THE EVALUATION OF 2,4-D ESTER AND DICAMBA ON WINTER CANOLA IN OKLAHOMA

By

SAMANTHA AMBROSE

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IN OKLAHOMA

Thesis Approved:

Dr. Chad Godsey

Thesis Adviser

Dr. Sarah Lancaster

Dr. Jeffrey Edwards

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Winter canola (*Brassica napus*) is a valuable rotational crop for wheat (*Triticum* spp.) producers in the Southern Plains and provides opportunity to improve control of some winter annual grass weed species; however, unintentional drift of herbicide in winter wheat and pastures may cause damage to winter canola, reducing seed yields and decreasing crop quality. This study was conducted in 2011-2012 and 2012-2013 to determine the effect of simulated 2,4-D and dicamba drift on winter canola seed yield, 100-seed weight, and seed oil content when applied at various vegetative and reproductive growth stages. 2,4-D and dicamba were applied at 1/200, 1/40, 1/20, 1/10, and 1/5 of the recommended use rates for pasture maintenance at Stage 1 (leaf production), Stage 4 (flowering), and Stage 5 (pod development). Recommended use rates were 526 g ae ha^{-1} for 2,4-D and 281 g ae ha^{-1} for dicamba. Canola yield decreased with increasing 2,4-D rates at Stage 1 and Stage 4 during both growing seasons. One hundred percent yield reduction was observed following application of 2,4-D at 1/5 the recommended rate in both 2011-2012 and at 1/10 the recommended rate in 2011-2012. Yield in 2012-2013 also decreased with increasing 2,4-D rates at Stage 5 in 2012-2013. Dicamba had less effect on yield; however, some applications increased yield when compared to the control. Seed oil content decreased with increasing 2,4-D rates following application at Stage 1 and Stage 4 in both seasons. Applications of 2,4-D at Stage 5 decreased oil content at the 1/10 and 1/5 rates. Seed weight also decreased with increasing 2,4-D rates at Stage 1. In contrast, Stage 4 applications increased seed weight with increasing 2,4-D rates in both growing seasons. Stage 5 applications in 2012-2013 also increased seed weight with increasing 2,4-D rates. Applications of dicamba did not significantly affect seed oil content or seed weight for either year. This study shows that 2,4-D application has greater effect on canola yield, seed weight, and oil content than dicamba at similar rates. Yield was more affected at Stage 1 and Stage 4 compared to Stage 5. Seed weight was most affected when applications were made at Stage 4 and Stage 5, while oil content was affected differently from year to year.

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CHAPTER I

INTRODUCTION

Winter Canola in Oklahoma

Canola (*Brassica napus* L.) is an annual crop grown in many parts of the world in a multitude of climates. Worldwide, canola ranks second in oilseed production, surpassing peanut (*Arachis hupogaea* L.), sunflower (*Helianthus annuus* L.) and cotton (*Gossypium hirsutum* L.) (Foreign Agricultural Service/USDA, 2013).

Canola was developed in 1974 by Canadian plant breeders through traditional plant breeding methods. Breeders were able to remove anti-nutritional components by crosses between 3 *Brassica* species, *Brassica napus, Brassica campestris*, and *Brassica juncea* (Shahidi, 1990). This research resulted in a seed with 7% saturated fat, the lowest percentage of any other vegetable oil and low levels of erucic acid and glucosinolates (Canola Council of Canada, 2011). According to the Canola Council of Canada (2011), to be considered canola, a *Brassica* species must meet the following internationally regulated standard: "Seeds of the genus *Brassica* (*Brassica napus*, *Brassica rapa* or *Brassica juncea*) from which the oil shall contain less than 2% erucic acid in its fatty acid profile and the solid component shall contain less than 30 micromoles of any one or any mixture of 3-butenyl glucosinolate, 4-pentenyl glucosinolate, 2-hydroxy-3 butenyl glucosinolate and 2-hydroxy- 4-pentenyl glucosinolate per gram of air-dry oil-free solid." The presence of erucic acid and glucosninolates leads to fatty acid deposits on the heart and skeletal muscles. Glucosninolates in canola meal are also linked to liver disease in poultry, swine, and ruminants (Przybylski et al., 2005). Canola oil is now listed on the USDA's Generally Recognized as Safe (GRAS) list and promoted by the American Heart Association as heart healthy oil (Canola Council of Canada, 2011).

The promotion of canola oil by the American Heart Association had led to increased demand for the product, and as a result, canola production in the United States has increased from 147,000 acres in 1991 to 1,729,000 acres in 2012 (NASS, 2012). The geographic areas in which canola is produced in the United States have expanded significantly as well. The primary production areas are the Northern Plains and Pacific Northwest where spring planted cultivars are utilized; however, production of winter planted cultivars has increased in the Midwest, Great Plains, and Eastern U.S. (Raymer et al., 1990).

Canola production in Oklahoma has also increased with the improvement of winter hardy canola cultivars. Approximately 130,000 acres of canola were harvested in Oklahoma during 2012, compared to only 2,287 acres in 2007 (NASS, 2012). This acreage increase may be related to the benefits a canola rotation system can provide to the continuous wheat (*Triticum aestivum* L.) production systems in the Great Plains. In general, crop rotation has proven to not only improve soil quality, but also decrease pest problems and in some cases increase crop yields (Karlen et al., 1994; Holtzer et al., 1996; Krupinksky et al., 2002). Studies of crop rotations involving cereal crops and oilseed crops have also shown a possible increase in net returns and reduced economic risk (Dhuyvetter et al., 1996; Lafond et al., 1993).

A crop rotation of winter canola and winter wheat is a viable alternative to continuous winter wheat production systems in Oklahoma because it provides an economic benefit as well as a strategy to control problematic weed species such as Italian ryegrass (*Lolium perenne*) and feral rye (*Secale cereal*). Yield analysis conducted by Duke et al. (2009) concluded that canola/dual-purpose wheat rotations resulted in higher net returns when compared to wheat-only and canola-only cropping systems in Oklahoma. Furthermore, studies by Bushong et al. (2012) concluded that wheat yields in the second year of a wheat-canola rotation were greater than wheat yields in a second year of a continuous wheat system. Based on wheat and canola prices, the wheat-canola rotation also showed a greater net return pooled across 24 herbicide treatments.

Synthetic Auxin Herbicides

Herbicides classified as synthetic auxins include benzoic acids, phenoxycarboxylic acids, pyridine carboxylic acids, and quinolone carboxylic acids. These herbicides act similarly to endogenous auxin (IAA) in plants. IAA influences virtually every aspect of plant development and growth and interacts with many phytohormones in plants (Ross et al., 2002). IAA is highly regulated and released in small doses to stimulate growth and development processes. Plants are able to control natural IAA production by causing inactivation through multiple pathways (Woodard and Bartel, 2005). Synthetic auxins cause the same reactions as IAA in the plant; however, synthetic auxins tend to be longer lasting and have a stronger intensity of action due to high stability in the plant. These synthetic auxins have multiple research uses, including growth regulators for yield improvements, media components in tissue culture, and herbicides for weed control (Gianfagna et al.; 1995, Krikorian et al.; 1987,Sterling and Hall, 1997).

Low doses of synthetic auxin herbicides mimic the growth inhibiting effects caused by IAA at a constant, very large concentration in plant tissue (Grossman, 2003). Synthetic auxin herbicides can induce cell elongation and increase production of RNA, DNA, and proteins, which leads to uncontrolled cell division and growth, destroying vascular tissue. Greater concentrations of these herbicides may inhibit cell division and growth in meristematic regions, giving epinastic symptoms (WSSA, 2007). The statement was made by Gilbert in 1946 that the plants simply "grow themselves to death."

Since Gilbert's time, research efforts have been able to define the metabolic process when auxin mimic herbicides are applied. The mode of action for these auxin mimic herbicides has been attributed to a hormonal interaction with

1-aminocyclopropane -1-carboxylic acid (ACC) synthase in ethylene biosynthesis. The level of herbicide received or amount of signal that is distributed is species and organ specific (Grossmann, 2003). Ethylene is produced in small amounts in all plant tissues. Ethylene is produced during certain life stages, including germination, fruit ripening, leaf abscission, and flower senescence. Ethylene production may also be induced in response to injury or environmental stress (Abeles, 1973).

Plants that are affected by auxin mimic herbicides move through three phases: stimulation, inhibition, and decay (Sterling and Hall, 1997). The stimulation phase occurs within hours after application. The plant begins to activate metabolic processes in the shoot tissue, resulting in abnormal growth such as leaf epinasty and stem curling. Cell elongation is also initiated. Within 24 hours, the inhibition phase takes place. A growth inhibition occurs in the root and shoot tissues, which decreases elongation and leaf area. The plant also intensifies green pigment production. Stomatal closure occurs, reducing transpiration, carbon assimilation, and starch formation. Reactive oxygen is overproduced within the plant. The decay phase occurs when the plant begins to accelerate senescence and tissue decay. The vascular system and membranes are destroyed, causing wilting, necrosis, and death (Cobb, 1992; Sterling and Hall, 1997; Grossmann, 2003).

Two synthetic auxin herbicides commonly used to control weeds in Oklahoma wheat fields and pastures are 2, 4-D (4-(2,4-dichlorophenoxy butyric acid) and dicamba (3,6-dichloro-2-methoxybenzoic acid). 2,4-D is a foliar applied synthetic auxin herbicide and is labeled in many crops, including wheat, barley (*Hordeum vulgare* L.), oats (*Avena sativa*), rye sorghum (*Sorghum* *bicolor*), field corn (*Zea mays*), soybean (*Glycine max*) (pre-plant), and fallow fields. 2,4-D controls many broadleaf weed species, including carpetweed (*Mollugo verticillata* L.), dandelion (*Taraxacum offincinale*), cocklebur (*Xanthium spp.*), horseweed (*Conyza Canadensis*), morningglory (*Ipomoea spp*.), pigweed (*Amaranthus spp.*), and lambsquarters (*Chenopodium album*). The mechanisms of action of 2,4-D is not completely understood; however, 2,4-D is similar to IAA and is metabolized by plants slowly. 2,4-D does contain non-herbicidal biological properties, acting as a plant synthetic auxin to induce rooting and blossom set when applied at low doses. 2,4-D is commonly used as an auxin source in some plant tissue culturing (WSSA, 2007).

Dicamba is also a foliar applied synthetic auxin herbicide. Dicamba is labeled in the following crops: corn, sorghum, small grains, pasture, rangeland, and turfgrass. Weed species controlled by dicamba include annual and perennial broadleaves, such as wild buckwheat (*Polygonum convolvulus*), pigweed, Canada thistle (*Cirsium arvense*), perennial sowthistle (*Sonchus arvensis*), and field bindweed (*Convolvulus arvensis*). Dicamba acts as an IAA mimicking herbicide. Dicamba readily penetrates the plant; however, it does not penetrate as rapidly as the phenoxyacetic acids like 2,4-D (WSSA, 2007).

Herbicide Drift Challenges

With canola acreage increasing in Oklahoma, off-target movement of synthetic auxin herbicides used in pasture and small grain production has become a greater concern. 2, 4-D and dicamba are commonly used in Oklahoma to control weeds prior to planting summer crops, in winter wheat crops, or in roadside treatments. They are also used to control broadleaved weeds in pastures, thereby exposing broadleaf crops to drift at different stages of growth and possibly multiple times during a single growing season (Marple et al., 2008). The effect of low dosages of both 2,4-D and dicamba due to drift is a problem in sensitive crops growing near production systems that utilize these herbicides. Although the annual economic loss due to herbicide drift is not large across the industry, those individuals who are affected could suffer severe losses (Dexter, 1980).

Research efforts have found that many factors influence herbicide drift, including environmental conditions and chemical properties (Al-Khatib et al., 1992). Boom height and wind speed are two of the major application variables contributing to off-target drift. Previous research has shown that drift from unshielded sprayers can range from 1-16% depending on these factors (Wolf et al., 1993).

Broadleaf crops, including cotton, soybean, and sunflower, have shown sensitivity to low doses of herbicides from drift. Cotton response to herbicide drift, for example, varies among herbicides. Cotton was more sensitive to glufosinate than to glyphosate drift 7 d after treatment; however, cotton maturity was not affected by either herbicide (Ellis and Griffin, 2002). The greatest effect on cotton was observed with drift simulation rates of quinclorac that were applied during early flower bud development. When cotton is in the reproductive phase of growth, systemic herbicides reduced cotton yields more than contact herbicides (Snipes et al., 1992). Studies conducted by Marple (2008) concluded that cotton plants are susceptible to both 2,4-D and dicamba drift; however, more damage was credited to 2,4-D. After testing four growth stages of cotton, it was concluded that both 2,4-D and dicamba affect plants the most at early growth stages.

Soybean has also shown sensitivity to potential herbicide drift. Dicamba injury evaluations showed that height reductions and plant morphology are excellent predictors for yield reduction in soybean. Some yield reductions, even at low dicamba rates of 1.3 g ha^{-1}, were attributed to droughty conditions, where soybean was less able to recover from injury compared to well-watered conditions (Weidenhamer et al., 1989). Increased herbicide injury due to dry conditions was also observed in a study conducted by Auch and Arnold (1978). Dicamba injury symptoms were also more severe when plants were exposed to higher temperatures after application (Al-Khatib,1999). This study also found that when applied at the 2-3 trifoiliate growth stage, plants began recovering by 30 d after treatment for the lowest dose ($^{1/}{}_{100}$ recommended rate) and by 45 d after treatment for the highest dose ($^{1/}{}_{3}$ recommended rate). A study evaluating both 2,4-D and dicamba effects at different stages of soybean growth concluded that fraction uses of 2,4-D at the prebloom growth stages increased branching, while dicamba delayed flowering. As plants matured, however, flower delay did not occur. Treatments of 2,4-D applied at the bloom stage showed more visual damage than dicamba, but dicamba treatments resulted in more yield loss. It was also found that dicamba was about 8-fold more injurious to soybean in the bloom stage than in the pre-bloom stage (Wax et. al, 1969).

Sunflower has also been reported to respond negatively to spray drift of dicamba and 2,4-D. Exposure to dicamba resulted in decreased plant dry weight with increasing dicamba rate. Seed yield decreased when dicamba was applied at 3.2 g ha^{-1}; however, yield did not decrease with rates less than this, even though visual injury to the plant was observed at the 2-4 leaf stage (Derksen, 1989). Wall (1996) found injury and reduced yields of sunflower following 2,4-D application at rates ranging from 9.5 to 151.2 g a.i. ha^{-1}. At the greatest dose, yield losses were 100% each year in 1992, 1993, and 1994. Sunflower yields showed less ability to recover during cooler years than in a year with near normal temperatures. Oil content also decreased with increasing 2,4-D rates. At the f 151.2 g a.i. ha^{-1}, reductions in oil content for each year were 16, 5, and 15%. Greenshields and Putt (1958) also found that yield reduction was correlated to those sunflower with small headsize, rows of empty seeds, and lighter weighted seed. Lighter seed weight contributed to low seed oil percentage.

Like other broadleaf crops, canola responds to a variety of herbicides. Research conducted in Australia evaluated canola cultivar response to 1x and 2x doses of clopyralid, benazolin/clopyralid, metolachlor, dicamba, pyridate, diflufenican, diuron, pyridate, ethameltsulfuron, isoxaben, and metazachlor/quinmeric (Heap et al., 1993). Most cultivars showed tolerance to a number of these treatments; however, dicamba is one of many treatments of which canola was not tolerant. Cultivar damage was noted following dicamba applications at rates of 150 and 300 g a.i. ha^{-1}. Canola yield following application of dicamba at both rates was less than the nontreated plots for each year in a six year period. Yield ranged from 66-93% of control when dicamba was applied at 150 g a.i. ha^{-1} and 43-97% of nontreated plots when dicamba was applied at 300 g a.i. ha^{-1}, depending on cultivar. Oil content was also influenced by dicamba applications at the higher rate and ranged from 97.1-98.1% of nontreated, depending on cultivar.

Canola response to thifensulfuron and tribenuron mixtures at low doses was evaluated in Canada at 2-3 leaf, 4-5 leaf, and 6-7 leaf (beginning to bolt) growth stages. Injury symptoms were visible following applications of doses greater than 0.9 g a.i. ha^{-1}, with some injury being induced by colder temperatures that slowed metabolism of the herbicides (Wall, 1997). This is similar to the results reported in Wall's (1994) earlier work with thifensulfuron andtribenuron in broadleaf crops. The dosage effect was greater when the herbicide was applied at the 6-7 leaf stage than at the other stages. Canola seed yield also decreased with increasing herbicide rate. An interaction was also observed between leaf stage and herbicide dosage. The herbicide application at the earliest growth stage of 2-3 leaves did not affect seed oil content; however, oil content decreased when herbicides were applied at doses greater than 0.9 g a.i. ha^{-1} at the 4-5 leaf and 6-7 leaf stages (Wall, 1997).

Currently, there is limited research evaluating winter canola response to herbicide drift. Wall (1996) conducted experiments to study the effect of 2,4-D drift on spring canola cultivars.

Growth and yield responses of canola to low rates of 2,4-D were monitored after application 2-3 weeks following crop emergence when canola was in the 3-4 leaf growth stage. Application rates were 0, 9.45, 18.9, 37.8, 75.6, and 151.2g a.i. ha^{-1} 2,4-D. These rates corresponded to 0, 1.5, 3, 6, 12, and 24% of the recommended rate from the Manitoba Agriculture Guide to Crop Production (630 g ha^{-1}).

According to Wall's results, injury to canola varied among years. During 1992, there was no response in any of the traits measured; however, 1993 and 1994 canola exhibited moderate to severe injury (>15%) when 2,4-D was applied at 151.2 g ha^{-1}. At harvest, no visual injury was distinguished between any treated plots compared to the untreated plots. Canola yields were unaffected in 1992. During both 1993 and 1994, a linear reduction in yield was noted with increasing 2,4-D rate. Canola yield was reduced 52% in 1993 and 16% in 1994 when 2,4-D was applied at 151.2 g ha^{-1}. Seed oil content was unaffected by 2,4-D in any year of the study. Wall attributed the varied response to 2,4-D to differing weather conditions among years. The conclusion for this particular study was that there is a strong relationship between visual estimates of crop injury and yield, suggesting that visual estimates of crop injury 2 weeks after application could be useful in estimating potential yield losses.

Betts and Ashford (1976) conducted a study on spring cultivars by treating with four rates of 2,4-D at four growth stages, including two vegetative stages, bolting, and flowering. 2,4-D rates had more visible damage on younger plants. Damage symptoms included leaf curling and leaf brittleness at early, vegetative stages and floral and apical meristem damage at bolting and flowering stages. Pod abortion was noted, and those plants with meristem damage did not continue initiating new growth or buds. Seed yield was decreased with increasing 2,4-D rates at early and late plant stages. Plants treated at bolting and flowering increased seed size with increasing 2,4-D rates.

Betts and Ashford (1976) also found that canola seed oil content and maturity was affected by 2,4-D. Spring cultivars contained less oil when applications were made at vegetative and flowering growth stages; however, oil content results were variable, so it was inconclusive as to which growth stage and which rate of 2,4-D had the greatest reduction.

Canola Response to Environmental Stress

Previous research concerning canola response to environmental stress factors could suggest possible outcomes if winter canola is affected by herbicide drift while experiencing environment-related stress (Gan et al., 2004). A study evaluating the influence of high temperature and drought on spring canola in Canada showed that temperatures of 35ºC for 10 d reduced pod production by approximately 25% compared to those plants grown at 20 ºC. Plants grown at 28ºC produced more than double the pods produced by plants grown at 20 ºC. All pods formed during 35 ºC stresses were sterile, except for one cultivar during bolting. Main stem pod production was lowest when stress was induced at the flowering stage and least affected at the budding stage, regardless of temperature and water stress.

High temperatures also reduced seeds per pod by almost 25% relative to the nontreated control. Gan et al. (2004) hypothesized that this was a result of the plant attempting to increase pod production. At high temperatures, seeds per pod were reduced by 13 to 44% with an 11 to 33% reduction in pods. Canola seed weight also suffered a 22% average loss at high temperatures; however, when plant available water was maintained at 50%, the seed weight was reduced by only 3%. Total yield was reduced by 54% at 28 ºC and 87% at 35 ºC.

