# Emergence Timing and Control of Dandelion (*Taraxacum officinale*) Using Fall or Spring Applications of Glyphosate and Florasulam in Spring Wheat Fields

BY

KRISTIN MICHELLE HACAULT

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

Department of Plant Science
University of Manitoba
Winnipeg, Manitoba

# Emergence Timing and Control of Dandelion (*Taraxacum officinale*) Using Fall or Spring Applications of Glyphosate and Florasulam in Spring Wheat Fields

BY

KRISTIN MICHELLE HACAULT

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

Department of Plant Science
University of Manitoba
Winnipeg, Manitoba

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

*****

COPYRIGHT PERMISSION

# Emergence Timing and Control of Dandelion (Taraxacum officinale) Using Fall or Spring Applications of Glyphosate and Florasulam in Spring Wheat Fields

by

**Kristin Michelle Hacault**

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

of

**Master of Science**

## ACKNOWLEDGMENTS

I would first of all like to extend my deepest appreciation to my advisor, Dr. Rene Van Acker for his willingness to take me on as a graduate student and for his support, guidance, and advice. It was an honour to work with you. I would also like to thank the members of my committee, Dr. Martin Entz and Dr. Annemieke Farenhorst for all their input and support. Many thanks also go out to Lyle Friesen for all of his statistical advice, technical assistance, and humour.

Gary Turnbull of Dow AgroSciences was instrumental in initiating and supporting this project. I would like to thank him for all of his time, effort, assistance, and advice. Dow AgroSciences Canada Inc. aided in funding this project through the Natural Sciences and Engineering Research Council of Canada (NSERC) Industrial Post-Graduate Scholarship program. Thanks to Glenn Lehmann and Norbert Satchivi from Dow AgroSciences for all their help in the field and for lending me their summer students when times were hectic.

I would also like to acknowledge the technical expertise and assistance of Rufus Oree and Andrea Bartlinski and your summer crew (Jenneke, Katie, Kim, Lindsay, Lisa, Michael, Morgan, and Stephanie) at the University of Manitoba. Without your help I could have never seeded, sprayed, or harvested my plots on time. Thanks to Keith Bamford for all your help in the spring with preparing the drill, and to Alvin Iverson and Wilf Mutcher at the University of Manitoba research farm in Carman for helping me with the equipment and land use. It was a pleasure to work with you all. In addition much gratitude is extended towards Doug and Linda Wilton,

Tim Erb, Derek Erb, and Denis and Wilma Garlick who graciously permitted me to initiate and carry out field experiments on their property.

Thanks to my fellow graduate students in the Department of Plant Science for your support, encouragement, and for all the memories. It was a pleasure to getting to know you all.

Lastly I would like to thank my family and friends for all their support, especially my parents Daniel and Debbie, and my siblings: Janelle and Steve, Tamara and Caitlin. There were definitely periods of discouragement during the course of my project, but your understanding, encouragement and support got me through some difficult times. I could have never completed my MSc. without your support.

Thank you all so very much!

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

**Figure** **Page**

## ABSTRACT

Hacault, Kristin M. MSc. The University of Manitoba, April 2005. Emergence timing and control of dandelion (*Taraxacum officinale*) using fall or spring applications of glyphosate and florasulam in spring wheat fields. Major Professor: Dr. Rene C. Van Acker.

The control of dandelion (*Taraxacum officinale* Weber in Wiggers) in annual field crops can vary tremendously but the cause for this variation is unknown. The abundance of dandelion in annual crops has increased greatly in Manitoba over the past decade, which may be attributed to the fact that there are few good control options available, and the reduced disturbance associated with minimum tillage practices provides an ideal niche for dandelion establishment and survival. Determining whether a dandelion plant in spring is arising from a newly established seedling or from a fall rosette is important because it influences the competitive ability of dandelion and impacts control strategies. Unfortunately, there is a lack of information concerning the behaviour and management of dandelion in annual cropping systems.

Field studies were conducted to determine the emergence period of dandelion arising either from seed or rootstock, and to determine the efficacy on dandelion of florasulam (a new ALS inhibitor with short soil residual activity) and glyphosate versus other herbicidal compounds applied at various rates in the fall (post-harvest) or spring (pre-seed). Results from the study show that dandelion emergence from rootstock was greatest early in the spring, commencing at less than 250 GDD, and diminished throughout the remainder of the year, while the majority of dandelion seedlings emerged at approximately 650 GDD, after the time when in-crop (post-emergence) herbicides would normally be applied. Differences in environmental

conditions between the two years of the study (2003 and 2004) had a significant effect on dandelion flowering period and seedling survivorship.

Dandelion is a simple perennial species that reproduces from either seed or rootstock, but the source of population spread is seed. Targeting the source of population spread is crucial to managing infestations. In-crop weed control targets over-wintered rosettes and shoots regenerating from rootstock but misses true seedlings which are the cause of population spread. Pre-seed herbicide applications target over-wintering dandelion rosettes (large and small), but the herbicide soil residual activity of florasulam or tribenuron is insufficient to provide control of dandelion seedlings emerging early in the summer. Fall herbicide applications can be an effective method of reducing dandelion rootstock densities and aboveground biomass production. Fall applications control both large dandelion rosettes and true seedlings which emerge in mid summer and early fall after the normal application time for the in-crop controls. In this study herbicide treatments that included glyphosate + florasulam, glyphosate + tribenuron or a high rate of glyphosate provided the greatest level of season long dandelion control, especially if these were fall applied.

## FOREWORD

This thesis has been written in manuscript style in accordance with the style requirements of Weed Science.

## 1.0 INTRODUCTION

The control of dandelion (*Taraxacum officinale*) can vary tremendously but the cause for this variation is mostly unknown (Froese, 2001). Dandelion was ranked 9$^{th}$ on the 2002 Manitoba Weed Survey, up from a rank of 13$^{th}$ in 1997, with a frequency of 20.6% in fields surveyed and a relative abundance of 7% (Leeson et al., 2002). This increase in dandelion abundance may be due to above average rainfall in Manitoba over the past few years (Van Acker et al., 2002) as moist soil conditions favour dandelion seedling recruitment (Boyd and Van Acker, 2003) and the fact that there are few good control options available to manage this weed. In addition, the reduced disturbance associated with minimum tillage practices provides an ideal niche for dandelion establishment and growth (Stevenson and Johnston, 1999).

Dandelion is a simple perennial species that is capable of reproducing from seed or rootstock but the source of population spread is the seed (Froese and Van Acker, 2003; Solbrig and Simpson, 1974). The vast majority of the literature regarding dandelion behaviour and management focuses on forage crops and turf grass systems, specifically alfalfa (*Medicago sativa* L.) crops (Moyer et al., 1990; Sheaffer and Wyse, 1982; Waddington, 1980). A greater understanding of the biology and ecology of dandelion, and the herbicidal management of this weed species, especially under western Canadian environmental and agricultural conditions, will aid in devising more effective management strategies for dandelion infestations in annual field crops. For example, in typical arable fields it is not known whether dandelion plants observed in the spring are plants that survived over winter, shoots emerging from rootstock, or new seedlings. This information would allow for

the development of management approaches that are based on an understanding of the population dynamics of given dandelion infestations, and are therefore, more effective. Investigating the emergence period of dandelion plants from either seed or rootstock may allow for informed management decisions and provide an explanation as to why dandelion plants differ in their tolerance to herbicides applied at various times throughout the growing season, and why dandelion infestations spread in some cropping system scenarios and not in others.

Previous research on dandelion recruitment patterns have provided inconsistent results, with fall (Stewart Wade et al., 2002; Vavrek et al., 1996), spring (Vavrek et al., 1996), and both spring and fall (Holm et al., 1997a; Roberts and Neilson, 1981; Watson et al., 2001) being reported as peak periods for dandelion seedling recruitment. The period of dandelion emergence from rootstock has not been well documented, especially for dandelion infestations in annual field crops. Considering that dandelion is a simple perennial species, information on the emergence period of dandelion plants from both rootstock and seed would be valuable because farmers want to control both weed infestations and limit weed population spread.

There are a wide variety of chemical controls available for use on dandelion, but generally these controls are directed towards managing dandelion infestations in lawns and alfalfa stands. For example, the phenoxy herbicides, such as 2,4-D, MCPA and dicamba, have been used successfully to control dandelion infestations in lawns. It is only in recent years that studies have aimed to examine the control of dandelion in annual crops (Dunn and Moyer, 1999; Froese et al., 2005; Moyer et al., 1990;

Roggenbuck and Penner, 1986; Sheaffer and Wyse, 1982; Stevenson and Johnston, 1999), but these studies focused primarily on glyphosate. With the adoption of reduced tillage farming and the rise in dandelion populations in western Canada, the herbicidal control of dandelion in annual cropping systems has become more important. Dandelion is a deep rooted perennial plant that requires adequate translocation of herbicides into the tap root or the uptake of soil applied herbicides for successful control (Buhler and Mercurio, 1988). Generally fall (post-harvest) is regarded as the best time to control dandelion with herbicides because they will be translocated to the roots and provide greater efficacy. However, many farmers do not control dandelion at this time of year because the yield loss attributed to dandelion infestations largely occurs in the spring. Deciding when to control dandelion infestations is often complicated given the lack of information on how to properly quantify dandelion infestations and the fact that it is difficult to assess when dandelion plants begin to compete (Ford, 1985).

In this project, dandelion control studies were designed to determine the best time for dandelion control (fall or spring), and the effects of adding either florasulam or tribenuron to glyphosate on dandelion control. In order to explore why some herbicide treatments and timings worked better than others, herbicide efficacy experiments are best conducted in relation to investigations of recruitment biology and recruitment timing. This is especially true for the management of simple perennial weeds such as dandelion.

## 2.0 LITERATURE REVIEW

## 2.1 EXTENT AND NATURE OF THE PROBLEM:

### 2.1.1 HISTORY

Dandelion (*Taraxacum officinale* Weber in Wiggers) is a perennial herb (Mitich, 1989; Whitson et al., 1996) belonging to the *Asteraceae* or *Compositae* family (Holm et al., 1997a; Roberts, 1936; Whitson et al., 1996) and is a relative of the lettuce genus *Lactuca* (Solbrig, 1971). The name *Taraxacum* is derived from the Greek word for disorder or disquiet (Mitich, 1989; Schmidt, 1979) and *officinale* refers to the medicinal properties that the plant possesses (Schmidt, 1979), as root exudates aid in the treatment of diabetes (Letchamo and Gosselin, 1996) and the plant is used as a mild diuretic (Mitich, 1989; Schmidt, 1979). Dandelion was used and cultivated as an herb since the Roman ages (Mitich, 1989). It was probably introduced into North America with the landing of the pilgrims (Schmidt, 1979) and is currently found throughout the United States and Canada (Royer and Dickinson, 1999). The common dandelion is known by a variety of names including piss-a-bed, lion's tooth, cankerwort, Irish Daisy, monk's head, priest's crown, yellow gowan, clock flower, blowball, and puffball (Mitich, 1989; Royer and Dickinson, 1999).

Dandelion is quickly becoming an increasing issue in western Canadian cropping systems due to its increased occurrence. Unfortunately a substantial portion of the research up to this point in time has concentrated on dandelion control in turf grass and alfalfa crops (*Medicago sativa* L.) (Froese, 2001). The lack of information on how to properly quantify dandelion infestations, and the yield loss associated with those infestations, is a major barrier faced by western Canadian farmers in combating

dandelion. Devising more effective management strategies in the control of dandelion requires research concerning its competitive ability, biology, ecology, and population demography in annual cropping systems.

### 2.1.2 DISTRIBUTION:

Dandelion is found in all the Canadian provinces and territories as well as in almost every temperate and sub-tropical region of the world (Stewart-Wade et al., 2002). However, it is primarily concentrated in the temperate and colder regions of the world (Solbrig and Simpson, 1974). Dandelion is a principal weed in 8 countries, a common weed in 21 countries, and present in almost all countries (Mitich, 1989). It is the sixth most important weed species occurring in corn (*Zea mays* L.), soybean (*Glycine max* L. Merr.), and winter wheat (*Trticum aestivum* L.), the sixth most abundant weed in reduced and no-till cropping systems, and is the tenth most abundant weed species in fields where conventional tillage is practiced (Stewart-Wade et al., 2002). Dandelion was ranked 9$^{th}$ on the 2002 Manitoba Weed Survey with a frequency of 20.6% in fields surveyed and a relative abundance of 7% (Leeson et al., 2002). It is the 12$^{th}$ most common weed in Manitoba wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and canola (*Brassica napus* L.) fields, and the 7$^{th}$ most common weed in Manitoba oat (*Avena sativa* L.) fields (Leeson et al., 2002). Dandelion infestations are often worse in cropping systems that include alfalfa in rotation compared to continuous cereal rotations (Ominski et al., 1999). Dandelion is considered a noxious weed in Saskatchewan and Quebec, a nuisance weed in Alberta, it may be declared a noxious weed in Manitoba (Stewart-Wade, et al., 2002), and is considered a noxious weed in many other countries of the world (Solbrig and

Simpson, 1974). Dandelion seeds are often found as an impurity in Kentucky bluegrass (*Poa pratensis* L.) seed (Anderson, 1999), a very popular and common lawn seed.

