THE CRITICAL PERIOD OF WEED CONTROL IN CANOLA (*Brassica napus* L.) IN MANITOBA

BY

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Abstract

Martin, Steven G. M.Sc., The University of Manitoba, February, 2000. The critical period of weed control in canola (*Brassica napus* L.) in Manitoba. Major Professor; Rene Van Acker.

The critical period of weed control is the time during the lifecycle of a crop during which it must be kept weed-free to prevent yield loss from weed interference. The advent of soil-applied herbicides and herbicide-tolerant canola varieties in western Canada has increased interest in research to find the proper timing for weed control in canola. A critical period experiment was performed at three sites in southern Manitoba in 1998 and 1999 and consisted of two sets of treatments. In the first set of treatments the crop was kept weed-free for increasing lengths of time to find the minimum weed-free period required to maintain maximum yield. In the second set of treatments, weeds were permitted to grow in the crop for increasing lengths of time to find the maximum tolerable weed-infested period. It was found that canola must be kept weed-free until the 6th leaf stage (20-39 DAE) to consistently prevent greater than 10% yield loss. In addition, the crop required the removal of weeds by the 4th leaf stage (14-32 DAE) to prevent greater than 5% yield reduction from interference. It was also found that after the 4th leaf stage not many weeds emerged, and those which did emerge did not accumulate significant biomass to compete with the crop. Comparative growth analysis of weed-free and weed-infested plots revealed that total dry weight, crop growth rate, leaf area index of the canola crop was reduced by weed interference. The stem weight ratio was increased, while the leaf weight ratio was reduced by weed interference. The presence of weeds also decreased the amount of branching observed in the crop and increased the proportion of biomass allocated to reproductive parts. This information will be useful for

making weed control recommendations to canola producers, in developing weed-crop interference models, and for breeding more competitive canola varieties.

Chapter 1

General Introduction

In the western Canadian prairies, canola is primarily grown as a spring-seeded, annual crop. The advent of soil-residual herbicides and the increased use of herbicide-tolerant varieties has increased the reliance on herbicides for the control of weeds in this crop (Manitoba Ag., 1999). These herbicides permit the control of a wide spectrum of weeds over a broad range of application timings. Through the implementation of integrated weed management (IWM) systems, the objective of reducing the reliance on herbicides may be achieved by increasing their effectiveness through proper timing of application and the use of competitive cultivars (Swanton and Weise, 1991). IWM is a holistic approach to weed control and incorporates knowledge of how the crop interacts with weeds. The critical period of weed control is one of the pillars of IWM as it can determine when there is no need for weed control during the lifecycle of a crop (Hall *et al.*, 1992; Van Acker *et al.*, 1993a). Comparative growth analysis of a crop under weed-infested and weed-free conditions can help explain how the duration of weed competition affects the growth and morphology of crop plants (Van Acker *et al.*, 1993b). These will help to optimize the use of herbicides and provide the basis for developing integrated alternatives for weed management strategies (Swanton and Weise, 1991).

To find the critical period of weed control, two sets of treatments must be used (Van Acker *et al.*, 1993). In the first, the crop is kept weed-free for increasing lengths of time to find the period that the crop must be kept weed-free to maintain maximum yield. In the second, weeds are allowed to grow with the crop for increasing lengths of time to find the maximum period that weed infestation can be tolerated by the crop before yield is reduced (Weaver *et al.*, 1992). The critical period of weed control is the combination of these two periods, and weed presence before and after this period will not cause significant yield reductions (Dawson, 1986; Weaver and Tan, 1983).

Critical period studies are ideal for making weed control recommendations as they indicate the optimum time for implementing and maintaining weed control (Hall *et al.*, 1992; Van Acker *et al.*, 1993). The critical weed-free period can be used to identify the length of residual activity required for preemergence herbicides, the proper time for cover crop planting, timing for in-crop cultivation, and the timing of additional postemergence weed control. In canola, the critical time of weed removal has become important for determining the length of time that weeds can be left in the crop, especially with the increased use of herbicide-tolerant canola (HTC) varieties (Manitoba Agriculture, 1999). Identifying the critical period of weed control may help to reduce the use of herbicides if it is found that a single, well-timed postemergence application can provide adequate weed control, making cropping practices more cost effective for producers and reducing the introduction of unneeded herbicide into the environment.

Previous research on the effect of timing of weed interference in canola has shown that yield reduction from volunteer barley (*Hordeum vulgare* L.) interference diminishes the later that it emerges relative to the crop (O'Donovan, 1992), implying that the critical weed-free period may be very short in some cases. Wall (1994) found that with wild mustard (*Brassica kaber* (D.C.) L. C. Wheeler),the critical weed-free period occurred before the first leaf stage. McMullan *et al.* (1994) showed that early in-crop removal of wild mustard from canola prevented yield loss, while Wall (1994) similarly found that wild mustard could grow with canola until the 4th or 6th leaf stage of development without causing yield reductions.

Although the preceding analyses were useful, they were not a complete examination of the critical period of weed control in canola. The studies by Wall (1994) and McMullan *et al.* (1994) examined only the critical time of weed removal with accuracy. Also, only one weed species was included in these studies, and this species was sown into the experimental plots. In a field situation there is a great range of species and emergence patterns (Baldwin and Santelmann, 1980; Stoller and Wax, 1973). These factors can greatly affect the critical period of weed control (Van Acker *et al.*, 1993a).

Relatively little work has been performed on the growth analysis of canola under weed competition, compared to other crops. Van Acker *et al.* (1993b) showed that in a soybean crop, the total dry weight (TDW), crop growth rate (CGR), and leaf area index (LAI) of soybean were significantly reduced by weed competition. The soybean crop also compensated for competition by increasing the proportion of reproductive weight produced in the plant and decreasing the amount of branching. Wilson (1966) showed that net assimilation rate (NAR) in rapeseed was strongly affected by light availability. Therefore, competition from mutual shading and weed interference will greatly affect the rate of plant dry matter produced per unit of leaf area. However, it is still unknown if the NAR of canola in a field situation will increase with reduced weed interference, or if increased branching of canola in a weed-free environment will maintain an optimum rate of dry matter production. The understanding of these growth analysis relationships and others described by Hunt (1978) in response to weed competition are still unknown for canola.

Growth analysis information may become useful in the design of weed-crop interference models and in explaining the critical period of weed control in terms of the physiology of the crop. It may also aid in the development of methods for determining the competitiveness of varieties for breeders through a better understanding of the components of canola that are affected by weed competition. Studying the critical period of weed control for canola will provide immediately useful information for making weed control recommendations to canola producers.

Chapter 2

Literature Review

2.1. Critical Period of Weed Control

2.1.1 General Definition and Purpose

2.1.1.1 Theoretical and Practical

The critical period of weed control is the primary analysis method for studying the magnitude of yield loss associated with the length of time that weeds affect a crop (Weaver *et al.*, 1992). It helps optimize herbicide use and provides a logical basis for developing integrated alternatives for managing weeds (Swanton and Weise, 1991). To do this, the critical period is predictive towards when, as opposed to if, weeds should be removed to prevent yield losses (Dawson, 1986). Some researchers believe that this study is more descriptive than predictive in nature, but regardless, it is very useful to determine the proper timing of weed control strategies and to better understand the nature of weed-crop competition (Weaver and Tan, 1987).

The critical period of weed control is the optimum time for weed control and should not be confused with periods of intense weed interference (Hall *et al.*, 1992). Within this period, weed control measures should be maintained to prevent loss by later emerging weeds.

Two sets of treatments must be used to establish the critical period of weed control (Van Acker *et al.*, 1993a). In the first set, the crop is kept weed-free for increasing lengths of time to find the minimum weed-free period required to maintain maximum potential yield. As the period of weed-free maintenance is increased, yield increases until the maximum is reached (Dawson, 1986). This is also known as the late-season period threshold, where further weeding does not affect yield. It illustrates when the minimum duration that weed control must be maintained in order to prevent yield losses (Swanton and Weise, 1991).

In the second set of treatments, weeds are left in the crop for increasing lengths of time to find the maximum tolerable length of weed-infestation (Weaver *et al.*, 1992). Although weed populations may reduce yields, they can often grow with the crop for a certain period before they cause permanent damage (Dawson, 1986). This duration is also known as the early season period threshold and is most important in defining when post-emergent controls must be applied to prevent yield losses due to competition. When these two periods are placed together, we get the critical period of weed control (Dawson, 1986; Weaver and Tan, 1983).

Weeds present before and after this time interval will not significantly reduce yields (Weaver and Tan, 1987; Kropff and Spitters, 1991), because their reduced growth rate does not allow them to attain sufficient size to effectively compete with the crop. However, they may need to be removed for harvesting efficiency or to prevent losses during harvesting operations (Weaver and Tan, 1983). Harvesting losses due to weed interference are usually not considered in critical period studies (Weaver and Tan, 1987). The critical period of weed control also does not account for return of weed seeds to the soil, but weeds can be very prolific in producing seed. The critical period is concerned with only the loss of yield and not loss of quality by contamination with weed seeds, such as wild mustard (*Sinapis arvensis* L.) that reduce the quality of canola oil and meal for processing (McMullan *et al.*, 1994).

Roberts (1976) described three relationships that exist with critical period studies. The first type occurs when the length of the weed-infested period is longer than the minimum weed-free period (Figure 2.1a). In this scenario, a critical period of weed control exists in the sense that there is a definite time when the crop must be kept weed-free. Some studies required up to two or three weed removal practices to prevent weed growth and crop yield loss during this period (Weaver and Tan, 1987).

In the second relationship, there is no definite critical "period" because the two curves meet at full yield potential (Figure 2.1b). Weeds could be left in the crop, or the crop could be kept weed-free for the same amount of time. It was proposed that a single weeding at the right time should be sufficient to prevent yield loss, in this scenario. However, finding this optimum time for removal is difficult with critical periods based on days after emergence or some other location-year dependent parameter. If the critical period is based on the phenological development of the crop, then finding the optimum time for weed removal would be much easier.

The third relationship exists where the length of time that a crop must be kept weed-free is significantly shorter than the duration that a weed infestation can be tolerated (Figure 2.1c). This often exists with a competitive annual crop, and theoretically a single removal between these two crop stages should provide sufficient weed suppression to prevent yield losses (Roberts, 1976; Weaver and Tan, 1987).

In some situations, permanent crop damage may occur very early (even before emergence) due to occupation of biological space or allelopathy (Dawson, 1986). Under such situations, the maximum weed-infested period would not exist and postemergence control would likely not be sufficient to prevent yield loss.

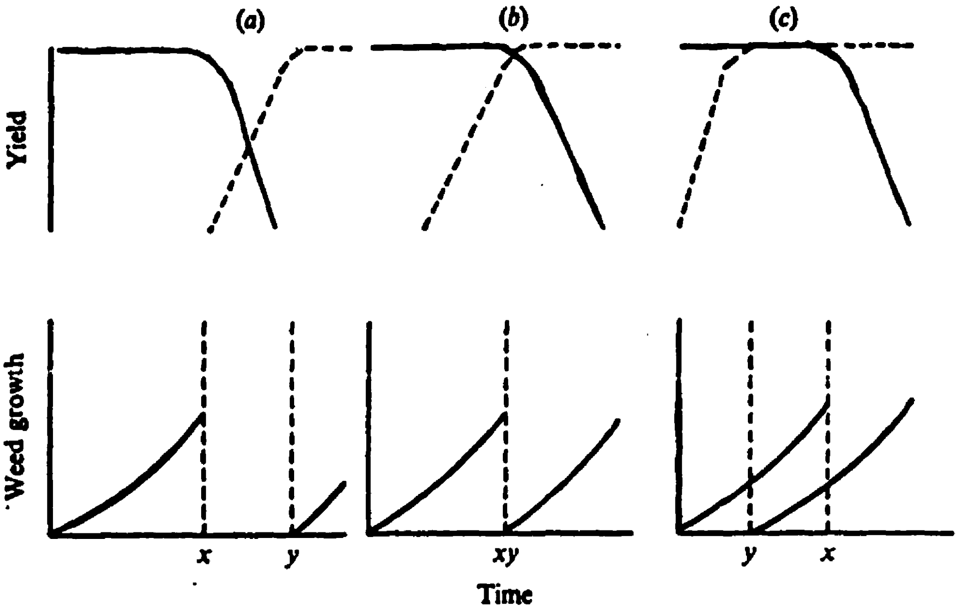

Figure 2.1 The three relationships describe by Roberts (1976) that may exist for the critical period of weed control. The dashed yield curve is the critical weed-free period and the solid yield curve is the critical timing of weed removal. The lower graphs represent the time during which weed growth can be tolerated by the crop.

Cousens (1988) suggests that fitted response curves are a more appropriate and useful method of analysis for critical period of weed control studies, because the curves are continuous and can be used to detect smaller changes in yield than comparing the means of the treatments. The model can be set with a maximum allowable level of yield loss to determine the endpoints of the critical period. The parameters for these curves will depend on the crop species, weed species, weed density, planting date, time of emergence of weeds relative to the crop, and environmental conditions (Weaver *et al.*, 1992; Dawson, 1986). Analysis has been performed on how some of these factors affect the critical period (Weaver *et al.*, 1992).

Research must be performed utilizing experimental designs under various environmental conditions since they affect the outcome of weed-crop competition studies (Vangessel and Renner, 1990)

2.1.1.2 Physiology and Phenology and the Critical Period of Weed Control

The benefit that comes from studying critical periods is a better understanding of the physiological basis for crop-weed competition and how it can be applied to aid in controlling weeds (Hall *et al.*, 1992).

The relative competitive ability and relative growth rates of the crop and weed populations affect the length and timing of the critical period (Weaver and Tan, 1987). Earlier shading and competition by the weeds for nutrients and water will reduce the length of time that the crop can tolerate weed infestation. The minimum length of time that the crop must be kept weed-free will depend on the ability of the crop to shade the weeds and the emergence pattern of the weed complex.

A shorter weed-free period generally leads to an earlier reduction in the dry weight and yield of the crop (Weaver and Tan, 1983). The earlier that weeds interfere with growth of the crop, the greater they can affect dry matter accumulation.

The point where the aboveground biomass of the weeds exceeded that of tomatoes (*Lycopersicon esculentum* L.), for example, in the weed-infested plots was indicative of the ability of the weeds to compete with the crop (Weaver and Tan, 1983). This shows that the relative growth rate of the weeds is crucial, because a higher rate allows the weeds to grow faster and capture resources. The length of time that causes a difference in the total biomass accumulation of plants kept weed-free and weedy all year is important for describing the impacts from the duration of weed infestation (Weaver and Tan, 1983).

In tomatoes, crop and weed dry weights had negative correlation and converged at what appeared to be the point of maximum weed and minimum tomato biomass (Weaver and Tan, 1983). It was suggested that weed biomass can be used as a predictor of tomato crop biomass approximately 6 weeks after transplanting.

Weather driven models which are based on physiological processes are generally more applicable for explaining biological relationships than empirical models that have parameter values tied to particular experimental circumstances (Weaver *et al.*, 1992). In other words, by relating the critical period to leaf stages of the crop rather than strictly using days after emergence, the variability due to the environment and location can be somewhat reduced.

Research needs to be performed on the effects of single and multiple weed population levels over varying lengths of time as related to the developmental stages of the crop on the yield of the crop (Baldwin and Santelmann, 1980).

2.1.2 Factors Affecting Critical Period

2.1.2.1 Weed Species

It is known that weeds and crop compete for the same resources, and this occurs as a result of the overlapping of their biological niche. This competition often suppresses crop dry matter production and yield (Bhaskar and Vyas, 1988). Weeds can compete for light, water, nutrients, and space; they hinder growth and harvesting, have objectionable appearance, and can act as a reservoir for other pests (Baldwin and Santelmann, 1980).

Species Spectrum

The relative competitive ability of weeds for obtaining resources will depend on the species of the weed and the crop that is grown. The degree of interference on the crop is affected by the relative competitive ability of the weeds. Therefore, the critical period will be affected.

One of the methods of determining the relative competitive ability of different species of plants is to compare the parameters for the models of the weed density and crop yield interaction (O'Donovan *et al.*, 1989). A larger change in yield from smaller changes in weed density (i.e. high slope) is indicative of a more competitive species. The regression coefficients from the negative hyperbolic response curve were 4.43, 3.2, 4.9, and 10.4 for densities of volunteer wheat (*Triticum aestivum* L.), wild oats (*Avena fatua* L.) (Dew and Keys, 1976), volunteer barley (*Hordeum vulgare* L.) (O'Donovan *et al.*, 1988), and Canada thistle (*Cirsium arvense* (L.) Scop.) (O'Sullivan *et al.*, 1985) in canola, respectively. This suggests that volunteer wheat and barley are similar in competitiveness, but are less competitive than Canada thistle, and more competitive than wild oat.

A second method of measuring the relative competitive ability of plant species is to analyze the effect of selected densities of different weed species on the yield and growth of the crop. Blackshaw *et al.* (1987) found that wild mustard was more competitive in reducing the dry weight of rapeseed than lambsquarters (*Chenopodium album* L.) This may be due to the similarity in growth habits of wild mustard and rapeseed (Mulligan and Bailey, 1975), which would cause them to compete for the same resources at the same time of the season. This would increase the effect of weed interference on the growth of the crop.

Barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.) was found to be more competitive than redroot pigweed (*Amaranthus retroflexus* L.) except when moisture was limited (Vangessel and Renner, 1990). High moisture, deep seeding, and a low barnyardgrass to redroot pigweed ratio favoured barnyardgrass.

The third method of measuring relative competitive ability is through replacement series experiments (Bhaskar and Yvas, 1988). The total density of plants is kept constant, but the proportion of weeds to crop plants is varied. The data can be used to calculate a relative crowding coefficient for each species, which is an indicator of relative competitive ability.

Competition for light

The growth and ability of different weed species to compete for light will determine the timing and duration of the critical period. The maximum length that weed infestations can be tolerated in a crop will depend on the ability of the weeds to shade the crop and compete for nutrients and water (Weaver and Tan, 1987). Conversely, the minimum critical weed-free period will depend on the ability of the crop to shade weeds and develop a closed canopy; late emerging weeds will have a reduced growth rate due to shading from the crop.

The net assimilation rate of canola responds strongly to light availability (Wilson, 1966). Therefore, the rate of dry matter increase for each unit of leaf area will be affected by weed interference, and this will affect the critical period.

Weaver and Tan (1987) showed that the height of the weeds and amount of photosynthetic active radiation (PAR) reaching a tomato crop were negatively correlated. By delaying the emergence of weeds until at least 8 weeks after seeding, the weed height would not surpass the crop and significant reductions in PAR did not occur. Increased weed interference was also noted to reduce the amount of PAR reaching the lower leaves in corn (*Zea mays* L.) (Hall *et al.*, 1992).

In transplanted tomatoes, reduced light levels from shading were directly related to the critical period of weed control (Weaver and Tan, 1983). With increased height of weeds, the crop would need to be kept weed-free for a longer period to prevent yield losses (Weaver *et al.*, 1992). Thus, competition for light is more important later in the season and the relative growth rates of the crop and weeds will affect the length of the critical period. The height of infesting weeds was found to have little effect on the ability of the crop to tolerate weeds, suggesting that competition for light was not as important as that for soil moisture and nutrients during early growth stages.

It was also noted, in field-seeded tomatoes, that yield losses occurred in the absence of shading (Weaver and Tan, 1987). Therefore, competition for other resources must be important, as well.

Fitness

The competitiveness of weeds that survive an unevenly applied herbicide treatment, or tolerate a low dosage that does not effectively kill them, may differ from untreated weeds (Adcock and Banks, 1991). This is especially evident early in the growing season, after pre-emergence herbicides are applied. Generally, the treated weeds will have reduced competitiveness. This should be considered when modeling the density-dependent effects of weed competition. Higher crop yields resulted when weeds were treated with low dosages of herbicide compared to where no herbicide had been applied (Adcock and Banks, 1991).

Mixed vs. Monoculture Weed Populations

Each weed species differs in its ability to compete with crops under each type of climatic and soil condition. However, most fields have a complex of different species, with each differing in competitive ability (Baldwin and Santelmann, 1980). In fact, each year from 10 to 50 different weeds may infest a given field. More information is needed on the effects on yield and growth of single and multiple weed population levels over varying lengths of time as related to the growth stage of the crop (Van Acker *et al.*, 1993a).

Many studies have been performed on single weed species interactions with canola yield (O'Donovan *et al.*, 1989, O'Donovan *et al.*, 1988, O'Sullivan *et al.*, 1985, and Dew and Keys, 1976) to find the effect of specific weeds. However, little work has been performed on multiple species populations in canola.

In a study by Blackshaw *et al.* (1987), the yield loss in canola from the presence of *Chenopodium album* and *Sinapis arvensis* was less than or equal to the sum of losses from each individual species. For example, with 20 weeds m^{-2} the yield loss was 36% with *S. arvensis*, 25% with *C. album*, and 39% with a mixed population of weeds in canola. Therefore, yield loss from multiple species weed populations may not have an additive effect.

2.1.2.2 Weed Density, Distribution, and Location

The damage to a crop from weeds tends to increase as the density of infesting weeds increases, until a point where further increases do not cause further reductions to the crop yield (Dawson, 1986). Such a saturating population of weeds often occurs in annual crops, where weeds must be controlled in order to prevent yield losses.

Current studies have focused on using weed densities to make decisions on herbicide use through finding the lowest density at which control is economically feasible (Brain and Cousens, 1990). Equations relating crop yield to weed density are easily fitted using non-linear regression. The importance of using such regressions was shown by Cousens *et al.* (1988). In particular, the rectangular hyperbola has the best fit and is the most biologically realistic relationship for canola yield and weed densities (O'Donovan *et al.*, 1988). Linear models often represent some yield loss with no weeds present and infinitely high loss with high weed densities. Models with parameters that reflect high and low density behaviors have a clear advantage for interpreting biological relationships. Such relationships have been examined in canola with densities of several different weed species (O'Donovan *et al.*, 1988; O'Donovan *et al.*, 1989; Dew and Keys, 1976). However, O'Sullivan *et al.* (1985) proposed that a linear equation defined the relationship between rapeseed yield loss and density of Canada thistle shoots with the greatest accuracy.

With certain perennial weeds, such as quackgrass (*Elytrigia repens* (L.) Nevski.), and highly branching weeds, such as wild oats, shoots per unit area are often used as a measurement of infestation level because it is simpler than determining weed density (O'Donovan, 1991; Dew and Keys, 1976).

The relationship of weed density to crop yield varies depending on the weeds present and the crop species. Weaver and Tan (1987) found that weed dry weights and tomato yield were inversely correlated.

Since weed density affects the level of interference on the crop, the critical period will also be affected by weed density. Increased weed density resulted in increased length of time that tomatoes must be kept weed-free to prevent yield loss (Weaver *et al.*, 1992). The length of time that weed infestation could be tolerated by the crop was also reduced, but the weed density had a greater effect on the minimum weed-free period than the maximum weed-infested period.

Usually, changes in soil moisture are correlated with changes in weed density. This means that increased weed density will deplete the moisture in the soil more quickly due to higher demand for it.

The level of yield reduction in canola by specific weeds has been the subject of several studies. As few as 1 volunteer wheat plant m^{-2} can reduce canola yield by 1% (O'Donovan *et al.*, 1989); 100 wild oat shoots m^{-2} could decrease canola yield 32% (Dew and Keys, 1976). Quackgrass at 50-100 shoots m^{-2} reduced canola yields by 18-32% (O'Donovan, 1991), however, the shoots of the weeds emerged 3 to 7 days before the canola, and this could explain the severe effects on yields. Blackshaw *et al.* (1987) found that 20 plants m^{-2} of lamb's quarters, wild mustard, and a mixed population of these two species decreased yield of canola by 36, 25, and 39%, respectively.

It was shown in the results from Forcella (1987) that even with weed removal at the 2 to 3 leaf stage of wild oat, 128 plants m^{-2} appeared to reduce the yield of canola. At densities below this, yield was not affected. This implies that a high density early in the growth of the crop may reduce yield, but a low density may not cause a yield reduction. O'Donovan *et al.* (1992) also showed that the effect of barley density on yield tended to diminish, the later that it emerged relative to the canola crop.

Distribution

In some experiments, weed populations are usually sown as evenly as possible to achieve desired densities. However, homogenous weed populations are uncommon in natural field situations. Yield loss models are developed for average densities across a field, but the aggregated nature of weeds will result in errors in these predictions, usually in the form of underestimation (Brain and Cousens, 1990). A factor for different degrees of aggregation was calculated by Brain and Cousens (1990), assuming a negative binomial distribution of weeds. This could improve the predictions for yield loss models based on weed density. This demonstrates that distribution has an effect on competition, and therefore, will affect the critical period of weed control.

Experiments can account for the natural distribution of weeds through using natural weed populations and integrating their patchiness into the measurements made for the experiment. This often makes the results more realistic and representative of the actual situations, but it also increases the variability within the trials.

Location

In potato (*Solanum tuberosum* L.) weed interference experiments, it was found that redroot pigweed and barnyardgrass emerging from between the rows did not reduce yields, but weeds emerging in the row did cause reductions in yield (Vangessel and Renner, 1990). This occurred because the proximity and number of neighboring plants will determine a plant's ability to capture and utilize resources (Ross and Harper, 1972); thus it will affect the critical period of weed control.

2.1.2.3 Weed Emergence Pattern/Periodicity

The length of the critical weed-free period will largely depend on the germination pattern of the weed species present (Weaver and Tan, 1987). Many species of weeds emerge during distinct periods of the year (Stoller and Wax, 1973). This periodicity can be used for determining the time necessary to maintain lethal dosage of preemergence herbicides in the soil and to plan other efficient weed control strategies. There is no need to maintain herbicide dose levels in the soil when weeds are no longer germinating (Egley and Williams, 1991; Stoller and Wax, 1973).

In temperate regions, early season rising soil temperature is mainly responsible for emergence flushes of weeds. Rainfall is the major cause for emergence of remaining flushes that occur in late spring (Stoller and Wax, 1973). Tillage type and depth of tillage did not significantly affect the emergence periodicity or the number of weeds that emerged (Egley and Williams, 1991). However, if the soil is undisturbed, seed banks are depleted, soil temperatures are high, or water deficits are high, weed seed germination and emergence may decline (Weaver and Tan, 1987).

The density of seedlings that are already present is the most important factor affecting the growth rate of an emerging seedling (Ross and Harper, 1972). Earlier emerging seedlings increase their ability to utilize resources at the expense of the later emerging plants. Emerging seedlings will exert less influence than individuals that are already established. Redroot pigweed emerged before barnyardgrass but this did not lead to greater competitiveness, because barnyardgrass had a higher relative competitive ability, except in low moisture conditions (Vangessel and Renner, 1990).

Date of weed emergence relative to the crop can describe a large amount of variability in yield loss prediction models (Lotz *et al.*, 1990). With winter wheat, for example, weeds emerging in fall had a much greater effect on yield than those that emerged in spring into a nearly closed canopy. Thus, late emerging weeds lack competitiveness to reduce crop yield.

Kropff and Spitters (1991) developed a method of incorporating early season relative leaf area of the weeds into yield loss prediction models. This was shown successful in predicting yield losses over a wide range of relative emergence times and weed densities. In the future, studies should be performed utilizing weed populations that are not manipulated. Then a true measure can be made of the critical period based on natural relationships and emergence patterns between crop and weeds.

2.1.2.4 The Effect of Water and Temperature (Climatic)

In field-seeded tomatoes, yield losses from weed interference occurred even in the absence of shading, showing that some aspects of interference are likely due to competition for water (Weaver and Tan, 1987). The stomatal conductance of tomato plants was reduced significantly when they were kept weed-free less than 8 weeks or weed-infested longer than 6 weeks after seeding. This pattern was similar to that for yield reduction, and again, significant reductions occurred where shading did not occur. This implies that competition for water could play an important role in the timing of the critical period.

The critical period will likely be longer in years with adequate water, because weeds are often able to use resources more efficiently than the crop (Weaver and Tan, 1987). Therefore, the crop would only tolerate short weed infestations early in the growing season, and it would need to be kept weed-free for a longer period to conserve soil moisture and prevent yield losses (Weaver *et al.*, 1992). In corn, the amount of water available to plants was reduced by weed interference (Hall *et al.*, 1992). This increased the interference from weeds and ultimately reduced the number of leaves produced.

Soil moisture can also have a different effect on a given weed species. *Chenopodium album* was less competitive with rapeseed under low rainfall conditions than *Sinapis arvesis* (Blackshaw *et al.*, 1987). On some occasions, variability in canola density between sites may be a result of variable soil moisture (O'Donovan *et al.*, 1989).