Although these responses in spring canola are environmentally induced, the reaction of the crop is a good indication of possible outcomes to herbicide injury stress. Because canola is an indeterminate plant, the number of flower initials that develop is usually limited. In field conditions, approximately 2% to 10% of the flowering potential is realized because of the natural abortion of flowers (Olsson, 1960). Early studies concluded that spring cultivars have only 45% of flowers open and develop into pods that are then harvested (Tayo and Morgan, 1975). Other experiments conducted with winter cultivars resulted in similar levels of pod development (Mendham and Scott, 1975). A study evaluating the effect of insect damaged pods on canola yield reported a correlation between the number of flowers produced and the amount of abortion. This was credited to the plants either producing more flowers to replace early flower loss due to insect damage or shedding flowers in scenarios of no damage to achieve a pre-determined pod carrying capacity (Williams and Free, 1979).

Williams and Free (1979) also found that when flowers and buds were removed from rapeseed, the flower and pod production increased. Another study on the effects of bud, flower, or pod removal from rapeseed and related species indicated that recovery is possible when injury occurs at early flowering (McGregor, 1981). In both McGregor's study (1981) and Tayo and Morgan's study (1975), most pod abortion occurred at the end of flowering. When buds or flowers were lost due to injury early in the season, there was potential for the plant to abort fewer pods at the end of the season and make up for potential yield loss.

Canola's ability to provide income similar to winter wheat and increase winter wheat yields makes it a competitive alternative to continuous wheat production practices in the Southern Great Plains. However, because of the abundance of wheat fields, the potential for damage to canola from drifting herbicides is great. This research will provide more knowledge on canola's response to synthetic auxin herbicides resulting from unintentional drifting of 2,4-D and dicamba.

CHAPTER II

THE EVALUATION OF 2,4-D ESTER AND DICAMBA DRIFT ON WINTER CANOLA IN OKLAHOMA

Introduction

Canola production in the United States has increased from 147,000 acres in 1991 to 1,729,000 acres in 2012 (NASS, 2012). In Oklahoma, canola production has increased with the improvement of winter hardy cultivars. Winter canola is often planted near wheat (*Triticum aestivum* L.) and pasture, which receive one or more applications of synthetic auxin herbicides, such as 2,4-D and dicamba, during a typical growing season. These circumstances expose canola to possible unintentional herbicide drift that may cause damage. The year-round potential for synthetic auxin herbicide applications expose winter canola to drift challenges at different growth stages.

Synthetic auxin herbicides can cause critical damage that may lead to severe economic losses (Dexter, 1980). Drift potential has been documented in broadleaf crops studies, including cotton (*Gossypium hirsutum* L.) (Marple, 2007), sunflower (*Helianthus annuus* L.) (Derksen, 1989), and soybean (*Glycine max*) (Weidenhamer et al., 1989).

Although injury to canola from herbicides has been documented, there is little information on 2,4-D and dicamba drift effects on winter canola cultivars. Spring canola cultivars reduced yields relative to the nontreated control when dicamba was applied at 150 and 300 g a.i. ha^{-1}. This same study showed oil content was affected by dicamba, but was dependent on canola cultivar (Heap et. al., 1993). Spring cultivars had more visible damage when 2,4-D was applied to younger plants. Damage symptoms included leaf curling and leaf brittleness at early vegetative stages and floral and apical meristem damage at bolting and flowering stages. Pod abortion was noted, and those plants with meristem damage did not continue initiating new growth or buds. Seed yield was decreased with increasing 2,4-D rates at early and late plant stages. Plants treated at bolting and flowering increased seed size with increasing 2,4-D rates (Betts and Ashford, 1976).

The objectives of this study were 1) to find which herbicide had the greatest effect on canola yield, seed weight, and oil content caused by simulated drift rates of 2,4-D ester and dicamba; 2) to determine when the plant would be most vulnerable during the growing season; and 3) to find the rate of 2,4-D ester and dicamba necessary to cause crop injury.

Material and Methods

Field trials were conducted during the 2011-2012 and 2012-2013 winter canola growing seasons at two locations in east central Oklahoma. The normal annual precipitation in this area (1971-2000) is 88 cm. The first site was located at the Oklahoma State University (OSU) Cimarron Valley Research Center near Perkins, Oklahoma (N 35.997563, W -97.045091). The primary soil found at this site was Udic Agriustoll. The second site was located at the OSU Efaw Research Center (N 36.131055, W -97.105489) in 2011 and the OSU Agronomy Farm (N 36.120654, W -97.088832) in 2012 in Stillwater, Oklahoma. The primary soil found at these sites was Fluventic Haplustoll at the Efaw research station with an organic matter content of 2-2.5% and a loam texture and Udic Paleustoll at the OSU agronomy farm with an organic matter content of 1-2% and a fine, silty texture. At all locations, canola was grown in a conventional tillage system under dry land conditions.

A glyphosate-resistant winter canola hybrid, ‘Dekalb 46-15’, was planted in late September of each year in 19 cm rows at a population density of 5.6 kg ha^{-1}. Experimental plots were 2.3 by 7.6 m. Approximately 34 kg ha^{-1}of nitrogen as urea was applied pre-plant and 112 kg ha^{-1} nitrogen as urea and 11 kg ha^{-1} sulfur applied top dress. Plots were kept pest free as needed with glyphosate + ammonium sulfate and lambdacyhalothrin.

Trials were arranged in a split-split plot design using randomized complete blocks, with application timing as the main plot, herbicide as the sub-plot, and herbicide rate as the sub-sub-plot. Treatments included five rates of 2,4-D ester (3, 13, 26, 53, 105 g ha^{-1}) or dicamba dimethylamine (DMA) salt (1, 7, 14, 28, 56 g ha^{-1}). These rates are based on 1/200, 1/40, 1/20, 1/10, and 1/5 of recommended pasture rates for Agri Star® 2,4-D LV4 (526 g ae ha^{-1}) and Dicamba DMA salt (280.5 g ae ha^{-1}) (Albaugh Inc., Ankeny, IA). Treatments were applied at either Stage1: leaf production, Stage 4: flowering or Stage 5: pod development (BayerCropScience, 2012). Applications were made during Stage 1 when 4-6 leaves were fully extended. Applications at Stage 4 were applied when 30% of flowers were open. Applications were made during Stage 5 when pod development started on the lowest 1/3 of the branches on the main stem. Tables 2.1-2.4 provide the exact dates of each treatment application. Non-ionic surfactant (NIS) at 0.25% v/v was included with all treatments (United Suppliers, Inc., Eldora, IA).

Treatments were applied at a volume of 56 L ha^{-1} using a CO_2-pressurized backpack sprayer with TeeJet 8001EVS flat fan nozzles (TeeJet, Sioux Falls, SD). Table 2.5 provides application equipment information. Drift boards were used during fall applications to prevent herbicide drift to neighboring plots.

Crop injury was visually estimated 7, 14, and 28 d after each application and approximately 5 to 7 d before swathing using a scale of 0 (no injury) to 100 (complete crop

Table 2.1. Treatment application information for 2,4-D and dicamba drift studies in Perkins, Oklahoma in 2011-2012.

	Stage 1	Stage 4	Stage 5
Application Date	October 28, 2011	March 26, 2012	April 10, 2012
Time of Day	1:00 pm	1:45 pm	1:00 pm
Air Temperature(℃)	14.4	27.8	23.7
Relative Humidity	61%	44.8%	49%
Wind Velocity(KPH)	6.4	10.1	6.6
Wind Direction	Northwest	Southwest	Northeast
Soil Temperature(℃)	15	17.8	17.8
Soil Moisture	Slightly wet	Adequate	Adequate
Cloud Cover	0%	10%	20%

Table 2.2. Treatment application information for 2,4-D and dicamba drift studies in Stillwater, Oklahoma in 2011-2012.

	Stage 1	Stage 4	Stage 5
Application Date	October 28, 2011	March 25, 2012	April 10, 2012
Time of Day	3:00 pm	3:00 pm	3:00 pm
Air Temperature(℃)	17.2	28.9	26.7
Relative Humidity	32%	38%	48.4%
Wind Velocity(KPH)	4.8	3.2	3.8
Wind Direction	North	South	Northeast
Soil Temperature(℃)	16.7	18.9	17.7
Soil Moisture	Adequate	Wet	Adequate
Cloud Cover	0%	0%	10%

Table 2.3. Treatment application information for 2,4-D and dicamba drift studies in Perkins, Oklahoma in 2012-2013.

	Stage 1	Stage 4	Stage 5
Application Date	October 26, 2012	April 16, 2013	May 6, 2013
Time of Day	10:30 am	4:15 pm	11:45 am
Air Temperature(℃)	5.6	28.3	20.8
Relative Humidity	60.4%	41.2%	55.1%
Wind Velocity(KPH)	14.7	3.7	10.6
Wind Direction	North	Northeast	North
Soil Temperature(℃)	13.4	15.8	14.3
Soil Moisture	Adequate	Adequate	Adequate
Cloud Cover	70%	0%	20%

Table 2.4. Treatment application information for 2,4-D and dicamba drift studies in Stillwater, Oklahoma in 2012-2013.

	Stage 1	Stage 4	Stage 5
Application Date	October 26, 2012	April 16, 2013	May 6, 2013
Time of Day	9:00 am	3:00 pm	10:00 am
Air Temperature(℃)	5.6	24.3	17.8
Relative Humidity	41%	52%	58.2%
Wind Velocity(KPH)	9.1	7.4	9.1
Wind Direction	North	Northeast	North
Soil Temperature(℃)	12.7	13.5	12.6
Soil Moisture	Dry	Slightly wet	Adequate
Cloud Cover	80%	0%	10%

Table 2.5. Application equipment used for 2,4-D and dicamba drift studies for the 2011-2012 and 2012-2013 growing seasons.

	2011-2012	2012-2013
Application equipment	Backpack	Backpack
Operating pressure (psi)	28	28
Nozzle type	Flat Fan	Flat Fan
Nozzle size	8001	8001
Nozzle spacing (cm)	50.8	50.8
Boom length (cm)	203.2	152.4
Boom height above canopy (cm)	50.8	50.8
Ground speed (KPH)	5.6	5.6
Carrier	H_20	H_20
Spray volume (GPA)	6	6
Propellant	CO_2	CO_2

mortality) (Frans, 1986). In the 2011-2012 growing season, prior to swathing, five random plants from each plot were removed from and evaluated for number of primary branches, secondary branches, infertile pods, and fertile pods. This data was not collected for 2012-2013.

Swathing was conducted when the average seed color change on the main stem was 40-60% and the seed contained 30 to 40% moisture (Plot Master F30, R-Tech Industries Ltd., Homewood, Canada).

Seven to 10 d after swathing an area of 1.5 m by 6.1 m was machine harvested from the center of all plots (Wintersteiger Delta, Wintersteiger Inc., Salt Lake City, UT). Seed weight was recorded and yield was adjusted to 10% seed moisture. Seed was cleaned and analyzed for seed oil content using Near Infrared Analysis (NIR) (7200 NIR Analyzer, Perten Instruments, Hagersten, Sweden) and weight for 100 seeds was determined.

Data were subjected to analysis of variance (ANOVA) using the mixed procedure in SAS® (SAS Institute Inc. Version 9.3). Treatment for crop injury, yield, number of primary branches, secondary branches, infertile pods, fertile pods, 100-seed weight, and seed oil content were compared using analysis of variance. Location was included in the model as a random effect and was combined for each year.

Results

The winter canola growing season for 2011-2012 was consistently dry and warm for both locations in Payne County when compared to the 30-yr average (Tables 2.6-2.7). Rainfall was less than average for each month and temperatures were higher for each month. Swathing and harvest occurred in mid-May.

Table 2.6. Average monthly air temperatures and monthly precipitation sums from September to May at Perkins, Oklahoma, during the 2011-2012 and 2012-2013 growing seasons.

	Precipitation (cm)			Temperature (℃)		
Months	2011-2012	2012-2013	30 yr.	2011-2012	2012-2013	30 yr.
September	2.18	1.34	4.17	21.7	23.3	22.2
October	2.88	0.87	3.33	16.7	15.6	15.6
November	3.81	0.65	2.62	10.0	11.7	9.4
December	2.07	0.59	1.85	4.4	4.4	3.3
January	0.96	1.77	1.26	5.6	4.4	2.2
February	2.41	3.29	1.65	6.7	5.0	4.4
March	4.52	0.54	3.08	15.6	8.9	20.0
April	5.06	5.10	3.49	17.8	12.2	15.0
May	1.12	16.2	5.70	23.3	18.9	20.0

Table 2.7. Average monthly air temperatures and monthly precipitation sums from September to May at Stillwater, Oklahoma, during the 2011-2012 and 2012-2013 growing seasons.

	Precipitation (cm)			Temperature (℃)		
Months	2011-2012	2012-2013	30 yr.	2011-2012	2012-2013	30 yr.
September	*	2.8	10.6	21.1	22.8	22.2
October	*	1.5	8.3	16.1	15.6	15.6
November	6.7	1.1	6.5	10.0	11.1	9.4
December	5.5	1.1	4.6	3.3	6.1	3.3
January	2.4	2.6	3.2	4.4	3.9	2.2
February	7.4	7.9	4.0	5.6	4.4	4.4
March	10.0	2.8	7.8	15.6	8.3	20.0
April	15.6	13.5	8.8	17.8	12.2	15.0
May	2.8	14.3	14.1	22.8	19.1	20.0

* Data unavailable

The 2012-2013 winter canola growing season started dry and cool for both locations in Payne County when compared to the 30-yr average (Tables 2.6-2.7). Rainfall was less than average for the months of September through December and greater than average for the months of January through May. Temperatures were higher than the 30-yr average from September to February; however, March, April, and May were much cooler than the 30 year average temperatures.

For all results when three way interactions were observed (herbicide*herbicide rate*timing of application) data will be presented and discussed by herbicide. Visual inspection of the data for all main effects of interest indicated a clear difference between herbicides. When averaged across rate, yield of 2,4-D was 1,542 kg $ha^{-1}$and dicamba was 2,203 kg ha^{-1}(Pr>F = <.0001) in 2011-2012 and 1,866 kg $ha^{-1}$and 2,345 kg ha^{-1} (Pr>F = <.0001) in 2012-2013, respectively. Seed oil content averaged 36.9% when canola was treated with 2,4-D and 43.8% when treated with dicamba (Pr>F = <.0001) in 2011-2012 and 38.6% and 42.4% (Pr>F = <.0001) in 2012-2013. Canola seed weight averaged 0.33 g 100-$seeds^{-1}$ when treated with 2,4-D and 0.37 g 100-$seeds^{-1}$ when treated with dicamba (Pr>F = <.0001) in 2011-2012 and 0.34 g 100-$seeds^{-1}$ and 0.32 g 100-$seeds^{-1}$ (Pr>F = <.0001) in 2012-2013.

Crop Injury

In general, canola injury symptoms and recovery were dependent on the type of herbicide applied. A three-way interaction was observed between herbicide, herbicide rate, and timing of application at each visual rating. During both growing seasons, overall visual injury was less severe with all dicamba applications when compared to 2,4-D applications.

2,4-D. In both growing seasons, applications of 2,4-D had a greater effect on younger, less established winter canola than older, more established plants (Tables 2.8-2.9). Visual injury

Table 2.8. Influence of 2,4-D application timing on visual injury of winter canola at Stillwater and Perkins, Oklahoma during the 2011-2012 growing season.

		Days after treatment			
Timing†	Rate‡	7	14	28	Swathing
		Visual injury ratings (%)			
Stage 1					
	$^{1}/_{200}$	0	0	0	2
	$^{1}/_{40}$	1	4	11	15
	$^{1}/_{20}$	7	21	31	47
	$^{1}/_{10}$	31	40	62	99
	$^{1}/_{5}$	41	48	78	99
Stage 4					
	$^{1}/_{200}$	2	13	9	0
	$^{1}/_{40}$	4	13	9	1
	$^{1}/_{20}$	10	18	5	5
	$^{1}/_{10}$	36	59	42	53
	$^{1}/_{5}$	70	76	63	72
Stage 5					
	$^{1}/_{200}$	0	0	0	0
	$^{1}/_{40}$	0	0	1	0
	$^{1}/_{20}$	0	0	1	1
	$^{1}/_{10}$	0	0	1	2
	$^{1}/_{5}$	0	1	1	1

†Timing corresponds to the following dates: Stage 1: October 28, 2011, Stage 4: March 26, 2012, Stage 5: April 10, 2012.

‡Use rate for 2,4-D was 526 g ae ha^{-1}.

Table 2.9. Influence of 2,4-D application timing on visual injury of winter canola at Stillwater and Perkins, Oklahoma during the 2012-2013 growing season.

		Days after treatment			
Timing†	Rate‡	7	14	28	Swathing
		Visual injury ratings (%)			
Stage 1					
	$^{1}/_{200}$	0	0	0	0
	$^{1}/_{40}$	1	3	5	3
	$^{1}/_{20}$	4	12	24	18
	$^{1}/_{10}$	19	36	58	68
	$^{1}/_{5}$	27	49	73	99
Stage 4					
	$^{1}/_{200}$	1	1	0	0
	$^{1}/_{40}$	2	3	0	1
	$^{1}/_{20}$	8	15	8	14
	$^{1}/_{10}$	29	46	48	57
	$^{1}/_{5}$	62	83	71	83
Stage 5					
	$^{1}/_{200}$	1	1	0	0
	$^{1}/_{40}$	1	2	2	2
	$^{1}/_{20}$	4	6	4	4
	$^{1}/_{10}$	8	10	8	8
	$^{1}/_{5}$	15	21	22	23

†Timing corresponds to the following dates: Stage 1: October 26, 2012, Stage 4: April 16, 2013, Stage 5: May 6, 2013.

‡Use rate for 2,4-D was 526 g ae ha^{-1}.

was more severe when 2,4-D was applied at higher doses for each application timing and intensified throughout the season.

Applications at Stage 1 caused leaf petiole elongation, general chlorosis of the leaves, and plant mortality with doses greater than 1/10 of the labeled rate. Visual injury intensified for every increase in 2,4-D application rate. The immediate effect of 2,4-D application was delayed in the 2012-2013 growing season when compared to the 2011-2012 growing season. The delay was most likely a result of cooler air temperatures following application; however, by the time 14 d observations were taken, injury was similar in both growing seasons.

Stage 4 applications of 2,4-D in both growing seasons caused stem epinasty and twisting, leaf cupping, and flower and bud mortality. Loss of flowers following 2,4-D application at Stage 4 greatly decreased the number of visible developing pods. Injury was evident for each 2,4-D rate at all rating dates; however, the greatest crop injury was observed at swathing in plots treated with 1/10 and 1/5 rates of 2,4-D.

Stage 5 applications did not result in visual injury above 16%; however, any flowers still blooming at the time of application were lost 7 d after application. Crop injury was initially higher at 7 d after application, but recovered prior to swathing.

Dicamba. Overall, applications of dicamba resulted in less crop injury than 2,4-D. Crop injury was visible throughout both seasons; however, the intensity and recovery varied for each winter canola stage. Visual injury was more severe with higher doses for each application (Tables 2.10-2.11).

Applications at Stage 1 showed the same injury symptoms as 2,4-D, but these symptoms were not as intense. Leaf cupping was also associated with dicamba injury. Injury was not above 11% 7 d after application, but increased by 28 d after application. Higher doses of dicamba had more

Table 2.10. Influence of dicamba application timing on visual injury of winter canola at Stillwater and Perkins, Oklahoma during the 2011-2012 growing season.

