Dandelion's (*Taraxacum officinale*) Distribution, Interference, and Control in Roundup-Ready™ Canola

BY

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A Thesis
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DANDELION'S (*Taraxacum officinale*) DISTRIBUTION, INTERFERENCE, AND CONTROL IN ROUNDUP-READY™ CANOLA

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ABSTRACT

Froese, Nathan Todd. M.Sc. The University of Manitoba, August, 2001. Dandelion (*Taraxacum officinale* Weber in Wiggers) Distribution, Interference, and Control in Roundup Ready™ Canola (*Brassica napus* L.). Major Professor; Rene C. Van Acker.

In Western Canada, dandelion has long been considered a major pest of lawns and forage crops. Recently, dandelion has become a more significant issue in annual cropping systems, due to increased occurrence in Western Canadian fields (Thomas et al., 1998). This research aimed to improve our understanding of dandelion's role as a crop pest in annual cropping systems. Distribution of dandelion was considered, attempting to understand how it is distributed in fields, and the production practices that exacerbate the problem. The interference of dandelion with canola yield was also studied in order to determine an effective measure of dandelion infestations, and provide an estimate of canola yield loss by dandelion interference. Dandelion control studies tested the effect of glyphosate rate, time of glyphosate application, and spring tillage intensity on dandelion control.

Five canola fields were surveyed in southern Manitoba and it was concluded that dandelion can be distributed in a patchy and non-patchy manner in both zero- and conventional-tillage fields. Dandelion appears to be more of a widespread concern in zero-tillage fields, however populations are more likely to be patchy if light tillage operations are used, or higher rates of glyphosate are applied in spring. In conventional-tillage fields, dandelion infestations appear to originate when less-competitive crops are in rotation.

To determine the ability of dandelion to interfere with canola, productivity of canola in quadrats containing ranges of dandelion infestations was determined. When

reduction in canola yield was plotted relative to measures of dandelion infestation, clearly dandelion interference with canola yield in conventional-tillage fields could not be predicted. In zero-tillage fields, predictability improved with narrower dandelion demography. The best measures of dandelion infestation were dandelion percent ground cover measured at the 2-4 leaf stage of canola, total dandelion root diameter m^{-2} measured at harvest, and total dandelion leaf diameter m^{-2} measured at the 2-4 leaf stage of canola.

Dandelion control studies were established in 1999 and 2000. Spring tillage alone was found to reduce dandelion biomass by greater than 50%. Spring tillage did not interact significantly with glyphosate rate or time of glyphosate application (when considering residual dandelion biomass). Increasing glyphosate rate significantly improved dandelion control only when a substantial crop canopy was present. The best times of glyphosate application were pre- or post-harvest as dandelion biomass was reduced the most by glyphosate applications at this time. The most efficient applications of glyphosate were made after harvest as at this time of year low rates provided excellent control of dandelion. Sequential glyphosate applications within one growing season provided near-complete control of dandelion if one of the applications included was a post-harvest treatment of 900 g a.i. ha^{-1}.

Dandelion has the ability to infest zero- and conventional-tillage fields to a significant extent (present in >50% of field, by area). These infestations can reduce yield to a significant extent (up to 100%), although predictability of yield loss is limited unless dandelion populations have a narrow demography. It is possible to achieve significant control of dandelion populations using spring tillage, or 900 g a.i. ha^{-1} applications of glyphosate before seeding or after harvest. Dandelion has the potential to develop into a widespread concern in annual cropping systems. Increasing our knowledge about this pest will limit its ability to spread, and reduce its impact on crop productivity.

FOREWORD

This thesis has been written in manuscript style. Chapter 3 was prepared in accordance with the style requirements of Weed Science. Chapter 4 was prepared in accordance with the style requirements of Weed Technology.

1. INTRODUCTION

In Western Canada, dandelion (*Taraxacum officinale* Weber in Wiggers) has long been considered an important weed. Until recently however, dandelion has not been considered a significant pest within annual cropping systems. Surveys of Western Canadian fields, conducted in 1986-9 and 1995-7, show an alarming increase in dandelion frequency in Western Canada (Thomas et al., 1998). In 1986-9 dandelion was present in 6 percent of wheat (*Triticum aestivum* L.) fields and 13 percent of canola (*Brassica napus* L.) fields in the Prairie Provinces. In 1995-7 however, dandelion presence increased to 20 percent of wheat fields and 23 percent of canola fields. Based on a relative abundance index, there was an increase in rank of 17 in wheat fields and an increase in rank of 7 in canola fields. In Manitoba alone, dandelion has not increased in rank, whereas in Alberta and Saskatchewan dandelion has increased in rank by 3 and 9, respectively. It is widely speculated that perennial weeds (including dandelion) have increased due to increased adoption of zero-tillage practices (Witt, 1984; Blackshaw et al., 1994; Froud-Williams et al., 1983).

The majority of the interest paid to dandelion by researchers in the past has been related to its ability to infest forage crops and urban lawns. A significant amount of research has focused on dandelion in alfalfa (*Medicago sativa* L.) (Hall et al., 1995; Sheaffer and Wise, 1982; Robison et al., 1978; Waddington, 1980; and Miller, 1986), orchardgrass (*Dactylis glomerata* L.) (Moyer, 1984), and red fescue (*Festuca rubra* L.) (Darwent and Lefkovitch, 1995). A large majority of lawn and garden herbicides are designed to manage dandelion infestations. Until recently, very little consideration has been given to dandelion's role as a pest of annual field crops.

Perennial weeds such as Canada thistle (*Cirsium arvense* (L.) Scop.), quackgrass (*Elytrigia repens* (L.) Nevski.), and perennial sowthistle (*Sonchus arvensis* L.) have garnered considerable research attention in Western Canada in recent years. A considerable amount of information has been gathered regarding their competitive ability, and management techniques have been devised. This research groundwork has not yet been laid for dandelion in field crop scenarios. Currently, there is a lack of information regarding how to properly quantify a dandelion infestation. It is expected that dandelion interference has the ability to reduce crop productivity, yet to what extent? Efficient methods of cultural and chemical control of dandelion populations have not yet been devised. This research aims to develop a foundation from which these concerns might be addressed.

The overall objective of this research was to improve the understanding of dandelion's role as a crop pest in Manitoba. This manuscript considers two aspects of dandelion as a weed in the Prairie Provinces: 1) Distribution and Interference, and 2) Control.

Distribution and interference studies aim to answer questions relating to dandelion's distribution throughout fields, it's ability to compete with crops, and it's propensity to reduce productivity on a whole-field basis. It is hypothesized that dandelion populations exist in patches throughout fields, much like other perennial weeds. As dandelion infestations increase, canola yield will be reduced to a greater degree. It is also expected that dandelion infestations might be accurately quantified by one (or more) of dandelion 1) leaf area, 2) ground cover, 3) density, 4) root diameter, 5) biomass, or 6) root diameter. Objectives are to determine 1) the effect of dandelion interference on canola yield, 2) an effective measure of dandelion infestation, 3) an estimate of canola yield loss from dandelion on a whole-field basis, and 4) the patchiness of dandelion in zero- and conventional-till fields.

Dandelion control studies were designed to address the questions of how tillage and glyphosate control dandelion populations. It is hypothesized that dandelion populations will be greatly reduced by high disturbance seeding, that increasing glyphosate rate should result in an increase in dandelion control, and that like other perennial (tap-rooted) weeds, fall application of glyphosate will provide greater control than early in the growing season. Efficacy could also be influenced by meteorological factors such as rainfall and temperature. The objectives of control studies were to determine the effects of 1) spring tillage intensity, 2) glyphosate rate, and 3) time of glyphosate application on dandelion control. The primary goal was to determine the most efficient use of glyphosate within low- and high-disturbance systems.

Currently, grain farmers in Western Canada do not possess the information needed to defend against an increased proliferation of dandelion in annual grain crops. This research aims to improve knowledge of dandelion biology as it relates to crop productivity. Enhancing knowledge of the competitive ability of dandelion and developing efficient control measures is the best defense against a pest which needs to be managed carefully to help avoid development of dandelion as a substantial weed for Western Canadian producers.

2. LITERATURE REVIEW

2.1. INTRODUCTION:

2.1.1. PAST PROBLEMS WITH DANDELION

In Western Canada, dandelion has long been considered a noxious weed. The majority of attention paid to dandelion, however, has been from those concerned about it's role in reducing the aesthetic appeal of lawns. It's ability to efficiently infest a lawn and thrive in an environment which routinely faces the unforgiving lawn mower has led to a respect for its ability to survive. Dandelion has a very low growth habit and only when the flower opens and seeds are ready for dispersal is it vulnerable to defoliation (Richardson, 1985). The widespread scourge of dandelion has led to a large number of chemicals being available at local hardware stores for the singular purpose of removing dandelion in residential lawns. Scientists considering dandelion control have considered chemical (Welton and Carroll, 1934), cultural (Mølgaard, 1977) and biological (Burpee, 1992) control methods.

Dandelion control is also a major concern in alfalfa (Hall et al., 1995; Sheaffer and Wise, 1982; Robison et al., 1978; Waddington, 1980; and Miller, 1986), orchardgrass (Moyer, 1984), red fescue (Darwent and Lefkovitch, 1995), peppermint (Brewster et al., 1988), and in orchards (Lipecki, 1985). Moyer et al. (1990) found that removing dandelion from sainfoin crops resulted in a dramatic increase in yield, however removal from alfalfa crops had no effect on alfalfa yield. It is widely known that alfalfa stands weaken over time, providing a niche for dandelion (Spandl et al., 1999). Common practice has been to maintain forage stands for an average of 6.5 years in Manitoba and Saskatchewan (Entz et al., 1995), however the economic optimum was shown by Jeffrey et al. (1993) to be 4 to 5 years. Ominski et al. (1999) found that dandelion populations were much greater in fields that had alfalfa in rotation relative to fields planted to straight cereal rotations. Dandelion is known to provide adequate protein and mineral nutrition for cattle (Bergen et al., 1990), however it has lower protein levels than alfalfa at the first cut and may reduce marketability of forage crops (Moyer et al., 1990). The large populations of dandelion that develop in forage crops can persist and reduce yields in annual crops which follow forages in fields. To-date, persistence and competition of dandelion in annual crops following a long-term forage crop remain an un-tested concern.

Dandelion has many positive attributes as well. It is a prominent tool for herbal medicine where it may be used for tonics, as a diuretic, and as a treatment for liver and gall bladder ailments (Dalby, 1999). Leaves and roots can be used in salads, the yellow blossoms made into wine, seeds used for snacks, leaves for tea, and roots for a coffee-like drink (Mitich, 1989; Schmidt, 1979). It is believed that dandelion originated in Greece and quickly spread throughout Europe and Asia Minor, leading to its deposition in North America by settlers who considered it a valuable plant (Mitich, 1989).

In the past, dandelion was not considered to be an economically important weed of annual field crops. In 1960 it was estimated that the total annual value of crop lost to weed competition in Manitoba was greater than 32 million dollars (Friesen and Shebeski, 1960) whereas in 1984 it was estimated that this value was greater than 125 million dollars (with dollar value adjusted to 1960 values) (Weed Science Society of America, 1984). Neither study mentioned dandelion's role in these losses. It is assumed that the role of dandelion in these losses was minimal.

2.1.2. CURRENT PROBLEMS WITH DANDELION

Surveys of Western Canadian fields conducted in 1986-9 and 1995-7 show an alarming increase in dandelion frequency (Thomas et al., 1998). In 1986-9, dandelion was present in 6 percent of wheat fields and 13 percent of canola fields in the Prairie Provinces. In 1995-7 however, dandelion presence increased to 20 percent of wheat fields and 23 percent of canola fields. Based on relative abundance index, there was an increase in rank of 17 in wheat fields and an increase in rank of 7 for canola fields. In Alberta, dandelion increased in rank by 3 overall. In Saskatchewan, dandelion increased in rank by 9 overall. In Manitoba however, perennial species were largely unchanged in rank among all weed species, and dandelion populations were seen as negligible.

Water availability in soils differed dramatically between the years in which the previously mentioned surveys were taken. 1988 was a very dry year, whereas moisture was abundant in the mid 1990's across the Prairie Provinces. The lack of moisture when original surveys were taken might have served to under-estimate dandelion populations at this time, resulting in a much more dramatic increase than had actually occurred. It has been demonstrated that dandelion populations do not increase after periods of high moisture (Ominski et al., 1999)

Reduced tillage systems have been popular in most countries for growing a large variety of crops (Watson and Allen, 1985). In the past, tillage was the primary method of weed control. This changed, however, with the advent of herbicide availability for field crops in the 1940's (Williams and Wicks, 1978). Herbicides made it easier for farmers to manage their weed problems within crops, however they still relied heavily on tillage for seedbed preparation and weed control when crops weren't grown. The dust-bowls which resulted from excess tillage and dry weather led to the discovery several decades ago that soil erosion could be managed by using zero tillage production practices (Domitruk and Crabtree, 1997).

Reduced and zero tillage has a significant impact on weed populations. Reducing tillage operations makes perennial weed species much more difficult to control, even with the large selection of herbicides available (Witt, 1984). Blackshaw et al. (1994) found that dandelion and perennial sowthistle densities increased slightly over time in minimum- and zero-tillage treatments. Perennial and wind-borne species were found to be more frequent on uncultivated plots (Froud-Williams et al., 1983). In the United States, the federal Conservation Reserve Program surveyed land that hadn't been tilled, hayed, or grazed for ten or more years and found that the most prevalent weeds were Canada thistle, Quackgrass, dandelion, and goldenrod (*Solidago spp.* L.) (Jewett et al., 1996). This argument has not been clearly accepted however; as Derksen et al. (1993) found that the association of perennial species with reduced-tillage was not consistent. Derksen did report, however that dandelion did associate with zero-tillage at one site (out of three) in 1989 and 1990. In a survey of 65 conventional- and 65 zero-tillage fields in 1994, Kelner (1995) found that weed populations were similar among tillage systems with the exception of wild mustard (which was far more abundant in conventional-tillage fields), and zero-tillage fields may host a more diverse weed community in the field borders. Kelner's data does show however that dandelion ranked as the thirteenth most abundant weed in zero-tillage fields and did not rank among the top fifteen in conventional-till fields.

Dandelion is also a pest in conventional-till fields due to its wind-dispersed seed and large primary root. When the root is cut (by a cultivator for example), callus tissue is formed on the root tip to plug the wound and one or more buds are formed on this tissue from which new leaves or an entirely new plant forms (Solbrig, 1971). Often this results in a ring of dandelion plants around the location of the original plant. Dandelion is an "r strategist" species (Solbrig, 1971), which means that it invests a high proportion of its energy into seed production. Cultivation is able to slowly overcome dandelion's persistent nature, however, as repeated cutting off of top growth starves even older roots of the photosynthate supply from the leaves (Georgia, 1933). Dandelion roots can also be starved in lawns using "spudding" tools that a gardener can use to cut off roots below ground. This is labor intensive however and is not feasible for large areas. Dandelion can become a serious pest in alfalfa crops because its low growth habit makes it difficult to defoliate by repeated cuttings (Ominski et al., 1999).

For the first few years following a major dandelion outbreak (i.e., following a poor forage stand), a large dandelion population can be present that may compete strongly with annual crops. Perennial species have been shown to increasingly infest forage stands of long duration. In one study, when no control measures were implemented, Canada thistle initially increased in density, but over time the population stabilized at a uniform density of roughly one to three plants per square foot (Schreiber, 1967). In this same study it was also shown that the productivity of alfalfa stands decreased with age, and this was accelerated by the presence of Canada thistle. Dandelion behaves in a similar manner. Perennial species can also travel into fields through seed rain. Hume and Archibold (1986) considered the movement of seeds from a weedy field edge into a field and found that nearly all the perennials in the field were a result of seed rain from an adjacent pasture, yet frequent cultivation prevented the establishment of these species.

In Europe, dandelion was found to reproduce sexually (Jenniskens et al., 1984; Jenniskens et al., 1985; Morita et al., 1990; Nijs and Sterk, 1984a; Nijs and Sterk, 1984b; Richards, 1970). Genetic recombination allows dandelion an increased ability to adjust to changing conditions (Raven et al., 1992). In North America however, dandelion reproduces exclusively in an asexual nature, both from apomixis during seed development, and also by vegetative propagation from cut pieces of roots. The threat of dandelion developing the ability to reproduce sexually in North America is alarming as it would dramatically change the population dynamics of dandelion, and allow it to develop into an even more dynamic competitor with crops. Even though hybridization does not provide genetic diversity, many genotypes exist with contrasting seasonal performance, leading to stability in long-term fitness (Vavrek, 1996). Different genotypes thrive in different habitats and over time within the same habitats, although at any one time many genotypes are present (Sterk et al., 1983; Solbrig and Simpson, 1974). For example, Welham and Setter (1998) determined that dandelion in an alfalfa field consisted mainly of genotypes with modified reproductive morphology relative to predominant genotypes found in an undisturbed grass field. Non-meiotic recombination occurs frequently in dandelion, yet not as rapidly as genetic recombination in sexual species (Mertens King and Schaal, 1990). Lyman and Ellstrand (1984) studied 22 populations of dandelion and found that they were more genetically diverse than other clonal species they had previously studied. Even low rates of non-meiotic recombination would allow for the accumulation of genotypic variation as individual plants are capable of colonizing widespread habitats (Mertens King and Schaal, 1990). Thus, dandelion is proficient at adapting to different environments, with diverse genotypes capable of displaying properties ideal for distinct niches (Ford, 1981).

Currently there has been little research on how to manage dandelion in annual field crops. As mentioned, increased concern over dandelion comes from its increasing presence in reduced-tillage cropping systems. It has been postulated that wind-blown weed species can be controlled economically by spraying effective herbicides around the edges of fields (Moyer et al., 1994). Effective, non-selective herbicides may not be very appropriate for controlling perennial weeds before seeding as weeds might not have emerged, or after harvest as cool weather and low moisture levels limit growth of weeds (Moyer et al., 1994). Canola varieties tolerant to herbicides that control dandelion might provide the tools necessary to control perennial weeds in-crop in a reduced tillage system.

One of the difficulties involved with developing dandelion control measures is that very little is known about dandelion population demography. Common sense would lead one to believe that established dandelion plants are more difficult to control than seedling plants as seedlings would not have had as much time to develop significant root storage reserves. For example, this difference could be more significant when considering plants that are 2 years old versus those that are 15 years old. Silversides (1938) attempted to address this problem by developing a measurement of relative dandelion age based on the number of rings formed in the primary root. By harvesting roots he was able to measure rings (assuming one ring was produced each year), and determine the relative age of plants. He found average ages of populations ranging from

9.57 years in lawns (short grass) to 14.2 years in long grass. He found however that the root cortex shrank significantly from July 1 to 15, due to large amounts of root reserves being used for leaf production. Silversides believed this might have skewed his data toward younger plants. Another problem with this technique is that plants had to be destroyed in order to measure age, meaning that accurately measured populations could not be subjected to control treatments. This method could be used to sample populations in order to estimate ages, however the sampling methodologies would have to be tested in order to ensure sufficient samples were taken. For example, a pre-determined number of plants could be randomly selected from a population, harvested, and measured, so that inferences could be made for the rest of the population.

2.1.3. PREDICTION OF FUTURE PROBLEM

The literature illustrates that dandelion is increasing in abundance across the Canadian Prairies. The increased adoption of reduced tillage practices provides a habitat for dandelion as an "opportunistic colonizer of reduced-cultivation situations" (Froud-Williams et al., 1981). In the past, seeing dandelion growing in a ditch alongside a field might not have caused producers alarm. Today however this view has changed, as dandelion can easily become a prominent pest in fields subjected to reduced-tillage practices (LeBaron, 1982).

No longer can dandelion be viewed as a weed of low importance in annual crops. We must understand the competitive ability of dandelion in field crops to determine the economic implications of increasing dandelion infestations. We must also develop appropriate control measures that may be used in a modern cropping system.

"Technological solutions to weed control problems must be integrated into larger aspects of crop production practice and farm finance." (Donald, 1990)

2.2. DANDELION COMPETITION:

2.2.1. DANDELION DISTRIBUTION IN FIELDS

It is very important to understand the distribution of a weed so as to better evaluate its interference with crop yield, and provide economic control measures. Weeds (especially perennial weeds) occur mainly in patches (Wiles et al., 1992a; Wiles et al., 1992b). The distribution of a weed influences the yield loss from competition, the design of the optimal scouting plan and the feasibility of patch spraying. The spatial distribution of a weed can also have a significant effect on the economic thresholds of control measures (Thornton et al., 1990). Dandelion population demographics tend to stay relatively stable over time (Ominski et al., 1999). To date, very little information has been gathered regarding dandelion distribution in fields.

Agronomy studies have considered the presence of dandelion in specific cropping systems. Wrucke and Arnold (1985) considered the distribution of weed species relative to tillage and herbicide treatment, however perennial weeds were controlled with glyphosate to prevent their domination. It was surmised that glyphosate applications might be necessary for control of perennial weeds in reduced-tillage systems. Buhler et al. (1994) found that dandelion populations increased in ridge and no-tillage soybean relative to moldboard- or chisel-plough tillage while the use of interrow cultivation maintained dandelion populations at very low densities. The greatest infestation was in no-tillage plots, however no mention was given of the distribution of dandelion within fields. De la Fuente et al. (1999) found that dandelion was present in areas of soybean

(*Glycine max* L.) fields where potential yield was high. A study of corn (*Zea mays* L.) grown in high and low disturbance conditions found that dandelion populations increased significantly in low disturbance plots relative to high disturbance plots (Triplett and Lytle, 1972). Dandelion was also found to increase in plots that had a high frequency of broadleaf crops in rotation (Stevenson and Johnston, 1999). This might also partially explain the increased dandelion populations found by Thomas et al. (1998), as Prairie producers grew more broadleaf (canola, pulse) crops in the mid 1990's relative to the late 1980's. Donald (1994) considered the distribution of Canada thistle and found that geostatistical measurements could be quite useful in determining changes in weed distribution across landscapes over time. Donald provided evidence that Canada thistle infestation occurred in patches, with infestation varying greatly across a patch. In a study of pastureland (grass species), Popolizio et al. (1994) found that percent foliage cover of land was dominated by dandelion in grazed areas as well as in land recently protected from grazing. Dandelion infested plots that had been grazed heavily by animals.

2.2.2. QUANTIFYING DANDELION INFESTATION

Weeds are not desired in fields due to their interference with crop productivity, and the resulting decrease in crop yield. A considerable effort has been undertaken to assess the most appropriate method of determining weed interference. Dew (1972) developed an index of competition for estimating crop loss due to weeds. The index of competition was a unique measure for each weed and crop combination and was independent of the estimated weed-free yield of the crop. It provided a numerical value for the competitive ability of a weed/crop combination using the slope and y-intercept of the regression equation for crop yield vs. weed density curves. Recent attempts to quantify competitive ability have focused more on the leaf area and dry weight of weeds (Lotz et al., 1994; Lotz et al., 1996; Lutman et al., 1996; Ngouajio et al., 1999). Lotz et al. (1994) found evidence that the simple method of determining weed interference would be very powerful if user-friendly methods to detect weed leaf area were available. It was shown by Lutman et al. (1994) that visual assessments of weed and crop ground cover could be a valuable tool to assess the potential competitive effects of weeds. Weed density was not a consistent predictor of yield loss, however relative dry weights of crops and weeds were when harvested while plants were still small. Measurements of relative leaf area and ground cover assessed subjectively and objectively (by use of pictures) provided similar results to measures of plant dry weights early in-crop. Lotz et al. (1996) found that competition models were more consistent using relative leaf area of white mustard (*Sinapis alba* L.) rather than density as it accounted for at least part of the effect of different emergence times of mustard plants. This mirrors the conclusions of Jasieniuk et al. (1999) that the predictive ability of a bio-economic model would be improved when yield loss functions incorporating time of emergence and crop density are built into a competition model's structure. It was concluded that the definition of a time window for prediction of competitive effect within an acceptable level of error is important and should be studied. Sample size was found by Ngouajio et al. (1996) to influence the type of model that best relates crop yield to weed relative leaf cover. With large data sets a flexible sigmoidal model may be more appropriate, however when using smaller data sets, a restricted model might be preferred to reduce the influence of extreme outliers.

Canola (oilseed rape) is a valuable cash crop on the Canadian Prairies and as such, considerable effort has been given to determining the effects of weed competition on canola yield. Canola has been shown to compete well against annual weeds. Lutman et al. (1994) found that oilseed rape was least affected by oat (*Avena sativa* L.) competition relative to beans (*Vicia faba* L.) and peas (*Pisum sativum* L.), and its competitive ability was similar to barley (*Hordeum vulgare* L.). Reduction of yield of oilseed rape did vary greatly between years, however. It was also shown that oilseed rape has greater sensitivity to competition in relatively wet years. In Lutman's study, oat density was used as the measure of competition, however the authors felt that oat density was not a sufficient measurement as it was correlated weakly with reduction in rapeseed yield, suggesting weed leaf area would be a better measure of infestation. Lemerle et al. (1995) also found that oilseed rape was more competitive than grain legumes, and more competitive than spring wheat (*Triticum aestivum* L.) and barley when annual ryegrass (*Lolium rigidum* L.) was used as the weed. This provides more evidence that canola is very competitive with weeds. Miller and Callihan (1995) found that oilseed rape was not affected by Proso millet (*Panicum miliaceum* L.) during the first four weeks of growth, however if millet was not removed during this period, yields of oilseed rape were significantly reduced. Perennial weeds have also been shown to reduce yields of rapeseed. A linear relationship was discovered between percentage yield loss of rapeseed relative to density of perennial sowthistle with a correlation coefficient of 0.5 (Peschken et al., 1983). Using counts of Canada thistle shoots per square meter, O'Sullivan and his fellow researchers (1985) were able to develop a regression equation that modeled the percent yield loss of rapeseed with a correlation coefficient of 0.44 for a linear model, and 0.43 for a square root model.

Crop interference by dandelion has already been demonstrated by Stevenson et al. (1998) where it was found that broadleaf plantain (*Plantago major* L.) and dandelion reduced midseason dry weight of barley by 36% and seed yield of barley by 59%. Other perennial weeds have also been demonstrated to significantly interfere with crop productivity. As mentioned previously, Peschken et al. (1983) found that perennial sowthistle reduced yield of canola. Survey data indicated that while perennial sowthistle occurred in 39% of the rapeseed fields surveyed in Manitoba and Saskatchewan, it infested only 7% of the hectares. Thus, weed competition by perennial weeds can be significant but isolated to smaller areas of large fields.

Using regression analysis, O'Sullivan et al. (1985) concluded that because they found the index of competition for Canada thistle in rapeseed to be very near to the proposed value from an earlier study (O'Sullivan et al., 1982), a straight-line analysis was likely valid for modeling reductions in rapeseed yield by other perennial weeds. Mclennan et al. (1991) found that a rectangular hyperbola best fit the relationship between Canada thistle density and yield reduction of winter wheat as it accounted for more of the variation in grain yield than a linear model.

2.3. DANDELION CONTROL:

2.3.1. CURRENT METHODS

Control of dandelion has in the past included biological, cultural, and chemical methods. Since the advent of selective chemical weed control in 1895 (Willard, 1954), chemical control of weeds has received extensive interest and research. Welton and Carroll (1934) considered sodium chlorate to be a herbicide and found that when it was applied in the fall or winter it would kill practically all weeds found on lawns, including dandelion. Thus, a chemical alternative was available to control dandelion without plowing. A study to consider removing noxious weeds such as dandelion was carried out by Buckardt (1936) with several furfural petroleum combination treatments. It was found that large dandelions (18 inch long roots) required over 3 times as much chemical for effective kill relative to seedling plants. The greatest control of dandelion in these studies was 70%. When dandelion shoots were removed to 3 inches below the crown, the remaining roots were able to produce new growth that appeared above ground 42 days following treatment. Mann (1981) also found that dandelion had a high capacity for root regeneration which was shown by poor control resulting from spudding. Control could be greatly improved by applying 2,4-D in combination with spudding during the spring. Long-term effectiveness of 2,4-D application was greatly reduced by removing dandelion leaves 2 weeks after application. It was reasoned that this was due to a resultant reduction in herbicide translocation. Moyer (1984) found that 2,4-D was effective at controlling 70% of dandelion populations. Substantial activity of metsulfuron on dandelion was shown (80% or better control) by Darwent and Lefkovitch (1995).

The reason dandelion populations are able to develop into major problems in broadleaf forage crops is the lack of chemical control methods. Application of cyanazine, diuron, metribuzin, pronamide, secbumeton, paraquat, simazine, or terbacil had little effect on dandelion populations (Robison et al., 1978). Waddington (1980) tackled the same problem and found that dichlobenil and terbacil could control dandelion, however significant damage to alfalfa stands could result. Simazine and diuron were found to slightly reduce dandelion populations without reducing alfalfa productivity. Scheaffer and Wyse (1982) considered this same problem and found that of multiple chemical treatments, only buthidazole consistently controlled dandelion in the year following applications. Buthidazole also had the tendency to reduce forage yield. Moyer et al. (1990) found that hexazinone, metribuzin, and chlorsulfuron application left plots almost dandelion-free. Recently, new options have been developed using herbicide treatments on dormant alfalfa. Application of hexazinone (0.75 lb a.i. acre^{-1}) to dormant alfalfa has been shown to provide fair (82%) control of dandelion (Miller, 1986). One factor limiting the development of effective chemical control methods in alfalfa is that weed control has not been proven to increase forage yield (Hall et al., 1995). Weeds reduce forage quality, however.

Considerable effort has also gone into developing cultural systems that effectively manage dandelion populations at acceptable levels, or eradicate dandelion altogether. The majority of this work has focused on managing dandelion in grass and forage fields. Dandelion density has been found to decrease with increasing grass height (Mølgaard, 1977). The greater the height of the competing grass, the more dandelion biomass was allocated to leaves rather than inflorescence. Darwent and Elliott (1979) found that narrower row spacing (20 cm) of intermediate wheatgrass (*Agropyron intermedium* (Host.) Beauv.), crested wheatgrass (*Agropyron cristatum* L.), bromegrass (*Bromus inermis* Leyss.), meadow fescue (*Festuca elatior* L.), creeping red fescue (*Festuca rubra* var. *genuine* L.), and timothy (*Phleum pratense* L.) resulted in reduced dandelion size and density. Reducing cutting frequency of alfalfa crops also reduces dandelion infestations.

Fertilizer can also influence dandelion populations, though not directly. Johnson and Bowyer (1982) found that in plots not receiving herbicides, dandelion cover was less in plots receiving nitrogen than in unfertilized plots. Dandelion cover was also lower in high nitrogen-treated plots than in low nitrogen-treated plots. The authors surmised that the encroachment of dandelions appeared to be stifled by greater turf density stimulated by greater fertility, and not directly by fertilizer application.

