	83.10	22.56	0.76
125	5 5	3.7	-2.99	0.26	97.70	40.30	2.03
126	5 6	7.11	-1.89	2.23	80.20	31.24	0
127	5 7	10.01	-3.1	4.1	68.05	24.64	0
128	5 8	6.58	0.85	3.42	97.20	42.00	10.92
129	5 9	3.99	0.03	1.32	100.50	53.61	13.97
130	5 10	14.93	-3.53	6.9	94.20	41.49	0
131	5 11	16.47	1.86	10.1	81.90	48.30	0.51
132	5 12	15.26	6.7	10.53	87.90	63.29	2.03
133	5 13	12.34	3.63	8.03	90.50	51.05	0
134	5 14	18.23	3.23	11.57	86.30	36.02	0
135	5 15	14.77	0.49	7.31	91.90	48.75	0.51
136	5 16	7.11	-2.23	2.03	79.50	44.24	0
137	5 17	10.29	-1.47	4.62	85.60	25.04	0
138	5 18	12.47	-0.04	6.76	79.10	25.74	0
139	5 19	14.43	1.25	8.27	65.08	27.10	0
140	5 20	19.5	0.57	12.23	74.90	17.57	0
141	5 21	24.17	4.05	16.04	57.34	19.14	0
142	5 22	20.4	2.96	13.21	94.30	30.19	1.52
143	5 23	6.24	0.63	3.04	91.20	55.87	0
144	5 24	14.98	-4.49	7.52	98.90	22.41	0
145	5 25	18.52	6.49	12.58	78.70	29.34	0
146	5 26	19.57	5.01	12.76	79.80	21.00	0
147	5 27	27.92	4.8	18.75	61.16	12.64	0
148	5 28	27.18	11.84	19.34	95.10	28.75	3.56
149	5 29	27.6	9.55	17.39	99.80	42.17	7.87
150	5 30	27.24	11.93	19.18	93.40	28.25	0
151	5 31	27.3	11.87	19.68	79.10	16.90	0
	Mean	15.17581	1.980968	8.9	84.75580645	33.69935	44.95
30 Year Avg.	Mean	19.2	4.8	12.0			58.8

Appendix 7.11. Summary of monthly weather data for June 2002 in Winnipeg.

Julian Day	Date	Max T C	Min T C	Mean T C	Max RH %	Min RH %	Precipitation mm
152	6 1	22.06	7.79	15.9	80.40	34.21	0
153	6 2	19.43	4.86	12.57	77.70	32.88	0
154	6 3	20	10.45	14.89	61.16	29.65	0
155	6 4	20.54	8.46	15.25	88.50	40.72	0
156	6 5	25.97	6.36	17.25	93.10	26.32	0
157	6 6	29.66	13.22	20.59	63.61	20.05	1.27
158	6 7	24.23	11.84	18.2	69.79	21.85	0
159	6 8	20.25	9.96	15.43	84.30	51.55	0.76
160	6 9	13.72	10.79	12.18	97.10	83.10	27.69
161	6 10	13.33	10.58	11.52	97.70	91.40	53.59
162	6 11	21.55	10.58	15.33	96.70	51.99	0.76
163	6 12	17.85	7.09	12.3	97.70	59.95	4.83
164	6 13	21.5	9.82	14.78	99.10	48.43	0.51
165[a]	6 14	23.11	10.28	17.03	91.30	31.75	0
166	6 15	25.72	6.77	17.21	93.60	25.24	0
167	6 16	24.58	8.87	18	83.10	31.36	0
168	6 17	26.13	14.44	20.75	78.00	31.63	0
169	6 18	23.28	16.47	20.24	89.80	61.59	8.64
170	6 19	21.99	14.24	17.34	99.30	73.00	8.13
171	6 20	25.8	10.45	18.14	93.60	31.27	0
172[b]	6 21	26.8	13.84	21.02	83.80	34.71	0
173	6 22	23.2	15.75	18.86	97.10	76.20	2.29
174	6 23	26.95	14.18	20.33	100.10	60.24	0
175	6 24	25.85	18.05	21.51	95.90	72.90	17.78
176	6 25	25.45	17.56	21.47	97.10	62.41	0
177[c]	6 26	29.75	17.73	23.95	92.80	37.01	0
178	6 27	32.56	19.28	26.18	82.80	37.41	0
179	6 28	31.23	20	25.97	82.40	50.74	0
180	6 29	34.36	23.46	28.77	72.80	55.23	0
181	6 30	31.44	20.48	26.37	67.80	31.68	0
	Mean	24.27633	12.78833	18.64433	86.93866667	46.549	126.25
30 Year Avg.	Mean	23.3	10.7	17.0			89.5

[a] Herbicide drift treatments applied to canola.
[b] Herbicide application for general weed control in canola.
[c] Herbicide drift treatments applied to field beans.