		Days after treatment			
Timing†	Rate‡	7	14	28	Swathing
		Visual injury ratings (%)			
Stage 1					
	$^1/_{200}$	0	0	0	0
	$^1/_{40}$	0	0	1	0
	$^1/_{20}$	0	0	1	0
	$^1/_{10}$	0	1	2	1
	$^1/_5$	8	6	9	1
Stage 4					
	$^1/_{200}$	0	4	1	0
	$^1/_{40}$	1	4	0	0
	$^1/_{20}$	1	3	0	0
	$^1/_{10}$	3	4	0	1
	$^1/_5$	11	16	3	3
Stage 5					
	$^1/_{200}$	0	0	0	0
	$^1/_{40}$	0	0	0	0
	$^1/_{20}$	0	0	1	1
	$^1/_{10}$	0	0	2	2
	$^1/_5$	0	1	1	1

†Timing corresponds to the following dates: Stage 1: October 28, 2011, Stage 4: March 26, 2012, Stage 5: April 10, 2012.

‡Use rate for dicamba was 281 g ae ha^{-1}.

Table 2.11. Influence of dicamba application timing on visual injury of winter canola at Stillwater and Perkins, Oklahoma during the 2012-2013 growing season.

		Days after treatment			
Timing†	Rate‡	7	14	28	Swathing
		Visual injury ratings (%)			
Stage 1					
	$^1/_{200}$	0	0	0	0
	$^1/_{40}$	0	0	1	0
	$^1/_{20}$	0	0	0	0
	$^1/_{10}$	0	1	2	0
	$^1/_5$	4	4	8	4
Stage 4					
	$^1/_{200}$	0	1	0	0
	$^1/_{40}$	1	3	1	1
	$^1/_{20}$	1	2	1	1
	$^1/_{10}$	2	5	2	4
	$^1/_5$	7	15	13	7
Stage 5					
	$^1/_{200}$	0	0	0	0
	$^1/_{40}$	0	1	0	0
	$^1/_{20}$	1	1	1	1
	$^1/_{10}$	3	3	1	1
	$^1/_5$	5	7	4	4

† Timing corresponds to the following dates: Stage 1: October 26, 2012, Stage 4: April 16, 2013, Stage 5: May 6, 2013.

‡ Use rate for dicamba was 281 g ae ha^{-1}.

effect than lower doses. In both growing seasons, visual injury in plots where dicamba was applied at Stage 1 was less at swathing that 28 d after application.

Similar to Stage 1, applications of dicamba at Stage 4 resulted in less intense symptoms compared to 2,4-D, including flower loss and slight stem twisting. Crop injury increased with increasing dicamba applications. Dicamba applications at Stage 4 resulted in the greatest crop injury compared to other timings; however, observations indicated winter canola was able to recover between 14 d after application and 28 d after application.

Stage 5 applications resulted in very few visual symptoms at time of observation, with only a small loss of flowers blooming during the application time.

Yield

Overall, winter canola yields were within Oklahoma's state average yield in the 2011-2012 and 2012-2013 growing seasons. The average yield for nontreated control plots was 2,225 kg ha^{-1} in 2011-2012 and 2,331 kg ha^{-1} in 2012-2013. A three-way interaction was observed between herbicide, herbicide rate, and timing of application for both growing seasons. 2,4-D and dicamba both affected winter canola at various rates and stages, but 2,4-D application resulted in greater yield loss compared to dicamba.

2,4-D. Applications of 2,4-D caused greater yield reductions when applied to younger winter canola than older, more established winter canola in both growing seasons. The rate of 2,4- that caused effects was dependent on growth stage, but overall, there was a greater effect with higher doses of 2,4-D (Figures 2.1-2.2). During both growing seasons, yield decreased with increasing rates of 2,4-D at Stage 1 and 4. This trend was also seen in Stage 5 in 2012-2013.

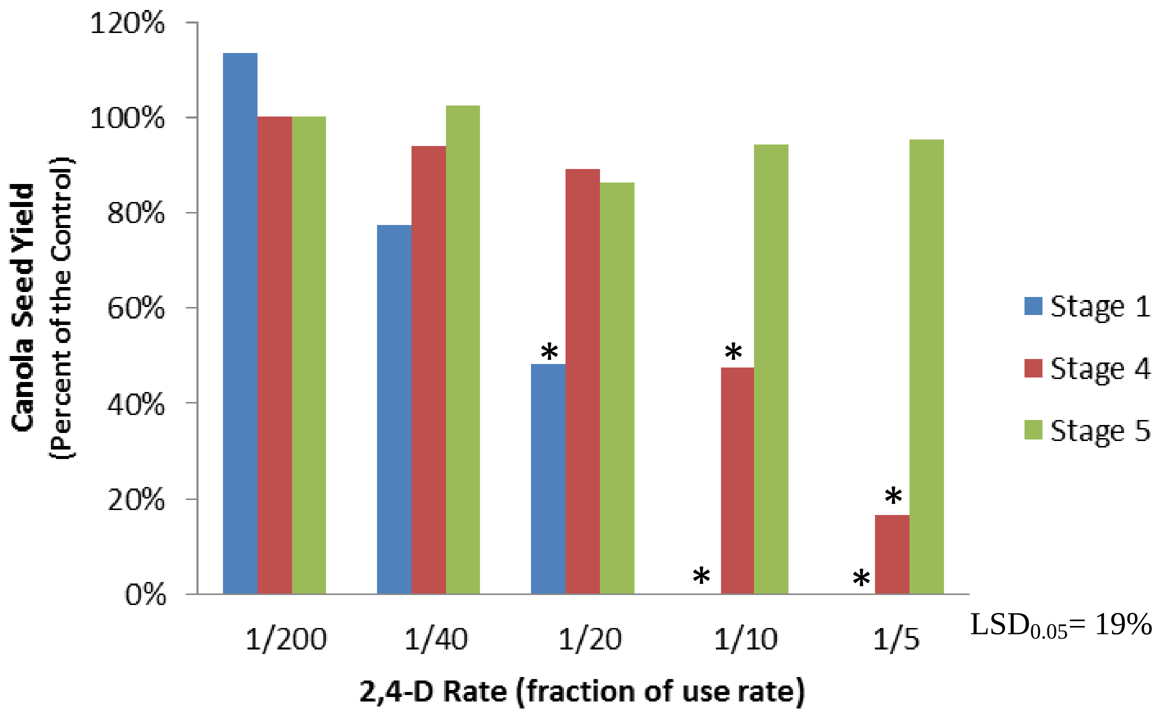

Figure 2.1. Canola yield as affected by simulated 2,4-D herbicide drift rates applied at Stage 1, Stage 4, and Stage 5 in the 2011-2012 growing season. Use rate was 526 g ae ha^{-1} of 2,4-D. Yields were averaged across both locations in Stillwater and Perkins, OK. Average yield of non-treated control was 2,225 kg ha^{-1}. An asterisks (*) indicates a significant difference compared to the nontreated control.

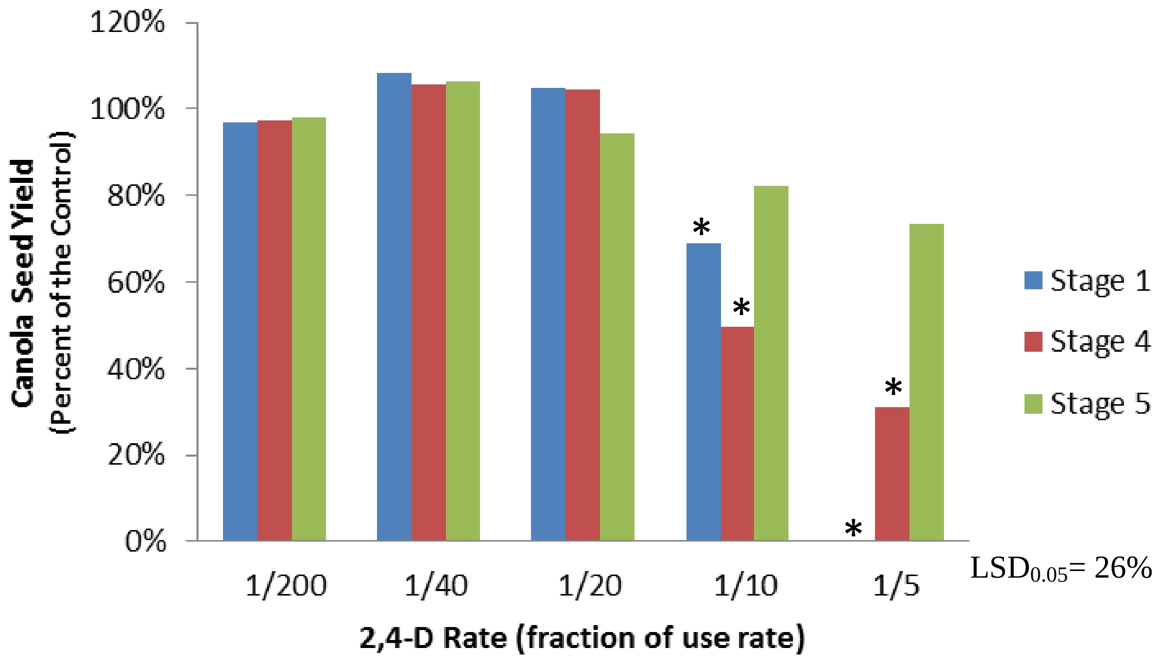

Figure 2.2. Canola yield as affected by simulated 2,4-D herbicide drift rates applied at Stage 1, Stage 4, and Stage 5 in the 2012-2013 growing season. Use rate was 526 g ae ha^{-1} of 2,4-D. Yields were averaged across both locations in Stillwater and Perkins, OK. Average yield of non-treated control was 2,331 kg ha^{-1}. An asterisks (*) indicates a significant difference compared to the nontreated control.

In 2011-2012, 2,4-D applications at Stage 1 decreased yield with increasing 2,4-D rates. 1/10 and 1/5 rates of 2,4-D applied at Stage 1 resulted in yield loss of 2225 kg ha^{-1}, which was a total loss (Figure 2.1). Likewise, Stage 4 applications resulted in a linear decrease in yield with increasing 2,4-D rates ($y=-0.213x+1.333$; $r^2=0.88$). Yield loss was greatest at the 1/5 rate of 2,4-D was applied, with a loss of 1,864 kg ha^{-1} when compared to the nontreated control. When compared to the nontreated plots, yield decrease was not observed following 2,4-D applications at Stage 4 below the 1/40 rate. Applications at Stage 5 did not show yield loss below the 1/20 rate of 2,4-D.

In 2012-2013, applications at Stage 1 resulted in a yield decrease with increasing 2,4-D rates starting at the 1/20 2,4-D rate. Applications at 1/5 rate had a yield loss of 2,331 kg ha^{-1}, which was a total loss. Stage 4 applications also showed a decrease in yield with increasing 2,4-D rates starting at the 1/20 rate; however, significant yield loss was only observed with 1/10 and 1/5 rates of 2,4-D. Yield losses resulting from applications at these rates were 1,174 and 1,612 kg ha^{-1} when compared to the nontreated control. Canola yield decreased when 2,4-D applied at rates greater than 1/40 at Stage 5.

Dicamba. Yield loss was less effected by dicamba applications compared to losses following 2,4-D applications during both growing seasons. In general, dicamba applications numerically increased yields compared to the nontreated control. This was especially the case for dicamba applications at earlier growth stages (Figures 2.3-2.4). Stage 1applications of 1/200 and 1/40 dicamba rates in 2011-2012 increased yield by 120 kg ha^{-1}relative to the nontreated control.

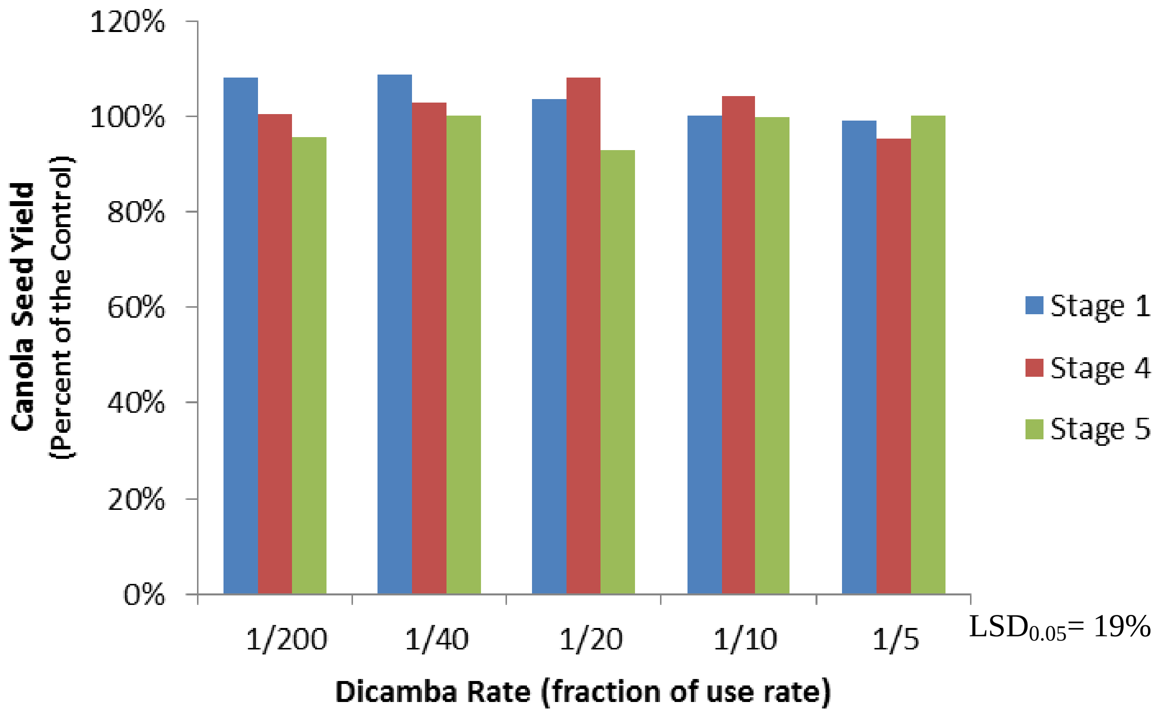

Figure 2.3. Canola yield as affected by simulated dicamba herbicide drift rates applied at Stage 1, Stage 4, and Stage 5 in the 2011-2012 growing season. Use rate was 280.5 g ae ha^{-1} of dicamba. Yields were averaged across both locations in Stillwater and Perkins, OK. Average yield of non-treated control was 2,225 kg ha^{-1}. An asterisks (*) indicates a significant difference compared to the nontreated control.

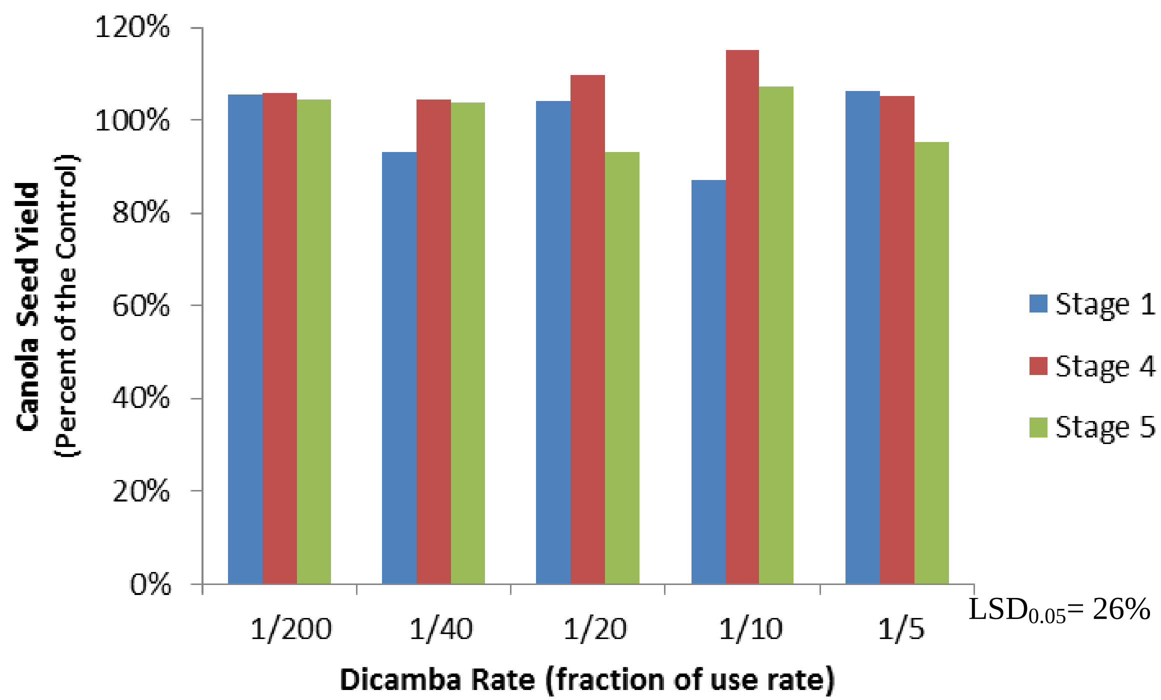

Figure 2.4. Canola yield as affected by simulated dicamba herbicide drift rates applied at Stage 1, Stage 4, and Stage 5 in the 2012-2013 growing season. Use rate was 280.5 g ae ha^{-1} of dicamba. Yields were averaged across both locations in Stillwater and Perkins, OK. Average yield of non-treated control was 2,331 kg ha^{-1}. An asterisks (*) indicates a significant difference compared to the nontreated control.

Seed Oil Content

The mean seed oil content for nontreated plots was 43.8% in 2011-2012 and 42.7% in 2012-2013. A three-way interaction was observed between herbicide, herbicide rate, and timing of application during both growing seasons. 2,4-D and dicamba both affected winter canola oil content at various rates and stages, but 2,4-D caused greater decreases of canola seed oil content than dicamba.

2,4-D. In 2011-2012, applications of 2,4-D at Stage 1 decreased oil content with increasing rates (Figures 2.5). There were no observations for1/10 and 1/5 rates of 2,4-D because of crop loss. Significant oil content loss occurred at 1/40 and 1/20 rates of 2,4-D. Stage 4 applications had a linear decrease in oil content with increasing rates of 2,4-D

($y= -0.0281x+1.0372$; $r^2=0.98$). Applications at Stage 5 decreased oil content, but only at rates greater than 1/20 rate of 2,4-D. Similar results were observed in 2012-2013 when higher application of 2,4-D decreased oil content (Figure 2.6).

Dicamba. Applications of dicamba did not affect oil content when compared to the nontreated control for both growing seasons.

Seed Weight

The mean seed weight for nontreated plots was 0.36 g 100 seeds^{-1} in 2011-2012 and 0.32 g 100 seeds^{-1} in 2012-2013. A three-way interaction was observed between herbicide, herbicide rate, and timing of application for both growing seasons. 2,4-D and dicamba both affected winter canola at various rates and stages, but 2,4-D effected seed weight more than dicamba.