Some success has also been demonstrated for biological control of dandelion. Burpee (1992) provided evidence that certain granular formulations of a bioherbicide containing the fungus *Sclerotinia sclerotiorum* (Lib.) de Bary, were effective at inhibiting production of new petioles and leaves from tap roots after exposure for 96 hours at 23°C and 100% relative humidity. Approval for applying these agents to the environment involves lengthy registration procedures. Many hurdles must be cleared, including proof that this biocontrol agent will not adversely affect species already present in the environment.

It is clear that dandelion control is a complex issue and involves limiting its niches in fields and providing appropriate tools for removal of established populations. Competitive crops are necessary as well as timely application of systemic herbicides. Currently, many tools are available to farmers to manage dandelion problems, however critical information is lacking with regards to the best method of eradicating dandelion in an annual cropping system. Many herbicides have been shown to effectively suppress dandelion populations, however they often have little effect one year after application. Removal of leaves does little to temper dandelion infestations as dandelion has very rapid leaf turnover (Calviere and Duru, 1995) and is able to quickly regenerate new leaves. The best option available for control is believed to be application of systemic herbicides such as 2,4-D or glyphosate in fall or early spring (Dunn and Moyer, 1999). Registered rates for glyphosate are 900 g ai/ha for dandelion plants less than 15 cm (seedlings) and up to 1800 g ai/ha for mature dandelion plants (Manitoba Agriculture, 2000). Amitrol-T (amitrole) is also registered for control of dandelion in fall at rates from 2 to 8 liters of product per acre (240 g a.i. L^{-1}) (Dunn and Moyer, 1999). In-crop suppression and seedling control is provided by applications of 2,4-DB, Attain (fluroxypyr and 2,4-D E), Curtail-M (clopyralid and MCPA E), Prestige (clopyralid and MCPA E), FlaxMax Ultra (sethoxydim, clopyralid and MCPA E), Prevail (tralkoxydim, clopyralid and MCPA E), Afolan (linuron) and MCPA, MCPA, and 2,4-D (Dunn and Moyer, 1999). Due to the advent of herbicide-tolerant crops such as Roundup Ready™ canola, soybeans, corn, and wheat, new options are available for glyphosate application throughout the growing season. To-date, no information is available regarding optimal uses of this new technology for dandelion control.

2.3.2. OVERVIEW OF GLYPHOSATE

Glyphosate (N-(phosphonomethyl) glycine) is one of many agricultural herbicides discovered using a screening process testing thousands of products, with only rare successes. From 1960 to 1972, Monsanto Agricultural Products Company tested over 51,000 compounds for herbicidal activity and only three of these were developed into commercial herbicides, one of them being glyphosate (Franz et al., 1997). Glyphosate was registered in the United States in 1974 and has since been used to control broadleaved, grass, and sedge species (Cox, 1998). The majority of glyphosate applications are agricultural (seventh most-used agricultural herbicide), however significant amounts are used in home and garden (second most-used home and garden herbicide) and industrial applications (third most-used industrial herbicide). Resistance of plants to glyphosate application was believed to be highly unlikely (Gressel, 1996), however Sindel (1996) discovered a population of annual ryegrass (*Lolium rigidum* Gaudin) in Australia that was able to tolerate five times the recommended field application rate. Considering the length of use preceding the first documented case of glyphosate resistance it appears that glyphosate resistance is not a major concern, however this remains to be seen, especially with the current increase in glyphosate application of 20% per year due to the advent of glyphosate-tolerant crops (Cox, 1998). Glyphosate is sold under the Roundup™ trademark in Canada by Monsanto and is available in either a liquid (isopropylamine salt formulated as a solution) or dry (mono-ammonium salt formulated as a dispersible granule) formulations. With the expiry of Monsanto's patent in recent years, several other companies have begun developing "generic" glyphosate herbicides to compete with Roundup™ for agricultural applications.

Due to it's systemic nature, it is imperative that glyphosate be effectively absorbed into the plant by overcoming barriers to entry into the plant. This is why it is mixed with surfactants. Considerable research still is performed today to develop new surfactants that improve the entry of glyphosate into the symplastic translocation systems of plants. Research has provided evidence that glyphosate absorption is greatest when a plant is actively growing (Duke, 1985). Once inside, glyphosate inhibits the shikimic acid pathway (an enzyme pathway) that in-turn prevents plants from synthesizing three aromatic amino acids that are essential for growth and survival of most plants (Cox, 1998). This is why glyphosate is non-selective and is so effective at killing all plants. The key enzyme is called EPSP (5-enolpyruvylshikimate-3-phosphate) synthase. Glyphosate is very effective at controlling annual weeds and has been successful in controlling perennial weeds as well because it translocates to the underground structures of perennial species and prevents regrowth from these propagules (Ross, 1999). Glyphosate's effectiveness on perennial plants is due to its rapid translocation from foliage to the roots, rhizomes, and apical tissues of treated plants (Franz, 1997). Symptoms of glyphosate injury are often not visible for 7 to 10 days (on perennial plants) following application (Manitoba Agriculture, 2000) and begin with yellowing and wilting of first newer and then older tissues (Ross, 1999).

Glyphosate has long been lauded for it's apparent safety for humans and the environment. It is virtually nontoxic to mammals, birds, fish, insects, and most bacteria, and does not bioaccumulate in the tissues of animals or agricultural crops (Franz, 1997). It has still been argued by some that Roundup™ is a potentially hazardous chemical as the surfactant is far more toxic than glyphosate itself. There has been some evidence of mild toxicity to laboratory animals and humans (Cox, 1998). Most questioning of glyphosate's "non-toxicity" is a result of the fact that most toxicology studies were performed by Monsanto and as such should not be subject to blind faith. Glyphosate does not exhibit residual soil activity as it is tightly bound to soil particles (Franz, 1997) and has a half-life in soil ranging from 3 to 141 days (Cox, 1998). Glyphosate products meet government safety standards and will provide valuable utility for agriculture.

Glyphosate applications are most effective when applied to "actively growing" plants (Cox, 1998). Cool, moist conditions favor rapid uptake and translocation of glyphosate to plant growing points.

Better understanding of genetic control of herbicide resistance has led to the development of transgenic crops, which are resistant to herbicides they had previously been susceptible to. Currently, transgenic crops have been developed for resistance to glyphosate (Roundup-Ready™), glufosinate (Liberty-Link™), and bromoxynil. In Western Canada, canola was the first crop to receive the Roundup-Ready™ trait, however it has been expanded to corn, soybean, and may soon be available in wheat. This has created opportunities for applying glyphosate in-crop, allowing perhaps for better control opportunities of perennial weeds (Ross, 1999), and a more rapid selection of resistant weeds.

2.3.3. COMPONENTS OF DANDELION CONTROL:

2.3.3.1. TIME OF CHEMICAL CONTROL

Herbicide application in an annual cropping system may generally occur at five different times during the growing season: Pre-seed, pre-emergence, in-crop, pre-harvest, and post-harvest. For control of dandelion, the effectiveness of each timing depends on the susceptibility of the plants to herbicide application. Dandelion growth rates fluctuate throughout the growing season. It begins growing quickly in spring and by early May, leaves are growing and expanding at an accelerated rate (Fletcher et al., 1969). Dandelion is believed to be a short-day plant (Solbrig, 1971), meaning that it flowers in early spring or early fall when the light period is shorter than a certain critical length (Raven et al., 1992). Sawada et al. (1982) found that the major flowering peak for dandelion is in May and a lower level occurs from July to September. Others have argued that dandelion is a day-neutral plant (Gray et al., 1973) due to its low association of flowering with day-length. Gray et al. (1973) also noted that peak flowering occurred in April and September. Again, the importance of root reserves for dandelion control and that this is an important consideration for timing of herbicide application. It was found that during the spring, depletion of carbohydrate reserves in dandelion roots was accompanied by flowering and toward the end of summer these reserves were restored (Rutherford and Deacon, 1974). Vavrek et al. (1997) found that the senescence of dandelion leaves in fall allowed the re-translocation of nutrients and carbohydrates to the roots prior to freezing. Rutherford and Deacon (1974) found that the growth response (decrease in dry weight) of dandelion root to 2,4-D was significantly limited by the availability of carbohydrate reserves. Thus, although root reserves are relatively low in spring and this may make plants vulnerable to control activities, chemical activity might be reduced at this time until reserves are re-established in fall.

To-date, a majority of perennial weed control studies have focused on spring and fall herbicide applications, as these timings are believed to be the most effective for control, largely because these were the only times glyphosate was registered for application. It has been demonstrated that systemic herbicide applications are most effective when they are not applied in combination with products that have a high level of foliar activity (Sprankle et al., 1975). Buhler and Mercurio (1988) found that relative to any other pre-plant or pre-emergence treatments, dandelion control was greatest when glyphosate, 2,4-D, or 2,4-D and dicamba were applied in fall or when atrazine was applied early pre-plant followed by atrazine plus paraquat in the spring. Frost has also been demonstrated to dramatically improve glyphosate efficacy. Davis et al. (1978) found that the most effective time in fall to apply glyphosate was the day after the first frost (low of -4°C) due to significantly higher uptake and translocation of glyphosate in quackgrass plants. As mentioned previously, control of dandelion in dormant alfalfa has received greater interest lately due to testing of application of sulfosulfuron (Sundance™, Monsanto) in late fall. After 6 years of sulfosulfuron application (10-20 g a.i. ha^{-1}), dandelion biomass was reduced by 77 to 93% relative to untreated plots (Moyer and Acharya, 1999). Thus, persistent residues in soil (sulfosulfuron) can effectively inhibit dandelion development and may in fact reduce dandelion populations.

2.3.3.2. RATE OF CHEMICAL CONTROL

Generally, control of perennial weeds increases with elevated herbicide applications rates, up to a point. Essentially, the more glyphosate that can reach the roots, the greater the likelihood of plant death. Increasing glyphosate rate in spring from 412 to 627 g a.i. ha^{-1} increased dandelion control from 74 to 81% (Holm et al., 1997b). When applied in-crop (canola), increased glyphosate rates improve dandelion control, however the greatest control achieved with the highest label rate (450 g a.i. ha^{-1}) was only 45% (Darwent and Drabble, 1995). In trials on quackgrass, application of glyphosate in the fall at rates of 400 g a.i. ha^{-1} had little effect, 800 g a.i. ha^{-1} had a slight effect, and 1500 g a.i. ha^{-1} was highly inhibitory to regrowth (Davis et al., 1978). In greenhouse studies, Claus and Behrens (1976) found that foliar glyphosate treatments of 280 g a.i. ha^{-1} reduced quackgrass rhizome survival and rates of 560, 840, and 1120 g a.i. ha^{-1} gave nearly complete bud kill. With fall applications of sulfosulfuron, increasing rates from 5 to 20 g a.i. ha^{-1} reduced dandelion biomass (Moyer and Acharya, 1999). Holm et al. (1997a) found that increasing the rate of fall-applied 2,4-D Ester improved dandelion control from 65 to 95%. Bosnic and Rourke (1997) found that increasing the rate of amitrole (applied in the spring) from 0.9 to 2 kg a.i. ha^{-1} increased dandelion control from 73 to 98%. Generally, increasing herbicide rate will result in enhanced dandelion control. To minimize the impact of herbicides on the environment however, it is imperative to determine minimum herbicide rates necessary to provide acceptable levels of perennial weed control.

2.3.3.3. TILLAGE INTENSITY: EFFECT ON CONTROL

It has been demonstrated that dandelion biotypes found in undisturbed and cultivated areas differ greatly in their growth strategies (Solbrig and Simpson, 1977). Plants from cultivated fields grow slowest early in the growing season and fastest later in the growing season (Bunce, 1980). Bunce (1980) also found that plants from cultivated fields had faster regrowth and best survival following complete defoliation relative to plants from undisturbed locations. This coincided with the greatest dry weight distribution in the taproot. Dandelion grows leaves that have been destroyed grow rapidly, allowing dandelion plants to survive in locations where cultivations occur infrequently. Dandelion uses a significant portion of its root reserves to maintain large leaf size. If root reserves are reduced beyond a critical level, dandelion plants can die. Cultivation can also serve to spread dandelion throughout a field, and to neighbouring fields. Dandelion's taproot can be up to 3 cm in diameter and reach a depth of 2 m (Mann and Cavers, 1979). Root fragments can very successfully establish new plants. Mann and Cavers (1979) found that germination of cuttings was consistently 100% in the laboratory and depth of planting (to 10 cm) of fragments did not significantly influence either percent survival or time for regeneration. Fragments cut in May (at peak flowering for dandelion) generally had much poorer survival than those cut between June and September. Fragments from the upper sections of roots had consistently better survival than those lower down, however, there is some capacity for regeneration along the entire root system. Fragments from second-year plants also had greater regenerative capacity than those of first-year plants. While tillage can effectively reduce dandelion root reserves and photosynthetic abilities, it can also serve to exacerbate dandelion infestations by spreading them throughout tilled areas. Proper tillage (complete defoliation of above-ground biomass) will effectively remove aboveground dandelion biomass, however infrequent use of tillage will do little to control dandelion populations.

2.3.4. MEASUREMENT OF DANDELION CONTROL:

Weed scientists have traditionally used a visual control assessment to determine efficacy of treatments on weeds (Miller, 1986; Waddington, 1980). Although widely accepted (Darwent and Lefkovitch, 1995), the accuracy of this measurement is questionable for determining dandelion control. When dandelion plants are subjected to tillage or glyphosate treatments, most or all aboveground biomass is removed. Thus, subjective measurements of residual dandelion populations several weeks after treatment can accurately gauge the ability of treatments to remove dandelion shoots, but are limited in their ability to quantify long-term dandelion control, as perennial weeds are capable of re-growing from rootstock. Measurements of residual perennial weed population's months or even years after treatments are recognized as accurate representations of perennial weed control (Burpee, 1992; Moyer and Acharya, 1999). The most common measurement of residual weed populations is weed density (Moyer, 1984; Schreiber, 1967), however measures of residual biomass are likely to provide improved accuracy as it represents total plant size in a defined area.

2.4. CONCLUSION:

Historically, dandelion has been an important pest of lawns and undisturbed habitats. With the increasing adoption of zero-tillage this is changing so that dandelion is now recognized as an important pest in annual cropping systems as well. Dandelion is now being recognized as a serious pest of annual cropping systems as well. To-date, little research has focused on this new role for dandelion. Weeds are unwanted in cropping systems as they compete for nutrients and limit the productivity of crops. Dandelion is no exception. As a perennial weed, dandelion is hypothesized to be present in patches within fields. These patches have the ability to compete strongly with annual crops. The most accepted method of dandelion control has been to till repeatedly, in order to deplete root reserves. Reduced tillage systems have placed more of an emphasis on chemical control methods for dandelion. Glyphosate has been proven effective for controlling dandelion in the past, and affords great potential for controlling dandelion in annual crops due to the registration of glyphosate-tolerant crops. Glyphosate control measures can now be implemented throughout the growing season. Dandelion has the potential to become a serious problem in Western Canada, however an improved understanding of the competitive ability of dandelion, coupled with more efficient control methods will lead to management options which will limit dandelion's impact on crop productivity in the Prairie Provinces.

CHAPTER 3:

Dandelion Distribution and Interference

ABSTRACT

It is widely accepted that reducing tillage will result in greater dandelion concerns, in terms of both more uniform infestations, as well as higher densities. Whenever a niche opens up that suits dandelion's requirements, it has the potential to infest.

Experiments were undertaken in the summer of 2000 to improve understanding of the distribution and interference of dandelion. Distribution of dandelion in fields appears to be influenced greatly by production practices. In both zero- and conventional-tillage fields, dandelion can be a widespread problem with the ability to dramatically reduce canola yield. Predictability of yield loss is very poor however. In conventional-tillage fields, there appears to be no relationship between reduction in canola yield and any measure of dandelion infestation. In zero-tillage fields there is a relationship, however it differs significantly between fields and model parameters do not always make sense from a biological standpoint. It appears that predictability is greater in fields with narrower dandelion demography. The most accurate measures of dandelion infestation are dandelion ground cover, root diameter, leaf diameter, and density.

3.1. INTRODUCTION

Dandelion has played an intriguing role in the "New World" since crossing the Atlantic with settlers as they began their pilgrimage toward a new life (Mitich, 1989). Originally esteemed for it's nutritive (Mitich, 1989; Schmidt, 1979) and medicinal (Dalby, 1999) qualities, dandelion earned new recognition in the Americas as a pest.

Dandelion (*Taraxacum* officinale Weber in Wiggers) has long been recognized as a significant pest of both lawns and forage crops. In lawns, dandelion exhibits a low growth habit and it's flowers open quickly to avoid lawn mowing (Richardson, 1985). Aesthetically, dandelion is unpleasing to homeowners.

In forage crops, dandelion is unwelcome because it can reduce productivity and quality. Moyer et al. (1990) found that removing dandelion from sainfoin (*Onobrychis viciaefolia* Scop.) resulted in a dramatic increase in yield, however removal from alfalfa (Medicago sativa L.) crops had no effect on alfalfa yield. Alfalfa stands are known to weaken over time (Spandl et al., 1999), yet common practice in Manitoba is for forage stands to be maintained for greater than 6 years (Entz et al., 1995). These weakened stands provide a niche, which dandelion can colonize. It has been demonstrated that dandelion populations are much greater in fields that have alfalfa in rotation relative to fields planted to straight cereal rotations (Ominski et al., 1999). To-date, persistence and competition of dandelion in annual crops following a long-term forage crop remain under-researched. There is evidence that as reduced-tillage production systems gain acceptance, dandelion populations will increase (Buhler et al., 1994; Triplett and Lytle, 1972) and dandelion will become a more serious pest in annual crops.

It is very important to understand the distribution of a weed so as to better evaluate its interference with crop yield, and justify economic control measures. Weeds (especially perennial weeds) occur mainly in patches (Wiles et al., 1992a). The distribution of a weed influences yield loss due to interference, the design of optimal scouting plans and the feasibility of patch spraying. The spatial distribution of a weed can also have a significant effect on economic thresholds (Thornton et al., 1990). For example, economic thresholds for a weed present in discrete patches are most valuable when spraying options are only considered on the portion of the field where the weed is present.

In order to develop a meaningful model relating crop yield loss relative to weed pressure, a suitable measure of weed infestation must be developed. Recent attempts to quantify weed infestation have focused on leaf area and dry biomass of weeds (Lotz et al., 1994; Lotz et al., 1996; Lutman et al., 1996; Ngouajio et al., 1999). The difficulty is that farmers cannot easily make these measurements during the growing season. Lutman et al. (1994) found that visual assessment of weed and crop ground cover could provide accurate assessments of the competitive effect of weeds.

Our goal is to improve the understanding of dandelion's role as a pest in canola in Manitoba. This includes gaining a better understanding of dandelion's distribution in fields, its ability to interfere with (reduce) canola yield, and to determine effective measures of the competitiveness of dandelion infestations.

3.2. MATERIALS AND METHODS

3.2.1. FIELD SELECTION

In spring 2000, fields across Southern Manitoba were identified that had a large dandelion population (densities of more than 10 plants m^{-2} in at least three areas of the field), and were being planted to canola. Six fields were found that met our criteria. Sites selected were Brandon, Carman, Dakota, Elie, New Bothwell, and Steinbach Manitoba. Field sizes are found in Table 3.2.1.

Table 3.2.1. Field descriptions for distribution and interference studies

Field	Field Size	Survey Parameters		
		Date	Distance between ATV passes across field	Distance between measurements
	-- ha --		-- m --	-- m --
Brandon	2.4	May 2	25	25
Carman	48.6	May 3	50	50
Dakota	113.4	May 22	50	50
Elie	97.1	[a]	[a]	[a]
New Bothwell	16.2	May 3	50	50
Steinbach	30.4	May 18	50	50

[a] Elie field not surveyed

3.2.2. FIELD SURVEYS

Fields were surveyed with an all terrain vehicle. Passes were made across fields at regular intervals (distance between passes) and dandelion density (plants m^{-2}) was determined at consistent distances (distance between counts) (Table 3.2.1). Surveys were conducted before crop seeding at all locations except Steinbach, which was included only after seeding. A survey was not performed at Elie because the canola was already in the 2-3 leaf stage when this field was included.

3.2.3. ESTABLISHMENT OF QUADRATS

For the zero-tillage sites (Brandon and Carman), co-operators planned to apply glyphosate pre-seed in order to reduce dandelion populations. Both co-operators were also using hoe drills, which would not remove pin flags. Thus, quadrats could be established prior to seeding. For the conventional-tillage sites (Dakota, Elie, New Bothwell, and Steinbach), fields were seeded before quadrats were set up because the seeding equipment (cultivators with sweeps) cut off all dandelion plants and would have removed pin flags used to locate quadrats. At each site, 13 to 35 1 m^2 quadrats were established on patches of varying levels of dandelion infestation (as determined by visual estimation). Dandelion densities were recorded for each quadrat at this time. Once canola reached the 2-4 leaf stage, weed-free quadrats were established within 5 m of each dandelion quadrat, and all quadrats were hand weeded to remove all species except dandelion and/or canola. When flushes of small grass or broadleaf weeds were present, all quadrats in each field were sprayed with sethoxydim (Poast Ultra[1]) at a rate of 378 g a.i. ha^{-1} and ethametsulfuron-methyl (Muster[2]) at a rate of 14.8 g a.i. ha^{-1}. Neither of these herbicides have an effect on dandelion. When co-operators sprayed their in-crop herbicide, all dandelion quadrats were covered with plastic.

3.2.4. MEASURES OF CANOLA AND DANDELION IN-CROP

After weeding and spraying were complete, several measurements were made of canola and dandelion. Canola density and percent ground cover were measured in each quadrat. Also, dandelion density, dandelion leaf diameter (distance between leaf tips), and canola and dandelion ground cover were measured in each dandelion infested quadrat. Dandelion and canola ground cover were determined by taking overhead photographs of each quadrat from a 1.5 m height. A transparency with a grid containing 100 random dots was placed over these photographs and counts were made of the number of times these dots touched either dandelion or canola. This value represented an estimation of percent ground cover.

3.2.5. FIELD MAINTENANCE

Throughout the growing season, co-operators continued to manage their fields as they normally would (Table 3.2.2). After fields had been sprayed and quadrats weeded, quadrats were checked routinely to ensure that unwanted weed species were removed in a timely fashion. Due to above-average precipitation levels in Southern Manitoba in the summer of 2000 (Figure 3.3.4), several of the fields had flooded areas. At Steinbach, 8 dandelion and corresponding weed-free quadrats had to be abandoned due to flooding. At Elie, 6 dandelion and corresponding weed-free quadrats had to be abandoned due to flooding. The New Bothwell and Dakota fields were also extremely wet but no quadrats within these fields were located in flooded areas.

Table 3.2.2. Management practices for canola interference sites in 2000

Site	Cultivar	Date Seeded	Seeding Rate Kg ha^{-1}	Tillage^{e}	N^{f}	P^{f}	K^{f}	S^{f}
					-------kg ha^{-1}-------			
Brandon	INV2573 (LL^{c})	May 17	5	None	80	16	5	16
Carman	46A76 (Smart^{d})	May 15/16	5.5	None	90	30	0	0
Dakota	46A76 (Smart^{d})	April 28	5	Sweeps	105	30	15	10
Elie	LG3311	April 28	5	Sweeps	a	a	a	a
New Bothwell	INV2273 (LL^{c})	May 15	5	Sweeps	b	b	b	b
Steinbach	LG 3311	May 3	5.5	Sweeps	97	35	4	0

a- Field received surface application of hog manure in fall, 1999 (estimated 300 lb N ac^{-1})
b- Field was in alfalfa for ~8 years previously, relied on organic N
[c] LL= Liberty Link™ canola, Aventis[6]
[d] Smart™ canola, BASF[1]
[e] Tillage operations during seeding
[f] Nutrients added (N, P, K, or S) for the 2000 growing season (applied fall 1999 / spring 2000)

3.2.6. DANDELION AND CANOLA HARVEST

When canola reached physiological maturity and was ready for swathing, both canola and dandelion plants were harvested from all quadrats. Canola stalks and siliques were removed from quadrats using hand sickles and placed in large burlap bags. These burlap bags were then hung outdoors to dry for a period of 14 to 28 days. Once the canola had fully ripened, the bags of canola were threshed using a Winter Steiger[3] NurseryMaster™ small-plot combine. Canola seed samples were placed in paper bags and left in a drying room for 5 days. Samples were then sieved to remove chaff and the clean grain was weighed. Moisture content of dry canola seed samples was 9.5%.

3.2.7. MEASUREMENTS OF DANDELION AT HARVEST

Within each quadrat, all above ground dandelion biomass as well as attached root matter was removed using forked dandelion pullers and several measures were made on these plants. All root biomass was removed from each plant. If the fresh weight of dandelion from an individual quadrat was greater than 400 grams, the sample was sub-sampled in order to make measurements feasible within an acceptable time frame. Measurements of sub-samples were then extrapolated to provide estimates for the entire quadrat sample. All dandelion plants were cut off at the leaf base and the diameter of the root at that point was measured in millimeters using calipers. Root diameters were summed for each quadrat. Dandelion density was determined by counting the number of plants in each quadrat. Leaves were removed from each plant and run through a LiCor[4] 3100 leaf area meter in order to determine leaf area for each quadrat. For each quadrat, all aboveground biomass was dried at 80°C for 48 hours, weighed, and recorded.

For each quadrat, several measurements of canola and dandelion were made: 1) dandelion ground cover in-crop, 2) canola ground cover in-crop, 3) dandelion density in-crop, 4) canola density in-crop, 5) weed-free canola density in-crop, 6) total dandelion leaf diameter in-crop, 7) dandelion leaf area at crop harvest, 8) dandelion fresh weight at crop harvest, 9) dandelion dry vegetative biomass at crop harvest, 10) dandelion reproductive dry biomass at crop harvest, 11) total dandelion dry biomass at crop harvest, 12) dandelion density at crop harvest, 13) total dandelion root diameter at crop harvest, 14) canola yield in weed-free and in dandelion infested quadrats. Two relative measures were calculated from the above measurements. Relative density was calculated by dividing dandelion density in-crop by the sum of dandelion and canola density in-crop. Relative cover was calculated by dividing dandelion ground cover in-crop by the sum of dandelion and canola ground cover in-crop.

3.2.8. DATA ANALYSIS

Canola grain yield was calculated as a percent of weed-free canola yield by dividing the canola yield for each dandelion infested quadrat by the pooled weed-free canola yield for the field in which the quadrat was located. Individual weed-free yields were not used as they resulted in many dandelion quadrats having yields greater than 100% of weed-free. When canola yield as a percent of weed-free yield was determined using pooled weed-free canola yield, few values were greater than 100% for conventional-tillage fields and no values were greater than 100% for zero-tillage fields.

To determine if there was any correlation between the dependent variable (canola yield as a percent of weed-free yield) and the independent variables (measures of dandelion infestation level) a correlation procedure was used (PROC CORR of SAS[5]), combining all sites in the analysis. When all sites were combined, some significant relationships were found (Table 3.3.2). When the strongest of these relationships was plotted (percent of weed-free canola yield by dandelion ground cover in-crop) the data clustered into zero- and conventional-tillage sites (Figure 3.3.3). Correlation analyses were conducted again on separate data sets for zero-tillage sites and conventional-tillage sites. No significant correlations were found between any measure of dandelion infestation level and canola yield as a percent of weed free yield for conventional-tillage fields. For the zero tillage sites, combined correlations were significant for all measures of dandelion infestation level (Table 3.3.4). When these correlations were plotted, data appeared to be clustered into individual zero-tillage sites (Figure 3.2.1). The correlation

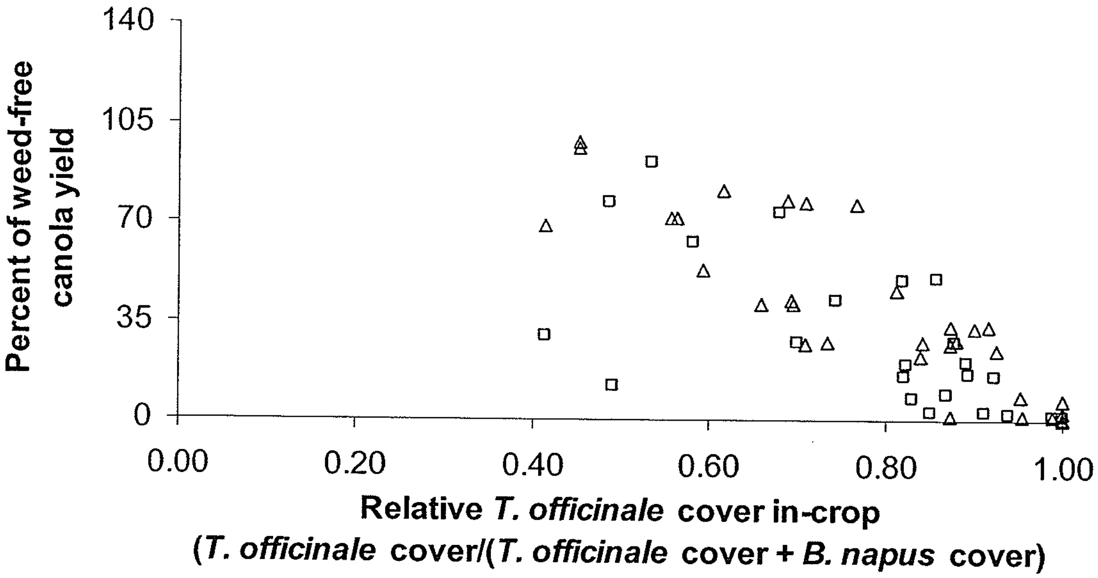


Figure 3.2.1. Reduction in canola yield due to dandelion interference as represented by relative ground cover of dandelion measured at the 2-4 leaf stage of canola for zero-tillage sites. (□) Brandon, (Δ) Carman

procedure was then conducted on data for each zero-tillage site individually (Table 3.3.5). Rectangular hyperbola and linear models were fit to data that showed significant correlation at both the Brandon and Carman sites.

The rectangular hyperbola developed by Cousens (1985) was used to model the relationship between measures of dandelion infestation and canola yield as percent of weed-free yield.

$$\%Y_{wf} = A * (1 - ((B * X) / 100 * (1 + ((B * X) / C)))) \quad (1)$$

Where $\%Y_{wf}$ denotes percent of weed-free canola yield, A denotes maximum yield, B denotes initial slope, C denotes maximum yield loss, and X denotes the measure of dandelion infestation. The model was fitted using a non-linear regression procedure (PROC NONLIN) of SAS. Coefficients of determination for the model fit was determined by dividing the residual Sum of Squares by the corrected total Sum of Squares, and subtracting from 1. When the rectangular hyperbola model visually did not appear to fit the data well, a simple linear model was fit using a linear regression procedure (PROC REG) of SAS[5].

$$\%Y_{wf} = A + BX \quad (2)$$

Where $\%Y_{wf}$ denotes percent of weed-free canola yield, A denotes the maximum yield, B denotes slope, and X denotes the measure of dandelion infestation.