Physiological processes should be used in the design of mechanistic models to take into account the effects of environmental factors, such as available water and temperature, on yield (Swanton and Weise, 1991). This will reduce the variability in model parameters due to these factors, and it will make crop-weed interference more predictable over a wider range of conditions (Spitters and Aerts, 1983).

In studies with canola, yield was strongly correlated to both precipitation and temperature in July (O'Donovan *et al.*, 1989). High precipitation and lower temperatures during this time favoured yield, because flowering and pod development normally occur at this time in Western Canada. Ample moisture is necessary during flowering and pod development in canola (Krogman and Hobbs, 1975). Maintaining adequate moisture in this period should increase the oil and seed yield, as well as increase the response of canola growth and yield to applied fertilizer. Adequate moisture will also result in increased photosynthetic surface area due to pod growth and a reduced rate of lower leaf senescence.

Cool temperatures during flowering also favour canola growth and development (Wilson, 1966). At lower temperatures (10°C), the net assimilation rate of canola is not greatly reduced, but higher temperatures (34-35°C) will cause abnormal plant growth. The optimum temperature range for rape growth is within 12-30°C. Vigil *et al.* (1997) found the base temperature for canola emergence was between 0.4 and 1.2°C, and emergence began after the accumulation of 1560 to 1940 growing-degree-hours. Also, if early season soil temperatures are sustained for a long duration below 8 degrees Celsius, severe stand reductions may occur.

2.1.2.5 Nutrients and Soil Factors (Edaphic)

For optimum yield, canola requires approximately 100 kg ha^{-1} NO_3-N, 10 ppm of $NaHCO_3$-extractable P, and 35 ppm NH_4OAc-extractable K (Soper, 1971). Weed interference may change these nutrient requirements.

The amount of available soil nitrogen was reduced by weed interference in corn (Hall *et al.*, 1992). Competitive interference for phosphorus and nitrogen also plays a significant role in reducing the growth of wheat plants in competition with *Chenopodium album* (Bhaskar and Vyas, 1988). Potassium was restricted from being utilized by the weeds from non-competitive interference exhibited by wheat.

Canola has relatively high requirements for nitrogen and phosphorus for maximum growth and yield (Scott *et al.*, 1973; Anderson and Kusch, 1968). Larger yield increases often occur for canola compared to wheat and flax (*Linum usitatissimum* L.) from the application of inorganic fertilizers (Racz *et al.*, 1965). Responses in growth and yield to phosphorus and nitrogen fertilizers also increased with adequate soil moisture (Krogman and Hobbs, 1975)

2.1.2.6 Cultural Practices

Crop Density

Incorporating the density of the canola crop improved the fit of the non-linear regression of weed density on crop yield, indicating that it has an effect on yield loss (O'Donovan *et al.*, 1989). Increased wheat density decreased canola yield, and decreased canola density, decreased canola yield. The same trend occurred with volunteer barley; at densities of 50 and 200 canola plants m^{-2}, 19 and 10 percent yield losses occurred, respectively, with 20 barley plant m^{-2} (O'Donovan *et al.*, 1988). Generally, volunteer wheat and barley densities were higher at low canola densities (O'Donovan *et al.*, 1988, 1989).

Seeding rate is the cultural practice that has the greatest influence on the crop density. Increasing the seeding rate will usually lead to a higher crop density; this will cause the crop to gain competitive advantage over weeds present and thus reduce overall weed interference. Therefore, the critical period of weed control should be shorter at higher crop densities because the crop will tolerate longer weed infestations and should not require weed-free maintenance for as long a period.

IWM

Integrated weed management is a component of integrated pest management; it incorporates more than one procedure (either of biological, mechanical, or cultural means) as a necessary means to manage a weed complex (Baldwin and Santelmann, 1980). Alternative weed control tactics must be involved with IPM to prevent and control herbicide resistance problems.

Tillage System

The results of a number of studies performed on weed interference as affected by tillage system are contradictory. Swanton and Weise (1991) stated that the presence of residue in zero-tillage fields causes weed suppression and did not result in requirements for increases in herbicide dosage or number of herbicide applications to control weeds. They stated that it has good potential for herbicide use reduction. Arshad *et al.* (1995) showed that neither tillage nor herbicide alone provided sufficient weed control, but a combination may be agronomically and environmentally desirable rather than depending on intensive use of either. They concluded based on their research that zero-tillage systems result in reduced weed control.

It is generally accepted that zero-tillage systems cause a shift in the species composition, for example, to more perennial weeds such as dandelion (*Taraxacum officinale* Web.) and wild rose (*Rosa spp.*). The use of conventional tillage in canola results in increased infestation of annual weeds such as wild buckwheat, but it often results in lower weed dry matter production by mid-season.

Reduced tillage is characterized by changing the intensity of tillage operations. For example, Arshad *et al.* (1995) compared conventional tillage (3 tillage operations) and zero-tillage to reduced tillage (one tillage operation per season). They found that reduced tillage did not have negative effects on soil properties or weed populations compared to conventional and zero-tillage. However, it did have a greater likelihood of yield improvement compared to zero tillage.

Cover Crop

The end of the critical period of weed control can be used for managing cover crops. This could be especially useful for row crops, such as corn, in conservation tillage systems (Swanton and Weise, 1991). The mulch produced by a cover crop should ideally suppress weeds during the critical period to avoid yield losses.

Cultivation

Initial flushes of annual weeds can be killed by shallow cultivation (Swanton and Weise, 1991). Tillage can be responsible for the degradation and erosion of soil over time. However, the benefits of weed destruction are noticed immediately, making it one of the most common cultural practices for weed control.

Biocontrol

Biological control of weeds, using insects and pathogens, can cause significant reductions in weed interference. Therefore, it can have an effect on the timing of when weeds should be removed. These can have a different effect on the cropping system than herbicides by promoting the growth of beneficial organisms.

Cultivar Selection

The competitive qualities of certain crops and varieties should be exploited for suppressing weed growth. Early emergence, high seedling vigour, fast rate of leaf expansion, rapid canopy development, rapid height development, early root growth, and increased root size should all be considered, because they can increase crop competitiveness. Therefore, the length of the critical period of weed control will decrease. Later maturing varieties of canola may be more susceptible to competition from weeds because weed interference may affect the crop for a longer period (O'Donovan *et al.*, 1989).

Planting Pattern

A uniform and dense plant distribution is desired to promote better use of resources (light water nutrients) and greater crop competitive ability. Planting in narrower rows can also suppress weed growth better. This was shown to occur in soybeans because of more rapid canopy closure (Légère and Schreiber, 1989).

Nutrient Placement

The availability of nutrients to the crop and weeds can affect the level of interference, and thus affect the critical period of weed control. It has been shown that weeds often use resources more rapidly and efficiently with added nutrients, which results in greater competitive ability (Walker and Buchanan, 1982).

The application of nutrients, such as nitrogen, can stimulate the germination of dormant weed seeds (Cavers and Benoit, 1989). Placement of the limiting nutrient close to the crop will greatly enhance their utilization of resources and competitiveness over the weeds, especially to those growing between the crop rows.

If the moisture content of the soil is low, canola emergence can be seriously reduced by nitrogen fertilizer placed with the seed at a rate of 11 to 22 kg/ha (Nyborg, 1961). The resulting poor emergence would give a competitive advantage to the weeds.

Crop Rotation

The composition and density of weed seed banks are often reflected by the rotation practices of the producer (Swanton and Weise, 1991) and thus can affect the level of weed interference in a given field.

Planting Date

In the Northern Plains, canola should be planted in early to mid-May to achieve optimum yield (Johnson *et al.*, 1995). If it is planted later, in late May to mid-June, reduced yield often occurs due to fewer pods produced per plant and a lower harvest index. Vigil *et al.* (1997) recommended planting be performed only when soil temperature is sustained above 8 degrees Celsius. At lower temperatures, certain cool season weeds, such as wild oats, may have a growth advantage over canola.

Weeds emerge during specific periods of the growing season (Stoller and Wax, 1973). Therefore, by delaying seeding, the peak emergence period of early emerging weeds may be avoided. These can be easily controlled by pre-seeding tillage, which will reduce the early season competitive stress on the crop.

Planting Depth

If small seeded crops, such as canola, are planted too deep, the emergence pattern will be uneven or sparse. This can lead to reduced yield and oil quality and increased competitive advantage for weed infestations. Therefore, it can affect the critical period, as well.

2.1.3 Practical Use of the Critical Period of Weed Control

The critical period of weed control is the optimum time to implement and maintain weed control in order to prevent yield losses (Hall *et al.*, 1992). Studies of the critical period provide useful information on which one can base weed control recommendations. Farmers rely heavily on herbicides for weed control. Any reduction in herbicide use will have beneficial effects by reducing their impact on non-target species, decreasing selection pressures for weed resistance, decreasing ground water contamination, creating cost effective cropping systems, and ensuring safe food supplies.

The critical length of the weed-free period is the minimum length of time that a crop must be maintained weed-free to prevent yield losses. One of its applications is to describe the length of residual activity required for pre-emergence herbicides (Weaver and Tan, 1987; Van Acker *et al.*, 1993a). If such herbicides remain effective for the duration of this period, there should not be any losses in yield due to competition from weeds. If the minimum weed-free period is relatively short in length, reliance on highly residual herbicides will be reduced. The dosage recommended to achieve sufficient control with these herbicides in a given crop may be decreased accordingly (Hall *et al.*, 1992; Swanton and Weise, 1991). With a rather long duration of the critical weed-free period, it may be wise to rely more heavily on the use of well-timed post-emergence herbicides (Weaver and Tan, 1983; Van Acker *et al.*, 1993a).

Another application of the critical weed-free period concept is in timing the planting of cover crops and implementing in-crop cultivation practices (Hall *et al.*, 1992). It can also illustrate when the timing of post-emergence weed control may be too early, because later emerging weeds may be able to cause a decrease in yields.

The second component of the critical period is the maximum length of time that emerging weeds can grow with the crop before they cause yield loss (Weaver and Tan, 1987). This is also known as the early season period threshold and is most important for defining when post-emergent controls must be applied to prevent yield losses due to interference. The critical timing of weed removal may also be useful to illustrate if late applications to a crop stand, which is under severe weed infestation, may have any value (Van Acker, personal comm.). After this weed-infested period, if weeds are allowed to remain in the crop, yields will decline due to interference.

Quantitative losses caused by weed interference at different stages of crop development are useful for making recommendations on the minimum control requirements, and they can be used to create a maximum effect when controls are limited (Roberts, 1976). Critical period studies also provide a guide for future studies in crop-weed interference and alternative methods of weed control.

2.2. Critical Period of Weed Control in *Brassica napus* L.

2.2.1 Background

In the past, few chemical herbicides have been available for weed control in canola. Trifluralin was introduced in 1970 as a pre-emergence herbicide for green foxtail (*Setaria viridis*) and broadleaf weeds. Hoegrass[1] (diclofop) was introduced in 1976, and Poast® (sethoxydim) in 1983, for grassy weed control. Triazine tolerant canola varieties became available in the early 1980's, which offered good weed control but poor yield relative to conventional varieties. Consistent reductions in yield and biomass from 10 to 20 percent

[1] AgrEvo Canada Inc., 295 Henderson Drive, Regina, Saskatchewan, S4N 6C2, Canada

could often be noticed in triazine tolerant varieties (Forcella, 1987). Other, post-emergence sulfonylurea herbicides such as Muster® (ethametsulfuron) were introduced in the late 1980's. Several additional grassy herbicides were introduced in the early 1990's.

In the mid-1980's, the promotion of integrated pest management increased the popularity of a reduced reliance on pesticides, and it encouraged alternative methods of pest control. This helped to create a declining trend in herbicide use (Thill *et al.*, 1991); other factors, which led to reduced actual use, included increasing herbicide costs and fewer available herbicides.

With the recent introduction of high yielding varieties of herbicide tolerant canola, the trends of herbicide application have shifted to an increase in post-emergence usage. This, along with wide windows of application for tolerant canola varieties, has developed interest in studies on the timing of herbicide application in canola.

To address public concern on reducing herbicidal impacts from crop production, studies are needed to evaluate the minimum number of applications and length of residual activity required for maintenance of maximum crop yield potential.

Manitoba canola production comprises about 23% of the total volume and 19.1% of the total area produced in Canada (Manitoba Agriculture, 1998b). Global rapeseed production increased 6.5% in 1998/99 relative to the 1997/98 season (Manitoba Agriculture, 1998a). In the past decade, the general trend has been toward a shift from decreasing production acreage of wheat to increasing production of canola (Dave Donaghy, personal comm.). The reason for recent interest in a critical period study in canola has been driven from these recent changes in crop production in western Canada.

2.2.2 Time of Weed Control in *Brassica napus* L.

Crop yield is affected by the phenological stage of development at which weeds are removed (Swanton and Chandler, 1989). When herbicide was applied at the 1st to 6th leaf stage of wild mustard, canola yields were similar to that of the weed-free treatment. However, when removal occurred at the early flower stage, yields were significantly reduced, indicating the need for early removal to prevent yield losses.

Early removal of wild mustard can minimize the negative effects of reduced yield from competition and quality reduction from seed contamination (McMullan *et al.*, 1994). When wild mustard and canola emerged at the same time, removal at the 4th to 8th leaf stage of the wild mustard plants resulted in significantly reduced yield compared to the yield of the weed-free treatment. However, the yield of the treatment with removal at the 2nd to 4th leaf stage of the wild mustard in the study by McMullan *et al.* (1994) was not significantly different from the weed-free treatment. Blackshaw *et al.* (1987) also found that significant reductions in the dry weight of rapeseed occurred rather early in the season, at 38 to 39 days after emergence, from infestation of 20 weeds m^{-2}.

It was occasionally noticed, in the study performed by McMullan *et al.* (1994) that yield increases from 2.2 to 8.9% over the treatment kept weed-free by herbicides occurred for treatments that were sprayed at the early (2nd to 4th leaf) stage. This occurred in all types of canola (*B. napus*, *B. rapa*, TTC) in 4 out of the 9 site-years. It may be a result of increased vigour of the plants from early stress placed on them by herbicide metabolism or a result of too much stress placed on the weed-free checks. The remaining five site-years were 3 to 17% below the yield of the weed-free treatment for the early removal (2-4 leaf) treatments.

The removal of wild mustard plants at the 2nd to 3rd leaf stage created increases in canola yield of 25, 139, and 86% (Kirkland, 1995). Weeds removed at the 5th leaf stage of canola development showed yield improvements of 55% to 180% over the weedy check (Chow and Dorrell, 1979). Oil content was also significantly higher than the check, however, fatty acid composition and protein content of the meal were unaffected.

Canola yields decreased when volunteer barley emerged earlier relative to canola (O'Donovan, 1992). For example, when barley emerged 8 days, before the canola yield was 90 g m^{-2}; when it emerged 8 days after the canola, yield was 156 g m^{-2}. The effect of density tended to diminish the later that barley emerged relative to canola. Even high densities of weeds may have a minimal impact on canola yield when emerging late. This implies that the minimum length of the weed-free period for canola may not be very long.

O'Donovan (1992) suggested that the control of early emerging weeds may be more critical to canola yields than those that emerge later. Forcella (1987) implied that 128 wild oat plants m^{-2} could reduce the growth and yield of canola, even with removal at the 2nd to 3rd leaf stage of the wild oat plants. Therefore, high densities of weeds early in the growing season may reduce canola yield, where low densities may not.

Blackshaw (1989) noted that weed control was always greatest at the earlier growth stages, and this sometimes could be correlated to greater canola yields. It was suggested that the stage of application might not be very important. However, a possibility existed for receiving higher yields and achieving better inhibition of weed growth and seed production by earlier removal (the 2nd leaf stage of the crop).

Wall (1994) performed a study on the critical period of weed control for wild mustard in canola from 1994 to 1995 using glufosinate tolerant canola. Treflan was applied at 1.1 kg/ha for control of other weeds. The wild mustard was broadcasted on the soil before the canola was seeded, which may have been partially responsible for resultant early emergence pattern of the wild mustard. Almost all weeds emerged before the 1st leaf stage of the canola, 9 days after the emergence of canola. Thus, it was found that the minimum duration of weed-free period that was required was only up to the 1st leaf stage of canola. It was shown that weed infestations could be tolerated up to the 4th leaf stage in 1994 and the 6th leaf stage in 1995 and 1996 before there were significant reductions in canola yield (Kelner, 1997). Oil content was not significantly affected by the period of weed infestation (Wall, 1994).

The results correspond with experiments conducted by the Canola Council of Canada (1998) on the timing of weed removal. These reported a yield increase from early removal (1st to 3rd leaf), as opposed to late removal (4th to 6th leaf). The results from Bowren (1974) show a similar relationship for rapeseed response to wild oats. With earlier weed removal, yields are generally better than the yields from the late removal of weeds.

2.3. Growth Analysis in *Brassica napus* L.

2.3.1 General

Harper and Berkenkamp (1975) designed a descriptive and illustrative key for identifying the development stages of canola. This method divides development into preemergence, seedling, rosette (several leaf stages), bud (inflorescence visible to yellowing), flowering (flowers opening to completely opened), and ripening (lower pods full to plant senescing).

The greatest increases in leaf area and dry weight occurred at low levels of applied nitrogen, larger application rates resulted in lower rates of increase (Scott *et al.*, 1973). Leaf area increased and peaked to about 4-5 weeks after emergence, and steadily declined after this period (Allen *et al.*, 1971).

The relative growth rate of canola (weight/weight) and relative growth rate of leaf area (area/area) were very similar (Wilson, 1966), and their response to temperature was greater than that for the net assimilation rate (weight/area). This difference was greatest at lower temperatures. This was mainly due to the increase in leaf area ratio (area/weight of plant) and specific leaf area (area/weight of leaf) with increased temperature.

Net assimilation rate responds strongly to light availability (Wilson, 1966). Narrowly spaced plants cause mutual shading that can decrease the net assimilation rate, which is the rate of dry matter increase that each unit of leaf area produces. Therefore, this will be affected by weed interference.

The need for information on the physiological processes that determine the yield of the plant is important to understand how to maximize yield in a given crop. Allen *et al.* (1971) found that when canola pods formed and developed, a large increase in dry weight occurred with a lower leaf area index compared to earlier development stages. A decrease in LAI occurring late in the season is compensated by an increase in the surface area of the pods. It is likely that pods produce much of the photosynthate for pod and seed growth (Allen *et al.*, 1971; Hozyo *et al.*, 1973). Freyman *et al.* (1973) used defoliation and $^{14}CO_2$ labeling to show that the leaves contribute to the dry matter accumulation of the seeds, and the photosynthate from the leaves moves selectively into the filling pods.

In canola, higher nitrogen levels have been shown to lead to more pods developed per plant and greater pod growth rates and yield (Allen *et al.*, 1971). Where moisture was adequate, the pods increased the total photosynthetic surface area of the plant and the senescing leaf area decreased this area more slowly (Krogman and Hobbs, 1975). Thus, yield increases under adequate moisture were likely due to increase the photosynthetic activity and area, giving a possibly better competitive advantage. In addition, the daily evapotranspiration and surface area of green tissue were closely related.

Johnson *et al.* (1995) showed that reduced yield from late planting of canola may result from fewer pods developed per plant and a decreased harvest index. Canola flowers over an extended period, so the decision of when to harvest must be a compromise between obtaining maximum oil yield and losing seed due to early pods shattering (Scott *et al.*, 1973).

2.3.2 Under Competition

Competition for light is more important later in the season and the length of the critical weed-free period will depend on the relative growth rates of the weeds and crop (Weaver *et al.*, 1992).

In corn, weed interference decreased the maximum predicted leaf area per leaf, total leaf area produced, and leaf area index (Hall *et al.*, 1992). It also reduced the number of expanded and emerged leaves and increased the number of senescent leaves

The net assimilation rate of canola is strongly affected by light availability, so weed interference will decrease the rate of dry matter increase per unit of leaf area (Wilson, 1966). Variations in net assimilation rate caused by temperature fluctuations will not be as large as the variations in light, due to the competition from mutual shading and weeds.

2.4.0 Crop Tolerance and Herbicide Efficacy

Generally, susceptibility of weeds to post-emergence herbicides declines after the 6th leaf stage, showing that herbicidal activity is affected by weed growth stage (Swanton and Chandler, 1989). The dry weight of wild mustard was not affected by applying herbicide at the early flower stage, but this may be because the maximum dry weight was already achieved by the plants. Lack to reduced biomass from herbicide application does not necessarily mean that the weeds were not controlled. Crop injury increased with increased dosage of imazamethabenz and declined with increased growth stage (Swanton and Chandler, 1989). With glufosinate herbicide on Innovator canola, it was found that repeated application did not have an effect on the yield of the canola crop (see Appendix 7.3).

2.5 Objectives

The objective of this thesis project was to determine the critical period of weed control in canola grown in Manitoba. It has already been shown that weed control is required by the 4th or 6th leaf stage and that the crop requires a weed-free period up to the 1st leaf stage in an artificially produced wild mustard population (Wall, 1994). However, it was not known if these responses to weed competition occur with a natural weed population. Our study should help to ascertain the yield response to a natural weed infestation and will be broadly applicable through the use of three distinct locations and by relating the critical period of weed control to the growth stages of the crop. Quantitative measurements of growth of the crop will also be made to compare the physiological response of the crop to weed interference. This will isolate growth characteristics of the species that contribute to competitive ability with weeds and contribute to the knowledge required to breed superior canola varieties in the future.

Chapter 3

The critical period of weed control in canola (*Brassica napus* L.) in Manitoba

Introduction

The critical period of weed control is the primary analysis method for studying the magnitude of yield loss associated with the length of time that weeds affect a crop (Weaver and Tan, 1987). Within this period, weed control measures should be maintained to prevent yield losses due to weed interference.

Two sets of treatments must be used to find the critical period of weed control (Van Acker *et al.*, 1993a). In the first set, the crop is kept weed-free for increasing lengths of time to find the period that the crop must be kept weed-free to maintain maximum yield. In the second set of treatments, weeds are allowed to grow with the crop for increasing lengths of time to find the maximum period that weed infestation can be tolerated by the crop before yield is reduced (Weaver *et al.*, 1992). The critical period of weed control is is combination of these two periods, and weed presence before and after this period will not cause significant yield reductions (Dawson, 1986; Weaver and Tan, 1983).

Critical period studies are ideal for making weed control recommendations as they reveal the optimum time for implementing and maintaining weed control (Hall *et al.*, 1992; Van Acker *et al.*, 1993a). The critical length of the weed-free period can be used to identify the length of residual activity required for preemergence herbicides to be effective, the proper time for cover crop planting, timing for in-crop cultivation, and the timing of multiple postemergence weed control events. In canola, critical period research has become important for determining the length of time that weeds can be left in the crop, especially with the increased use of herbicide-tolerant canola (HTC) varieties. In Manitoba, the proportion of canola planted as HTC varieties increased from 14% in 1996 to 64% in 1999 (Manitoba Agriculture, 1999). Identifying the critical period of weed control may help to reduce the use of herbicides if it is found that a single, well-timed postemergence application can provide adequate weed control. This will make cropping practices more cost effective for producers and reduce the amount of unneeded herbicide that is introduced into the environment.

Previous research on the effect of timing of weed interference in canola has shown that yield reduction from volunteer barley (*Hordeum vulgare* L.) competition diminishes the later that it emerges relative to the crop (O'Donovan, 1992). This implies that the critical weed-free period may be very short in some cases. Wall (1994) for example, found that with wild mustard (*Brassica kaber* (D.C.) L. C. Wheeler), the weed-free period required to prevent yield losses in canola ended before the first leaf stage. McMullan *et al.* (1994) showed that early in-crop removal of wild mustard from canola prevented yield loss, while Wall (1994) found that wild mustard could grow with canola until the 4^{th} or 6^{th} leaf stage of development without causing yield reductions.

Although the preceding analyses were useful, they were not a complete examination of the critical period of weed control in canola. The studies by Wall (1994) and McMullan *et al.* (1994) examined only the critical time of weed removal with accuracy. Also, only one weed species was included in these studies, and this species was sown into the experimental plots. In a commercial field situation there is a great range of species and emergence patterns (Baldwin and Santelmann, 1980; Stoller and Wax, 1973). These factors can greatly affect the critical period of weed control (Van Acker *et al.*, 1993a).

The objective of this study was to define the critical period of weed control for canola in Manitoba. To ensure the greatest applicability of the results, a natural weed population was used, and the weed control timing was related to the crop growth stages as well as days after canola emergence.

Materials and Methods

Site Selection and Experimental Design

Trials were conducted at three distinct locations in 1998 and 1999. The first site was located at the University of Manitoba research station in Carman, Manitoba and will be referred to as Carman. This was located on a Winkler Series soil comprised of 60% sand, 15% silt, and 25% clay with a mean pH of 5.8 and soil organic matter content of 6.5%. Plots at this site were 1.9m by 8m in 1998 and 1.9m by 7m in 1999; plot sizes varied in the experiment due to spatial constraints and the equipment available for the seeding and harvesting operations at each site and year.

The second site was located at Kelburn Farm[2] near Winnipeg, Manitoba and will be referred to as Winnipeg. The soil was classified as orthic, dark gray, St. Norbert Clay, having a composition of 7% sand, 27% silt, and 66% clay with a pH of 7.4 and organic matter content of 3%. Plots were 3.05m by 8m in 1998 and 1.8m by 8m in 1999. In each plot, only the center 1.22m was harvested for yield.

The third site was located at the Cyanamid Research Farm, near Homewood, Manitoba and will be referred to as Homewood. The soil at this site was a gleyed, black, Rignold Series soil with a texture of 68% sand, 19% silt, and 13% clay, pH of 8.4, and

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[2]James Richardson International Ltd., 2800 Lombard Place, Winnipeg, Manitoba, R3B 0X8, Canada

organic matter content of 2.3%. The plots at this site were 1.85m by 8m, but only the center 1.22 m of the plots were harvested for yield.

The plots were cultivated in the spring, and in some instances sprayed, shortly before the crop was seeded at a rate of 6 kg ha^{-1}. At Carman, cultivation was performed with a field cultivator, while at Homewood a tandem-disc plow was used. Fall chisel plow and spring spraying were used at the Winnipeg site to prevent forming an unsuitably lumpy seedbed in the heavy clay soil. Terbufos (Counter 5G[3]) granular insecticide was applied along with the seed at all sites at a rate of 6 kg ha^{-1} as a preventative measure against insects.

At Carman, 200 kg ha^{-1} of 23-10-5-5 was applied and incorporated on April 28, 1998 and April 22, 1999; the crop was seeded at this site on May 5, 1998, April 26, 1999, and May 14, 1999. In 1999 and the early and late-seeded experiments at Carman were situated next to each other. The Homewood site received 127.8 kg ha^{-1} of 8.9-33.0-6.7-0.25 prior to seeding and 55 kg ha^{-1} of 11-51-0 with the seeding operation on May 28, 1999. The Winnipeg site received no fertilizer application, and it was seeded on May 23, 1998 and May 27, 1999.

Rainfall and temperature data for each site is shown in Appendix 7.1.

The timing of removal of weeds was based on the growth stage of the canola crop (Harper and Berkenkamp, 1975). This made the results biologically based rather than site-year specific. The critical period of weed control was determined by using two sets of treatments in a randomized complete block design with four reps. In the first set, the crop was kept weed-free up until the cotyledon, 2nd leaf, 4th leaf, 6th leaf, 8-10th leaf, and

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[3]Cyanamid Crop Protection, 88 McNabb Street, Markham, Ontario, L3R 6E6, Canada

early flower growth stages of the canola. In the second set of treatments weeds were allowed to interfere with the crop for increasing durations up until the cotyledon, 2nd leaf, 4th leaf, 6th leaf, 8-10th leaf, and early flower growth stages of the canola. In both sets of treatments, mid-flower was used as the last growth stage if 8-10th leaf and early flower occurred at the same time.

The variety of canola used was Innovator[3], which is tolerant to glufosinate ammonium. Weed control for the different treatments was accomplished using the herbicide, glufosinate (Liberty[4]). The herbicide was applied via a backpack sprayer with a 1.5 m boom, held 0.5 m above the crop canopy. Some hand weeding of the larger and more difficult to control weeds was required at times. The rate of Liberty used in 1998 was 2 L ac^{-1} (741.29 g a.i. ha^{-1}) at a water volume of 45 L ac^{-1}. The sprayer was equipped with Teejet 80015 nozzles and was regulated to a pressure of 30 psi. In 1999, the rate of Liberty was reduced to 1.3 L ac^{-1} (593 g a.i. ha^{-1}) because it was thought that control was sufficient at the recommended rate. Due to their significantly non-uniform distribution across trials, perennial weeds were controlled at all locations using 1.1 L ac^{-1} (967 g a.i. ha^{-1}) glyphosate (Roundup[5]) herbicide prior to seeding. To prevent sclerotinia infection, iprodione (Rovral Flo[6]) fungicide was applied at the 25% bloom stage of the crop for the Carman and Winnipeg locations.