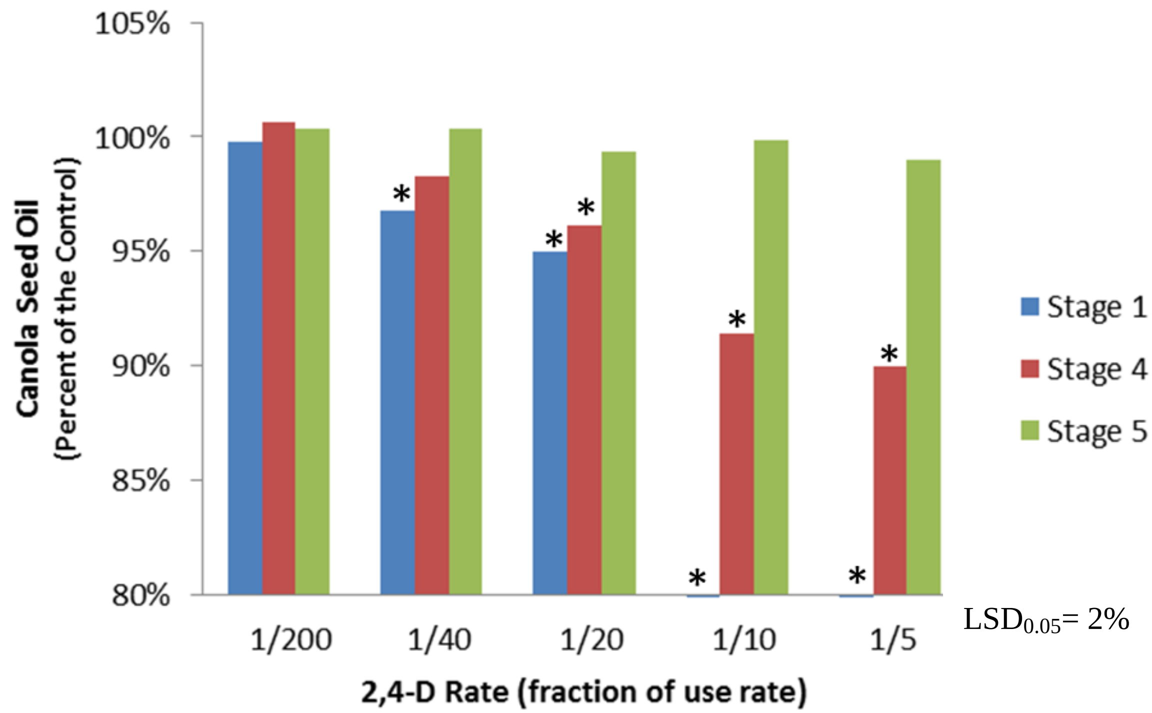

Figure 2.5. Canola seed oil content as affected by simulated 2,4-D herbicide drift rates applied at Stage 1, Stage 4, and Stage 5 in the 2011-2012 growing season. Use rate was 526 g ae ha^{-1} of 2,4-D. Oil contents were averaged across both locations in Stillwater and Perkins, OK. Average seed oil content of non-treated control was 43.8%. No samples were available for 1/10 and 1/5 rates in Stage 4 and Stage 5 due to crop loss. An asterisks (*) indicates a significant difference compared to the nontreated control.

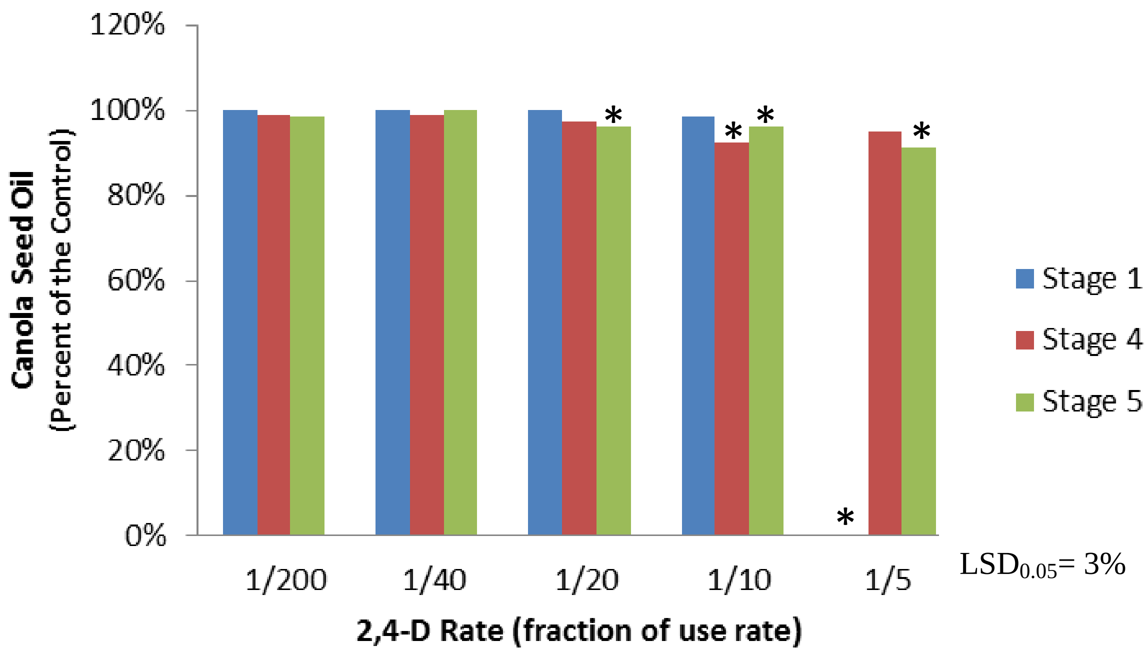

Figure 2.6. Canola seed oil content as affected by simulated 2,4-D herbicide drift rates applied at Stage 1, Stage 4, and Stage 5 in the 2012-2013 growing season. Use rate was 526 g ae ha^{-1} of 2,4-D. Oil contents were averaged across both locations in Stillwater and Perkins, OK. Average seed oil content of non-treated control was 42.7%. No samples were available for 1/5 rate in Stage 5 due to crop loss. An asterisks (*) indicates a significant difference compared to the nontreated control.

2,4-D. 2,4-D had greater effect on seed weight when applied at Stage 4 in 2011-2012 and Stage 5 in 2012-2013. In both growing seasons, seed weight increased when the doses of 2,4-D increased (Figure 2.7-2.8).

When 2,4-D was applied at Stage 1 in 2011-2012, seed weight decreased with increasing rates of 2,4-D; however, seed weight loss was not significant. There were no observations for 1/10 and 1/5 rates of 2,4-D because of crop loss. Applications at Stage 4 resulted in seed weight greater than the nontreated average for each 2,4-D rate. Seed weight increased with increasing 2,4-D rates until 1/10 rate of 2,4-D. Seed weight at following herbicide applications at Stage 4 increased at 1/20 and 1/10 2,4-D rates when compared to the nontreated plots. No differences were observed between Stage 5 applications and the nontreated plots.

In 2012-2013, seed weight decreased with increasing 2,4-D rates when the herbicide was applied at Stage 1 (Figure 2.8). A significant loss of 15.6% was observed at 1/10 rate of 2,4-D compared to the nontreated control. There were no observations at 1/5 rate of 2,4-D due to crop loss. In contrast to application at Stage 1, applications at Stage 4 increased seed weight at rates of 1/10 to 1/5 of 2,4-D. Stage 5 applications of 2,4-D also increased seed weight with increasing rates. All rates greater than 1/200 increased seed weight significantly when compared to the nontreated plots.

Dicamba. Applications of dicamba at each growth stage did not affect seed weight when compared to the nontreated control during both growing seasons.

Primary Branches

Primary branch data were only collected for the 2011-2012 growing season. The average primary branches for nontreated plots were 5 branches per plant. A three-way interaction was

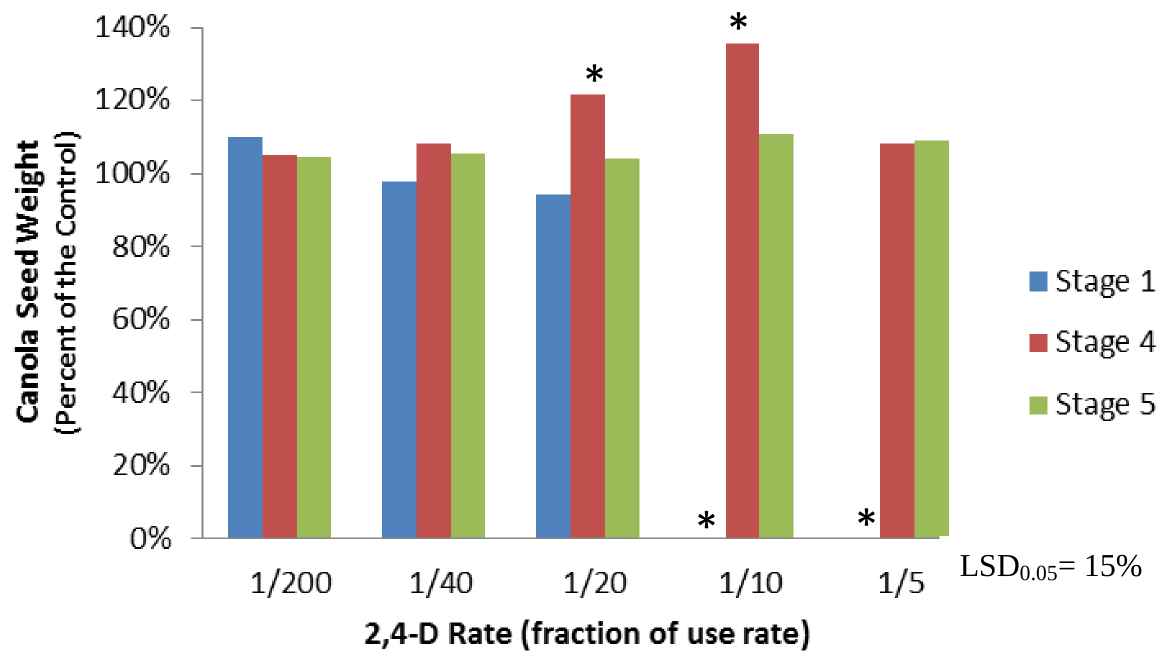

Figure 2.7. Canola seed weight per 100 seeds as affected by simulated 2,4-D herbicide drift rates applied at Stage 1, Stage 4, and Stage 5 in the 2011-2012 growing season. Use rate was 526 g ae ha^{-1} of 2,4-D. Seed weights were averaged across both locations in Stillwater and Perkins, OK. Average seed weight of non-treated control was 0.36 g per 100 seeds. No samples were available for 1/10 and 1/5 rates in Stage 4 and Stage 5 due to crop loss. An asterisks (*) indicates a significant difference compared to the nontreated control.

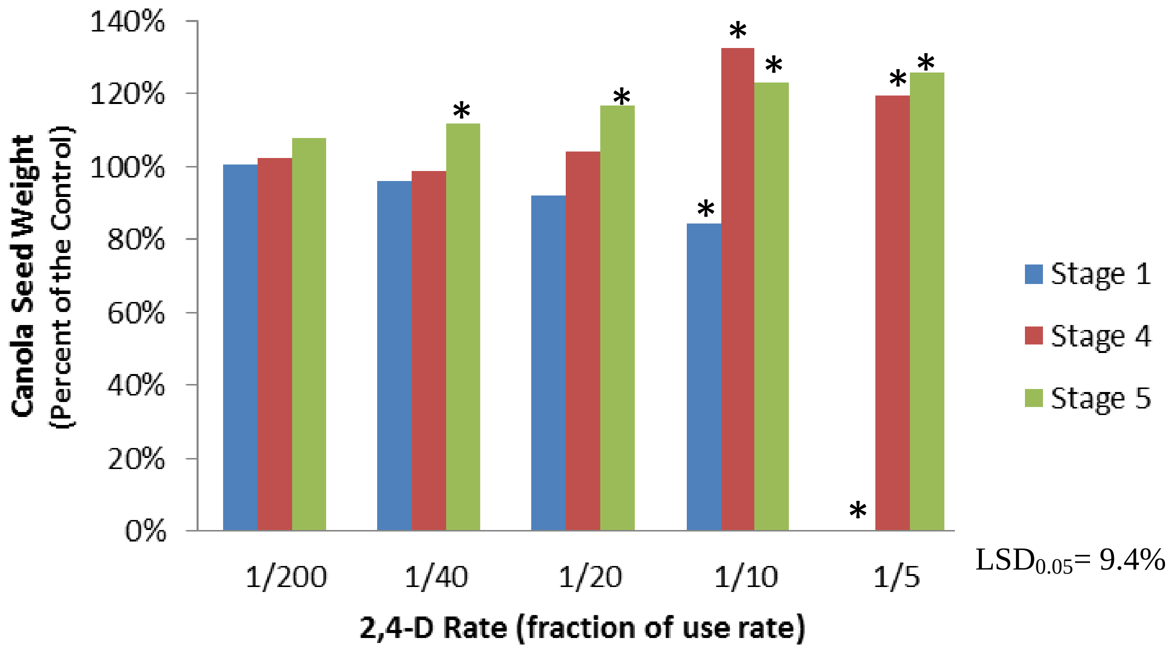

Figure 2.8. Canola seed weight per 100 seeds as affected by simulated 2,4-D herbicide drift rates applied at Stage 1, Stage 4, and Stage 5 in the 2012-2013 growing season. Use rate was 526 g ae ha^{-1} of 2,4-D. Seed weights were averaged across both locations in Stillwater and Perkins, OK. Average seed weight of non-treated control was 0.32 g per 100 seeds. No samples were available for 1/5 rate in Stage 5 due to crop loss. An asterisks (*) indicates a significant difference compared to the nontreated control.

observed between herbicide, timing, and herbicide rate. Overall, neither 2,4-D or dicamba affected primary branch number compared to the nontreated control. There were no trends when 2,4-D or dicamba were applied at any rate or time.

Secondary Branches

Secondary branch data were only collected for the 2011-2012 growing season. The average secondary branches for nontreated plots were 1.7 secondary branches per plant. The average secondary branches per plant showed an interaction between timing and rate of herbicide. 2,4-D applications had more effect on secondary branches compared to dicamba applications. No trends were observed with 2,4-D or dicamba; however, the 1/20 rate of 2,4-D at Stage 1 increased branching to 4.2 branches per plant (Figure 2.9).

Total Pods

Pod data were only collected for the 2011-2012 growing season. The average pods for the nontreated plots were 190 total pods, with approximately 75 fertile and 115 infertile pods per plant. A three way interaction was observed between application timing, herbicide, and herbicide rate for fertile, infertile, and total pods.

2,4-D. Stage 1 applications of 2,4-D increased overall pod number with increasing herbicide rates (Figure 2.10). No trend was observed at Stage 1 with fertile pods; however, infertile pods increased with increasing 2,4-D rates at this application timing (Figure 2.11). A significant increase in total pods was observed at 1/20 rate of 2,4-D applications at Stage 1. Stage 4 applications of 2,4-D decreased overall pod number with increasing herbicide rates. The only significant decrease was associated with the 1/5 application of 2,4-D at Stage 4. No trend was

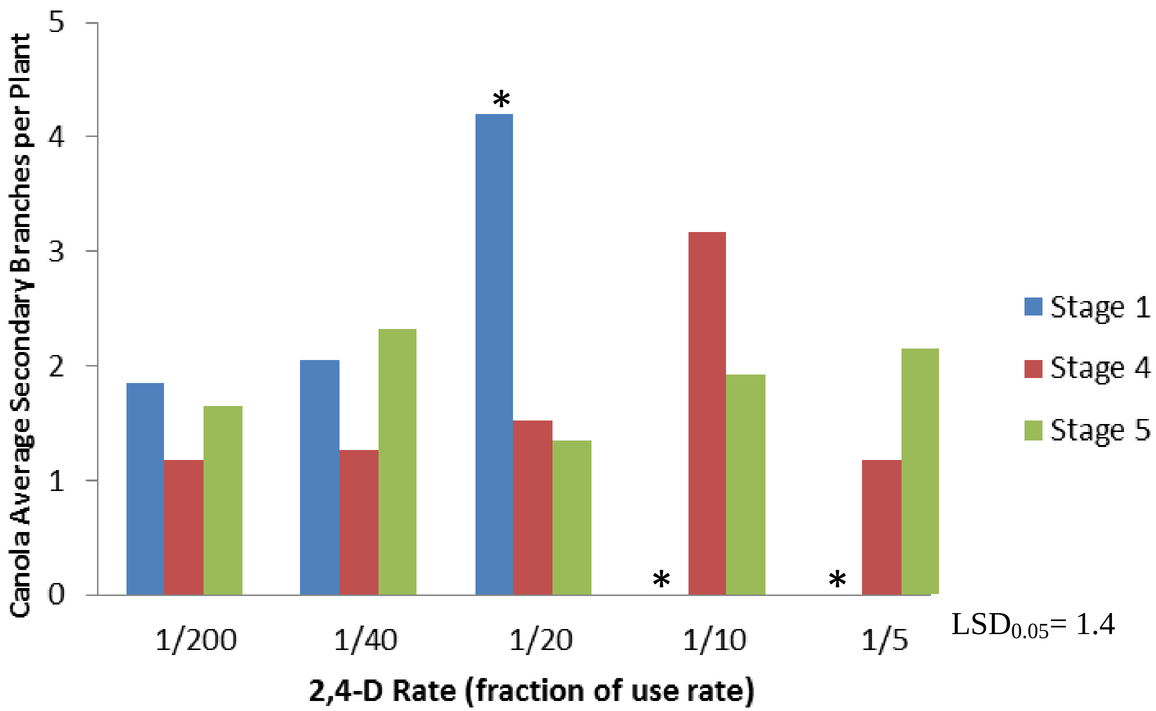

Figure 2.9. Canola average secondary branches per plant as affected by simulated 2,4-D herbicide drift rates applied at Stage 1, Stage 4, and Stage 5 in the 2011-2012 growing season. Use rate was 526 g ae ha^{-1} of 2,4-D. Secondary branches were averaged across both locations in Stillwater and Perkins, OK. Average secondary branches of non-treated control were 2 branches per plant. No samples were available for 1/10 and 1/5 rates in Stage 4 and Stage 5 due to crop loss. An asterisks (*) indicates a significant difference compared to the nontreated control.

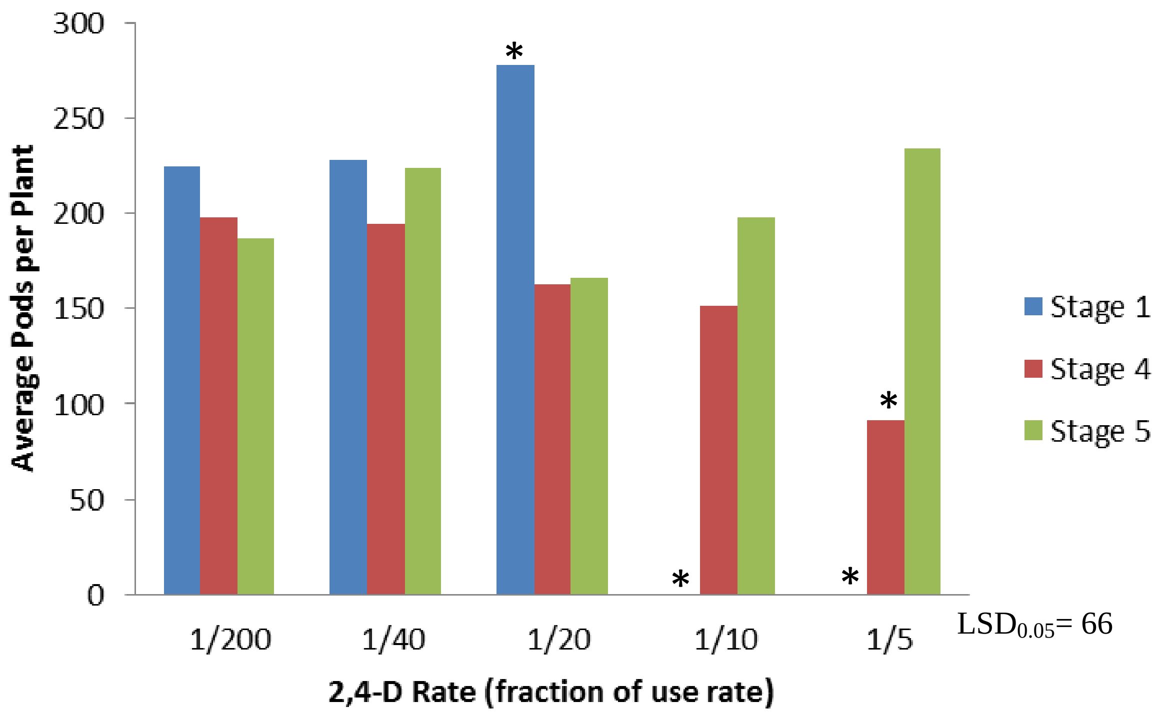

Figure 2.10. Canola average pods per plant as affected by simulated 2,4-D herbicide drift rates applied at Stage 1, Stage 4, and Stage 5 in the 2011-2012 growing season. Use rate was 526 g ae ha^{-1} of 2,4-D. Pods were averaged across both locations in Stillwater and Perkins, OK. Average pods of non-treated control were 190 pods per plant. No samples were available for 1/10 and 1/5 rates in Stage 4 and Stage 5 due to crop loss. An asterisks (*) indicates a significant difference compared to the nontreated control.