When significant relationships were found between percent of weed-free canola yield and measures of dandelion infestation, F-tests were performed according to Seefeldt et al. (1995) to determine if models were significantly different between sites (Appendix 7.8).

3.3. RESULTS AND DISCUSSION

3.3.1. DANDELION DISTRIBUTION IN FIELDS

Zero-tillage field surveys provided evidence of patchy dandelion distribution at Carman and uniform distribution at Brandon (Figure 3.3.1). The Brandon field was much smaller and had a very uniform dandelion population throughout. In the Carman field, dandelion was distributed in discrete patches. At Brandon, dandelion was present in 93% of the quadrats whereas at Carman, it was present in only 18% of the quadrats. Average density in the Brandon field was 8.8 plants m^{-2} whereas at Carman it was 0.6 plants m^{-2}.

Surveys of conventionally-tilled fields also yielded stark contrasts in distribution of dandelion among fields (Figure 3.3.2). The Steinbach and Dakota fields had similar distributions of dandelion. The New Bothwell field had a large population of dandelion relative to the other conventional-till fields. Dandelion was present in 10% of the quadrats in the Dakota field, 12% in the Steinbach field, and 80 % in the New Bothwell

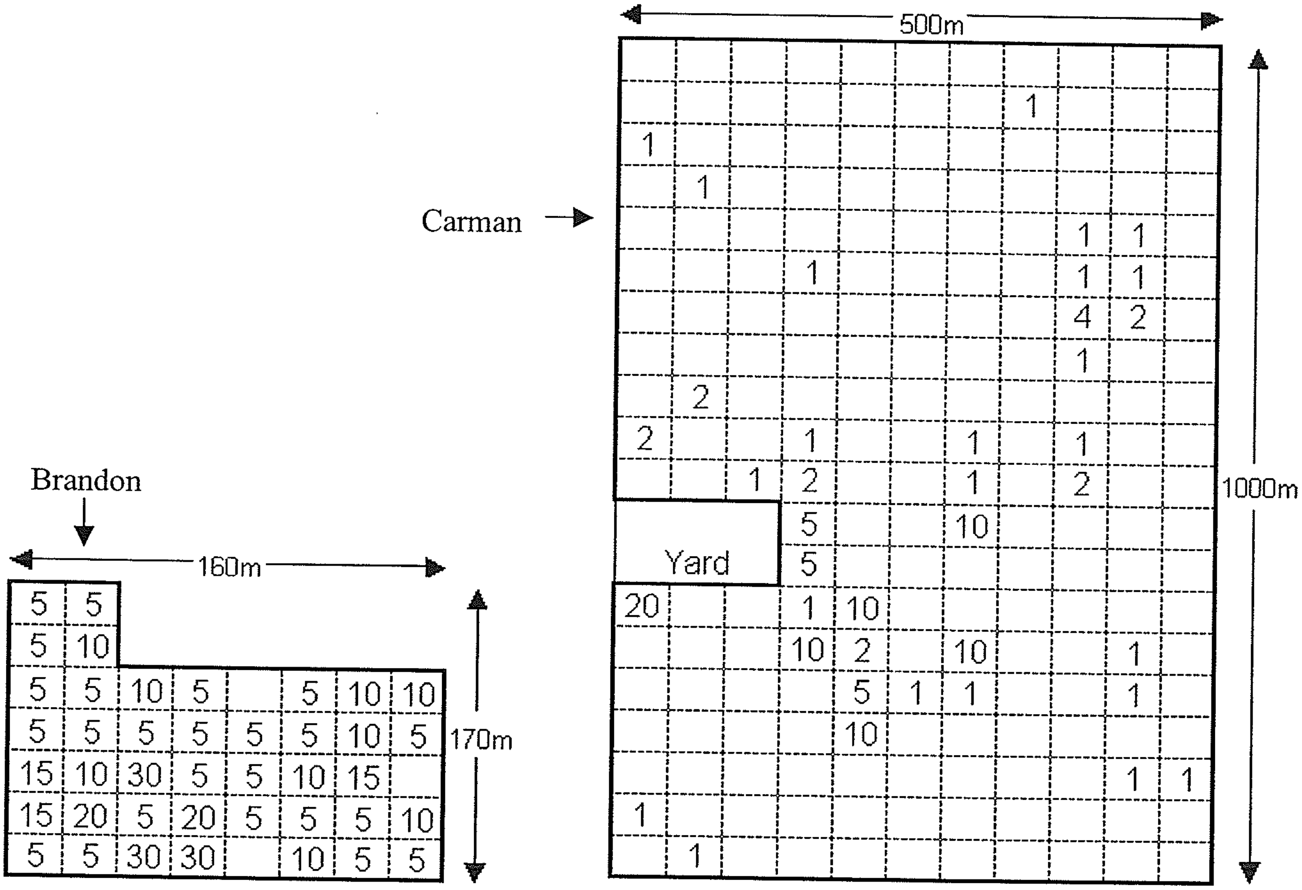
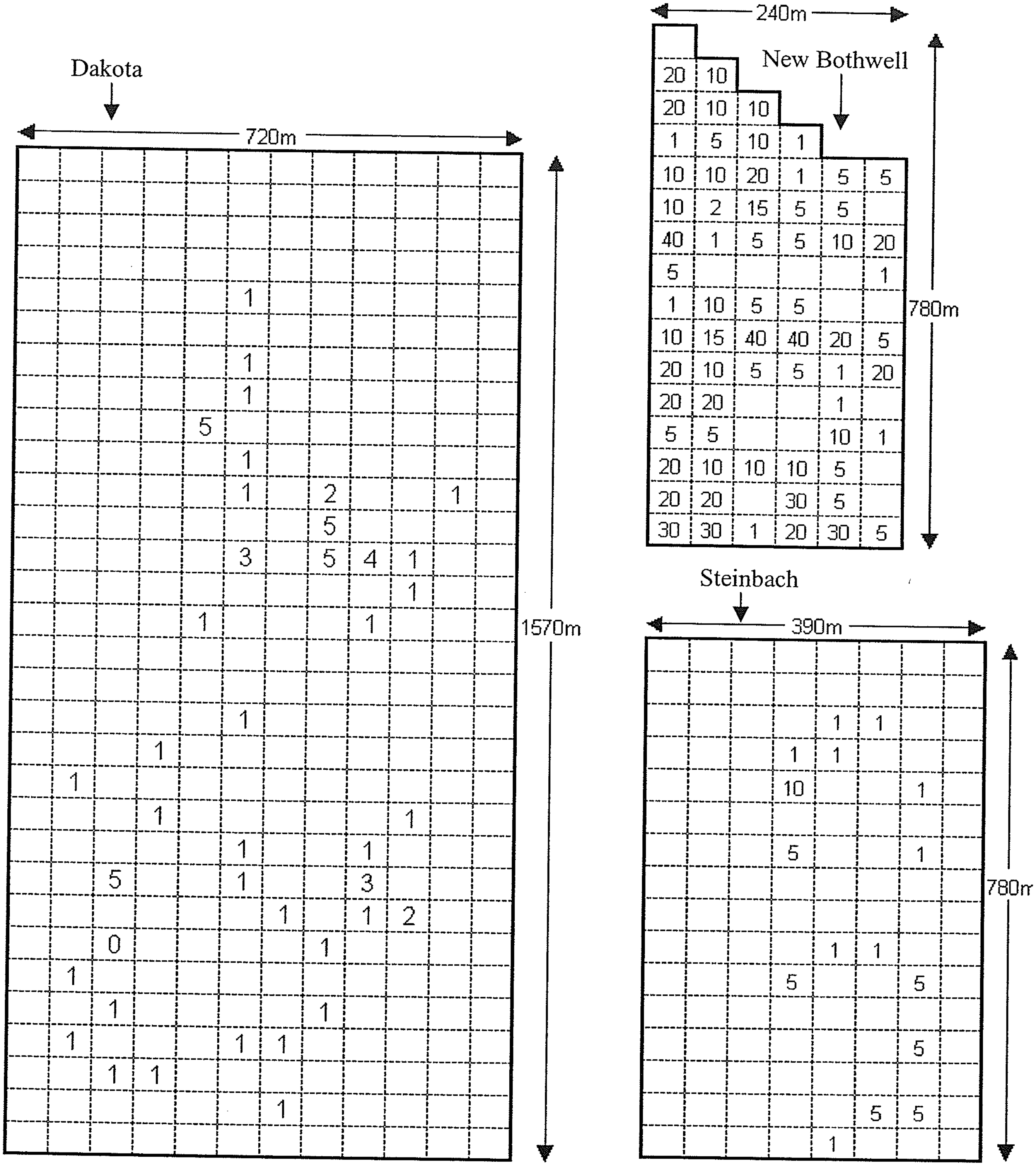


Figure 3.3.1. Surveys of dandelion distribution in zero-tillage fields. Each square represents 625 m^2 at Brandon and 2500 m^2 at Carman. Values in boxes represent surveyed dandelion density within the square (plants m^{-2})



Dakota

					1						
					1						
					1						
				5							
					1						
					1		2			1	
							5				
					3		5	4	1		
									1		
				1				1			
					1						
			1								
	1										
			1						1		
					1			1			
		5			1			3			
						1		1	2		
		0					1				
	1										
		1					1				
	1				1	1					
		1	1								
						1					

New Bothwell

20	10				
20	10	10			
1	5	10	1		
10	10	20	1	5	5
10	2	15	5	5	
40	1	5	5	10	20
5					1
1	10	5	5		
10	15	40	40	20	5
20	10	5	5	1	20
20	20			1	
5	5			10	1
20	10	10	10	5	
20	20		30	5	
30	30	1	20	30	5

Steinbach

				1	1		
			1	1			
			10			1	
			5			1	
				1	1		
			5			5	
						5	
					5	5	
				1			

Figure 3.3.2. Surveys of dandelion distribution in conventional-tillage fields. For all fields, each square represents 2500 m^2. Values in boxes represent surveyed dandelion density within the square (plants m^{-2})

Table 3.3.1. Field histories for canola interference sites in 2000

Brandon

Year	Crop	Tillage	Herbicides
1999	Dry Beans	None	Ethafluralin, sethoxydim, imazethapyr
1998	Oats	None	Glyphosate[f], dicamba, mecoprop
1997	Canola	None	Glyphosate[f] *2
1996	Wheat	None	Glyphosate[f], dicamba

Carman

Year	Crop	Tillage	Herbicides
1999	Wheat	Rotary Harrow[a]	Glyphosate[g], fenoxaprop, thifensulfuron
1998	Oats	Rotary Harrow[a]	Glyphosate[g], bromoxynil, MCPA E
1997	Flax	Rotary Harrow[a]	Glyphosate[g], bromoxynil, MCPA E
1996	Oats	Rotary Harrow[a]	Glyphosate[g], bromoxynil, MCPA E

Dakota

Year	Crop	Tillage	Herbicides
1999	Wheat	Sweeps[b],Harrow[c]	Fenoxaprop, clopyralid, MCPA E,
1998	Canola	Sweeps,Harrow	Sethoxydim, ethametsulfuron-methyl
1997	HRS Wheat	Sweeps,Harrow	Bromoxynil, MCPA E, thifensulfuron
1996	HRS Wheat	Sweeps,Harrow	Dichlorprop, 2,4-D E

Elie

Year	Crop	Tillage	Herbicides
1999	Flax	Sweeps	Sethoxydim, bromoxynil, MCPA E
1998	Wheat	Sweeps	None
1997	Alfalfa	Plough[d], Disk[e]	2,4-D E
1996	Alfalfa	None	None

New Bothwell

Year	Crop	Tillage	Herbicides
1999	Alfalfa	Plough, Disk	None
1998	Alfalfa	None	None
1997	Alfalfa	None	None
1996	Alfalfa	None	None

Steinbach

	Crop	Tillage	Herbicides
1999	Oats	Sweeps,Harrow	None
1998	Alfalfa	Disk,Sweeps	Glyphosate[g]
1997	Alfalfa	None	None
1996	Alfalfa	None	None

[a] Field was rotary harrowed once in the fall

[b] Field was cultivated twice using sweeps (8 inches wide or more) in the fall

[c] Field was harrowed using tine or diamond harrows once in the fall

[d] Field was ploughed once in the fall

[e] Field was tandem disked once in the fall

[f] Glyphosate applied at a rate of 450 g a.i. ha^{-1}

field. The average density of dandelion was 0.2, 0.4, and 9.7 plants m^{-2} in Dakota, Steinbach and New Bothwell fields, respectively.

The field histories highlight important differences in how each field was managed during the past four growing seasons (Table 3.3.1), and they help to explain differences in dandelion distribution between fields. The two zero-tillage fields had similar rotations except for one difference. In the past 4 years, the Brandon field had been seeded to broadleaf crops twice, whereas the Carman field had been seeded to broadleaf crops only once. It was shown by Stevenson and Johnston (1999), that a greater frequency of broadleaf crops in rotation is often associated with increased populations of dandelion. Both zero-tillage fields were seeded with similar low-disturbance hoe drills, with the Carman field receiving an additional rotary harrowing each fall. Rotary harrows disturb the soil slightly, but this disturbance might have been enough to limit the establishment (and spread) of dandelion throughout the field. If the rotary harrowing was aggressive enough, it would have removed dandelion top-growth. Because the harrowing was done each fall in this field, dandelion plants might not have been able to recover enough to supply the roots with the photosynthate necessary for winter survival. It is likely that rotary harrowing would have had the greatest impact on seedling plants. Proportional recruitment of dandelion seedlings from soil depths of 2 cm has been shown to be very low (Boyd and Van Acker, 2001). Thus, it is very likely that dandelion seedlings had shallow rooting, and were vulnerable to removal from shallow tillage. The Carman field received glyphosate at a rate of 900 g a.i. ha^{-1} each spring whereas the Brandon field received only 450 g a.i. ha^{-1}. When herbicide application coverage on dandelion plants is poor, dandelion control can be improved by increasing glyphosate rate (Chapter 4).

These factors combined will have contributed to a smaller population of dandelion at Carman, which was likely comprised of a greater proportion of adult plants. The dandelion population at Carman was also far more spatially heterogeneous than at Brandon.

Except for the Dakota field, the one factor that all conventional-tillage fields had in common was the inclusion of alfalfa in the rotation. Alfalfa stands are known to weaken over time, and become infested with dandelion (Spandl et al., 1999). While the Dakota field was not seeded to alfalfa in the past four years, in 1994 it was seeded to lentils. The producer stated that this was when the dandelion problem became noticeable in the field. The year 1994 was also very wet, and large areas of this field were flooded. The producer also noted that an application of metribuzin (Sencor) did not influence the dandelion plants present in this field. The wind-dispersed nature of dandelion seed makes it possible for dandelion to locate and establish in open weak areas of a field (Moyer et al., 1994). Field edges have been recognized as the source of wind-blown weed species (Moyer et al., 1994). Dandelion invasion into weakened, undisturbed alfalfa stands or into an uncompetitive annual crop in which inadequate in-crop measures were used to control dandelion seedlings are the suspected reason for its proliferation in the conventional-tillage fields (Ominski et al., 1999). Dandelion proliferates in alfalfa crops because its low growth habit allows it to escape mowings (Ominski et al., 1999). This is the likely reason for the substantial dandelion population at New Bothwell relative to the other fields as a long-term alfalfa crop had only been broken in this field in the fall of 1999. There had been only one spring tillage operation made since it was moved into an annual crop rotation. Also, dandelion populations were far more spatially heterogeneous at Dakota and Steinbach relative to New Bothwell, indicating that the tillage operations made since the origin of the dandelion problem have reduced dandelion population spread.

3.3.2. CANOLA YIELD AS AFFECTED BY DANDELION INTERFERENCE

When sites were combined, there was significant correlation between the reduction in canola grain yield and several measures of dandelion infestation (Table 3.3.2). Overall, the only measures of dandelion that did not yield significant relationships were relative density in-crop and total leaf diameter in-crop. When the strongest of these relationships was plotted (percent of weed-free canola yield relative to dandelion cover), it became clear that while some of these relationships were significant, they could not be used to develop meaningful models (Figure 3.3.3) because the data were highly scattered and offered no trend. Thus, sites were grouped according to tillage system and re-tested.

When data sets were separated on the basis of tillage and correlation analyses conducted, significant relationships between reduction in canola yield and all measures of dandelion were found for the zero-tillage data set (Table 3.3.2). For the conventional-tillage data set no significant relationships between reduction in canola yield and any measure of dandelion was found, even when conventional-tillage sites were tested individually. Thus, in conventional-tillage fields no relationships between reduction in canola yield and measures of dandelion infestation was modeled.

The lack of correlation between reduction in canola yield and any measure of dandelion infestation for all conventional-tillage fields could have been related to several factors. First, all conventional-tillage fields were cultivated prior to crop seeding. The sweeps from the cultivator would have removed most dandelion top growth. Thus, dandelion seeds would have been germinating at the same time as dandelion plants

Table 3.3.2. Correlation of reduction in canola yield with measures of dandelion infestation

All sites combined, n=125			
Time of Measurement	Measurement	Correlation Coefficient (r)	Significance P(r=0)[a]
In Crop	Dandelion Cover	-0.42489	0.0001 [b]
	Relative Cover	-0.41101	0.0001 [b]
	Dandelion Density	0.1915	0.0324 [b]
	Relative Density	-0.10365	0.25
	Total dandelion Leaf Diameter	-0.03651	0.686
At Harvest	Total dandelion Leaf Area	-0.25966	0.0035 [b]
	Total dandelion Root Diameter	-0.36969	0.0001 [b]
	Total dandelion Biomass	-0.28244	0.0014 [b]
	Dandelion Density	-0.2634	0.003 [b]
Zero-tillage sites, n=57			
Time of Measurement	Measurement	Correlation Coefficient (r)	Significance P(r=0)[a]
In Crop	Dandelion Cover	-0.69717	0.0001 [b]
	Relative Cover	-0.74168	0.0001 [b]
	Dandelion Density	-0.47918	0.0002 [b]
	Relative Density	-0.48075	0.0002 [b]
	Total dandelion Leaf Diameter	-0.53852	0.0001 [b]
At Harvest	Total dandelion Leaf Area	-0.3194	0.0154 [b]
	Total dandelion Root Diameter	-0.55443	0.0001 [b]
	Total dandelion Biomass	-0.31969	0.0153 [b]
	Dandelion Density	-0.45491	0.0004 [b]
Conventional-tillage sites, n=68			
Time of Measurement	Measurement	Correlation Coefficient (r)	Significance P(r=0)[a]
In Crop	Dandelion Cover	-0.05219	0.6725
	Relative Cover	-0.10062	0.4143
	Dandelion Density	0.09416	0.445
	Relative Density	0.11249	0.3611
	Total dandelion Leaf Diameter	0.06554	0.5954
At Harvest	Total dandelion Leaf Area	-0.19801	0.1055
	Total dandelion Root Diameter	-0.17362	0.1736
	Total dandelion Biomass	-0.15569	0.2049
	Dandelion Density	-0.09983	0.4179

[a] Significance tested to determine the probability that correlation was equal to zero.
[b] Represents significance at the ∝=0.05 level.

regenerated from roots, while canola germinated from seed. Depth of germination and regeneration of dandelion could have varied greatly in conventional-tillage fields, providing a great range of plant sizes and some dandelion plants would have escaped cultivation altogether. In conventional-tillage fields, therefore, the dandelion stand was likely very demographically diverse.

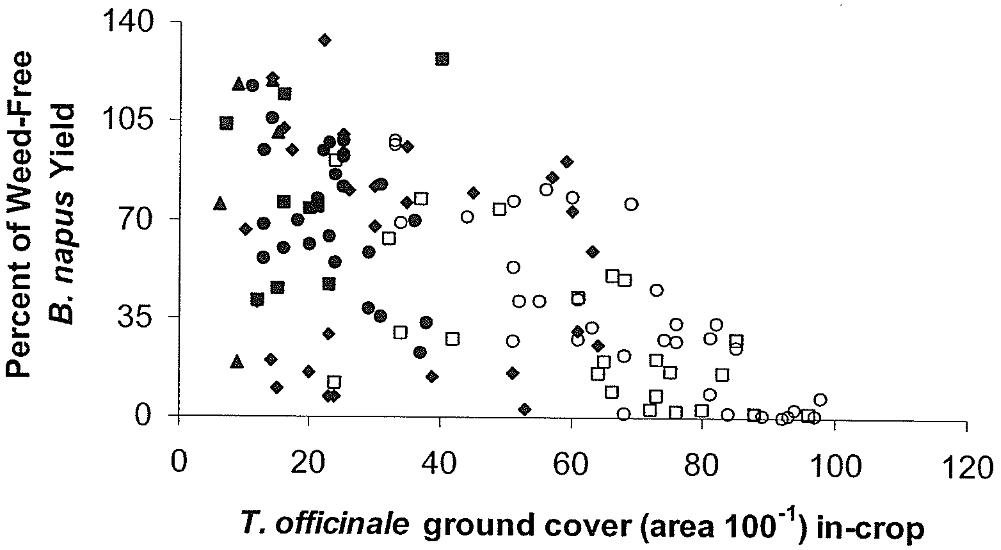


Figure 3.3.3. Reduction in canola yield due to dandelion interference as represented by ground cover of dandelion measured at the 2-4 leaf stage of canola for all field sites. (■) Elie, (♦) New Bothwell, (▲) Steinbach, (●) Dakota, (□) Brandon, (△) Carman. Closed symbols represent conventional-tillage sites, open symbols represent zero-tillage sites.

Silversides (1938) found that age of dandelion plants could be determined by counting the number of rings in a dandelion root. Thus, it is possible that dandelion root diameter might represent age of an individual plant. Several measurements of dandelion plants were made, expecting that they would account for diverse demography. These included leaf diameter measured in-crop, leaf area measured in-crop, as well as root diameter at harvest. However, not one of these means was significantly related to percent canola yield loss in conventional tillage fields. This could suggest, perhaps that these measures are not adequate measures of dandelion demography. Because of the nature of our study, destructive measures of dandelion demography in-crop could not be used although they have been shown to be useful (Silversides, 1938).

Weather could have also contributed to the poor correlation between measures of dandelion infestation level and canola yield loss for the conventional-tillage fields. Accumulated growing degree days (GDD) (Figure 3.3.4) were similar at all sites, but

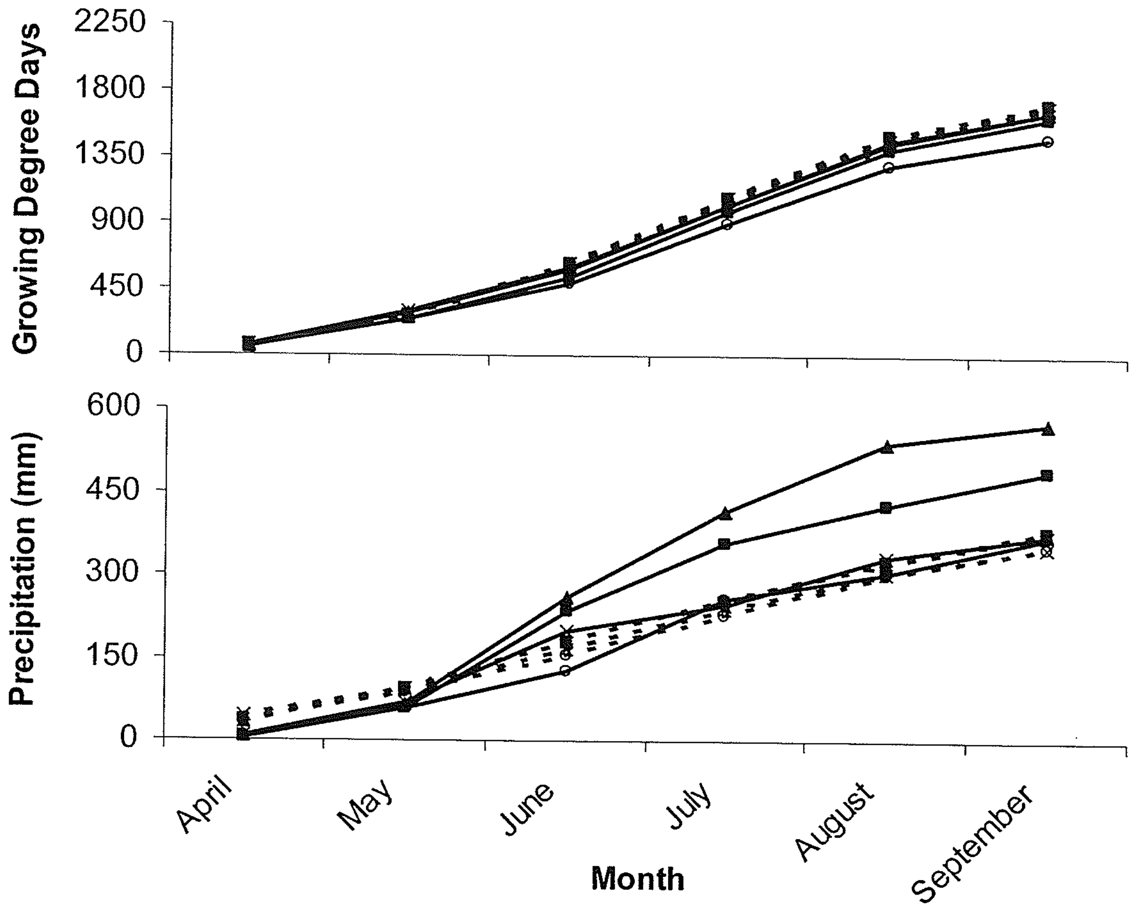


Figure 3.3.4. Accumulated growing degree days (GDD- base temperature 5°C) and precipitation (mm) for the months of April through September 2000 for all interference fields. Steinbach represents both New Bothwell and Steinbach. Winnipeg represents both Dakota and Elie. (▲) Steinbach, (■) Winnipeg, (□) Brandon, (×) Carman. Solid lines represent 2000 values. 30-year averages for each location are represented by dotted lines. The 30-year average for accumulated growing degree days at Carman was measured at Graysville. Weather data was obtained from the nearest Environment Canada weather station.

precipitation levels were greatest at Steinbach and New Bothwell, followed by Dakota and Elie, followed by both Brandon and Carman (the two zero-tillage sites). Precipitation at Steinbach, New Bothwell, Dakota, and Elie was much greater than the 30-year average. It has been demonstrated that oilseed rape is most susceptible to competition in wet years (Lutman et al., 1994).

When correlation analysis was conducted on the zero tillage sites separately, only 4 of the 9 measures of dandelion were significantly related to canola yield loss for the Brandon site. However, for the Carman site, all 9 measures of dandelion produced significant correlations (Table 3.3.3). Measures of dandelion that correlated most

Table 3.3.3. Correlation of reduction in canola yield with measures of dandelion infestation at individual zero tillage sites

Brandon site, n=23

Time of Measurement	Measurement	Correlation (r)	Significance P(r=0)[a]	
In Crop	Dandelion Cover	-0.62072	0.0016	[b]
	Relative Cover	-0.58399	0.0034	[b]
	Dandelion Density	-0.3436	0.1084	
	Relative Density	-0.28627	0.1854	
	Total Dandelion Leaf Diameter	-0.458	0.028	[b]
At Harvest	Total Dandelion Leaf Area	-0.25659	0.2373	
	Total Dandelion Root Diameter	-0.46659	0.0248	[b]
	Total Dandelion Biomass	-0.15831	0.4706	
	Dandelion Density	-0.40555	0.0549	

Carman site, n=34

Timing	Measurement	Correlation (r)	Significance P(r=0)[a]	
In Crop	Dandelion Cover	-0.82052	0.0001	[b]
	Relative Cover	-0.85228	0.0001	[b]
	Dandelion Density	-0.60523	0.0001	[b]
	Relative Density	-0.63099	0.0001	[b]
	Total Dandelion Leaf Diameter	-0.663	0.0001	[b]
At Harvest	Total Dandelion Leaf Area	-0.5317	0.0012	[b]
	Total Dandelion Root Diameter	-0.81727	0.0001	[b]
	Total Dandelion Biomass	-0.65613	0.0001	[b]
	Dandelion Density	-0.66304	0.0001	[b]

[a] Significance tested to determine the probability that correlation was equal to zero

[b] Represents significance at the ∝=0.05 level

strongly with canola yield as a percent of weed-free yield were relative ground cover in-crop, ground cover in-crop, root diameter at harvest, density at harvest, and leaf diameter in-crop (Table 3.3.4). Measures of infestation were presented separately for Brandon and Carman as they differ in rank order according to strength of correlation with canola yield loss. The proportion of ground covered by dandelion leaves was the best measure of dandelion interference (Figure 3.3.5). Plant size is an important indicator of the ability of dandelion to interfere with canola yield. This has been recognized to be true for weed interference, generally (Lotz et al., 1994). Determining ground cover using photography was also effective, yet practical applicability for producers is limited to subjective observations. Incorporating ground cover of canola into the measurement (relative cover) also provides a valuable measure of infestation (Figure 3.3.6). At Carman, relative measures of density and ground cover were more strongly related to reduction in canola yield than individual measures of density and ground cover. The reverse was true at Brandon. It has been shown that weed interference models based on crop and weed leaf

Table 3.3.4. Ranking of measures of dandelion infestation that were significantly correlated with reduction in canola yield at Brandon and Carman

Brandon			Carman		
Rank[a]	Measurement	Time	Rank[a]	Measurement	Time
1.	Dandelion Cover	IC[b]	1.	Relative Cover	IC[b]
2.	Relative Cover	IC[b]	2.	Dandelion Cover	IC[b]
3.	Dandelion Root Diameter	H[c]	3.	Dandelion Root Diameter	H[c]
4.	Dandelion Leaf Diameter	IC[b]	4.	Dandelion Density	H[c]
			5.	Dandelion Leaf Diameter	IC[b]
			6.	Dandelion Biomass	H[c]
			7.	Relative Density	IC[b]
			8.	Dandelion Density	IC[b]
			9.	Dandelion Leaf Area	H[c]

[a] Rank in order of strongest to weakest correlation using PROC CORR (SAS)
[b] IC represents measurement made in-crop (2-4 leaf stage of canola)
[c] H represents measurement made at harvest (physiological maturity of canola)

area are more accurate than thresholds based on weed density alone (Kropff and Spitters, 1991; Lotz et al., 1996).