Dandelion distribution within Canadian cropping systems may be a direct result of the implementation of reduced tillage practices. As reduced tillage systems gain acceptance, dandelion infestations may continue to increase (Froese and Van Acker, 2003; Légère and Samson, 1999; Stevenson and Johnston, 1999; Triplette and Lytle, 1972) because the root systems of the dandelion plants remain relatively undisturbed under these conditions (Buhler et al., 1994). In western Canada, the increase in perennial weed infestations, such as dandelion, may possibly be due to the fact that there are fairly few control options available for many perennials and the reduced disturbance associated with minimum tillage provides an ideal niche for its establishment and survival (Stevenson and Johnston, 1999). Stevenson and Johnston (1999) showed that fluctuations in weather patterns and soil fertility in any given year affected the growth and distribution of annual broadleaf species. Dandelion distribution is either uniform or heterogeneous, in terms of dandelion density (plants/$m^2$), rosette diameter, percent dandelion ground cover, and root diameter in field crops (Froese and Van Acker, 2003). A uniform dandelion infestation is a direct consequence of both the propagation of the species and unrestricted invasion opportunities (Froese and Van Acker, 2003). The distribution of dandelion is affected not only by the type of tillage regime practiced, but also by the past cropping history of a field (Froese and Van Acker, 2003). Froese and Van Acker (2003), referring to research on dandelion interference, stated that dandelion distribution is not generally

associated with tillage regime, which is in agreement with the findings of Derksen et al. (1993), who found that perennial weeds infestations, such as dandelion, are not necessarily associated with a reduction in tillage.

### 2.1.3 HABITAT

It is imperative that dandelion be adapted to the agricultural management practices of its habitat to ensure survival (Sterk et al., 1983). Dandelion plants are able to adapt to and tolerate a broad range of climatic conditions and mature plants are able to survive drought conditions (Georgia, 1933; Stewart-Wade et al., 2002), while young seedlings are sensitive to soil moisture levels (Stewart-Wade et al., 2002). Dandelion prefers a basic pH, up to a maximum of a pH of 8, but will grow and survive in acidic soils (Watson et al., 2001).

Dandelion commonly infests lawns, gardens, waste grounds, roadsides, pastures, fields, disturbed areas (Royer and Dickinson, 1999; Stewart-Wade et al., 2002; Vavrek et al., 1997), and even more stable areas, such as meadows, mountains, and areas of the arctic (Solbrig, 1971). In addition, dandelion is a major problem in golf courses, parks, and horticultural crops, and an increasing problem in annual cereal and oilseed crop production in western Canada (Stewart-Wade et al., 2002).

## 2.2 DANDELION GROWTH AND DEVELOPMENT:

Dandelion plants are characterized by a relatively short life cycle, a small size, primarily asexual reproduction in North American populations, and the capacity to adapt to a variety of environmental situations (Solbrig, 1971). Dandelion is a $C_3$ non-rhizomatious plant (Watson et al., 2001) that is historically classified as a ruderal

grassland species (Roberts and Neilson, 1981). It reproduces primarily by vegetative means and has a capacity for rapid regeneration (Fay, 1990).

### 2.2.1 ROOT SYSTEM

Dandelion is considered a broadly successful species and this is partly due to its large competitive taproot, which may be greater than 2 m in length in mature plants (Mann and Cavers, 1979; Royer and Dickinson, 1999; Watson et al., 2001). The taproot, similar to a short vertical rhizome (Anderson, 1999), and numerous secondary roots, if fragmented, have the capacity to regenerate into new shoots (Buhler and Mercurio, 1988; Mann, 1981; Mann and Cavers, 1979). The root serves as a storage organ (Solbrig, 1971), containing carbohydrates that are transported from the root to the shoot when conditions are conducive for growth (Buhler and Mercurio, 1988). Under severe winter conditions the taproot permits the survival of the dandelion plant (Anderson, 1999). When growth is terminated at the end of the season the root contracts, pulling the growing point 2 to 3 cm into the soil, and protects it from adverse conditions (Holm et al., 1997a; Mitich, 1989; Stewart-Wade et al., 2002).

### 2.2.2 LEAF MORPHOLOGY

Dandelion leaves are spread flat against the ground and form a prostrate rosette (Stewart-Wade et al., 2002). Dandelion survives mild winters as a rosette (Anderson, 1999) and, in rosette form, dandelion plants endure and overcome mowing operations, animal grazing, and competition from other plant species (Stewart-Wade et al., 2002). Leaves of dandelion plants arise from the crown, located at or just below the soil surface (Anderson, 1999). Leaf morphology varies

from season to season (Mølgaard, 1977) with immature plants exhibiting smooth rounded leaves and mature plants possessing deeply incised leaves (Stewart-Wade et al., 2002). Calivière and Duru (1995) found that dandelion leaves had a life span of approximately 500-degree days and there was a rapid leaf turnover rate.

### 2.2.3 FLOWERING

The processes leading to the initiation of flowering of dandelion commences when a bud forms in the middle of the rosette and a distinctive leafless shoot, referred to as a scape, elongates, thrusting the bud upwards until the flower blooms (Solbrig, 1971; Stewart-Wade et al., 2002). This is the only time in the life cycle of the dandelion that the stalk grows (Richardson, 1985). Dandelion plants flower on average from one day (Solbrig, 1971) up to 3 days (Gray et al., 1973). When flowering is complete the shoot becomes flaccid and falls to the ground, protecting the growing point from mowers and grazers while the seeds mature in the head (Richardson, 1985; Stewart-Wade et al., 2002). Once the seeds mature, the shoot stiffens again and thrusts the seeds upward for dispersal (Richardson, 1985; Solbrig, 1971; Stewart-Wade et al., 2002).

#### 2.2.3.1 TIMING OF FLOWERING

Dandelion is often classified as a short day plant, meaning that it will only flower when there are fewer than 12 hours of daylight (Solbrig, 1971). A study of dandelion plants in the United States revealed that dandelion flowered throughout the year, with the greatest amount of flowering occurring in spring, when temperatures approached 16 C and there were 13 hours of day length (Gray et al., 1973). In cases such as this, dandelion acts as a day neutral plant (Listowski and Jackowska, 1965;

Stewart-Wade et al., 2002). Dandelion has the ability to flower early in the spring, which is to its competitive advantage due to the fact that the taproot stores a considerable amount of food reserves (Sterk et al., 1983). Dandelions generally flower in April and May, remain reproductively dormant during the extreme heat of summer, and resume flowering in late August up until the middle of October (Dunn and Moyer, 1999; Mølgaard, 1977). In some habitats, dandelion plants flower throughout the growing season (Listowski and Jackowska, 1965; Sterk and Luteijn, 1984), although flowering predominately occurs in the spring and again, to a lesser extent, in the autumn (Listowski and Jackowska, 1965; Solbrig, 1971; Sterk and Luteijn, 1984). Sawada et al. (1982) found the main flowering period for *T. officinale* in Japan was in May, with a less intensive flowering period occurring from July to September. Dandelion flowers under a wide range of conditions, with lower temperatures intensifying the degree of flowering (Listowski and Jackowska, 1965). Prevailing environmental conditions, especially temperature, dictate flowering rhythms (Sterk and Luteijn, 1984) in addition to the interactions between precipitation, day length, and temperature (Gray et al., 1973).

### 2.2.4 GROWTH HABIT

Dandelion plants grow late into the fall and resume growth in the cold temperatures of spring (Dunn and Moyer, 1999). New seedlings arise from either shoots or rootstocks (Ford, 1981). Determining whether a dandelion plant in spring is arising from a newly established spring seedling, or from a seedling that established the previous fall, is an area that requires greater consideration because it impacts control strategies and affects the competitive ability of dandelion. Early plant growth

in the spring allows for early resource capture and permits dandelions to achieve a competitive advantage over neighbouring plant species (Vavrek et al., 1997).

## 2.3 DANDELION REPRODUCTION:

### 2.3.1 REPRODUCTIVE STRATEGIES

Dandelion is classified as an apomictic species, reproducing in the absence of embryo fertilization (Mann and Cavers, 1979; Richardson, 1985; Solbrig, 1971; Solbrig and Simpson, 1974; Stewart-Wade et al., 2002). Dandelion is a simple perennial species that is capable of reproducing from either seed or from rootstock (Solbrig and Simpson, 1974, Watson et al., 2001), but seed is the source of population spread (Froese and Van Acker, 2003; Solbrig and Simpson, 1974). Dandelion reproduction is almost exclusively asexual in North American populations (Solbrig and Simpson, 1974). Triploid biotypes of dandelion are sometimes produced which are genetically identical to the parent plant (Jenniskens et al., 1984; Solbrig, 1971). Asexual reproduction is beneficial in some scenarios, but a detriment in others. Producing plants that are identical to the parent plant is advantageous as it decreases the production of types that are unsuitable for the environment in which the parents grow. Conversely, asexual reproduction reduces the ability of plants to better adapt to changing ecological conditions (Solbrig, 1971). There is a balance between vegetative and reproductive dandelion growth (Solbrig and Simpson, 1977) and the time in which it takes for the production of new dandelion plants is a function of the prevailing environmental conditions (Bostock and Benton, 1979; Mann and Cavers, 1979), which also influences whether regeneration is from seed or rootstock (Bostock and Benton, 1979). Dandelions, in undisturbed (non-annual cropping) situations,

invest little energy into reproduction and direct their energies towards biomass production (Welham and Setter, 1998), perhaps suggesting that vegetative growth is more predominant in undisturbed areas, and reproductive growth is more prevalent in disturbed areas, including agricultural habitats.

### 2.3.2 REGENERATION FROM ROOTSTOCK

The capacity for dandelion plants to regenerate from root segments, formed during cultivation, permits the dandelion to become established in tilled fields. Most dandelion root fragments possess the ability to regenerate into new plants (Bostock and Benton, 1979; Ford, 1981; Georgia, 1933; Mann, 1981; Mann and Cavers, 1979; Stewart-Wade et al., 2002) when conditions are favourable. Stewart-Wade et al. (2002) reported that root segments that were 125 mm in diameter required a length of approximately 6 to 10 mm to regenerate, and root fragments that were less than 2 mm in length would only regenerate if their diameter was greater than 4 mm, however Mann and Cavers (1979) found that even smaller dandelion root fragments would regenerate. Generally, regenerative capacity is lower for fragments coming from further down the root and from immature root pieces (Mann and Cavers, 1979). As root fragment volume diminishes, so does the capacity for regeneration (Stewart-Wade et al., 2002). The time period for regeneration is a function of the depth of soil at which the root fragment is located, with deeper fragments requiring a greater amount of time to produce a new plant (Mann and Cavers, 1979).

When roots are fragmented by disturbance, the wound where fragmentation occurred is covered over by callus tissue (Solbrig, 1971). Following the formation of callus tissue, buds appear on the tissue and new leaves are generated (Solbrig, 1971).

Anderson (1999) found that 1 to 5 new plants may arise from the callus tissue formed on a single wound of a root fragment. Regeneration from rootstock ensures the longevity of a weed population primarily by increasing the opportunities for seed production through the formation of new plants in the vicinity of the parent plant (Ford, 1981). Mann and Cavers (1979) examined the regenerative capacity of root cuttings of dandelion under natural conditions and found that dandelion plant fragments, such as root pieces, germinated even when buried 10 cm deep in the soil, and stated that planting depth had little impact on the capacity of dandelion root regeneration.