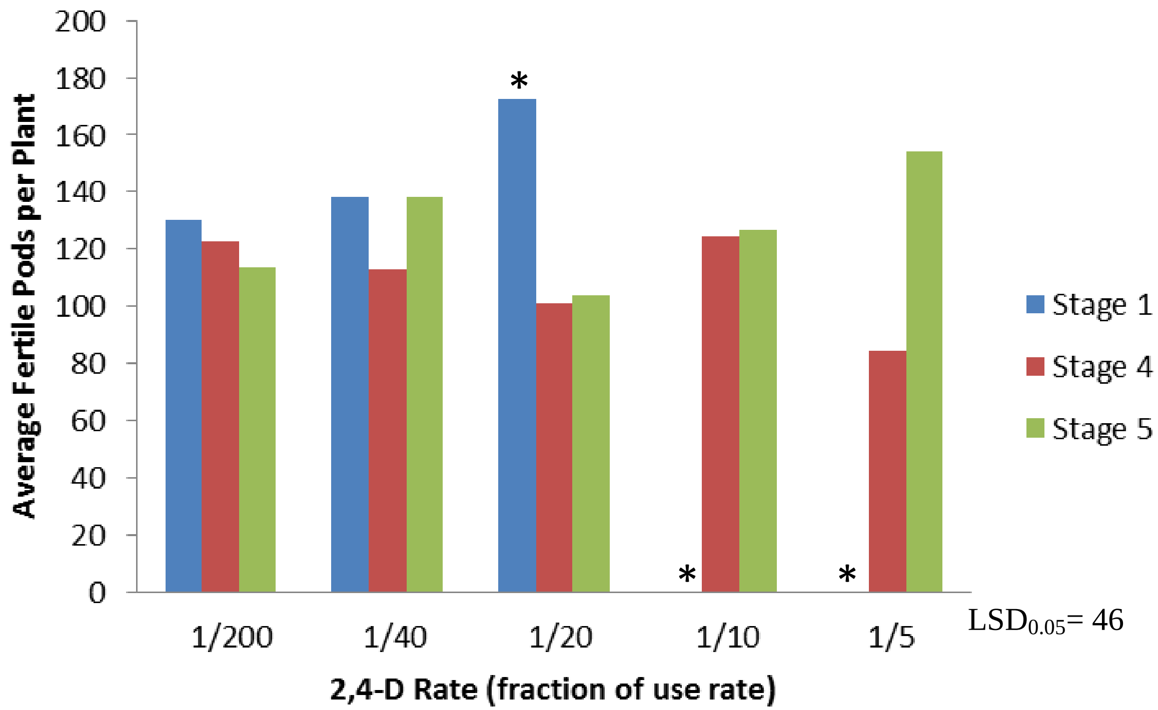

Figure 2.11. Canola average infertile pods per plant as affected by simulated 2,4-D herbicide drift rates applied at Stage 1, Stage 4, and Stage 5 in the 2011-2012 growing season. Use rate was 526 g ae ha^{-1} of 2,4-D. Infertile pods were averaged across both locations in Stillwater and Perkins, OK. Average infertile pods of non-treated control were 115 pods per plant. No samples were available for 1/10 and 1/5 rates in Stage 4 and Stage 5 due to crop loss. An asterisks (*) indicates a significant difference compared to the nontreated control.

observed at Stage 4 with fertile pods, but infertile pods decreased with increasing 2,4-D applications until 1/10 rate of 2,4-D. No trends were observed at Stage 5 applications of 2,4-D with total pods, fertile pods, or infertile pods per plant.

Dicamba. Dicamba applications at Stage 1 did not cause any trends in overall pods, fertile pods, or infertile pods per plant. Stage 4 applications caused a decrease in overall pod number with low doses of dicamba, but caused increased pod numbers at rates greater than 1/20 (Figure 2.12). No trends in fertile or infertile pod numbers were observed. Stage 5 applications decreased pod number with increasing rates of dicamba until 1/20 rate of dicamba. There were no trends when compared to the nontreated control.

Discussion

In general, injury symptoms were greater in 2011-2012 compared to 2012-2013 following fall applications of herbicides. The difference in injury may be a result of higher temperatures and dryer conditions during herbicide application and throughout the growing season in 2011-2012. Earlier research has shown that dry conditions can result in greater injury rates and greater yield reduction (Andersen et al., 2004). Gan et al. (2004) reported that canola grown under drought conditions reduced pod production by 25% compared to those grown at normal conditions, causing a reduction in seed yield. Increased herbicide injury due to higher temperatures has also been reported in soybean (Auch and Arnold, 1978). Higher injury rates during spring applications for 2012-2013 could be due to cooler temperatures compared to 2011-2013, which slows the plants' ability to metabolize the herbicides (Wall, 1997).

Similar to our findings, increasing yield reduction following application of increasing rates of 2,4-D was also reported by Betts and Ashford (1976) at each growth stage of rapeseed. This trend has also been reported in sunflower, including complete yield losses (Wall, 1996). Exposing sunflower to dicamba did not cause yield loss until 3.2 g a.i. ha^{-1} of dicamba (Derksen,

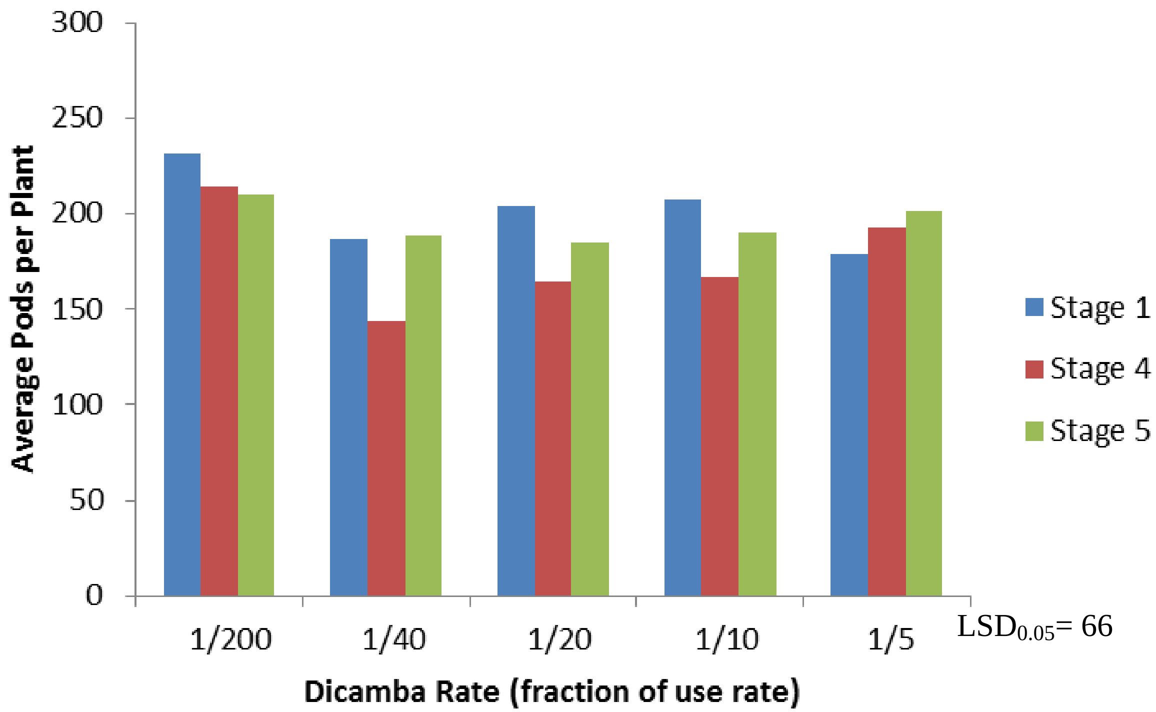

Figure 2.12. Canola average pods per plant as affected by simulated dicamba herbicide drift rates applied at Stage 1, Stage 4, and Stage 5 in the 2011-2012 growing season. Use rate was 280.5 g ae ha^{-1} of dicamba. Pods were averaged across both locations in Stillwater and Perkins, OK. Average pods of non-treated control were 190 pods per plant. An asterisks (*) indicates a significant difference compared to the nontreated control.

1989), which is what we observed in our study. 2,4-D application results are also similar to results reported in cotton. Cotton yield was more affected by 2,4-D than dicamba, and plants were more susceptible at early growth stages (Marple, 2008). In 2011-2012, Yield increase caused by dicamba applications could possibly be attributed to dicamba's mode of action and canola plant development. Dicamba applications made at Stage 4 increased yields compared to the nontreated plots and caused an increase in total pod numbers per plant. This increase could have been caused by the interaction dicamba has with ethylene biosynthesis. An interaction with ACC synthase could have stimulated enough growth and development to increase plant production without causing the plant to overdevelop and destroy plant tissue. Low doses of herbicides like dicamba are used in laboratory settings for tissue culture and yield improvements. (Sterline and Hall, 1997).

Seed oil content variability from year to year has been observed in previous canola studies. Pritchard et al. (2000) observed greater oil content when canola was grown in cooler spring temperatures and greater spring rainfall when compared to dry years. Similar results were also found for other rapeseed cultivars and flax (Canvin, 1965). Reduction of oil content with increasing 2,4-D applications at Stage 1 and 4 was also noted in spring cultivars (Betts and Ashford, 1976). Oil content reductions could be contributed to delayed maturity from applications. Most oil production occurs in the last 20 d of maturation; therefore, immature seeds collected at time of harvest could have less oil (Sinha and Agrawal, 1963). Sunflower have also shown less seed oil content when treated with 2,4-D drift rates (Greenshields and Putt, 1958). A similar study revealed sunflower oil content decreased up to 15% compared to a nontreated control with increasing 2,4-D rates (Wall, 1996).

Previous research also supports the finding that applying greater amounts of 2,4-D caused increased seed weight in canola. This can possibly be attributed to the reduction in the number of flowers and flower buds following application. Loss of flower and buds reduced the number of sinks available for photosynthate, thereby increasing the size of the seed that was available to develop normally (Betts and Ashford, 1976).

Summary

Winter canola is susceptible to both 2,4-D and dicamba drift; however, winter canola is affected by 2,4-D more than dicamba. 2,4-D applications had greater effect on yield, oil content, and seed weight compared to dicamba for each growing season. Canola yield reduction was greatest when drift occurred during Stage 1. Oil content was mostly affected when applications were made at Stage 1and Stage 4 in 2011-2012; however, Stage 4 was affected most in 2012-2013. Seed weight was most affected when applications were made at Stage 4 and Stage 5. The amount of drift required for damage varied for each component, but overall, higher rates of herbicides had more effect on yield and yield components.

Yield and yield components had a three way interaction between herbicide, herbicide rate, and timing of application. Visual crop injury was less severe with dicamba applications compared to 2,4-D applications. 2,4-D had more effect on the youngest growth stage and injury was more severe at higher doses. Dicamba crop injury was visible; however, the intensity and recovery varied for each growth stage.

Yield loss was mostly associated with 2,4-D applications over dicamba applications. There was a greater effect with higher doses of 2,4-D for both growing seasons. Both growing seasons saw a decrease in yield with increasing 2,4-D rates at Stage 1 and Stage 4, with complete losses in 2011-2012 for 1/10 and 1/5 rates and in 2012-2013 for 1/5 rate of 2,4-D. 2012-2013 also saw a decrease with increasing rates at Stage 5 applications. Dicamba had less effect on yield for both growing seasons, but overall dicamba applications increased yields when compared to the nontreated control, especially at younger growth stages.

Seed oil content in plots treated with 2,4-D was similar for both growing seasons . Oil content decreased with increasing 2,4-D rates following application at Stage 1 and Stage 4. 2,4-D rates above 1/10 also decreased oil content at Stage 5. Decreases in oil content relative to the nontreated control occurred when 2,4-D was applied at Stage 1 and Stage 4 in 2011-2012 and at Stage 4 and Stage 5 in 2012-2013. Seed oil content was not significantly affected by applications of dicamba when compared to the nontreated control for both growing seasons.

Seed weight in plots treated with 2,4-D was similar for both growing seasons when applied at Stage 1 and Stage 4. 2,4-D applications at Stage 1 decreased seed weight with increasing 2,4-D rates. In contrast, 2,4-D applications at Stage 4 increased seed weight with increasing 2,4-D rates. There was no differences between observations at Stage 5 applications in 2011-2012, but applications in 2012-2013 resulted in seed weight increasing with increasing 2,4-D rates. Both Stage 4 and Stage 5 applications in 2012-2013 resulted in increased seed weight when compared to the nontreated control. Applications of dicamba did not affect seed weight when compared to the nontreated control for both growing seasons.

Conclusions

This study shows that 2,4-D has greater effects on canola yield, seed weight, and oil content compared to dicamba at similar simulated drift rates. Yield was more affected when 2,4-D applications were made during Stage 1, leaf production, compared to Stage 4, flowering, and Stage 5, pod production. Seed weight was most affected by herbicide applications at Stage 4 and Stage 5, while oil content results varied each growing season. The amount of drift necessary to affect canola varied among yield, oil content, and seed weight; however, higher doses of 1/10 and 1/5 rates caused more damage.

Producers and commercial applicators should be cautious when applying 2,4-D in areas near winter canola, especially in the fall when canola is most sensitive. When possible, applicators should chose dicamba over 2,4-D for weed control in situations where drift is possible. Failure to take proper precautions when spraying either herbicide could cause variable damage to winter canola yield and seed components.

CHAPTER III

USING VIDEO MODULES TO HELP STUDENTS SOLVE AGRONOMIC CALCULATIONS

Introduction

Technology in the classroom has become a common complementary learning component. An increase in demand for innovative ways to provide alternative teaching methods has led to a change in learning technology (Zhang et al, 2004). Online learning and traditional classrooms have several advantages and disadvantages. Many online classroom tools have proven to be an important aide to new learners (Samsel et al, 2004). Nichols et al. (2003) summarized several studies concerning library tutorials with either online or in-class instruction. The two methods were similar in all studies; therefore, many libraries have decided to use newer technologies to provide introductory instruction.

Virtual technology has become an important tool in many of the science disciplines to reinforce classroom information and to provide further preparation regarding class material. Grizzle et al. (2008) reported that a virtual lab in animal reproductive physiology was an asset to students; however, it required a large commitment of time and use in order to be effective. Grizzle concluded from this study that a wet dissection was still necessary for students to succeed in this course. In a chemistry course, fewer than half the students chose to use the online supplements; however, assessment from the students that used the resource found it to be a valuable preparation tool and would recommend it for further use (Dalgarno et al., 2009). A U.S. Department of Education report prepared by Means et al. (2010) concluded that blending both online and in the classroom instruction provided more effectiveness than either alone. When online learning was used by itself, the online instruction is just as effective as in the classroom settings; however, the online and classroom conditions differed in terms of time spent and the curriculum for the courses. This was supported from the comparison of combining classroom and virtual experiments for electrical circuits. Results showed that the combination of the classroom and virtual experiments enhanced student learning compared to classroom experiments alone (Zacharia, 2007). Alternatively, another study reported that web-based learning programs alone were more effective for student learning in an undergraduate nursing class (Jang et al., 2005).

The objective of this study was to evaluate the impact of video modules on student ability to solve agronomic calculations and student response to using the modules. The plant and soil sciences course, Introduction to Plant and Soil Systems (PLNT 1213), was the focus for this study.

Materials and Methods

PLNT 1213 is an undergraduate plant and soil sciences course with an enrollment of approximately 200-280 students in the Fall and 100-135 students in the Spring semesters. PLNT 1213 is generally one of the first courses taken by students studying plant and soil science and is a requirement or controlled elective for students in several other majors in the College of Agriculture Sciences and Natural Resources at Oklahoma State University. Some students have a general background in plant or soil sciences, while other students do not have any previous background experience.

Students enrolled in PLNT 1213 are required to learn several agronomic calculations as part of the course concepts. In the seeding section of the course, class objectives include calculating percent pure live seed and calculating the number of seeds needed to seed a given acre. Objectives in the plant nutrition and soil fertility section include determining and calculating fertilizer application rates. In pest management, class objectives include calculating pesticide application rates.

Preparing for Calculations

During the Fall 2010 and Spring 2011 semesters, students were prepared for calculations with in-class examples during lecture. Homework assignments and written keys were posted to Desire2Learn, Oklahoma State University's course management system. Desire2Learn is a course content management system that allows anywhere, anytime access to class materials, quizzes, grades, project files, and other class supplements. Assignments for PLNT 1213 on this class site allowed students to practice a variety of calculations before the examinations. Review sessions were also available to students before exams. These sessions were available as a "question and answer" type session.

It was decided during the Fall 2011 semester that calculation written assignments would be replaced by online quizzes using Desire2Learn. The graduate teaching assistant conducted evening exam review sessions 1-2 days before the exam. Attendance at these review sessions varied based on students' other activities and busy school schedules.

Video Implementation

During the Spring 2012 semester, videos designed to reinforce methods for solving the calculations were constructed. The videos were recorded by the class graduate teaching assistant using Educreations, an application available on Apple products. These videos used the same examples that were used in class lecture. The video includes the PowerPoint slides from the class lecture with voice narration and hand-written messages. The calculation is shown on the slide and the teaching assistant walks through solving the problem by talking through each step and writing on the screen. Students can pause or replay from any point in the video presentation.

These presentations were available on Desire2Learn. After the deadline for online calculation quizzes passed, videos were uploaded that explained how to solve each quiz problem. Videos were a voluntary study aide available to all students. The videos were available for study before each semester exam and also for preparation for the end semester final exam. The graduate teaching assistant also conducted exam review sessions 2 days before the exam and covered 2 practice calculation problems.

Data Collection

To compare scores, final examinations from two semesters during which students could not access the videos (Fall 2010 and Spring 2011) and two semesters during which students did have access to online videos, (Fall 2012 and Spring 2012) were used. Fall 2011 was not used in this assessment because students were assigned a term paper in lieu of a final exam. During each semester, final exams contained similar calculation sets for all students; however, numbers were altered between semesters and two versions of the questions were used within each semester.

A voluntary survey containing seven questions related to video use in preparation for the class exams was administered twice during the Fall 2012 semester to students in lecture, following exams that contained calculations (Table 3.1).This survey instrument asked students to respond to questions about how they prepared themselves for the exam, if they had used similar videos, how helpful the videos were, and why they did not use the videos. Students who used the videos were also asked to respond to a series of statements using a Likert-type scale where 1 = strongly disagree and 4 = strongly disagree. Students were also encouraged to write additional comments about their experience using or not using the videos.

Data were subjected to analysis of variance (ANOVA) in SAS® (SAS Institute Inc. Version 9.3). Final exam scores were compared using F-tests at the P=0.05 significance level. Mean, standard error, and standard deviation was calculated for final exam scores and student survey responses.

Results and Discussion

Overall, student enrollment varied between semesters. More students were enrolled during the fall semesters compared to the spring semesters due to more open seats available in the course. Fall semesters had 203 (Fall 2010) and 278 students (Fall 2012), whereas spring semesters had 133 (Spring 2011) and 137 students (Spring 2012).

Final exam scores

Mean scores and standard deviations were calculated for seeding, fertilizer, and pesticide calculations depending on video accessibility or semester (Table 3.2). Each semester's scores were not significantly different from the other; however, semesters with videos available had a

Table 3.1. Voluntary student survey administered during fall semester 2013 in PLNT 1213 lecture after exam 3 and exam 4.

1. How many credit hours have you completed?

2. What is your current GPA?

3. How did you prepare yourself for the calculations portion of this exam? (Check all that apply)
   a. I used the class notes.
   b. I used the videos that were posted on D2L.
   c. I attended the exam review session help by my class teaching assistant.
   d. I took the online quiz over the calculations.
   e. I used outside resources.
   f. I did not use any resources except my own knowledge on the subject.