A natural, mixed weed species population was present at each site, which meant that the experiments tested for general weed interference. In 1998, the weed population at Winnipeg was augmented with seeds of wild oat (*Avena fatua* L.), green foxtail (*Setaria viridis* (L.) Beauv.), redroot pigweed (*Amaranthus retroflexus* L.), wild mustard, and

[4] AgrEvo Canada Inc., 295 Henderson Drive, Regina, Saskatchewan, S4N 6C2, Canada
[5] Monsanto, 800 North Lindbergh, St. Louis, Missouri 63167, USA

volunteer barley at rates of 1.82, 0.133, 0.04, 0.3, and 1.12 g m^{-2}, respectively applied prior to seeding. At the Winnipeg site in 1999, barley, green foxtail, and redroot pigweed were applied at rates of 1.12, 0.266, and 0.08 g m^{-2}, respectively. At the Carman site in 1999, wheat (*Triticum aestivum* L.) seeds were added at a rate of 0.672 g m^{-2}.

Measurements

To track the emergence periodicity of weeds at each site, the densities of plants (weed and crop) were counted throughout the growing season from fixed 0.25 m^2 quadrats in the plots kept weedy all year. In 1998, measurements were made at each canola growth stage, but more samples were taken earlier in the season in 1999 to accurately characterize the emergence periodicity of weeds before the cotyledon stage and between crop growth stages.

To monitor the amount of weed regrowth that occurred after each duration of weed-free period, a 0.25 m^2 sample of weedy material was removed from the back of the plots that were kept weed-free for increasing periods. Sampling was done at the late flowering stage of the canola. The samples were separated by species, counted, dried at 80°C for 24 hours, and weighed. The weed dry biomass, densities, and species for the weedy control at each site are listed in Table 3.3.

Method of harvesting was dependent on the availability of equipment at each location. At Carman, entire plots were swathed on August 7, 1998 and on August 10 and August 17, 1999 for the early and late-seeded trials, respectively. These plots were then harvested using a Wintersteiger[7] combine on August 17, 1998 and on August 24 and August 25, 1999 for the early and late-seeded trials, respectively. At Homewood, plots

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[6] **Rhone Poulenc, Winnipeg, MB**

[7] **Wintersteiger, 964 Bergar, Laval, Québec, H7L 5A1, Canada**

were desiccated with 544 g a.i. ha^{-1} of diquat (Reglone Pro[8] herbicide) on August 30, 1999, and the center 1.22 m of each plot was harvested directly on September 16, 1999 with a Hege[9] combine. At Winnipeg, the plots were desiccated with 544 g a.i. ha^{-1} of diquat on August 17, 1998 (no desiccation was applied in 1999) and the center 1.22 m was harvested directly with a Hege combine on August 31, 1998 and September 1, 1999.

Non-crop dockage was removed from the yield samples using a Carter[10] dockage tester and the method outlined by the Canadian Grain Commission (1991). The yield after dockage was expressed as a percentage of the yield of the weed-free control.

Statistical Analysis

Nonlinear regression functions were fitted to the yield data using SAS[11] statistical software. This was performed separately for each site and each year. The Gompertz equation (1) (Ratkowsky, 1990) was used to describe the effect of length of weed-free period on yield.

$$Y=A\exp(-B\exp(-kT)) \quad (1)$$

Where Y is the yield as a percentage of the weed-free control, A is the yield asymptote, B and k are constants, and T is time in days after emergence of the crop. The logistic equation (2) (Ratkowsky, 1990) was used to describe the effect of increasing duration of weed infestation on the yield of canola.

[8] Zeneca Agro, Suite 250, 3115 -12 Street NE, Calgary, Alberta, T2E 7J2, Canada
[9] Hege Maschinen GmbH, Domäne Hohebuch, D-74638, Waldenburg, Germany
[10] Carter Day International Inc., 500-73[rd] Ave. NE, Minneapolis, Minnesota 55432, USA
[11] SAS Institute Inc., SAS Campus Drive, Cary, NC 27513-2414, USA

$$Y=C+D/(1+\exp(-A+BT)) \quad (2)$$

Where Y is the yield of the crop expressed as a percentage of the weed-free control, A and B are constants, C is the lower yield asymptote, D is the difference between the upper and lower yield asymptotes, and T is time in days after emergence. The critical period of weed control was determined in days after emergence for the predetermined yield loss levels of 2.5, 5, and 10% using these equations. The parameters of the equations for each site are shown in Tables 3.1 and 3.2. The same regression procedure was implemented for fitting trends to the density and dry biomass of weed regrowth as a function of length of the weed-free period (Figure 3.2). The logistic and exponential decay functions were chosen for the density and dry biomass of weed regrowth relationships, based on their biologically realistic fits to the data. Standard error of the mean for each of the sample timings was calculated for the emergence periodicity of total weeds at each site (Figure 3.3).

Table 3.1. Parameter estimates and standard errors for the Gompertz equation describing the critical weed-free period.

		Parameter Estimates		
Location	Year	k	A	B
Carman	1998	0.10 (0.28)	98.11 (1.37)	0.02 (0.03)
Winnipeg	1998	0.03 (0.04)	99.60 (9.13)	0.20 (0.10)
Carman (early-seeded)	1999	0.06 (0.01)	100.05 (4.91)	1.25 (0.18)
Carman (late-seeded)	1999	0.60 (0.86)	112.73 (4.97)	0.82 (0.24)
Winnipeg	1999	0.16 (0.19)	97.34 (2.02)	0.08 (0.04)
Homewood	1999	0.50 (0.59)	94.71 (3.75)	0.41 (0.14)

Table 3.2. Parameter estimates and standard errors for the logistic equation describing the critical timing of weed removal.

Location	Year	Parameter Estimates							
		A		B		C		D	
Carman	1998	47.66	(105.92)	1.10	(2.47)	95.13	(2.13)	9.63	(2.53)
Winnipeg	1998	20.99	(9.42)	0.06	(0.28)	79.39	(1.61)	18.00	(1.57)
Carman (early-seeded)	1999	60.01	(42.08)	1.52	(1.08)	34.39	(3.53)	66.75	(4.67)
Carman (late-seeded)	1999	9.39	(6.53)	0.41	(0.28)	44.50	(8.16)	54.34	(10.21)
Winnipeg	1999	21.06	(34.68)	0.63	(1.08)	91.00	(2.69)	9.52	(2.95)
Homewood	1999	2.90	(8.98)	0.05	(0.37)	48.91	(284.68)	58.17	(332.66)

Results and Discussion

The Critical Period of Weed Control

The critical period of weed control is often thought of as the single discrete period described by Nieto *et al.* (1968). However, in our study the critical period varied considerably in terms of the days after emergence and the growth stages of the crop between locations. Other studies have shown this phenomenon for other crop species (Hall *et al*, 1992; Van Acker *et al.*, 1993a). The factors most greatly affecting the critical period of weed control are the relative competitive abilities and growth rates of the crop and weeds (Weaver and Tan, 1987), but the critical period of weed control is also influenced by factors that affect weed interference (Hall *et al.*, 1992). Therefore, differences in the diversity of weed species, weed density, distribution, and emergence periodicity, the nutrient status of the soil, weather, and cultural practices can cause variation in the critical period of weed control between locations (Swanton and Weise, 1991). Differences in the species composition and densities of weed populations between sites are shown in Table 3.3.

As a result of these differences between sites, the six site-years were analyzed separately (Figure 3.1). The Winnipeg site in 1998 and early-seeded Carman site in 1999

Table 3.3. Species spectrum, mean weed dry biomass, and density in unweeded treatments, measured at late flowering.

Location	Weed species	Total weed dry biomass	Total weed density	Species dry biomass	Species density
		g m^{-2}	plants m^{-2}	g m^{-2}	plants m^{-2}
Carman 1998	Green foxtail	277.13	68	4.34	13
	Redroot pigweed			17.16	33
	Wild oat			10.32	8
	Lambsquarters (*Chenopodium album* L)			61.99	9
	Yellow foxtail (*Setaria glauca* (L.) Beauv.)			116.12	2
	Barnyard Grass (*Echinochloa crus-galli* (L). Beauv.)			0.20	2
	Wild mustard			67.00	1
Winnipeg 1998	Green foxtail	99.29	138	13.17	65
	Redroot pigweed			1.47	29
	Wild oat			20.54	15
	Lambsquarters			1.36	2
	Barnyard Grass			0.22	1
	Wild mustard			51.05	7
	Volunteer wheat			9.82	28
	Volunteer barley			0.20	1
	Dandelion (*Taraxacum officinale* Weber in Wiggers)			1.46	4
Carman (early-seeded) 1999	Green foxtail, Yellow foxtail, Barnyardgrass	386.12	831	65.95	221
	Redroot pigweed			28.49	131
	Wild buckwheat (*Polygonum convolvulus* L.)			90.79	384
	Smartweed (*Polygonum persecaria* L.)			39.91	35
	Wild oat			121.20	20
	Common lambsquarters			7.34	11
	Volunteer flax (*Linum usitatissimum* L.)			16.87	27
	Volunteer wheat			15.57	2
Carman (late-seeded) 1999	Wild buckwheat	387.19	406	63.89	127
	Redroot pigweed			96.65	113
	Green foxtail, Yellow foxtail , Barnyardgrass			137.30	136
	Common lambsquarters			4.81	4
	Smartweed			31.81	8
	Volunteer flax			10.55	10
	Dandelion			4.05	2
	Clover (*Trifolium* spp.)			0.13	1
	Volunteer wheat			38.00	5
	Wild oat			93.87	10
	Quackgrass (*Elytrigia repens* (L.) Nevski)			9.54	4
	Round-leaved mallow (*Malva parviflora* L.)			0.94	1
Homewood 1999	Redroot pigweed	47.28	70	43.33	49
	Green foxtail, Yellow foxtail, Barnyardgrass			2.03	12
	Common purslane (*Portulaca oleracea* L.)			0.21	2
	Common lambsquarters			0.36	3
	Wild oat			1.24	2
	Wild buckwheat			0.06	1
	Wild mustard			0.05	1
Winnipeg 1999	Volunteer barley	27.97	80	25.28	16
	Green foxtail, Yellow foxtail, Barnyardgrass			2.26	44
	Common lambsquarters			0.06	3
	Dandelion			0.02	4
	Redroot pigweed			0.23	8
	Stinkweed (*Thlaspi arvense* L.)			0.01	1
	Wild mustard			0.09	1
	Other			0.03	3

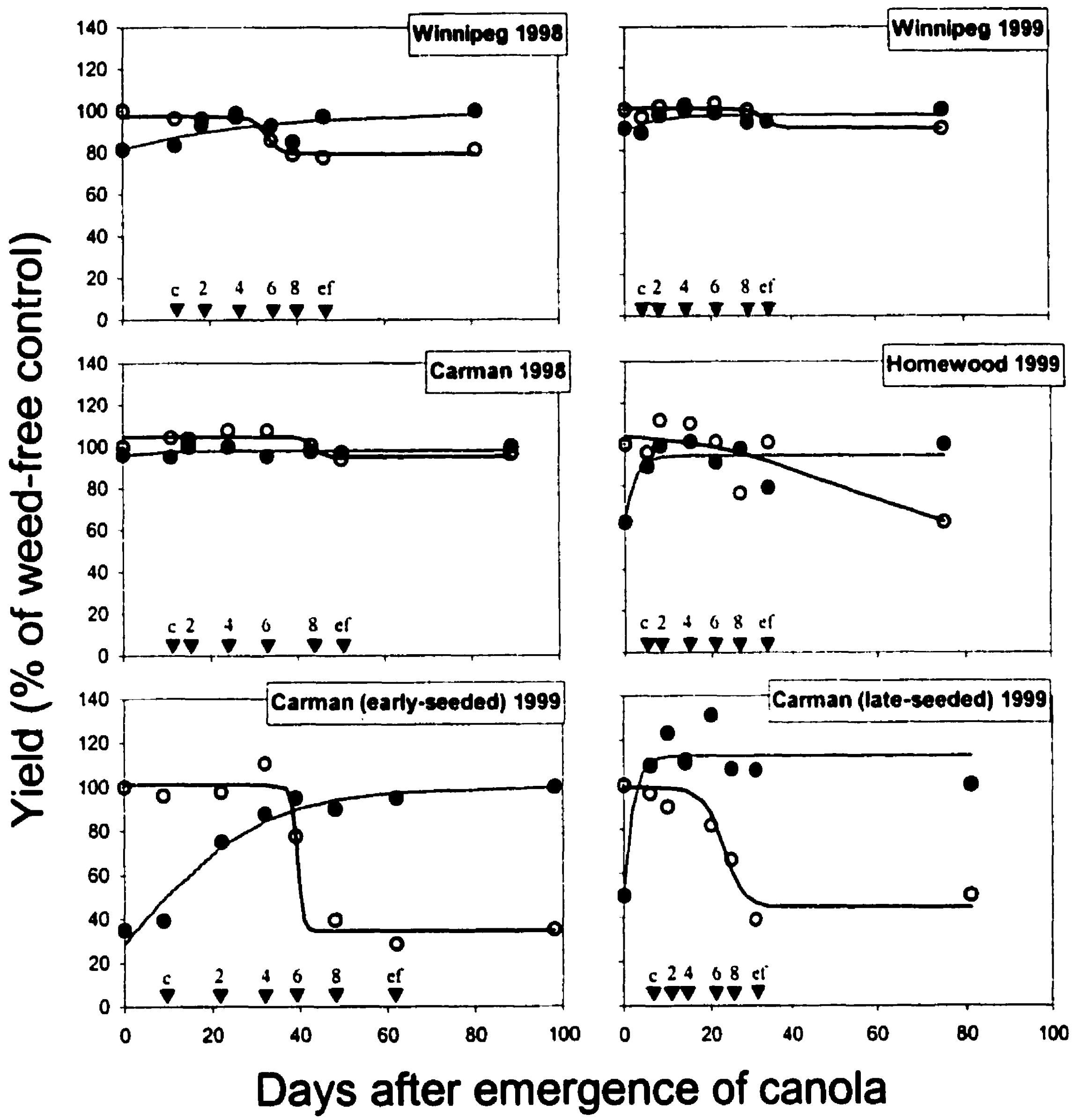

Figure 3.1. Canola yield response to increasing length of weed-free period ( ) or duration of weed infestation ( ) in days after emergence of the crop at three locations in 1998 and 1999 as calculated from the parameters in Tables 3.2 and 3.3. The development stages of the crop, indicated by the arrows, were cotyledon (c), 2nd leaf (2), 4th leaf (4), 6th leaf (6), 8-10th leaf (8), and early flowering (ef).

were the only locations in which the Gompertz and logistic curves overlapped in a manner that produced a critical period of weed control. In all other instances, the critical timing of weed removal was longer than the critical weed-free period.

Roberts (1976) described three relationships that can exist within critical period studies. In the first, the weed-infested period is longer than the minimum weed-free period, and the crop must be kept free of weeds between these timings to prevent yield loss. In the second, weeds can remain in the crop for the same duration that a weed infestation can be tolerated. In this situation, yield loss prevention will be successful if weed control is maintained at this one critical point in time. In the third, the critical timing of weed removal is longer than the critical weed-free period. In this case, yield loss will not occur if weeds are controlled at any point between these critical times. Therefore, we will discuss the critical period of weed control for canola in terms of the critical weed-free period and the critical timing of weed removal.

The Critical Weed-Free Period

The critical weed-free period was variable at the lower levels of acceptable yield loss (Table 3.4). At the 2.5% yield loss level, this period ranged from cotyledon to harvest stage (3 to 75 DAE). At the 5% yield loss level, the weed-free period ranged from seeding to harvest (0 to 73 DAE). However, if the acceptable level of yield loss was increased to 10%, the crop required a weed-free period ranging only from seeding to the 6^{th} leaf stage (0 to 39 DAE).

The stability in yield when canola was kept weed-free up to the 6^{th} leaf stage can be related to a sharp decline in the regrowth of weeds as the weed-free period increased (Figure 3.2). After the 4^{th} leaf stage, the density of weeds emerging into the crop was reduced to less than 15% of the plots kept weedy all year (Figure 3.2a). In addition, the weeds that emerged after the 4th leaf stage produced less biomass compared to earlier emerging weeds (Figure 3.2b). Among sites, the weed biomass and density was variable for weeds emerging up to the 4th leaf stage, which helps to explain the variability in yield loss between sites that existed for short weed-free periods (Figure 3.1).

Table 3.4. The critical weed-free period for canola in days after emergence and growth stage of the crop, calculated from the Gompertz equation for 2.5, 5, and 10% yield loss levels (dashes denote where yield loss, less than that specified, was never achieved).

		Length and stage of weed-free period required					
		2.5%		5%		10%	
Location	Year	DAE	Stage	DAE	Stage	DAE	Stage
Carman	1998	13	2nd	0	seed	0	seed
Winnipeg	1998	65	late fl.	42	early fl.	20	4th
Carman (early-seeded)	1999	62	early fl.	51	8-10th	39	6th
Carman (late-seeded)	1999	3	cotyledon	3	cotyledon	2	cotyledon
Winnipeg	1999	75	harvest	8	2nd	1	cotyledon
Homewood	1999	73	harvest	73	harvest	4	2nd

Canopy closure by the crop may have prevented some weeds from emerging after the 4th leaf stage (Ross and Harper, 1972). O'Donovan (1992) found that the effect of weed density on crop yield tended to diminish the later that volunteer barley emerged relative to canola. Therefore, even high densities of weeds may have a minimal impact on canola if they emerge after the crop.

According to our data, many weeds did not typically emerge beyond the timing of 4th leaf stage of canola. Previous studies have shown that the critical weed-free period depends largely on the germination pattern of the weed species present (Weaver and Tan, 1987). After the 4th leaf stage (approximately 32 DAE), the emergence of weeds had ceased at all sites (Figure 3.3). The considerable differences between sites in density and characteristics (texture, drainage), climate and weather (rainfall, temperature)

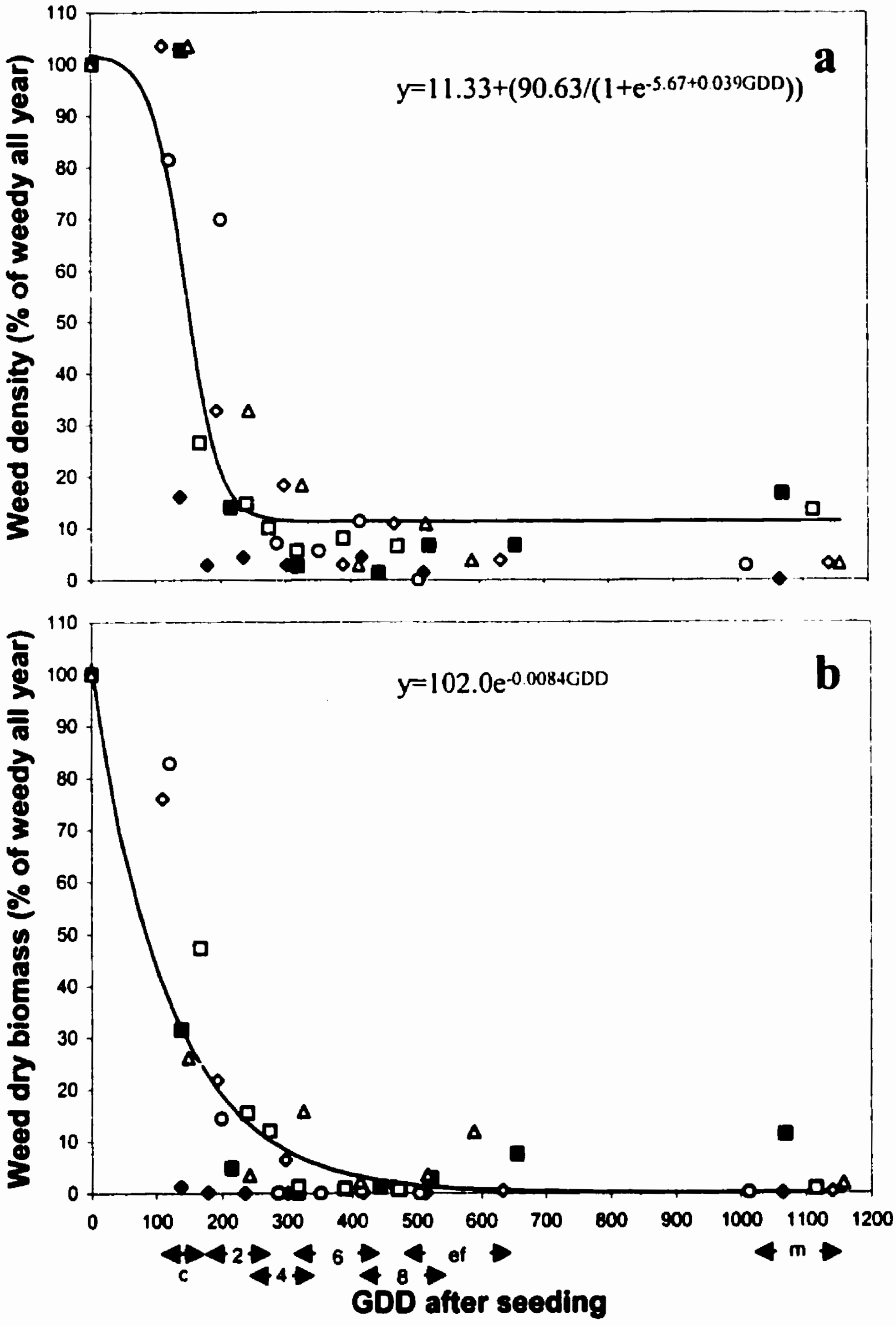

Figure 3.2. The density (a) and dry biomass (b) of total weed regrowth after increasing lengths of weed-free period at all sites. The sites were ◆ Carman 1998, ■ Winnipeg 1998, ◇ Carman (early-seeded) 1999, □ Carman (late-seeded) 1999, Homewood 1999, and Δ Winnipeg 1999 at the development stages of cotyledon (c), 2nd leaf (2), 4th leaf (4), 6th leaf (6), 8-10th leaf (8), early flowering (ef), and physiological maturity (m).

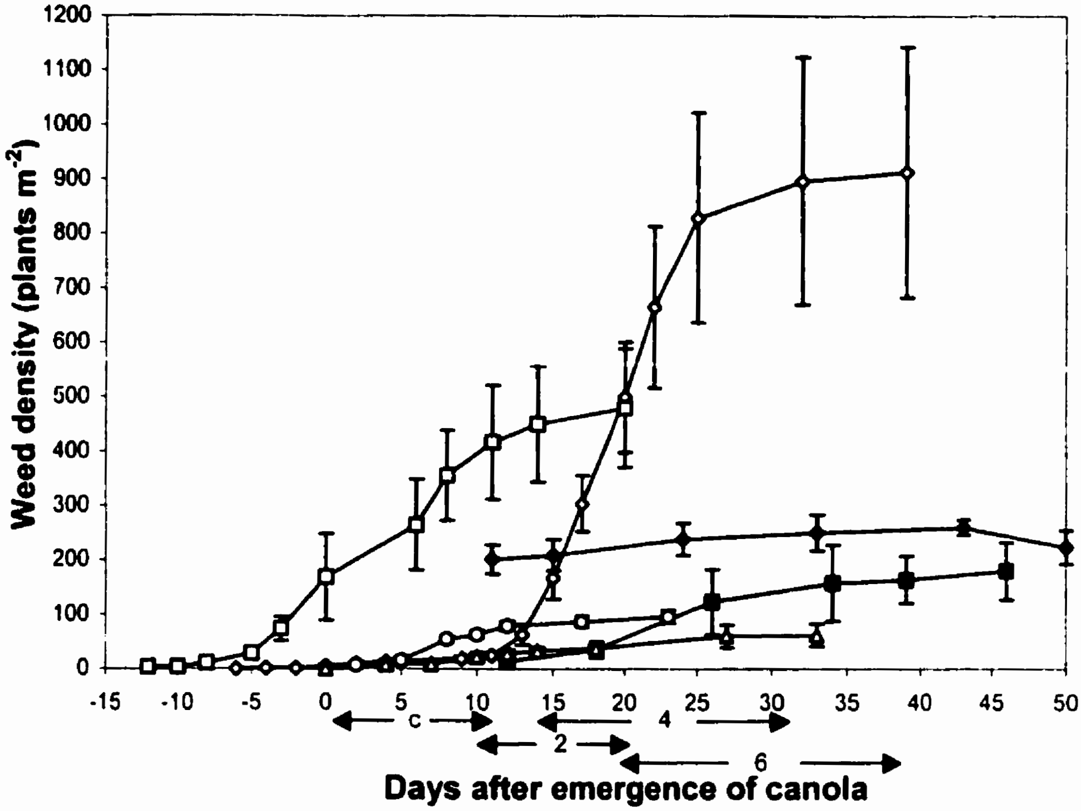

Figure 3.3. The emergence periodicity of the total weed population at each site. The sites were ◆ Carman 1998, ■ Winnipeg 1998, ◇ Carman (early-seeded) 1999, □ Carman (late-seeded) 1999, Homewood 1999, and Δ Winnipeg 1999 at the canola development stages of cotyledon (c), 2nd leaf (2), 4th leaf (4), and 6th leaf (6).

composition of species of weeds emerging were most likely caused by differences in soil (see appendix 7.1), and cropping systems (rotational differences, herbicide histories) implemented at each site.

The plots were cultivated or sprayed just prior to seeding to create a clean seedbed. Therefore, planting dates would have affected the species composition and density of weeds at each site. In 1999, at the 5% yield loss level, the critical weed-free period for the early-seeded Carman site ended at the 8-10th leaf stage (51 DAE) (Table 3.4). However, at the late-seeded Carman site, which was seeded adjacent to the early-seeded site, the critical weed-free period ended at the cotyledon stage (3 DAE). The large difference in the critical period between these sites suggests that it is highly dependent on the planting date of the crop. In contrast, the critical time of weed removal at the 5% yield loss level was consistent between the two experiments (at the 4th leaf stage, 38 and 17 DAE for the early and late-seeded Carman locations) (Table 3.5) suggesting that the critical time of weed removal is not dependent upon seeding date.

In addition to differences in the length of the critical weed-free period, the experiments at the Carman site in 1999 resulted in different weed species spectrums. The early-seeded experiment had higher densities of wild buckwheat and smartweed, whereas the late-seeded experiment was dominated by green foxtail, yellow foxtail, barnyardgrass, and redroot pigweed (see appendix 7.2). For the late-seeded experiment, much of the wild buckwheat and smartweed population that emerged between the early and late seeding dates was removed by the pre-seeding cultivation.

Critical Timing of Weed Removal

Weeds can often grow with the crop for a certain period before they cause yield loss (Dawson, 1986). Ideally, when postemergence herbicides are used, control should be delayed for as long as possible to capture most weed flushes. The timing of weed removal required to prevent yield loss will depend on the biology of the crop and its ability to tolerate weed competition. If removal was performed when the crop was established, the shade produced by the crop might prevent the growth of weeds emerging after this point, or the plants might be able to tolerate the reduced interference from the late-emerging weeds (O'Donovan, 1992).

Previous studies have shown that canola may not tolerate weed infestation early in its lifecycle (Canola Council of Canada, 1998; McMullan *et al.*, 1994). Our yield results suggest that canola is quite competitive and can tolerate weed infestation during the early portion of its lifecycle. At the 2.5% yield loss level, for example, the critical time of weed removal ranged from seeding to 8-10th leaf (0 to 44 DAE) (Table 3.5). However, this range was narrower, extending only from the 4th leaf stage to harvest at the 5% (17 to 89 DAE) and 10% (19 to 89 DAE) yield loss levels.

Table 3.5. The critical time of weed removal for canola in days after emergence and crop growth stages, calculated from the logistic equations for 2.5, 5, and 10% yield loss levels.