Appendix 7.12. Summary of monthly weather data for July 2002 in Winnipeg.

Julian Day	Date	Max T C	Min T C	Mean T C	Max RH %	Min RH %	Precipitation Mm
182	7 1	26.01	14.31	20.77	88.50	51.32	2.03
183	7 2	28.28	13.5	21.49	78.20	20.37	0
184	7 3	22.02	12.62	18.05	81.00	44.60	0
185	7 4	20.78	9.63	15.17	96.80	55.68	51.31
186	7 5	28.73	15.21	22.08	94.60	67.50	16.51
187	7 6	26.52	15.94	22.13	89.00	34.38	0
188	7 7	26.03	14.54	19.61	94.50	53.46	1.78
189	7 8	27.38	16.84	22.26	98.10	40.31	0
190	7 9	25.69	15.27	20.17	73.70	51.47	0
191	7 10	27.28	16.14	22.1	72.50	35.72	0
192	7 11	-[a]	-[a]	-[a]	87.00	40.15	-[a]
193	7 12	28.08	14.38	21.97	88.90	49.12	0
194	7 13	31.08	18.94	24.88	86.60	46.32	0
195	7 14	31.62	20.16	25.72	92.10	48.02	0
196	7 15	31.97	20.83	26.87	85.00	57.16	0
197	7 16	31.15	19.59	26.14	91.30	31.01	0
198	7 17	27.13	16.61	23.16	87.30	43.89	0
199	7 18	30.11	13.03	22.55	98.60	31.84	0
200	7 19	30.63	17.79	25.08	91.30	60.87	0
201	7 20	28.43	19.87	23.78	95.10	74.10	6.35
202	7 21	27.94	17.3	22.65	97.00	38.11	0
203	7 22	21.9	13.84	17.71	93.20	44.76	0
204	7 23	24.71	11.34	18.68	86.50	40.31	0
205	7 24	23.45	12.68	17.96	95.30	67.54	0
206	7 25	27.46	15.21	21.39	98.90	43.19	0.25
207	7 26	31.16	17.32	24.52	84.10	48.42	0
208	7 27	28.68	19.12	23.79	92.90	63.44	2.29
209	7 28	28.06	16.28	21.59	85.60	43.15	0
210	7 29	28.34	15.42	21.5	86.70	33.74	0
211	7 30	26.39	15.94	21.15	86.70	26.37	0
212	7 31	28.6	15.28	21.36	90.90	45.40	14.73
	Mean	26.63258	15.32032	21.17032	89.28709677	46.18452	95.25
30 Year Avg.	Mean	25.8	13.3	19.5			70.6

[a] Time sync problems caused loss of data.

Table 7.13. Summary of average weather data in Carman, 2001 7 days prior, 4 days prior, 4 days after and 7 days after simulated herbicide drift application to canola and field beans. Application date was June 20, 2001.

	7 days prior	4 days prior	4 days after	7 days after
Ave. Min T (°C)	9.00	7.53	11.75	13.11
Ave. Max T (°C)	17.64	18.63	28.35	25.84
Ave. Mean T (°C)	13.31	13.08	20.03	19.46
Ave. Min RH (%)	68.97	59.37	44.25	59.20

Table 7.14. Summary of average weather data in Winnipeg, 2001 7 days prior, 4 days prior, 4 days after and 7 days after simulated herbicide drift application to canola and early seeded field beans. Application date was June 27, 2001.

	7 days prior	4 days prior	4 days after	7 days after
Ave. Min T (°C)	14.08	17.13	13.01	13.01
Ave. Max T (°C)	27.50	29.25	24.75	24.21
Ave. Mean T (°C)	20.75	22.78	18.24	18.01
Ave. Min RH (%)	-[a]	-	-	-

[a] Relative humidity data not available for Winnipeg 2001.

Table 7.15. Summary of average weather data in Winnipeg, 2001 7 days prior, 4 days prior, 4 days after and 7 days after simulated herbicide drift application to late seeded field beans. Application date was June 30, 2001.

	7 days prior	4 days prior	4 days after	7 days after
Ave. Min T (°C)	16.69	16.16	11.63	12.32
Ave. Max T (°C)	27.61	25.18	23.08	24.83
Ave. Mean T (°C)	21.72	20.20	17.02	18.54
Ave. Min RH (%)	-[a]	-	-	-

[a] Relative humidity data not available for Winnipeg 2001.

Table 7.16. Summary of average weather data in Carman, 2002 7 days prior, 4 days prior, 4 days after and 7 days after simulated herbicide drift application to canola. Application date was June 17, 2002.