4. Have you used videos similar to these before? Explain.

5. If you DID use the videos, please rank the following statements using the following scale:

   1= strongly disagree 2= disagree 3=agree 4=strongly agree

   a. The videos were at a pace suitable for me to follow along.
   b. It was helpful for me to have a resource available outside the classroom.
   c. The videos increased my understanding of how to perform the calculations.
   d. I would recommend to friends/fellow students to use these videos.
   e. If similar videos are available in this course or other courses; I will use them as a study aide.
   f. Additional reasons for why you decided to use the class videos:

6. If you DID NOT use the videos, please specify reasons why you did not. (Check all that apply)

   a. I understood the class material in lecture and did not need to watch the videos.
   b. I did not have time to watch the videos.
   c. I did not think the videos would have been useful.
   d. The other resources I used to prepare were adequate enough.

7. Please specify any other comments about the videos.

Table 3.2. Mean, minimum, maximum, and standard deviation of student scores on PLNT 1213 final examinations in semesters with and without video access.

Semester	Video Access	Exam Question	Mean (%)	Minimum (%)	Maximum (%)	Standard Deviation
Fall 2010	Unavailable	Seeding	59.5	20	100	24.3
		Fertilizer	55.8	0	100	36.2
		Pesticide	52.9	0	100	32.0
Spring 2011	Unavailable	Seeding	80.1	40	100	18.7
		Fertilizer	67.9	0	100	28.2
		Pesticide	73.7	0	100	27.6
Fall 2012	Available	Seeding	76.2	0	100	29.5
		Fertilizer	59.2	0	100	40.5
		Pesticide	57.8	0	100	38.9
Spring 2012	Available	Seeding	63.8	0	100	32.5
		Fertilizer	57.0	0	100	38.7
		Pesticide	55.5	0	100	41.5

wider range in scores in comparison to semesters without the videos. There was no difference in average exam scores when comparing students enrolled in semesters with video access and students enrolled in semesters without video access (Table 3.3). This could be attributed to other available study aides during Fall 2010 and Spring 2011, including access to homework keys before exams. These results are similar to findings by Nichols et al. (2003), which concluded that classroom lecture and online videos are statistically similar for learning class concepts.

Wieling and Hofman (2010) also concluded that students viewing online video lectures compared to students attending lectures did approximately the same on course grades in a collegiate law course. Wieling and Hofman concluded that e-learning should be a blended approach with both online and in-class lectures.

First student survey

The first survey was administered after exam 3, on which students completed seeding calculations. One hundred sixty two students participated, approximately 58% of the Fall 2012 class (Table 3.4). Forty six percent of these students used the videos to prepare for the exam, while the other 54% did not use the videos. Only 13% of the respondents had used similar videos in other classes. Math and accounting were other courses in which students had used videos.

Participants that used the videos ranked all statements on the survey an average ranking of 3.5-3.7 out of 4 (Table 3.5). Students ranked the statement “It was helpful for me to have a resource available outside the classroom.”

Ninety students did not use the videos for exam preparation. Eighty two percent of these students indicated that they felt the class material in lecture was adequate for learning the calculations (Table 3.6). Thirty seven percent of these students used other resources; however, these other resources were not specified.

Table 3.3. Analysis of variance of exam scores for seeding, fertilizer, or pesticide calculations in semesters with video access compared to semesters without video access.

Source	Dependent Variable	DF	Den DF	F Value	Pr > F
Video Access	Seeding Calculations	1	747	0.00	0.977
	Fertilizer Calculations	1	747	0.31	0.579
	Pesticide Calculations	1	747	0.38	0.535

Table 3.4. Summary of student responses to in-class survey administered following the exam with seeding calculations.

	Number of students	Percentage of participants
Survey participants	162	100
Participants that used the videos	74	46
Participants that did not use the videos	88	54
Participants that had used similar videos	21	13

Table 3.5. Student response to survey question “If you DID use the videos, please rank the following statements.”

Given Statement	First survey		Second survey	
	Mean	Standard Deviation	Mean	Standard Deviation
The videos were at a pace suitable for me to follow.	3.6	0.6	3.5	0.8
It was helpful for me to have a resource available outside the classroom.	3.7	0.6	3.5	0.9
The videos increased my understanding of how to perform calculations.	3.5	0.6	3.4	0.9
I would recommend friends/fellow students use these videos.	3.6	0.6	3.4	0.8
If similar videos are available in this course or other courses; I will use them as a study aide.	3.6	0.6	3.5	0.8

*Students ranked statements on a scale of 1 to 4, where 1= strongly disagree 2= disagree 3=agree 4=strongly agree.

Table 3.6. Summary of why students did not use the video modules.

Given Statement	Exam 3 survey*	Exam 4 survey**
I understood the class material in lecture and did not need to watch the videos.	82.2	69.5
I did not have time to watch the videos.	20.0	31.5
I did not think the videos would have been useful.	4.4	3.7
I used other resources.	36.7	31.5

*Students could choose all statements that applied.
** Exam 3 survey had 90 students indicate they did not use the videos.
***Exam 4 survey had 54 students indicate they did not use the videos.

Table 3.7. Second student survey results, including the number of participants and participant response to video use.

	Number of students	Percentage of participants
Survey participants	167	100
Participants that used the videos	113	68
Participants that did not use the videos	54	32
Participants that had used similar videos	24	15

Second student survey

The second survey was administered after exam 4, on which students completed fertilizer and pesticide calculations. This survey contained the same information and questions as the survey given after exam 3. There were 167 participants, approximately 60% of the Fall 2012 class (Table 3.7). Seventy percent of these students used the videos to prepare for the exam, an increase of 39 students over the seedling calculation survey. Only 15% of these students had used similar videos in other classes. Students again indicated that math and accounting courses were the primary courses that used these types of videos.

Participants that used the videos responded to each given statement ranking at 3.4 or 3.5 out of 4 (Table 3.4). Of 54 students that did not use the videos, 70% indicated that they felt the class material in lecture was adequate information to learn the calculations (Table 3.5). Thirty two percent of these students indicated that did not have time to watch the videos and they used other resources.

Student Comments

The last question on the survey allowed students an opportunity to provide additional comments regarding the videos. Approximately 8 students indicated that they wanted to use the videos because they did not understand the material in class. It was also mentioned that students liked being able to pause and reply the videos several times while using them at home. Students that did not use the videos indicated that class notes and examples were sufficient, so videos were not needed. Many also indicated their time schedule did not allow for them to sit down and watch the videos.

Additional comments about the videos included that videos were clear and helpful, they were extremely helpful for those that struggle with math, and some of the students that did not use the videos heard from others that the videos were an excellent resource. Some students did feel that the writing could be improved on videos and that the videos should have been a resource for different examples, rather than providing the same examples given in class.

Both surveys revealed similar feedback given by students in previously published analyses of other online methods. Students responded enthusiastically to podcast recordings and videos of lecture materials for exam preparation at the University of Southampton (Copley, 2007). Students taking online courses at Deakin University felt more confident going into exams in these courses compared to their traditional on-campus courses. This survey reported 44.8% of students were at least generally satisfied with online classroom methods (Palmer and Holt, 2009). Another analysis reported 54% of students using online videos for a psychology lecture reported it was useful to have the ability to pause the lecture and replay (Bassili and Joordens, 2008).

Conclusions

Students that used the videos "agreed" or "strongly agreed" that it was helpful to have a resource outside the classroom and they would recommend friends use the videos. This shows the same results that Dalgarno et al. (2009) found after assessing students using online supplements for a chemistry course. Students who did not use the videos felt that the in-class lecture prepared them for exams.

Using the videos did not give students an advantage on the final exam over those students who did not have access to videos, but students who used the videos strongly believed they were beneficial and would benefit others. Because of the student feedback, it is recommended to use these videos and similar videos as an outside resource for class material. Videos can act as a reliable outside the classroom resource and students feel better prepared for exams.

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APPENDICES

APPENDIX A. 2011-2012 ANOVA TABLES AND COMPONENT DATA

Table A.1. Analysis of variance of average winter canola yield expressed as control average yield difference from treatment average yield for 2011-2012

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	12	6.88	0.0102
HERB	1	18	101.10	<.0001
TIME*HERB	2	18	26.17	<.0001
RATE	4	143	65.75	<.0001
TIME*RATE	8	143	20.86	<.0001
HERB*RATE	4	143	53.57	<.0001
TIME*HERB*RATE	8	143	11.09	<.0001

Table A.2. Analysis of variance of average winter canola yield expressed as percent of control for 2011-2012.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	12	5.85	0.0168
HERB	1	18	81.05	<.0001
TIME*HERB	2	18	21.61	<.0001
RATE	4	143	63.37	<.0001
TIME*RATE	8	143	21.09	<.0001
HERB*RATE	4	143	50.91	<.0001
TIME*HERB*RATE	8	143	11.14	<.0001

Table A.3. Average winter canola yield† for each treatment expressed as control average yield difference from treatment average yield for 2011-2012.

		Yield (kg ha^{-1})				
		Herbicide Rate‡ (fraction of use rate)				
Timing§	**Herbicide**	$^{1}/_{200}$	$^{1}/_{40}$	$^{1}/_{20}$	$^{1}/_{10}$	$^{1}/_{5}$
Stage 1	2,4-D	260¶	-530	-1168	-2225	-2225
	Dicamba	120	120	5	-61	-57
Stage 4	2,4-D	-52	-165	-297	-1208	-1864
	Dicamba	9	9	157	54	-132
Stage 5	2,4-D	-16	-35	-329	-204	-176
	Dicamba	-130	-86	-227	-56	-47

†The average control yield was 2,225 kg ha^{-1}.

‡Use rate for 2,4-D was 526 g ae ha^{-1}and dicamba was 281 g ae ha^{-1}.

§Timing corresponds to the following dates: Stage 1: October 28, 2011, Stage 4: March 26, 2012, Stage 5: April 10, 2012.

¶Values within 380 kg h^{-1} are not significantly different at $P \leq 0.05$ level.

Table A.4. Analysis of variance of average winter canola seed oil content for 2011-2012.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	14.1	1017.03	<.0001
HERB	1	21.3	3426.09	<.0001
TIME*HERB	2	21.3	2359.33	<.0001
RATE	4	164	2240.75	<.0001
TIME*RATE	8	164	1771.81	<.0001
HERB*RATE	4	164	2188.86	<.0001
TIME*HERB*RATE	8	164	1728.67	<.0001

Table A.5. Analysis of variance of average winter canola seed oil content expressed as percent of control for 2011-2012.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	14.1	1662.90	<.0001
HERB	1	20.1	5430.85	<.0001
TIME*HERB	2	20.1	3757.94	<.0001
RATE	4	161	2392.30	<.0001
TIME*RATE	8	161	1900.67	<.0001
HERB*RATE	4	161	2311.27	<.0001
TIME*HERB*RATE	8	161	1850.67	<.0001

Table A.6. Average winter canola seed oil content† for each treatment expressed as control average oil content difference from treatment average oil content for 2011-2012.

		Oil content (%)				
		Herbicide Rate‡ (fraction of use rate)				
Timing§	**Herbicide**	1/200	1/40	1/20	1/10	1/5
Stage 1	2,4-D	-0.2¶	-1.5	-2.1	-43.8	-43.8
	Dicamba	-0.2	0.2	-0.0	-0.1	-0.4
Stage 4	2,4-D	0.3	-0.8	-1.7	-3.8	-4.5
	Dicamba	0.1	0.2	-0.1	0.3	-0.5
Stage 5	2,4-D	0.2	0.2	-0.3	-0.1	-0.4
	Dicamba	0.2	0.2	0.1	0.3	0.2

†The average control seed oil content was 43.8%.

‡Use rate for 2,4-D was 526 g ae ha^{-1} and dicamba was 281 g ae ha^{-1}.

§Timing corresponds to the following dates: Stage 1: October 28, 2011, Stage 4: March 26, 2012, Stage 5: April 10, 2012.

¶Values within 0.8 are not significantly different at $P \leq 0.05$ level.

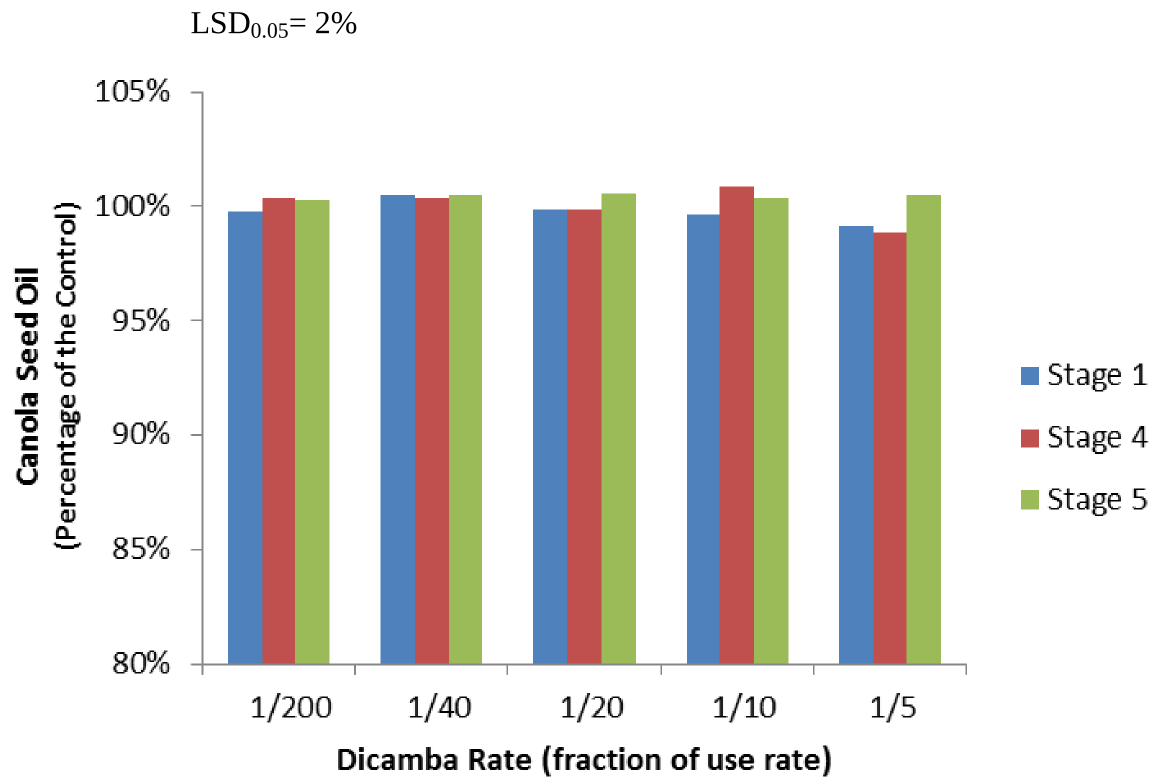

Figure A.1. Canola seed oil content as affected by simulated dicamba herbicide drift rates applied at stage 1, stage 4, and stage 5 in the 2011-2012 growing season. Use rate was 280.5 g ae ha^{-1} of dicamba. Oil contents were averaged across both locations in Stillwater and Perkins, OK. Average seed oil content of non-treated control was 43.8%. An asterisks (*) indicates a significant difference compared to the nontreated control.

Table A.7. Analysis of variance of average winter canola seed weight per 100 seeds for 2011-2012.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
TIME	2	10.3	48.47	<.0001
HERB	1	132	27.63	<.0001
TIME*HERB	2	132	73.42	<.0001
RATE	4	132	13.46	<.0001
TIME*RATE	8	132	22.44	<.0001
HERB*RATE	4	132	15.02	<.0001
TIME*HERB*RATE	8	132	20.23	<.0001

Table A.8. Analysis of variance of average winter canola seed weight per 100 seeds expressed as percent of control for 2011-2012.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
TIME	2	10.3	44.62	<.0001
HERB	1	132	26.73	<.0001
TIME*HERB	2	132	73.51	<.0001
RATE	4	132	12.48	<.0001
TIME*RATE	8	132	22.49	<.0001
HERB*RATE	4	132	14.61	<.0001
TIME*HERB*RATE	8	132	20.77	<.0001

Table A.9. Average winter canola seed weight† for each treatment expressed as control average seed weight difference from treatment average seed weight for 2011-2012.

		Weight (g 100 seed^{-1})				
		Herbicide Rate‡ (fraction of use rate)				
Timing§	**Herbicide**	$^1/_{200}$	$^1/_{40}$	$^1/_{20}$	$^1/_{10}$	$^1/_5$
Stage 1	2,4-D	0.04¶	-0.01	-0.03	-0.36	-0.36
	Dicamba	0.02	0.02	0.01	0.00	0.02
Stage 4	2,4-D	0.02	0.03	0.08	0.13	0.01
	Dicamba	0.02	0.00	0.02	0.02	0.03
Stage 5	2,4-D	0.02	0.02	0.01	0.04	0.03
	Dicamba	0.02	0.02	-0.01	0.02	0.00

†The average control seed weight 0.36 g 100 seed^{-1}.

‡Use rate for 2,4-D was 526 g ae ha^{-1}and dicamba was 281 g ae ha^{-1}.

§Timing corresponds to the following dates: Stage 1: October 28, 2011, Stage 4: March 26, 2012, Stage 5: April 10, 2012.

¶Values within 0.05 are not significantly different at $P \leq 0.05$ level.

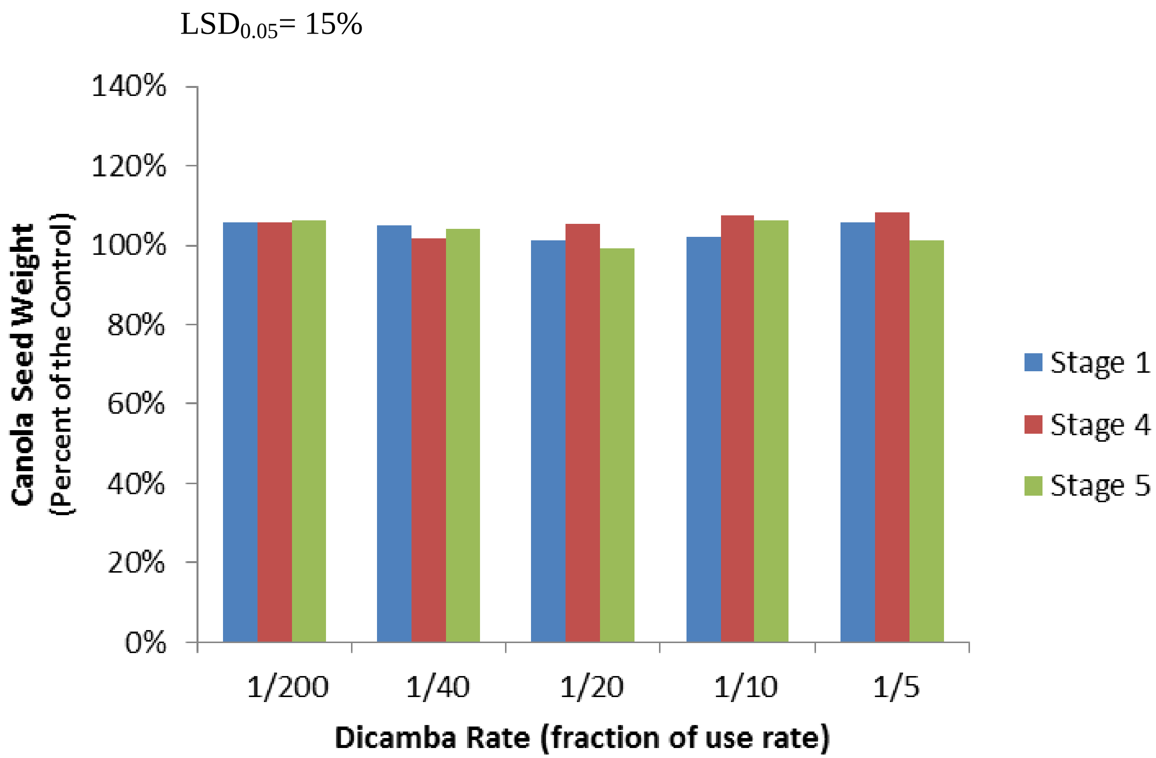

Figure A.2. Canola seed weight per 100-seeds as affected by simulated dicamba herbicide drift rates applied at stage 1, stage 4, and stage 5 in the 2011-2012 growing season. Use rate was 280.5 g ae ha^{-1} of dicamba. Seed weights were averaged across both locations in Stillwater and Perkins, OK. Average seed weight of non-treated control was 0.36 g per 100-seeds. An asterisks (*) indicates a significant difference compared to the nontreated control.