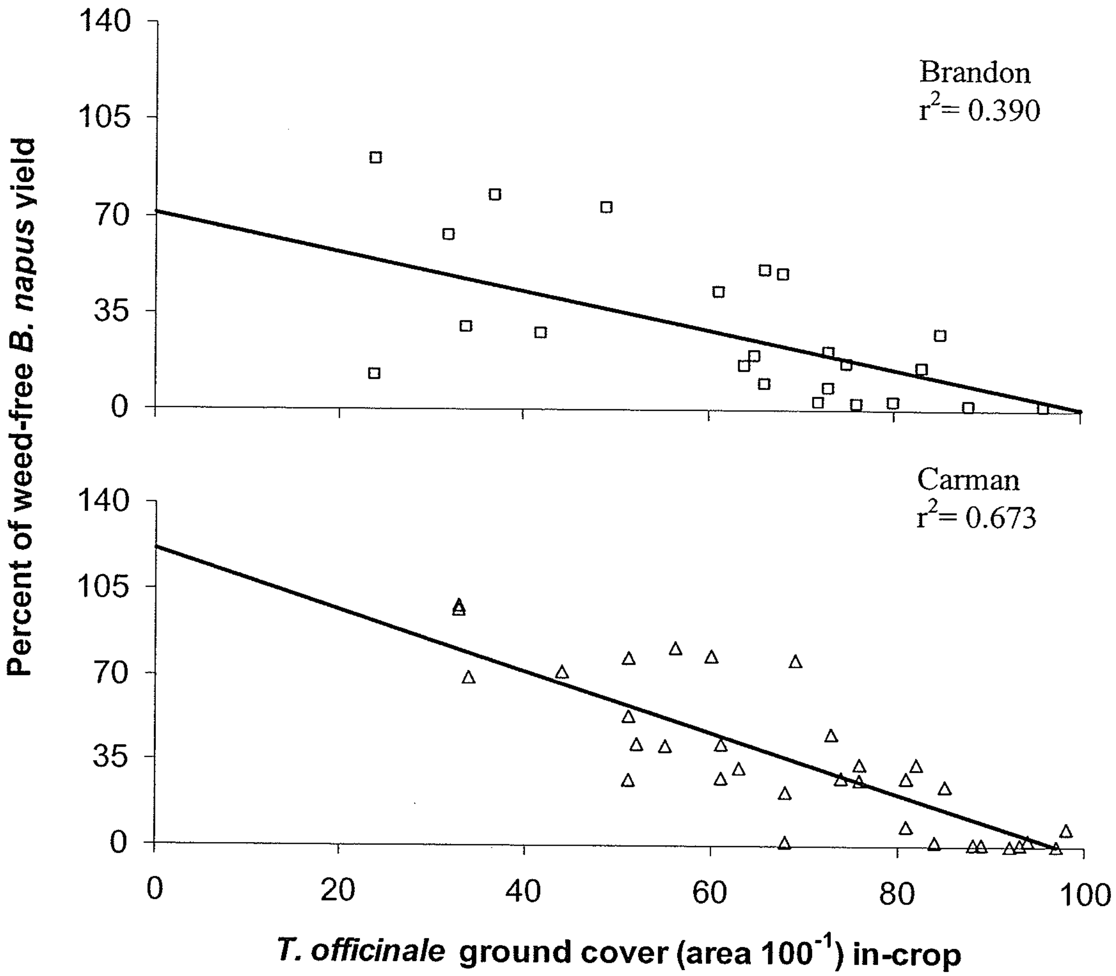


Figure 3.3.5. Reduction in canola yield as influenced by dandelion ground cover measured at the 2-4 leaf stage of canola at Brandon and Carman. Markers represent data points and lines represent fitted models.

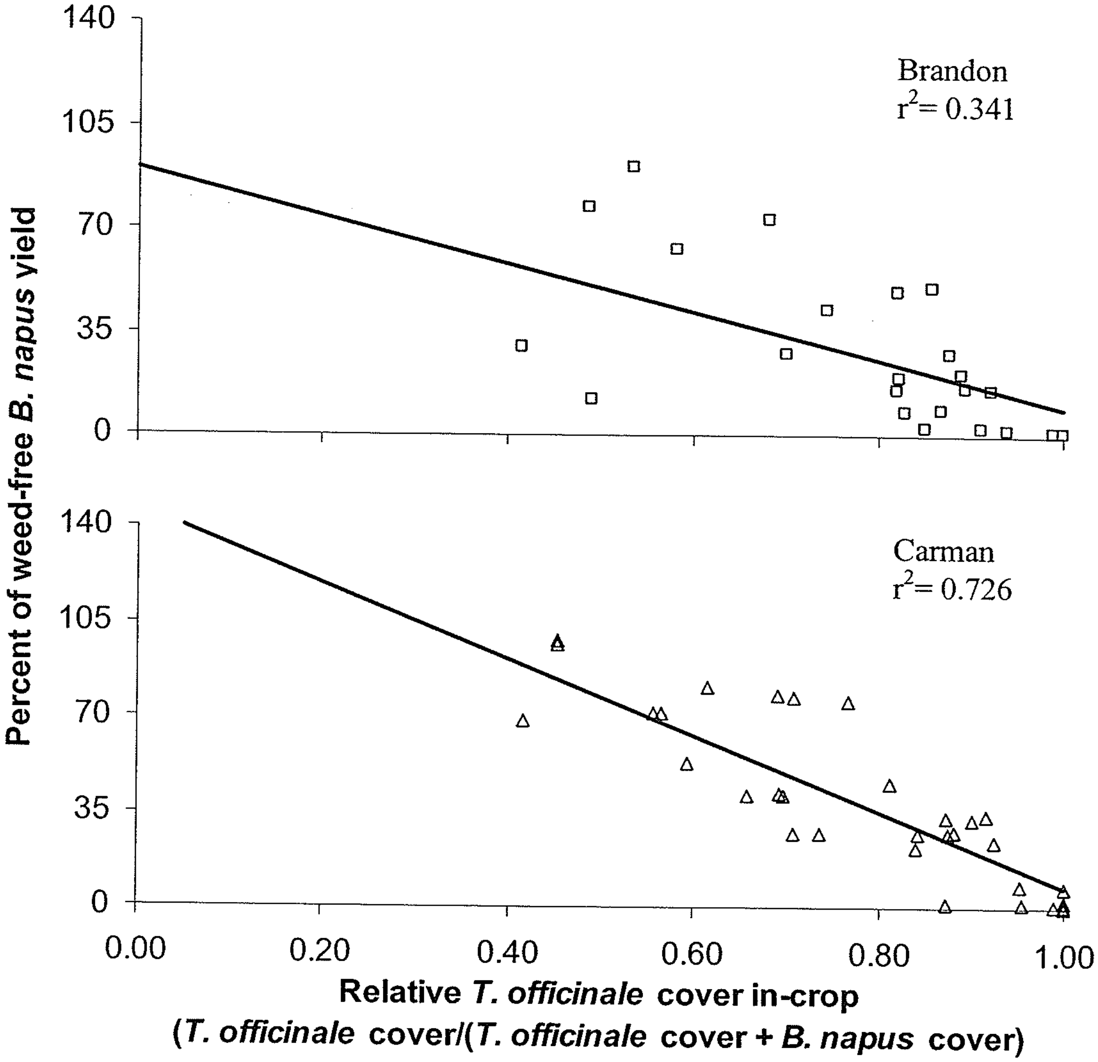


Figure 3.3.6. Reduction in canola yield as influenced by relative dandelion ground cover measured at the 2-4 leaf stage of canola at Brandon and Carman. Markers represent data points and lines represent fitted models.

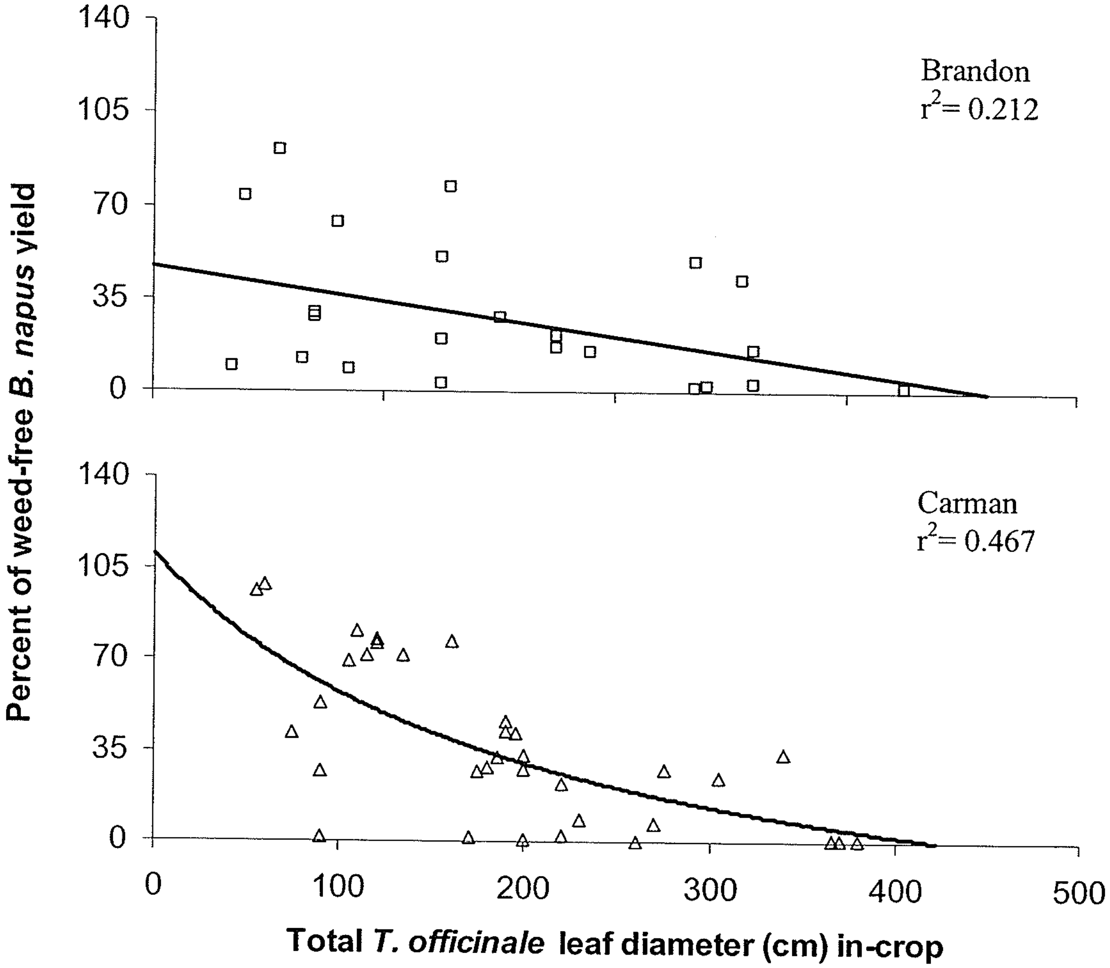


Figure 3.3.7. Reduction in canola yield as influenced by total dandelion leaf diameter measured at the 2-4 leaf stage of canola at Brandon and Carman. Markers represent data points and lines represent fitted models.

For all measurements of dandelion except leaf diameter (which had the poorest model fit at Brandon), the slope of reduction in dandelion yield was greater at Brandon than at Carman for a given unit measure of dandelion infestation. This is surprising as the variety seeded at Brandon was a hybrid whereas the variety seeded at Carman was an open pollinated variety. Hybrid varieties are known for being very competitive, however this was not the case in these experiments.

Dandelion leaf diameter was a less accurate measure of plant size than other measures of ground cover and as such it was not surprising that it did not provide as precise an estimate of interference as ground cover (Figure 3.3.5), for example. The fit of the model at Brandon was significant, yet poor (r^2= 0.212). Leaf diameter was an easy measurement to make and it is possible for farmers to use for assessing infestation levels of dandelion on small areas of a field.

The easiest measurement of dandelion infestation level for a farmer to make is density, although subjective measures of ground cover might also be realistic. Significant correlation between dandelion density and reduction in canola yield was exhibited only for the Carman field. Dandelion density measured at harvest (Figure 3.3.8) provided stronger correlation with reduction in canola yield than did dandelion density measured in-crop. Increased correlation for measures of dandelion density at crop was slight at both sites. Likely the increased correlation at harvest was because seedling dandelion had not germinated when the spring measurement was made, and as such were not accounted for with the in-crop measurement. Time of measurement of dandelion infestation does not seem to be as critical for dandelion as it is for other weeds. The stronger correlation at harvest poses a dilemma for producers, however. This measurement can only be made after yield loss has already occurred. For this reason, spring measurements are more useful to farmers.

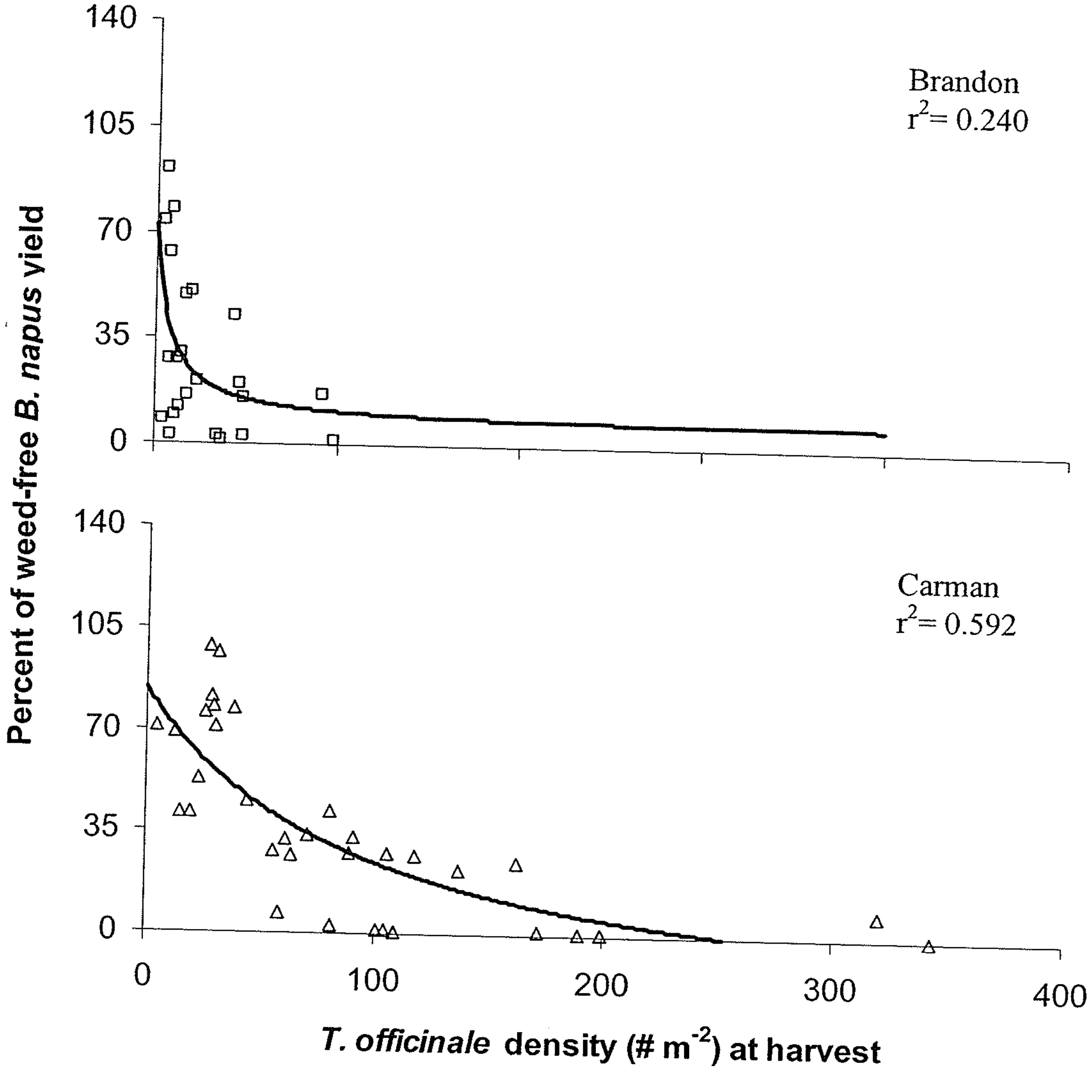


Figure 3.3.8. Reduction in canola yield as influenced by dandelion density measured at physiological maturity of canola at Brandon and Carman. Markers represent data points and lines represent fitted models.

The models relating dandelion ground cover, relative ground cover, density, relative density, leaf diameter, leaf area, root diameter, biomass, or density to reduction in canola yield differed significantly between Brandon and Carman (Appendix 7.8). Why did dandelion influence canola yield differently at Brandon and Carman? The main reason is due to the fact that different management techniques were used at each location. Different varieties and fertility programs were used. Canola has been found to be a very competitive crop (Lemerle et al., 1995), yet its competitive ability often differs significantly between location, environmental conditions, and weed species (Lutman et al., 1994; Lemerle et al., 1995, Martin et al., 2001). The competitive scenarios of Brandon and Carman were quite different. Precipitation was greater at Carman in June. Also, the demography of the dandelion population at Carman might have been narrower due to management techniques that favored resilient (older) plants. The density and spatial homogony of dandelion at Brandon was also much greater than at Carman. Individually or in combination, these factors might have influenced the competitive

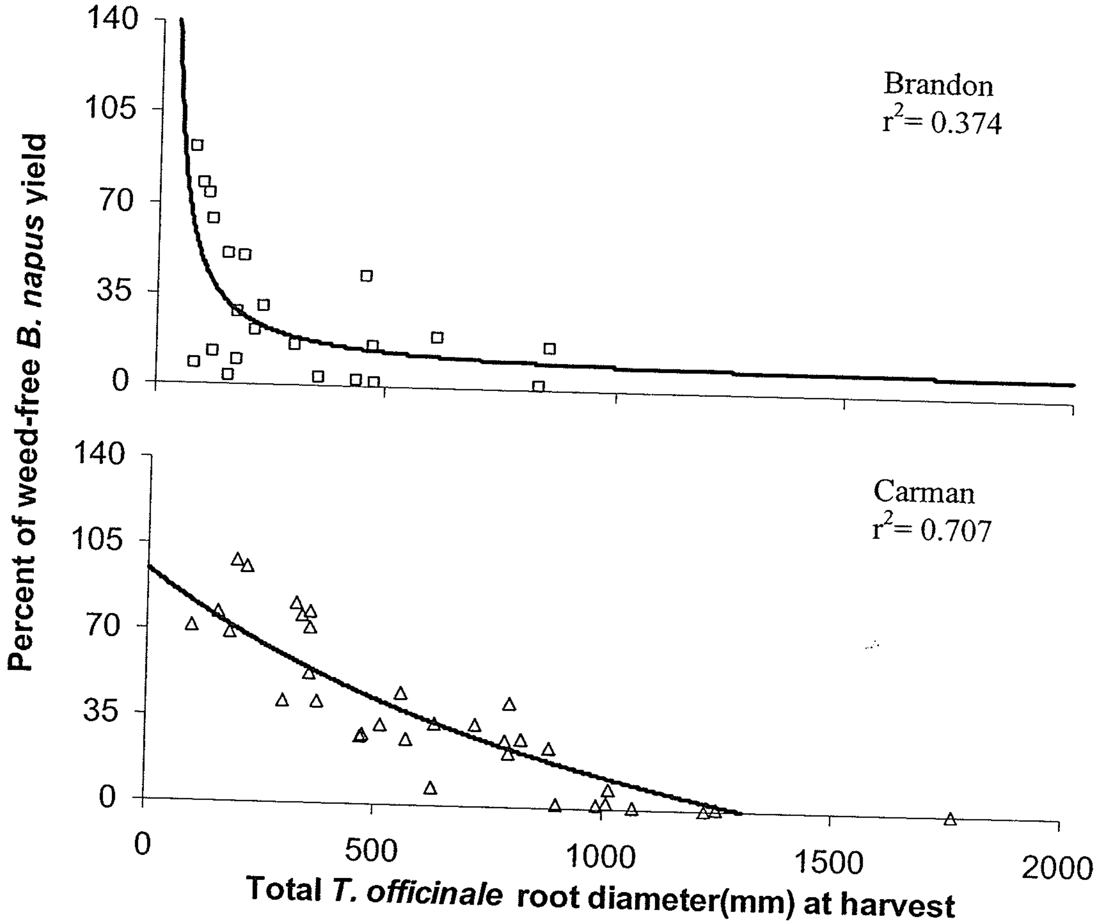


Figure 3.3.9. Reduction in canola yield as influenced by total dandelion root diameter measured at physiological maturity of canola at Brandon and Carman. Markers represent data points and lines represent fitted models.

relationships between dandelion and canola at the two sites. At Brandon, canola yield dropped off sharply with increasing root diameter (Figure 3.3.9). The reduction in canola yield as influenced by dandelion root diameter was much more gradual at Carman. If dandelion root diameter m^{-2} were 250 mm, at Brandon yield would have been reduced by 80% whereas at Carman yield would have been reduced by only 40%. For all measurements of dandelion except leaf diameter (which had the poorest fit at Brandon), the slope of reduction in canola yield was greater at Brandon for any given unit measure of dandelion infestation. The greater sensitivity of canola to dandelion interference at Brandon is difficult to explain. The theory that the dandelion population at Brandon was more demographically diverse would make one expect that canola yield would drop off more sharply at Carman with increasing dandelion interference. It may be that the dandelion populations at Brandon and Carman differed genetically and that one population was more competitive than the other. Further experiments would be necessary to test this theory. A conclusive method of determining dandelion plant age would be valuable for research of this nature. Consultation of the literature as well as discussion with experts on this weed provided no viable options for making this measurement.

3.3.3. SUMMARY

Distribution of dandelion in fields is usually patchy, but it is possible for dandelion to be present in high densities throughout fields. The most accurate measures of dandelion infestation were ground cover, root diameter, leaf diameter, and plant density. Infestations of dandelion will reduce yield of canola, yet predictability of yield loss is limited. For conventional-tillage fields, models of dandelion interference with canola yield could not be fitted to the data. More experiments need to be performed to determine if there are other means of reliably assessing the potential of dandelion to cause yield loss in conventionally-tilled fields. For zero-tillage fields, models could be fitted to the data but the parameters estimated for these models differed significantly between sites. I have hypothesized that the stronger correlation between reduction in canola yield and measures of dandelion infestations at Carman relative to Brandon was due to less diverse demography in the Carman versus the Brandon dandelion population. It is likely that in the Carman zero-tillage field, rotary harrow operations each fall removed a majority of dandelion seedlings, leaving mostly adult plants. This would be supported by the observation of a more patchy dandelion plant infestation at Carman versus Brandon. This less diverse infestation would be more predictable in its interference with canola yield. On a whole-field basis, dandelion certainly has the potential to dramatically reduce canola yield. For example, at Carman, even though dandelion was present in only 18% of the quadrats, if dandelion density averaged 5 plants m^{-2}, yield could be reduced by 11% for the entire field. Producers can scout fields to determine whether dandelion affects small areas of a field, or the entire field. If dandelion is present to a significant extent, ground cover or leaf diameter are the most accurate measures of interference potential.

Sources of Materials

[1]BASF Canada Inc. 345 Carlingview Drive, Toronto, Ontario, Canada, M9W 6N9

[2]Dupont Canada Inc. Box 2200, Streetsville, Mississauga, Ontario, Canada, L5M 2H3

[3]Wintersteiger Inc. 217 Wright Brothers Drive, Salt Lake City, Utah, U.S.A., 84116

[4]Li-Cor Inc. 4421 Superior St., Lincoln, Nebraska, U.S.A., 68504

[5]SAS Institute Inc., SAS Campus Drive, Cary, North Carolina, U.S.A., 27513-2414

[6] Aventis Canada Inc., 295 Henderson Dr., Regina, SK, S4N 6C2, Canada

CHAPTER 4:

Dandelion Control

ABSTRACT

Controlling dandelion populations using tillage and glyphosate requires an understanding of the biology of dandelion. Objectives of this study were to determine the influence of spring tillage, glyphosate rate, and time of glyphosate application on residual dandelion populations.

Tillage can cut off plants and remove aboveground biomass. Results show that spring tillage alone can provide greater than 52% control of a dandelion population. It also serves to delay the growth of dandelion during the growing season.

Glyphosate applications can effectively control dandelion. We observed limited control benefit from increasing rates of glyphosate. Increased rates provided improved control with pre- and post-harvest applications, yet did not influence control at other timings. A minimum rate of 900 g a.i. ha^{-1} of glyphosate appears to be necessary to provide significant dandelion control, especially with post-harvest applications.

The best time to apply glyphosate appears to be post-harvest. Dandelion biomass was reduced most by pre- and post-harvest applications, however a lower rate was adequate for post-harvest timings, relative to pre-harvest. In fall, dandelion is mobilizing its carbohydrate reserves, and transporting them to the roots. This provides an effective vehicle for delivery of glyphosate to dandelion's most important organ; the root.

Sequential applications of glyphosate provided the greatest overall reduction in dandelion biomass. By including 900 g a.i. ha^{-1} of glyphosate, applied post-harvest, with

another application during the growing season, populations were nearly eliminated according to biomass measurements taken in the spring following the year of application.

4.1. INTRODUCTION

While dandelion has long been loathed as an un-wanted pest in Western Canada, only recently has it been considered a significant pest of annual cropping systems. Surveys of Western Canadian fields, conducted in 1986-9 and 1995-7, show an alarming increase in dandelion frequency in annual crops in Western Canada (Thomas et al., 1998). In 1986-9 dandelion was present in 6 percent of wheat fields and 13 percent of canola fields in the Prairie Provinces. In 1995-7 however, dandelion presence increased to 20 percent of wheat fields and 23 percent of canola fields. Based on a relative abundance index, there was an increase in rank of 17 in wheat fields and an increase in rank of 7 in canola fields. In Manitoba alone, dandelion has not increased significantly in rank, whereas in Alberta and Saskatchewan dandelion has increased in rank by 3 and 9, respectively.

The majority of the interest paid to dandelion by researchers in the past has been related to its ability to infest forage crops and urban lawns. A significant amount of research has focused on dandelion interference and control in alfalfa (Hall et al., 1995; Sheaffer and Wise, 1982; Robison et al., 1978; Waddington, 1980; and Miller, 1986), orchardgrass (Moyer, 1984), and red fescue (Darwent and Lefkovitch, 1995). The urban pesticide market is booming as homeowners aim for aesthetic perfection. Very little consideration has been given to dandelion's role as a pest in annual field crops.

In the past, tillage was the primary method of weed control. This changed however with the advent of synthetic organic herbicide (eg. 2, 4-D) availability for field crops in the 1940's (Williams and Wicks, 1978). Herbicides made it easier and cheaper for farmers to manage their weed problems within crops, however they still relied heavily on tillage for seedbed preparation and weed control when crops weren't grown. The dust-bowls which resulted from excess tillage and dry weather led to the discovery several decades ago that soil erosion could be managed by using zero tillage production practices (Domitruk and Crabtree, 1997).

It is believed that increased adoption of reduced-tillage practices has been the primary factor leading to the increased abundance of perennial weed species, including dandelion, in annual cropping systems. Reducing tillage operations makes perennial weed species much more difficult to manage, even with the large selection of herbicides available in annual crops (Witt, 1984). Although Derksen et al. (1993) found that perennial weed species were not generally associated with zero-tillage systems, Blackshaw et al. (1994) found that dandelion and perennial sowthistle densities increased slightly over time in minimum- and zero-tillage treatments. Perennial and wind-borne species were found to be more frequent on uncultivated plots (Froud-Williams et al., 1983). Kelner (1995) found that dandelion was more abundant in zero-tillage fields than conventional-tillage fields.

The main reason for dandelion's persistence is its large taproot. Many herbicides have been tested for use on dandelion with fairly poor results. Buckardt (1936) found that large dandelions (those with 18 inch long roots) required over 3 times as much herbicide (petroleum oil/furfural mixtures) for control relative to seedling plants. The greatest level of control of dandelion in these studies was 70%. Moyer (1984) found that 2,4-D was effective at controlling 70% of dandelion populations in orchardgrass

(*Dactylis glomerata* L.) while Darwent and Lefkovitch (1995) achieved 80% control of dandelion with metsulfuron in fields of creeping red fescue (*Festuca rubra* L.). However, Mann (1981) showed that dandelion has a high capacity for regeneration from roots. Removal of top growth alone does not mean a dandelion plant is dead.

The research aim in the present study was to improve the understanding of cultural and chemical control measures for dandelion. Experiments considered the effects of glyphosate application and spring tillage intensity on residual dandelion populations. Objective were to determine the effects of 1) spring tillage intensity, 2) glyphosate rate, and 3) time of glyphosate application on dandelion control. The underlying goal was to determine the most efficient method of dandelion control in an annual cropping system.

4.2. MATERIALS AND METHODS

4.2.1. TRIAL LOCATIONS

In the spring of 1999 and 2000, controls trials were established on clay loam soil (Typic Eigenhof) at the University of Manitoba Research Farm at Carman, Manitoba and on clay soil (Typic Osborne) at the Monsanto Research Farm at Oakville, Manitoba. All sites had a large area infested with dandelion. These trials were set up in a split-plot, randomized complete block design with three replicates. Once the trial area was denoted, dandelion density was determined in each plot by counting dandelion in several 0.25 or 1 m^2 quadrats per plot. This was done to test for uniformity of dandelion populations for all treatments in all replications. At Carman in 1999, four 1 m^2 quadrats were counted per plot on May 17. At Oakville in 1999, three 1 m^2 quadrats were counted per plot on May 29. At all three sites in 2000, three 0.25 m^2 quadrats were counted per plot, on May

9 at Oakville and at the Carman early seeded site, and on May 19 at the Carman late seeded site.