		Length and stage of weed infestation tolerated					
		2.5%		5%		10%	
Location	Year	DAE	Stage	DAE	Stage	DAE	Stage
Carman	1998	44	8-10th	89	harvest	89	harvest
Winnipeg	1998	0	Seed	30	4th	33	4th
Carman (early-seeded)	1999	38	4th	38	4th	38	4th
Carman (late-seeded)	1999	14	4th	17	4th	19	4th
Winnipeg	1999	32	6th	34	8-10th	75	harvest
Homewood	1999	24	6th	29	8-10th	37	early fl.

These results indicate that if producers are willing to accept relatively minor yield losses, weeds can remain in canola at least up to the 4th leaf stage (17-89 DAE), even under high levels of weed competition. Yield loss tended to vary considerably among sites as the length of weed-infested period increased beyond the 4th leaf stage (Table 3.5). When weed densities were low, weeds could be left in the crop longer or without causing more than 10% yield loss and at some sites, no weed control was required at all. For example, at Carman in 1998 and Winnipeg in 1999 yield loss did not exceed 11% if weeds were allowed to grow for the entire growing season.

Application of the Critical Period of Weed Control

Currently, in western Canada there are two major options for herbicidal weed control in canola. The first option is to use preemergence herbicides. However, the duration of the weed-free period created by using these chemicals must be long enough to prevent yield loss from later emerging weeds. Our study shows that to prevent yield loss greater than 10%, crop must be maintained weed-free up to the 6th leaf stage of the canola (20-39 DAE). To obtain a consistently lower yield loss, greater variability occurred in the required length of control to a point where maintaining a weed-free period did not exist and the crop needed to be kept weed-free for the entire season. The critical weed-free period was largely dependent on weed population present (species composition, densities, and emergence periodicity) and the crop seeding date relative to the emergence periodicity of the weed population. Delayed seeding reduced the length of the critical weed-free period by removing much of the weed population with pre-seeding weed control.

The second option for herbicidal weed control in canola is to use post-emergence herbicides. This has become increasingly popular in western Canada with the advent of herbicide-tolerant canola (HTC) varieties. In 1999, HTC varieties comprised 64% of the acres planted to canola in Manitoba (Manitoba Agriculture, 1999). With this option, the crop must be able to tolerate weed infestation for a period that allows herbicides to be applied when most of the weeds have emerged. By using well-timed herbicide applications the costs to the producer and impact on the environment from unneeded chemical use may be reduced. When weeds were left in the crop until the 4^{th} leaf stage (14-32 DAE) yield loss did not exceed 5%. However, in early seeded canola with subsequent weed flushes up to the 6^{th} leaf stage (20-39 DAE), a second application may be required to prevent yield loss. Weeds emerging after the 6^{th} leaf stage of canola did not affect yield. In most cases, the majority of weeds present in the field had already emerged by 4^{th} leaf stage, and those that did emerge after this stage did not accumulate considerable biomass.

Chapter 4

Comparative growth analysis of canola (*Brassica napus* L.) grown under weed interference

Introduction

Canola is primarily grown as a spring-seeded, annual crop in the western Canadian prairies. Herbicides have become increasingly important for the control of weeds in this crop due to the advent of soil-residual herbicides and the increased use of herbicide-tolerant varieties (Manitoba Ag., 1999). These chemicals permit the control of a wide spectrum of weeds over a broad range of application timings. Through the implementation of integrated weed management (IWM) systems, the objective of reducing the reliance on herbicides may be achieved by increasing their effectiveness through proper timing of application and the use of competitive cultivars (Swanton and Weise, 1991). IWM is a holistic approach to weed control and incorporates knowledge of how the crop interacts with weeds. Comparative growth analysis of a crop under weed-infested and weed-free conditions can help explain how the duration of weed competition affects the growth and morphology of crop plants (Van Acker *et al.*, 1993b).

Weeds can be tolerated in different crops for different durations (Roberts, 1976). In addition, a naturally occurring weed complex will be composed of several different weed species that differ in relative competitive ability (Blackshaw *et al.*, 1987). Therefore, a comparative growth analysis study on weed interference must utilize naturally occurring, mixed weed populations and measure responses in relation to the development stages of the crop in order for it to be more agronomically practical (Baldwin and Santelmann, 1980). Incorporating development stages will allow a better explanation of the crop response to weed interference, because the models will be based on physiologically linked processes rather than parameters tied to particular experimental elements (Weaver *et al.*, 1992).

Growth analysis information may become useful in the design of weed-crop interference models and in explaining the critical period of weed control in terms of the physiology of the crop. It may also aid breeders in the development of competitive varieties through a better understanding of the components of canola that are affected by weed competition.

Relatively little work has been performed on the growth analysis of canola under weed competition, compared to other crops. Van Acker *et al.* (1993b) showed that in a soybean crop, the total dry weight (TDW), crop growth rate (CGR), and leaf area index (LAI) of soybean were significantly reduced by weed competition. The soybean crop also compensated for weed interference by increasing the proportion of reproductive weight produced in the plant and decreasing the amount of branching. Wilson (1966) showed that net assimilation rate (NAR) in rapeseed was strongly affected by light availability. Therefore, competition from mutual shading and weed interference will greatly affect the rate of plant dry matter produced per unit of leaf area. However, it is still unknown if NAR of canola in a field situation will increase with reduced weed interference, or if increased branching of canola in a weed-free environment will maintain an optimum rate of dry matter production. The understanding of these growth analysis relationships and others described by Hunt (1978) in response to weed competition are still unknown for canola.

The objective of this project was to study the morphological responses of canola to competition from a naturally occurring weed population, using growth analysis techniques.

Materials and Method

Trials were conducted at three distinct locations in southern Manitoba in 1999. The first site was at the University of Manitoba research station in Carman, Manitoba. This was located on a Winkler Series soil comprised of 60% sand, 15% silt, and 25% clay with a mean pH of 5.8 and soil organic matter content of 6.5%. Plots at this site were 1.9m by 7m; plot size at each site was dependent on the equipment available for seeding and harvest at each location.

The second site was located at the Kelburn Farm[12] near Winnipeg, Manitoba. The soil was classified as orthic, dark gray, St. Norbert Clay, having a composition of 7% sand, 27% silt, and 66% clay with a pH of 7.4 and organic matter content of 3%. Plots were 1.8 x 8 m, but only the center 1.22m of the plots were harvested for yield.

The third site was located at the Cyanamid Research Farm near Homewood, Manitoba. The soil at the site was gleyed, black, Rignold Series soil texture of 68% sand, 19% silt, and 13% clay with a pH of 8.4 and organic matter content of 2.3%. Plots at this location were 1.85 x 8m, however only the center 1.22 m of each plot was harvested for yield.

The plots were cultivated with a field cultivator prior to seeding at Carman and Homewood, while preseeding spraying was used at Winnipeg instead of tillage to prevent creation of an uneven seedbed in the heavy clay soil. Seeding was performed at a rate of

6 kg ha^{-1}, with granular terbufos (Counter 5G[13]) applied at a rate of 6 kg ha^{-1} along with the seed for insect control. Fertilizer was applied at suitable rates for each site. Carman received 200 kg ha^{-1} of 23-10-5-5 incorporated on April 22, 1999, prior to seeding on May 14, 1999. Homewood received 127.8 kg ha^{-1} of 8.9-33.0-6.7-0.25 prior to seeding and 55 kg ha^{-1} of 11-51-0 with the seeding operation on May 28, 1999. Winnipeg received no fertilizer application, and it was seeded on May 27, 1999.

Innovator, a glufosinate-tolerant canola variety was used for the experiments. Weed control for the different treatments was accomplished using the herbicide, glufosinate (Liberty[14]). This was applied via a backpack sprayer at a rate of 1.3L ac^{-1} (482g a.i. ha^{-1}) with a 1.5m boom, carried 0.5m above the crop canopy with a water volume of approximately 104 L ac^{-1}. To prevent sclerotinia infection, iprodione (Rovral Flo[15]) fungicidal treatment was applied at the 25% bloom stage of the crop at the Carman and Winnipeg locations, and perennial weeds were controlled at Carman and Homewood with 0.97 kg a.i. ha^{-1} of glyphosate (Roundup[16]) on April 22 and June 2, 1999 applied pre-seeding.

A natural weed population was used in the experiment, with some weed augmentation at the Winnipeg and Carman sites. At Winnipeg, barley (*Hordeum vulgare* L.), green foxtail (*Setaria viridis* L.), and redroot pigweed (*Amaranthus retroflexus* L.) seed were applied at rates of 1.12, 0.266, and 0.08 g m^{-2}, respectively. The Carman site was augmented with 0.672 g m^{-2} of wheat seed (*Triticum aestivum* L.) to simulate a volunteer infestation.

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[12] James Richardson International Ltd., 2800 Lombard Place, Winnipeg, Manitoba, R3B 0X8, Canada
[13] Cyanamid Crop Protection, 88 McNabb Street, Markham, Ontario, L3R 6E6, Canada
[14] AgrEvo Canada Inc., 295 Henderson Drive, Regina, Saskatchewan, S4N 6C2, Canada
[15] Rhone Poulenc Canada Inc., Winnipeg, Manitoba, Canada

At the mid–flower stage of the crop, weeds were removed from $0.25m^2$ quadrats at the back of the plots that were kept weed-infested all year. Weed samples were separated by species, counted, dried at 80°C for 24 hours, and weighed.

The design of the experiment was part of a study performed on the critical period of weed control, where plots were kept weed-free or weed-infested for increasing lengths of time. The growth stages of canola used for these times were determined using an index developed by Harper and Berkenkamp (1975); these included cotyledon, 2, 4, 6, 8 to 10-leaf, and early flowering treatment stages (see Chapter 3).

At each canola development stage, seven canola plants were removed as a sample from within the back 1m of the plots that were maintained weed-infested and weed-free to that particular development stage. These plots represented the weed-infested and weed-free treatments, respectively. The treatments that were kept weedy and weed-free all year were sampled at late flowering to prevent shattering and loss of canola siliques. Prior to final crop grain yield determination, the rear meter of each plot was removed to compensate for the yield effects that may have resulted from plants being removed for growth analysis.

The plants from each sample were separated into leaf, main stem, branch stem, and reproductive parts. The leaf area was measured using a LICOR Li3100[17] area meter. The plant parts were dried at 80°C for 24 hours and weighed. LAI, CGR, NAR, the leaf area ratio (LAR) and the specific leaf area (SLA) and plant component weight ratios were calculated using formulae as described by Hunt (1978). Significant differences between the treatments for the growth analysis ratios were determined by means of ANOVA

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[16] Monsanto, 800 North Lindbergh, St. Louis, Missouri 63167, USA
[17] LI-COR Inc., Lincoln, NE 68501, USA

calculated for each growth stage at the 95% confidence level using SAS[18] statistical software.

The ratio of the branch stem weight to total stem weight (BSW:TSW) was used to explain how weed competition affected branching in canola. Although there is no formal method to distinguish main stems from branches in canola, the longest stem was given the designation of the main stem and all others were designated as branch stems.

At Carman, the plots were swathed on August 17, 1999 and harvested on August 25, 1999 with a Wintersteiger[19] plot combine for yield analysis. Winnipeg and Homewood were harvested without swathing on August 27, 1999 and September 16, 1999 with Hege[20] harvesters. Homewood received 544g ha^{-1} of diquat (Reglone Pro[21] herbicide) on August 30, 1999 to desiccate the weed population in preparation for harvesting. Dockage was removed from yield samples using a Carter[22] dockage tester via the method outlined by the Canadian Grain Commission (1991). The resulting yield with dockage removed for each treatment was reported as a percentage of the treatments kept weed-free all year.

Results and Discussion

The yield data from each site shows that yield reduction was greatest at the Carman site (Table 4.1). McMullan *et al.* (1994) and Wall (1994) showed that early removal of wild mustard from canola could prevent yield reductions from weed interference. The relatively greater reduction in canola yield at Carman, as compared to other sites, was due to a greater level of weed interference (Table 4.2). The diversity of weed species, weed

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[18] SAS Institute Inc., SAS Campus Drive, Cary, NC 27513-2414, USA
[19] Wintersteiger, 964 Bergar, Laval, Quebec, H7L 5A1, Canada
[20] Hege Maschinen GmbH, Domane Hohenbuch, D-74638, Waldenburg, Germany
[21] Zeneca Agro, Suite 250, 3115-12 Street NE, Calgary, Alberta, T2E 7J2, Canada

density, and weed dry biomass at the Carman site was much greater than that at both the Winnipeg and Homewood sites (Table 4.2). As a result, the effects of weed interference on the different growth indices were most noticeable at this location.

Table 4.1. Mean canola yield in weed-infested and weed-free (with dockage removed) at each location.

	Weed-free yield	Weedy yield	Weedy yield as Percent of Weed-free yield
	(kg/ha)	(kg/ha)	(%)
Carman	1763.93	879.81	49.9
Winnipeg	2073.15	1807.97	87.2
Homewood	1350.84	846.64	62.7

The total dry weight (TDW) of canola was reduced when weed infestation persisted in the crop longer than the 8-10th leaf stage (25-33 DAE) (Figure 4.1). Similarly, Blackshaw *et al.* (1987) found significant reductions in rapeseed dry biomass after 38 to 39 DAE due to interference from 20 plants m^{-2} of either common lambsquarters or wild mustard. The differences in TDW between weed-infested and weed-free treatments at Homewood and Winnipeg were not as large as those at the Carman site. Differences in TDW were statistically significant at the 6th leaf stage at Carman and at the 2nd and 6th leaf stages at Winnipeg. In these cases, the TDW of canola was greater in weed-infested plots than in the weed-free plots. These differences in TDW were likely a result of mechanical damage from herbicide application and the response of the plants to injury from the herbicide applied to the weed-free plots, however these differences were not apparent in the yield of the crop (Appendix 7.3).

[22] Carter Day International Inc., 500-73rd Ave. NE, Minneapolis, Minnesota 55432, USA

The presence of weeds in canola caused a reduction in the crop growth rate (CGR) after the 8-10th leaf stage at all locations (Figure 4.1). This was likely caused by the reduction in total dry weight. Earlier in the season, canola plants in the weedy plots accumulated biomass at a greater rate than those in the weed-free plots, but after the 8-10th leaf stage weed interference caused reductions in CGR.

Table 4.2. Species spectrum, mean weed dry biomass and density in unweeded treatments, measured at late flowering.

	Weed species	Total weed dry biomass	Total weed density	Species dry biomass	Species density
		$g\ m^{-2}$	plants m^{-2}	$g\ m^{-2}$	plants m^{-2}
Carman	Wild buckwheat (Polygonum convolvulus L.)	387.19	406	63.89	127
	Redroot pigweed (Amaranthus retroflexus L.)			96.65	113
	Green foxtail (Setaria viridis (L.) Beauv.)			137.30	136
	Yellow Foxtail (Setaria glauca (L.) Beauv.)				
	Barnyardgrass (Echinochloa crus-galli (L). Beauv.)				
	Common lambsquarters (Chenopodium album L.)			4.81	4
	Smartweed (Polygonum persecaria L.)			31.81	8
	Volunteer flax (Linum usitatissimum L.)			10.55	10
	Dandelion (Taraxacum officinale Weber in Wiggers)			4.05	2
	Clover (Trifolium pratense L.)			0.13	1
	Volunteer wheat (Triticum aestivum L.)			38.00	5
	Wild oat (Avena fatua L.)			93.87	10
	Quackgrass (Elytrigia repens (L.) Nevski)			9.54	4
	Little mallow (Malva parviflora L.)			0.94	1
Homewood	Redroot pigweed	47.28	70	43.33	49
	Green foxtail			2.03	12
	Yellow foxtail				
	Barnyardgrass				
	Common purslane (Portulaca oleracea L.)			0.21	2
	Common lambsquarters			0.36	3
	Wild oat			1.24	2
	Wild buckwheat			0.06	1
	Wild mustard (Brassica kaber (DC.) L.C.Wheeler)			0.05	1
Winnipeg	Volunteer barley (Hordeum vulgare L.)	27.97	80	25.28	16
	Green foxtail			2.26	44
	Yellow foxtail				
	Barnyardgrass				
	Common lambsquarters			0.06	3
	Dandelion			0.02	4
	other			0.03	3
	Redroot pigweed			0.23	8
	Stinkweed (Pluchea camphorata (L.) DC.)			0.01	1
	Wild mustard			0.09	1

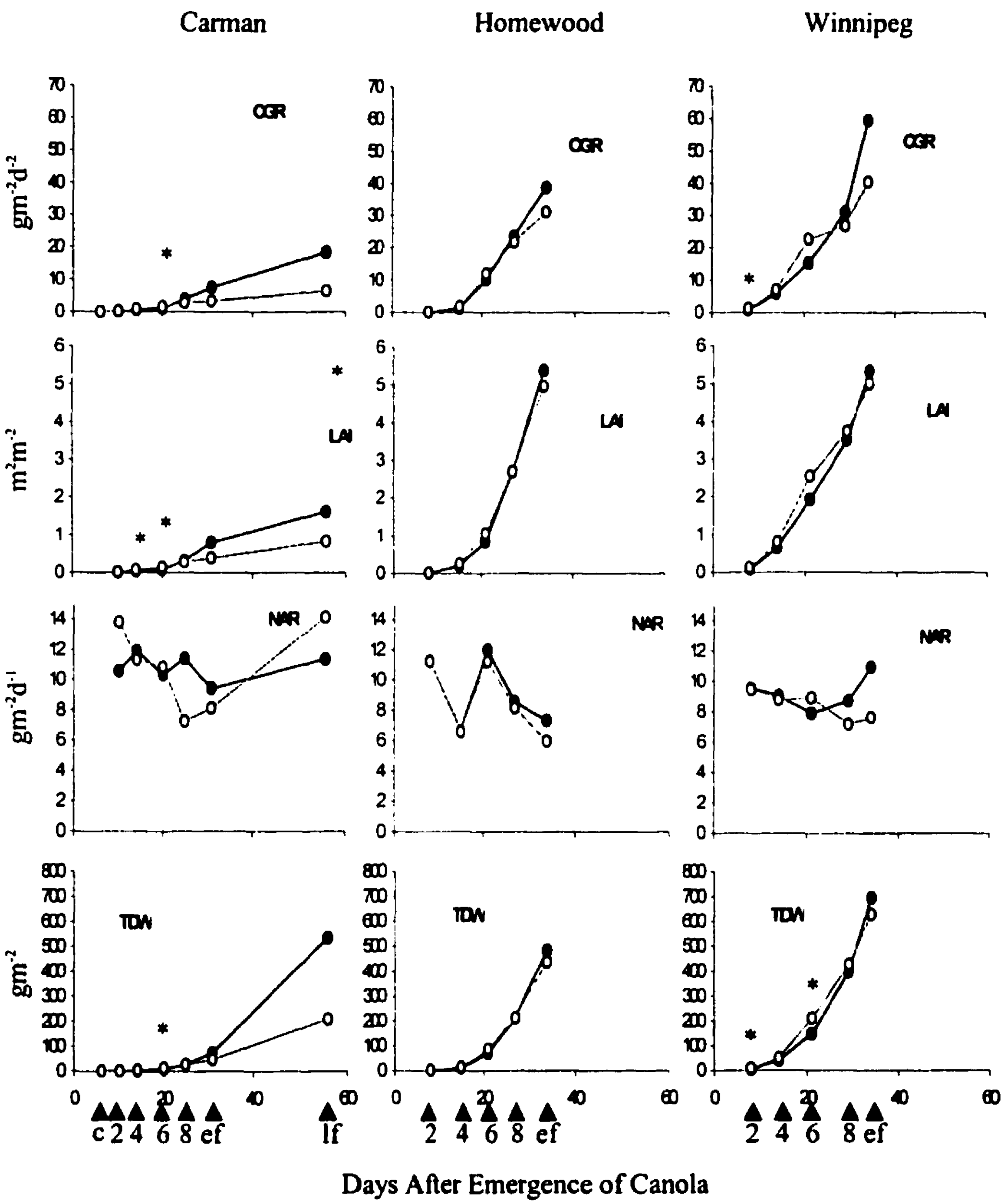

Figure 4.1. Growth response of canola crop growth rate (CGR), leaf area index (LAI), net assimilation rate (NAR), and total dry weight (TDW) to weed-infested (O) and weed-free conditions (●). The arrows indicate development stages of the canola for cotyledon (c), 2nd leaf (2), 4th leaf (4), 6th leaf (6), 8-10th leaf (8), early flowering (ef), and late flowering (lf).

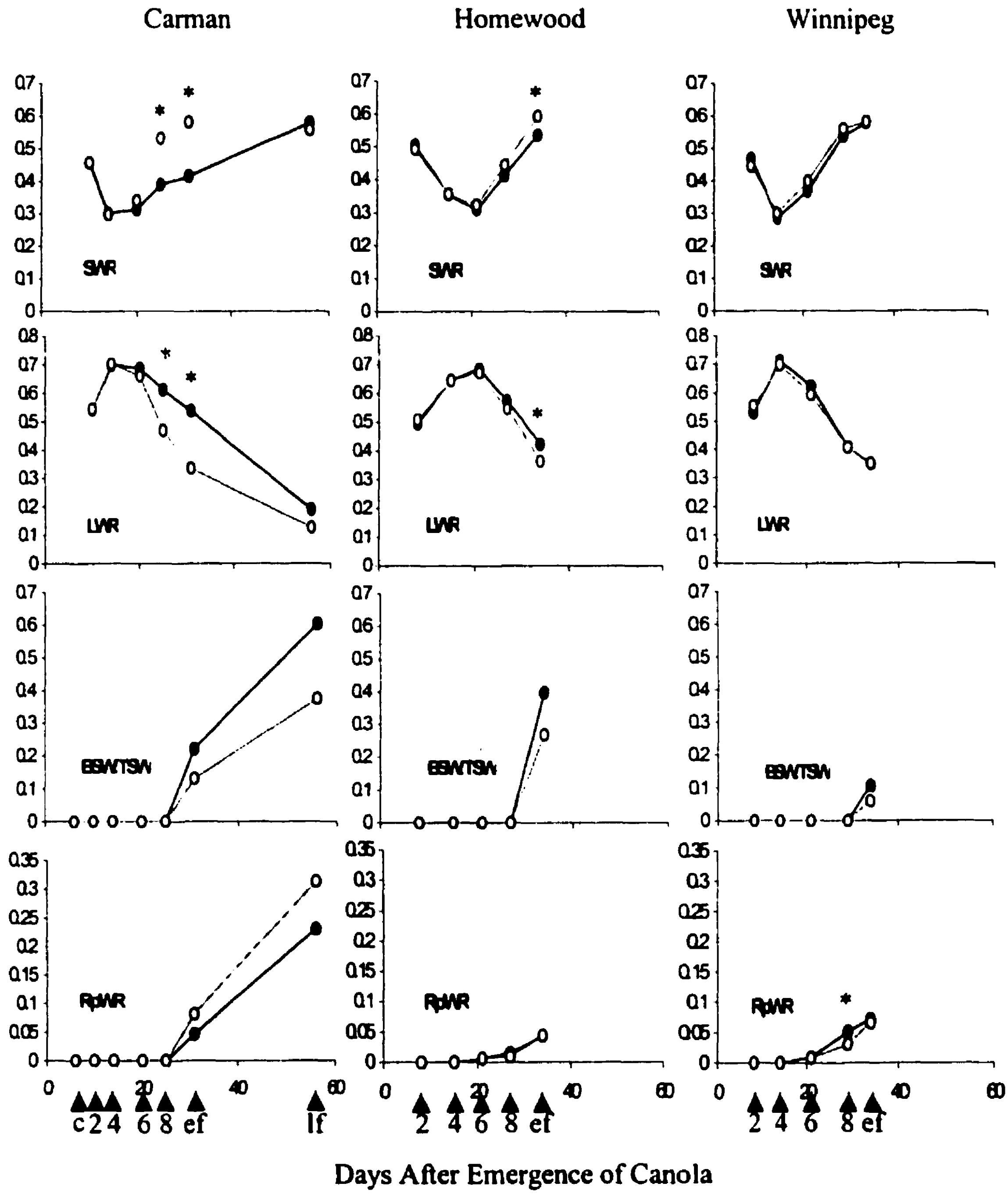

Figure 4.2. Growth response of canola stem weight ratio (SWR), leaf weight ratio (LWR), branch stem to total stem ratio (BSW:TSW), and reproductive weight ratio (RpWR) to weed-infested (O) and weed-free conditions (●). The arrows indicate development stages of the canola for cotyledon (c), 2nd leaf (2), 4th leaf (4), 6th leaf (6), 8-10th leaf (8), early flowering (ef), and late flowering (lf).

Differences between the weed-infested and weed-free treatments in canola leaf area index (LAI) were apparent after the 8-10th leaf stage at the Carman location (Figure 4.1). LAI was greater in the weed-infested plots at the 4th and 6th leaf stages, but by late flowering LAI was greatly reduced in the weed-infested plots versus the weed-free plots due to weed interference. At the Homewood and Winnipeg locations, the LAI of the canola crop exhibited great plasticity in response to weed interference, as no noticeable reductions occurred in weed infested versus weed-free plots, even when weed interference continued to the early flower growth stage. The canola may have compensated for competition for light by shifts to a canopy architecture that intercepts a greater fraction of incoming photosynthetic photon flux (Jordan, 1993). More growth analysis research should be performed on the effect of weed competition on the vertical distribution of leaf area within the crop canopy.

Wilson (1966) showed that the net assimilation rate (NAR) of rapeseed decreased with a decrease in the availability of light for an individual plant. Therefore, increased dry matter production per unit of leaf area might occur in the weed-free treatments until mutual shading by the crop plants resulted in a reduction in NAR. However, there was no consistent increase or decrease in NAR of canola as a result of weed interference (Figure 4.1). Perhaps the canola grown under weed-free conditions occupied the additional space by increasing branching and LAI without increasing NAR.

The stem weight ratio (SWR) of the canola crop increased significantly in weed-infested versus weed-free plots by the 8-10th and early flowering stages at Carman, and by the early flowering stage at Homewood (Figure 4.2), implying that the weed infestation caused a greater partitioning of assimilates tot the stem biomass. Differences between treatments were not apparent at Winnipeg, which had the lowest weed density of the three sites.

Greater branching of the canola occurred in the weed-free versus the weed-infested plots as is shown by the increase in branch stem to total stem weight ratio (BSW:TSW) due to weed interference (Figure 4.2). Less branching in weed-infested plots may suggest a plant strategy to keep LAI on the main stem, and perhaps, at a greater height in the canopy.

The leaf weight ratio (LWR) responded to weed interference in a manner opposite to that found for the stem weight ratio. Significant reductions in the LWR occurred at the 8-10^{th} leaf and early flower stages for the Carman site due to weed interference, and at the early flower stage at Winnipeg (Figure 4.2). The LWR can be considered a function of the interaction between the LAI and TDW, so the larger differences noticed at the 8-10^{th} leaf and early flowering stages could be attributed to differences in LAI and TDW between the weed-infested and weed-free treatments. Under the influence of weed interference the proportional leaf biomass production in canola decreased possibly permit the increased proportional stem biomass production as weed interference persisted beyond the 8-10^{th} leaf stages.

At Carman, the weed-infested plants increased their reproductive weight ratio (RpWR) after the 8-10^{th} leaf stage (Figure 4.2), suggesting that due to weed interference, canola plants will partition more of their relative biomass to reproductive structures. These observations were only based on pre-seed filling measurements, and even though a greater proportion of assimilates were used for the development of reproductive structures, the plants were not able to adequately compensate for the reduced growth due to weed interference and yield loss still occurred (Table 4.1).

More experiments will be required to ascertain the statistical significance of the effects of weed competition duration on canola growth and morphology. Our results showed trends in morphological growth response to weed interference, but canola is a variable crop in terms of plant stand, plant size, and leaf area production. As a result, we were unable to find significant differences between the weed-infested and weed-free treatments for many of the growth analysis measurements. Great variability in canola yield studies has also been shown, where the crop has been exposed to weed interference for only a short period of time, and causing yields to increase (McMullan *et al.*, 1994). To ensure the validity of conclusions from future growth analysis studies, greater sample sizes should be used and great attention should be paid to achieving homogenous plant stands in experiments in order to decrease the amount of overall variation, and improve the confidence in discriminating differences between treatments when performing growth analysis experiments on canola.

Comparative growth analysis of canola under competition from the weeds showed that the crop is tolerant of low levels of weed interference. Reductions from weed interference in the crop growth rate, total dry weight, leaf area index, branch stem to total stem weight ratio, and reproductive weight ratio did not become apparent until later in the lifecycle of the canola crop (at the 8-10th leaf stage of the canola). However, due to the great variability in plant size and crop density, many of these reductions were statistically non-significant. The leaf weight ratio was greater in the weed-free treatment, while the stem weight ratio was greater in the weed-infested treatment, showing that production of leaf area was greater in a weed-free environment. Differences in the net assimilation rate were not consistent and implied that the crop compensated for space unoccupied by weeds with increased branching.