	7 days prior	4 days prior	4 days after	7 days after
Ave. Min T (°C)	9.74	9.52	12.18	13.69
Ave. Max T (°C)	19.39	21.95	23.63	24.07
Ave. Mean T (°C)	14.57	15.73	17.91	18.88
Ave. Min RH (%)	60.98	48.68	54.45	64.64

Table 7.17. Summary of average weather data in Carman, 2002 7 days prior, 4 days prior, 4 days after and 7 days after simulated herbicide drift application to field beans. Application date was June 28, 2002.

	7 days prior	4 days prior	4 days after	7 days after
Ave. Min T (°C)	15.72	17.29	14.86	11.24
Ave. Max T (°C)	26.56	28.06	28.88	22.20
Ave. Mean T (°C)	21.14	22.67	21.87	16.72
Ave. Min RH (%)	62.02	58.05	40.16	41.25

Table 7.18. Summary of average weather data in Winnipeg, 2002 7 days prior, 4 days prior, 4 days after and 7 days after simulated herbicide drift application to canola. Application date was June 14, 2002.

	7 days prior	4 days prior	4 days after	7 days after
Ave. Min T (°C)	10.09	9.52	11.64	12.15
Ave. Max T (°C)	18.92	18.56	24.93	24.90
Ave. Mean T (°C)	14.25	13.48	19.05	18.96
Ave. Min RH (%)	58.32	62.94	37.46	41.26

Table 7.19. Summary of average weather data in Winnipeg, 2002 7 days prior, 4 days prior, 4 days after and 7 days after simulated herbicide drift application to field beans. Application date was June 26, 2002.

	7 days prior	4 days prior	4 days after	7 days after
Ave. Min T (°C)	14.87	16.39	20.81	17.66
Ave. Max T (°C)	25.15	25.36	32.40	29.41
Ave. Mean T (°C)	19.81	20.54	26.82	23.94
Ave. Min RH (%)	58.68	67.94	43.77	41.62

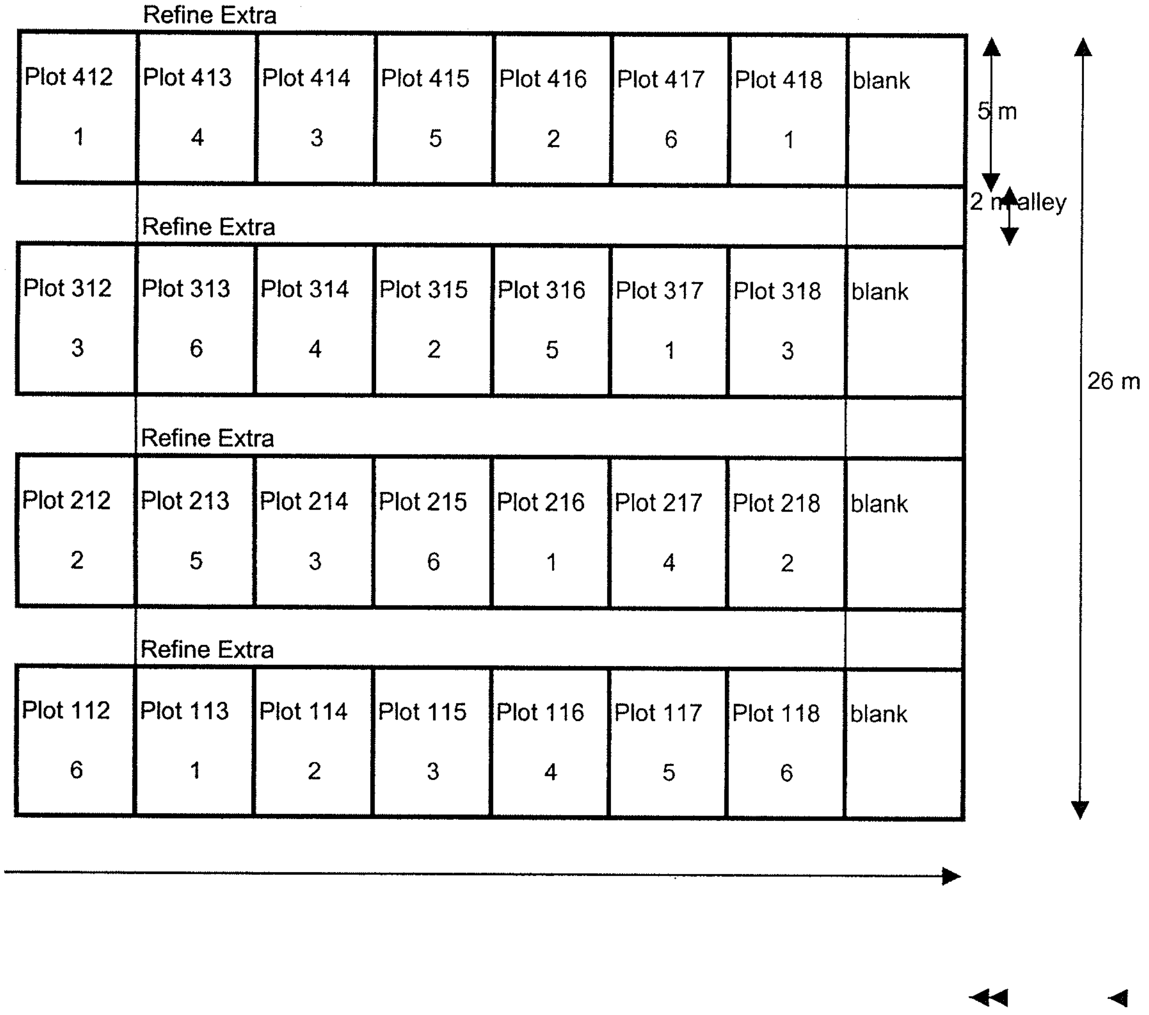
Appendix 7.20. Plot Plan for Summer 2001 and Summer 2002