4.2.2. TREATMENTS

Main plot treatments were combinations of glyphosate rates and times of application. The split-plot treatment was spring tillage intensity and it was applied across replications. The two tillage treatments were low and high disturbance. Low disturbance plots were direct-seeded with either a hoe-drill (Edwards[1], model HD 812) or double-disk press drill (John Deere[2], model 9350) whereas high disturbance plots were cultivated intensively before seeding (Table 4.2.1). Canola (*Brassica napus* L. Limagrain[3] 'LG 3235®') was seeded at a depth of 2.5 cm below the soil surface. Because of a dense annual weed population at Oakville in 1999, several tillage passes had to be made in high-disturbance plots to eliminate other weed species. Because of a large population of stinkweed (*Thlaspi arvense* L.) and redroot pigweed (*Amaranthus retroflexus* L.) at Oakville, on May 17, 1999 low disturbance plots were over-sprayed with paraquat (Gramaxone PDQ[4]) at a rate of 396 g a.i. ha^{-1} and diquat (Gramaxone PDQ) at a rate of 198 g a.i. ha^{-1}. To avoid weed flushes later in the season, ethafluralin (Edge DC[5]) was applied at a rate of 1.11 kg product ha^{-1} at Carman and Oakville on May 17, 1999. No herbicide over-sprays were applied before seeding at any site in 2000. When the canola

Table 4.2.1. Seeding and tillage implements used in dandelion efficacy trials

Site	Seeding Method	Tillage Implements
Carman99	Hoe Drill	1 x Rotovator
Oakville99	Double-Disk Press Drill	2 x Cultivator with Sweeps, 1 x Double-Disk
CarmanN00[a]	Double-Disk Press Drill	1 x Cultivator with Sweeps
CarmanS00[b]	Hoe Drill	1 x Cultivator with Sweeps
Oakville00	Double-Disk Press Drill	1 x Cultivator with Sweeps

[a] CarmanN00 represents the north trial at Carman in 2000

[b] CarmanS00 represents the south trial at Carman in 2000

in each trial reached the 3-4 leaf stage, sethoxydim (Poast Ultra[6]) was applied at a rate of 378 g a.i. ha^{-1} and ethametsulfuron-methyl (Muster[7]) was applied at a rate of 15 g a.i. ha^{-1} to all plots to remove annual weeds.

The main plot treatment was glyphosate rate and timing. Each trial consisted of 14 main plot treatments, from which 6 subsets could be selected to make specific comparisons between groups of 3 to 6 treatments (Table 4.2.2). Plot size was 2 m by 4 m at all sites. The glyphosate product used was Roundup Transorb[8] (360 g a.i. L^{-1}). The treatment list for each subset is presented in Table 4.2.2. Pre-seed applications of

Table 4.2.2. Treatment list of glyphosate rates (g a.i. ha^{-1}) and times of application.

		Glyphosate Rate				
		Application Timing				
Subset	Trt #	Pre-seed	0-3 Leaf[a]	4-6 Leaf	Pre-harvest	Post-harvest
		g a.i. ha^{-1}				
Pre-seed	1	0				
	3	900				
	4	1350				
	5	1800				
0-3 Leaf[a]	1		0			
	6		450			
	7		900			
Pre-harvest	1				0	
	8				900	
	9				1800	
Post-harvest	1					0
	10					900
	11					1800
	12					2700
Timing	1	0	0	0	0	0
	2		450	450		
	3	900				
	7		900			
	8				900	
	10					900
Sequential	1	0	0	0	0	0
	2		450	450		
	13	900				900
	14		450	450		900

[a] Leaf stage of canola crop.

glyphosate were made in all years. Spray treatments were made with a 2m hand-held boom calibrated to apply a spray solution volume of 110 L/ha. Dates for each treatment are presented in Table 4.2.3. Before glyphosate applications, plots to be treated were surveyed. Dandelion density was determined in one 0.25 m^2 quadrat per plot. Leaf diameters of dandelion plants were also measured in each 0.25 m^2 quadrat. Meteorological conditions at time of spraying are presented in Appendix 7.9. Four weeks after treatment, treated plots were again surveyed to estimate dandelion size and a visual control rating was done for dandelion in each plot.

Table 4.2.3. Dates for tillage, seeding, and spraying treatments at all sites.

Site	---------- Application Timing ----------						
	Initial Counts	Tillage/ Planting	Pre-seed	0-3 Leaf[c]	4-6 Leaf[c]	Pre-harvest	Post-harvest
	---------- Date ----------						
Carman99	May 17	May 27	May 18	June 7	June 25	August 10	Sept. 17
Oakville99	May 29	June 3	May 31	June 23	July 7	August 24	Sept. 21
CarmanN00[a]	May 9	May 16	May 10	June 5	June 19	August 9	Sept. 21
CarmanS00[b]	May 19	May 29	May 24	June 17	June 30	August 17	Sept. 21
Oakville00	May 9	May 15	May 10	June 5	June 19	August 9	Sept. 21

[a] CarmanN00 represents the north trial at Carman in 2000.
[b] CarmanS00 represents the south trial at Carman in 2000.
[c] Leaf stage of canola.

4.2.3. CANOLA HARVEST

Several days after pre-harvest glyphosate treatments were applied, plots were swathed to allow time for the canola to cure. Both 1999 trials were swathed on August 26 and all three 2000 trials were swathed on August 25. Plots were harvested with a plot combine (Winter Steiger[9] Model: NurseryMaster®). Seed bags were placed in a drying room for 7 to 14 days before being sieved and clean grain weighed. After harvest, plots were re-swathed in order to windrow the canola residue. These windrows were then baled and removed by hand. After the dandelion had time to recover from the harvest (7-14 days), post-harvest treatments were applied.

4.2.4. DETERMINATION OF DEGREE OF DANDELION CONTROL

Trials were left untouched until the spring following treatment application. As soon as dandelion plants began flowering, dandelion was harvested from three 0.25 m^2 quadrats in each plot. For the 1999 and 2000 trials this occurred on May 11, 2000 and May 12, 2001, respectively. Several measures were then made of the harvested dandelion. All dandelion plants were cut off at their base and root diameter measured at this point. Leaves were removed and reproductive material separated from vegetative material.

4.2.5. DATA ANALYSIS

Statistical analyses were performed on initial dandelion populations as determined at the outset of trials, as well as on the final dandelion populations in the spring following treatment applications (root diameter, leaf area, biomass, and density). PROC GLM in SAS (The SAS Institute[11], V. 9) was used to test for significance of factor effects in each data subset (Pre-seed, 0-3 leaf, pre-harvest, post-harvest, timing, and sequential). To ensure uniformity of initial dandelion populations, initial dandelion densities in each plot were tested (5 sites, 14 glyphosate treatments at each site, 2 disturbance levels, 3 replications at each site), using ANOVA and it was found that only site and rep(site) were significant factors. In order to correct for differences in initial dandelion density between sites, measures of residual dandelion populations had to be converted so measures for each plot were represented as a percentage of untreated checks (UTC) for respective sites. The formula used is as follows:

$$\text{Dandelion measure (\% of Untreated Check(UTC))} = \frac{\text{Dandelion biomass m}^{-2}\text{ in respective plot}}{\text{Dandelion biomass m}^{-2}\text{ averaged for UTC's (3 replications) at respective site}} \tag{A}$$

Dandelion biomass measured in the spring, the year following application was selected as the most appropriate measure of residual dandelion populations as it best quantified dandelion populations. Dandelion biomass was more accurate than density as it did not over-estimate dandelion populations when large numbers of tiny seedlings were present. Bartlett's test for homogeneity of variance (Damon and Harvey, 1987) was used on residual dandelion biomass (represented by percentage of untreated check) to determine if data needed to be transformed. For pre-seed, 0-3 leaf, and pre-harvest subsets, variance was shown to be homogenous (Appendix 7.10). For post-harvest, timing, and sequential subsets, variance was found to be non-homogenous. Because ANOVA assumes homogeneity of variance, the post-harvest, timing, and sequential subsets were ($\log_{10}$+1)-transformed for all analyses. Variability of residual dandelion biomass was very low in treatments sprayed post-harvest, making variability non-homogenous in all subsets containing post-harvest treatments. Although it should not be considered necessary to transform data (Ahrens et al., 1990), and there is evidence that non-homogeneity of variance scarcely affects ANOVA (Geng et al., 1982), transformation of data did provide additional means separation.

Using ANOVA on residual dandelion shoot biomass it was found that for each subset, significant differences were present for very few factors and interactions (Table 4.2.4). The only significant factor for all subsets was glyphosate treatment. Site alone was a significant factor for the pre-seed, pre-harvest and post-harvest subsets. Because

Table 4.2.4. Test of significance (ANOVA) to determine if initial dandelion densities at the outset of trials differed significantly between sites, replications within sites, treatments, or disturbance levels. Interactions were also tested for. Tests were performed on data subsets individually. Post-harvest, timing, and sequential subsets were ($\log_{10}$+1)-transformed for analysis.

	Data Subset					
Source	Pre-seed	0-3 Leaf	Pre-harvest	Post-harvest[g]	Timing[g]	Sequential[g]
	Probability >F					
Site	0.006*	0.854	<0.001*	0.0094*	0.0516	0.5508
Rep(Site)[a]	0.123	0.024	0.999	0.8422	0.0783	0.6802
Treatment	<0.001*	0.008*	<0.001*	<0.001*	<0.001*	<0.001*
Site*Trt[b]	0.080	0.797	0.227	0.1347	<0.001*	0.0148*
Rep*Trt(Site)[c]	0.360	0.273	0.307	0.4313	0.1055	0.0206*
Disturbance	0.104	0.458	0.061	0.0370*	0.0270*	0.2312
Trt*Distur[d]	0.574	0.869	0.384	0.7999	0.0131*	0.5212
Site*Distur[e]	0.034*	0.053	0.242	0.0274*	0.0395*	0.6770
Site*Trt*Distur[f]	0.940	0.629	0.926	0.8870	0.2597	0.0955

[a] Represents replication within site
[b] Represents the site by treatment interaction
[c] Represents the replication by treatment within site
[d] Represents the treatment by disturbance interaction
[e] Represents the site by disturbance interaction
[f] Represents the site by treatment by disturbance interaction
[g] ANOVA of log-transformed data
* Represents significance at the α=0.05 level

site by treatment interactions were found for only the timing and sequential subsets, sites were combined for analysis of glyphosate treatments for all other subsets. For the timing and sequential subsets, treatments were analyzed separately within sites. Within subsets, differences in residual aboveground dandelion biomass were tested using the LSD (least significant difference) test with PROC GLM in SAS (The SAS Institute, V. 9). Site by disturbance interactions were significant for the pre-seed, post-harvest and timing subsets. Comparison of untreated checks in low and high disturbance plots illustrated this interaction. For the post-harvest and timing subsets, disturbance was a significant factor. Because treatments and disturbance levels interacted significantly for the timing subset, treatments were compared separately within disturbance levels (within sites). All other factors and interactions were non-significant.

Dandelion efficacy trials were planted to canola to provide realism to our experiments. As such, canola yield was not a primary focus of our study. Bartlett's test for homogeneity of variance was used on canola yields to determine if data needed to be transformed. For all 6 data subsets, variance was homogenous ($P>0.25$). The influence of glyphosate and tillage treatments on canola yield was analyzed using ANOVA for each subset individually in order to test the influence of spring tillage intensity, glyphosate rate, and time of glyphosate application on canola yield. ANOVA of canola yields illustrated that site, glyphosate treatment, and tillage treatment were all significant factors, as well as most interactions (data not shown). As such, differences between glyphosate treatments for each data subset within respective sites and disturbance levels were analyzed separately and are presented in Appendices 7.11 through 7.17.

4.2.6. DANDELION GROWTH AND DEVELOPMENT STUDY:

4.2.6.1. EXPERIMENTS

In order to determine dandelion biomass, leaf diameter, and leaf area at time of herbicide application, one additional unsprayed control treatment in each of the tilled and untilled areas was added to two of the 2000 trials (00CarmanN and 00Oakville). Whenever spray treatments were applied (pre-seed, 0-3 leaf, 4-6 leaf, pre-harvest, and post-harvest), ten dandelion plants were randomly selected from each of these additional unsprayed control plots. For each dandelion plant leaf diameter, leaf area, and root diameter were measured. For each plot all ten plants were bulked and reproductive and vegetative biomass separated, dried at 80°C for 48 hours, and weighed.

4.2.6.2. DATA ANALYSIS

Data were prepared to illustrate growth and development of dandelion over time under tilled and un-tilled conditions.

4.3. RESULTS AND DISCUSSION

4.3.1. INITIAL DANDELION POPULATIONS

The analysis of initial populations of dandelion (Table 4.3.1) revealed no significant differences in dandelion density between treatments or disturbance levels. Thus, initial dandelion populations could be considered uniform between glyphosate and tillage treatments. Initial dandelion populations m^{-2} differed between sites ($p<0.0006$) and replications within sites ($p<0.0052$). Dandelion densities before either tillage or herbicide treatments were very different between years, with densities being much lower, generally, in 1999 than in 2000 (Table 4.3.2).

Table 4.3.1. Test of significance for differences in dandelion density (all five sites) at the outset of efficacy trials (ANOVA, alpha=0.05).

Source	D.F.	Sum of Squares	Mean Square	F value	Prob > F	
Site	4	35037.0	8759.2	12.73	0.0006	*
Rep (Site)	10	6880.8	688.1	2.68	0.0052	*
Treatment	13	1199.4	92.3	0.36	0.9799	
Site * Trt	52	11136.5	214.2	2.91	<0.0001	*
Rep * Trt (Site)	130	33437.9	257.2	3.50	<0.0001	*
Disturbance	1	35.3	35.3	0.48	0.4899	
Trt * Distur	13	1036.3	79.7	1.08	0.3781	
Site * Distur	4	317.1	79.3	1.08	0.3700	
Site * Trt * Distur	52	4072.0	78.3	1.06	0.3793	

* represents significance at the 0.05 level

Table 4.3.2. Mean dandelion densities (standard errors in parenthesis) for each site before tillage or herbicide treatments were applied.

Site	Dandelion Density
	--- Plants m^{-2} ---
Carman 1999	16.0 (0.5)
Oakville 1999	18.5 (0.8)
CarmanN 2000[a]	39.3 (2.0)
CarmanS 2000[b]	33.7 (1.5)
Oakville 2000	32.9 (1.7)

[a] CarmanN00 represents the north trial at Carman in 2000

[b] CarmanS00 represents the south trial at Carman in 2000

4.3.2. DANDELION BIOMASS AFTER TREATMENT

When residual dandelion shoot biomass was calculated so that it was expressed as a percentage of biomass in untreated plots, very few significant factors were found for most subsets (Table 4.2.4). As expected, treatment (combinations of glyphosate rates and times of application) was a significant factor for each subset. Spring tillage (disturbance) was a significant factor for only the post-harvest and timing subsets. Numeric differences between tillage treatments overall were reduced by conversion of data to percentage of untreated within respective disturbance levels. For example, while 900 g a.i. ha^{-1} applied post-harvest reduced dandelion shoot biomass by ~4% in both low and high disturbance plots, actual biomass was 5.2 and 2.4 g m^{-2} in low and high disturbance plots, respectively.

When all 5 sites were combined, the treatment by disturbance interaction was not significant (using biomass represented as a percentage of untreated checks) for 5 of the six data subsets. This is important as it illustrates the fact that dandelion plants are equally susceptible to glyphosate treatments in both zero- and conventional-tillage systems. For the timing subset, however, glyphosate applications influenced residual dandelion populations differently in low and high disturbance plots.

4.3.3. SPRING TILLAGE INTENSITY

Dandelion spring residual biomass in the year following treatment was not significantly affected by level of spring tillage for any subset. However, when all 5 site-years and 14 treatments were combined, dandelion biomass was 129.5 (+/- 22.3) g m^{-2} for untreated low disturbance plots and 61.0 (+/- 12.7) g m^{-2} for untreated high disturbance plots (significant at 0.05 level). Thus, an intensive tillage in spring resulted in greater than 52% control of dandelion (Table 4.3.3). The cultivations made at all 5 sites must have weakened the dandelion stands to the extent that they could not fully recover. In spring, carbohydrate reserves in dandelion roots are mobilized to aboveground tissues, possibly making them more susceptible at this time to control measures (Rutherford and Deacon, 1974). Dandelion roots can be up to 3 cm in diameter and reach a depth of 2 m (Mann and Cavers, 1979) making it surprising that spring cultivation alone could provide such a significant level of dandelion control.

Table 4.3.3. Dandelion shoot biomass in untreated low and high disturbance plots measured in the spring, the year following treatments. Dandelion shoot biomass is measured in g m^{-2} (standard errors in parenthesis.). Percent of LDS values represent dandelion shoot biomass in high disturbance plots as a percentage of dandelion shoot biomass in low disturbance plots. LSD represents least significant difference.

Site	Dandelion Shoot Biomass		LSD	Percent of LDS
	LDS	HDS		
	---- g m^{-2} ----	---- g m^{-2} ----		
Carman99	83.6 (25.4)	13.4 (6.3)	89.1[**]	16.0 (7.5)
Oakville99	52.0 (21.1)	11.6 (5.2)	110.4	22.3 (9.9)
CarmanN00[a]	114.2 (19.4)	93.3 (3.9)	94.2	81.7 (3.4)
CarmanS00[b]	277.4 (15.7)	129.6 (6.2)	43.0[*]	46.7 (2.2)
Oakville00	120.3 (22.9)	57.3 (17.3)	41.0[*]	47.6 (14.4)
Overall	129.5 (22.3)	61.0 (12.7)	18.7[*]	52.8 (7.0)

[a] CarmanN00 represents the north trial at Carman in 2000
[b] CarmanS00 represents the south trial at Carman in 2000
[*] Significant at the α=0.05 level
[**] Significant at the α=0.10 level

Because of greater intensity of tillage operations in 1999 trials it was expected that differences between low and high disturbance plots would be greater for the 1999 versus 2000 trials. This was not the case. Tillage significantly reduced dandelion biomass in high disturbance plots for the 1999 trial at Carman (at the α=0.10 level) however no significant difference was found between low and high disturbance plots at Oakville in 1999. Large numerical differences in residual dandelion biomass were shown at both 1999 sites, however, due to large amounts of variability within sites, significant differences were not found. For the 2000 sites, two trials exhibited significant differences between tillage treatments (Oakville and CarmanS). These sites had less variability between replications than did other sites. Statistically, increasing intensity of tillage did not improve dandelion control.

Our results provide some evidence that the intensive cultivations made in 1999 weakened dandelion plants to a greater extent than those made in 2000 as dandelion populations were reduced at Oakville and Carman by 77.7 and 84.0 % respectively, in 1999. A single cultivation with sweeps reduced dandelion biomass by only 41% (average of 3 trials in 2000). This illustrates the difficulties producers might have in controlling dandelion populations in minimum tillage systems. Our growth and development studies provide evidence that average dandelion leaf diameter, leaf area, and aboveground biomass plant^{-1} increase quickly in spring in low disturbance plots (Figures 4.3.1; 4.3.2) relative to plants in high disturbance plots. Clearly, spring tillage limits dandelion growth. Where suitable, intensive tillage operations could be used to effectively reduce dandelion populations. These results were not justified by statistical tests, as a result of a high variability between replications and only 2 degrees of freedom (3 replications per site) at all sites. However, the much greater reduction in dandelion biomass by intensive tillage in the 1999 versus minimum tillage in 2000 serves to bolster the theory that dandelion populations are increasing as a result of increased adoption of reduced- and zero-tillage practices. In summary, increasing spring tillage intensity reduced residual dandelion biomass, but not significantly. Increasing tillage intensity is not recommended as this results in increased moisture loss and can lead to erosion concerns.

For the timing subset, significant treatment by disturbance interactions were observed (Table 4.3.5). In both low and high disturbance plots, post-harvest applications provided the greatest efficacy. In high disturbance plots other times of application did not, generally, result in significant levels of dandelion control. In low disturbance plots, other treatments did provide significant levels of control, especially at Carman. In 1999, split, pre-seed and 0-3 leaf applications of glyphosate significantly reduced dandelion populations in low disturbance plots, and in 2000, pre-harvest applications of glyphosate provided a significant level of dandelion control as well. Spring tillage appears to reduce the effectiveness of glyphosate applications made in-crop, although this result was not consistent. Plants in cultivated fields grow slowest early in the season and more quickly late in the growing season (Bunce, 1980). It is possible that the dandelions that were in high disturbance plots were too small and were growing too slowly to uptake as much glyphosate as the larger plants in low disturbance plots. In 2000, plants in the low disturbance treatments were much larger in terms of leaf diameters than those in the high disturbance treatments (Figure 4.3.2). Observations at time of glyphosate application suggest that dandelion populations were very small numerically and in some cases nonexistent in high disturbance plots at time of spraying. Thus, there was little regenerated dandelion leaf area aboveground to take up glyphosate.

The 1999 trials (Oakville and Carman) both received intense cultivations in spring, yet at Oakville glyphosate applications were more effective in high disturbance plots, whereas at Carman the reverse was true. Spring tillage might have dried out the soil in Carman more (lighter soil than Oakville), limiting soil moisture in the top of the profile, and limiting the growth of plants, and resultant translocation of glyphosate to growing points. Increasing intensity of tillage operations does not consistently reduce residual dandelion populations.

4.3.4. GLYPHOSATE RATE

Dandelion biomass (as percent of untreated) was significantly reduced by the application of glyphosate at all rates applied. Early in the season, increasing glyphosate rate did not result in a significantly better control (Table 4.3.4). Glyphosate rate was a significant factor at the pre- and post-harvest timings, however. Fall applications of glyphosate (pre- and post-harvest) have consistently proven to provide the greatest control of dandelion (Dunn and Moyer, 1999; Ross, 1999).

For pre-seed and 0-3 leaf applications all glyphosate rates provided equally effective dandelion control. For the pre-seed application, all glyphosate rates (900, 1350, 1800 g a.i. ha^{-1}) reduced dandelion biomass by roughly 60%. For the 0-3 leaf stage of canola, applying glyphosate at a rate of 450 or 900 g a.i. ha^{-1} provided a 32 and 39% reduction in dandelion spring residual biomass, respectively.

When applied pre-harvest, glyphosate rate significantly influenced residual dandelion populations. A rate of 900 g a.i. ha^{-1} significantly reduced dandelion biomass

Table 4.3.4. The influence of glyphosate rate on dandelion shoot biomass (as a percentage of untreated) measured in the spring following year of glyphosate application (standard errors in parenthesis). Glyphosate applied pre-seed, at the 0-3 leaf stage of canola, pre-harvest, or post-harvest. Mean dandelion shoot biomass was 129.5 g m^{-2} (+/- 22.3) and 61.0 g m^{-2} (+/- 12.7) for the untreated low and high disturbance plots, respectively. Data combined over disturbance treatments and site-years. Post-harvest treatments were ($\log_{10}$+1)-transformed for analysis(LSD values in Appendix 7.19).

Application Time	Glyphosate Rate	Dandelion Biomass[a]	
	--- g a.i. ha^{-1} ---	----- % of untreated-----	
Pre-seed	0	100 (7.6)	a
	900	39.7 (6.0)	b
	1350	35.6 (7.4)	b
	1800	37.8 (7.5)	b
	LSD	16.0	
	--- g a.i. ha^{-1} ---	----- % of untreated -----	
0-3 Leaf[b]	0	100 (7.6)	a
	450	68.2 (9.5)	b
	900	60.9 (8.6)	b
	LSD	21.3	
	--- g a.i. ha^{-1} ---	----- % of untreated-----	
Pre-harvest	0	100 (7.6)	a
	900	46.5 (8.4)	b
	1800	25.3 (5.0)	c
	LSD	19.9	
	--- g a.i. ha^{-1} ---	---- % of untreated----	
Post-harvest	0	100 (7.6)	a
	900	4.0 (1.4)	b
	1800	5.7 (3.3)	b
	2700	1.9 (1.1)	c

[a] Values followed by different letters are significantly different at $\propto = 0.05$ for comparisons among rates within application time

[b] Leaf stage of canola crop

relative to the untreated check. Increasing the rate to 1800 g a.i. ha^{-1} improved control significantly. When pre-harvest applications of glyphosate were made, dandelion had reached its peak average leaf area, leaf diameter, and aboveground biomass $plant^{-1}$ (Figures 4.3.1; 4.3.2). At the pre-harvest timing, dandelion plants would likely have begun to mobilize carbohydrate reserves back to the root, however the canola canopy likely influenced efficacy of glyphosate at this stage. The dense canola canopy would have likely intercepted a large portion of the glyphosate applied to plots. For both glyphosate rates, spray volume per unit area was identical (110 L ha^{-1}), meaning that glyphosate would have been twice as concentrated in the spray solution for the higher rate. Clearly, at this time of year dandelion plants respond to glyphosate application. The 75% reduction in dandelion biomass when 1800 g a.i. ha^{-1} of glyphosate is applied pre-harvest is greater than for any pre-seed or 0-3 leaf treatments. Increasing pre-harvest rates even further might have reduced dandelion populations to an even greater extent.

For post-harvest applications of glyphosate there was a significant difference in residual dandelion biomass between glyphosate rates. Rates of 900 and 1800 g a.i. ha^{-1} both significantly reduced dandelion biomass relative to the untreated check. Dandelion spring residual biomass was reduced to an even greater extent when 2700 g a.i. ha^{-1} of glyphosate was applied. A rate of 900 g a.i. ha^{-1} applied post-harvest reduced biomass by 96%, and a rate of 1800 g a.i. ha^{-1} reduced dandelion biomass by 94% (with a larger standard error). A rate of 2700 g a.i. ha^{-1} reduced biomass by 98%. Producers will have to balance the slight increase in control with a tripling in cost to roughly \$30 $acre^{-1}$ (not including application costs). A rate of 900 g a.i. ha^{-1} appeared to be sufficient to provide excellent control of dandelion post-harvest. Claus and Behrens (1976) found that high rates of glyphosate were not required for fall applications in order to provide excellent control of quackgrass. Like quackgrass, in fall, dandelion mobilizes reserves below ground. This was illustrated by the rapid decrease in average dandelion leaf diameter, leaf area, and aboveground biomass $plant^{-1}$ (Figures 4.3.1; 4.3.2).

4.3.5. TIME OF GLYPHOSATE APPLICATION

A comparison of dandelion spring residual biomass after 900 g a.i. ha^{-1} of glyphosate was applied at various timings throughout the growing season reveals the effect of timing of glyphosate application on dandelion control (Table 4.3.5).

Because significant differences between treatments within disturbance levels at each site were tested using ($\log_{10}$+1)-transformed data, LSD values could not be included for the timing subset. When disturbance levels were analyzed separately within sites, generally, glyphosate applications made in-crop did not provide a significant level of dandelion control, especially in high disturbance plots (Table 4.3.5). One exception was pre-harvest applications of glyphosate, which provided significant efficacy. Pre-harvest applications of glyphosate for dandelion control might have greater utility in years when crop stands are weak (reducing spray solution interception). Darwent and Drabble (1995) also found that efficacy of glyphosate on dandelion was limited when treatments were made in-crop. This directly contradicts the results reported in Table's 4.3.4 and 4.3.6 which indicate that all rates at each timing provided significant control of dandelion. This is likely a result of fewer degrees of freedom in Table 4.3.5, resulting from separation into individual sites and disturbance levels. Mean separations with disturbance levels combined increased discrimination and provided evidence that in-crop treatments significantly reduced residual dandelion populations (Appendix 7.22).

The major difference between tillage regimes was that post-harvest applications were the only ones to consistently perform well in high disturbance plots, whereas in low disturbance plots most treatments out-performed the untreated check. This is likely due to a much larger dandelion population being present in low disturbance plots, both in terms of plant size (Figure 4.3.1) and density (pers. obs.). In high disturbance plots cultivation removed most dandelion top-growth early in the growing season, providing far less leaf area to intercept and take up glyphosate.

Several anomalies were found between sites in ranking of treatments within low disturbance plots. Oakville 1999 was the only site where pre-seed applications performed exceptionally well, and it was also the only site where the split treatment significantly out-performed the 0-3 leaf treatment. The high efficacy (~98%) of the pre-seed treatment at Oakville in 1999 was likely a result of the Gramaxone PDQ application made 2 weeks prior to application of pre-seed treatments. Gramaxone PDQ is a contact herbicide, which burns off top-growth and has no systemic activity. Thus, the Gramaxone must have weakened dandelion plants to a significant degree at this time, making them more vulnerable to pre-seed applications of glyphosate (in both low and high disturbance systems). The improvement of the split treatments over the 0-3 leaf treatments (66% vs. 0%) for this site-year was not statistically significant and appears to be largely a result of high variability in the 0-3 leaf treatment (standard error= 54.0). Split glyphosate applications in-crop cannot be expected to consistently reduce dandelion populations to a greater extent than single applications in-crop.

The best and most consistent treatments over both tillage systems were post-harvest applications. In both disturbance systems at all sites, the post-harvest treatment was the best treatment in 8 of the 10 cases. Post-harvest treatments was also consistently significantly efficacious. Fall applications of glyphosate are generally accepted as the most efficacious as this is the time of year when dandelion transfers resources to the roots (Rutherford and Deacon, 1974; Vavrek et al., 1997). There was no canola canopy present

Table 4.3.5. Dandelion shoot biomass (as a percentage of untreated) measured in spring after 900 g a.i. ha^{-1} of glyphosate applied at various timings (standard errors in parenthesis). Mean dandelion shoot biomass was 129.5 g m^{-2} (+/- 22.3) and 61.0 g m^{-2} (+/- 12.7) for the untreated low and high disturbance plots, respectively. Statistical tests were performed on (log$_{10}$+1)-transformed data.

Timing	1999							
	Oakville				Carman			
	LDS[c]		HDS[c]		LDS[c]		HDS[c]	
	------- % of untreated -------				------- % of untreated -------			
Untreated	100 (40.6)	a	100 (44.5)	a	100 (30.4)	a	100 (47.1)	a
Split[b]	33.6 (14.4)	a b	11.0 (2.6)	a b	18.3 (4.6)	b	50.2 (24.8)	a
Pre-seed	2.2 (1.1)	c	3.1 (3.1)	b	19.5 (5.7)	b	22.7 (3.4)	a
0-3 Leaf[a]	100.7 (54.0)	a	49.5 (42.0)	a b	23.4 (8.8)	b	52.3 (24.7)	a
Pre-harvest	25.2 (11.4)	a b	1.9 (0.6)	b	89.8 (16.2)	a	89.1 (52.6)	a
Post-harvest	7.4 (0.8)	b c	17.6 (11.6)	a b	8.3 (3.2)	c	0.1 (0.1)	b

Trt	2000											
	Oakville				CarmanN				CarmanS			
	LDS[c]		HDS[c]		LDS[c]		HDS[c]		LDS[c]		HDS[c]	
	------- % of untreated -------				------- % of untreated -------				------- % of untreated -------			
Untreated	100 (19.1)	a	100 (30.2)	a	100 (17.0)	a	100 (4.2)	a	100 (5.7)	a	100 (4.8)	a
Split[b]	39.4 (15.1)	b	47.2 (21.4)	a	61.8 (2.3)	a	46.5 (6.4)	abc	33.5 (7.1)	bc	90.0 (6.7)	a
Pre-seed	46.7 (10.5)	a b	84.5 (25.3)	a	76.9 (3.4)	a	37.6 (11.0)	bc	35.3 (0.9)	bc	69.1 (17.6)	a
0-3 Leaf[a]	35.7 (17.5)	b	78.1 (28.1)	a	79.6 (19.3)	a	63.4 (24.8)	ab	40.7 (7.1)	b	85.3 (19.0)	a
Pre-harvest	59.2 (28.4)	a b	46.3 (9.9)	a	101.7 (12.7)	a	23.4 (8.5)	c	21.4 (3.3)	c	7.4 (4.1)	b
Post-harvest	0.9 (0.8)	c	0 (0)	b	1.1 (0.7)	b	1.3 (1.3)	d	1.5 (0.4)	d	1.8 (1.8)	c

---

[a] 900 g a.i. ha^{-1} applied at the 0-3 leaf stage of canola

[b] 450 g a.i.ha^{-1} applied 0-3 leaf, 450 g a.i. ha^{-1} applied 4-6 leaf

[c] Numbers followed by different letters are significantly different at $\propto = 0.05$ for comparison among rates within disturbances and time treatments for each site-year.

at this time to intercept glyphosate, and dandelion plants were actively growing in order to develop sufficient reserves for surviving the harsh Canadian Prairie winter. Pre-harvest applications of glyphosate are also made in fall however the herbicide must first penetrate the canola canopy, before reaching dandelion leaves. While pre-harvest applications at both Carman sites in 2000 provided significant efficacy, at all other sites pre-harvest treatments were not statically better than the other treatments. Without a canola canopy to penetrate, pre-harvest applications may have been more effective. Dandelion shoot biomass per plant increased steadily during the growing season and reached a climax near the pre-harvest timing (August 9- Figure 4.3.1). After this time, aboveground biomass diminished as dandelion plants moved resources below ground. The significant increase in the efficacy of pre-harvest applications of glyphosate may be a result of transport to the root shortly after application. Because of its dense canopy, canola is poorly suited to pre-harvest applications of glyphosate for weed control.