Chapter 5

General Discussion

The Findings

Our study has shown that the critical period of weed control in canola grown under Manitoba conditions does not exist as a discrete, single period. By analyzing the differences between each site, we were able to develop an estimate of the critical period of weed control for different levels of acceptable yield loss.

It was found that the canola crop needed to be kept weed-free at most up to the 6^{th} leaf stage (20-39 DAE) to prevent greater than 10% yield loss. Weeds in the crop needed to be removed by at least the 4^{th} leaf stage (14-32 DAE) to prevent greater than 5% yield loss. These results imply that soil-applied herbicides must remain active up to the 6^{th} leaf stage and that post-emergence herbicides should be applied by the 4^{th} leaf stage in order to prevent yield losses of 10% or greater.

Many factors affect the critical period of weed control. The level of weed emergence declined sharply after the 4^{th} leaf stage of the canola. This greatly affected the critical weed-free period because after this time weeds would not emerge in great numbers and would not accumulate significant biomass to compete with the crop. Examination of the emergence periodicity of weeds showed that the species present at each location did not typically emerge after this 4^{th} leaf stage of the canola, showing that the emergence periodicity may be responsible for the critical weed-free period ending at the 6^{th} leaf stage.

Comparative growth analysis of canola under competition from the weeds showed that the crop is tolerant of low levels of weed interference. It was surprising to see that leaf area index was not greatly affected by low levels of weed interference. Reductions from weed interference in the crop growth rate, total dry weight, leaf area index, branch stem to total stem weight ratio, and reproductive weight ratio did not become apparent until later in the lifecycle of the canola crop (at the 8-10th leaf stage of the canola). However, due to the great variability in plant size and crop density, many of these reductions were statistically non-significant. The leaf weight ratio was greater in the weed-free treatment, while the stem weight ratio was greater in the weed-infested treatment, showing that production of leaf area was greater in a weed-free environment. Differences in the net assimilation rate were not consistent and implied that the crop compensated for space unoccupied by weeds with increased branching.

The ideotype for canola breeders, as defined by our study, is a variety that will have rapid ground cover and rapid production of leaves. This will reduce the amount of photosynthetically active radiation reaching the weeds that emerge after the crop and might reduce the critical weed-free period. Therefore, the crop would not need to be kept weed-free as long and with post-emergence herbicides, only one application may be required under all conditions. Other improvements in tolerance for weed competition duration may be noticed through increasing the amount of assimilate partitioning to the reproductive structures. However, this shift to increased reproductive biomass may also result in decreased competitiveness, allowing the weeds to compete with greater intensity with the crop for resources.

The Options

With the advent of effective soil-residual herbicides and herbicide-tolerant varieties of canola, the options for chemical weed control in canola have increased. In my opinion, either choice has unique benefits and utility.

With soil residual herbicides, the producer can benefit from a shorter critical weed-free period with delayed seeding with spring application. Fall application will likely require higher residual activity. This form of chemical weed control may require a later postemergence application of herbicide for later flushing weeds, if herbicide activity is not maintained up to the 6^{th} leaf stage of the canola or if weeds escape control. However, a great benefit may be noticed from the use of soil residual herbicides if weed control is maintained up to the 6^{th} leaf stage and where significant weed infestations do not accumulate in the crop. In this latter case, post-emergence weed control would not be required.

For the use of herbicide-tolerant crop varieties and postemergence herbicides, the crop will likely require seeding into a clean seedbed. Therefore, spring cultivation or chemical burn-off will be required to prevent a large, in-crop weed infestation. In my opinion, the use of chemical burn-off may be best for canola production because moisture in the upper soil layer is conserved. This application should not be performed until just before the crop is seeded, which should be late in spring when the soil is warm, allowing for germination of the canola and providing the crop with a competitive advantage over weeds. If substantial weed pressure is present at the mid to late 4^{th} leaf stage, post-emergence chemical weed control should be implemented. If early weed control is successful beyond 4^{th} leaf stage, the majority of weeds present in the field would have already emerged and would not obtain enough biomass to interfere with the crop. However, with early seeded canola, subsequent flushes up to the 6^{th} leaf may require a second application.

The Problems

The preceding recommendations are based upon the knowledge of weed control timing gained from these few experiments, which tested for only a limited number of scenarios. It is not known how a zero-till system would affect the critical timing of weed control in canola since only a conventional tillage system was used in our experiments. One might assume that the results would be similar to that in a conventional tillage system. Previous studies have been contradictory, showing that zero-tilled fields required or did not require increases in dosage or numbers of herbicide applications (Swanton and Weise, 1991; Arshad *et al.*, 1995). Zero-till systems also promote a shift in the species composition of the weed population to more perennial and winter annual species. One cannot conclude how the critical period of weed control will be affected by tillage until further experiments are performed.

In this study we used natural weed populations with some minor augmentation. Most fields contain a complex of different species, with each species differing in competitive ability (Baldwin and Santelmann, 1980). The degree of interference imposed by different species can have a great influence on the critical period of weed control. In our experiments, perennial weeds were controlled before seeding because of their highly aggregated distribution in the field, so it could not be determined if the influence of perennial species would cause a difference in the timing of the critical period of weed control. These species are generally much more aggressive in competitiveness than annual species as they often emerge much earlier in the season from vegetative, over-wintering structures. It is likely that the presence of perennial weed species would decrease the critical time of weed removal because of their higher relative competitive ability compared to annual species. If the control method implemented only caused suppression of these weeds, the critical weed-free period may also be increased because of their resurgence.

Winter annuals and less common annuals were not present at any site as such their effect on the critical period of weed control could not be examined. One could speculate, however, that because winter annuals, if not controlled in fall or early spring, can be very competitive, weed populations which had a high proportion of winter annuals would cause a shorter critical timing of weed removal. If they were controlled in pre-seeding or in-crop, their presence should not affect the length of the weed-free period because winter annuals tend not to emerge in late spring or early summer.

The use to fall-seeded canola, compared to the spring-seeded system that was used in the experiment, would likely have an effect on the timing of the critical period of weed control. A longer critical weed-free period would be required due to the slow growth and poor germination of canola under cool temperatures in early spring. Therefore, the cool-season species of weeds would have a competitive advantage over the crop. Also, the crop would be exposed to a broader emergence period of the weeds. A reduced critical timing of weed removal may also occur because of the advantage that cool-season weed species would have over the crop, however it was found from our experiment that the critical timing of weed removal would be less likely affected by the seeding date of the crop.

Innovator, a canola variety tolerant to glufosinate, was the only variety used in the experiment. Although this strategy was effective in eliminating the effect of different varieties from our findings, it did not allow us to observe how other varieties would have affected the critical period of weed control in canola. For example, hybrid varieties are considered to be more competitive due to a heterosis effect. This increased vigor might cause a reduction in the critical weed-free period since the hybrid varieties might be more competitive with later emerging weeds. The critical time of weed removal might be increased because the hybrid varieties could tolerate weed infestation for a longer duration. In addition, there may be differences for conventional (compared to transgenic) varieties and difference between different HTC varieties. O'Donovan *et al.* (1989) showed, for example, that later maturing varieties of canola may be more susceptible to interference from weeds because weed interference can affect the crop for a longer period of time. Also, Innovator is a less competitive, open-pollinated variety which allowed us to assume a conservative approach for determining the critical period of weed control, as it allows a better measurement of the effects of weed competition on yield and growth, the maximum required weed-free period, and minimum tolerable duration of weed infestation.

Weeds were removed by the use of a chemical herbicide, glufosinate. Although Innovator can tolerate this product at rates up to 5 times the recommended dosage (Ron Kelher, pers. comm.), it was noticed that a bronzing effect occurred on the leaves of the crop after application. We conducted an experiment on the effects of repeated application of glufosinate on Innovator (Appendix 7.3) which showed no significant effect of repeated application on crop yield in the absence of weed interference.

The Future

In the future, I would like to see the testing of other scenarios that would be useful for canola production. For example, we should explore what effect not controlling weeds prior to planting and only spraying at the 4^{th} leaf stage would have on canola yield. This treatment should be compared to treatments where weeds are controlled at seeding and at the 4^{th} leaf stage. We should also consider if there is a difference in the critical period of weed control of canola when weeds are controlled prior to seeding versus when they are not. This will show us the value of achieving good weed control prior to seeding.

Canola is a variable crop in terms of plant stand density, plant sizes, stages, and various growth measurements in a field situation and we must take great care to provide the greatest homogeneity in the plant stand within experiments. In addition, sample sizes should be large to increase the accuracy of measurements and to improve the level of confidence when comparing treatments.

In the end, the information gained from the experiments in this project will be useful for the development of a complete model for the control of weeds in canola. Future models would include many possible options for weed control in canola and would produce predictions of yield loss and the probabilities for these predictions. The goal of such integrated models of weed management would not only assist canola producers in achieving the most effective control of weeds, but it would also facilitate the most efficient use of the available weed control methods.

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Chapter 7

Appendices

Appendix 7.1

Rainfall and Temperature Data

Temperature data from Carman was used to calculate the thermal time for the Carman and Homewood locations due to their relative proximity.

Temperature data from the weather station at the University of Manitoba in Winnipeg, Manitoba was used to calculate thermal time for the Winnipeg site.

The formula used for calculation of thermal time in accumulated growing degree days (GDD) is shown below (the base temperature used was 5°C).

GDD=mean daily temperature-base temperature

1998 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm
4 1	0	1998	10.8	0.2	5.5	0.0
4 2	0	1998	12.9	-0.9	6.0	0.0
4 3	0	1998	14.8	-1.5	6.6	0.0
4 4	0	1998	14.6	0.1	7.3	0.0
4 5	0	1998	12.2	0.4	6.3	2.4
4 6	0	1998	6.3	0.6	3.5	13.6
4 7	0	1998	8.0	-0.9	3.5	0.0
4 8	0	1998	10.3	-0.4	4.9	0.0
4 9	0	1998	12.4	0.6	6.5	0.0
4 10	0	1998	15.1	3.3	9.2	0.0
4 11	0	1998	16.8	0.5	8.6	0.0
4 12	0	1998	13.4	7.7	10.6	18.0
4 13	0	1998	10.1	3.1	6.6	5.6
4 14	0	1998	5.5	-1.0	2.3	0.0
4 15	0	1998	6.4	-3.4	1.5	0.0
4 16	0	1998	11.0	-2.3	4.4	0.0
4 17	0	1998	9.8	-0.4	4.7	0.0
4 18	0	1998	10.9	-2.6	4.2	0.0
4 19	0	1998	11.8	-0.6	5.6	0.0
4 20	0	1998	15.5	-2.8	6.3	0.0
4 21	0	1998	19.4	-1.7	8.9	0.0
4 22	0	1998	23.8	1.1	12.5	0.0
4 23	0	1998	20.7	6.8	13.8	0.0
4 24	0	1998	18.3	2.0	10.1	0.0
4 25	0	1998	19.6	7.6	13.6	0.0
4 26	0	1998	19.8	4.5	12.2	0.0
4 27	0	1998	23.4	1.2	12.3	0.0
4 28	0	1998	24.1	6.1	15.1	0.0
4 29	0	1998	27.4	6.9	17.1	0.0
4 30	0	1998	26.4	8.0	17.2	0.0

1998 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm
5 1	0	1998	9.9	3.4	6.7	0.0
5 2	0	1998	17.4	0.7	9.0	0.0
5 3	0	1998	23.0	1.2	12.1	0.0
5 4	0	1998	17.3	5.6	11.5	0.0
5 5	0	1998	18.5	2.5	10.5	0.0
5 6	0	1998	6.7	1.8	4.3	2.4
5 7	0	1998	13.9	3.1	8.5	0.8
5 8	0	1998	21.3	4.4	12.9	0.0
5 9	0	1998	23.3	6.6	14.9	0.0
5 10	0	1998	24.0	9.6	16.8	6.2
5 11	0	1998	20.0	6.4	13.2	2.6
5 12	0	1998	14.0	3.2	8.6	0.0
5 13	0	1998	22.4	3.1	12.7	8.8
5 14	0	1998	17.8	9.7	13.8	1.0
5 15	0	1998	21.4	12.1	16.7	0.0
5 16	0	1998	19.9	7.8	13.8	1.4
5 17	0	1998	24.5	4.7	14.6	5.2
5 18	0	1998	24.5	10.0	17.3	0.0
5 19	0	1998	19.7	8.6	14.2	0.0
5 20	0	1998	23.0	6.0	14.5	0.0
5 21	0	1998	22.1	5.2	13.7	0.0
5 22	0	1998	23.0	5.1	14.1	0.0
5 23	0	1998	23.7	5.4	14.6	0.0
5 24	0	1998	25.8	6.0	15.9	0.0
5 25	0	1998	24.7	9.9	17.3	0.0
5 26	0	1998	28.2	7.8	18.0	0.0
5 27	0	1998	25.4	11.1	18.2	6.4
5 28	0	1998	19.1	2.7	10.9	3.4
5 29	0	1998	13.2	-0.2	6.5	0.0
5 30	0	1998	23.6	2.8	13.2	0.0
5 31	0	1998	19.7	3.2	11.5	0.0

1998 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm
6 1	0	1998	12.5	5.6	9.0	1.4
6 2	0	1998	9.1	3.0	6.1	0.0
6 3	0	1998	14.0	1.8	7.9	0.0
6 4	0	1998	13.6	2.9	8.2	0.0
6 5	0	1998	11.6	3.8	7.7	0.4
6 6	0	1998	15.5	3.5	9.5	0.0
6 7	0	1998	19.6	3.4	11.5	0.0
6 8	0	1998	20.9	3.0	12.0	0.0
6 9	0	1998	21.6	7.5	14.5	0.0
6 10	0	1998	18.7	12.5	15.6	18.2
6 11	0	1998	16.2	12.8	14.5	2.8
6 12	0	1998	24.3	11.4	17.9	0.0
6 13	0	1998	27.1	9.5	18.3	0.4
6 14	0	1998	15.8	13.9	14.8	25.2
6 15	0	1998	21.4	12.5	17.0	0.0
6 16	0	1998	18.7	12.2	15.4	0.0
6 17	0	1998	20.4	13.6	17.0	2.0
6 18	0	1998	23.6	17.2	20.4	2.6
6 19	0	1998	21.3	14.2	17.7	10.2
6 20	0	1998	19.8	12.9	16.3	2.6
6 21	0	1998	16.6	11.3	13.9	0.4
6 22	0	1998	19.6	10.5	15.0	0.0
6 23	0	1998	20.5	7.4	14.0	1.6
6 24	0	1998	24.0	14.7	19.4	7.2
6 25	0	1998	28.5	13.8	21.1	3.0
6 26	0	1998	26.8	17.5	22.2	5.6
6 27	0	1998	23.2	15.8	19.5	8.8
6 28	0	1998	20.5	13.0	16.8	0.2
6 29	0	1998	23.0	14.1	18.5	2.0
6 30	0	1998	25.6	14.2	19.9	0.0

1998 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm
7 1	0	1998	27.8	12.1	20.0	0.0
7 2	0	1998	24.6	14.0	19.3	1.2
7 3	0	1998	22.1	10.8	16.5	0.2
7 4	0	1998	24.3	8.5	16.4	1.8
7 5	0	1998	22.9	15.1	19.0	1.4
7 6	0	1998	19.6	14.1	16.9	4.8
7 7	0	1998	25.6	15.8	20.7	0.4
7 8	0	1998	27.8	14.7	21.2	0.2
7 9	0	1998	28.9	14.9	21.9	0.0
7 10	0	1998	30.5	15.5	23.0	0.2
7 11	0	1998	31.3	17.6	24.4	0.0
7 12	0	1998	28.6	16.8	22.7	0.0
7 13	0	1998	27.3	14.9	21.1	0.0
7 14	0	1998	29.0	13.2	21.1	0.2
7 15	0	1998	18.8	7.4	13.1	0.0
7 16	0	1998	22.9	4.9	13.9	0.0
7 17	0	1998	26.3	10.6	18.4	0.0
7 18	0	1998	27.4	15.7	21.5	5.8
7 19	0	1998	25.6	13.9	19.8	0.0
7 20	0	1998	26.3	11.0	18.7	14.6
7 21	0	1998	20.5	12.1	16.3	0.0
7 22	0	1998	20.9	10.0	15.5	0.0
7 23	0	1998	21.5	9.0	15.3	0.0
7 24	0	1998	23.7	6.4	15.1	0.0
7 25	0	1998	27.3	7.8	17.6	0.0
7 26	0	1998	27.1	15.6	21.3	2.6
7 27	0	1998	27.3	11.4	19.3	0.0
7 28	0	1998	24.5	13.3	18.9	0.0
7 29	0	1998	22.3	9.7	16.0	0.0
7 30	0	1998	22.8	9.4	16.1	0.0
7 31	0	1998	25.9	6.5	16.2	0.0

1998 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm
8 1	0	1998	28.4	9.9	19.1	0.0
8 2	0	1998	26.2	17.7	21.9	0.0
8 3	0	1998	24.1	18.3	21.2	0.4
8 4	0	1998	28.4	14.9	21.6	0.0
8 5	0	1998	30.1	12.6	21.4	0.0
8 6	0	1998	31.3	12.7	22.0	0.0
8 7	0	1998	31.3	11.3	21.3	0.0
8 8	0	1998	31.3	11.7	21.5	0.0
8 9	0	1998	29.3	13.9	21.6	0.0
8 10	0	1998	29.0	10.5	19.7	0.0
8 11	0	1998	32.6	13.1	22.8	0.0
8 12	0	1998	31.2	18.4	24.8	25.0
8 13	0	1998	29.3	16.7	23.0	0.0
8 14	0	1998	22.7	10.5	16.6	0.0
8 15	0	1998	26.4	8.4	17.4	0.0
8 16	0	1998	22.3	12.5	17.4	0.0
8 17	0	1998	22.3	11.9	17.1	0.0
8 18	0	1998	19.3	9.4	14.3	5.8
8 19	0	1998	30.2	15.7	22.9	0.6
8 20	0	1998	26.3	13.3	19.8	0.0
8 21	0	1998	28.2	10.2	19.2	0.2
8 22	0	1998	26.0	16.0	21.0	5.0
8 23	0	1998	25.6	14.8	20.2	0.0
8 24	0	1998	25.4	11.6	18.5	0.0
8 25	0	1998	29.8	9.7	19.8	1.0
8 26	0	1998	28.8	12.8	20.8	2.0
8 27	0	1998	28.8	13.2	21.0	1.6
8 28	0	1998	28.9	12.6	20.7	0.0
8 29	0	1998	25.4	9.6	17.5	0.0
8 30	0	1998	27.8	8.0	17.9	0.0
8 31	0	1998	30.9	10.4	20.6	3.8

1998 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm
9 1	0	1998	22.2	6.6	14.4	0.0
9 2	0	1998	19.4	6.1	12.8	0.8
9 3	0	1998	28.6	7.9	18.2	0.0
9 4	0	1998	31.4	10.0	20.7	0.0
9 5	0	1998	26.2	9.4	17.8	0.0
9 6	0	1998	23.2	8.4	15.8	0.0
9 7	0	1998	21.1	5.6	13.3	0.0
9 8	0	1998	23.2	2.1	12.7	0.0
9 9	0	1998	28.4	13.7	21.0	0.0
9 10	0	1998	34.0	14.6	24.3	0.0
9 11	0	1998	24.1	8.3	16.2	0.0
9 12	0	1998	24.3	6.0	15.1	0.0
9 13	0	1998	25.7	10.4	18.0	0.0
9 14	0	1998	22.6	7.7	15.1	0.0
9 15	0	1998	25.3	3.4	14.3	0.0
9 16	0	1998	25.6	13.2	19.4	0.0
9 17	0	1998	25.3	9.4	17.4	0.0
9 18	0	1998	18.2	8.7	13.4	0.0
9 19	0	1998	13.1	8.2	10.6	3.4
9 20	0	1998	13.5	6.5	10.0	1.0
9 21	0	1998	15.6	0.8	8.2	0.0
9 22	0	1998	20.0	1.9	10.9	0.0
9 23	0	1998	18.3	5.0	11.7	0.0
9 24	0	1998	20.2	1.4	10.8	0.2
9 25	0	1998	16.5	10.1	13.3	0.8
9 26	0	1998	15.7	8.3	12.0	5.8
9 27	0	1998	20.6	5.6	13.1	0.0
9 28	0	1998	24.9	2.9	13.9	0.0
9 29	0	1998	15.1	5.7	10.4	0.0
9 30	0	1998	10.0	-0.2	4.9	0.0
10 1	0	1998	11.8	-2.2	4.8	0.0
10 2	0	1998	13.2	-6.4	3.4	0.0
10 3	0	1998	15.3	-2.5	6.4	0.0
10 4	0	1998	13.3	4.2	8.8	4.0
10 5	0	1998	10.5	7.2	8.9	23.6

1998 Winnipeg Weather Data and Total Precipitation

JDATE	MMDD	TEMP1 MEAN	TEMP1 MIN	TIME MIN	TEMP1 MAX	TIME MAX	TEMP SOIL	PPT1 mm	SOLAR cal/cm2
4	1 4	-17.33	-25.13	103	-10.7	1427	-13.75	0	71.9
5	1 5	-14.89	-18.37	239	-11.51	2347	-11.25	0	18.04
6	1 6	-12.97	-15.67	1710	-9.57	1506	-7.03	0	55.74
7	1 7	-10.4	-13.08	1	-7.81	2006	-5.727	0	17.82
8	1 8	-8.48	-12.6	0	-4.033	1853	-4.805	0	13.81
9	1 9	-18	-19.13	735	-12.61	2	-5.414	0	37.77
10	1 10	-16.68	-18.66	2249	-13.59	1231	-5.212	0	41.01
11	1 11	-19.57	-25.32	0	-16.71	1226	-5.648	0	35.28
12	1 12	-27.67	-30.65	851	-24.14	1433	-6.326	0	42
13	1 13	-25.91	-30.05	543	-20.04	1223	-6.998	0	59.6
14	1 14	-15.89	-21.95	1	-11.43	1351	-5.957	0	16.86
15	1 15	-12.02	-14.63	837	-9.05	2332	-4.967	0	22.3
16	1 16	-8.73	-12.1	0	-6.779	1347	-4.151	0	14.99
17	1 17	-14.13	-15.39	1002	-12.1	1	-3.97	0	37.95
18	1 18	-16.3	-20.52	0	-12.5	1231	-4.044	0	84
19	1 19	-18.56	-22.7	441	-7.17	1404	-4.582	0	80
20	1 20	-17.23	-22.76	702	-8.96	1451	-5.015	0	104
21	1 21	-13.31	-21.55	523	-7.14	1945	-4.917	0	59.21
22	1 22	-6.672	-10.81	12	-4.226	1441	-3.673	0	41.59
23	1 23	-8.27	-12.89	1918	-3.094	1252	-3.139	0	20.96
24	1 24	-10.83	-13.99	944	-7.96	2319	-3.265	0	15.47
25	1 25	-10.51	-11.85	916	-7.97	9	-3.05	0	63.85
26	1 26	-8.23	-11.76	141	-5.158	1507	-2.943	0	46.7
27	1 27	-5.25	-8.99	0	-3.558	1503	-2.572	0	25.04
28	1 28	-6.311	-9.26	126	-4.674	1445	-2.508	0	38.86
29	1 29	-6.105	-9.2	538	-3.256	2139	-2.343	0	35.92
30	1 30	-4.32	-7.03	2024	-1.245	1353	-2.047	0.254	109.2
31	1 31	-5.756	-10.1	512	-2.802	1245	-2.167	0	18.95
32	2 1	-9.97	-18.04	0	-5.25	1	-2.165	0	54.51
33	2 2	-18.15	-22.66	804	-8.96	1421	-3.115	0	143.9
34	2 3	-16.01	-23.78	325	-9.43	1541	-3.813	0	150.1
35	2 4	-8.39	-12.14	1	-6.273	1941	-3.158	0	49.66
36	2 5	-6.696	-8.32	408	-5.124	1520	-2.612	0	27.6
37	2 6	-6.113	-7.42	0	-4.867	1558	-2.323	0	59.68
38	2 7	-6.711	-11.11	753	-1.292	1547	-2.48	0	91.5

392	8	-7.78	-13.72	710	-2.645	1348	-2.587	0	124.2
402	9	-4.289	-7.52	2332	-1.397	1211	-2.073	0	62.72
412	10	-6.56	-7.97	640	-4.833	1535	-2.091	0	42.88
422	11	-3.324	-5.352	1	-0.259	1106	-1.876	0	111
432	12	-4.349	-9.5	2354	-1.796	1330	-1.723	0	85.3
442	13	-8.6	-14.14	823	-2.055	1552	-2.626	0	179.8
452	14	-3.255	-4.805	1	-1.045	2349	-2.249	0	35.88
462	15	-0.872	-3.663	2301	0.843	1426	-1.4	3.048	71.6
472	16	0.619	-3.371	23	2.672	1547	-0.975	1.524	38.22
482	17	2.481	1.465	405	4.078	1305	0.116	1.016	63.96
492	18	1.656	0.346	2358	3.551	1355	0.585	0	89.1
502	19	0.85	-1.016	408	3.258	1207	0.7	0	55.92
512	20	-0.082	-4.664	633	4.322	1253	0.625	0	78.6
522	21	0.937	-1.525	32	2.149	1403	0.722	0	35.07
532	22	2.151	0.631	1	2.844	1053	1.656	0.254	12.76
542	23	2.58	-1.658	0	7.8	1409	4.503	0.254	142.6
552	24	1.325	-2.549	717	7.36	1249	1.015	0	230
562	25	1.363	-0.799	5	4.272	1514	1.805	6.35	11.36
572	26	2.689	1.574	426	3.278	1819	8.74	16.26	8.33
582	27	1.411	0.73	0	2.644	110	23.57	5.842	4.369
592	28	-0.631	-2.368	1745	0.731	1	15.87	0	38.08
603	1	-1.991	-2.998	2359	-1.007	9	12.3	0	108.5
613	2	-4.176	-6.272	2359	-2.845	1423	11.17	0	80.6
623	3	-8.81	-11.65	911	-6.287	1	12.44	0	195.5
633	4	-7.03	-11.46	706	-2.941	1435	11.49	0	285
643	5	-3.186	-10.19	701	3.948	1405	8.45	1.016	260.2
653	6	-3.252	-4.717	703	-0.813	1251	2.417	0.762	122.5
663	7	-6.144	-12.39	0	-3.855	1339	-0.04	0	158.9
673	8	-13.87	-17.64	2359	-10.77	1509	-1.399	0	306.9
683	9	-19.07	-22.12	720	-16.04	1421	-3.037	0	311.8
693	10	-19.92	-23.35	544	-15.94	1537	-4.587	0	319.9
703	11	-16.64	-22.46	641	-10.52	1557	-5.341	0	330.7
713	12	-12.03	-15.66	633	-8.09	2207	-5.219	0	148.6
723	13	-10.32	-13.6	2358	-6.755	728	-4.191	0	280.7
733	14	-11.5	-16.12	654	-6.618	1621	-3.821	0	327.2
743	15	-6.998	-15.02	642	0.984	1417	-3.539	0	320.5
753	16	-3.898	-8.86	649	-1.069	1602	-2.944	0	96.2
763	17	-0.173	-1.715	601	1.252	1655	-2.146	0	72
773	18	-1.151	-3.774	746	2.572	1541	-1.877	0	313.2