Table A.10. Analysis of variance of average winter canola injury at 7 days after treatment for 2011-2012.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	23.8	211.26	<.0001
HERB	1	23.7	811.59	<.0001
TIME*HERB	2	23.7	194.30	<.0001
RATE	4	181	584.21	<.0001
TIME*RATE	8	181	164.45	<.0001
HERB*RATE	4	181	324.98	<.0001
TIME*HERB*RATE	8	181	94.00	<.0001

Table A.11. Analysis of variance of average winter canola injury at 14 days after treatment for 2011-2012.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	225	78.07	<.0001
HERB	1	225	161.23	<.0001
TIME*HERB	2	225	41.83	<.0001
RATE	4	225	39.37	<.0001
TIME*RATE	8	225	11.28	<.0001
HERB*RATE	4	225	24.31	<.0001
TIME*HERB*RATE	8	225	7.17	<.0001

Table A.12. Analysis of variance of average winter canola injury at 28 days after treatment for 2011-2012.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
TIME	2	225	83.11	<.0001
HERB	1	225	259.9	<.0001
TIME*HERB	2	225	70.63	<.0001
RATE	4	225	59.25	<.0001
TIME*RATE	8	225	16.71	<.0001
HERB*RATE	4	225	42.94	<.0001
TIME*HERB*RATE	8	225	13.51	<.0001

Table A.13. Analysis of variance of average winter canola injury at swathing after treatment for 2011-2012.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
TIME	2	16.1	344.98	<.0001
HERB	1	23.8	1121.67	<.0001
TIME*HERB	2	23.8	384.03	<.0001
RATE	4	181	334.93	<.0001
TIME*RATE	8	181	92.65	<.0001
HERB*RATE	4	181	298.66	<.0001
TIME*HERB*RATE	8	181	91.4	<.0001

Table A.14. Analysis of variance of average winter canola fertile pods per plant for 2011-2012.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
TIME	2	37.6	2.04	0.1442
HERB	1	37.6	12.28	0.0012
TIME*HERB	2	37.6	3.91	0.0287
RATE	4	176	14.64	<.0001
TIME*RATE	8	176	4.86	<.0001
HERB*RATE	4	176	11.29	<.0001
TIME*HERB*RATE	8	176	4.40	<.0001

Table A.15. Analysis of variance of average winter canola infertile pods per plant for 2011-2012.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
TIME	2	14.3	4.04	0.0408
HERB	1	21.9	0.93	0.3460
TIME*HERB	2	21.9	4.19	0.0289
RATE	4	177	4.07	0.0035
TIME*RATE	8	177	7.05	<.0001
HERB*RATE	4	177	4.97	0.0008
TIME*HERB*RATE	8	177	5.37	<.0001

Table A.16. Analysis of variance of average winter canola total pods per plant for 2011-2012.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
TIME	2	37.1	3.75	0.0330
HERB	1	37.1	4.85	0.0339
TIME*HERB	2	37.1	3.50	0.0407
RATE	4	177	8.62	<.0001
TIME*RATE	8	177	6.97	<.0001
HERB*RATE	4	177	8.17	<.0001
TIME*HERB*RATE	8	177	5.45	<.0001

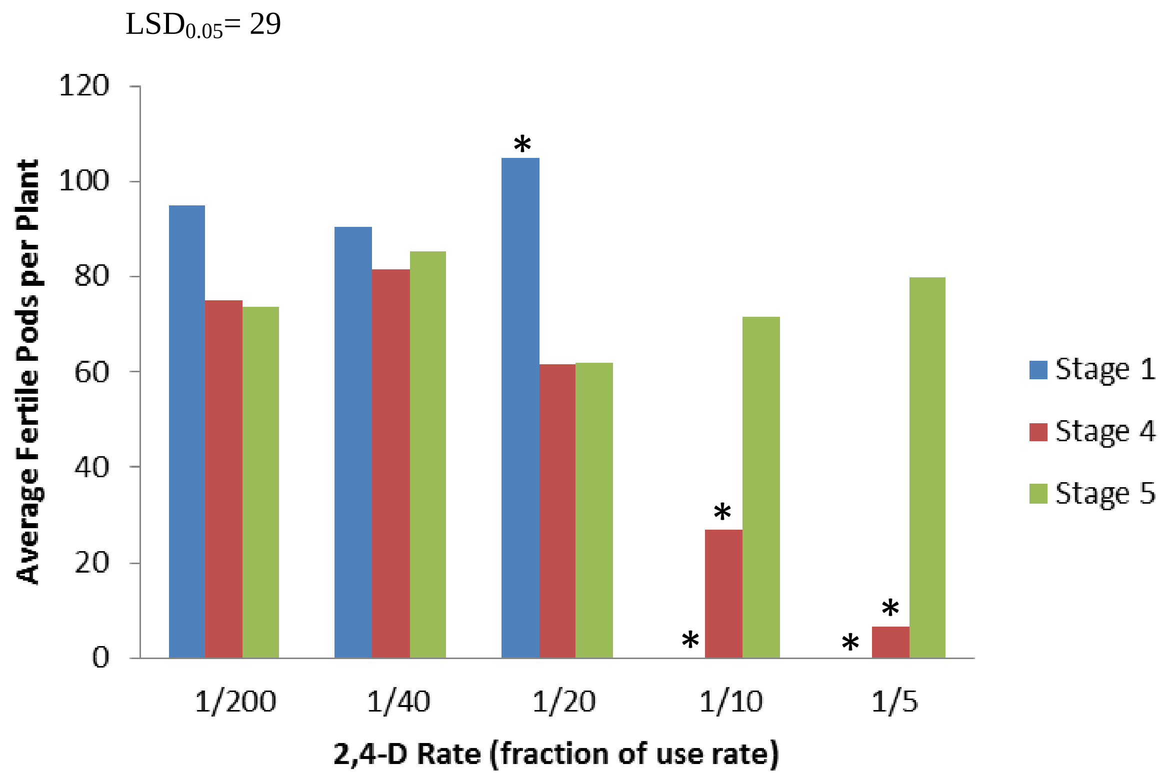

Figure A.3. Canola average fertile pods per plant as affected by simulated 2,4-D herbicide drift rates applied at stage 1, stage 4, and stage 5 in the 2011-2012 growing season. Use rate was 526 g ae ha^{-1} of 2,4-D. Fertile pods were averaged across both locations in Stillwater and Perkins, OK. Average fertile pods of non-treated control were 75 pods per plant. No samples were available for 1/10 and 1/5 rates in stage 4 and stage 5 due to crop loss. An asterisks (*) indicates a significant difference compared to the nontreated control.

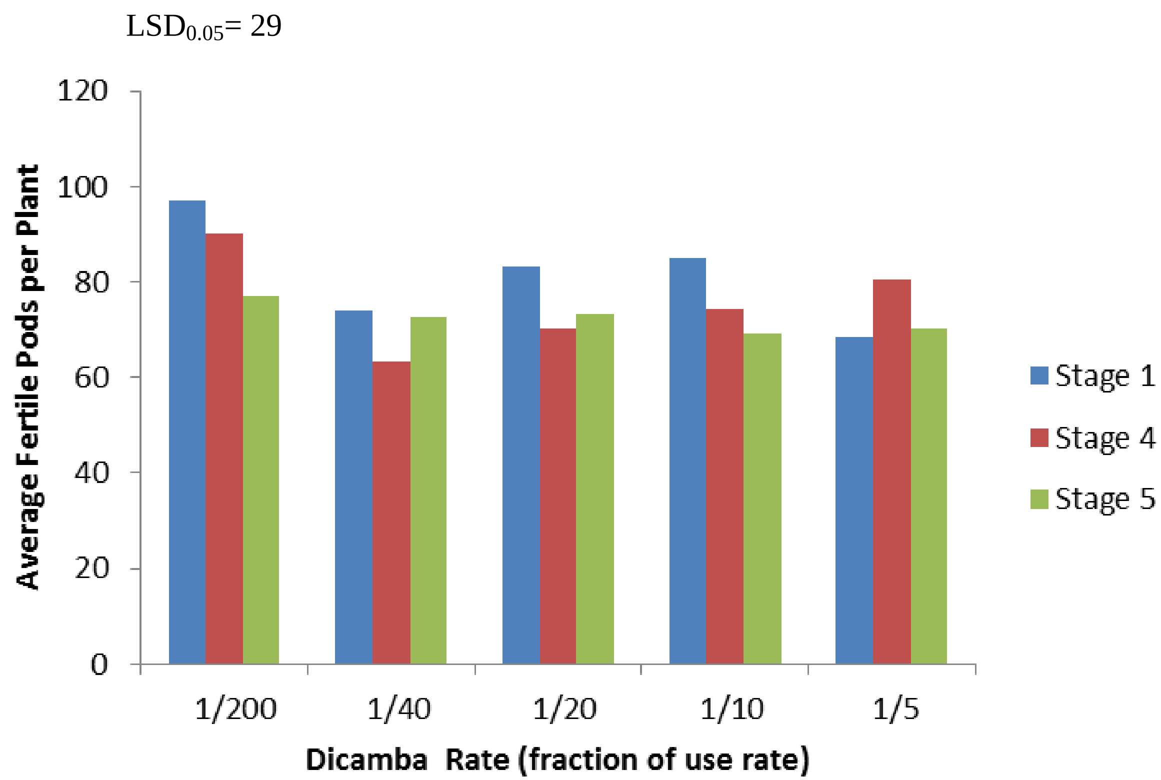

Figure A.4. Canola average fertile pods per plant as affected by simulated dicamba herbicide drift rates applied at stage 1, stage 4, and stage 5 in the 2011-2012 growing season. Use rate was 280.5 g ae ha^{-1} of dicamba. Fertile pods were averaged across both locations in Stillwater and Perkins, OK. Average fertile pods of non-treated control were 75 pods per plant. An asterisks (*) indicates a significant difference compared to the nontreated control.

LSD$_{0.05}$= 46

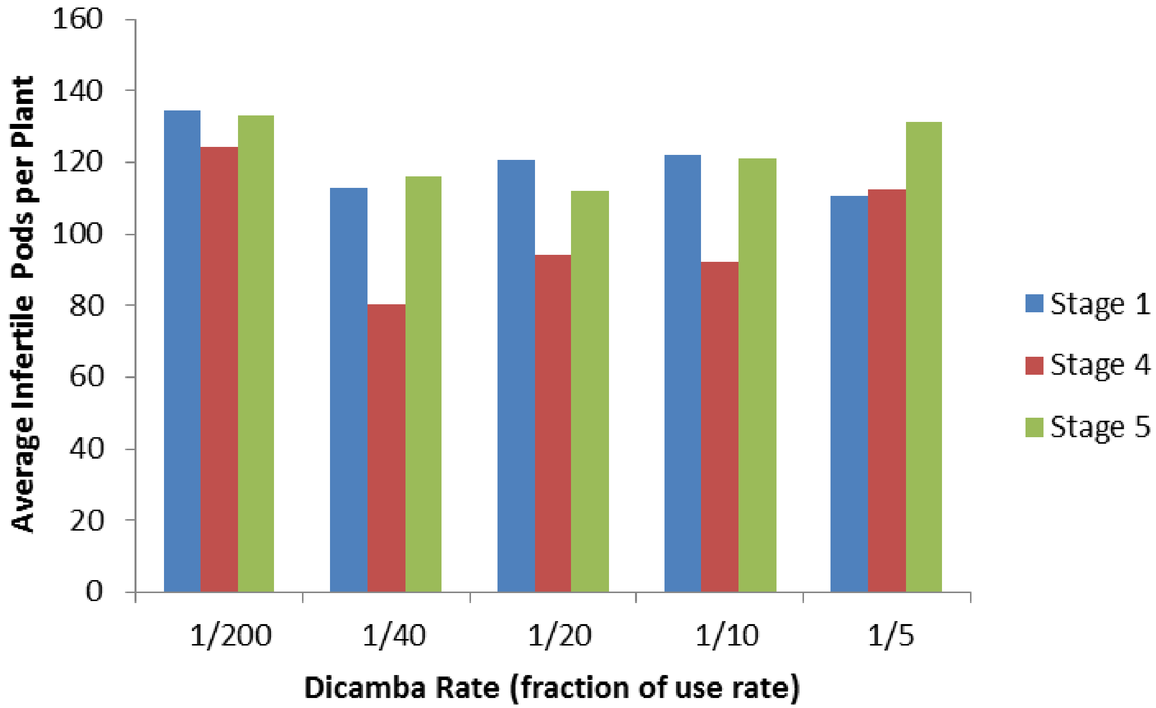

Figure A.5. Canola average infertile pods per plant as affected by simulated dicamba herbicide drift rates applied at stage 1, stage 4, and stage 5 in the 2011-2012 growing season. Use rate was 280.5 g ae ha^{-1} of dicamba. Infertile pods were averaged across both locations in Stillwater and Perkins, OK. Average infertile pods of non-treated control were 115 pods per plant. An asterisks (*) indicates a significant difference compared to the nontreated control.

Table A.17. Analysis of variance of average winter canola primary branches per plant for 2011-2012.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	16.2	13.31	0.0004
HERB	1	200	8.80	0.0034
TIME*HERB	2	200	21.89	<.0001
RATE	4	200	7.86	<.0001
TIME*RATE	8	200	9.51	<.0001
HERB*RATE	4	200	5.94	0.0002
TIME*HERB*RATE	8	200	6.69	<.0001

Table A.18. Analysis of variance of average winter canola secondary branches per plant for 2011-2012.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	13.4	0.45	0.6452
HERB	1	20.8	1.73	0.2033
TIME*HERB	2	20.8	0.22	0.8076
RATE	4	176	0.69	0.6031
TIME*RATE	8	176	4.33	<.0001
HERB*RATE	4	176	3.64	0.0070
TIME*HERB*RATE	8	176	3.39	0.0012

Table A.19. Analysis of variance of average winter canola tertiary branches per plant for 2011-2012.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
TIME	2	46.8	1.80	0.1762
HERB	1	46.8	5.01	0.0300
TIME*HERB	2	46.8	2.94	0.0626
RATE	4	181	0.48	0.7501
TIME*RATE	8	181	2.59	0.0105
HERB*RATE	4	181	0.72	0.5790
TIME*HERB*RATE	8	181	2.23	0.0270

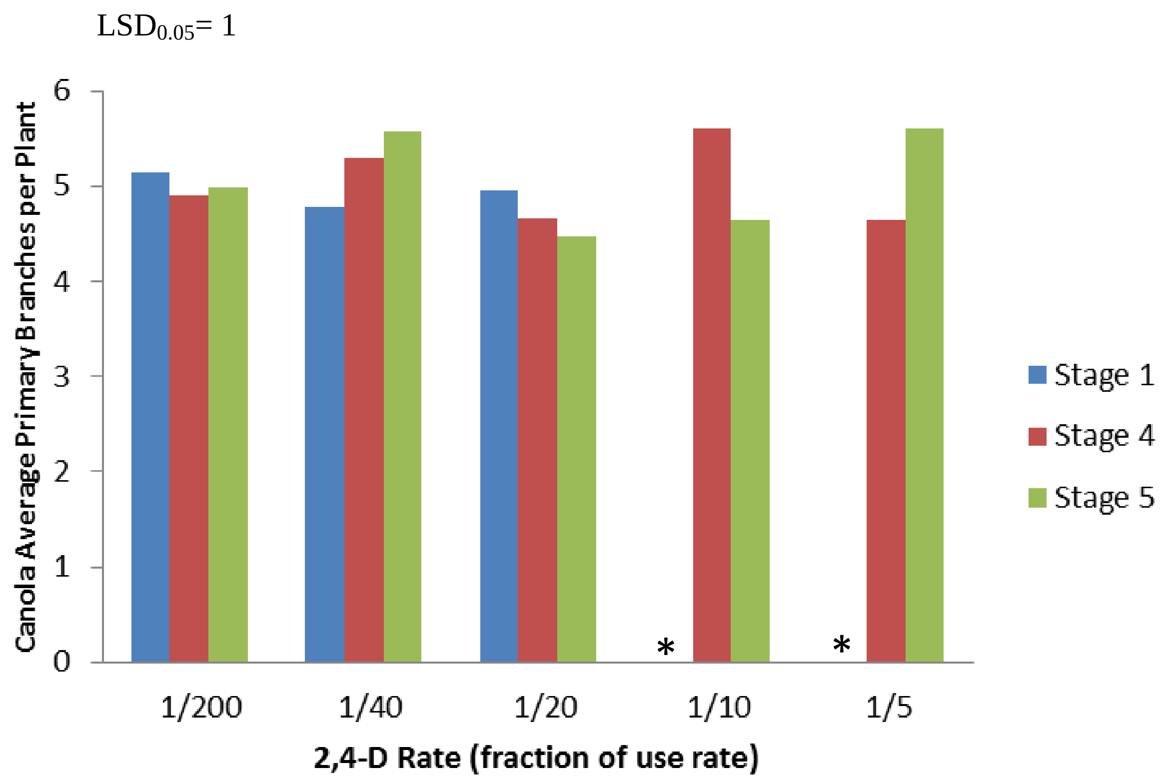

Figure A.6. Canola average primary branches per plant as affected by simulated 2,4-D herbicide drift rates applied at stage 1, stage 4, and stage 5 in the 2011-2012 growing season. Use rate was 526 g ae ha^{-1} of 2,4-D. Primary branches were averaged across both locations in Stillwater and Perkins, OK. Average primary branches of non-treated control were 5 branches per plant. No samples were available for 1/10 and 1/5 rates in stage 4 and stage 5 due to crop loss. An asterisks (*) indicates a significant difference compared to the nontreated control.

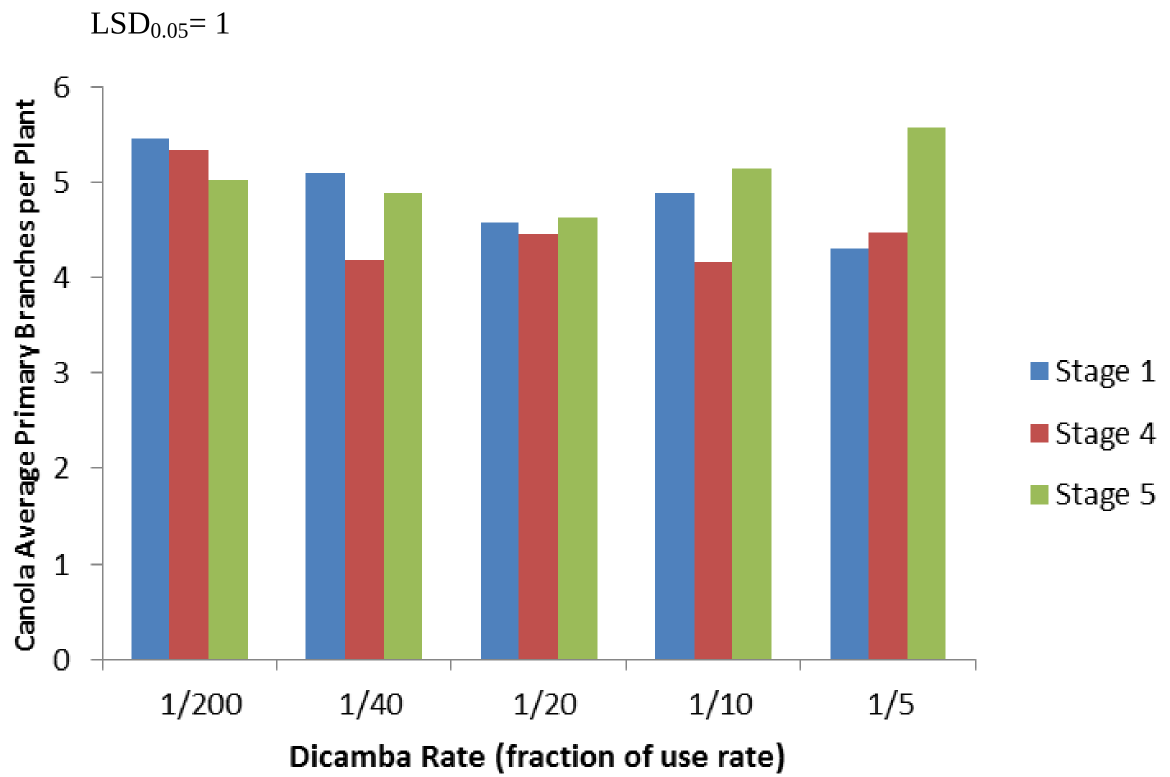

Figure A.7. Canola average primary branches per plant as affected by simulated dicamba herbicide drift rates applied at stage 1, stage 4, and stage 5 in the 2011-2012 growing season. Use rate was 280.5 g ae ha^{-1} of dicamba. Primary branches were averaged across both locations in Stillwater and Perkins, OK. Average primary branches of nontreated control were 5 branches per plant. An asterisks (*) indicates a significant difference compared to the nontreated control.