4.3.6. SEQUENTIAL GLYPHOSATE APPLICATIONS

Several sequential glyphosate treatments were tested to determine the efficacy of more than one application of glyphosate within a growing season (Table 4.3.6). A split treatment in-crop provided a significant reduction in dandelion biomass for all site-years (38 to 78% relative to untreated plots). Thus, two low rate (450 g a.i. ha^{-1}) applications of glyphosate can provide a significant level of control of dandelion. The first application killed all top growth (visual observations) and when the plant re-grew, the second application was effective in eliminating the weakened plants. Producers may consider two sequential applications of glyphosate a viable option to reduce dandelion populations in Roundup Ready™ canola. However, level of reduction in spring residual

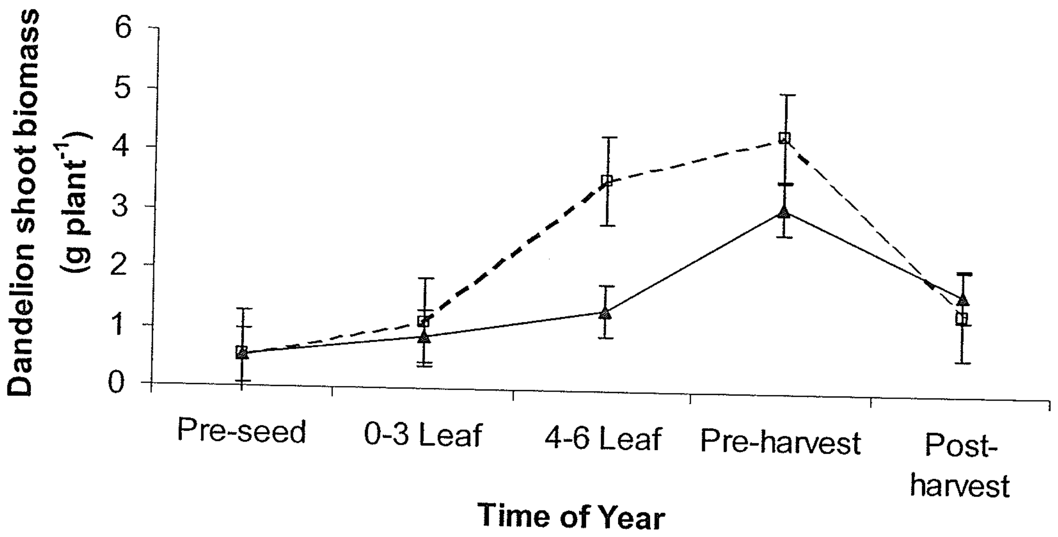


Figure 4.3.1. Average total dry shoot biomass of individual dandelion plants harvested from low and high disturbance plots of control trials throughout the growing season at Carman and Oakville in 2000. (□) Low Disturbance Seeding, (▲) High Disturbance Seeding. Bars represent +/- standard errors of means.

dandelion biomass varied considerably between site-years (Table 4.3.5). Split applications in-crop provide a significant reduction in spring residual dandelion biomass, yet do not eliminate dandelion entirely.

Overall, the best sequential treatments were 900 g a.i. ha^{-1} pre-seed or the split treatment in-crop applied in combination with 900 g a.i. ha^{-1} post-harvest. These two treatments provided the greatest reduction in dandelion biomass, providing 98% (or greater) control in both tillage systems. Both of these treatments include a post-harvest application of glyphosate, which has already been shown to be extremely efficacious. The early applications in-crop (pre-seed or split) must have weakened dandelion to such a significant extent that post-harvest applications were able to almost completely eliminate all plants that had survived the initial application. Early applications of glyphosate would have limited (or reduced) the ability of either seedling or adult dandelion plants to produce adequate root reserves for winter survival. Application of 900 g a.i. ha^{-1} of

Table 4.3.6. Dandelion shoot biomass (as a percentage of untreated) after sequential applications of glyphosate (standard errors in parenthesis). Mean dandelion shoot biomass was 129.5 g m^{-2} (+/- 22.3) and 61.0 g m^{-2} (+/- 12.7) for the untreated low and high disturbance plots, respectively. Statistical tests were performed on ($\log_{10}$+1)-transformed data.

Time of Application	1999			
	Oakville[d]		Carman[d]	
	% of untreated			
Untreated	100 (26.9)	a	100 (25.1)	a
Split[c]	22.3 (8.3)	b	34.2 (13.4)	b
PS[b], PH[c]	1.0 (0.6)	c	0.4 (0.2)	c
Split[a] PH[c]	2.4 (1.6)	c	0.1 (0.1)	c

	2000					
	Oakville[d]		CarmanN[d]		CarmanS[d]	
	% of untreated					
Untreated	100 (16.0)	a	100 (7.8)	a	100 (3.3)	a
Split[c]	43.3 (11.8)	b	54.1 (4.6)	b	61.8 (13.4)	b
PS[b] PH[c]	2.0 (1.7)	c	0.0 (0.0)	c	0.4 (0.2)	c
Split[a] PH[c]	0.0 (0.0)	d	0.0 (0.0)	c	0.6 (0.3)	c

[a] 450 g a.i. ha^{-1} applied at the 0-3 leaf stage of canola, 450 g a.i. ha^{-1} applied at the 4-6 leaf stage of canola

[b] 900 g a.i. ha^{-1} applied pre-seed

[c] 900 g a.i. ha^{-1} applied post-harvest

[d] Numbers followed by different letters are significantly different at $\propto = 0.05$ for comparisons among rates within disturbances and time treatments.

glyphosate post-harvest alone provided 96% control. The advantage of sequential applications where in-crop glyphosate is used is that the applications made early in the season would have limited the ability of dandelion to interfere with canola yield, caused dandelion plants to use up a portion of their root reserves to develop new leaf mass above ground and limited the ability of dandelion to develop sufficient root reserves for over-wintering.

4.3.7. DANDELION GROWTH

Throughout the growing season, dandelion shoots increased in size. Leaf diameter and area per plant increased dramatically from before seeding (pre-seed) to before harvest (pre-harvest) (Figure 4.3.2). After this point, leaf diameter and leaf area decreased dramatically. The same was true of reproductive biomass (Appendix 7.18), and total biomass (Figure 4.3.1). In all cases, after cultivation had occurred, dandelion leaf diameter, leaf area, and biomass in high disturbance plots slowly increased, so increases in size occurred in parallel with low disturbance plants. By the end of the season (post-harvest), average plant size (leaf area, leaf diameter, or biomass) was not visually different between low and high disturbance plots. Cultivation in spring appeared

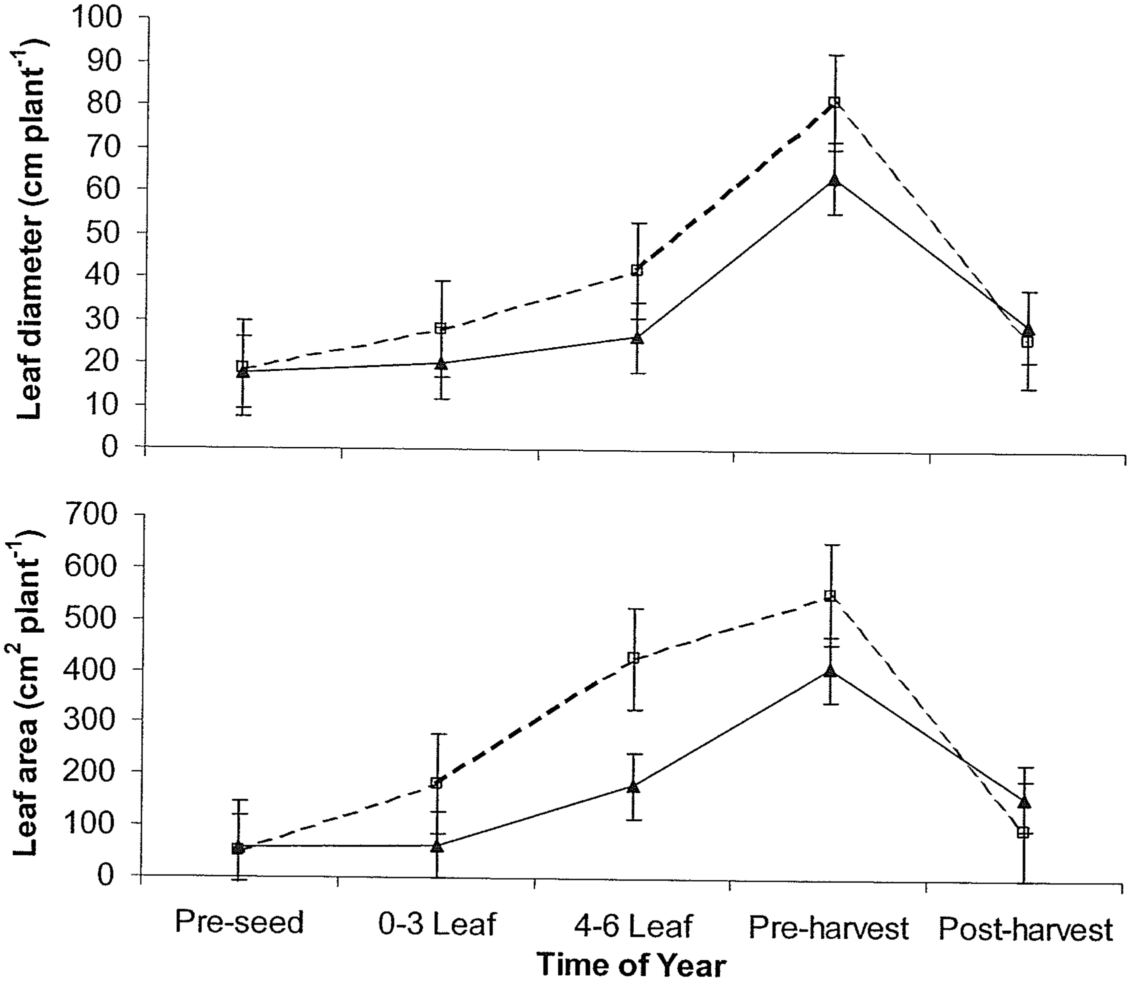


Figure 4.3.2. Average leaf diameter and area of individual plants harvested from low and high disturbance plots throughout the growing season at Carman and Oakville in 2000. (□) Low Disturbance Seeding, (▲) High Disturbance Seeding. Bars represent +/- standard errors of means.

to set plant size back several weeks. Flowering of dandelion began in early spring (pre-seed) and continued through the pre-harvest period (Appendix 7.18).

4.3.8. CANOLA YIELD FOLLOWING TREATMENTS

Dandelion effect on canola yield is very difficult to predict (Chapter 3). When yields in untreated checks of low and high disturbance plots at all sites were compared, it was shown that yield in high disturbance plots averaged 1027% of low disturbance plots (Table 4.3.7). The level of yield improvement due to control of dandelion via tillage varied (from 148% at Carman99 to 3918% at CarmanS00) considerably, with tillage significantly improving canola yield at 3 of the 5 sites. Tillage removed enough dandelion biomass to significantly limit its ability to interfere with canola yield at 3 sites.

For the timing subset, canola yield did not generally improve with applications of glyphosate under high disturbance conditions, although in some cases yield improved with pre-seed, 0-3 leaf, or split applications of glyphosate (Appendix 7.12). Generally, under low disturbance conditions, pre-seed, 0-3 leaf and split applications of glyphosate improved canola yield, although not always to a significant extent. For the pre-seed and

Table 4.3.7. Canola yield in untreated low and high disturbance plots measured in fall, the year of tillage and glyphosate treatments. Canola yield is measured in kg ha^{-1} (standard errors in parenthesis.). Percent values represent canola yield in high disturbance plots as a percentage of canola yield in low disturbance plots.

Site	Dandelion Shoot Biomass		LSD	Percent of LDS
	LDS	HDS		
	---- kg ha^{-1} ----	---- kg ha^{-1} ----		
Carman99	1582.8 (293.8)	2340.9 (11.3)	1238.1	147.9 (0.9)
Oakville99	487.3 (132.1)	1767.9 (336.1)	1241.7*	362.8 (69.0)
CarmanN00[a]	148.6 (96.0)	670.8 (235.7)	672.0	451.2 (158.6)
CarmanS00[b]	31.8 (5.1)	1244.7 (73.4)	334.4*	3917.8 (231.3)
Oakville00	363.9 (122.5)	936.9 (177.0)	237.5*	257.5 (48.7)
Overall	522.9 (159.8)	1392.2 (177.3)	199.1*	1027.5 (390.3)

[a] CarmanN00 represents the north trial at Carman in 2000

[b] CarmanS00 represents the south trial at Carman in 2000

* Represents significance at the α=0.05 level

0-3 leaf subsets, canola yield was not influenced consistently by increased glyphosate rates (Appendices 7.13, 7.14). Not surprisingly, glyphosate application at the pre- and post-harvest timings had no influence on canola yield, as dandelion interference would have occurred long before these applications were made (Appendices 7.15, 7.16).

Comparisons of yield between sequential glyphosate treatments illustrated the importance of distinguishing between the influence of glyphosate and tillage on dandelion efficacy and canola yield. The split treatment alone (450 g a.i. ha^{-1} at the 0-3 leaf stage of canola, 450 g a.i. ha^{-1} at the 4-6 leaf stage of canola) significantly improved canola yield, however a third application of glyphosate (Treatment 14: Split, 900 g a.i. ha^{-1} applied post-harvest) did not improve canola yield to a greater extent. Treatments which eliminate dandelion populations early in the growing season have economic benefit in the first year, while treatments made late in the growing season (i.e. post-harvest applications of glyphosate) provide exceptional longer-term control of dandelion. A balance must be met of short- and long-term costs and benefits of treatments used to suppress or control dandelion.

4.3.9. SUMMARY

Spring cultivation reduces dandelion biomass by more than 52%. It also serves to delay the growth of dandelion plants although by late fall plants in tilled locations are indistinguishable from those in un-tilled locations (pers. obs.). Because of the tendency of tillage to exacerbate erosion and soil moisture problems, tillage alone should not be used to manage dandelion populations.

Generally, glyphosate rate does not significantly improve efficacy of dandelion as long as a minimum rate of 900 g a.i. ha^{-1} is used. With pre- and post-harvest applications, increasing glyphosate rate did improve dandelion control, although higher rates were not justifiable economically. When dandelion plants are large and allowed to grow un-impeded, higher rates of glyphosate may be necessary for glyphosate to be effective. For in-crop treatments (0-3 leaf and pre-harvest), increasing glyphosate rate improved control, but not significantly.

Pre-seed and in-crop applications of glyphosate did not provide an acceptable level of dandelion control (75% or greater). Post-harvest treatments provided excellent control of dandelion at all rates. It appears that, generally, glyphosate efficacy on dandelion is greatest when it is applied in fall. Dandelion populations could be almost entirely eliminated when sequential applications of glyphosate were used, as long as the final treatment was made post-harvest. The most efficient individual applications of glyphosate were made post-harvest, at a rate of 900 g a.i. ha^{-1}.

Producers considering the use of spring tillage and glyphosate to manage dandelion populations need to keep several things in mind. Spring tillage will effectively slow down dandelion growth and can control weaker plants. Results of the present study did not show that dandelion control increases proportionally with tillage intensity. Statistically, the reverse was true. Tremendous variability in residual dandelion populations within treatments limited our ability to identify significant differences between treatments. On a percentage basis, dandelion control did increase with increasing tillage intensity. Weakened dandelion plants are easy prey for glyphosate, especially in fall because of reduced root reserves. Spring application of glyphosate or tillage, combined with post-harvest application of glyphosate can eliminate dandelion populations to very low levels. With dandelion, as with most perennial weeds, timing is everything.

Sources of Materials

[1] Edwards Manufacturing Inc., USA.

[2] John Deere Inc., One John Deere Place, Moline, Illinois 61265-8098.

[3] Limagrain Canada Seeds Inc., 4-411 Downey Road, Saskatoon SK, Canada S7N 4L8.

[4] Zeneca Agro, Suite 250, 3115 –12 Street NE, Calgary, Alberta, T2E 7J2, Canada.

[5] Dow AgroSciences, 9330 Zionsville Road, Indianapolis, IN, 46268-1054.

[6] BASF Canada Inc. 345 Carlingview Drive, Toronto, Ontario, M9W 6N9, Canada.

[7] Dupont Canada Inc. Box 2200, Streetsville, Mississauga, Ontario, L5M 2H3, Canada.

[8] Monsanto Inc., 800 North Lindbergh, St. Louis, Missouri 63167.

[9] Wintersteiger Inc. 217 Wright Brothers Drive, Salt Lake City, Utah, 84116, U.S.A.

[10] Li-Cor Inc. 4421 Superior St., Lincoln, Nebraska, 68504, U.S.A.

[11] SAS Institute Inc., SAS Campus Drive, Cary, North Carolina, 27513-2414, U.S.A.

5. GENERAL DISCUSSION

The distribution of dandelion in fields varies considerably from location to location. In zero-tillage fields, dandelion was distributed in both a patchy and a non-patchy nature. In each field, dandelion was initially present in patches and it is hypothesized that patches spread throughout the field if seedlings are allowed to establish. In our study, dandelion distribution in the Carman field was patchy, likely as a result of it being rotary-harrowed each fall. This harrowing might have been sufficient to limit dandelion population spread by killing all seedling plants. The shallow root and small size of seedling dandelion might allow for easy removal via tillage. At Brandon where the dandelion distribution was not patchy, the fields received no cultivation other than minimal disturbance during seeding in spring. We speculate that this allowed dandelion to spread throughout this field.

Several other management practices could have influenced the distribution of dandelion in zero-tillage fields. Brandon had a greater frequency of broadleaf crops in rotation. Broadleaf crops have fewer herbicide options for dandelion control, providing dandelion populations a greater opportunity to increase. Another consideration could be the application of glyphosate each spring. At Brandon, glyphosate was applied at 450 g a.i. ha^{-1} each spring whereas at Carman glyphosate was applied at 900 g a.i. ha^{-1}. In our control studies we found that increasing glyphosate rate sometimes improved efficacy, although not usually to a significant degree. Thus, it is possible that reducing the rate to 450 g a.i. ha^{-1} would result in poorer control of dandelion, allowing more dandelion plants (especially seedlings) to survive and this would facilitate dandelion spread throughout this field.

In conventional-tillage fields, dandelion was also distributed in both a patchy and a non-patchy nature. This was surprising, as it was assumed that tillage would reduce dandelion infestations and not allow dandelion populations to spread throughout entire fields. This theory remains valid when you consider the cropping history of these fields. Dandelion populations developed in conventional-tillage fields when weak crop stands were present, and in years when no tillage operations were performed. Of our four conventional-tillage fields, three had alfalfa in rotation within the last four years. The Dakota site had no alfalfa in rotation, however in 1994 it was seeded to lentils. 1994 was a very wet year and most of the lentil field was flooded, providing large open areas where dandelion could proliferate.

Three of the conventional-tillage fields had a patchy distribution while in the remaining field dandelion was distributed in a non-patchy manner (New Bothwell). The New Bothwell site was in its first year of grain cropping after an alfalfa crop that had been in rotation for more than four years. A very large population of dandelion had developed in the alfalfa crop. It is expected that repeated cultivation operations in this field will reduce dandelion populations over time, as it had in the other three conventional-tillage fields. In addition, glyphosate had not been applied to this field after the termination of the alfalfa stand. Instead, the field was ploughed and then double-disked. Glyphosate applied in mid-September would likely have helped to reduce the dandelion population in this field.

It was surprising that there were no significant relationships between percent of weed-free canola yield and any measure of dandelion infestation for any of the conventional-tillage sites. Weather may have played an important role. Precipitation at the conventional-tillage sites likely did not move down through the soil profile as quickly as it would have in zero-tillage fields (Domitruk and Crabtree, 1997). Fields managed using zero-tillage production practices for a considerable length of time (several years), have a larger earthworm population, increasing porosity of the soil. Also, roots from dead plants are allowed to decay, leaving channels throughout the soil profile. Thus, in zero-tillage fields any excess water moves downward quickly, limiting negative effects of excess water on dandelion and canola growth and development. It is possible, therefore, that a general lack of correlation exists between dandelion infestation and reduction in canola yield, in conventional-tillage fields generally, and that excess moisture made these relationships even less predictable. Excess moisture might have, for example, pooled in low areas of the conventional-tillage fields, affecting seedling dandelion plants to a greater extent than adult dandelion plants.

In conventional-tillage fields, dandelion begins to grow as soon as the soil temperature increases, however the seeding operation tends to cut off a high percentage of these plants. As such, when the canola seed is germinating, dandelion is present as seed, rootstock and developed plants. It is likely that the tillage operation would remove seedlings that germinated prior to crop seeding, leaving mostly adult dandelion plants. Dandelion plants developing from both seed and rootstocks would then be emerging at roughly the same time as canola. This creates a much more demographically diverse scenario than one would expect in zero-tillage fields where dandelion plants germinating in spring would not be significantly influenced by the seeding operation. If a producer were to apply a non-selective herbicide in spring, this might have a similar effect on dandelion populations, as would a spring tillage operation. By eliminating the spring herbicide application in the present trial, results might illustrate a stronger relationship between reduction in canola yield and measures of dandelion infestation than what exists in an average zero-tillage field. Obviously, measures of dandelion size are not sufficient for prediction of crop yield loss in conventional-tillage fields. It is possible that older dandelion plants dominate zero-tillage fields and in conventional-tillage fields there exists a mix of old and young dandelion plants. I had hoped that dandelion root diameter might be significantly correlated with reduction in canola yield, as it is a measure that should incorporate both plant size and age. It is possible that measurement of root diameter in-crop would provide greater correlation with percent of weed-free canola yield, as canola is susceptible to weed interference in the first 4 weeks of growth (Martin et al., 2001; Miller and Callihan, 1995). Unfortunately this measurement was not possible, as it would have involved destroying plants before trials were completed.

The population dynamics of dandelion may influence our ability to predict yield loss due to dandelion interference. It is understood that dandelion populations exist as a mixture of genotypes, with one dominant genotype occupying a particular niche (Sterk et al., 1983; Solbrig and Simpson, 1974). There could be significant differences between dominant genotypes in conventional- and zero-tillage fields and these genotypes could have very different competitive abilities. To test this theory, it would be useful to conduct identical experiments to determine if similar results would be found in subsequent years and an additional experiment could be added to test for differences in dominant dandelion genotypes throughout fields (this would require genetic analysis of plants). The genetic analysis could be used to test for dominance of genotypes throughout zero- and conventional-tillage fields. Greenhouse trials could then be initiated to compare the competitive ability of dandelion genotypes.

In zero-tillage fields, significant correlation between percent of weed-free canola yield and measures of dandelion infestation were observed, however, more significant correlations were observed at the Carman site versus the Brandon site. This difference between the two zero-tillage sites was likely a result of differences in dandelion demography between the two sites. Dandelion had a patchy distribution at Carman and a non-patchy distribution at Brandon. I have already pointed out that dandelion demography would likely be narrower at Carman as seedlings would have been removed by harrowing each fall and/or by higher rates of glyphosate application in spring versus the Brandon site. This relatively narrow demography might be the reason for the greater number of significant relationships and stronger relationships between reduction in canola yield and all measures of dandelion infestation at Carman versus Brandon. It is possible that when dandelion seedlings are eliminated each year, measures of dandelion infestation can be strongly correlated with percent of weed-free canola yield as adult plants interfere with canola yield in a similar fashion according to physical plant size. Limiting dandelion populations to mature plants (>1 year old) might allow for more reliable measures of infestation. I had expected that total dandelion root diameter m^{-2}, which represents both dandelion size and age would be a good measure of competitive infestation level. It should have accounted for differences in age of dandelion plants, yet it showed much stronger correlation at the Carman site than at the Brandon site. Again, it is possible that the measurement of total dandelion root diameter m^{-2} would have shown stronger correlation with reduction in canola yield at Brandon if it could have been measured in-crop. Further experiments should be done to determine if measures of root diameter accurately represent dandelion plant age by counting the number of rings in dandelion roots to determine age of all dandelion plants in a stand.

At both zero-tillage sites, the best measures of dandelion infestation for predicting interference effect were dandelion percent ground cover (ranked first at Brandon and second at Carman) and relative dandelion ground cover (ranked first at Carman and second at Brandon). Both measures assess the amount of ground or relative amount of ground that is covered by dandelion leaf material. The competitive ability of dandelion must, therefore, be strongly related to its ability to compete for light early in the season. Several other infestation level measures are related to competition for light such as leaf diameter (ranked fourth at Brandon and fifth at Carman), biomass (ranked sixth at Carman), and leaf area (ranked ninth at Carman). Time of measurement was also important. There was a stronger relationship between measurements of dandelion infestation and percent of weed-free canola yield when those measures were made in-crop (ranked 1, 2, and 4 at Brandon; 1, 2, 5, 7, and 8 at Carman) rather than at harvest. This is perhaps because canola is more susceptible to competition at earlier development stages relative to late in the season. Also, in-crop measures of dandelion represent plants that are actively competing and do not consider late-emerging seedlings or post-harvest dandelion growth which do not contribute to interference effects. I would have expected that leaf area and biomass would have been effective predictors of competitive ability, however they could only be measured at harvest.

Other measurements of dandelion infestation that related significantly to percent of weed-free canola yield were dandelion root diameter (ranked third at Brandon and

Carman), density measured at harvest (ranked fourth at Carman), relative density measured in-crop (ranked seventh at Carman), and density measured in-crop (ranked eighth at Carman). It was surprising that dandelion root diameter did not rank higher as a measure of competitive effect of dandelion. This shows weakness in the ability of this measure to represent plant age. Because of the large variation in dandelion plant sizes and ages in a field, it was surprising that dandelion density provided a predictable measure of dandelion infestation. It was especially surprising that density measured at harvest ranked higher than density measured in-crop. Densities increased dramatically from the in-crop timing to the measurement at harvest. The majority of dandelion seedlings must therefore germinate after the 2-4 leaf stage of canola. Because it includes these later emerging seedlings, density measured at harvest is a better predictor of competitiveness of a dandelion infestation than density measured in-crop. This also provides evidence that a significant amount of dandelion interference with canola yield must occur after the 2-4 leaf stage of canola, with seedling dandelion contributing significantly to the interference effect.

When dandelion interference studies were integrated with examination of dandelion's distribution in fields, it was very difficult to predict the ability of dandelion to reduce canola yield on a whole-field basis. In conventional-tillage fields it seemed almost impossible, given the afore-mentioned results. In zero-tillage fields some estimates can be made. Dandelion distribution in zero-tillage fields was patchy at one site and non-patchy at the other. Distribution should be assessed before any management techniques are devised, as control techniques should consider the homogeneity of a dandelion infestation. If dandelion is present in discrete patches, control strategies need not be applied to the entire field. In the 2 zero-tillage fields we found that in surveyed quadrats dandelion densities before seeding ranged from zero to thirty dandelion plants m^{-2}. The relationship between percent of weed-free canola yield and dandelion density measured in-crop was only significant for the Carman site (Appendix 7.3). This relationship showed that densities of 5 dandelion plants m^{-2} reduced canola yield by 60%, densities of 10 dandelion plants m^{-2} reduced canola yield by more than 90%, and dandelion densities of 15 plants m^{-2} reduced canola yield by 100%. Although dandelion distribution was patchy at Carman, dandelion was present in 18% of the field, and may reduce yield to negligible levels in these regions if present at high enough densities. If 18% of a canola field had dandelion at a density of 5 plants m^{-2}, yield reduction for the entire field would be almost 11% (100% weed-free yield *18% of the field * 60% reduction in yield). If a weed-free crop would have yielded 40 bushels $acre^{-1}$, the loss would have been 4.4 bushels $acre^{-1}$, which represents roughly \$20 $acre^{-1}$ at today's prices (\$5 $bushel^{-1}$). With losses this severe, control measures applied over the entire field would be economically justifiable. Herbicide applications on the patches alone could increase profitability as long as the cost of mapping patches was low .

In our control trials, large variation in dandelion spring residual biomass and canola yield amongst replications sometimes resulted in large differences between treatments being not significantly different. One could argue, however, that the differences were significant from a biological perspective. The likelihood of making a type I errors however, is still very low regardless of our statistical test because the chance of finding significant differences between treatments when there were not any was unlikely. Type II errors are a far greater concern, as they represent a non-recognition of a significant difference between treatments when one does in fact exist. The least significant difference (LSD) test was chosen as it was more discriminating. The increased discrimination allowed an increased awareness of differences between treatments. Glyphosate is relatively inexpensive, justifying the risk (for some producers) of applying glyphosate at higher rates if there is evidence that dandelion control will likely be improved.