### 2.3.3 REGENERATION FROM SEED

Dandelion seeds, sometimes referred to as achenes, mature in the head following flowering and are primarily wind dispersed with the aid of an adaptive structure on the seed, referred to as pappi (Sheldon, 1974; Stewart-Wade et al., 2002). Water (Holm et al., 1997a) and animal excreta (Stewart-Wade et al., 2002) are also mechanisms of dandelion seed dispersal. Dandelion is a prolific seed producer (Dunn and Moyer, 1999), but the amount of seeds produced per head and per plant varies. Royer and Dickinson (1999) reported that, on average, 200 seeds are produced per head and about 5000 seeds are produced per plant per year. Dunn and Moyer (1999) found that some dandelion plants set over 20,000 seeds per year, whereas Holm et al. (1997a) revealed that dandelions could produce approximately 3000 seeds per head. Roberts (1936) reported that some plants had the ability to produce over 23,000 seeds per year with the possibility of 246 to 273 million dandelion seeds produced per acre per year. A substantial portion of the energy dandelion plants utilize is invested into

seed production processes, due to the abundance of dandelion seeds produced from a single plant (Solbrig, 1971; Solbrig and Simpson, 1974; Watson et al., 2001), to ensure longevity and proliferation. Seeds are produced throughout the growing season, with peaks in seed production occurring in April and again in September and October (Vavrek et al., 1997). The longevity of seeds within the seed bank varies. Holm et al. (1997a) stated that a dandelion seed with over 5% moisture content survived less than 3 years under controlled conditions and survival was greater than 2 years when seed moisture content was near 4%. Seed longevity is a function of the prevailing temperature and moisture conditions, and dandelion seed persistence is generally considered short (Bostock, 1978; Vavrek et al., 1997). The time to maturation for most dandelion seeds is anywhere from 2 to 12 days (Vavrek et al., 1997) and seed viability is generally regarded as high.

## 2.4 DANDELION SEED GERMINATION AND ESTABLISHMENT:

### 2.4.1 MICROSITE REQUIREMENTS

Dandelion seeds, once dispersed from the plant, must find suitable sites within the soil substrate for recruitment to occur. These soil "safe sites" are areas within the soil where dormancy is broken, and where adequate supplies of water and oxygen allow for germination (Froud-Williams et al., 1981). The number of safe sites, sometimes referred to as microsites, in conjunction with seed supply, influence the proportion of seeds that germinate (Sheldon, 1974). Microsites change throughout the course of a growing season and therefore the proportion of dandelion seeds germinating within a given year is dependent upon the favourability of the microsite during the season (Sheldon, 1974). To optimize germination, seeds in the soil must

be positioned so there is maximum contact between the soil stratum and the area of the seed that takes up water for imbibition (Sheldon, 1974; Stewart-Wade et al., 2002).

### 2.4.2 GERMINATION REQUIREMENTS

There are numerous conditions that must be satisfied prior to the commencement of dandelion seed germination. Germination generally occurs over a temperature range of 5 to 35 C (Stewart-Wade et al., 2002). Watson et al. (2001) noticed that germination took place between 4 and 30 C, with optimum germination occurring at 23 C, and Ogawa (1978) found that germination occurred over a temperature range of 5 to 25 C. Dandelion seeds are more apt to germinate when there is light and under higher temperatures (Letchamo and Gosselin, 1996). Dandelion seeds possess an inducible light requirement, which prevents deeply buried seeds within the soil profile from germinating (Stewart-Wade et al., 2002). The depth of a seed within the soil profile profoundly affects a seed's capability to germinate. The deeper the seed is buried in the profile, the less of a chance it has to successfully germinate (Stewart-Wade et al., 2002; Watson et al., 2001). The greatest percentage of dandelion seed germination occurs in the first 0 to 2 cm of the soil profile (Royer and Dickinson, 1999; Watson et al., 2001), with optimum germination taking place at 1 cm (Bostock, 1978) and no germination occurring when seeds are located deeper than 8 cm (Watson et al., 2001). In an experiment under greenhouse conditions, Letchamo and Gosselin (1996) observed that dandelion seeds exhibited the greatest germination in the first 0 to 1 cm of the soil, and seeds, sown at 0 cm and 1 cm respectively, germinated 50% faster than seeds that were sown at depths of 2.5 cm

and 5 cm. The proportion of dandelion seeds that germinated when planted at 0 cm and 1 cm (25 C) was near 100%, whereas the proportion of dandelion seeds that germinated when planted at 2.5 cm and 4 cm (25 C) varied from just over 70% up to 90% respectively (Letchamo and Gosselin, 1996). Dandelion emergence is significantly higher when dandelion seeds are at or near the soil surface and soils are at field capacity (Boyd and Van Acker, 2003). Boyd and Van Acker (2003) reported that seeding depths of 0 cm, 1 to 2 cm, and 3 to 4 cm did not significantly affect the maximum percentage of dandelion emergence when soil moisture levels fluctuated between field capacity, one-third field capacity, and one-sixth field capacity, suggesting that fluctuating soil moisture levels result in a decline in emergence of seeds located at the soil surface as opposed to when moisture levels remain at field capacity. Soil compaction also decreases the germination capacity of dandelion seeds (Derksen et al., 1996), with dandelion seeds germinating best in undisturbed conditions (Watson et al., 2001). Perhaps dandelion is so prevalent in reduced tillage cropping systems because reduced tillage practices not only alter the microsites where seeds germinate, but also concentrates weed seeds at the soil surface where environmental factors are most conducive for dandelion seed germination (Wrucke and Arnold, 1985). In a study in England, researchers seeded an old pasture to barley for two consecutive seasons. The pasture was divided into areas that were left untilled, tilled monthly, tilled quarterly, or tilled annually. The researchers reported that the highest rates of dandelion seedling emergence occurred when tillage was absent, and the least amount of emergence occurred when the plots were tilled on a monthly basis (Holm et al., 1997a).

### 2.4.3 DORMANCY AND POPULATION REGULATION

Dandelions are prolific seed producers and large quantities of dandelion seed exist in the soil. Dandelion seeds germinate almost immediately after they leave the parent plant as seeds lack primary dormancy (Martinkova and Honek, 1997; Stewart-Wade et al., 2002). Seed longevity in the soil is fairly short lived (Ogawa, 1978); however, Watson et al. (2001) discovered that dandelion seeds could survive in the soil for up to a maximum of four years. This indicates that a given proportion of dandelion seeds must possess some sort of dormancy, even though most seeds germinate within one year of leaving the parent plant. Dandelion seeds may form a persistent, short term seed bank that lasts for more than one year but generally does not persist over five years (Martinkova and Honek, 1997). A study in Japan on the germination patterns of dandelions showed that most seeds of dandelion germinated within one and a half months of being planted (Ogawa, 1978). Germination decreases as the proximity or density of dandelion seeds in the soil increases (Holm et al., 1997a; Stewart-Wade et al., 2002), suggesting that some type of population regulating mechanism operates during the germination processes to minimize intra-specific competition.

### 2.4.4 RECRUITMENT AND EMERGENCE PERIODICITY

Generally, dandelion seeds will germinate throughout the year, except in winter (Derksen et al., 1996; Ogawa, 1978; Roberts and Neilson, 1981). Some authors suggest that dandelion seedling recruitment is greatest in autumn (Vavrek et al., 1996). A study in West Virginia showed that the rate of dandelion population increase was greatest in the fall and diminished throughout the remainder of the year

(Stewart-Wade et al., 2002). A high recruitment rate in the fall suggests that dandelion plants in the following spring will be extremely competitive and capable of capturing necessary resources (Vavrek et al., 1997). Other research proposes that dandelion seedling recruitment is high in both spring and fall (Holm et al, 1997a; Watson et al., 2001). Derksen et al. (1996) found that dandelion seedlings emerged year round, but the premium times of seedling emergence were in May and September. Roberts and Neilson (1981) reported that dandelion emergence peaked in June and again in August and September. In temperate areas, mid spring is the season in which the greatest numbers of dandelion plants establish (Vavrek et al., 1997). In a greenhouse study, Vavrek et al. (1996) explored the recruitment and emergence patterns of dandelion and determined that establishment was greatest in spring and lowest in fall.

The timing of seedling establishment varies from year to year and the timing of recruitment and emergence contributes to species richness in the environment (Vavrek et al., 1997). Plants with the largest recruitment rates are those that deposit their seeds directly onto the ground (Welham and Setter, 1998). The periodicity of seedling recruitment holds implications for the timing and application of weed control methods and the efficacy of these methods.

## 2.5 GENETIC VARIABILITY AND POPULATION DYNAMICS:

### 2.5.1 HYBRIDIZATION

Hybridization refers to the production of offspring from genetically dissimilar parents, which results in the maintenance of genetic diversity (Raven, et al., 1999). The result of hybridization is a hybrid offspring, which is generally more vigorous

than its parents (Richards, 1970). For hybridization to occur a sexual species must cross with another sexual species or a sexual species must cross with an agamospermous species (Richards, 1970). Since there is only evidence of asexual individuals in the North American population of dandelion, hybridization activities have not yet been documented in North America (Vavrek et al., 1996). There is evidence of hybrid dandelions existing in Japan (Stewart-Wade et al., 2002) and Europe (Richards, 1970), but hybrids are normally found only under experimental conditions, and it is believed that dandelion hybrids do not commonly occur in natural field situations (Richards, 1970).

### 2.5.2 BIOTYPES

The reproductive strategy of dandelion populations in North America is strictly apomictic (Richardson, 1985; Solbrig, 1971; Solbrig and Simpson, 1974; Stewart-Wade, et al., 2002; Taylor, 1987; Vavrek et al., 1996) with the embryo of dandelion plants developing without the mechanism of fertilization (Roberts, 1936; Stewart-Wade et al., 2002). There is considerable morphological variability in North American dandelion populations, which is attributed to their significant phenotypic plasticity (Richards, 1973; Solbrig, 1971; Stewart-Wade et al., 2002). In Europe, dandelion populations are identified as many different microspecies (Richards, 1973; Solbrig and Simpson, 1977; Stewart-Wade et al., 2002), whereas North American populations are broadly defined as one species exhibiting large morphological variation due to phenotypic plasticity (Richards, 1973; Solbrig, 1971; Stewart-Wade, et al., 2002). But, Stewart-Wade et al. (2002), quoting Janzen (1977), stated that there is very little genetic variation in most dandelion populations. The different

dandelion phenotypes, demonstrating extreme genetic diversity, are referred to as biotypes. The number of biotypes in the North American dandelion population number in the 50 to 60 range (Mitich, 1989) and morphological variations within dandelion populations are constantly occurring. Is it possible that there is absolutely no sexual reproduction occurring in North American dandelion populations and the numerous biotypes that exist are a direct consequence of phenotypic plasticity and morphological variation? Perhaps sexual reproduction in North American dandelion populations does occur, but there is inadequate evidence to support the claim. There is a hypothesis that variation in the North American population is due to the introduction of numerous European micro-species of dandelion (Stewart-Wade et al., 2002). In addition, asexually producing species, such as dandelion, can preserve genetic diversity via non-meiotic processes, and evolve and adapt by amassing various genotypes within a given population (Mertens King and Schaal, 1990).

In previous studies, leaf morphology was employed to distinguish dandelion biotypes (Vavrek et al., 1996), but Silversides (1938) found that using leaf characteristics to classify biotypes was questionable. Enzyme electrophoresis is one method by which biotypes are reliably distinguished from one another (Holm et al., 1997a; Solbrig and Simpson, 1977). Researchers in the United States, employing electrophoresis analysis, discovered 21 different allozyme patterns in 518 dandelion plants collected from 22 different populations (Lyman and Ellstrand, 1984). This further supports the notion that many biotypes have not yet been identified and considerable genetic diversity does exist within and between populations of *T. officinale*.

### 2.5.2.1 BIOTYPE COMPETITIVE ABILITY

Dandelion biotypes differ in their competitive ability (Froese and Van Acker, 2003) and some biotypes display a greater competitive ability than others (Solbrig and Simpson, 1977; Taylor, 1987) because each biotype is adapted to its own habitat (Ford, 1981). The competitive ability of a given biotype within an infestation is directly proportional to the evolution and the responsive nature of that biotype under contrasting levels of disturbance within its environment, and its ability to capture necessary resources (Ford, 1981; Solbrig, 1971). For example, a pre-plant tillage pass may result in a greater degree of heterogeneity of dandelion biotypes within a field (Froese and Van Acker, 2003). Older dandelion plants and dandelion plants in undisturbed habitats may possess a more competitive nature (Froese and Van Acker, 2003). Solbrig and Simpson (1977) conducted a series of experiments to test the differences in competitive abilities between two different dandelion biotypes. They hypothesized that the biotype that exhibited prolific seed production and minor vegetative growth would out-compete other biotypes in disturbed conditions. This is partly due to the fact that a seed producing biotype leaves a greater number of offspring than a predominately vegetative biotype in disturbed conditions. The vegetative biotype is more likely to incur injury or death via disturbance, resulting in fewer offspring that are able to propagate and survive (Solbrig and Simpson, 1977).