Canola

		MCPA Ester						Roundup Transorb				
REP 4	blank	Plot 401 4	Plot 402 3	Plot 403 5	Plot 404 2	Plot 405 6	Plot 406 1	Plot 407 4	Plot 408 3	Plot 409 5	Plot 410 2	Plot 411 6
		MCPA Ester						Roundup Transorb				
REP 3	blank	Plot 301 6	Plot 302 4	Plot 303 2	Plot 304 5	Plot 305 1	Plot 306 3	Plot 307 6	Plot 308 4	Plot 309 2	Plot 310 5	Plot 311 1
		MCPA Ester						Roundup Transorb				
REP 2	blank	Plot 201 5	Plot 202 3	Plot 203 6	Plot 204 1	Plot 205 4	Plot 206 2	Plot 207 5	Plot 208 3	Plot 209 6	Plot 210 1	Plot 211 4
		MCPA Ester						Roundup Transorb				
REP 1	blank	Plot 101 1	Plot 102 2	Plot 103 3	Plot 104 4	Plot 105 5	Plot 106 6	Plot 107 1	Plot 108 2	Plot 109 3	Plot 110 4	Plot 111 5

2.6 m

52 m



Refine Extra

Plot 412 1	Plot 413 4	Plot 414 3	Plot 415 5	Plot 416 2	Plot 417 6	Plot 418 1	blank

Refine Extra

Plot 312 3	Plot 313 6	Plot 314 4	Plot 315 2	Plot 316 5	Plot 317 1	Plot 318 3	blank

Refine Extra

Plot 212 2	Plot 213 5	Plot 214 3	Plot 215 6	Plot 216 1	Plot 217 4	Plot 218 2	blank

Refine Extra

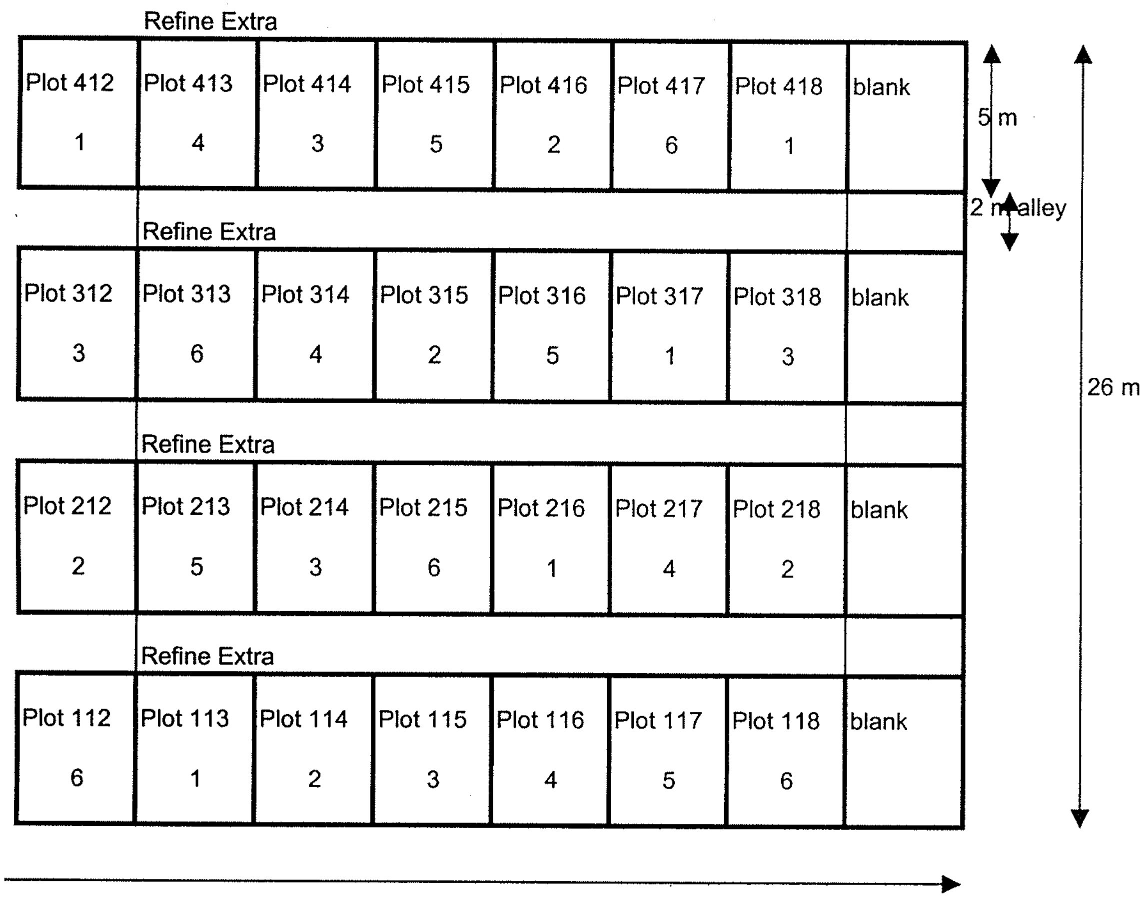
Plot 112 6	Plot 113 1	Plot 114 2	Plot 115 3	Plot 116 4	Plot 117 5	Plot 118 6	blank