78 3	19	-1.398	-4.25	652	2.181	1323	-1.627	0.254	301
79 3	20	0.338	-2.158	610	4.679	1447	-0.428	0	202.1
80 3	21	0.56	-1.126	536	3.44	1435	1.651	1.524	86.6
81 3	22	-1.735	-4.92	0	0.444	1459	1.003	0	187
82 3	23	-2.776	-7.29	609	2.939	1440	-0.062	0	382.9
83 3	24	-1.025	-7.56	136	3.039	1410	1.516	0	215.1
84 3	25	4.347	0.563	101	10.24	1543	13.66	0	298.8
85 3	26	6.599	2.728	618	13.97	1348	17.64	0	266.1
86 3	27	6.634	0.615	143	12.28	1617	21.74	0	271.8
87 3	28	5.229	1.612	616	9.58	1310	25.46	0	383.5
88 3	29	3.032	-0.66	731	8.15	1534	8.57	0	374.6
89 3	30	4.06	-2.941	552	10.54	1533	6.477	0	417.8
90 3	31	5.463	-2.564	512	12.91	1309	8.12	0	412.4
91 4	1	6.184	1.155	2303	12.22	1528	5.938	0	407.2
92 4	2	6.756	-1.949	505	13.76	1412	6.959	0	430.2
93 4	3	8.16	-2.016	522	18.24	1756	9.42	0	431.4
94 4	4	7.41	-1.497	615	15.53	1306	8.7	0	415.5
95 4	5	7.97	1.559	427	15.68	1308	9.99	1.524	253.3
96 4	6	5.272	1.631	0	8.2	1335	31.2	6.604	66.54
97 4	7	3.587	-0.239	637	9.47	1607	11.14	0	311.5
98 4	8	5.493	0.241	358	11.48	1441	6.893	0	289.1
99 4	9	6.716	0.691	0	12.68	1715	7.92	0	187.9
100 4	10	8.28	0.653	47	16.97	1412	11.97	0.508	298.5
101 4	11	10.44	0.269	502	18.26	1348	17.39	0	381.4
102 4	12	11.3	10.26	49	13.2	351	17.05	16.51	11.64
103 4	13	7.61	3.041	0	11.09	7	14.05	11.18	58.38
104 4	14	1.911	-0.533	625	5.353	1337	4.451	0	233.4
105 4	15	2.036	-2.969	549	7.57	1617	4.277	0	489.5
106 4	16	5.265	-1.597	129	11.42	1628	7.31	0	419.9
107 4	17	4.696	-1.635	0	10.9	1247	8.31	0	485.6
108 4	18	3.622	-3.453	525	11.4	1543	7.05	0	501.4
109 4	19	5.845	-0.291	542	12.86	1509	9.59	0	494.8
110 4	20	7.96	-1.963	505	16.01	1518	11.73	0	494.3
111 4	21	10.48	-1.787	518	19.84	1529	14.51	0	517.1
112 4	22	14.7	1.92	536	24.56	1614	18.13	0	506.7
113 4	23	13.68	7.19	551	20.21	1306	16.45	0	479.6
114 4	24	9.96	2.219	519	16.77	1438	13.49	0	464.5
115 4	25	12.56	8.01	509	20.07	1542	14.9	0	312.3
116 4	26	12.06	5.958	534	20.08	1622	15.31	0	456.4

1174	27	14.21	4.02	224	22.56	1508	18.59	0	528.8
1184	28	17.4	9.53	526	24.58	1426	14.58	0	495.7
1194	29	19.82	9.17	521	29	1612	17.1	0	509.2
1204	30	17.78	8.98	0	28.07	1142	17.36	0	433.8
1215	1	7.09	4.072	1031	11.25	1517	12.31	0	287.5
1225	2	10.41	2.005	521	18.64	1559	12.87	0	553.4
1235	3	14.72	3.069	505	23.89	1445	15.38	0	555.9
1245	4	12.61	5.103	0	16.76	1118	13.9	0.508	361.1
1255	5	9.77	2.29	510	17.19	1442	12.8	0	522.3
1265	6	3.516	2.081	745	4.889	1	8.38	25.15	22.27
1275	7	9.87	4.208	406	16.25	1450	10.38	3.048	382.8
1285	8	14.06	7.25	400	21.7	1527	13.98	0	543.8
1295	9	16.4	7.65	451	24.77	1559	17.36	0	540
1305	10	16.59	6.864	348	24.54	1615	18.5	5.842	416.3
1315	11	15.22	8.99	2341	21.39	1613	19.19	5.334	424.8
1325	12	10.62	6.381	515	14.93	1234	15.49	0	349.1
1335	13	14.11	3.664	321	23.62	1633	17.04	11.94	441.3
1345	14	14.53	11.13	455	20.48	1224	17.78	12.95	235.6
1355	15	16.43	12.65	128	21.94	1325	19.16	4.826	224
1365	16	13.56	9.86	2340	17.9	1810	17.06	24.38	304.8
1375	17	16.93	6.53	437	24.54	1544	19.66	0	542.8
1385	18	19.67	12.84	455	26.54	1354	22.68	1.778	593.5
1395	19	15.06	9.47	0	20.46	1716	18.75	0	332.9
1405	20	14.31	8.93	435	20.06	1437	18.6	0	596.4
1415	21	15.05	6.46	445	23.44	1605	19.22	0	624.5
1425	22	16.83	7.26	330	25.26	1455	20.72	0	584.3
1435	23	17.76	7.46	429	27.19	1552	21.62	0	601
1445	24	19.44	9.24	459	27.39	1444	21.49	0	554.4
1455	25	17.83	12.75	2244	22.88	1438	21.73	0	605.7
1465	26	19.61	9.74	331	29.17	1301	21.39	1.524	394.5
1475	27	19.62	13.63	456	28.12	1155	21.66	8.64	375.1
1485	28	12.24	2.669	0	19.51	1351	18.14	12.7	152.2
1495	29	7.5	0.843	514	14.33	1831	14.53	0	634.9
1505	30	12.07	4.036	441	23.81	1514	16.86	0	498.8
1515	31	11.29	4.164	500	17.24	1813	16.15	0	447.4
1526	1	8.62	5.474	1142	13.62	49	13.64	0.762	218.7
1536	2	7.28	4.007	546	10.35	1344	11.79	0	313.8
1546	3	8.91	3.155	504	14.08	1518	12.9	0	443.7
1556	4	9.15	4.57	443	13.08	1129	13.37	0	353.2

1566	5	9.46	5.972	438	12.51	1356	13.53	0	328.6
1576	6	11.33	4.608	445	17.28	1729	14.47	0	381.9
1586	7	14.55	6.697	438	21.87	1623	16.93	0	551.9
1596	8	16.56	5.143	447	24.9	1345	19.23	0	600.1
1606	9	18.66	12.48	355	24.86	1228	20.78	0	400.1
1616	10	16.69	13.37	2326	22.4	1114	19.85	18.54	243
1626	11	15.8	13.44	9	19.36	1331	17.93	4.064	156.5
1636	12	18.48	12.17	455	25.13	1604	20.3	0	562
1646	13	20.15	13.32	38	29.78	1300	22.1	0.508	453.4
1656	14	16.33	14.65	2358	18.92	1207	19.12	6.096	167
1666	15	17.77	14.46	59	22.52	1420	19.81	0	416.9
1676	16	16.62	14.82	400	19.05	1747	19.15	0.762	190.2
1686	17	21.78	19.64	2153	24.83	1404	22.26	0.508	31.21
1696	18	21.12	18.21	506	25.74	1431	21.04	1.106	184.1
1706	19	18.73	15.11	2332	25.08	1338	21.23	12.95	246.5
1716	20	16.81	14.14	748	20.54	1537	18.85	0.762	175.1
1726	21	14.57	11.83	444	17.31	1431	17.71	0.762	219.1
1736	22	16.04	12.71	509	23.05	1715	18.63	1.778	355
1746	23	18.14	9.09	404	24.86	1451	21.19	1.524	479.2
1756	24	19.89	16.04	426	25.62	1826	21.42	3.302	216
1766	25	23.86	17.57	242	30.84	1642	25.61	0	544.8
1776	26	23.11	17.3	430	31.9	1336	25.25	4.064	282.7
1786	27	21.41	15.72	2358	27.84	1321	24.47	3.302	434.6
1796	28	17.85	15.39	453	21.01	1321	22.03	5.334	344.3
1806	29	19.04	15.7	525	23.63	1340	21.69	5.08	274.3
1816	30	22.32	17.56	2359	28.05	1417	23.89	0	515.3
1827	1	21.88	14.73	433	29.96	1649	25.53	9.65	581.5
1837	2	21.25	16.88	201	27.93	1009	24.14	0	341.4
1847	3	20.17	14.49	0	23.9	1403	24.07	0	596
1857	4	20.31	11.13	432	26.91	1341	24.06	0	484.4
1867	5	19.73	15.81	125	24.41	1536	23.04	0	191.5
1877	6	19.59	14.6	503	25.8	1504	23.19	0.254	320.9
1887	7	21.76	17.98	26	27.62	1641	24.39	0	317.7
1897	8	23.24	16.01	411	29.42	1639	25.59	0	463.7
1907	9	25.07	17.09	418	33.16	1515	27.28	0	541.2
1917	10	25.45	19.21	439	32.89	1544	27.77	15.24	500.4
1927	11	27.35	20.93	439	32.98	1501	28.19	0.254	594.3
1937	12	25.28	21.01	645	30.04	1613	26.99	11.68	491.4
1947	13	24.19	18.47	444	29.29	1526	25.82	0	619.9

1957	14	24.15	17.42	350	31.1	1549	25.75	0.254	514.3
1967	15	17.23	11.54	2349	20.56	1253	22.55	0	382.7
1977	16	17.88	9.45	340	24.08	1713	21.91	0	566.8
1987	17	21.13	13.68	431	26.93	1347	23.56	0	491.5
1997	18	21.64	17.01	607	27.4	1812	22.69	23.11	298.4
2007	19	21.53	16.4	445	26.74	1801	22.7	0	580.3
2017	20	20.71	14.18	446	27.84	1540	21.55	1.778	328.3
2027	21	17.8	14.38	0	21.02	1146	20.45	0	362.3
2037	22	16.09	10.8	459	21.08	1319	19.15	0	457.4
2047	23	17.2	11.57	355	23.25	1459	19.59	0	522.2
2057	24	17.99	10.21	349	25.88	1404	20.01	0	483.2
2067	25	20.4	10.38	458	27.77	1641	21.4	0	581.7
2077	26	22.7	18.32	428	27.23	1240	22.44	3.81	533.3
2087	27	22.14	13.75	501	28.94	1540	22.07	1.778	575.5
2097	28	20.27	15.24	2303	24.47	1425	21.47	0	556.5
2107	29	18.42	13.1	543	23.3	1436	20.57	0	428.4
2117	30	17.57	12.15	512	23.02	1613	20.64	0	499.1
2127	31	19.67	8.93	509	28.41	1645	20.96	0	558.5
2138	1	21.99	12.58	417	29.31	1640	22.19	0	378.5
2148	2	23.62	19.45	0	29.72	1627	23.28	2.54	201.7
2158	3	22.09	18.77	525	25.84	1204	22.27	0.508	159
2168	4	23.71	17.69	504	30.22	1630	23.41	0	461.8
2178	5	24.24	14.93	439	33.06	1454	24.26	0	552.4
2188	6	24.37	15.68	515	32.11	1432	24.99	0	531.4
2198	7	24.38	14.66	434	33.01	1503	24.82	0	508.2
2208	8	23.93	15.93	456	30.37	1310	24.26	0	418.2
2218	9	-6999	-6999	29	46.32	1046	-6999	0	227.2
2298	17	20.07	13.85	0	24.29	1624	23.15	0	258.4
2308	18	17.85	11.46	336	23.79	1636	19.72	0	206.7
2318	19	22.88	16.84	200	31.94	1618	22	1.778	273.8
2328	20	20.19	14.8	107	25.6	1258	21.75	0	465.9
2338	21	21.61	12.82	410	30.72	1618	22.37	0.254	436.6
2348	22	21.3	17.34	110	28.38	1313	22.64	6.858	259.7
2358	23	20.33	17.07	644	25.22	1204	21.76	0.254	328.9
2368	24	19.95	13.65	551	26.25	1421	21.42	0	409.2
2378	25	21.62	12.97	556	30.5	1346	21.62	0.508	408.1
2388	26	22.13	13.54	506	31.57	1543	22.52	0.254	391.3
2398	27	22.63	16.64	2359	28.51	1624	22.62	2.032	323.5
2408	28	20.61	13.59	341	27.98	1425	20.97	0	344.5

241	8	29	18.64	11.95	520	25.16	1411	20.39	0	440
242	8	30	19.74	8.85	549	29.86	1602	20.39	0	445
243	8	31	19.53	10.69	456	30.16	1405	20.21	0	330.6
244	9	1	15.66	9.83	714	20.53	1550	18.67	0	421.2
245	9	2	15.3	7.77	434	23.65	1634	17.92	0	260
246	9	3	18.32	8.35	708	28.81	1631	18.86	0	376.5
247	9	4	22.82	11.67	718	31.14	1615	20.87	0	393
248	9	5	20.77	12.96	0	24.92	1	21.47	0	396.7
249	9	6	16.6	9.46	427	23.55	1320	18.78	0	400.6
250	9	7	14.79	9.14	629	20.51	1431	18.13	0	404.6
251	9	8	15.83	6.25	611	23.76	1535	17.87	0	406.1
252	9	9	20.65	14.23	437	28.35	1457	19.57	0	302
253	9	10	24.26	16.36	223	35.39	1745	21.86	0	343.9
254	9	11	19.28	12.23	2337	24.38	1526	21.31	0	347.8
255	9	12	18.26	8.31	450	26.78	1236	19.27	0	248.1
256	9	13	19.43	12.91	556	28.09	1645	20.46	0	273.2
257	9	14	18.22	11.49	0	23.2	1401	19.45	0	362.9
258	9	15	17.71	8.57	426	25.53	1713	18.6	0	340.7
259	9	16	19.61	13.72	741	24.87	1407	19.53	0	352.1
260	9	17	19.84	14.09	640	27.61	1242	20.3	0	330.6
261	9	18	13.44	9.73	0	18.62	1232	16.35	5.334	168
262	9	19	11.49	9.33	0	14.45	1853	13.14	1.016	11.96
263	9	20	9.49	7.03	2359	13.47	1645	11.52	3.302	123.6
264	9	21	9.44	2.718	608	15.64	1640	12.02	0	331.7
265	9	22	12.72	5.923	706	20.26	1324	13.71	0	306.8
266	9	23	11.83	7.97	659	17	1343	12.81	0	141.3
267	9	24	11.21	3.53	655	16.88	2003	11.88	0.254	71.9
268	9	25	12.82	10.44	604	16.62	1534	13.45	0.508	165
269	9	26	12.16	9.25	0	17.2	1337	13.24	3.302	104.3
270	9	27	13.38	8.24	640	21.27	1631	13.32	0	306.1
271	9	28	13.58	5.285	428	25.2	1319	13.5	0	250.9
272	9	29	11.01	4.895	326	17.1	1329	12.84	0.508	218.9
273	9	30	7.34	3.06	2305	12.12	1438	10.49	0	180.3
274	10	1	5.958	-0.68	0	12.04	1529	9.22	0	294.4
275	10	2	6.062	-3.151	629	14.73	1400	8.35	0	274
276	10	3	8.31	0.246	702	17.63	1437	9.35	0	277.5
277	10	4	10.04	3.399	518	16.63	1432	10.02	1.778	183.5
278	10	5	9.67	8.36	2	11.07	1439	10.35	25.15	4.416
279	10	6	9.36	6.972	2052	10.75	1120	10.46	5.334	9.83

280	10	7	8.99	3.84	2242	15.67	1524	9.89	0	263.3
281	10	8	12.69	4.868	1	19.62	1601	10.27	0	257.1
282	10	9	12.98	8.1	703	22.96	1410	11.84	0	213.6
283	10	10	6.727	4.846	624	9.51	1	9.77	0	56.36
284	10	11	8.37	5.577	327	11.54	2348	9.02	16.26	3.483
285	10	12	4.046	1.891	1952	11.53	1	7.49	0.762	59.59

1999 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm	WGP mm
1 1	0	1999	-18.8	-27.6	-23.2	0.0	4.4
1 2	0	1999	-19.3	-23.2	-21.3	0.0	2.5
1 3	0	1999	-21.6	-27.6	-24.6	0.0	0.0
1 4	0	1999	-20.0	-32.3	-26.2	0.0	0.0
1 5	0	1999	-16.9	-23.4	-20.2	0.0	0.6
1 6	0	1999	-21.6	-27.8	-24.7	0.0	0.0
1 7	0	1999	-18.7	-25.9	-22.3	0.0	0.0
1 8	0	1999	-21.7	-29.0	-25.4	0.0	0.0
1 9	0	1999	-19.1	-30.0	-24.6	0.0	0.0
1 10	0	1999	-21.9	-30.3	-26.1	0.0	0.6
1 11	0	1999	-22.3	-29.3	-25.8	0.0	1.4
1 12	0	1999	-26.3	-36.5	-31.4	0.0	8.3
1 13	0	1999	-18.6	-35.9	-27.3	0.0	1.9
1 14	0	1999	-13.2	-29.2	-21.2	0.0	0.6
1 15	0	1999	3.7	-13.2	-4.7	3.6	2.6
1 16	0	1999	0.5	-8.0	-3.7	0.0	5.3
1 17	0	1999	-3.8	-10.9	-7.4	0.0	0.0
1 18	0	1999	-9.8	-19.4	-14.6	0.0	0.0
1 19	0	1999	-16.1	-18.9	-17.5	0.0	1.6
1 20	0	1999	-16.7	-28.3	-22.5	0.4	4.2*
1 21	0	1999	-7.2	-24.6	-15.9	0.0	2.2
1 22	0	1999	-7.1	-9.1	-8.1	0.0	0.7
1 23	0	1999	-9.1	-10.8	-9.9	0.0	0.0
1 24	0	1999	-10.5	-20.9	-15.7	0.0	0.0
1 25	0	1999	-8.5	-23.5	-16.0	0.0	0.7
1 26	0	1999	-8.4	-18.3	-13.3	0.0	0.0
1 27	0	1999	-9.2	-11.8	-10.5	0.0	0.0
1 28	0	1999	-6.1	-18.3	-12.2	0.0	0.0
1 29	0	1999	-1.8	-12.9	-7.3	0.0	0.0
1 30	0	1999	-2.3	-12.8	-7.6	0.0	0.0
1 31	0	1999	-2.1	-13.2	-7.6	0.0	0.9

1999 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm	WGP mm
2 1	0	1999	2.9	-8.1	-2.6	0.0	20.1*
2 2	0	1999	-2.9	-9.7	-6.3	0.0	250.6*
2 3	0	1999	-6.8	-21.1	-14.0	0.0	30.3*
2 4	0	1999	-16.5	-25.3	-20.9	0.0	470.8*
2 5	0	1999	-9.1	-21.4	-15.2	0.0	0.0
2 6	0	1999	-12.4	-21.3	-16.9	0.0	17.1*
2 7	0	1999	-1.5	-17.1	-9.3	0.0	0.7
2 8	0	1999	4.4	-9.1	-2.3	2.2	20.2*
2 9	0	1999	-5.0	-15.5	-10.3	0.0	0.8
2 10	0	1999	2.3	-9.1	-3.4	0.0	0.6
2 11	0	1999	-6.7	-12.6	-9.6	0.0	0.6
2 12	0	1999	-9.4	-19.4	-14.4	0.0	2.4
2 13	0	1999	-1.3	-19.5	-10.4	0.0	0.0
2 14	0	1999	1.5	-6.6	-2.6	0.0	0.0
2 15	0	1999	-5.4	-11.7	-8.6	0.0	0.0
2 16	0	1999	-10.7	-15.4	-13.0	0.0	0.0
2 17	0	1999	-11.5	-21.2	-16.3	0.0	0.0
2 18	0	1999	-9.8	-22.1	-16.0	0.0	0.0
2 19	0	1999	-7.1	-18.5	-12.8	0.0	0.0
2 20	0	1999	-3.7	-14.0	-8.8	0.0	0.0
2 21	0	1999	-1.0	-9.3	-5.2	0.0	0.0
2 22	0	1999	-2.5	-9.5	-6.0	0.0	0.8
2 23	0	1999	-2.4	-4.8	-3.6	0.0	2.0
2 24	0	1999	0.3	-10.1	-4.9	0.0	0.7
2 25	0	1999	0.6	-13.3	-6.4	0.0	13.1*
2 26	0	1999	1.9	-2.7	-0.4	0.2	0.6
2 27	0	1999	1.1	-2.4	-0.6	4.6	11.3*
2 28	0	1999	-2.2	-4.5	-3.4	0.2	0.0

1999 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm	WGP mm
3 1	0	1999	-2.2	-5.7	-4.0	0.0	0.0
3 2	0	1999	-3.5	-15.1	-9.3	0.0	4.6
3 3	0	1999	-8.2	-20.1	-14.1	0.0	0.7
3 4	0	1999	-5.5	-12.8	-9.2	0.0	0.0
3 5	0	1999	-7.7	-16.4	-12.1	0.0	0.0
3 6	0	1999	-6.1	-18.5	-12.3	0.0	0.0
3 7	0	1999	-2.6	-10.7	-6.7	0.0	0.0
3 8	0	1999	-3.3	-6.6	-4.9	0.0	5.2
3 9	0	1999	-1.6	-10.1	-5.8	0.6	1.2
3 10	0	1999	-2.5	-10.2	-6.4	0.6	0.7
3 11	0	1999	-2.7	-11.8	-7.3	0.0	0.0
3 12	0	1999	-1.6	-12.4	-7.0	0.0	0.0
3 13	0	1999	-0.5	-11.0	-5.7	0.0	0.0
3 14	0	1999	0.4	-5.7	-2.6	0.0	0.0
3 15	0	1999	8.2	-4.8	1.7	0.0	0.6
3 16	0	1999	3.0	-1.7	0.6	0.0	0.0
3 17	0	1999	0.5	-6.4	-3.0	0.0	6.8
3 18	0	1999	0.8	-8.6	-3.9	0.0	0.0
3 19	0	1999	4.7	-3.8	0.5	0.0	0.6
3 20	0	1999	3.1	-2.4	0.4	0.0	0.0
3 21	0	1999	4.3	-5.5	-0.6	0.0	0.0
3 22	0	1999	7.8	-3.5	2.2	0.2	0.0
3 23	0	1999	1.4	-4.3	-1.4	0.0	14.3
3 24	0	1999	1.8	-7.1	-2.7	0.0	0.0
3 25	0	1999	6.1	-3.1	1.5	0.0	144.7
3 26	0	1999	10.0	-0.4	4.8	0.0	46.9
3 27	0	1999	10.8	0.8	5.8	0.0	83.8
3 28	0	1999	11.3	-0.2	5.6	0.6	188.1
3 29	0	1999	12.1	-0.8	5.6	0.0	165.5
3 30	0	1999	10.8	-2.0	4.4	0.0	11.8
3 31	0	1999	6.9	-0.5	3.2	0.0	117.7

1999 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm	WGP mm
4 1	0	1999	0.7	-2.6	-0.9	0.0	157.8
4 2	0	1999	-0.4	-2.8	-1.6	0.6	1.6
4 3	0	1999	-0.5	-3.8	-2.1	0.0	23.8
4 4	0	1999	-0.1	-5.3	-2.7	11.2	8.6
4 5	0	1999	1.8	-10.5	-4.4	0.0	0.0
4 6	0	1999	3.8	-3.2	0.3	0.0	0.6
4 7	0	1999	13.0	-2.0	5.5	0.0	0.0
4 8	0	1999	15.1	-0.5	7.3	0.0	6999.0
4 9	0	1999	12.9	0.4	6.6	0.0	0.0
4 10	0	1999	10.9	0.5	5.7	0.0	0.0
4 11	0	1999	11.5	-2.1	4.7	0.0	0.0
4 12	0	1999	14.7	-1.2	6.7	0.0	0.0
4 13	0	1999	21.0	0.1	10.6	2.6	2.0
4 14	0	1999	12.5	2.8	7.7	0.0	0.0
4 15	0	1999	3.7	-3.4	0.2	0.4	0.0
4 16	0	1999	1.2	-4.4	-1.6	0.0	0.0
4 17	0	1999	5.3	-4.4	0.5	0.0	0.0
4 18	0	1999	12.5	-3.3	4.6	0.4	0.7
4 19	0	1999	12.4	-0.8	5.8	0.2	0.0
4 20	0	1999	12.7	3.2	8.0	0.0	0.0
4 21	0	1999	13.3	0.5	6.9	0.0	0.0
4 22	0	1999	13.5	-2.0	5.7	0.0	0.0
4 23	0	1999	16.7	-2.7	7.0	0.0	0.0
4 24	0	1999	20.9	-0.6	10.2	0.0	0.0
4 25	0	1999	22.5	3.3	12.9	0.0	0.0
4 26	0	1999	23.2	2.7	13.0	0.0	0.0
4 27	0	1999	19.9	9.1	14.5	0.0	0.0
4 28	0	1999	23.4	7.3	15.3	0.0	0.0
4 29	0	1999	24.1	2.5	13.3	0.0	0.0
4 30	0	1999	26.8	2.7	14.8	0.0	0.6

*Note: There was an hourly anomaly in the hourly weather data. In one hour on Dec. 4th it said we had 50.5 mm of precipitation. Checked with environment Canada and they ignored the reading as an error because it occurred within one hour.

1999 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm	WGP mm
5 1	0	1999	26.4	4.1	15.3	0.0	0.7
5 2	0	1999	25.2	8.0	16.6	0.0	0.7
5 3	0	1999	21.3	12.3	16.8	6.6	6.1
5 4	0	1999	23.2	12.6	17.9	3.0	2.9
5 5	0	1999	17.4	12.4	14.9	12.0	12.6
5 6	0	1999	12.4	5.3	8.8	8.2	8.4
5 7	0	1999	7.7	0.3	4.0	0.0	0.0
5 8	0	1999	10.0	-1.2	4.4	0.0	0.0
5 9	0	1999	11.8	-1.4	5.2	0.0	0.0
5 10	0	1999	6.3	2.9	4.6	25.0	25.0
5 11	0	1999	13.0	3.6	8.3	1.6	1.5
5 12	0	1999	12.1	2.5	7.3	0.0	0.0
5 13	0	1999	12.4	7.5	10.0	0.0	0.0
5 14	0	1999	13.4	7.6	10.5	10.8	11.3
5 15	0	1999	20.2	9.1	14.6	3.6	4.3
5 16	0	1999	19.2	7.9	13.6	1.4	0.7
5 17	0	1999	13.1	6.6	9.8	0.0	0.0
5 18	0	1999	15.9	3.1	9.5	0.0	0.0
5 19	0	1999	21.8	9.5	15.6	2.2	2.0
5 20	0	1999	15.5	8.4	11.9	26.4	26.7
5 21	0	1999	11.7	6.6	9.1	6.2	6.3
5 22	0	1999	9.7	7.3	8.5	25.8	27.2
5 23	0	1999	14.0	6.4	10.2	0.6	0.7
5 24	0	1999	16.6	5.2	10.9	0.2	0.0
5 25	0	1999	20.5	6.3	13.4	0.0	0.6
5 26	0	1999	26.9	6.9	16.9	0.6	0.0
5 27	0	1999	24.3	10.9	17.6	0.0	0.6
5 28	0	1999	31.9	10.6	21.2	0.0	0.0
5 29	0	1999	23.8	13.2	18.5	0.0	0.0
5 30	0	1999	13.2	6.9	10.0	7.8	7.0
5 31	0	1999	15.8	3.6	9.7	0.0	0.6

Total Precipitation for the month of May

142.
0 mm

Last year for the month of May we received 38.2 mm of precipitation.