### 2.5.2.2 BIOTYPE AGE AND SEASONALITY

Biotypes vary in age within any given infestation (Silversides, 1938). The age of any given individual is determined by counting the growth rings, composed of latex tubes that run alongside sieve elements (Anderson, 1999) that are laid down

each year in the main root of the plant (Stewart-Wade et al., 2002), analogous to growth rings in trees. Unfortunately, determining the age structure of a dandelion plant population is often difficult and, in many cases, impossible (Vavrek et al., 1997). Perhaps differences in plant age are responsible for the variation in competitive ability and in the tolerance of plants to environmental factors such as frost, moisture stress, or human manipulations. There is proof of dandelion plants that range from 10 to 13 years in age (Roberts, 1936). Froese and Van Acker (2003) found evidence suggesting that tillage regime affected the age structure of biotypes within a field. They hypothesized that there was a broader age structure in fields that were tilled, compared to fields where tillage was reduced, due to the fact that yield loss and the level of dandelion infestation in untilled fields was strongly correlated.

Biotypic diversity within a population can vary from season to season as a result of biotic and abiotic factors operating in the environment and seasonal deviations (Vavrek et al., 1996). These factors and deviations assist in the maintenance of genetic diversity and the alteration of survival and recruitment patterns, ultimately influencing the relative growth and survival of a given biotype within a population (Vavrek et al., 1996). Changes in seasonal conditions impact the relative fitness of a given biotype within a dandelion population (Vavrek et al., 1996), which may explain the differences in tolerance, exhibited by dandelions, to herbicides throughout the course of a growing season.

### 2.5.3 PHENOTYPIC PLASTICITY

Dandelion employs phenotypic plasticity to cope with varying environmental situations (Solbrig, 1971; Vavrek et al., 1997). Temporal and spatial environmental

differences regulate the degree or magnitude of diversity occurring within a population (Vavrek et al., 1996). The persistence of genetic variability within any apomictic population is important because no new genes are introduced into the population during reproductive activities (Vavrek et al., 1996). Taylor (1987) quoted May (1975) who stated that "physiological adaptation to local habitats occurs within a genetically determined framework". Research on the co-existence of dandelion biotypes reveals that the ability of contrasting biotypes to establish and dwell in a specific local is due to the culmination of an assortment of previous biotypes, adapted to the region and inhabiting the area in proportion to the suitability and allotment of favourable microsites (Ford, 1981). Hence, biotypes are present in areas that are best suited to their adaptive abilities and characteristics.

### 2.5.4 INTER AND INTRA- POPULATION VARIATION

Intra and inter-population variation also appears in dandelion populations (Lyman and Ellstrand, 1984). Fecundity and survival differ between populations and among individuals within populations (Stewart-Wade et al., 2002). Stewart-Wade et al. (2002), quoting Kennison (1978), noted that there was greater variation among populations than within populations, but Taylor (1987) stated that intra-population variability was greater than the variability between populations, based on leaf morphology, flowering rhythms and achene characteristics. Heterogeneity within a population is possible because environmental conditions fluctuate considerably in time and space (Vavrek et al., 1997). Differences in soil moisture and soil type, tillage regime and disturbance, competition from other plant species, and nutrient availability (de la Fuente et al., 1999; Vavrek et al., 1996; Vavrek et al., 1997) are

some of the environmental factors that trigger inter and intra-population diversity. The degree to which a species alters its phenotype is a function of the variability existing in the region that a particular species inhabits (Solbrig, 1971).

### 2.5.5 POPULATION DYNAMICS

Dandelion is a ruderal species (Roberts and Neilson, 1981) that is classified as an r-strategist, investing a significant proportion of its energy into seed production and is perceived to exhibit colonizing strategies (Solbrig, 1971; Solbrig and Simpson, 1974; Stewart-Wade et al., 2002; Watson et al., 2001), infesting a wide range of ecological niches and environmental conditions. Dandelion is categorized as a perennial species (Fay, 1990; Royer and Dickinson, 1999; Stewart-Wade et al., 2002), but in long-term crop rotation studies, Légère and Samson (1999) discovered that it could produce large flushes of seedlings, behaving somewhat like an annual ruderal species under certain situations. Growth and reproductive strategies vary from biotype to biotype (Holm et al., 1997a; Richards, 1973), considering that both the genetic composition of a biotype and the environment it inhabits affects biotype functional expression (Solbrig and Simpson, 1974). Under agricultural conditions, the environment in which dandelion populations reside is continually altered due to tillage, fertilizer practices, and pesticide application. These farm management practices significantly impact the proportion and density of biotypes existing within a given field (Sterk et al., 1983). Sterk et al. (1983) found different dandelion biotypes in the Netherlands corresponding to differing levels of soil nitrogen and soil moisture. For example, *Taraxacum obliquum* was found in conditions where soil nitrogen was deficient but soil moisture was high, whereas *Taraxacum rubicundum* was found in

areas where soil nitrogen levels were sufficient but soil moisture levels were low (Sterk et al., 1983). Since dandelion possess a generalist phenotype (Stewart-Wade et al., 2002), whenever environmental disturbance occurs, dandelion plants seize the opportunity and colonize the area by means of seed dispersal and seedling recruitment (Solbrig, 1971).

## 2.6 DANDELION COMPETITION:

Dandelion competes with neighbouring plants for moisture, nutrients, light and space (Royer and Dickinson, 1999; Silversides, 1938). The degree of competitiveness that individual plants of dandelion possess is often difficult to predict as dandelion competitive ability varies greatly among individuals and among infestations (Froese and Van Acker, 2003). Relative competitiveness is not necessarily related to age (Solbrig and Simpson, 1974), but older, undisturbed dandelion plants usually possess a greater competitive ability than younger plants (Froese and Van Acker, 2003; Moyer et al., 1990; Solbrig and Simpson, 1974). The degree to which a dandelion plant competes is a function of its long taproot, which is capable of accessing water and nutrients at depth (Stewart-Wade et al., 2002), thus out-competing plants with shorter root systems. Dandelion plants also compete with neighbouring plants for light by means of shading. When grass stands provide sufficient ground cover, dandelion infestations are greatly reduced (Mølgaard, 1977). Stewart-Wade et al. (2002) found evidence of dandelions exhibiting allelopathy by releasing ethylene, which inhibited the growth of nearby plants.

## 2.7 IMPACT OF CROPPING SYSTEMS:

The impact of cropping systems on the proliferation of dandelion plants within a given field is largely a result of the management practices and decisions made. Differences in cropping systems create spatial diversity, which weed populations tend to adapt to and exploit (de la Fuente et al., 1999) to ensure successful colonization and establishment. Combating weed species invasion requires a comprehensive assessment of past and current cropping practices, taking into consideration crop rotation, tillage systems, herbicide regimes (Derksen et al., 1993) and weed biology (Altieri and Liebman, 1988), in order to formulate effective management strategies.

### 2.7.1 CROP ROTATION

A substantial portion of the literature regarding the incidence of dandelions in various crop rotations focuses primarily on infestations in alfalfa crops. Perhaps this is a direct result of the fact that yield loss attributed to dandelions in forage cropping systems is well documented. There is little documentation of the yield loss attributed to dandelion infestations in annual crops (Froese and Van Acker, 2003). Annual rotations that include alfalfa exhibit relatively robust dandelion populations when compared to continuous grain rotations (Ominski et al., 1999). Dandelion infestations are more severe in rotations that included a high frequency of broadleaf crops, such as peas, canola, flax, beans, and sunflowers, due to a decreased competitive ability exhibited by these crops (Stevenson and Johnston, 1999) and a deficiency of suitable in-crop herbicides to combat dandelion in broadleaf crops (Froese and Van Acker, 2003). The use of crops that are highly competitive early in the spring may enhance

weed control in conservation tillage systems (Derksen et al., 1993), as these crops capture essential environmental resources prior to the emergence of dandelion flushes (Vavrek et al., 1997). Unfortunately, establishing when dandelion plants begin to compete is difficult considering that the timing of dandelion establishment differs from year to year, depending on seedling mortality, plant densities, and germination timing (Ford, 1985).

### 2.7.2 TILLAGE SYSTEM

Tillage systems, which modify residue levels at the soil surface, alter soil moisture and temperature, and change the distribution of weed seeds in the soil profile ultimately influence the types of weed species that establish in an area (de la Fuente et al., 1999). Prior to the advent of herbicides, tillage was the primary method of weed control (Witt, 1984). The current adoption of reduced tillage practices allows for shallow germinating weeds to proliferate in the spring when they would normally be controlled by pre-plant cultivation (Witt, 1984). Reduced tillage systems are low disturbance systems that can enhance the germination and proliferation of wind disseminated species (Légère and Samson, 1999) including perennial broadleaf species (Watson and Allen, 1985) such as dandelion.

### 2.7.3 HERBICIDES

The loss of tillage as a method of weed control places the burden of weed control in reduced tillage cropping systems on herbicides and crop rotation (Witt, 1984). LeBaron and Gressel (1982) noted that Strykers, in 1950, documented one of the first cases of herbicide resistance in a population of dandelions in Belgium that were repeatedly exposed to 2,4-D or MCPA. Herbicides select for resistant biotypes,

and herbicide use patterns also modify the weed species composition of a field (Légère and Samson, 1999).

## 2.8 DANDELION CONTROL:

### 2.8.1 CHEMICAL CONTROL

The herbicidal control of weed populations has made the practice of zero-tillage possible (Witt, 1984). There are a variety of chemicals available in the marketplace for the control of dandelions, but a substantial portion of the literature on the herbicidal control of dandelion is dedicated to those herbicides that suppress dandelion infestations in alfalfa stands. Dandelion is a deep-rooted perennial weed that requires the translocation of chemicals into the taproot or the uptake of soil applied herbicides for adequate control (Buhler and Mercurio, 1988). Dandelion plants may germinate after the in-crop herbicide application window and therefore, control should occur in the late fall or early spring when the plants are still immature (Dunn and Moyer, 1999).

#### 2.8.1.1 GLYPHOSATE

Glyphosate [N-(phosphonomethyl)glycine] inhibits ESPS (5-enolpyruvoylshikimate 3-phosphate) synthase, which prevents the synthesis of 3 key aromatic amino acids, namely tryptophan, tyrosine, and phenylalanine, that are essential for plant growth and development (Cox, 1998; WSSA, 1994). It is a systemic, non-selective, broad-spectrum, foliar applied herbicide that was registered in the United States in 1974 (Cox, 1998). In the Canadian System of Herbicide Classification, glyphosate is a group 9 herbicide.

Glyphosate is translocated in the symplastic pathway of plants and accumulates in below ground organs, immature leaves, and meristimatic regions (WSSA, 1994). Susceptible plants exhibit necrosis and chlorosis at the growing points and in immature leaves (WSSA, 1994). In some instances, glyphosate application causes leaves to turn a purplish-red colour and foliar re-growth of treated plant leaves exhibit whitish markings and are deformed (WSSA, 1994). Glyphosate injury symptoms usually occur within 7 to 10 days of application (Manitoba Agriculture, Food and Rural Initiatives, 2004), with the first symptoms being the yellowing and wilting of immature plant organs (Ross and Lembi, 1999).

A pre-harvest glyphosate application is an economical means of controlling dandelion weed infestations, but glyphosate unfortunately only offers partial dandelion control when applied at this time (Stevenson and Johnston, 1999). In canola, Froese (2001) found that the best time to apply glyphosate was either pre or post-harvest but sequential glyphosate applications during the growing season provided dandelion control provided that one of the glyphosate applications was applied at 900 g a.e. $ha^{-1}$ (1L formulated product $ac^{-1}$) post-harvest. Implementing glyphosate control in-crop fits well into rotations that include herbicide tolerant crops. Darwent and Drabble (1995) found that glyphosate efficacy was reduced when applied in-crop and Froese (2001) stated that pre-seed and in-crop glyphosate applications did not always effectively control dandelions. Froese (2001) found that pre-seed applications of glyphosate reduced dandelion biomass by 60%, but when the glyphosate was applied at the 0-3 leaf stage of canola, dandelion biomass was only

reduced by 30 to 40%. The optimum time for glyphosate application to control dandelion infestations is post-harvest (Froese, 2001).