Spring tillage is an effective method for dramatically reducing dandelion populations. In the 1999 trials, dandelion biomass was reduced by more than 80% with spring tillage alone (although differences at neither site were found to be statistically significant). The high intensity of these tillage operations (rotovator at Carman, multiple cultivations at Oakville) were expected to provide significant control. Cultivation in 1999 was also to a slightly greater depth than in 2000 (10-15 vs. 5-10 cm). Tillage in spring was quite effective because at this time dandelion roots have moved a large portion of their reserves aboveground, leaving the root in a weakened state. Tillage early in the fall would likely have provided even greater control, however, as plants are beginning to mobilize reserves to roots at this time. It was expected that dandelion control due to tillage would not be as great in the 2000 trials as only one pass was made with the cultivator in high disturbance plots. This hypothesis was correct as the 3 trials in 2000 exhibited only a 40% reduction in dandelion biomass. Statistically however, our results proved opposite. For both trials in 1999, spring cultivation did not significantly reduce residual dandelion populations. For the 2000 trials, 2 sites exhibited a significant reduction in biomass by spring tillage whereas the other showed no significant difference. Large variability between replications, combined with only 2 degrees of freedom (3 replications per site) at all sites did not allow for differences between tillage systems to be shown statistically. In most conventional-tillage systems, farmers use seeding systems that are designed to cut off all aboveground plant matter. Although not verified statistically, our results provide some evidence that the more intense the tillage in the seeding system, the greater the dandelion control will be. No interaction was noted between spring tillage and glyphosate treatments (except for the timing subset). Thus, glyphosate control programs will likely have similar effectiveness in zero-, minimum-, and conventional-tillage systems.

For the most part, increased glyphosate rate had no influence on residual dandelion populations. The only exceptions were at the pre- and post-harvest timings. For pre-seed applications, increasing glyphosate rate from 900 to 1800 g a.i. ha^{-1} resulted in a significant improvement in dandelion control. The dense crop canopy found in these treatments likely intercepted a large portion of the glyphosate treatment. Thus, for the high rate (1800 g a.i. ha^{-1}) glyphosate concentration in droplets would have been twice as high and would have greatly enhanced the amount of glyphosate reaching the leaves. Clearly, at the low rate (900 g a.i. ha^{-1}) the majority of dandelion plants required a greater amount of glyphosate for effective control. The 75% reduction in dandelion biomass with the high rate of glyphosate at the pre-harvest timing was greater than any pre-seed or 0-3 leaf treatments. Increasing rate to 2700 g a.i. ha^{-1} might have improved control to levels similar to post-harvest treatments. At the post-harvest timing, increasing glyphosate rate to 2700 g a.i. ha^{-1} reduced biomass to a greater extent than rates of 900 or 1800 g a.i. ha^{-1}. Clearly, fall treatments resulted in the greatest efficacy, and provided the greatest opportunity for high levels of dandelion control (especially with increased rates).

At the 0-3 leaf stage of canola, glyphosate rates of 450 and 900 g a.i. ha^{-1} provided significant control of dandelion. The same was found for rates of 900, 1350, and 1800 g a.i. ha^{-1} of glyphosate at the pre-seed timing. Pre-seed applications all provided roughly 60% reduction in dandelion biomass whereas 0-3 leaf treatments reduced biomass by only 30-40%.

Post-harvest applications of glyphosate (900 to 2700 g a.i. ha^{-1}) provided significant control with control improved significantly by increasing glyphosate rate to 2700 g a.i. ha^{-1}. The fact that control was excellent (94 to 98%) for all post-harvest rates provides good evidence that post-harvest applications of glyphosate provided the greatest efficacy.

If a simple herbicide system is desired to control dandelion, a post-harvest application of glyphosate at a rate of 900 g a.i. ha^{-1} in either zero- or conventional-tillage systems is recommended based on results of the present study. It is possible that 900 g a.i. ha^{-1} is a more than adequate rate and a lesser rate could be used post-harvest but this was not tested. Further research could be done to test the influence of even lower rates of glyphosate on dandelion, at the post-harvest timing. The value of even lower rates is limited however, because glyphosate is relatively inexpensive, and the cost savings from reduced rates might not balance the increased risk of weed escapes. Increasing glyphosate rate to 2700 g a.i. ha^{-1} did improve control, although only to a limited extent (98% vs. 96% for the 900 g a.i. ha^{-1} rate). Producers may also want to intensify their tillage operations to improve effectiveness in cutting off all aboveground dandelion biomass, possibly at greater depths in the soil profile. Fall tillage is likely to control dandelion significantly as well. The beneficial aspects of tillage must be balanced however by the detrimental results such as loss of soil moisture and susceptibility to erosion.

When residual dandelion populations were compared among treatments receiving 900 g a.i. ha^{-1} of glyphosate at different times during the growing season it became clear that post-harvest applications provided the greatest control. Rankings of treatments varied between sites and disturbance treatments, however the only treatment that consistently performed as well or better than the others was a post-harvest application of 900 g a.i. ha^{-1}. Pre-harvest applications often ranked highly, however at Carman in 1999, pre-harvest applications did not provide significant control relative to the check. Pre-seed applications of glyphosate ranked among the best treatments in 1999, however for all 3 trials in 2000 this was not the case. Growing conditions must have favored glyphosate uptake in spring more in 1999 than in 2000. For both 1999 sites, weather conditions at time of pre-seed treatment applications were optimum for glyphosate uptake by plants (15°C, cloudy). For the three 2000 sites, temperatures were much cooler (10°C), which likely limited glyphosate uptake by dandelion plants. Glyphosate applications provided the greatest efficacy when they did not have to penetrate a canola canopy. From a biological standpoint, applications of glyphosate provide the most value when they are made in the fall; the time when glyphosate is most likely to move down to the roots of dandelion and limit dandelion's ability to regenerate after winter. Temperature was 20°C at both sites in 1999 when post-harvest applications were made, yet only 10°C when post-harvest applications were made at all sites in 2000. Low temperatures did not reduce post-harvest glyphosate efficacy, unlike pre-seed applications. This is likely a result of dandelion plants mobilizing reserves to roots after post-harvest treatments were made.

If multiple applications of glyphosate fit nicely into a producer's production system, residual dandelion populations can be reduced to near-negligible levels. Two 450 g a.i. ha^{-1} applications of glyphosate in-crop can provide significant control of dandelion in low and high disturbance systems, however the greatest control was found when 900 g a.i. ha^{-1} application was made post-harvest, following an application(s) earlier in the year. Weakening the dandelion plants earlier in the growing season with glyphosate appears to make them more susceptible to post-harvest applications of 900 g a.i. ha^{-1} and kills newly emerged seedlings. If producers can justify several passes across a field, sequential applications of glyphosate might be the preferred method for reducing dandelion populations to negligible levels, while also limiting the ability of dandelion to interfere with canola productivity.

Spring tillage and glyphosate application can greatly minimize the ability of dandelion populations to interfere with canola yield. The yield data collected from control trials exhibited tremendous variability, much like the data collected from interference studies conducted on conventional-tillage sites. Spring tillage usually minimizes the ability of dandelion to interfere with canola yield, however in some cases glyphosate application did improve canola yields. Glyphosate applied pre-seed, at the 0-3 leaf stage of canola, and split into two in-crop applications consistently reduced the ability of dandelion to interfere with canola yield. At all timings, a rate of 450 g a.i. ha^{-1} of glyphosate was sufficient to eliminate the competitive effect of dandelion. This is in agreement with my observation that all glyphosate applications, regardless of rate, eliminated dandelion top growth completely, if only temporarily.

The information from distribution and interference studies can be combined with control studies to demonstrate the importance of proper dandelion management techniques. Earlier I mentioned that the patchy distribution of dandelion at the Carman site might have led to a reduction in profits of roughly \$20 acre^{-1}. Given that the Carman field was managed using zero tillage production practices, I assume tillage is not an option (the producer has chosen zero-tillage practices for a reason). The cost of making a pass with a field sprayer is roughly \$5 acre^{-1}. If Roundup Transorb™ were used, glyphosate costs would be roughly \$5 for every ½ L of product acre^{-1} (450 g a.i. ha^{-1}). If only the current crop year were considered, a pre-seed application of 900 g a.i. ha^{-1} would cost roughly \$15 acre and should reduce dandelion residual biomass by roughly 60%. While only 60% of the residual dandelion population would be removed, for the current cropping year all dandelions would be eliminated during the time when interference occurs. This would increase profits by \$5 acre^{-1}. Increasing glyphosate rate to 1800 g a.i. ha^{-1} would not be justifiable, as it would only improve control by 2%. Another option would be to follow-up the 900 g a.i. ha^{-1} pre-seed application with another 900 g a.i. ha^{-1} post-harvest. This would cost \$30 acre^{-1} (in total, including application costs), but would improve control to a point where residual biomass was reduced by more than 99%. Producers need to establish their own balance between cost and long-term control goals. A patchy distribution of dandelion would make patch-spraying a far more attractive option. This could lower costs considerably and still provide effective dandelion control. Time spent on mapping dandelion populations in order to avoid whole-field chemical applications could provide economic benefits. Patch spray applications would best be made pre-seed or post-harvest because it is during these times when dandelion could be identified by the sprayer operator or mapped out before spraying. Patches would remain stable if seedling dandelion were not allowed to colonize fields. This could be accomplished with regular tillage operations, broadleaf-weed herbicide applications in-crop, or pre-seed applications of non-selective herbicides. The best option however would be to attempt dandelion control measures in fall as soon as dandelion patches are noticed.

5.1. GENERAL CONCLUSIONS

I speculate that dandelion distribution in fields is a result of field management techniques. Our surveys showed that distribution in zero- and conventional-tillage fields could be either patchy or non-patchy. It appears that assessing the competitive ability of non-patchy populations of dandelion is very difficult. Further studies considering dandelion demography in patches within fields would be useful in order to verify that non-patchy distributions are more likely to have narrow demography. Within conventional-tillage fields it is very difficult to predict the ability of dandelion populations to interfere with canola yield. This could be related to either weather conditions, demography of dandelion populations in conventional-tillage fields, population dynamics of dandelion populations in conventional-tillage fields, or combinations of these factors. In zero-tillage fields, the best measures of competitiveness of dandelion infestation were percent ground cover in-crop, relative ground cover in-crop, total root diameter at harvest, leaf diameter in-crop, and density measured at harvest. Plotting these measures of infestation against reduction in canola yield illustrates the ability of dandelion to reduce canola yield to a significant extent when it is present at high levels of infestation. On a whole-field basis, it was found that even in fields with a patchy distribution of dandelion, canola yields could be reduced to an extent that would justify chemical control of dandelion with glyphosate over the entire field.

Control studies provided evidence that both tillage and glyphosate can be efficiently used to manage dandelion populations. Tillage in spring alone resulted in a 52% reduction in residual dandelion biomass. Dandelion control was influenced by increased glyphosate rates only at the pre- and post-harvest timings. To receive the greatest value, applications of glyphosate should be made in fall, with the most efficient applications being made post-harvest. Sequential applications of glyphosate can provide near-complete control of dandelion if a post-harvest application is included as one of the treatments.

In summary, this study raises one very important question, concerning the true nature of dandelion demography in fields. More research must be performed to determine the demography of dandelion populations in annual cropping systems. Dandelion has the potential to develop into an important pest of annual field crops. To-date, Manitoba has experienced a relatively minor outbreak of dandelion in fields seeded to annual crops. Alberta and Saskatchewan have not been as fortunate. An increased adoption of zero-tillage practices in these provinces is likely a contributing factor. Producers should be concerned about dandelion's increased presence in annual cropping systems. We were unable to find definitive answers regarding the ability of dandelion to interfere with canola yield in conventional-tillage fields, however our results did provide evidence that dandelion certainly can reduce canola productivity. Conventional-tillage producers should work to limit the encroachment of dandelion into their fields, so that large-scale infestations are avoided. Zero-tillage producers must develop dandelion management programs that include appropriate crop rotations, glyphosate applications, and tillage operations (if necessary) in order to limit dandelion spread through fields. Improving our understanding of dandelion's role as a crop pest in Manitoba will give producers the tools needed to minimize the influence of dandelion on crop productivity, and maximize the value of dandelion control measures.

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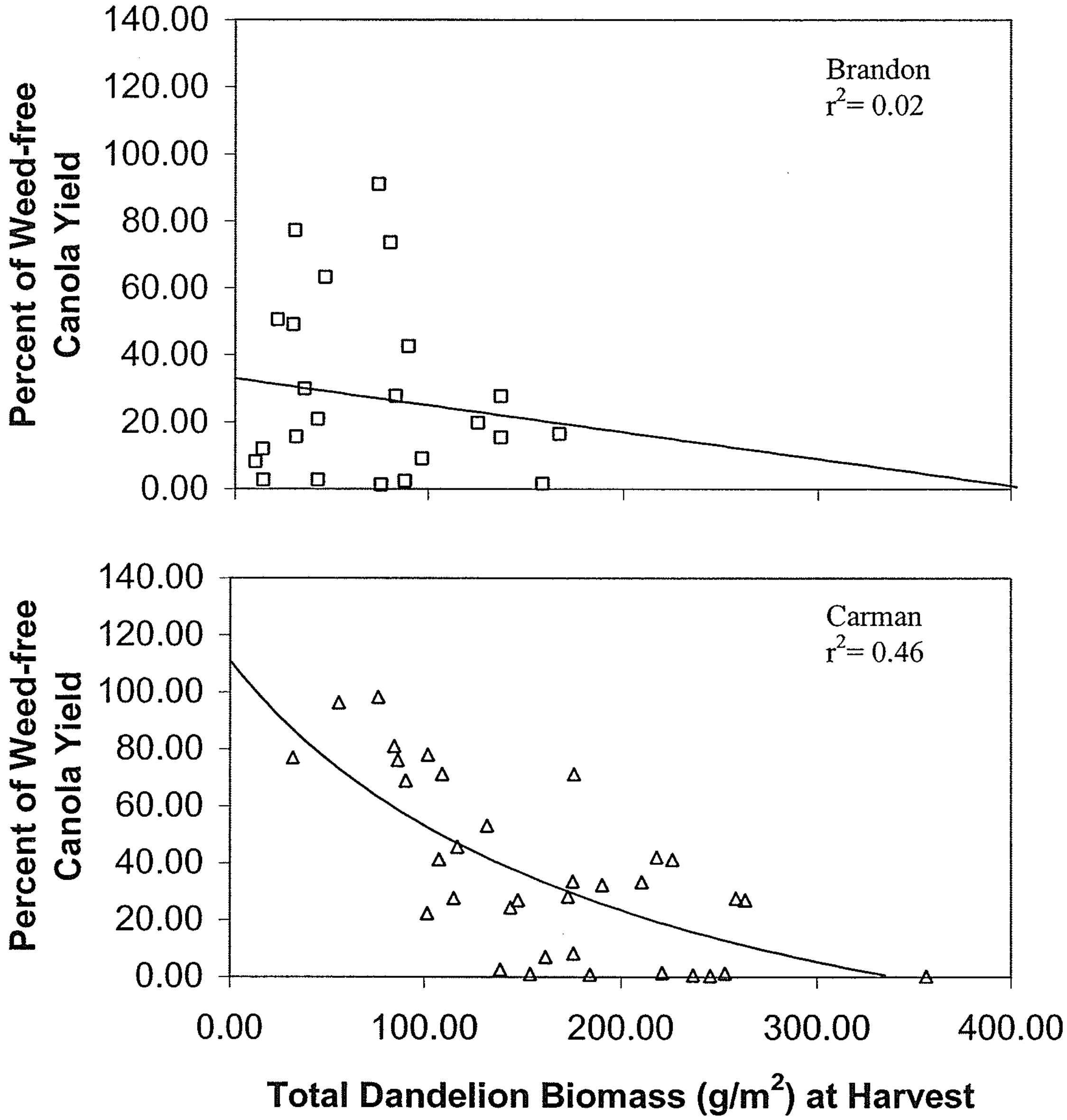
7. APPENDICES

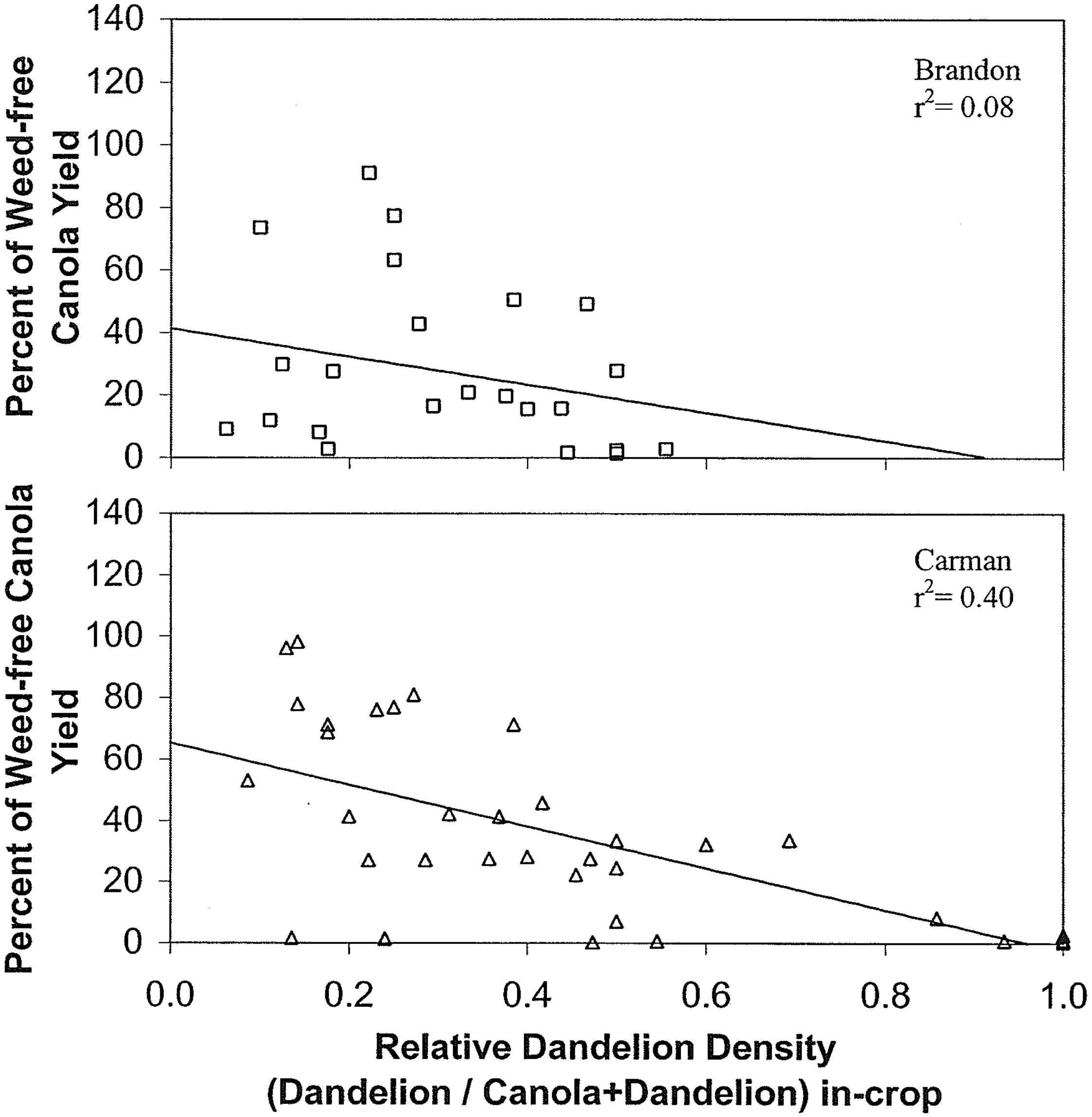
Appendix Page

Appendix 7.1. Reduction in canola yield as related to total dandelion biomass at harvest. Markers represent data points, lines represent models fitted to data. Models and model parameter estimates and standard errors of estimates are presented at bottom.



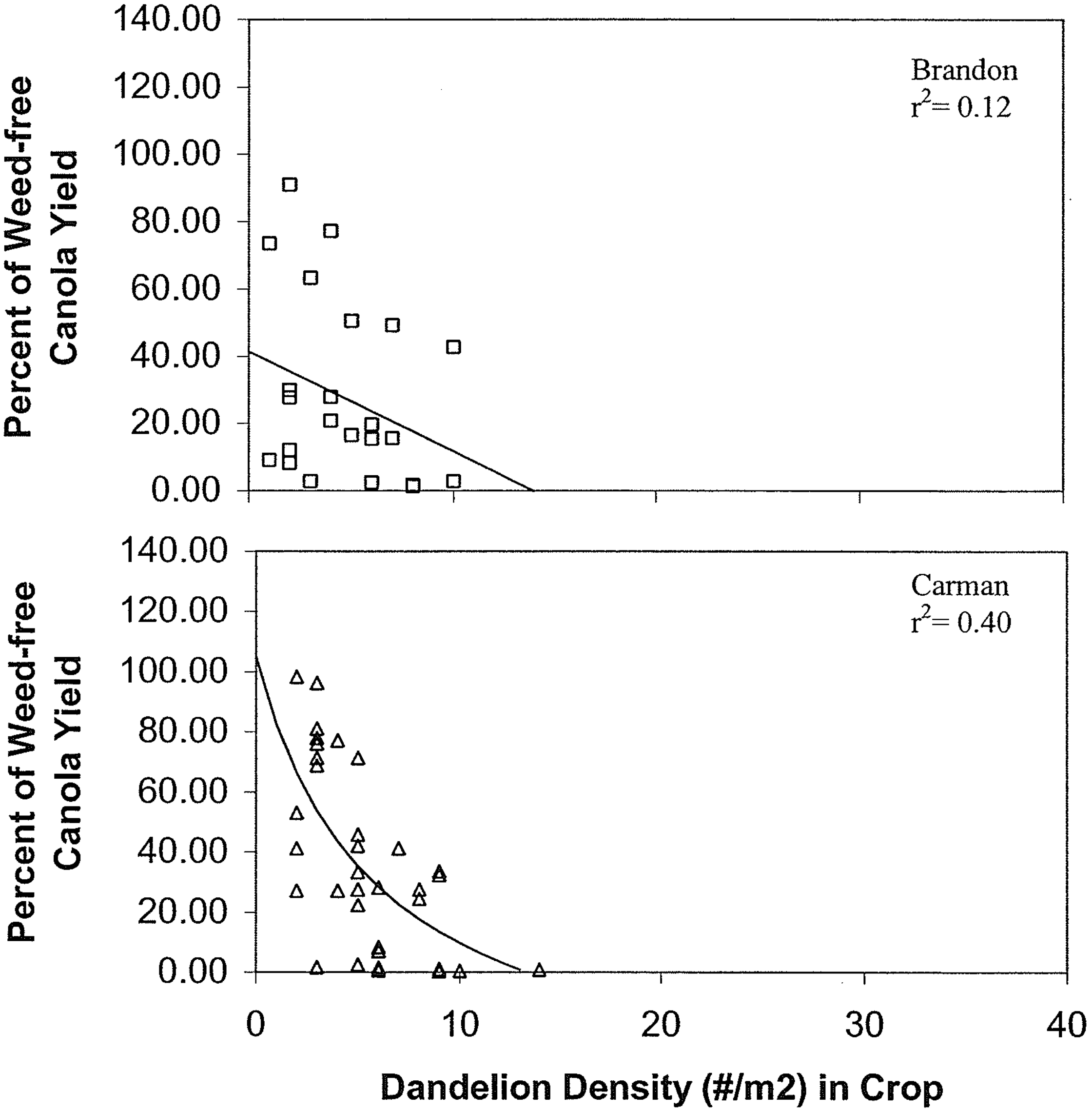
Site	Model	Model Parameters			
		A	B	C	r^2
Brandon	Not Significant	-	-	-	-
Carman	Rectangular Hyperbola (1)	111.0	0.8	162.5	0.46

Appendix 7.2. Reduction in canola yield as related to relative dandelion density in-crop. Markers represent data points, lines represent models fitted to data. Models and model parameter estimates and standard errors of estimates are presented at bottom.



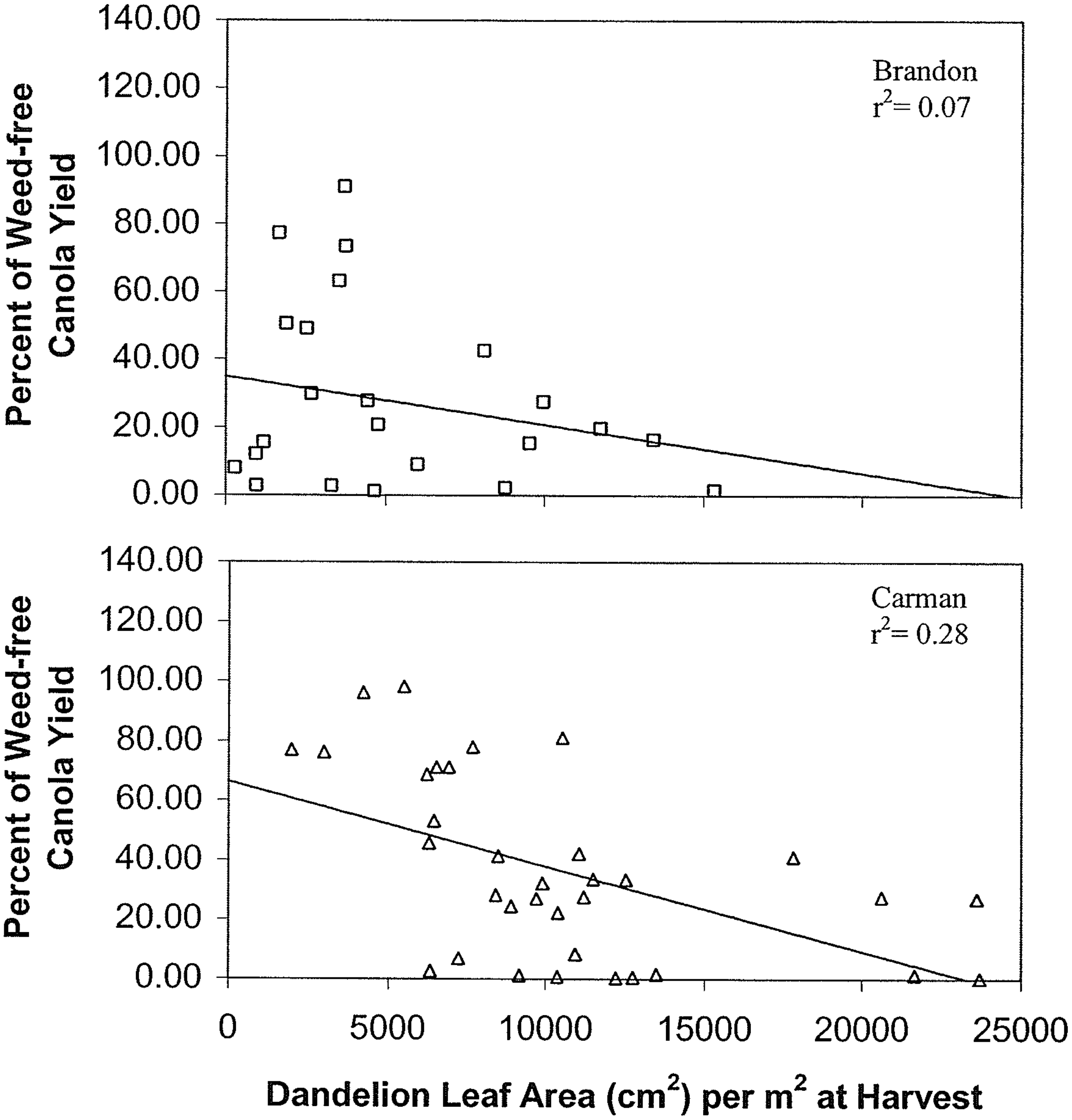
Site	Model	Model Parameters			
		A	B	C	r^2
Brandon	Not Significant	-	-	-	-
Carman	Linear (2)	65.4	-68.2	-	0.40

Appendix 7.3. Reduction in canola yield as related to dandelion density in-crop. Markers represent data points, lines represent models fitted to data. Models and model parameter estimates and standard errors of estimates are presented at bottom.



Site	Model	Model Parameters			
		A	B	C	r^2
Brandon	Not Significant	-	-	-	-
Carman	Rectangular Hyperbola (1)	104.9	24.7	143.7	0.40

Appendix 7.4. Reduction in canola yield as related to dandelion leaf area at harvest. Markers represent data points, lines represent models fitted to data. Models and model parameter estimates and standard errors of estimates are presented at bottom.