Beans

		MCPA Ester						Roundup Transorb				
REP 4	blank	Plot 401 4	Plot 402 3	Plot 403 5	Plot 404 2	Plot 405 6	Plot 406 1	Plot 407 4	Plot 408 3	Plot 409 5	Plot 410 2	Plot 411 6
		MCPA Ester						Roundup Transorb				
REP 3	blank	Plot 301 6	Plot 302 4	Plot 303 2	Plot 304 5	Plot 305 1	Plot 306 3	Plot 307 6	Plot 308 4	Plot 309 2	Plot 310 5	Plot 311 1
		MCPA Ester						Roundup Transorb				
REP 2	blank	Plot 201 5	Plot 202 3	Plot 203 6	Plot 204 1	Plot 205 4	Plot 206 2	Plot 207 5	Plot 208 3	Plot 209 6	Plot 210 1	Plot 211 4
		MCPA Ester						Roundup Transorb				
REP 1	blank	Plot 101 1	Plot 102 2	Plot 103 3	Plot 104 4	Plot 105 5	Plot 106 6	Plot 107 1	Plot 108 2	Plot 109 3	Plot 110 4	Plot 111 5

2.6 m

52 m



	Refine Extra						
Plot 412 1	Plot 413 4	Plot 414 3	Plot 415 5	Plot 416 2	Plot 417 6	Plot 418 1	blank
	Refine Extra						
Plot 312 3	Plot 313 6	Plot 314 4	Plot 315 2	Plot 316 5	Plot 317 1	Plot 318 3	blank
	Refine Extra						
Plot 212 2	Plot 213 5	Plot 214 3	Plot 215 6	Plot 216 1	Plot 217 4	Plot 218 2	blank
	Refine Extra						
Plot 112 6	Plot 113 1	Plot 114 2	Plot 115 3	Plot 116 4	Plot 117 5	Plot 118 6	blank

Appendix 7.21. Calculations for bicycle sprayer calibration and herbicide rate calculations for 2001.

Calculations for Bicycle Sprayer Calibration:
(output verified as of June 1, 1993)
Output of a set of 80015 nozzles in shrouded boom on large frame sprayer with 1 gal container at 40 PSI (40 PSI while spraying) =
500 mL/min/nozzle

		Walking speed			
No. of nozzles	Spray width (m)	Distance (m)	Time (sec)	(m/sec)	Sprayer output (L/ha)
4	2	47	30	1.57	106.4

This is 10 meters in 6 seconds (1.57 m/sec = 3.5 mph).
With sprayer 'running', **WAIT AT LEAST 10 SECONDS (use a stopwatch) BEFORE** starting to walk to flush rinse water or previous treatment out of lines. This applies for the small sprayers (wait longer for the big sprayer).

When spraying a series of rates of a specific herbicide, do NOT rinse between rates but start with the lowest rate and continue up to the highest rate. Following this procedure will minimize error as compared to rinsing each time (resulting in some dilution of each treatment by the residual rinse water). BE SURE TO RINSE BETWEEN DIFFERENT HERBICIDES, THOUGH.