In a Manitoba study, dandelion plants that were less than 15 cm in diameter were sufficiently controlled with a glyphosate rate of 900 g a.e. $ha^{-1}$, with 1800 g a.e. $ha^{-1}$ of glyphosate required for the control of larger, more mature plants (Froese, 2001). Holm et al. (1997b) stated that by increasing the rate of glyphosate in the spring from 413 g a.e. $ha^{-1}$ to 622 g a.e. $ha^{-1}$, dandelion control increased from 74% to 81%. Glyphosate, applied at 900 g a.e. $ha^{-1}$ is the most effective control option in combating dandelion infestations (based on level of control and economic profitability) and post-harvest glyphosate applications, ranging from 900 g a.e. $ha^{-1}$ to 2700 g a.e. $ha^{-1}$, give adequate dandelion control, with the level of control increasing as herbicide rates increase (Froese, 2001). Tank mixing glyphosate with ammonium sulfate, 2,4-D, or dicamba may provide greater activity on dandelion (Roggenbuck and Penner, 1986). Derksen et al. (2002) found that fall-applied glyphosate provided better control of dandelion than a single tillage pass. Frost also improves glyphosate efficacy, with the day after the first frost in the fall (-4°C) being an effective time for glyphosate application (Froese, 2001).

#### 2.8.1.2 FLORASULAM

Florasulam is a relatively new systemic herbicide belonging to the triazolopyramidine family (Jackson et al., 2000; Krieger et al., 2000a; Krieger et al., 2000b; Thompson et al., 1999), registered for post-emergent broadleaf weed control in cereals in Canada and Europe (Krieger et al., 2000a). According to the Canadian System of Herbicide Classification, florasulam is a group 2 herbicide. It inhibits

acetolactate synthase (ALS) and exhibits superior efficacy on weeds belonging to the *Compositae*, *Polygonaceae*, *Caryophyllaceae*, *Rubiaceae* and *Crucifereae* families (Krieger et al., 2000a; Krieger et al., 2000b; Thompson et al., 1999). Florasulam provides excellent control of dicotyledonous plants (Rijckaert and Lepiece, 2001) and grasses are only susceptible to florasulam if it is tank mixed with a graminicide (Thompson et al., 1999).

Florasulam is taken up by plant shoots and roots and is xylem and phloem mobile (Thompson et al., 1999). The symptoms of susceptible weeds treated with florasulam include necrosis or cholorsis in the meristimatic regions of the plant (Thompson et al., 1999). Injury symptoms may only be visible several days after application (Thompson et al., 1999) depending upon growing conditions and weed susceptibility (Dow AgroSciences, 2002). Florasulam is rapidly degraded by soil micro-organisms and its persistence in the soil is quite low, with an average half life ranging from 2 to 18 days, depending upon soil moisture and temperature conditions (Alberta Agriculture, Food, and Rural Development, 2004). Krieger et al. (2000a) found that the half life for florasulam was 9 days. Jackson et al. (2000) stated that microbial degradation of florasulam has an average half-life of 2.4 days with a range of 0.4 days to 4.5 days. The residual activity of florasulam allows for the control of some susceptible weed seedlings that are not yet emerged at the time of application.

Florasulam tank mixed with glyphosate is commercially marketed by Dow AgroSciences Canada Inc. as PrePass™. PrePass™ is registered in Canada for application prior to planting barley, oats, or wheat to control volunteer RoundupReady™ canola, wild buckwheat, the top growth of dandelion, and many

other broadleaf and grassy weed species (Manitoba Agriculture, Food and Rural Initiatives, 2004). PrePass™ is sold commercially as 50 g $L^{-1}$ of florasulam in combination with 360 g $L^{-1}$ of glyphosate IPA salt (Manitoba Agriculture, Food and Rural Initiatives, 2004). Under ideal conditions, weed control usually occurs within 7 to 10 days of application, whereas under non-ideal environmental conditions, control may only happen after a time period of 6 to 8 weeks (Dow AgroSciences, 2004). PrePass™ controls dandelion seedlings and rosettes up to 15 cm in diameter and it suppresses dandelion rosettes that are greater than 15 cm in diameter (Manitoba Agriculture, Food and Rural Initiatives, 2004).

#### 2.8.1.3 PHENOXY HERBICIDES

Traditionally, phenoxy herbicides such as 2,4-D, mecoprop, dicamba (Neuwmann and Boland, 1999; Stewart-Wade et al., 2002) and MCPA (Neuwmann and Boland, 1999) have been used to control dandelion, but mature plants are often able to withstand and tolerate 2,4-D applications (Stewart-Wade et al., 2002). Herbicides such as Banvel, Curtail M, Lontrel, and 2,4-D sometimes only offer top growth control (Watson et al., 2001). Attain (fluroxypyr + 2,4-D), Curtail M (clopyralid + MCPA), Prestige (clopyralid + MCPA + fluroxypyr), Flax Max Ultra (sethoxydim + clopyralid + MCPA), Prevail (tralkoxydim + clopyralid + MCPA), Afola (linuron), MCPA, and 2,4-D provide in crop suppression of dandelion and dandelion seedling control (Froese, 2001), as well as Target (MCPA + mecoprop + dicamba) (Manitoba Agriculture, Food and Rural Initiatives, 2004). Combinations of 2,4-D, mecoprop and dicamba are sold commercially as Killex for dandelion control in lawns (Stewart-Wade et al., 2002).

2,4-D, or 2,4-dichlorophenoxy acetic acid, is a foliar applied herbicide that accumulates in the root and shoot regions of susceptible broadleaf plants (WSSA, 1994) and was first registered in Canada in 1946 (Government of Canada, 1994). 2,4-D is first absorbed by the leaves and is translocated symplastically throughout the plant, eventually accumulating in the growing points of the plant roots and shoots. Following root uptake, 2,4-D is translocated apoplastically (WSSA, 1994). Symptoms of 2,4-D applications include epinasty (Klingman, 1946; WSSA, 1994), and abnormal leaf shape and venation, wilting, chlorosis and necrosis (WSSA, 1994). Complete plant death usually occurs within three to five weeks of the application (WSSA, 1994), but injury symptoms may be evident within one day of the 2,4-D application (Klingman, 1946). The residual activity of 2,4-D is, on average, 10 days (WSSA, 1994).

The effect of 2,4-D exposure on dandelion plants is a reduction in root carbohydrate content (Rutherford and Deacon, 1974; Wilson and Michiels, 2003). Plants with lower carbohydrate root content in the autumn are, in most instances, more susceptible to killing frosts and sub-zero temperatures (Wilson and Michiels, 2003). Moyer (1984) stated that superior dandelion control with 2,4-D was achieved when 2,4-D was applied in both the fall and the spring, but Mann (1981) found that 2,4-D only offered partial control of dandelion in any season. In a greenhouse study examining the use of 2,4-D on dandelion control, Moyer (1984) reported that 2,4-D ester formulations were more effective than 2,4-D amine formulations in controlling dandelion, which is in agreement with the findings of Devine et al. (1993) who stated that ester formulations were more effective than amine forms due to the fact that

esters are more readily absorbed through plant cuticles and cell membranes. Waddington (1980) found that 2,4-D amine applied to an alfalfa stand at the beginning of the growing season at 1.1 kg $ha^{-1}$ provided excellent dandelion control but severely devastated the alfalfa crop. 2,4-D ester applied at 1.1 kg $ha^{-1}$ on dormant alfalfa effectively controls dandelion seedlings, but does not control mature dandelion plants (Sheaffer and Wyse, 1982). There are also reports of synergistic effects of 2,4-D with dicamba on dandelions (Neal, 1990). Weeds express differential responses to 2,4-D applications based on their growth stage, which influences herbicide penetration and translocation in the plant (Mann, 1981). The constraining factor in using phenoxy herbicides on dandelion is that for effective control to occur it is imperative that adequate top growth be present (Buhler and Mercurio, 1988) to intercept foliar applied systemic herbicides and allow for maximum herbicide penetration into the plant and translocation throughout the plant's vascular system to the root tissue.

#### 2.8.1.4 TRIBENURON

Tribenuron belongs to the sulfonylurea chemical family (WSSA, 1994; Zollinger et al., 1992) displaying a wide spectrum of activity on a number of annual and perennial broadleaf species (Kotoula-Syka and Hatzios, 1996; Zollinger et al., 1992). In the Canadian System of Herbicide Classification tribenuron is considered a group 2 herbicide. Tribenuron inhibits acetolactate synthase (ALS), also referred to as acetohydroxyacid synthase (AHAS), and prevents the biosynthesis of the amino acids isoleucine, leucine, and valine (Stenlund and Alkali, 1989; WSSA, 1994; Zollinger et al., 1992).

Tribenuron is absorbed by the foliage and roots of plants and translocated in the xylem and phloem (WSSA, 1994). Plants susceptible to tribenuron exhibit injury symptoms consisting of the chlorosis and necrosis of meristimatic regions followed by the chlorosis and necrosis of leaf tissue (WSSA, 1994). Some affected species may display signs of purple coloured leaves, leaf abscission, vein discolouration, and the loss of leaf nyctinasty (WSSA, 1994), which is the nighttime movement of some plant species leaves from a horizontal to a vertical position due to interactions between the environment and a plant's internal biological clock (Salisbury and Ross, 1992). Most susceptible plant species die within 7 to 21 days after application, but symptoms are usually evident within a few hours of tribenuron applications (WSSA, 1994). Zollinger et al. (1992), examining the movement and activity of tribenuron in perennial sow thistle, found that leaf chlorosis and necrosis was visible 14 days after application, with leaf discolouration beginning in immature foliage and meristimatic regions. Tribenuron has limited absorption and translocation properties, but small amounts of the herbicide are sufficient to inhibit plant growth (Zollinger et al., 1992). Degradation of tribenuron in the soil is rapid and occurs via hydrolysis, with a half life of 1 to 9 days depending upon soil temperature, soil pH, and soil moisture (Stenlund and Alkali, 1989).

### 2.8.2 TIMING OF CHEMICAL CONTROL

In annual cereal and oilseed cropping systems, foliar chemicals (herbicides) are applied either pre-plant, in-crop, pre-harvest, or post-harvest. Dandelion is most susceptible to herbicides with a systemic mode of action, such as glyphosate or 2,4-D, in the fall or early spring (Dunn and Moyer, 1999). Fall applications of herbicide

seem to provide superior dandelion control due to increased herbicide translocation into the roots at this time in the growing season (Dunn and Moyer, 1999). In the spring, dandelion plants rapidly increase in biomass due to vegetative growth, resulting in the translocation of carbohydrate reserves from the roots to the upper portions of the plant, which results in decreased herbicide translocation to the roots. Spring herbicide applications may only cause top growth suppression of dandelion plants, with new shoots emerging from the relatively unaffected root tissue (Buhler and Mercurio, 1988). Dunn and Moyer (1999) discovered that post-harvest is the ideal time for dandelion control and herbicide application in the autumn reduces the competitive ability of dandelion plants in the following spring. Some producers notice that herbicide application in the fall, followed by a pre-plant herbicide application in the spring, is the most effective strategy for suppressing dandelion infestations (Dunn and Moyer, 1999). In a two-year trial in Wisconsin, dandelion infestations were not adequately controlled by pre-emergent herbicide applications, and this result was attributed to the spring growth habit and life cycle of dandelion (Buhler and Mercurio, 1988). In-crop applications are not always as effective as fall applications for controlling dandelion considering that dandelion seedlings may recruit after the in-crop herbicide application period (Dunn and Moyer, 1999). Although fall applications are more efficacious, the yield loss attributed to dandelion infestations occurs primarily in the spring, and this creates a conundrum for farmers (D. Derksen, Weed Scientist, Agriculture and Agri-Food Canada, Brandon, MB, personal communication, 2002).