$LSD_{0.05}$= 1.4

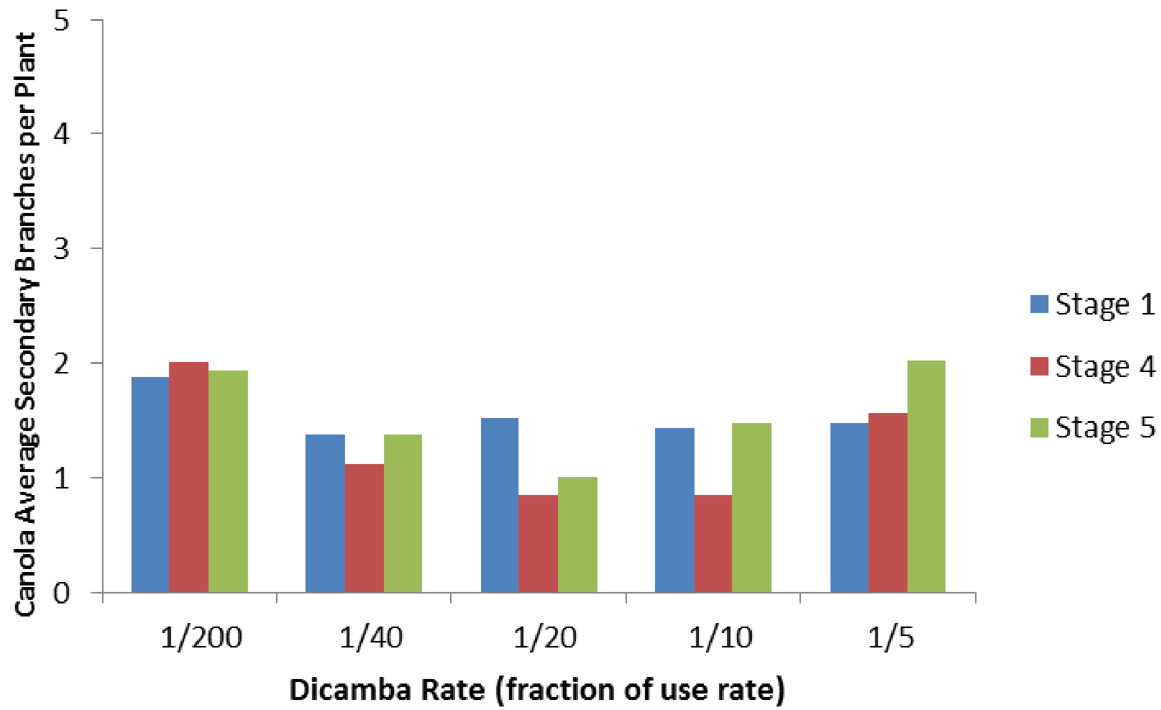

Figure A.8. Canola average secondary branches per plant as affected by simulated dicamba herbicide drift rates applied at stage 1, stage 4, and stage 5 in the 2011-2012 growing season. Use rate was 280.5 g ae ha^{-1} of dicamba. Secondary branches were averaged across both locations in Stillwater and Perkins, OK. Average secondary branches of nontreated control were 2 branches per plant. An asterisks (*) indicates a significant difference compared to the nontreated control.

APPENDIX B. 2012-2013 ANOVA TABLES AND COMPONENT DATA

Table B.1. Analysis of variance of average winter canola yield expressed as control average yield difference from treatment average yield for 2012-2013.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
TIME	2	14.3	0.71	0.5081
HERB	1	19.5	33.05	<.0001
TIME*HERB	2	19.5	2.06	0.1544
RATE	4	144	21.01	<.0001
TIME*RATE	8	144	2.24	0.0278
HERB*RATE	4	144	22.58	<.0001
TIME*HERB*RATE	8	144	4.16	0.0002

Table B.2. Analysis of variance of average winter canola yield expressed as percent of control for 2012-2013.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
TIME	2	12	5.85	0.0168
HERB	1	18	81.05	<.0001
TIME*HERB	2	18	21.61	<.0001
RATE	4	143	63.37	<.0001
TIME*RATE	8	143	21.09	<.0001
HERB*RATE	4	143	50.91	<.0001
TIME*HERB*RATE	8	143	11.14	<.0001

Table B.3. Average winter canola yield† for each treatment expressed as control average yield difference from treatment average yield for 2012-2013.

		Yield (kg ha^{-1})				
		Herbicide Rate‡ (fraction of use rate)				
Timing§	**Herbicide**	$^{1}/_{200}$	$^{1}/_{40}$	$^{1}/_{20}$	$^{1}/_{10}$	$^{1}/_{5}$
Stage 1	2,4-D	-183¶	85	105	-754	-2331
	Dicamba	158	-183	55	-321	168
Stage 4	2,4-D	-38	91	129	-1174	-1612
	Dicamba	73	124	179	293	36
Stage 5	2,4-D	-67	145	-171	-515	-664
	Dicamba	38	24	-171	141	-84

†The average control yield was 2,331 kg ha^{-1}.

‡Use rate for 2,4-D was 526 g ae ha^{-1}and dicamba was 281 g ae ha^{-1}.

§Timing corresponds to the following dates: Stage 1: October 26, 2012, Stage 4: April 16, 2013, Stage 5: May 6, 2013.

¶Values within 614 kg h^{-1} are not significantly different at $P \leq 0.05$ level.

Table B.4. Analysis of variance of average winter canola oil content expressed as control average oil content difference from treatment average oil content for 2012-2013.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	15.4	3.63	0.0510
HERB	1	24.5	34.25	<.0001
TIME*HERB	2	24.3	0.39	0.6844
RATE	4	163	11.21	<.0001
TIME*RATE	8	162	2.07	0.0420
HERB*RATE	4	163	12.22	<.0001
TIME*HERB*RATE	7	162	2.24	0.0339

Table B.5. Analysis of variance of average winter canola seed oil content expressed as percent of control for 2012-2013.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	38.9	4.48	0.0177
HERB	1	42.3	43.73	<.0001
TIME*HERB	2	41.7	1.73	0.1904
RATE	4	166	6.87	<.0001
TIME*RATE	8	165	1.94	0.0568
HERB*RATE	4	166	9.25	<.0001
TIME*HERB*RATE	7	165	1.47	0.1821

Table B.6. Average winter canola seed oil content† for each treatment expressed as difference from control average seed oil content for 2012-2013.

		Oil content (%)				
		Herbicide Rate‡ (fraction of use rate)				
Timing§	**Herbicide**	$^{1}/_{200}$	$^{1}/_{40}$	$^{1}/_{20}$	$^{1}/_{10}$	$^{1}/_{5}$
Stage 1	2,4-D	0.1¶	-0.2	-0.7	-1.0	-42.7
	Dicamba	-0.3	0.1	0.1	0.1	-0.1
Stage 4	2,4-D	0.0	-0.4	-1.6	-3.3	-1.2
	Dicamba	-0.4	-0.3	-0.3	-0.4	-0.4
Stage 5	2,4-D	-0.6	-0.5	-0.9	-1.9	-3.4
	Dicamba	-0.6	-0.4	-0.6	-0.6	-0.5

†The average control oil content was 42.7%.

‡Use rate for 2,4-D was 526 g ae $ha^{-1}$and dicamba was 281 g ae ha^{-1}.

§Timing corresponds to the following dates: Stage 1: October 26, 2012, Stage 4: April 16, 2013, Stage 5: May 6, 2013.

¶Values within 0.97% are not significantly different at $P \leq 0.05$ level.

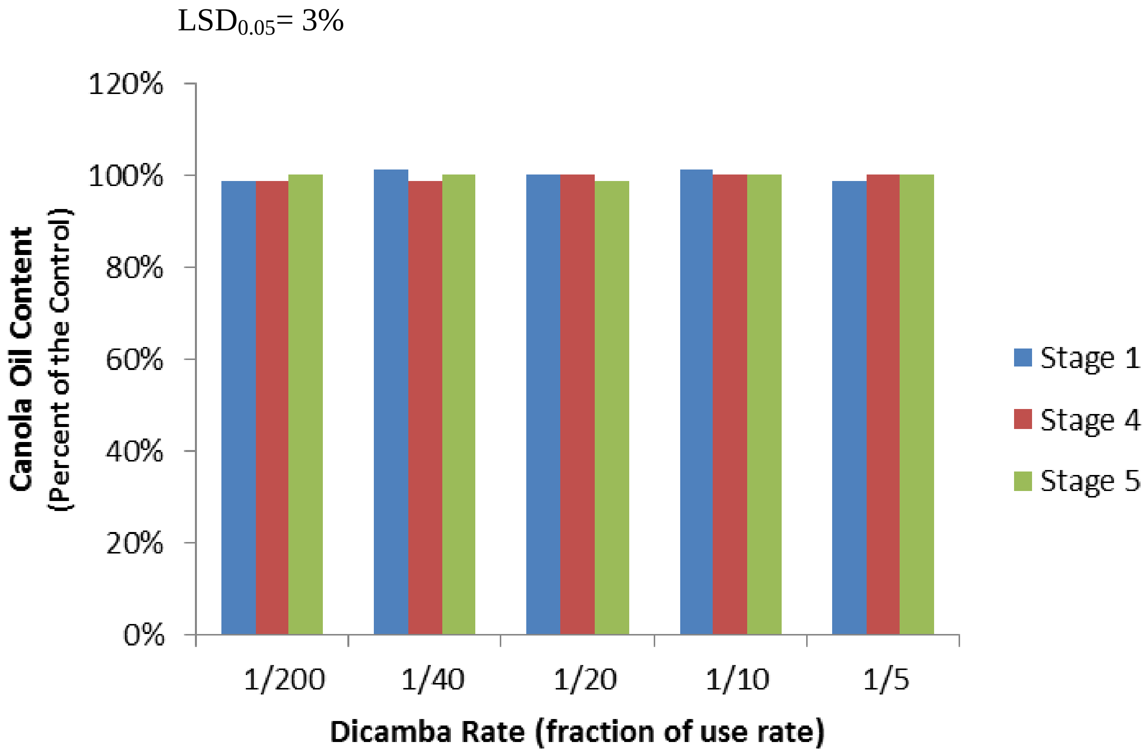

Figure B.1. Canola seed oil content as affected by simulated dicamba herbicide drift rates applied at stage 1, stage 4, and stage 5 in the 2012-2013 growing season. Use rate was 280.5 g ae ha^{-1} of dicamba. Oil contents were averaged across both locations in Stillwater and Perkins, OK. Oil contents were averaged across both locations in Stillwater and Perkins, OK. Average seed oil content of non-treated control was 42.7%. An asterisks (*) indicates a significant difference compared to the nontreated control.

Table B.7. Analysis of variance of average winter canola seed weight expressed as control average seed weight difference from treatment average seed weight for 2012-2013.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	25.2	18.26	<.0001
HERB	1	25.8	10.07	0.0039
TIME*HERB	2	26.1	11.20	0.0003
RATE	4	116	5.22	0.0007
TIME*RATE	8	116	6.98	<.0001
HERB*RATE	4	116	4.85	0.0012
TIME*HERB*RATE	7	116	5.96	<.0001

Table B.8. Analysis of variance of average winter canola seed weight per 100 seeds expressed as percent of control for 2012-2013.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	26.1	16.90	<.0001
HERB	1	26.6	11.51	0.0022
TIME*HERB	2	27	11.44	0.0003
RATE	4	117	5.66	0.0003
TIME*RATE	8	117	7.19	<.0001
HERB*RATE	4	117	4.81	0.0012
TIME*HERB*RATE	7	117	6.95	<.0001

Table B.9. Average winter canola seed weight per 100 seeds† for each treatment expressed as difference from control average seed weight per 100 seeds for 2012-2013.

		Weight (g 100 seed^{-1})				
		Herbicide Rate‡ (fraction of use rate)				
Timing§	**Herbicide**	$^{1}/_{200}$	$^{1}/_{40}$	$^{1}/_{20}$	$^{1}/_{10}$	$^{1}/_{5}$
Stage 1	2,4-D	0.00¶	-0.02	-0.03	-0.05	-0.32
	Dicamba	0.01	0.00	-0.01	-0.01	-0.01
Stage 4	2,4-D	0.01	-0.01	0.01	0.10	0.06
	Dicamba	0.00	-0.01	0.01	0.00	0.01
Stage 5	2,4-D	0.02	0.04	0.05	0.07	0.08
	Dicamba	0.01	0.01	0.00	0.01	0.02

†The average control seed weight 0.32 g 100 seed^{-1}.

‡Use rate for 2,4-D was 526 g ae ha^{-1}and dicamba was 281 g ae ha^{-1}.

§Timing corresponds to the following dates: Stage 1: October 26, 2012, Stage 4: April 16, 2013, Stage 5: May 6, 2013.

¶Values within 0.29 g are not significantly different at P ≤ 0.05 level.

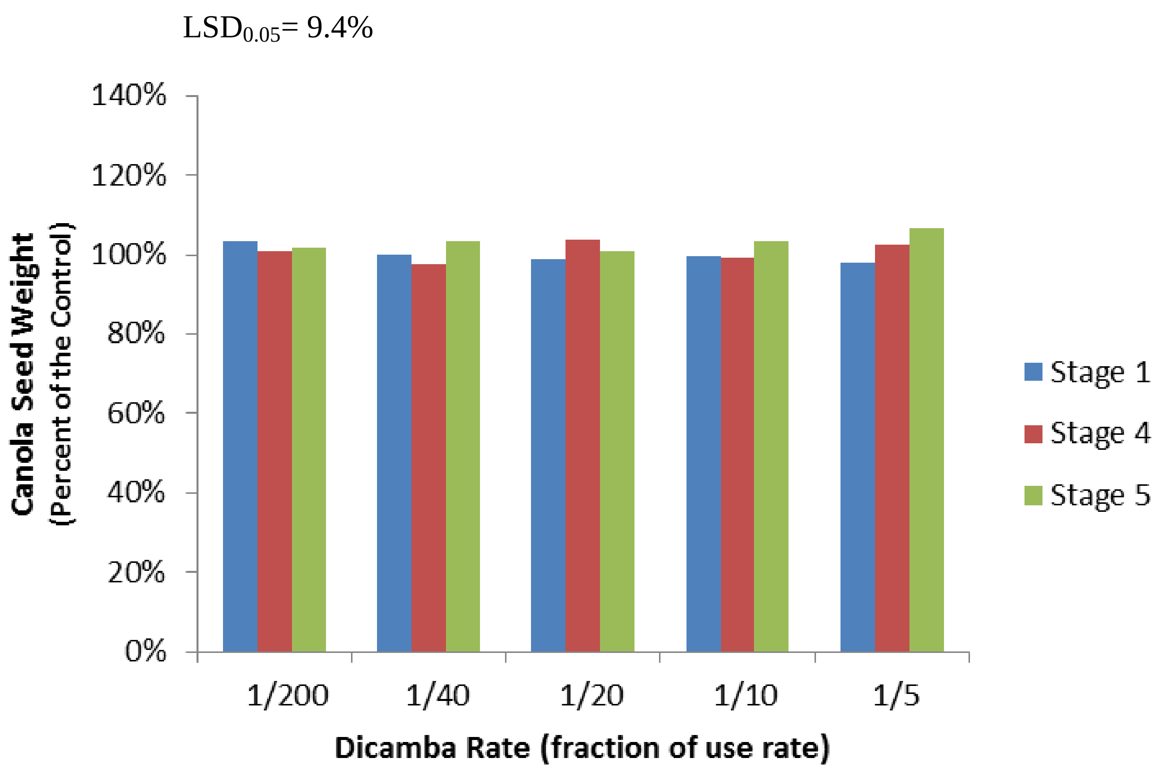

Figure B.2. Canola seed weight per 100-seeds as affected by simulated dicamba herbicide drift rates applied at stage 1, stage 4, and stage 5 in the 2012-2013 growing season. Use rate was 280.5 g ae ha^{-1} of dicamba. Seed weights were averaged across both locations in Stillwater and Perkins, OK. Average seed weight of non-treated control was 0.32 g per 100-seeds. An asterisks (*) indicates a significant difference compared to the nontreated control.

Table B.10. Analysis of variance of average winter canola injury at 7 days after treatment for 2012-2013.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
TIME	2	39	108.19	<.0001
HERB	1	39	612.86	<.0001
TIME*HERB	2	39	87.82	<.0001
RATE	4	181	407.84	<.0001
TIME*RATE	8	181	57.34	<.0001
HERB*RATE	4	181	226.95	<.0001
TIME*HERB*RATE	8	181	49.26	<.0001

Table B.11. Analysis of variance of average winter canola injury at 14 days after treatment for 2012-2013.

Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
TIME	2	47.4	121.66	<.0001
HERB	1	47.4	643.15	<.0001
TIME*HERB	2	47.4	73.14	<.0001
RATE	4	181	480.64	<.0001
TIME*RATE	8	181	62.70	<.0001
HERB*RATE	4	181	265.73	<.0001
TIME*HERB*RATE	8	181	40.93	<.0001

Table B.12. Analysis of variance of average winter canola injury at 28 days after treatment for 2012-2013.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	23.6	79.33	<.0001
HERB	1	23.8	695.98	<.0001
TIME*HERB	2	23.8	93.37	<.0001
RATE	4	181	437.23	<.0001
TIME*RATE	8	181	47.64	<.0001
HERB*RATE	4	181	267.90	<.0001
TIME*HERB*RATE	8	181	34.67	<.0001

Table B.13. Analysis of variance of average winter canola injury at swathing after treatment for 2012-2013.

Effect	Num DF	Den DF	F Value	Pr > F
TIME	2	23.4	101.00	<.0001
HERB	1	24.4	693.60	<.0001
TIME*HERB	2	24.4	104.76	<.0001
RATE	4	181	504.51	<.0001
TIME*RATE	8	181	61.71	<.0001
HERB*RATE	4	181	393.23	<.0001
TIME*HERB*RATE	8	181	59.51	<.0001

VITA

Samantha Kay Ambrose

Candidate for the Degree of

Master of Science

Thesis: EVALUATION OF 2,4-D ESTER AND DICAMBA DRIFT IN WINTER CANOLA IN OKLAHOMA

Major Field: Plant and Soil Sciences

Biographical:

Education:

- Completed the requirements for the Master of Science/Arts in your major at Oklahoma State University, Stillwater, Oklahoma in July, 2013.

- Completed the requirements for the Bachelor of Science in your major at Purdue University, West Lafayette, Indiana in May 2011.

Experience:

- Oklahoma State University, Graduate Research/Teaching Assistant
- Dow AgroSciences, Research Lab Assistant
- Beck's Hybrids, Field Research Intern
- Monsanto Company, Field Advisor Intern

Professional Memberships:

- Gamma Sigma Delta Honor's Society
- North American Colleges and Teachers of Agriculture (2012-2013)
- Western Society of Weed Science (2011-2013)
- American Society of Agronomy (2008-2013)

Awards:

- 2013 NACTA Graduate Student Teaching Award
- 2013 Honorary Graduate Spring Commencement Marshal
- Western Society of Weed Science Student Oral Paper Contest, 2nd place
- American Society of Agronomy Research Poster Contest, 3rd place
- Frank D. Keim Graduate Fellowship from the American Society of Agronomy