Site	Model	Model Parameters			
		A	B	C	r^2
Brandon	Not Significant	-	-	-	-
Carman	Linear (2)	66.3	-0.003	-	0.28

Appendix 7.5. Weather information for canola interference sites in 2000

Brandon

Month	Maximum	Minimum	Mean	G.D.D.	Precipitation
	Mean Temperature				
	---°C---	---°C---		--Base 5--	-----mm-----
April	11.2	-3.1	4.1	55.6	7.2
May	18.0	3.5	10.8	184.9	51.8
June	19.2	7.0	13.1	244.7	66.0
July	25.1	11.9	18.5	419.3	133.0
August	24.5	10.5	17.5	388.2	46.0
September	17.9	5.1	11.5	198.4	65.8

Carman

Month	Maximum	Minimum	Mean	G.D.D.	Precipitation
	---°C---	---°C---		--Base 5--	-----mm-----
April	12.4	-2.9	4.8	71.4	6.0
May	19.1	5.1	12.1	222.3	62.4
June	20.5	9.5	15.0	301.6	130.0
July	25.3	12.6	19	432.6	46.8
August	25.5	11.8	18.7	424.0	86.0
September	18.3	5.3	11.8	206.8	40.0

Dakota / Elie

Month	Maximum	Minimum	Mean	G.D.D.	Precipitation
	---°C---	---°C---		--Base 5--	-----mm-----
April	11.8	-3.9	4.0	65.4	4.4
May	18.7	3.1	10.9	185.5	53.1
June	20.0	8.9	14.5	285.4	177.4
July	25.7	12.9	19.3	444.9	122.6
August	25.6	12.0	18.8	429.1	67.3
September	18.2	5.0	11.6	207.1	63.6

New Bothwell / Steinbach

Month	Maximum	Minimum	Mean	G.D.D.	Precipitation
	---°C---	---°C---		--Base 5--	-----mm-----
April	11.9	-2.8	4.5	74.15	7.7
May	19.1	4.9	12	217.7	58.4
June	20.3	9.0	14.7	290.15	195.5
July	25.7	13.1	19.4	447.05	154.8
August	24.8	12.6	18.7	424.95	123.4
September	18.1	5.9	12	209.8	35.1

Appendix 7.6. Correlation coefficients for conventional-tillage sites

Conventional-tillage sites, n=68

Timing	Measurement	Correlation (r)	Significance P(r=0)[a]
In Crop	Dandelion Cover	-0.05219	0.6725
	Relative Cover	0.12869	0.2956
	Dandelion Density	0.09416	0.445
	Relative Density	-0.05316	0.6668
	Total Dandelion Leaf Diameter	0.06554	0.5954
At Harvest	Total Dandelion Leaf Area	-0.19801	0.1055
	Total Dandelion Root Diameter	-0.17362	0.1736
	Total Dandelion Biomass	-0.15569	0.2049
	Dandelion Density	-0.09983	0.4179

Dakota site, n=25

Timing	Measurement	Correlation (r)	Significance P(r=0)
In Crop	Dandelion Cover	-0.25803	0.213
	Relative Cover	0.37363	0.0658
	Dandelion Density	0.2109	0.3116
	Relative Density	0.33789	0.0985
	Total Dandelion Leaf Diameter	0.16658	0.4261
At Harvest	Total Dandelion Leaf Area	-0.3794	0.0614
	Total Dandelion Root Diameter	-0.27911	0.1766
	Total Dandelion Biomass	-0.40732	0.0433 *
	Dandelion Density	-0.18379	0.3792

Elie site, n=9

Timing	Measurement	Correlation (r)	Significance P(r=0)
In Crop	Dandelion Cover	0.50386	0.1667
	Relative Cover	-0.31238	0.4131
	Dandelion Density	-0.20076	0.6045
	Relative Density	-0.55253	0.1229
	Total Dandelion Leaf Diameter	0.01785	0.9637
At Harvest	Total Dandelion Leaf Area	0.4913	0.1792
	Total Dandelion Root Diameter	0.34887	0.3575
	Total Dandelion Biomass	0.04092	0.9168
	Dandelion Density	0.59728	0.0895

* Represents significance at the 0.05 level

New Bothwell site, n=29

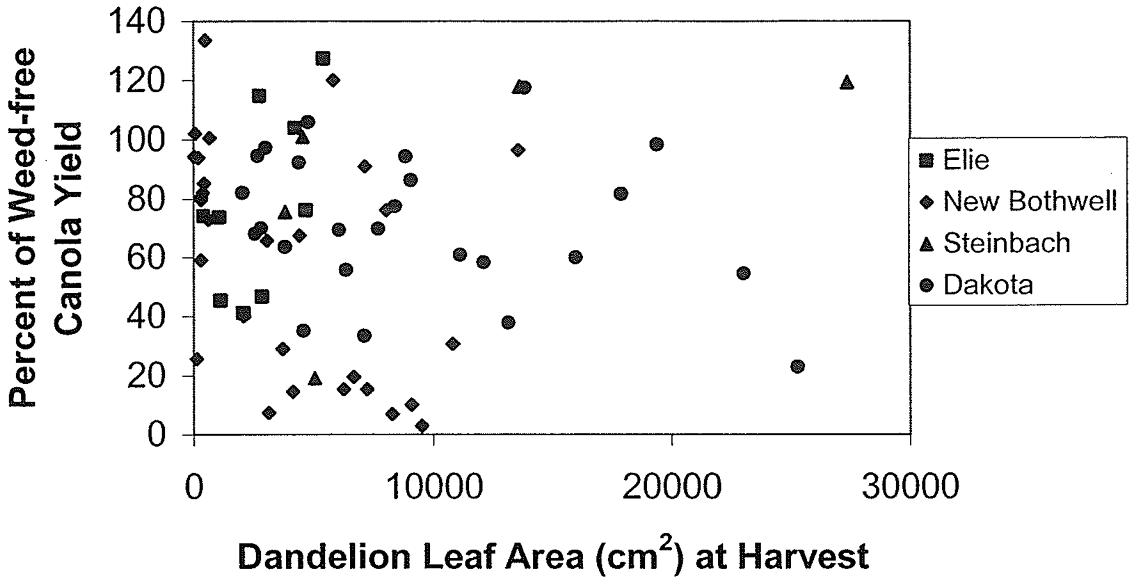
Timing	Measurement	Correlation (r)	Significance P(r=0)	
In Crop	Dandelion Cover	-0.06944	0.7204	
	Relative Cover	0.18624	0.3335	
	Dandelion Density	0.11518	0.5519	
	Relative Density	-0.08543	0.6595	
	Total Dandelion Leaf Diameter	0.05635	0.7716	
At Harvest	Total Dandelion Leaf Area	-0.36248	0.0533	
	Total Dandelion Root Diameter	-0.18205	0.3446	
	Total Dandelion Biomass	-0.38387	0.0398	*
	Dandelion Density	-0.11702	0.5455	

Steinbach site, n=5

Timing	Measurement	Correlation (r)	Significance P(r=0)
In Crop	Dandelion Cover	-0.11598	0.8527
	Relative Cover	-0.69274	0.1948
	Dandelion Density	0.43068	0.4691
	Relative Density	-0.50667	0.3837
	Total Dandelion Leaf Diameter	0.37518	0.5338
At Harvest	Total Dandelion Leaf Area	0.70545	0.1832
	Total Dandelion Root Diameter	b	b
	Total Dandelion Biomass	0.67228	0.2138
	Dandelion Density	0.30873	0.6133

[a] Significance determined relative to the probability that correlation (r) is equal to zero
[b] Total dandelion root diameter not measured at Steinbach
* Represent significance at the 0.05 level

Appendix 7.7. Reduction in canola yield as related to dandelion leaf area at harvest (Conventional-tillage fields). Markers represent data points.



Appendix 7.8. F-tests to determine if models differ significantly between sites.

Dandelion Measure	Test	SS Error	D.F. Error	F statistic		Result
Root Diameter (at harvest)	Common A	16173	52	0.83		A the same
	Common A,B	25916	53	31.33	*	B different
	Common A,C	18219	53	6.58	*	C different
	Common A,B,C	28579	54	19.94	*	B, C different
	Summary					Curves are different
Dandelion Cover (in-crop)	Common A	16714	54	9.39	*	A different
	Common B	18328	54	5.12	*	B different
	Summary					Models are different
Relative Cover (in-crop)	Common A	17730	54	6.58	*	A different
	Common B	17131	54	4.57	*	B different
	Summary					Models are different

* Represents significance at the 0.05 level

Appendix 7.9. Meteorological information at the time of glyphosate applications for control trials

Site		Application Timing				
	Variable	Pre-seed	0-3 Leaf	4-6 Leaf	Pre-harvest	Post-harvest
99Carman	Time	0815	1930	0130	1030	1900
	Temp.[a]	15	25	15	20	20
	Sky	P-cloudy	Clear	Clear	P-cloudy	Clear
	Wind[b]	5 E	2 W	0	5 NW	5 S
99Oakville	Time	2000	1100	1930	0945	1930
	Temp.[a]	15	18	21	18	20
	Sky	Cloudy	Clear	Clear	Clear	Clear
	Wind[b]	5 NE	15 W	5 N	1 N	5 NW
00CarmanN	Time	2100	2345	1030	2045	1530
	Temp.[a]	10	18	20	22	10
	Sky	Cloudy	Clear	Clear	Clear	Cloudy
	Wind[b]	5 NE	2 W	10 SE	0	5 N
00CarmanS	Time	2145	1900	0845	0815	1600
	Temp.[a]	15	15	22	15	10
	Sky	P-cloudy	P-cloudy	Clear	Clear	Cloudy
	Wind[b]	5 N	5 E	5 SW	5 NE	5 N
00Oakville	Time	1930	2130	1130	2000	1400
	Temp.[a]	10	20	20	25	12
	Sky	Clear	Clear	Clear	Clear	Cloudy
	Wind[b]	5 NE	2 E	10 SE	0	5 N

[a] Temperature in degrees Celsius

[b] Wind speed and direction (km hour^{-1}, direction)

Appendix 7.10. Bartlett's test for homogeneity of variance of residual dandelion biomass (percent of untreated)

Subset	Corrected x^2	Degrees of freedom	P(variance is homogenous)
Pre-seed	0.344812	3	>0.25
0-3 leaf	0.223811	2	>0.25
Pre-harvest	1.222247	2	>0.25
Post-harvest	19.5236	3	<0.001
Timing	11.98222	5	0.01 to 0.05
Sequential	41.84705	3	<0.001

Appendix 7.11. The influence of spring tillage and time of glyphosate application on yield of Roundup Ready™ canola at two sites over 2 years (2 sites are Carman in 2000). Yields are presented in kg ha^{-1} (standard errors in parenthesis).

Timing	1999							
	Oakville				Carman			
	LDS[c]		HDS[c]		LDS[c]		HDS[c]	
	------- kg ha^{-1} -------				------- kg ha^{-1} -------			
Untreated	487 (132)	a	1768 (336)	a	1583 (294)	a	2341 (11)	a
Pre-seed	1987 (120)	b	1855 (648)	a	2024 (279)	a	2354 (289)	a
0-3 Leaf[a]	1950 (140)	b	2068 (228)	a	1981 (310)	a	2793 (61)	a
Split[b]	1897 (72)	b	1930 (417)	a	1686 (203)	a	2328 (168)	a
Pre-harvest	372 (218)	a	1419 (371)	a	1917 (266)	a	2280 (98)	a
Post-harvest	363 (214)	a	1148 (133)	a	1562 (279)	a	2543 (108)	a
LSD	499		1229		712		520.5	

Trt	2000											
	Oakville				CarmanN				CarmanS			
	LDS[c]		HDS[c]		LDS[c]		HDS[c]		LDS[c]		HDS[c]	
	------- kg ha^{-1} -------				------- kg ha^{-1} -------				------- kg ha^{-1} -------			
Untreated	364 (122)	a	937 (177)	a	149 (96)	a	671 (236)	a	32 (5)	a	1245 (73)	a b
Pre-seed	1081 (43)	b c	1475 (104)	b c	1204 (278)	b	1701 (413)	b c	1627 (82)	c	1550 (134)	a
0-3 Leaf[a]	1020 (173)	a b c	1004 (228)	a	1306 (412)	b	1196 (210)	a b c	848 (130)	b	1013 (109)	b
Split[b]	1333 (312)	c	1535 (107)	c	1075 (259)	b	1947 (231)	c	220 (44)	a	952 (218)	b
Pre-harvest	528 (223)	a b	1045 (75)	a b	244 (73)	a	1124 (203)	a b	259 (229)	a	1171 (147)	a b
Post-harvest	832 (386)	a b c	1310 (156)	a b c	248 (160)	a	1367 (241)	a b c	33 (12)	a	1203 (152)	a b
LSD	670		452		787		776		376		491	

[a] 900 g a.i. ha^{-1} applied at the 0-3 leaf stage of canola

[b] 450 g a.i.ha^{-1} applied 0-3 leaf, 450 g a.i. ha^{-1} applied 4-6 leaf

[c] Numbers followed by different letters are significantly different at $\propto = 0.05$ for comparison among rates within disturbances and time treatments.

Appendix 7.12. The influence of spring tillage and rate of glyphosate application (at the pre-seed timing) on yield of Roundup Ready™ canola at two sites over 2 years (2 sites are Carman in 2000). Yields are presented in kg ha^{-1} (standard errors in parenthesis).

Glyphosate Rate (g a.i. ha^{-1})	1999							
	Oakville				Carman			
	LDS[a]		HDS[a]		LDS[a]		HDS[a]	
	------- kg ha^{-1} -------				------- kg ha^{-1} -------			
0	487 (132)	a	1768 (336)	a	1583 (294)	a	2341 (11)	a
900	1987 (120)	b	1855 (648)	a	2024 (279)	a	2355 (289)	a
1350	1887 (231)	b	2046 (258)	a	2250 (266)	a	2357 (154)	a
1800	1701 (146)	b	2027 (161)	a	2170 (216)	a	1781 (179)	b
LSD	622		818		1033		482	

Glyphosate Rate (g a.i. ha^{-1})	2000											
	Oakville				CarmanN				CarmanS			
	LDS[a]		HDS[a]		LDS[a]		HDS[a]		LDS[a]		HDS[a]	
	------- kg ha^{-1} -------				------- kg ha^{-1} -------				------- kg ha^{-1} -------			
0	364 (123)	a	937 (177)	a	149 (96)	a	671 (236)	a	31.8 (5)	a	1245 (73)	a
900	1081 (43)	a	1475 (104)	c	1204 (278)	b	1701 (413)	b	1627 (82)	b	1550 (134)	a
1350	1056 (256)	a	1224 (220)	b	1231 (161)	b	1275 (145)	b	1530 (75)	b	1345 (89)	a
1800	957 (264)	a	1013 (112)	a b	1429 (357)	b	1392 (273)	b	1590 (175)	b	1372 (224)	a
LSD	748		246		473		487		355		508	

[a] Numbers followed by different letters are significantly different at $\propto = 0.05$ for comparison among rates within disturbances and time treatments.

Appendix 7.13. The influence of spring tillage and rate of glyphosate application (at the 0-3 leaf timing) on yield of Roundup Ready™ canola at two sites over 2 years (2 sites are Carman in 2000). Yields are presented in kg ha^{-1} (standard errors in parenthesis).

Glyphosate Rate (g a.i. ha^{-1})	1999							
	Oakville				Carman			
	LDS[a]		HDS[a]		LDS[a]		HDS[a]	
	------- kg ha^{-1} -------				------- kg ha^{-1} -------			
0	487 (132)	a	1768 (336)	a	1583 (294)	a	2341 (11)	a b
450	2019 (211)	b	1955 (129)	a	2547 (111)	a b	2202 (194)	a
900	1951 (140)	b	2067 (228)	a	1981 (310)	b	2793 (61)	b
LSD	290		1018		598		481	

Glyphosate Rate (g a.i. ha^{-1})	2000											
	Oakville				CarmanN				CarmanS			
	LDS[a]		HDS[a]		LDS[a]		HDS[a]		LDS[a]		HDS[a]	
	------- kg ha^{-1} -------				------- kg ha^{-1} -------				------- kg ha^{-1} -------			
0	364 (123)	a	937 (177)	a	149 (96)	a	671 (236)	a	32 (5)	a	1245 (73)	a
450	1545 (64)	b	1342 (191)	a	1233 (454)	a	1535 (60)	b	386 (149)	a	1015 (56)	a
900	1020 (173)	b	1007 (228)	a	1306 (412)	a	1196 (210)	a b	848 (130)	b	1013 (109)	a
LSD	614		825		1434		531		372		265	

[a] Numbers followed by different letters are significantly different at ∝ = 0.05 for comparison among rates within disturbances and time treatments.

Appendix 7.14. The influence of spring tillage and rate of glyphosate application (at the pre-harvest timing) on yield of Roundup Ready™ canola at two sites over 2 years (2 sites are Carman in 2000). Yields are presented in kg ha^{-1} (standard errors in parenthesis).

Glyphosate Rate (g a.i. ha^{-1})	1999							
	Oakville				Carman			
	LDS[a]		HDS[a]		LDS[a]		HDS[a]	
	------- kg ha^{-1} -------				------- kg ha^{-1} -------			
0	487 (132)	a	1768 (336)	a	1583 (294)	a	2341 (11)	a
900	372 (218)	a	1419 (371)	a	1917 (265)	a	2280 (97)	a
1800	599 (176)	a	1157 (211)	a	1504 (658)	a	2261 (282)	a
LSD	662		1244		1425		771	

Glyphosate Rate (g a.i. ha^{-1})	2000											
	Oakville				CarmanN				CarmanS			
	LDS[a]		HDS[a]		LDS[a]		HDS[a]		LDS[a]		HDS[a]	
	------- kg ha^{-1} -------				------- kg ha^{-1} -------				------- kg ha^{-1} -------			
0	364 (123)	a	937 (177)	a	149 (96)	a	671 (236)	a	32 (5)	a	1245 (73)	a
900	528 (223)	a	1045 (75)	a	244 (73)	a	1124 (203)	a	259 (229)	a	1171 (147)	a
1800	621 (49)	a	851 (70)	a	30 (11)	a	850 (173)	a	33 (12)	a	808 (35)	a
LSD	701		493		335		742		516		442	

[a] Numbers followed by different letters are significantly different at $\propto = 0.05$ for comparison among rates within disturbances and time treatments.

Appendix 7.15. The influence of spring tillage and rate of glyphosate application (at the post-harvest timing) on yield of Roundup Ready™ canola at two sites over 2 years (2 sites are Carman in 2000). Yields are presented in kg ha^{-1} (standard errors in parenthesis).

Glyphosate Rate (g a.i. ha^{-1})	1999							
	Oakville				Carman			
	LDS[a]		HDS[a]		LDS[a]		HDS[a]	
	------- kg ha^{-1} -------				------- kg ha^{-1} -------			
0	487 (132)	a	1768 (336)	a	1583 (294)	a	2341 (11)	a
900	363 (177)	a	1149 (133)	a	1562 (279)	a	2543 (108)	a
1800	676 (613)	a	1557 (432)	a	1618 (130)	a	2679 (38)	a
2700	591 (283)	a	1545 (422)	a	1985 (157)	a	2464 (257)	a
LSD	1007		1252		666		448	

Glyphosate Rate (g a.i. ha^{-1})	2000											
	Oakville				CarmanN				CarmanS			
	LDS[a]		HDS[a]		LDS[a]		HDS[a]		LDS[a]		HDS[a]	
	------- kg ha^{-1} -------				------- kg ha^{-1} -------				------- kg ha^{-1} -------			
0	364 (123)	a	937 (177)	a	149 (96)	a	671 (236)	a	32 (5)	a	1245 (73)	a
900	832 (386)	a	1310 (156)	b	248 (160)	a	1367 (241)	b	33 (12)	a	1203 (152)	a b
1800	529 (158)	a	981 (58)	a b	499 (484)	a	1013 (93)	a b	25 (17)	a	1039 (155)	a b
2700	697 (214)	a	1117 (75)	a b	195 (12)	a	903 (82)	a b	166 (44)	a	821 (43)	b
LSD	879		363		988		940		75		413	

[a] Numbers followed by different letters are significantly different at $\propto = 0.05$ for comparison among rates within disturbances and time treatments.

Appendix 7.16. The influence of spring tillage and sequential glyphosate applications on yield of Roundup Ready™ canola at two sites over 2 years (2 sites are Carman in 2000). Yields are presented in kg ha^{-1} (standard errors in parenthesis).

Glyphosate Rate (g a.i. ha^{-1})	1999							
	Oakville				Carman			
	LDS[d]		HDS[d]		LDS[d]		HDS[d]	
	------- kg ha^{-1} -------				------- kg ha^{-1} -------			
0	487 (132)	a	1768 (336)	a	1583 (294)	a	2341 (11)	a
Split[a]	1897 (72)	b	1931 (417)	a	1686 (203)	a	2328 (168)	a
Split[a]/PH[b]	2429 (348)	b	1242 (281)	a	2139 (256)	a	2184 (152)	a
PS[c]/PH[b]	2140 (277)	b	2301 (184)	a	1352 (278)	a	1898 (306)	a
LSD	533		1225		994		690	

Glyphosate Rate (g a.i. ha^{-1})	2000											
	Oakville				CarmanN				CarmanS			
	LDS[d]		HDS[d]		LDS[d]		HDS[d]		LDS[d]		HDS[d]	
	------- kg ha^{-1} -------				------- kg ha^{-1} -------				------- kg ha^{-1} -------			
0	364 (123)	a	937 (177)	a	149 (96)	a	371 (236)	a	32 (5)	a	1245 (73)	a
Split[a]	1333 (312)	b	1535 (107)	b	1075 (259)	b	1947 (231)	c	220 (44)	b	952 (218)	a
Split[a]/PH[b]	1184 (138)	b	1105 (115)	a	1342 (123)	b	1424 (259)	b c	1544 (36)	d	1170 (21)	a
PS[c]/PH[b]	1387 (368)	b	1229 (196)	a b	890 (417)	a b	1386 (205)	b	374 (73)	c	1243 (118)	a
LSD	725		415		853		559		135		428	

[a] 450 g a.i.ha^{-1} applied 0-3 leaf, 450 g a.i. ha^{-1} applied 4-6 leaf

[b] 900 g a.i. ha^{-1} applied post-harvest

[c] 900 g a.i. ha^{-1} applied pre-seed

[d] Numbers followed by different letters are significantly different at $\propto = 0.05$ for comparison among rates within disturbances and time treatments.

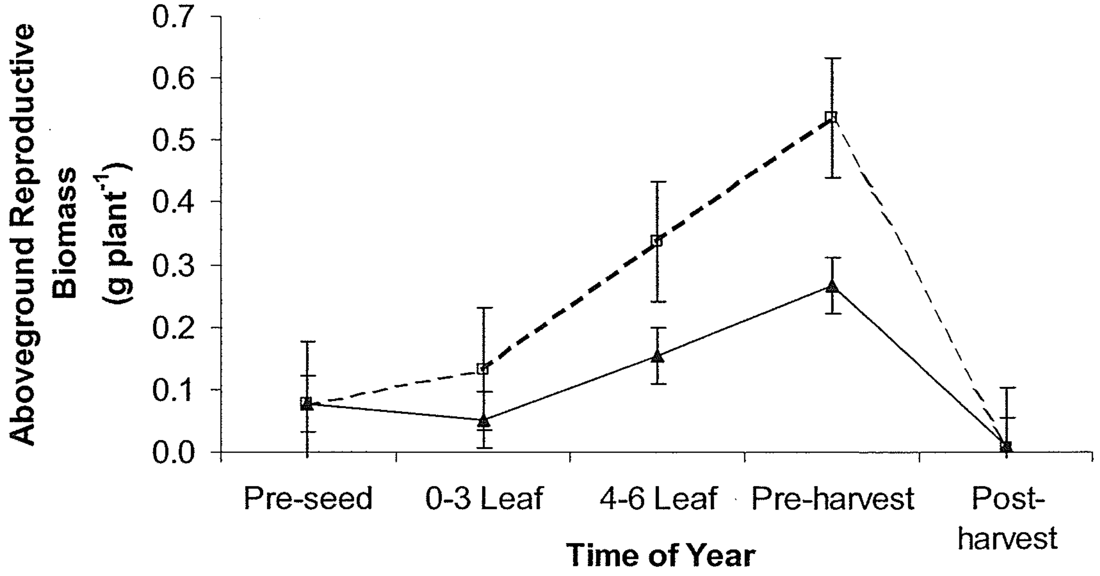
Appendix 7.17. Canola yield (+/- SE) after 900 g a.i. ha^{-1} of glyphosate applied at various timings

	Low Disturbance			High Disturbance		
Time of Application	Dandelion Biomass[b]			Dandelion Biomass[b]		
	kg ha^{-1}			kg ha^{-1}		
Pre-seed	1581.0	(125.8)	a	1783.0	(164.1)	a
0-3 Leaf	1542.4	(214.9)	a	1606.4	(124.8)	a
Split[a]	1239.4	(174.2)	a	1734.6	(156.3)	a
Pre-harvest	662.7	(187.3)	b	1404.6	(144.1)	a
Untreated	521.7	(159.4)	b	1389.1	(176.9)	a
Post-harvest	606.1	(171.9)	b	1511.0	(151.8)	a
L.S.D.	403.3			621.7		

[a] 450 g a.i.ha^{-1} applied 0-3 leaf, 450 g a.i. ha^{-1} applied 4-6 leaf

[b] Numbers followed by different letters are significantly different at $\propto = 0.05$ for comparison among rates within disturbances and time treatments.

Appendix 7.18. Average aboveground reproductive biomass of individual plants harvested from low and high disturbance plots throughout the growing season. (□) Low Disturbance Seeding, (▲) High Disturbance Seeding



Appendix 7.19. The influence of glyphosate rate on dandelion shoot biomass ($\log_{10}$-transformed on percentage of untreated) measured in the spring following year of glyphosate application (standard errors in parenthesis). Glyphosate applied post-harvest.

Application Time	Glyphosate Rate	Dandelion Biomass[a]	
	--- g a.i. ha^{-1} ---	---- % of untreated----	
Post-harvest	0	1.94 (0.05)	a
	900	0.42 (0.08)	b
	1800	0.40 (0.09)	b
	2700	0.18 (0.07)	c
	LSD	0.20	

[a] Values followed by different letters are significantly different at $\propto = 0.05$ for comparisons among rates within disturbances and time treatments.

Appendix 7.20. The influence of spring tillage and time of glyphosate application on dandelion shoot biomass (log$_{10}$-transformed from percent of untreated) of Roundup Ready™ canola at two sites over 2 years (2 sites are Carman in 2000). Yields are presented in kg ha^{-1} (standard errors in parenthesis).

Time of glyphosate application	1999			
	Oakville		Carman	
	LDS[c]	HDS[c]	LDS[c]	HDS[c]
	% of untreated		% of untreated	
Untreated	1.91 (0.21) a	1.80 (0.36) a	1.95 (0.16) a	1.80 (0.35) a
Split[b]	1.40 (0.29) a b	1.06 (0.09) a b	1.25 (0.12) b	1.58 (0.25) a
Pre-seed	0.44 (0.16) c	0.34 (0.34) b	1.28 (0.12) b	1.36 (0.07) a
0-3 Leaf[a]	1.75 (0.41) a	1.21 (0.53) a b	1.29 (0.23) b	1.46 (0.43) a
Pre-harvest	1.30 (0.25) a b	0.44 (0.10) b	1.94 (0.08) a	1.80 (0.26) a
Post-harvest	0.92 (0.04) b c	0.92 (0.48) a b	0.92 (0.14) c	0.04 (0.04) b
LSD	0.75	1.09	0.24	0.84

Time of glyphosate application	2000					
	Oakville		CarmanN		CarmanS	
	LDS[c]	HDS[c]	LDS[c]	HDS[c]	LDS[c]	HDS[c]
	% of untreated		% of untreated		% of untreated	
Untreated	1.99 (0.08) a	1.96 (0.15) a	1.99 (0.07) a	2.00 (0.02) a	2.00 (0.03) a	2.00 (0.02) a
Split[b]	1.50 (0.24) b	1.48 (0.36) a	1.80 (0.02) a	1.67 (0.06) abc	1.52 (0.10) bc	1.96 (0.03) a
Pre-seed	1.65 (0.10) a b	1.88 (0.15) a	1.89 (0.02) a	1.55 (0.12) bc	1.56 (0.01) bc	1.81 (0.13) a
0-3 Leaf[a]	1.44 (0.25) b	1.84 (0.16) a	1.87 (0.12) a	1.75 (0.15) ab	1.61 (0.08) b	1.91 (0.11) a
Pre-harvest	1.68 (0.21) a b	1.65 (0.10) a	2.01 (0.05) a	1.31 (0.20) c	1.34 (0.06) c	0.82 (0.21) b
Post-harvest	0.21 (0.17) c	0.0 (0.0) b	0.28 (0.15) b	0.23 (0.23) d	0.39 (0.08) d	0.28 (0.26) c
LSD	0.44	0.58	0.28	0.42	0.22	0.53

[a] 900 g a.i. ha^{-1} applied at the 0-3 leaf stage of canola

[b] 450 g a.i.ha^{-1} applied 0-3 leaf, 450 g a.i. ha^{-1} applied 4-6 leaf

[c] Numbers followed by different letters are significantly different at $\propto = 0.05$ for comparison among rates within disturbances and time treatments

Appendix 7.21. Dandelion shoot biomass ($\log_{10}$-transformed from percent of untreated) after 900 g a.i. ha^{-1} of glyphosate applied at sequential timings (standard errors in parenthesis). Mean dandelion shoot biomass was 129.5 g m^{-2} (+/- 22.3) and 61.0 g m^{-2} (+/- 12.7) for the untreated low and high disturbance plots, respectively.

Time of Application	1999			
	Oakville[a]		Carman[a]	
	% of untreated			
Untreated	1.86 (0.19)	a	1.88 (0.18)	a
Split[c]	1.23 (0.16)	b	1.42 (0.14)	b
Split/PH	0.19 (0.12)	c	0.12 (0.07)	c
PS/PH	0.33 (0.18)	c	0.04 (0.03)	c
LSD	0.60		0.23	

	2000					
	Oakville[a]		CarmanN[a]		CarmanS[a]	
	% of untreated					
Untreated	1.97 (0.07)	a	2.00 (0.03)	a	2.00 (0.01)	a
Split[c]	1.49 (0.19)	b	1.73 (0.04)	b	1.74 (0.11)	b
Split/PH	0.24 (0.17)	c	0.0 (0.0)	c	0.12 (0.06)	c
PS/PH	0.0 (0.0)	d	0.0 (0.0)	c	0.17 (0.08)	c
LSD	0.21		0.08		0.19	

[a] Numbers followed by different letters are significantly different at $\propto = 0.05$ for comparisons among rates within disturbances and time treatments.

[b] Leaf stage of canola crop

[c] 450 g a.i. ha^{-1} applied at the 0-3 leaf stage of canola, 450 g a.i. ha^{-1} applied at the 4-6 leaf stage of canola

Appendix 7.22. Dandelion shoot biomass (as a percentage of untreated) after 900 g a.i. ha^{-1} of glyphosate applied at various timings (standard errors in parenthesis). Mean dandelion shoot biomass was 129.5 g m^{-2} (+/- 22.3) and 61.0 g m^{-2} (+/- 12.7) for the untreated low and high disturbance plots, respectively.

Time of Application	1999			
	Oakville[a]		Carman[a]	
	% of untreated			
Untreated	100 (26.9)	a	100 (25.1)	a
0-3 Leaf[b]	75.1 (32.7)	a b	37.8 (13.4)	b
Split[c]	22.3 (8.3)	b c	34.2 (13.4)	b
Pre-harvest	13.6 (7.3)	c	89.4 (24.6)	a
Post-harvest	12.5 (5.7)	c	4.2 (2.3)	b
Pre-seed	2.6 (1.5)	c	21.1 (3.0)	b
LSD	57.1		50.1	

	2000					
	Oakville[a]		CarmanN[a]		CarmanS[a]	
	% of untreated					
Untreated	100 (16.0)	a	100 (7.8)	a	100 (3.3)	a
0-3 Leaf[b]	56.9 (17.6)	b	71.5 (14.5)	b	63.0 (13.5)	b
Split[c]	43.3 (11.8)	b	54.1 (4.6)	b	61.8 (13.4)	b
Pre-harvest	52.7 (13.7)	b	62.6 (18.8)	b	14.4 (3.9)	c
Post-harvest	0.4 (0.4)	c	1.2 (0.7)	c	1.7 (0.8)	c
Pre-seed	65.6 (14.9)	b	57.2 (10.2)	b	52.2 (10.9)	b
LSD	31.0		22.3		15.4	

[a] Numbers followed by different letters are significantly different at $\propto = 0.05$ for comparisons among rates within disturbances and time treatments.

[b] Leaf stage of canola crop

[c] 450 g a.i. ha^{-1} applied at the 0-3 leaf stage of canola, 450 g a.i. ha^{-1} applied at the 4-6 leaf stage of canola

Appendix 7.23. Dandelion present in plot 206 (treatment 2) at Carman in 1999. Top picture represents plot at time of glyphosate application (450 g a.i. ha^{-1}). Middle picture represents plot 18 days after glyphosate application. Bottom picture represents plot 45 days after glyphosate application.