### 2.8.3 CULTURAL CONTROL

#### 2.8.3.1 TILLAGE

The literature is divided on the question of whether tillage is essential or detrimental in suppressing dandelion populations in agricultural cropping systems. Froese (2001) found that spring tillage, even in only one year, greatly reduced the level of dandelion infestation within a field. This holds implications for producers who practice reduced or zero-tillage methods, as these systems do not allow for the control of perennial weeds in as effective a manner as traditionally tilled systems (Doll, 1978). Derksen et al. (2002) found that dandelion infestations are increasing in western Canada due to reduced tillage in general, not just zero-tillage, as the frequency and timing of cultivation operations promote and determine the types of perennial weeds that germinate and establish within a given field (Fay, 1990; Stewart-Wade et al., 2002). Weed frequency in reduced tillage situations is influenced by changes in weed seed microsite conditions (Wruke and Arnold, 1985). Buhler et al. (1994) reported that perennial weed populations are increasing in reduced tillage systems because the root systems of these weeds are no longer disturbed and many of the herbicides that control annual weeds are relatively ineffective in controlling perennial species.

Plowing was originally considered a suitable method of controlling dandelion infestations since the more viable sections of the root were buried by plowing operations (Stewart-Wade et al., 2002). However, dandelion plants are extremely persistent and even small pieces of any portion of the root have the potential to propagate into new plants (Bostock and Benton, 1979; Mann and Cavers, 1979;

Stewart-Wade et al., 2002). In addition, tillage tends to scatter dandelion root and shoot fragments which can intensify the problem (Watson et al., 2001). Dunn and Moyer (1999) found that sweep tillage and disking does not effectively control mature dandelion plants that are well advanced, and re-emergence usually occurs three to five weeks after the tillage operation. Similarly, cutting the crown from the roots does not kill dandelion (Georgia, 1933; Silversides, 1938). For tillage to be a plausible means of dandelion control the whole taproot of the plant must be removed (Mitich, 1989; Stewart-Wade et al., 2002), a difficult feat considering that in some mature dandelion plants, the taproot is greater than 2 m in length (Mann and Cavers, 1979; Watson et al., 2001). In general, there is an inadequate amount of information and research with respect to the long-term effects of tillage systems on the population dynamics of perennial weeds, such as dandelion, in various cropping systems (Buhler et al., 1994).

#### 2.8.3.2 MOWING

Mowing is an ineffective method of managing dandelion infestations as energy packed roots and leaves survive mowing, and mowing operations permit dandelions to thrive in their habitat by reducing the competition between dandelion and grass species (Richardson, 1985). Mowing grants dandelion a competitive advantage because dandelion is sensitive to shading by competitors (Vavrek et al., 1997). Grass stands that are cut often and over-grazed are at risk for severe dandelion invasions (Dunn and Moyer, 1999) due to the decreased competition exhibited by the grasses and the provision of conditions leading to the successful colonization of dandelion plants (Welham and Setter, 1998). Dandelion survives mowing simply

because of its prostrate rosette growth habit that is not easily defoliated by mowing implements (Stewart-Wade et al.; 2002). Mowing can actually intensify dandelion problems because the root to shoot ratio of dandelion is shifted towards the root (Stewart-Wade et al., 2002) and the persistence of the plant is favoured.

#### 2.8.3.3 CROP COMPETITION

Competition with other perennial species might, in some cases, be a feasible means of controlling dandelion infestations. Superior crop competition during peak periods of seedling recruitment can result in the suppression of dandelion infestations (Dunn and Moyer, 1999). Silversides (1938) found that when dandelion competed with Kentucky blue grass, the dandelion plants were very small and less competitive due to dandelion's extreme sensitivity to shading from taller, more competitive species (Stewart-Wade et al., 2002; Vavrek et al., 1997).

In alfalfa production systems, alfalfa crops are often seeded with a companion crop, such as oats or a forge grass to suppress weed populations (Spandl et al., 1990). As alfalfa stands age they are prone to severe dandelion invasion due to a decline in their competitive ability, and using a companion crop reduces competition from weeds as time progresses (Spandl et al., 1990). Mølgaard (1977) recorded the intense competition between dandelion and grass species and reported that dandelion establishment is inhibited by dense grass cover due to limited light penetration as a result of the grass canopy.

#### 2.8.3.4 RESOURCE LIMITATION

Increasing phosphorus levels in the soil may increase dandelion density, as phosphorus affects root growth (Stewart-Wade et al., 2002; Watson et al., 2001).

Dandelion is a poor competitor for potassium and biomass is limited by a deficiency of this nutrient (Tilman et al., 1999). Potassium deficiency limits dandelion biomass production, and in field trials, areas that were potassium deficient had reduced dandelion infestations compared to areas that had adequate levels of potassium in the soil (Tilman et al., 1999). Dandelion is not sensitive to nitrogen levels (Watson et al., 2001) but fertilizing grass stands may result in increased competition (Holm et al., 1997a; Stewart-Wade et al., 2002) for light and space, with grass stands gaining a competitive advantage over dandelion. Holm et al. (1997a) stated that dandelion growth decreased by more than 20% and root discolouration was observable when soil aluminum levels were increased from 2 to 8 ppm. Tilman et al. (1999) also observed a sensitivity of dandelion to calcium and magnesium levels in the soil.

### 2.8.4 BIOLGICAL CONTROL

The vast majority of the research concerning biological control methods implemented to suppress dandelion focuses primarily on the control of dandelion in greenhouse conditions or in turf grass systems. Biological control agents, such as insects and fungi, in addition to sheep and geese, who eat the leaves of dandelion, historically have been implemented as a means of control, and sheep and geese have successfully controlled dandelions in Christmas tree plantations in North America (Stewart-Wade et al. 2002). Corn gluten meal (CGM), a protein that is the by-product of corn wet-milling (Liu and Christians 1997) has exhibited success as a biological control agent when applied to dandelion plants under greenhouse conditions. In one study, CGM decreased dandelion survival by more than 75% by inhibiting root formation during germination (Stewart-Wade et al. 2002). Bingaman

and Christians (1995) found that CGM, applied at rates of 324 g $m^{-2}$, 649 g $m^{-2}$, and 973 g $m^{-2}$ respectively, all decreased dandelion shoot lengths by greater than 50% in greenhouse tests. Turf grass treated with the fungal pathogen *Sclerotinia scerotiorum* exhibited a greater than 80% reduction in dandelion infestation levels (Burpee, 1992). Unfortunately, *S. scerotiorum* is also a fungal pathogen of many common field crops, including canola (Riddle et al., 1991), and therefore commercial exploitation in cereal and oilseed cropping systems is not feasible. Research indicates that the utilization of resource ratio supply rates is an alternative means of biological control in dandelion populations. In grass plots and greenhouse studies, it was found that by altering nutrient ratios, specifically potassium, dandelion populations were effectively controlled. A study at Rothamsted, U.K. revealed that plots that received no potassium fertilization showed a dramatic decrease in the number of dandelion plants (Tilman et al., 1999). In Manitoba, most of the arable land possesses adequate amounts of potassium for crop production, with only 6% of arable fields requiring potassium fertilization (Manitoba Agriculture, 2000) and consequently, altering potassium levels as a means of dandelion biological control is not likely to be effective in Manitoba.

## 2.9 PURPOSE AND OBJECTIVES:

Dandelion is quickly becoming a significant problem weed in western Canadian cropping systems, especially in reduced tillage systems. Historically, dandelion infestations were more problematic in forage crops, resulting in a lack of information regarding the behaviour and management of this weed in annual crops. A greater understanding of the biology and ecology of dandelion, and herbicide

efficacy on this species, especially under western Canadian environmental and agricultural conditions, will aid in devising more effective management strategies for dandelion in annual field crops. Management will be facilitated in particular by an investigation of seasonal patterns and variations in dandelion recruitment, flowering timing, survival and behaviour, and will provide greater insight into the life cycle, persistence and spread of dandelion in annual crops. For example, it is uncertain whether dandelion rosettes that farmers observe in the spring are rosettes that survived over the winter, shoots emerging from pieces of rootstock, or new seedlings. This information would help in devising management strategies that are synchronized with the life cycle of dandelion. Exploring the emergence periodicity of dandelion plants from either rootstock or seed may possibly influence and enhance management decisions and explain why dandelion plants differ in their tolerance to herbicides applied at various times throughout the course of a growing season, and why dandelion infestations are allowed to spread in some field crop situations. Dandelion seeds possess short seed longevity and no dormancy, but dandelion is a prolific seed producer. Investigating the impact of preventing dandelion seed return to the seed bank and the existence of no seed dormancy on future infestations is crucial in planning for the effective management of dandelion. The general goal of this project was to determine the optimum time to control dandelion and to relate the relative efficacy of the herbicidal products used in this study to the emergence patterns of dandelion infestations. This information will assist in our understanding of the relative competitive nature of dandelion infestations, which infestations most urgently

require control, and the most effective time, rate and herbicide to utilize to manage infestations in annual field crops.

The specific objectives of this project are to:

1) explore dandelion recruitment biology, in terms of timing of dandelion emergence from either seed or rootstock through the growing season.

2) determine the efficacy of glyphosate alone and glyphosate + florasulam versus other herbicidal compounds applied at various rates in either the fall (post-harvest) or the spring (pre-seed) on dandelion infestations in spring wheat.

3) relate the efficacy of herbicide applications on dandelion to recruitment biology and recruitment timing.

## 3.0 MATERIALS AND METHODS

### 3.1 FIELD SELECTION

Field trials were established at three locations in the fall of 2002 (2003 sites) and at two locations in the fall of 2003 (2004 sites). All five sites were located in annually cropped agricultural fields in southern Manitoba which contained relatively uniform populations of dandelion and which were previously planted to cereal crops. For the 2003 trials, two sites were located near Oak Bluff, Manitoba. Oak Bluff 1 was situated on a Gleyed Rego Humic Vertisol, Red River Series soil (Typic Humicryert), consisting of 8.4% sand, 26.3% silt, and 65.3% clay with a pH of 7.9 and a soil organic matter content of 4%. Oak Bluff 2 was situated on a Rego Humic Vertisol, Osborne Series soil (Cyric Epiaquert) consisting of 12.8% sand, 26.3% silt, and 60.9% clay with a pH of 6.9 and a soil organic matter content of 7.4%. The third site in 2003 was established near Carman, Manitoba (Carman) on a Gleyed Black Chernozem, Rignold Series soil (Udic Boroll) comprised of 34% sand, 34.6% silt, and 31.3% clay with a pH of 6.1 and a soil organic matter content of 6%. In 2004, one site was located near Roland, Manitoba (Roland) on a Gleyed Black Chernozem, Scanterbury Series soil (Typic Humicryert), consisting of 48% sand, 34% silt, and 18% clay, with a pH of 7.8 and a soil organic matter content of 4.7%. The second site in 2004 was established at the University of Manitoba research farm at Carman, Manitoba (Carman UM) on an Orthic Black Chernozem, Eigenhof Series soil (Udic Boroll), comprised of 41.4% sand, 34.5% silt, and 24.1% clay with a pH of 7.3 and a soil organic matter content of 5.3% (refer to Figures 7.2, 7.3, 7.4, 7.5, and 7.6 for complete soil analyses). Oak Bluff 1, Oak Bluff 2, Roland and Carman UM were

considered tilled sites because at each of these sites at least one tillage operation was performed prior to seeding in the year previous to experimental site establishment. Carman was considered a reduced-tillage site because for at least the past five years prior to trial establishment, no more than one harrow pass per year was performed prior to seeding, and the site was direct seeded with no other tillage operations occurring prior to crop seeding in the spring (refer to Table 7.1 for complete field histories).

## 3.2 TREATMENTS

The experimental design was a randomized complete block design. Treatments were replicated four times. Each subplot was 2 m wide by 10 m long with a 1 m untreated strip between plots. Treatments consisted of various rates of glyphosate isopropylamine salt alone and in combination with florasulam or tribenuron (refer to sources of materials for further details)[1,2] applied at various times of the year. A nontreated control plot was also included in each replicate (Table 3.2.1).

All herbicide treatments (post-harvest and pre-seed) were applied with a bicycle wheel mounted sprayer calibrated to deliver 60 L $ha^{-1}$ spray volume at 310 kPa with four flat fan 80067 Teejet nozzles[3] (refer to Table 3.3.1 for post-harvest and pre-seed herbicide application timings and Table 7.2 for meteorological conditions at time of herbicide applications). According to the Manitoba Guide to Crop Protection (Manitoba Agriculture, Food and Rural Initiatives, 2005) to control dandelion rosettes less than 15 cm in diameter, the recommended glyphosate application rate is 1 L $ac^{-1}$ (900 g a.e. $ha^{-1}$), and 1.5 L $ac^{-1}$ (1350 g a.e. $ha^{-1}$) to control rosettes greater than 15 cm

in diameter. The registered rate for PrePass™ for dandelion seedling control is 0.5 L $ac^{-1}$ of glyphosate (450 g a.e. $ha^{-1}$) in combination with 0.04 L $ac^{-1}$ (5 g a.i. $ha^{-1}$) of florasulam. For tribenuron + glyphosate, the registered rate to control dandelion rosettes (up to 15 cm in diameter) is 4 g $ac^{-1}$ (7.41 g a.i. $ha^{-1}$) of tribenuron in combination with 0.5 L $ac^{-1}$ (450 g a.e. $ha^{-1}$) of glyphosate (Manitoba Agriculture, Food and Rural Initiatives, 2005).