ALWAYS SHAKE THE SPRAY CONTAINER JUST BEFORE SPRAYING THE TREATMENT.
Note: This spreadsheet is formatted to 5 decimal places for weighing the Refine Extra on the 4-decimal balance. For liquid formulations, roundoff to nearest 0.1 mL.

Sprayer output (L/ha) =	107
Total amount of spray soln (L) =	1.5

Trt no.	Item "no."	Name of product	% Conc	Rate of product (g ai/ha or % v/v)	Amt of product needed (g or ml)	
Canola						
	1 a	Untreated	--	0	0.00000	
	2 a	Refine Extra	75	0.01	0.00019	grams
	2 b	Agral 90	--	0.2	3.00000	mL
	3 a	Refine Extra	75	0.05	0.00093	grams
	3 b	Agral 90	--	0.2	3.00000	mL
	4 a	Refine Extra	75	0.15	0.00280	grams
	4 b	Agral 90	--	0.2	3.00000	mL
	5 a	Refine Extra	75	0.5	0.00935	grams
	5 b	Agral 90	--	0.2	3.00000	mL

6 a	Refine Extra	75	2.0	0.03738 grams
6 b	Agral 90	--	0.2	3.00000 mL

1 a	Untreated	--	0	0.00000
2 a	Roundup Transorb	36	13	0.50623 mL
2 b	Agral 90	--	0.2	3.00000 mL
3 a	Roundup Transorb	36	25	0.97352 mL
3 b	Agral 90	--	0.2	3.00000 mL
4 a	Roundup Transorb	36	50	1.94704 mL
4 b	Agral 90	--	0.2	3.00000 mL
5 a	Roundup Transorb	36	100	3.89408 mL
5 b	Agral 90	--	0.2	3.00000 mL
6 a	Roundup Transorb	36	200	7.78816 mL
6 b	Agral 90	--	0.2	3.00000 mL

Normal use rate for Buctril M is 1.0 L/ha product (or 0.405 L/ACRE as in the Crop Protection Guide). This normal rate would provide 280 g ai/ha of MCPA ester.

Use the specially formulated Buctril M blanks (from Aventis). The use rate is marked on the label (L/ha product). For use rates of less than normal for the MCPA ester 'blank', add the correct proportion of solvent/emulsifier 'blank'. Special formulations: MCPA ester rate = 0.670 L/ha (670 mL/ha), Solvent/emulsifier blank rate = 0.230 L/ha (230 mL/ha) (marked on containers).

1 a	Untreated	--	0	0.00000
2 a	MCPA ester		25	0.83862 mL
2 b	Solvent/emulsifier blank			2.93642 mL
3 a	MCPA ester		50	1.67724 mL
3 b	Solvent/emulsifier blank			2.64853 mL

	4 a	MCPA ester			100	3.35447 mL
	4 b	Solvent/emulsifier blank				2.07276 mL
	5 a	MCPA ester			150	5.03171 mL
	5 b	Solvent/emulsifier blank				1.49700 mL
	6 a	MCPA ester			280	9.39252 mL
	6 b	Solvent/emulsifier blank				0.00000 mL
Beans						
	1 a	Untreated	--		0	0.00000
	2 a	Refine Extra		75	0.3	0.00561 grams
	2 b	Agral 90		--	0.2	3.00000 mL
	3 a	Refine Extra		75	1.0	0.01869 grams
	3 b	Agral 90		--	0.2	3.00000 mL
	4 a	Refine Extra		75	3.0	0.05607 grams
	4 b	Agral 90		--	0.2	3.00000 mL
	5 a	Refine Extra		75	6.0	0.11215 grams
	5 b	Agral 90		--	0.2	3.00000 mL
	6 a	Refine Extra		75	12.0	0.22430 grams
	6 b	Agral 90		--	0.2	3.00000 mL
	1 a	Untreated	--		0	0.00000
	2 a	Roundup Transorb		36	30	1.16822 mL
	2 b	Agral 90		--	0.2	3.00000 mL
	3 a	Roundup Transorb		36	60	2.33645 mL
	3 b	Agral 90		--	0.2	3.00000 mL
	4 a	Roundup Transorb		36	125	4.86760 mL
	4 b	Agral 90		--	0.2	3.00000 mL
	5 a	Roundup Transorb		36	250	9.73520 mL
	5 b	Agral 90		--	0.2	3.00000 mL
	6 a	Roundup Transorb		36	500	19.47040 mL
	6 b	Agral 90		--	0.2	3.00000 mL

Normal use rate for Buctril M is 1.0 L/ha product (or 0.405 L/ACRE as in the Crop Protection Guide). This normal rate would provide 280 g ai/ha of MCPA ester.