1999 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm	WGP mm
6 1	0	1999	12.2	8.0	10.1	0.6	0.7
6 2	0	1999	21.1	8.0	14.5	0.0	0.6
6 3	0	1999	22.2	9.5	15.9	0.0	0.0
6 4	0	1999	26.0	14.5	20.3	7.0	7.2
6 5	0	1999	25.7	11.2	18.5	0.0	0.0
6 6	0	1999	26.6	9.9	18.3	7.6	6.8
6 7	0	1999	26.5	11.1	18.8	0.2	0.7
6 8	0	1999	28.3	14.6	21.4	0.0	0.0
6 9	0	1999	22.5	12.8	17.6	16.8	17.8
6 10	0	1999	21.6	8.7	15.2	0.0	0.0
6 11	0	1999	22.5	9.8	16.2	0.0	0.0
6 12	0	1999	21.1	10.7	15.9	0.2	0.0
6 13	0	1999	15.3	5.0	10.2	0.0	0.0
6 14	0	1999	15.8	4.2	10.0	1.4	1.5
6 15	0	1999	18.3	5.3	11.8	0.0	0.0
6 16	0	1999	20.0	3.1	11.6	0.0	0.0
6 17	0	1999	22.9	6.2	14.6	0.0	0.0
6 18	0	1999	25.0	8.3	16.6	0.0	0.0
6 19	0	1999	20.9	9.6	15.2	0.0	0.0
6 20	0	1999	23.1	14.5	18.8	0.2	0.0
6 21	0	1999	27.6	15.3	21.5	0.0	0.6
6 22	0	1999	31.0	17.3	24.2	1.8	1.7
6 23	0	1999	25.7	14.0	19.9	0.8	1.3
6 24	0	1999	24.0	9.2	16.6	0.0	0.0
6 25	0	1999	16.5	8.2	12.3	2.4	2.5
6 26	0	1999	21.4	11.7	16.5	12.0	12.1
6 27	0	1999	17.6	10.6	14.1	0.0	0.0
6 28	0	1999	20.8	10.7	15.8	0.0	0.0
6 29	0	1999	20.0	8.1	14.1	22.0	23.8
6 30	0	1999	20.3	9.3	14.8	1.0	1.1

1999 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm	WGP mm
7 1	0	1999	18.4	9.6	14.0	0.0	0.0
7 2	0	1999	19.7	7.1	13.4	2.2	2.2
7 3	0	1999	23.0	13.4	18.2	2.6	2.8
7 4	0	1999	22.2	14.6	18.4	0.2	0.0
7 5	0	1999	22.6	14.7	18.6	9.2	9.7
7 6	0	1999	26.2	13.9	20.1	0.0	0.0
7 7	0	1999	22.0	9.3	15.6	0.0	0.0
7 8	0	1999	20.6	12.5	16.6	20.8	20.9
7 9	0	1999	22.3	12.5	17.4	2.6	3.2
7 10	0	1999	25.4	10.8	18.1	0.0	0.0
7 11	0	1999	26.2	12.1	19.2	0.0	0.0
7 12	0	1999	26.0	15.2	20.6	1.8	1.5
7 13	0	1999	26.2	12.8	19.5	19.0	20.0
7 14	0	1999	25.1	14.9	20.0	0.2	0.6
7 15	0	1999	19.1	14.5	16.8	17.6	17.1
7 16	0	1999	19.9	9.8	14.8	0.2	0.0
7 17	0	1999	19.2	7.0	13.1	0.0	0.0
7 18	0	1999	22.3	11.5	16.9	0.0	0.0
7 19	0	1999	25.5	15.3	20.4	0.2	0.0
7 20	0	1999	28.1	15.5	21.8	0.0	0.6
7 21	0	1999	29.2	18.5	23.8	0.0	0.0
7 22	0	1999	29.3	18.5	23.9	3.8	3.5
7 23	0	1999	29.7	16.0	22.9	0.0	0.0
7 24	0	1999	29.4	14.1	21.8	0.0	0.0
7 25	0	1999	27.3	13.5	20.4	2.6	2.4
7 26	0	1999	23.2	11.4	17.3	0.2	0.0
7 27	0	1999	27.3	8.9	18.1	0.0	0.0
7 28	0	1999	30.4	12.3	21.3	0.0	0.0
7 29	0	1999	32.4	14.2	23.3	0.0	0.6
7 30	0	1999	26.9	15.2	21.1	0.0	0.0
7 31	0	1999	19.2	10.1	14.7	0.0	0.0

1999 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm	WGP mm
8 1	0	1999	22.1	9.0	15.5	0.0	0.0
8 2	0	1999	24.0	8.5	16.3	0.0	0.0
8 3	0	1999	25.0	9.9	17.4	0.0	0.0
8 4	0	1999	25.2	13.4	19.3	0.0	0.0
8 5	0	1999	27.3	11.4	19.3	0.6	0.0
8 6	0	1999	26.5	13.8	20.2	10.2	11.1
8 7	0	1999	19.5	9.2	14.3	0.2	0.0
8 8	0	1999	22.4	5.5	14.0	0.0	0.6
8 9	0	1999	25.0	14.0	19.5	2.0	2.4
8 10	0	1999	24.5	12.5	18.5	1.4	0.0
8 11	0	1999	21.0	12.6	16.8	10.6	10.0
8 12	0	1999	19.3	10.4	14.9	0.0	0.0
8 20	0	1999	27.3	12.1	19.7	0.0	0.0
8 21	0	1999	28.2	10.8	19.5	0.0	0.0
8 22	0	1999	28.3	14.1	21.2	6.0	0.0
8 23	0	1999	24.0	14.4	19.2	0.0	0.0
8 24	0	1999	27.5	11.0	19.3	0.0	0.0
8 25	0	1999	31.6	12.5	22.0	0.0	0.0
8 26	0	1999	28.2	12.3	20.2	0.0	0.0
8 27	0	1999	28.0	11.2	19.6	0.0	0.0
8 28	0	1999	21.0	6.8	13.9	0.0	0.0
8 29	0	1999	22.7	4.0	13.3	0.0	0.0
8 30	0	1999	20.4	14.1	17.3	0.0	0.0
8 31	0	1999	32.8	15.9	24.3	0.0	0.0

1999 Carman Weather Mean Data and Total Precipitation

Date	Time CST	Year	Max T C	Min T C	Mean T C	TBRG mm	WGP mm
9 1	0	1999	21.0	10.1	15.5	0.0	0.0
9 2	0	1999	15.8	8.6	12.2	0.0	0.0
9 3	0	1999	17.8	10.2	14.0	0.0	0.0
9 4	0	1999	12.7	10.7	11.7	14.6	31.3
9 5	0	1999	15.0	5.1	10.1	5.2	11.1
9 6	0	1999	26.6	4.0	15.3	0.2	0.6
9 7	0	1999	21.7	10.5	16.1	3.2	3.0
9 8	0	1999	12.6	7.8	10.2	2.4	2.0
9 9	0	1999	15.3	6.8	11.1	0.2	0.7
9 10	0	1999	14.2	4.3	9.2	0.0	0.0
9 11	0	1999	13.6	2.5	8.1	4.8	5.2
9 12	0	1999	15.1	5.3	10.2	1.2	1.4
9 13	0	1999	11.8	8.6	10.2	0.6	0.8
9 14	0	1999	14.7	7.3	11.0	0.2	0.0
9 15	0	1999	19.1	2.1	10.6	0.0	0.0
9 16	0	1999	22.6	1.8	12.2	0.0	0.0
9 17	0	1999	28.1	5.8	17.0	0.0	0.6
9 18	0	1999	20.3	9.3	14.8	0.0	0.0
9 19	0	1999	10.3	-0.6	4.9	1.2	0.8
9 20	0	1999	15.4	-3.4	6.0	0.0	0.6
9 21	0	1999	27.4	6.5	16.9	0.0	0.7
9 22	0	1999	24.7	6.3	15.5	0.0	0.6
9 23	0	1999	18.5	5.1	11.8	0.0	0.0
9 24	0	1999	26.1	5.1	15.6	0.0	0.7
9 25	0	1999	18.6	3.6	11.1	0.0	0.0
9 26	0	1999	13.9	7.2	10.6	2.2	1.9
9 27	0	1999	13.8	4.6	9.2	0.4	0.0
9 28	0	1999	14.4	0.5	7.5	0.2	0.6
9 29	0	1999	14.5	-3.2	5.7	0.0	0.6
9 30	0	1999	9.8	2.0	5.9	0.0	0.0
10 1	0	1999	5.2	0.1	2.6	0.0	0.0
10 2	0	1999	6.8	-5.2	0.8	0.0	0.0
10 3	0	1999	10.3	-3.9	3.2	0.0	0.0
10 4	0	1999	13.7	-3.0	5.4	0.6	0.6
10 5	0	1999	6.7	-2.6	2.0	0.0	0.0
10 6	0	1999	7.8	-7.1	0.4	0.0	0.0
10 7	0	1999	11.2	-0.7	5.3	0.0	0.0
10 8	0	1999	13.7	0.7	7.2	0.4	0.7
10 9	0	1999	15.6	2.7	9.1	0.0	0.0
10 10	0	1999	16.2	-0.4	7.9	0.0	0.0
10 11	0	1999	11.1	-1.8	4.7	1.8	1.1

10 12	0	1999	9.3	2.4	5.9	0.0	0.0

1999 Carman Weather Data and Total Precipitation

JDATE	MMDD	TEMP1 MEAN	TEMP1 MIN	TIME MIN	TEMP1 MAX	TIME MAX	TEMP SOIL	PPT1 mm	SOLAR cal/cm2
14.01	14	-13.0	-14.1	1746.0	-11.9	2340.0	-8.7	0.0	7.2
15.01	15	-6.1	-12.1	10.0	1.6	2154.0	-7.7	0.3	51.3
16.01	16	-2.8	-7.6	0.0	0.4	1.0	-6.2	0.3	102.9
17.01	17	-7.7	-12.3	335.0	-4.6	1622.0	-5.9	0.0	24.3
18.01	18	-15.7	-23.6	2359.0	-9.0	1.0	-6.1	0.0	101.7
19.01	19	-19.0	-24.5	451.0	-15.6	1429.0	-6.8	0.0	37.9
20.01	20	-19.3	-26.6	809.0	-11.6	1327.0	-6.9	0.0	107.5
21.01	21	-11.1	-21.9	139.0	-6.1	1558.0	-6.7	0.0	45.3
22.01	22	-7.6	-8.8	2210.0	-6.5	1416.0	-5.5	0.0	30.8
23.01	23	-8.6	-9.2	2352.0	-7.8	1221.0	-5.1	0.0	19.2
24.01	24	-13.5	-20.1	2157.0	-9.2	1.0	-4.9	0.0	98.3
25.01	25	-16.5	-21.6	712.0	-10.3	1356.0	-5.2	0.0	108.2
26.01	26	-13.3	-22.5	741.0	-5.4	1354.0	-5.2	0.0	131.0
27.01	27	-9.3	-13.3	2334.0	-5.9	1407.0	-4.9	0.0	101.6
28.01	28	-11.6	-20.1	817.0	-5.6	1315.0	-5.0	0.0	94.7
29.01	29	-5.8	-9.8	822.0	0.3	1306.0	-4.7	0.0	130.2
30.01	30	-4.6	-7.1	828.0	-0.8	1350.0	-4.3	0.0	131.0
31.01	31	-2.4	-7.2	357.0	1.3	1441.0	-4.0	0.0	100.1
32.02	1	-0.9	-7.1	0.0	1.1	1848.0	-3.5	1.8	46.4
33.02	2	-5.9	-9.6	304.0	-1.5	1347.0	-3.5	0.0	140.1
34.02	3	-12.4	-19.4	0.0	-5.6	11.0	-4.5	0.0	122.7
35.02	4	-18.4	-24.1	645.0	-13.2	1443.0	-5.1	0.0	130.4
36.02	5	-12.2	-17.7	833.0	-6.6	1230.0	-4.9	0.0	119.4
37.02	6	-13.1	-19.9	618.0	-8.9	1507.0	-4.7	0.0	143.0
38.02	7	-6.9	-15.2	505.0	1.1	1610.0	-4.4	0.0	84.8
39.02	8	-0.8	-6.9	0.0	3.7	1151.0	-3.6	2.8	129.6
40.02	9	-8.5	-13.9	820.0	-3.8	1635.0	-3.5	0.0	142.5
41.02	10	-1.7	-11.1	2353.0	5.7	1322.0	-3.2	0.0	85.8
42.02	11	-10.6	-13.3	2241.0	-7.4	1406.0	-4.4	0.0	152.0
43.02	12	-12.7	-17.3	2357.0	-9.2	1633.0	-5.4	0.0	187.6
44.02	13	-9.1	-18.4	205.0	-3.7	1422.0	-4.8	0.0	163.0
45.02	14	-3.8	-8.7	732.0	1.7	1349.0	-4.0	0.0	153.4
46.02	15	-6.8	-10.1	0.0	-4.7	111.0	-3.9	0.0	100.2
47.02	16	-11.9	-15.1	813.0	-8.0	1606.0	-4.5	0.0	196.5
48.02	17	-14.8	-19.7	711.0	-10.0	1628.0	-5.3	0.0	210.4
49.02	18	-14.3	-20.6	659.0	-5.0	1640.0	-5.9	0.0	199.8

50.02	19	-10.5	-17.8	108.0	-2.9	1413.0	-6.1	0.0	160.0
51.02	20	-8.3	-13.8	738.0	-0.8	1321.0	-5.9	0.0	209.2
52.02	21	-6.4	-14.6	325.0	-1.2	1523.0	-5.5	0.0	99.2
53.02	22	-3.8	-9.5	724.0	1.3	1441.0	-4.7	0.0	180.4
54.02	23	-3.6	-4.3	745.0	-2.5	1319.0	-4.1	0.0	94.2
55.02	24	-1.7	-3.3	1.0	-0.5	1435.0	-3.6	0.0	54.7
56.02	25	-1.5	-10.4	723.0	4.3	1428.0	-3.5	3.1	212.9
57.02	26	3.8	1.3	829.0	8.6	1322.0	-2.4	0.0	172.8
58.02	27	0.3	-1.6	2357.0	2.4	13.0	-0.4	4.8	15.6
59.02	28	-3.1	-4.6	849.0	-0.7	1418.0	-0.3	0.0	76.8
60.03	1	-2.3	-3.8	2131.0	0.0	1340.0	-0.9	0.0	27.1
61.03	2	-8.6	-12.7	0.0	-3.3	1.0	-2.8	0.0	262.9
62.03	3	-11.0	-16.9	723.0	-4.1	1516.0	-4.0	0.0	259.1
63.03	4	-9.4	-12.9	309.0	-5.2	1439.0	-4.2	0.0	188.1
64.03	5	-11.3	-16.2	739.0	-6.1	1537.0	-4.9	0.0	294.3
65.03	6	-9.8	-16.5	739.0	-1.3	1427.0	-5.6	0.0	266.2
66.03	7	-5.5	-13.0	223.0	0.6	1335.0	-5.1	0.0	222.8
67.03	8	-3.3	-5.7	253.0	-0.6	1424.0	-4.0	0.5	74.3
68.03	9	-2.2	-5.1	523.0	2.7	1208.0	-3.3	6.6	174.4
69.03	10	-2.0	-6.1	305.0	5.3	1340.0	-2.9	0.3	242.1
70.03	11	-3.2	-10.5	2319.0	6.0	1338.0	-2.6	0.0	283.2
71.03	12	-4.4	-10.9	517.0	4.7	1340.0	-2.5	0.0	286.8
72.03	13	-1.5	-6.8	1.0	3.0	1456.0	-2.3	0.0	174.6
73.03	14	-0.4	-6.0	319.0	4.1	1503.0	-1.4	0.0	278.8
74.03	15	1.9	-1.3	650.0	7.1	1643.0	-0.3	0.0	246.6
75.03	16	1.2	-4.3	633.0	8.3	1312.0	0.0	0.0	267.7
76.03	17	-2.1	-6.0	2354.0	2.0	46.0	-0.2	0.0	228.0
77.03	18	-3.5	-8.7	703.0	4.9	1217.0	-1.0	0.0	351.5
78.03	19	1.1	-4.7	56.0	6.3	1312.0	-0.9	0.0	217.1
79.03	20	1.0	-1.9	2357.0	4.7	1603.0	0.2	0.0	260.2
80.03	21	0.3	-6.6	626.0	7.2	1340.0	-0.1	0.0	351.0
81.03	22	2.7	-3.8	226.0	9.4	1625.0	-0.2	0.0	366.1
82.03	23	-3.0	-6.3	1045.0	1.7	51.0	0.2	0.0	374.6
83.03	24	-3.0	-7.6	624.0	2.1	1652.0	0.1	0.0	384.1
84.03	25	0.2	-5.8	119.0	5.2	1508.0	0.2	0.0	372.0
85.03	26	5.6	0.9	625.0	10.4	1714.0	0.7	0.0	371.9
86.03	27	5.6	1.5	0.0	8.7	1721.0	3.3	0.0	151.2
87.03	28	4.2	0.1	712.0	11.0	1429.0	5.7	0.0	274.2
88.03	29	4.7	0.0	642.0	11.6	1426.0	6.7	0.0	290.9
89.03	30	6.1	-1.7	231.0	15.1	1346.0	5.4	0.0	294.1

90.03	31	3.1	0.2	0.0	6.9	1301.0	4.7	0.0	350.9
91.04	1	-0.4	-2.1	751.0	2.1	1718.0	1.6	0.0	65.7
92.04	2	-1.4	-3.1	704.0	-0.1	1624.0	1.6	0.0	165.0
93.04	3	-1.8	-3.6	737.0	0.1	1733.0	1.7	2.0	108.2
94.04	4	0.0	-2.1	2100.0	2.6	1520.0	1.9	11.2	171.8
95.04	5	2.1	-4.5	528.0	9.6	1359.0	2.0	11.4	359.8
96.04	6	2.6	0.4	53.0	5.7	836.0	1.9	0.0	245.8
97.04	7	5.8	0.2	125.0	13.0	1758.0	3.0	0.0	426.1
98.04	8	8.9	0.1	515.0	18.0	1639.0	8.4	0.0	432.3
99.04	9	8.5	1.4	619.0	15.0	1637.0	7.6	0.0	431.7
100.04	10	6.7	0.9	601.0	13.1	1552.0	6.1	0.0	313.5
101.04	11	7.5	0.2	409.0	15.1	1437.0	6.2	0.0	465.2
102.04	12	8.6	1.2	644.0	16.2	1505.0	7.7	0.0	464.4
103.04	13	12.0	2.1	309.0	19.9	1449.0	9.6	4.6	447.2
104.04	14	8.2	4.0	659.0	13.1	1528.0	8.4	0.0	453.7
105.04	15	1.7	-2.4	2357.0	4.8	3.0	3.8	0.0	117.0
106.04	16	-1.0	-3.2	520.0	2.2	1603.0	1.7	0.0	199.6
107.04	17	1.7	-2.5	226.0	7.1	1443.0	3.6	0.0	243.5
108.04	18	5.5	0.6	305.0	14.3	1605.0	5.2	0.0	220.5
109.04	19	6.7	-0.9	551.0	13.9	1555.0	8.5	0.0	488.4
110.04	20	8.6	3.0	448.0	15.7	1401.0	8.8	0.0	275.4
111.04	21	7.0	1.1	542.0	13.3	1448.0	9.3	0.0	516.6
112.04	22	7.1	-0.2	507.0	12.9	1741.0	8.0	0.0	442.5
113.04	23	10.4	-0.1	527.0	19.1	1604.0	10.3	0.0	522.7
114.04	24	13.8	3.0	533.0	21.8	1519.0	12.2	0.0	535.5
115.04	25	14.9	5.4	544.0	23.1	1434.0	14.0	0.0	530.6
116.04	26	15.7	4.8	539.0	24.7	1409.0	14.4	0.0	501.2
117.04	27	15.3	10.0	615.0	19.8	1557.0	14.0	0.0	196.9
118.04	28	16.7	10.1	2333.0	24.5	1447.0	16.0	0.0	483.7
119.04	29	15.9	6.0	516.0	25.3	1627.0	15.8	0.0	541.4
120.04	30	17.7	6.4	521.0	26.4	1604.0	16.7	0.0	543.0
121.05	1	18.6	8.8	640.0	26.0	1535.0	17.0	0.0	532.1
122.05	2	19.0	11.8	510.0	25.2	1722.0	17.4	0.0	496.3
123.05	3	16.9	10.9	200.0	21.9	1956.0	15.5	0.8	157.3
124.05	4	18.8	13.4	559.0	24.2	1743.0	16.4	1.8	284.6
125.05	5	15.4	13.2	2344.0	17.4	1246.0	15.8	13.2	109.5
126.05	6	13.8	6.1	2359.0	19.6	1210.0	15.1	3.1	286.2
127.05	7	4.6	1.9	2315.0	7.7	1639.0	8.9	0.0	198.9
128.05	8	4.8	-0.3	621.0	10.7	1847.0	9.3	0.0	497.4
129.05	9	7.3	0.0	513.0	12.4	1518.0	10.5	0.0	468.1

130.05	10	4.4	3.3	1418.0	8.6	1.0	7.4	16.3	17.9
131.05	11	8.3	4.6	1.0	13.6	1836.0	8.4	9.7	63.3
132.05	12	8.6	5.0	403.0	13.1	1403.0	9.2	4.6	91.0
133.05	13	10.4	8.0	652.0	15.6	1911.0	11.3	0.0	203.6
134.05	14	12.7	9.6	102.0	18.2	1534.0	12.0	3.1	154.3
135.05	15	14.7	10.3	452.0	21.2	1828.0	14.1	7.6	343.4
136.05	16	15.0	10.1	626.0	20.6	1723.0	15.3	0.5	377.9
137.05	17	10.7	6.2	0.0	13.3	1726.0	13.6	0.0	345.0
138.05	18	9.1	2.1	554.0	17.7	1913.0	13.7	0.0	606.4
139.05	19	15.1	9.6	16.0	22.5	1638.0	15.1	2.0	256.0
140.05	20	14.8	10.7	0.0	19.6	1420.0	16.3	5.8	503.9
141.05	21	9.8	6.3	514.0	12.4	1749.0	12.9	0.0	169.3
142.05	22	8.9	6.5	2337.0	10.5	1118.0	11.3	18.8	68.1
143.05	23	11.5	6.7	1.0	16.7	1646.0	12.8	0.3	447.2
144.05	24	11.8	5.8	542.0	17.7	1703.0	13.0	5.8	344.6
145.05	25	15.4	7.8	530.0	22.1	1657.0	15.2	0.0	638.9
146.05	26	18.5	6.7	546.0	27.1	1817.0	17.5	0.0	633.6
147.05	27	19.7	12.8	539.0	25.8	1834.0	19.5	0.0	640.4
148.05	28	23.1	13.7	410.0	31.5	1809.0	20.5	0.0	583.3
149.05	29	19.4	15.5	626.0	23.4	1544.0	19.9	0.0	550.6
150.05	30	11.4	8.4	0.0	15.6	1.0	14.8	9.7	135.5
151.05	31	11.6	5.3	534.0	17.9	1808.0	14.0	0.0	614.6
152.06	1	11.1	8.7	623.0	13.7	1635.0	14.0	0.0	103.0
153.06	2	14.3	9.5	551.0	19.8	1819.0	16.0	2.8	357.5
154.06	3	16.7	9.6	504.0	22.6	1321.0	16.2	0.3	225.0
155.06	4	20.9	14.5	432.0	27.4	1523.0	19.4	8.4	552.4
156.06	5	20.1	13.7	2346.0	27.0	1840.0	20.2	0.0	438.4
157.06	6	19.0	10.8	330.0	26.9	1714.0	19.1	0.0	317.4
158.06	7	21.3	13.9	546.0	29.0	1559.0	21.6	0.0	601.3
159.06	8	23.5	15.0	519.0	30.8	1440.0	23.3	0.0	518.5
160.06	9	19.7	14.6	0.0	22.7	251.0	21.4	9.4	311.1
161.06	10	17.4	11.8	543.0	23.1	1720.0	19.4	0.0	591.5
162.06	11	19.4	11.2	531.0	25.3	1719.0	20.0	0.0	447.9
163.06	12	18.3	12.3	0.0	22.7	1255.0	20.2	0.0	437.9
164.06	13	11.3	7.4	533.0	16.0	1509.0	17.1	0.0	485.6
165.06	14	10.9	4.8	444.0	17.1	1827.0	15.1	0.0	310.7
166.06	15	12.8	7.1	454.0	16.9	1547.0	16.7	0.0	624.9
167.06	16	14.3	5.5	452.0	21.2	2014.0	17.2	0.0	515.7
168.06	17	17.4	7.9	536.0	24.7	1741.0	19.4	0.0	634.0
169.06	18	19.5	11.1	615.0	27.1	1324.0	20.8	0.0	558.8

170.06	19	18.8	10.6	543.0	24.8	1714.0	21.5	0.0	475.5
171.06	20	19.8	16.1	602.0	24.8	1506.0	21.4	0.0	195.8
172.06	21	22.9	15.5	533.0	29.6	1552.0	23.1	0.0	461.6
173.06	22	24.1	18.1	2006.0	31.7	1520.0	24.6	20.8	468.9
174.06	23	20.3	16.7	603.0	26.4	1409.0	22.1	2.8	495.7
175.06	24	18.5	12.9	538.0	24.0	1837.0	19.8	0.0	640.2
176.06	25	13.5	9.0	413.0	17.7	1407.0	16.5	24.6	175.3
177.06	26	16.0	12.8	121.0	22.0	1741.0	17.2	16.0	362.4
178.06	27	14.5	10.4	400.0	18.8	1703.0	17.0	0.0	449.8
179.06	28	15.8	11.5	656.0	21.3	1834.0	17.8	0.0	408.7
180.06	29	15.9	10.0	537.0	22.8	1613.0	17.8	5.8	284.0
181.06	30	15.8	12.8	618.0	20.1	1930.0	18.2	4.6	304.1
182.07	1	15.1	11.8	547.0	19.0	1706.0	17.5	0.3	291.0
183.07	2	17.3	10.1	439.0	23.8	1458.0	18.9	0.5	496.4
184.07	3	19.6	15.4	203.0	25.7	1330.0	20.3	2.3	226.7
185.07	4	19.5	15.0	339.0	24.8	1409.0	20.3	0.0	282.9
186.07	5	20.2	15.6	656.0	25.0	1451.0	20.5	2.8	539.9
187.07	6	20.6	14.5	533.0	27.4	1757.0	20.6	0.0	620.3
188.07	7	18.4	11.5	538.0	23.8	1758.0	20.5	0.0	642.0
189.07	8	16.3	13.6	636.0	23.0	1422.0	19.1	20.8	211.2
190.07	9	18.1	13.3	502.0	24.1	1835.0	18.8	12.7	555.0
191.07	10	20.5	12.5	600.0	27.4	1601.0	21.3	0.0	592.9
192.07	11	22.4	15.1	535.0	28.6	1530.0	23.1	0.0	608.7
193.07	12	21.6	17.2	603.0	27.0	1632.0	22.4	0.3	302.1
194.07	13	21.2	15.4	543.0	27.3	1502.0	23.0	5.1	498.9
195.07	14	22.1	16.9	0.0	26.8	1549.0	23.5	1.3	621.0
196.07	15	17.8	15.3	209.0	20.5	1216.0	19.7	21.8	40.8
197.07	16	16.6	12.7	0.0	20.8	1750.0	19.0	0.0	339.8
198.07	17	16.4	8.9	523.0	23.0	1554.0	19.0	0.0	558.2
199.07	18	19.1	11.8	208.0	26.6	1759.0	20.5	0.0	440.6
200.07	19	22.1	15.9	448.0	28.2	1705.0	22.7	0.0	461.6
201.07	20	23.9	18.4	618.0	30.0	1911.0	24.3	0.0	487.3
202.07	21	25.7	20.4	203.0	31.3	1641.0	25.7	0.0	523.6
203.07	22	25.6	19.7	529.0	31.3	1927.0	26.1	1.0	493.1
204.07	23	26.4	19.9	610.0	32.1	1643.0	26.5	0.0	585.7
205.07	24	24.2	15.9	556.0	32.3	1559.0	25.8	0.0	580.6
206.07	25	24.4	19.3	0.0	30.5	1600.0	24.8	3.6	359.4
207.07	26	19.4	13.4	621.0	24.8	1755.0	22.0	0.0	579.5
208.07	27	20.8	12.4	553.0	28.4	1838.0	22.5	0.0	513.6
209.07	28	24.3	14.9	613.0	32.1	1804.0	24.4	0.0	570.5