Table 3.2.1. Herbicide treatment list.

| Treatment no. | Treatment | Application dose[a] | Application timing[b] |
|---|---|---|---|
| | | g $ha^{-1}$ | |
| 1 | Nontreated control | --- | --- |
| 2 | Glyphosate | 450 | Fall |
| 3 | | | Spring |
| 4 | Glyphosate | 675 | Fall |
| 5 | | | Spring |
| 6 | Glyphosate | 1350 | Fall |
| 7 | | | Spring |
| 8 | Glyphosate + Florasulam | 450 + 5 | Fall |
| 9 | | | Spring |
| 10 | Glyphosate + Florasulam | 675 + 7.5 | Fall |
| 11 | | | Spring |
| 12 | Glyphosate + Florasulam | 900 + 5 | Fall |
| 13 | | | Spring |
| 14 | Glyphosate + Tribenuron | 450 + 7.5 | Fall |
| 15 | | | Spring |

[a] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.
[b] Fall applications made post-crop harvest. Spring applications made prior to crop seeding.

## 3.3 AGRONOMIC PRACTICES

At all sites in both 2003 and 2004, 112 kg $ha^{-1}$ of ammonium nitrate (34-0-0) granular fertilizer was broadcast in the spring one day prior to crop seeding using a pull-type granular fertilizer applicator[4]. Hard red spring wheat (cv. "AC Barrie") was seeded at 108 kg $ha^{-1}$ to a depth of 2.5 cm using a small plot no-till drill[5] with 20 cm

row spacings and narrow 2.5 cm single shoot openers. Due to drill calibration error in 2003, Oak Bluff 1, Oak Bluff 2 and Carman were seeded at twice the intended rate (236 kg $ha^{-1}$). During the crop seeding, a granular fertilizer blend with a minimum of 11-52-0 percentage of total nitrogen (N), available phosphate ($P_2O_5$), and soluble potash ($K_2O$), respectively, was banded between crops rows (to a depth of 5 cm) at a rate of 94 and 47 kg $ha^{-1}$ in 2003 and 2004, respectively.

Table 3.3.1. Timing of post-harvest and pre-seed herbicide applications and other agronomic management practices for all 5 site-years.

| | Site-years | | | | |
|---|---|---|---|---|---|
| Management practice | Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
| Post-harvest herb. appl.[a] | Sept. 25 | Sept. 30 | Sept. 30 | Oct. 3 | Oct. 3 |
| Pre-seed herb. appl.[b] | May 12 | May 8 | May 7 | May 17 | May 27 |
| Crop planting | May 14 | May 13 | May 13 | May 19 | May 28 |
| In-crop herb. appl.[c] | June 10 | June 11 | June 11 | June 16 | June 23 |
| Crop harvest | Aug. 18 | Aug. 18 | Aug. 18 | Sept. 17 | Sept. 27 |

[a] Post-harvest herbicide application applied in the fall of 2002 for the 2003 experimental sites and in the fall of 2003 for the 2004 experimental sites.
[b] Pre-seed herbicide application applied in the spring of 2003 for the 2003 experimental sites and in the spring of 2004 for the 2004 experimental sites.
[c] In-crop herbicide application applied at the 3 to 4 leaf stage of the wheat crop.

Trials were seeded in a direction parallel to the direction of herbicide application so as to confine straw movement and minimize the effect of the residual nature of the spring applied florasulam and tribenuron treatments in plots where no florasulam or tribenuron was applied. All sites were treated as minimum tillage sites and no tillage operations were performed in the fall prior to site establishment or in the spring prior to crop seeding.

To control a wide range of common annual weeds, all plots, with the exception of the nontreated controls, were oversprayed with 280 g a.i. $ha^{-1}$ of bromoxynil + 280 g a.i. $ha^{-1}$ of MCPA ester + 3.33 g a.i. $ha^{-1}$ of thifensulfuron + 1.68 g a.i. $ha^{-1}$ of tribenuron + 56.4 g a.i. $ha^{-1}$ of clodinafop-propargyl + 0.8% v/v Score adjuvant[6]. This in-crop herbicide application was applied with an all terrain vehicle mounted sprayer calibrated to apply a spray solution volume of 56 L $ha^{-1}$ with 11001VS Teejet nozzles[3] at 275 kpa. Previous experience and visual assessment indicated that these herbicides have little effect on dandelion growth and development (Gary Turnbull, Senior Scientist, Dow AgroSciences Canada Inc., Winnipeg, MB, personnel communication, 2003) (refer to Table 3.3.1 for timing of agronomic management practices).

## 3.4 MEASUREMENTS

### 3.4 1 ESTABLISHMENT AND SAMPLING OF IN-FIELD PERMANENT QUADRATS

An observational study was conducted in southern Manitoba at three field sites in 2003 and at two field sites in 2004, as described in section 3.1, to determine the emergence period of dandelion plants originating from either rootstock or seed. Three permanent 0.25 $m^{-2}$ quadrats were randomly established in each nontreated control plot of the herbicide efficacy experiment (refer to section 3.2). Quadrats were marked with plastic stakes that were not displaced by seeding operations. Observation of dandelion emergence in fields occurred approximately every three to seven days until emergence from either rootstock or seed ceased for a period of at least 14 days (refer to Table 3.4.1 for timing of quadrat establishment and monitoring termination at each site). Newly emerged dandelion plants from either rootstock or

seed were tagged using coloured rings with a unique colour for each sampling date. Densities of dandelion originating from rootstock and dandelion originating from seed were recorded at each sampling date. Seedlings were deemed to be from rootstock if cotyledons were absent, there was substantial shoot biomass, a prominent mid vein was present on true leaves, and there was a large deep tap-root (Stewart-Wade et al., 2002). Dandelion plants were considered to have originated from seed if cotyledons were present and, when excavated, the entire tap-root was easily removed. Any dandelion plants observed on the first sampling date of the year were assumed to be dandelion plants that had over-wintered from the previous growing season and were not included in the cumulative emergence density counts. Dandelions, from either rootstock or seed, were not removed from within monitored quadrats and were not protected during seeding operations, but they were protected with non-permeable plastic sheets laid over all the quadrats at the time of in-crop herbicide application. During harvest operations, quadrats were marked with metal stakes that were flush with the ground surface and were replaced by plastic stakes after harvest was completed. As the growing season progressed and dandelion seedling densities increased dramatically, monitoring was limited to a 0.06 $m^{-2}$ sub-quadrat area within the original 0.25 $m^{-2}$ quadrat. The density of mature dandelion plants flowering (not number of flowering heads) was monitored when rootstock and seedling emergence counts were conducted (every 3 to 7 days throughout the growing season) in the 0.25 $m^{-2}$ quadrats established in the nontreated control plots (the same quadrats in which dandelion rootstock and seedling emergence was monitored).

Table 3.4.1. Timing of quadrat establishment and termination.

| | Site-years | | | | |
|---|---|---|---|---|---|
| Timing | Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
| Quadrat establishment | April 24 | April 24 | April 21 | April 29 | April 29 |
| Quadrat termination | Aug. 13 | Aug. 13 | Aug. 13 | Sept. 29 | Oct. 11 |

### 3.4.2 DANDELION AND WHEAT GROWTH

Dandelion rootstock and seedling density counts (plants per $m^{-2}$), and the number of plants flowering (not number of flowering heads) were measured throughout the course of the growing season at each site and in each treatment. Measurements were made: prior to the pre-seed herbicide application in the spring, prior to the in-crop herbicide application, post-in crop herbicide application (approximately at the boot stage of the wheat crop according to Zadok's growth stages for cereal crops), prior to crop harvest, and prior to fall herbicide application or tillage (post-harvest). Densities and number of dandelion plants flowering were determined in three 0.25 $m^{-2}$ quadrats placed randomly in each plot. As dandelion densities increased, specifically seedling densities, during the growing season, counting was facilitated by using 0.10 $m^{-2}$ instead of a 0.25 $m^{-2}$ quadrats. Differentiating between dandelion plants originating from either seed or rootstock was determined using the criteria and methodology described earlier. This criterion was employed at each density and biomass sampling time.

Dandelion aboveground shoot biomass and wheat aboveground shoot biomass was measured post-in crop herbicide application (at approximately the boot stage of the wheat crop), and dandelion aboveground shoot biomass was assessed again prior to fall herbicide application or tillage (post-harvest). Aboveground plant material

within three randomly placed 0.10 $m^{-2}$ quadrats was harvested in each plot using hand sickles. The harvested plant material was separated by species, dried at 80 C for 48 hours and weighed. In 2003, at both biomass sampling periods, only dandelions arising from rootstocks were harvested because dandelion seedlings were either absent or too small to harvest. In 2004 at the post in-crop herbicide sampling date only mature dandelion plants originating from rootstock were harvested because the true seedling were too small to harvest at this time. However, at the post-harvest sampling period in 2004, some dandelion plants arising from seed were large enough to be harvested.

### 3.4.3 SOIL THEMAL TIME

At each field site, hourly soil temperatures were monitored using self contained temperature data loggers[7]. One data logger was placed at a 2.5 cm depth in the soil in one of the nontreated control plots at each site. Data loggers were removed during planting operations for a period of a less than one hour and immediately replaced afterward. Since there is a strong association between soil temperature and air temperature (Reimer and Shaykewich, 1980), soil temperatures during the period when the data loggers were removed from the soil were interpolated from air temperature data.

Hourly soil temperatures were used to calculate a daily mean. Growing degree days (GDD) and cumulative GDD were calculated from summed daily mean soil temperatures beginning on the day of site establishment (Table 3.4.1), using the equations

$$GDD_{daily} = ([T_{max} + T_{min}]/2) -- T_{base} \quad \text{and}$$

$$\text{Cumulative GDD} = \sum_{i=1}^{n} GDD_{daily} \qquad [1]$$

where $T_{max}$ represents maximum daily soil temperature, $T_{min}$ refers to minimum daily soil temperature, and $T_{base}$ is the base temperature (0 C) (McMaster and Wilhelm, 1997). A base temperature of 0 C was employed because the base temperature required to instigate dandelion germination or emergence is not known (Stewart-Wade et al., 2002).

### 3.4.4 VOLUMETRIC SOIL MOISTURE

Volumetric soil moisture was measured for incremental depths of 0 to 2.5 cm, 2.5 to 5.0 cm, and 5.0 to 7.5 cm in the nontreated control plots at each site for each sampling date. The core method was employed in collecting the soil samples as described by McKeague (1978). This method involved preparing a smooth soil surface at the desired sampling depth. The soil surface was considered to be the soil and not the residue surface. All plant material and crop residues were removed with minimal soil disturbance. Samples were taken from between the crop rows. The soil surface was leveled and a vertical plane of soil was exposed by removing a wedge of soil. A copper cylinder with a diameter of 5 cm and a height of 2 cm was placed on the soil surface. The cylinder was pressed into the soil far enough to fill the cylinder and a sharp trowel was used to cut into the soil plane immediately below the cylinder, allowing it to be removed while keeping the soil sample intact. Nine samples were taken from each nontreated control plot (3 cylinder samples per depth). Samples taken at the same depth and from the same plot were pooled in plastic containers and

hermetically sealed. Soil samples were weighed and dried in an oven at 95 C for 48 hours. Dry weights were obtained and samples were discarded. Volumetric soil moisture was determined using the equation

$$Pv = Pw \times Dbm \quad [2]$$

where Pv is soil water content expressed on a percent volume basis (%), Pw is soil water content expressed on a percent weight basis, and Dbm is bulk density of the soil at field water content (g $cm^{-3}$) (McKeague, 1978). Volumetric soil moisture data is presented in Table 7.4.