Use the specially formulated Buctril M blanks (from Aventis). The use rate is marked on the label (L/ha product). For use rates of less than normal for the MCPA ester 'blank', add the correct proportion of solvent/emulsifier 'blank'. Special formulations: MCPA ester rate = 0.670 L/ha (670 mL/ha), Solvent/emulsifier blank rate = 0.230 L/ha (230 mL/ha) (marked on containers).

1 a	Untreated	--	0	0.00000
2 a	MCPA ester		50	1.67724 mL
2 b	Solvent/emulsifier blank			2.64853 mL
3 a	MCPA ester		100	3.35447 mL
3 b	Solvent/emulsifier blank			2.07276 mL
4 a	MCPA ester		280	9.39252 mL
4 b	Solvent/emulsifier blank			0.00000 mL
5 a	MCPA ester		560	18.78505 mL
5 b	Solvent/emulsifier blank			0.00000 mL
6 a	MCPA ester		1120	37.57009 mL
6 b	Solvent/emulsifier blank			0.00000 mL

To calculate Refine Extra sequential dilution:

Product required in 1.5 L water (g)	Active in 1.5 L water (g)	Stock solution (g product in **1.0 L** water)	Stock solution (g active in **1.0 L** water)	Final spray solution (g product in **1.5 L** water)	Final spray solution (g active in **1.5 L** water)
0.00019	0.0001425	0.019	0.01425	0.00019	0.0001425

Take 10 mL of stock solution and add to 1.490 L of spray solution.
Make first solution indoors on the day of application (**shake really well!!!**).

0.00093	0.0006975	0.019	0.01425	0.00095	0.0007125

Take 50 mL of stock solution and add to 1.450 L of spray solution.

0.0028	0.0021	0.019	0.01425	0.00285	0.0021375

Take 150 mL of stock solution and add to 1.350 L of spray solution.
DON'T ADD SURFACTANT TO STOCK SOLUTION, BUT BE SURE TO ADD SURFACTANT TO THE FINAL SOLUTION (IN BICYCLE SPRAY CONTAINER OR POP BOTTLES) & SHAKE.

Appendix 7.22. Calculations for bicycle sprayer calibration and herbicide rate calculations for 2002.

Calculations for Bicycle Sprayer Calibration:
(output verified as of June 1, 1993)
Output of a set of 80015 nozzles in shrouded boom on large frame sprayer with 1 gal container at 40 PSI (40 PSI while spraying) =
500 mL/min/nozzle

No. of nozzles	Spray width (m)	Walking speed			Sprayer output (L/ha)
		Distance (m)	Time (sec)	(m/sec)	
4	2	47	30	1.57	106.4

This is 10 meters in 6 seconds (1.57 m/sec = 3.5 mph).
With sprayer 'running', **WAIT AT LEAST 10 SECONDS (use a stopwatch) BEFORE** starting to walk to flush rinse water or previous treatment out of lines. This applies for the small sprayers (wait longer for the big sprayer).

When spraying a series of rates of a specific herbicide, do NOT rinse between rates but start with the lowest rate and continue up to the highest rate. Following this procedure will minimize error as compared to rinsing each time (resulting in some dilution of each treatment by the residual rinse water). BE SURE TO RINSE BETWEEN DIFFERENT HERBICIDES, THOUGH.

ALWAYS SHAKE THE SPRAY CONTAINER JUST BEFORE SPRAYING THE TREATMENT.
Note: This spreadsheet is formatted to 5 decimal places for weighing the Refine Extra on the 4-decimal balance. For liquid formulations, roundoff to nearest 0.1 mL.

Sprayer output (L/ha) = 107
Total amount of spray soln (L) = 1.5

Trt no.	Item "no."	Name of product	% Conc	Rate of product (g ai/ha or % v/v)	Amt of product needed (g or ml)	
Canola						
1	a	Untreated	--	0	0.00000	
2	a	Refine Extra	75	0.05	0.00093	grams
2	b	Agral 90	--	0.2	3.00000	mL
3	a	Refine Extra	75	0.15	0.00280	grams
3	b	Agral 90	--	0.2	3.00000	mL
4	a	Refine Extra	75	0.5	0.00935	grams
4	b	Agral 90	--	0.2	3.00000	mL
5	a	Refine Extra	75	0.8	0.01495	grams
5	b	Agral 90	--	0.2	3.00000	mL
6	a	Refine Extra	75	2.0	0.03738	grams
6	b	Agral 90	--	0.2	3.00000	mL

To calculate Refine Extra sequential dilution:

Product required in 1.5 L water (g)	Active in 1.5 L water (g)	Stock solution (g product in **1.0 L** water)	Stock solution (g active in **1.0 L** water)	Final spray solution (g product in **1.5 L** water)	Final spray solution (g active in **1.5 L** water)
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Make first solution indoors on the day of application **(shake really well)!!**

0.00093	0.0006975	0.093	0.06975	0.00093	0.0006975

Take 10 mL of stock solution and add to 1.490 L of spray solution.