210.07	29	26.6	17.4	625.0	33.7	1911.0	26.4	0.0	567.6
211.07	30	23.4	18.3	622.0	28.3	1641.0	25.0	0.0	411.9
212.07	31	16.7	11.7	623.0	20.1	1725.0	21.6	0.0	361.3
213.08	1	17.3	11.1	626.0	23.7	1614.0	21.1	0.0	433.3
214.08	2	18.5	10.8	514.0	25.0	1514.0	21.4	0.0	542.2
215.08	3	19.8	12.3	633.0	26.1	1715.0	21.8	0.0	505.5
216.08	4	20.6	15.7	627.0	26.3	1602.0	23.0	0.0	521.4
217.08	5	21.4	15.0	636.0	28.5	1410.0	22.7	0.0	465.3
218.08	6	20.0	14.4	2246.0	29.7	1530.0	22.3	5.8	397.6
219.08	7	16.1	11.1	0.0	20.0	1634.0	19.0	1.5	486.4
220.08	8	16.2	7.7	610.0	23.7	1734.0	18.3	0.5	382.5
221.08	9	20.1	14.9	112.0	26.5	1601.0	21.0	1.0	406.9
222.08	10	19.1	15.2	629.0	24.1	1548.0	20.3	0.0	342.4
223.08	11	17.8	13.9	700.0	23.3	1644.0	19.3	0.0	428.3
224.08	12	16.4	12.3	619.0	20.6	1743.0	17.2	0.0	292.0
225.08	13	17.8	11.0	731.0	24.7	1648.0	18.5	0.0	486.2
226.08	14	19.0	9.4	518.0	27.1	1636.0	19.8	0.0	474.8
227.08	15	21.6	16.2	653.0	28.9	1810.0	21.6	0.0	327.3
228.08	16	17.5	14.7	816.0	21.3	1501.0	19.6	10.2	155.7
229.08	17	17.9	15.4	718.0	24.3	1357.0	19.2	4.3	198.1
230.08	18	18.9	14.8	2330.0	25.2	1859.0	19.4	0.0	386.3
231.08	19	19.9	12.1	636.0	28.5	1634.0	19.9	0.0	417.6
232.08	20	21.2	13.7	649.0	28.7	1857.0	20.9	0.0	312.8
233.08	21	21.8	13.7	551.0	30.1	1537.0	21.7	0.0	445.0
234.08	22	20.6	16.5	512.0	28.1	1228.0	21.3	11.7	204.9
235.08	23	19.6	15.5	705.0	25.7	1706.0	20.3	0.3	245.9
236.08	24	21.5	15.2	615.0	29.6	1704.0	21.3	0.0	438.9
237.08	25	23.9	17.0	703.0	30.7	1505.0	22.6	0.0	451.4
238.08	26	23.9	17.6	2216.0	29.6	1617.0	23.1	0.0	454.9
239.08	27	21.4	14.4	733.0	27.9	1655.0	21.8	0.0	447.0
240.08	28	18.2	12.3	0.0	22.1	1556.0	20.6	0.0	463.0
241.08	29	16.3	8.0	703.0	24.5	1655.0	19.4	0.0	427.3
242.08	30	16.7	14.4	1.0	19.2	1657.0	18.6	0.0	37.7
243.08	31	22.5	15.2	734.0	31.1	1702.0	21.4	0.0	226.7
244.09	1	18.3	13.9	743.0	23.2	1.0	20.3	0.0	145.3
245.09	2	13.8	10.7	706.0	17.0	1452.0	16.5	0.5	113.5
246.09	3	14.2	11.8	313.0	16.7	1733.0	15.6	0.0	72.9
247.09	4	13.0	12.1	2049.0	14.7	1.0	14.9	21.8	16.9
248.09	5	12.2	8.9	0.0	15.2	1321.0	14.2	4.1	170.7
249.09	6	15.8	5.5	802.0	26.2	1614.0	15.5	0.0	344.8

250.09 7	18.1	13.3	0.0	23.0	1736.0	17.7	3.1	289.7
251.09 8	11.8	8.7	0.0	15.0	1245.0	14.3	0.5	78.6
252.09 9	9.8	6.8	710.0	13.5	2217.0	11.8	2.0	23.2
253.09 10	12.3	9.7	2353.0	14.6	1707.0	13.1	0.0	159.4
254.09 11	11.4	5.2	737.0	17.0	1312.0	13.2	0.8	173.9
255.09 12	11.9	9.8	2226.0	17.3	1515.0	14.2	12.2	110.3
256.09 13	10.0	8.7	724.0	12.1	1655.0	12.4	4.6	104.4
257.09 14	10.9	8.2	2354.0	14.9	1338.0	12.2	2.3	182.8
258.09 15	11.2	4.6	619.0	19.3	1852.0	12.5	0.0	366.8
259.09 16	13.7	6.1	655.0	23.0	1542.0	14.0	0.0	376.6
260.09 17	17.1	8.1	633.0	26.1	1743.0	16.5	0.0	332.0
261.09 18	16.3	11.7	0.0	20.3	1502.0	17.0	0.0	269.0
262.09 19	7.7	4.2	0.0	11.7	1.0	12.3	0.0	261.7
263.09 20	7.3	-0.9	622.0	15.6	1823.0	11.0	0.0	357.5
264.09 21	15.8	8.2	804.0	26.0	1431.0	14.3	0.0	337.9
265.09 22	15.3	7.2	449.0	24.4	1515.0	14.8	0.0	155.4
266.09 23	12.3	5.3	811.0	19.0	1656.0	13.9	0.0	322.7
267.09 24	14.1	4.2	430.0	23.7	1555.0	13.9	0.0	311.3
268.09 25	14.5	7.7	822.0	20.8	1600.0	15.3	0.0	240.6
269.09 26	10.5	7.7	2351.0	13.7	1545.0	12.5	3.8	52.1
270.09 27	8.8	2.8	755.0	15.4	1418.0	10.9	1.5	210.4
271.09 28	9.4	5.9	0.0	14.6	1833.0	11.7	1.0	230.2
272.09 29	7.5	0.3	747.0	13.1	1536.0	9.3	0.0	115.1
273.09 30	6.1	3.2	2335.0	8.7	112.0	7.8	0.3	49.5
274.010 1	2.7	0.8	2229.0	5.2	1325.0	6.0	0.0	123.9
275.010 2	1.9	-3.4	603.0	7.4	1700.0	5.0	0.0	154.4
276.010 3	3.6	-1.7	524.0	10.1	1554.0	5.7	0.0	154.4
277.010 4	5.2	0.2	406.0	11.5	1635.0	6.4	5.1	113.6
278.010 5	3.2	-0.3	2151.0	6.8	1741.0	6.2	0.0	280.7
279.010 6	3.3	-2.8	806.0	8.6	1645.0	5.5	0.8	150.3
280.010 7	6.0	1.7	2358.0	11.3	1634.0	7.3	0.3	145.3
281.010 8	6.8	1.4	29.0	14.0	1732.0	7.8	0.3	167.4
282.010 9	9.8	5.1	134.0	14.2	1810.0	8.5	1.3	49.2
283.010 10	8.3	3.0	831.0	16.2	1526.0	7.8	0.0	241.9
284.010 11	5.1	0.0	746.0	10.9	1327.0	6.1	1.5	38.1
285.010 12	6.8	4.4	817.0	10.9	1752.0	7.1	0.0	107.5
286.010 13	5.4	-1.1	912.0	11.7	1659.0	6.5	0.0	147.0
287.010 14	9.4	3.6	2310.0	17.4	1713.0	8.6	0.0	221.7
288.010 15	8.3	4.4	1.0	10.5	454.0	8.3	0.0	47.8
289.010 16	4.9	2.6	805.0	7.7	1521.0	7.3	6.4	105.7

290.010	17	5.0	1.9	928.0	8.7	1711.0	6.7	0.0	133.1
291.010	18	4.8	2.6	0.0	6.8	1612.0	6.5	5.1	39.9
292.010	19	-0.1	-2.3	0.0	2.8	1724.0	3.9	0.0	86.4
293.010	20	6.4	-2.4	10.0	15.0	1601.0	5.1	0.0	163.8
294.010	21	9.7	6.3	0.0	12.9	1418.0	7.4	0.0	155.0
295.010	22	2.9	0.1	0.0	6.3	1.0	5.5	0.0	151.0
296.010	23	1.0	-5.3	810.0	7.6	1623.0	3.7	0.0	195.3
297.010	24	5.8	-0.3	803.0	13.1	1630.0	4.6	0.0	170.8
298.010	25	9.4	-0.1	0.0	14.0	249.0	6.6	0.0	189.3
299.010	26	3.2	-3.4	857.0	9.8	1549.0	4.5	0.0	108.8
300.010	27	4.3	-0.2	2353.0	8.0	1300.0	4.9	2.3	26.3
301.010	28	2.9	-3.1	830.0	10.2	1531.0	3.7	0.0	116.1
302.010	29	5.8	1.0	0.0	10.9	1535.0	5.2	0.0	88.5
303.010	30	6.6	0.3	33.0	12.5	1606.0	5.8	0.0	118.6
304.010	31	9.3	-1.2	437.0	19.1	1607.0	6.3	0.0	158.2
305.011	1	4.6	-1.9	0.0	13.6	16.0	5.8	1.5	32.6
306.011	2	-0.5	-5.5	847.0	7.6	1635.0	2.4	0.0	153.8
307.011	3	0.0	-7.5	748.0	11.4	1609.0	1.8	0.0	145.9
308.011	4	3.9	-3.2	406.0	12.0	1838.0	2.3	0.0	43.0
309.011	5	1.8	-2.4	2349.0	6.0	1405.0	2.7	0.0	156.1
310.011	6	1.1	-4.0	237.0	7.8	1403.0	2.2	0.0	122.8
311.011	7	5.4	-1.8	19.0	17.0	1512.0	3.2	0.0	137.8
312.011	8	7.5	-0.9	340.0	19.0	1439.0	4.0	0.0	73.6
313.011	9	2.8	-0.5	2233.0	7.2	31.0	3.8	0.0	65.6
314.011	10	2.3	-0.1	448.0	4.5	1523.0	3.9	0.0	21.7
315.011	11	5.9	3.2	805.0	11.7	1421.0	5.2	0.0	100.3
316.011	12	5.0	-2.3	414.0	10.8	1517.0	4.6	0.0	47.4
317.011	13	8.1	3.1	2127.0	15.7	510.0	6.2	0.0	42.1
318.011	14	2.8	-1.6	1909.0	6.5	1520.0	4.7	0.0	99.9
319.011	15	3.2	-2.4	742.0	9.2	1534.0	3.9	0.0	105.6
320.011	16	-0.1	-2.9	556.0	4.1	1355.0	2.6	0.0	33.5
321.011	17	1.3	-3.1	231.0	7.1	1304.0	2.3	0.0	100.4
322.011	18	-2.9	-4.2	2353.0	-1.1	9.0	1.2	0.0	44.0
323.011	19	-2.9	-7.8	458.0	3.1	1526.0	0.7	0.0	88.5
324.011	20	0.5	-6.5	57.0	5.1	1351.0	1.1	0.0	39.9
325.011	21	2.6	-3.1	825.0	7.7	1343.0	2.3	0.0	94.3
326.011	22	0.4	-5.8	2348.0	5.9	1422.0	2.2	0.0	75.7
327.011	23	-2.3	-7.8	553.0	6.4	1413.0	0.4	0.0	75.4
328.011	24	-3.1	-9.0	638.0	4.3	1501.0	-0.2	0.0	84.6
329.011	25	-2.2	-9.2	403.0	3.6	1457.0	-0.3	1.0	12.9

330.011	26	-0.3	-2.8	2341.0	0.6	1137.0	0.4	1.8	1.7
331.011	27	-3.1	-4.8	2359.0	-1.1	1415.0	0.4	0.3	83.7
332.011	28	-6.1	-8.5	459.0	-3.8	1428.0	-0.1	0.0	79.4
333.011	29	-6.4	-8.1	851.0	-2.8	0.0	-0.5	0.0	48.9
334.011	30	2.1	-2.8	1.0	5.0	2044.0	-0.1	0.0	25.4
335.012	1	3.4	-1.0	2239.0	9.1	1404.0	0.6	0.0	89.6
336.012	2	2.2	-2.2	2356.0	7.2	1414.0	1.3	2.8	19.2
337.012	3	-0.1	-3.8	752.0	3.3	1404.0	0.7	0.0	29.3
338.012	4	-2.6	-7.1	2329.0	1.9	156.0	0.8	0.0	60.3
339.012	5	-7.0	-8.0	153.0	-5.5	0.0	-0.4	0.0	10.7
340.012	6	-3.0	-6.5	0.0	4.4	1432.0	-0.9	0.0	76.1
341.012	7	-1.6	-7.1	625.0	5.2	1326.0	-1.1	0.0	60.2
342.012	8	-2.0	-6.2	2359.0	0.4	1704.0	-0.7	0.0	40.4
343.012	9	-5.0	-8.2	415.0	-1.7	1418.0	-1.6	0.0	46.7
344.012	10	-3.3	-4.6	808.0	-1.4	1202.0	-1.1	0.0	39.4
345.012	11	-1.1	-5.4	2110.0	3.3	1455.0	-0.8	0.0	62.4
346.012	12	-4.7	-8.7	2336.0	0.5	1424.0	-1.9	0.0	24.7
347.012	13	-0.7	-9.8	116.0	4.6	1559.0	-1.6	0.0	29.2
348.012	14	-1.4	-7.7	0.0	2.0	41.0	-0.4	0.0	30.8
349.012	15	-16.7	-21.4	0.0	-7.7	1.0	-1.1	0.0	62.7
350.012	16	-21.8	-24.9	754.0	-19.1	1303.0	-2.5	0.0	51.7
351.012	17	-17.2	-24.8	615.0	-8.5	2318.0	-3.0	0.0	43.2
352.012	18	-4.2	-9.5	242.0	-0.3	1756.0	-1.9	0.0	24.7
353.012	19	-8.5	-20.2	0.0	-1.1	3.0	-1.2	0.0	9.5
354.012	20	-23.9	-27.0	810.0	-20.2	1.0	-2.1	0.0	63.8
355.012	21	-25.0	-31.0	606.0	-19.9	1420.0	-2.7	0.0	73.7
356.012	22	-23.9	-31.0	819.0	-17.8	0.0	-2.9	0.0	61.5
357.012	23	-10.8	-17.8	1.0	-7.2	1257.0	-2.3	0.0	12.8
358.012	24	-5.3	-8.8	4.0	-0.5	1428.0	-1.6	0.3	62.8
359.012	25	0.4	-7.9	0.0	6.7	1423.0	-1.2	3.6	58.5
360.012	26	-10.5	-14.9	2359.0	-8.0	1.0	-1.2	0.0	1.4
361.012	27	-12.7	-22.3	859.0	4.1	0.0	-1.5	1.3	0.5
362.012	28	-0.5	-3.0	2008.0	4.8	44.0	-1.0	2.0	21.8
363.012	29	-3.1	-14.1	2352.0	3.4	919.0	-0.6	0.3	23.3
364.012	30	-13.2	-17.9	455.0	-8.8	1819.0	-1.2	0.0	0.7
365.012	31	-11.9	-18.3	623.0	-7.6	1617.0	-1.5	0.0	19.4

Appendix 7.2

Emergence Periodicity of Each Species at Each Site

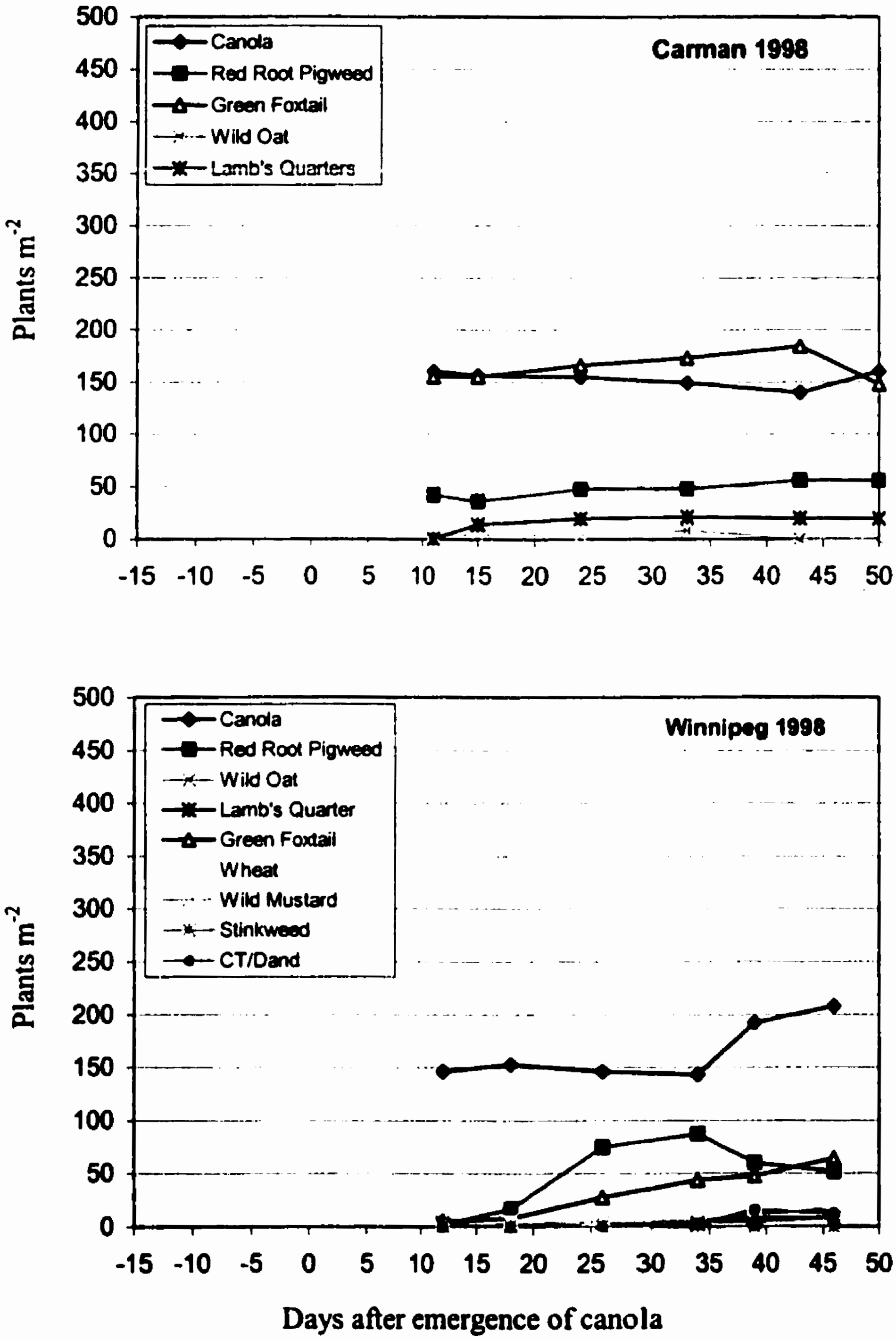

Figure 7.2.1. Emergence periodicity of each species at Carman and Winnipeg sites in 1998, measured from fixed quadrats of 0.25 m^2 in the weed-infested controls.

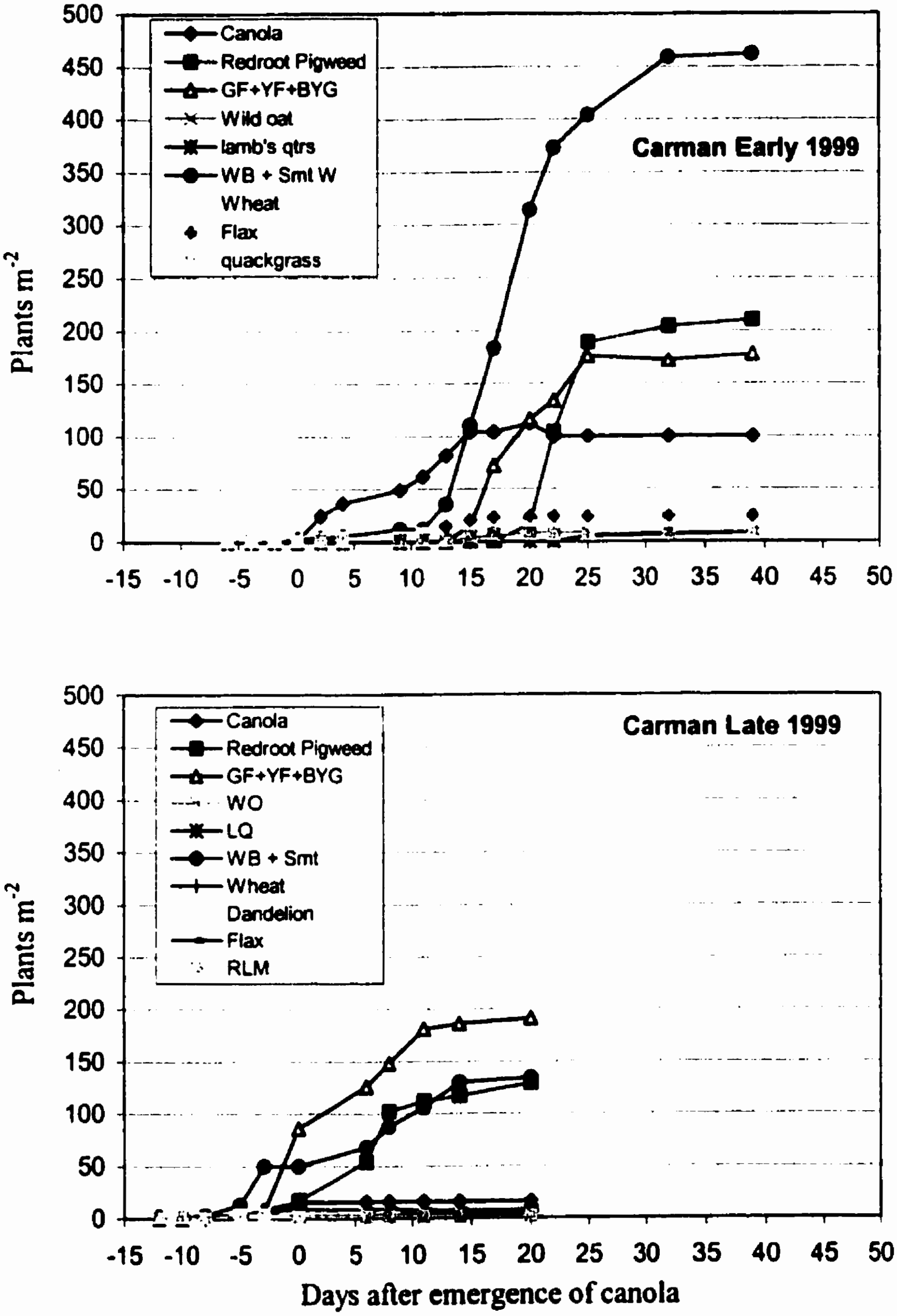

Figure 7.2.2. Emergence periodicity of each species at Carman early and late seeded sites in 1999, measured from fixed quadrats of 0.25 m^2 in the weed-infested controls.

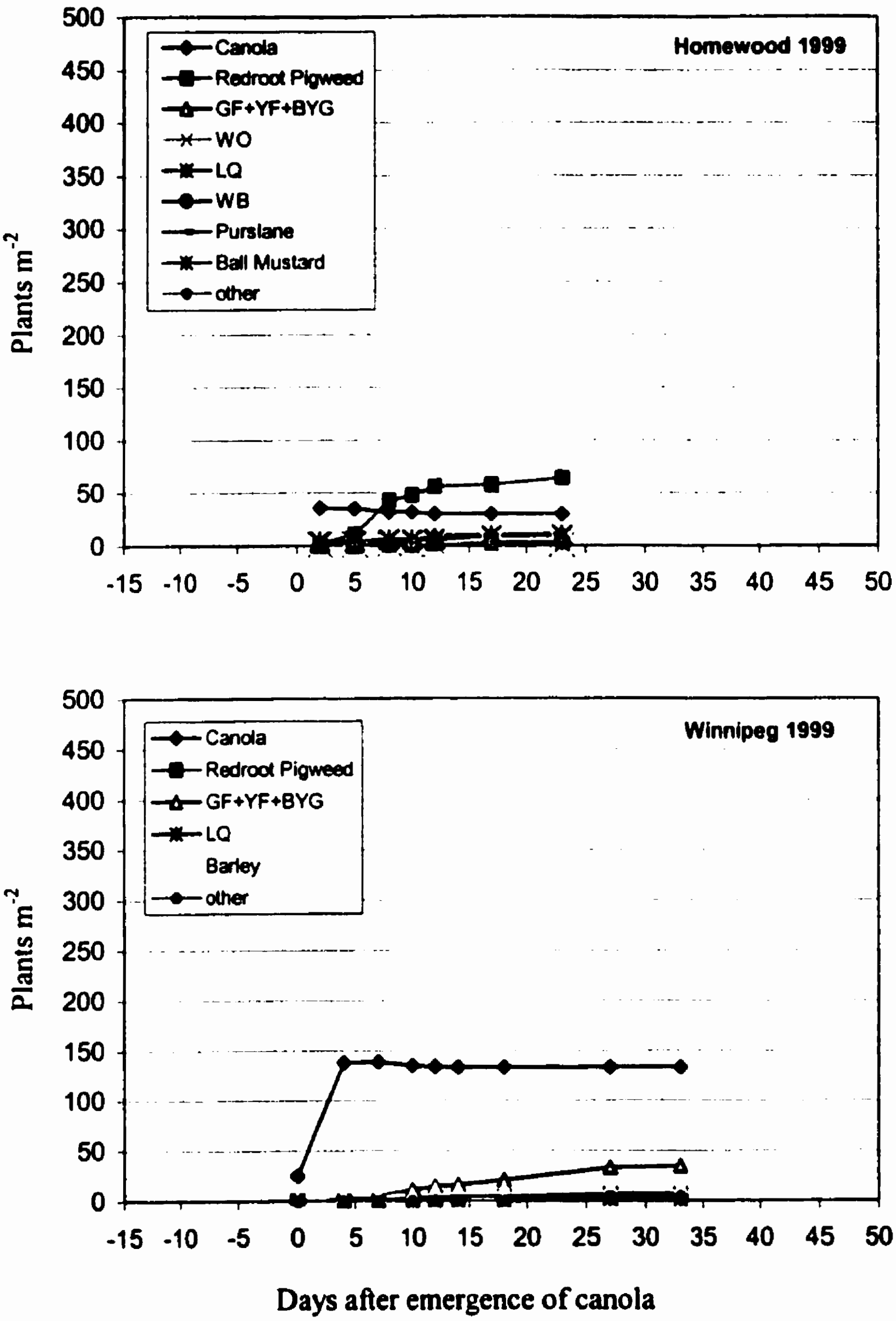

Figure 7.2.3. Emergence periodicity of each species at Homewood and Winnipeg in 1999, measured from fixed quadrats of 0.25 m^2 in the weed-infested controls.

Appendix 7.3

The effects of repeated treatment of glufosinate on Innovator canola

Introduction

A small side experiment was performed in 1999 to assess if there was any effect from the repeated treatment of glufosinate herbicide on Innovator canola variety used in our preceding experiments.

Materials and Methods

The same seed source was used for this experiment as the previous experiments. Plots were seeded at the University of Manitoba's Carman Research Farm on May 25, 1999 at 3 kg ha^{-1} in double-spaced rows (40 cm). This was to facilitate hand weeding that was performed frequently throughout the season, at the 2^{nd}, 4^{th}, and 6^{th} leaf stages to keep all plots free from weeds. Because of poor emergence of the crop, the plots were tilled and reseeded on June 4, 1999 at the increase rate of 4.5 kg ha^{-1}, and terbufos insecticide was placed with the seed at the same rate as previously stated. Also, a soil-applied, ethafluralin (Edge[23]) herbicide was applied at 1.1 kg a.i. ha^{-1} on May 25, 1999 to prevent the growth of earlier weeds. Plots were 5.4m^2, but only 2.5 m^2 of the plots were harvested for yield. These areas were swathed by hand on August 20, 1999 and threshed in a stationary harvester October 13, 1999.

The applications with glufosinate herbicide were performed at 1.3 L ac^{-1} (593 g a.i. ha^{-1}) at the 2^{nd} leaf, 6^{th} leaf, and early flowering stages of the canola for the given treatments.

Results

Table 7.3.1. The effect of repeated treatments of glufosinate on the yield of Innovator canola.

Treatment Timing (Canola development stage)	Yield ($g/2.5m^2$)
None	329.71
2nd leaf	284.73
6th leaf	316.58
early fl.	329.68
2nd and 6th leaf	257.60
2nd leaf and early fl.	325.62
6th leaf and early fl.	351.56
2nd leaf, 6th leaf, and early fl.	231.76
LSD (0.05)	**107.13**

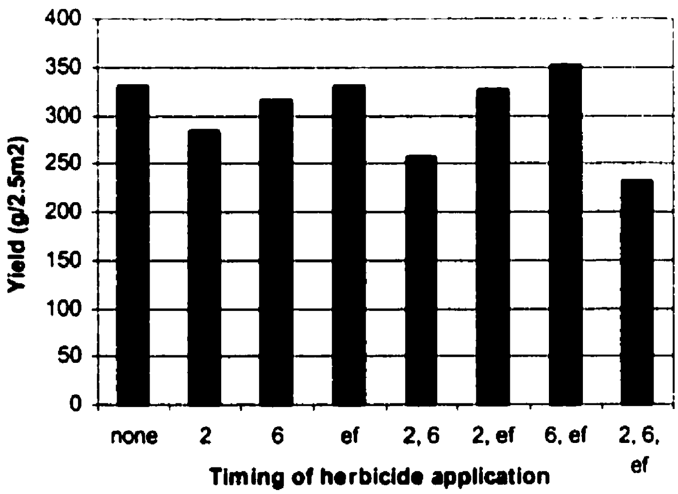

Figure 7.3.1. The effect of repeated treatments of glufosinate on the yield of Innovator canola.

Conclusion

Repeated treatment of glufosinate on Innovator did not significantly affect the yield of the crop.

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