0.0028	0.0021	0.093	0.06975	0.00279	0.0020925

Take 30 mL of stock solution and add to 1.470 L of spray solution.

DON'T ADD SURFACTANT TO STOCK SOLUTION, BUT BE SURE TO ADD SURFACTANT TO THE FINAL SOLUTION (IN BICYCLE SPRAY CONTAINER OR POP BOTTLES) & SHAKE.

1 a	Untreated	--	0	0.00000
2 a	Roundup Transorb	36	13	0.50623 mL
2 b	Agral 90	--	0.2	3.00000 mL
3 a	Roundup Transorb	36	25	0.97352 mL
3 b	Agral 90	--	0.2	3.00000 mL
4 a	Roundup Transorb	36	50	1.94704 mL
4 b	Agral 90	--	0.2	3.00000 mL
5 a	Roundup Transorb	36	100	3.89408 mL
5 b	Agral 90	--	0.2	3.00000 mL
6 a	Roundup Transorb	36	200	7.78816 mL
6 b	Agral 90	--	0.2	3.00000 mL

Normal use rate for Buctril M is 1.0 L/ha product (or 0.405 L/ACRE as in the Crop Protection Guide). This normal rate would provide 280 g ai/ha of MCPA ester.
Use the specially formulated Buctril M blanks (from Aventis). The use rate is marked on the label (L/ha product). For use rates of less than normal for the MCPA ester 'blank', add the correct proportion of solvent/emulsifier 'blank'. Special formulations: MCPA ester rate = 0.670 L/ha (670 mL/ha), Solvent/emulsifier blank rate = 0.230 L/ha (230 mL/ha) (marked on containers).

1 a	Untreated	--	0	0.00000
2 a	MCPA ester		25	0.83862 mL
2 b	Solvent/emulsifier blank			2.93642 mL
3 a	MCPA ester		50	1.67724 mL
3 b	Solvent/emulsifier blank			2.64853 mL
4 a	MCPA ester		100	3.35447 mL
4 b	Solvent/emulsifier blank			2.07276 mL
5 a	MCPA ester		150	5.03171 mL
5 b	Solvent/emulsifier blank			1.49700 mL
6 a	MCPA ester		280	9.39252 mL
6 b	Solvent/emulsifier blank			0.00000 mL

Beans

1 a	Untreated	--	0	0.00000
2 a	Refine Extra	75	1.0	0.01869 grams
2 b	Agral 90	--	0.2	3.00000 mL
3 a	Refine Extra	75	3.0	0.05607 grams
3 b	Agral 90	--	0.2	3.00000 mL
4 a	Refine Extra	75	6.0	0.11215 grams
4 b	Agral 90	--	0.2	3.00000 mL
5 a	Refine Extra	75	12.0	0.22430 grams
5 b	Agral 90	--	0.2	3.00000 mL
6 a	Refine Extra	75	20.0	0.37383 grams
6 b	Agral 90	--	0.2	3.00000 mL

1 a	Untreated	--	0	0.00000
2 a	Roundup Transorb	36	30	1.16822 mL
2 b	Agral 90	--	0.2	3.00000 mL
3 a	Roundup Transorb	36	60	2.33645 mL
3 b	Agral 90	--	0.2	3.00000 mL
4 a	Roundup Transorb	36	90	3.50467 mL
4 b	Agral 90	--	0.2	3.00000 mL
5 a	Roundup Transorb	36	125	4.86760 mL
5 b	Agral 90	--	0.2	3.00000 mL
6 a	Roundup Transorb	36	250	9.73520 mL
6 b	Agral 90	--	0.2	3.00000 mL

Normal use rate for Buctril M is 1.0 L/ha product (or 0.405 L/ACRE as in the Crop Protection Guide). This normal rate would provide 280 g ai/ha of MCPA ester.
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2 a	MCPA ester		50	1.67724 mL
2 b	Solvent/emulsifier blank			2.64853 mL
3 a	MCPA ester		100	3.35447 mL
3 b	Solvent/emulsifier blank			2.07276 mL
4 a	MCPA ester		280	9.39252 mL
4 b	Solvent/emulsifier blank			0.00000 mL
5 a	MCPA ester		560	18.78505 mL
5 b	Solvent/emulsifier blank			0.00000 mL
6 a	MCPA ester		1120	37.57009 mL
6 b	Solvent/emulsifier blank			0.00000 mL