### 3.4.5 AIR TEMPERATURE AND PRECIPIATION

Data for daily air temperature and precipitation amounts were obtained from Environment Canada weather stations located nearest to the experimental sites. For Oak Bluff 1 and Oak Bluff 2 the Environment Canada weather station located at the Winnipeg International Airport was used. For Carman, Roland, and Carman UM, data was obtained from the Environment Canada station located at the University of Manitoba Research Farm in Carman, Manitoba. Average monthly and long-term normal air temperature and precipitation is listed for Winnipeg, MB and Carman MB in Table 7.3.

## 3.5 SOIL SEEDBANK ANALYSIS

Soil samples were taken early in the spring of 2004 immediately following snow melt at all five site-years to determine dandelion seed dormancy and placement within the soil profile. A spring sampling period was selected as spring soil sampling periods are consistently more reliable than autumn sampling periods for predicting weed seedling densities in the soil seedbank (Forcella, 1992). Samples were taken in

each of the four replicates at incremental depths of 0 to 2.5 cm and 2.5 cm to 7.5 cm using a 6 cm diameter sampling cylinder. At the 2003 site-years, soil samples were taken in the nontreated control plots and in plots that received a fall applied treatment of 900 g a.e. $ha^{-1}$ glyphosate + 5 g a.i. $ha^{-1}$ of florasulam. This was the herbicide treatment deemed visually to be the most efficacious on dandelion in 2003. At the 2004 site-years, soil samples were only obtained from the nontreated control plots. The core method of sampling was employed as described in section 3.4.4. The sampling technique and prediction of weed seedling densities from buried seed reserves approximately followed the methods described by Forcella (1992). Ten soil samples per soil depth increment were obtained from each plot. Soil samples from the same depth, treatment, and replicate were pooled and mixed thoroughly. A greenhouse grow-out procedure was selected for its consistent correlation to weed seedling densities in the field (Cardina and Sparrow, 1996). The soil samples were placed in plastic trays with a length of 17 cm, and a width of 12.5 cm. Soil was added to the trays to a depth of approximately 2.5 cm. The samples were placed in a greenhouse with day/ night temperatures of 24/18 C, respectively, and kept moist for a three week period. Dandelion seedlings that emerged were identified, counted and removed. Following the three week period, the trays were frozen to -20 C, for 30 days. Trays were then removed from the freezer and placed in the greenhouse. This process was repeated three times. At the end of each grow-out period any emerged dandelion seedlings were identified and counted. Refer to Table 7.6 for results of the soil seedbank analysis study.

## 3.6 VISUAL PERCENT CONTROL EVALUATIONS

Dandelion control was determined visually by comparing the treated area of the plot with the untreated area between the plots using a rating scale of 0 (no control) to 100 (complete control or death). Dandelion control was visually estimated approximately one month after the spring herbicide application (hereafter referred to as early season) and again post crop harvest (hereafter referred to as late season). Control was based on an estimate of living biomass loss between treated and untreated areas.

## 3.7 WHEAT HARVEST

When wheat reached physiological maturity, the crop was harvested using small plot combines (Hege[8] in 2003 and a Wintersteiger [9] in 2004). Harvest samples were placed in a cloth bags on an ambient temperature drying bed for a minimum of three days. Samples were then sieved to remove chaff and the clean grain weighed. For each plot, sub-samples consisting of 100 g of clean grain were placed in paper envelopes and set in a drying oven for a minimum of 48 hours at 80 C. Samples were weighed and weights were then corrected to 14.5% moisture content.

## 3.8 STATISTICAL ANALYSIS

Cumulative dandelion emergence originating from either rootstock or seed was analyzed across all field sites, and mean separations were determined ($P \leq 0.05$) using Fisher's Protected LSD test (Steel et al., 1997). Emergence period was expressed as a cumulative percent of the total emergence. Emergence period was analyzed with nonlinear (logistic) regression analysis as a function of cumulative soil growing degree days (GDD) using the NLIN procedure in SAS[10] with iterations

derived by the Gauss-Newton algorithm. Soil GDD represented the temperature at 2.5 cm depth that was unique to each field. A logistic model was fitted to the data. This model was chosen for its simplicity, data-fitting ability, and biological meaning (Friesen et al., 1992). The model fitted was

$$Y = a/(1 + be^{-cx}) \quad [3]$$

Where $Y$ is the dependent variable (dandelion emergence), $x$ is the emergence percentage expressed in soil GDD (base temperature of 0 C), and e is the base of the natural logarithm. The parameters $a$, $b$, and $c$ are the nonlinear parameters estimated where $a$ is the estimated value of maximum emergence, $a/2$ is emergence at the inflection point, $(\ln b)/c$ is soil GDD at the inflection point, and $ac/4$ is the maximum rate of emergence at inflection (Bullied et al., 2003). Lack-of-fit $F$-tests, as described by Seefeldt et al. (1995), were used to test significance ($P \leq 0.05$) between parameters of models fitted to data. Coefficients of determination ($R^2$) were calculated as described by Kvalseth (1985) using the residual sum of squares value from overall model estimates. Soil GDD values required to obtain 50% emergence for dandelion plants emerging from either rootstock or seed were determined by the following equation

$$X = -\ln ((a - y)/yb)/c \quad [4]$$

Where $X$ is accumulated soil GDD; $y$ is the percentage of emergence; and $a$, $b$, and $c$ are the nonlinear parameters described for equation 3 (Bullied et al., 2003). To determine significance of site-year on number of emerged dandelion plants, originating from either seed or rootstock, and end of season seedling survivorship data was subjected to analysis of variance (ANOVA) using Proc GLM in SAS and

means separated using Fisher's Protected LSD at the 0.05 significance level (Gomez and Gomez, 1984).

Volumetric soil moisture for a given sampling date was analyzed using Proc GLM and means separated using Fisher's Protected LSD at $P \leq 0.05$. Sampling date values were averaged across depths for each individual site as depth was found to be insignificant. Results for volumetric soil moisture sampling are presented in Table 7.4.

In all instances where multiple samples were taken per plot, a sample mean was calculated prior to further statistical analysis. To statistically separate the influence of herbicide treatment on dandelion density (rootstock or seedling), dandelion biomass, wheat biomass, and wheat yield, data were subjected to analysis of variance (ANOVA) using Proc GLM in SAS and means separated using Fisher's Protected LSD test at the 0.05 significance level (Gomez and Gomez, 1984) to evaluate the effect of various fall and spring applied herbicides on dandelion control. Site was determined to be a significant factor for the majority of the response variables; therefore data were analyzed and reported for individual site-years. Residuals were tested for normality and homogeneity of variance prior to analysis using the UNIVARIATE procedure within SAS (Blackshaw et al., 2004). Means that had a value of zero were removed prior to statistical analysis to prevent biasing the estimation of variance for the other treatments (Finney, 1989). Data that did not meet the assumptions of ANOVA were subject to $\log_{10}$ transformation to improve normality of the error terms and homogeneity of variance of the error terms (Brainard et al., 2004; Gomez and Gomez, 1984). The $\log_{10}$ function is defined as $\log_{10}(x)$,

where x is equal to a value greater than zero. Gomez and Gomez (1984) suggested that prior to a $\log_{10}$ transformation all zero values in a data set be converted to a value of 0 + ¼(n), where n is equal to the smallest value in the data set. In most instances in this study, n was assigned a value of 1 and transformation of remaining zero values in the data set was $\log_{10}(0.25)$. Non-transformed means are presented in tables. A $\log_{10}(x+1)$ transformation was used as suggested by Gomez and Gomez (1984) to analyze dandelion aboveground biomass from rootstock assessed at the boot stage of the wheat crop for Oak Bluff 1 and Roland as the data had many small values.

Dandelion control was visually estimated for early season control and for late season control. An arcsine-square root transformation was used to improve homogeneity of variance of these data sets (Gomez and Gomez, 1984). For visually estimated late season control at Carman and Roland, the arcsine-square root transformation did not improve homogeneity of variance or normality, and so for these site-years non-transformed data were used in the analysis. For visually estimated early season control at Oak Bluff 1, Carman, and Carman UM, data met assumptions of ANOVA and transformations were not performed. Data from nontreated control plots were deleted prior to statistical analysis to stabilize variance because these visual weed control ratings are arbitrary zero values (Corbett et al., 2004). Untransformed means of early and late season dandelion control are presented in Tables 7.11 and 7.12.

## 4.0 RESULTS AND DISCUSSION

## 4.1 DANDELION ROOTSTOCK AND SEEDLING EMERGENCE

### 4.1.1 ROOTSTOCK EMERGENCE

Based on soil thermal time (soil GDD) the emergence period of dandelion plants originating from rootstock at all 5 site-years was most pronounced early in the growing season and diminished throughout the remainder of the year, with emergence of dandelion plants originating from rootstock at all five site-years commencing at less than 250 GDD (Figure 4.1). Fifty percent emergence of dandelion plants from rootstock ($E_{50}$) was achieved between 370 and 625 GDD with a mean $E_{50}$ of 429 GDD for all five site-years.

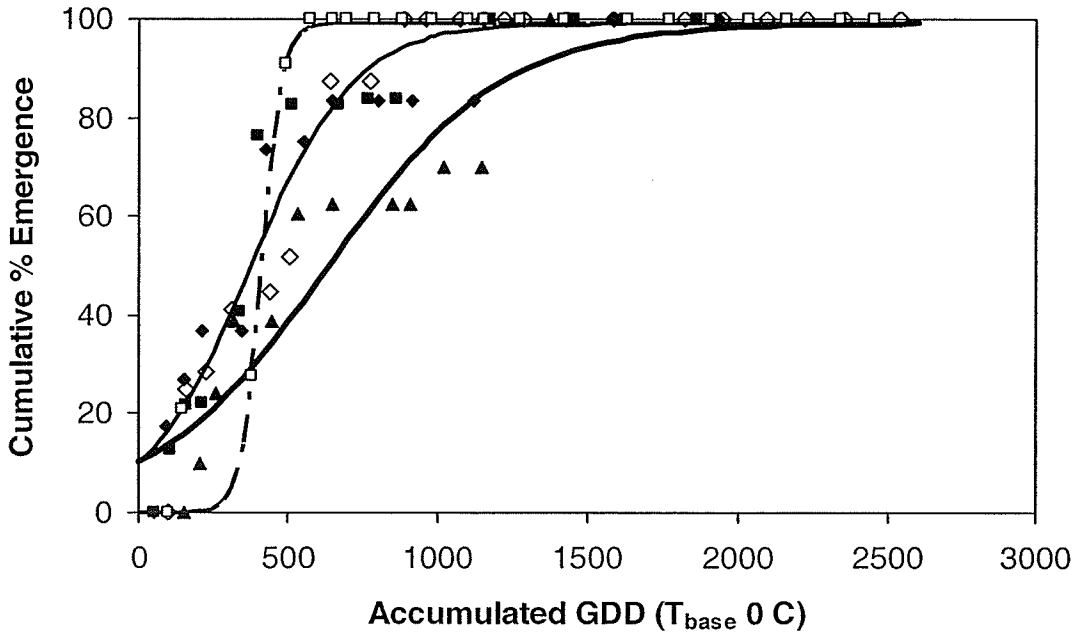



Figure 4.1. Emergence period of dandelion emerging from rootstock in the spring as related to soil growing degree days (accumulated GDD). Markers represent field data points for Oak Bluff 1 (♦), Oak Bluff 2 (■), Carman (▲), Roland (◇) and Carman UM (□). Lines represent fitted regression equations for Oak Bluff 1 and Oak Bluff 2, and Roland ( ___ ), Carman ( ——— ), and Carman UM (_ . _ . ). Based on the Lack-of-fit *F* test, a common regression curve was fitted for Oak Bluff 1, Oak Bluff 2 and Roland. For model see materials and methods. For parameter values see Table 4.1.1.

In some instances, differences in emergence period between site-years were statistically significant based on Lack-of-fit *F* tests at $P \leq 0.05$. The rapid emergence of dandelion plants from rootstock at the Carman UM site in 2004 (Figure 4.1) was likely a direct result of irregular emergence monitoring due to adverse environmental conditions at the beginning of the growing season. Because of an unusually early May snow storm, emergence monitoring at this site ceased for a period of approximately one month from the beginning until the end of May, a critical time for rootstock emergence. Other differences in emergence period between site-years may be attributed to differences among site-year infestations in biotype competitive ability (Froese and Van Acker, 2003), population age structure (Silversides, 1938), and orientation (Mann and Cavers, 1979), depth (Letchamo and Gosselin, 1996; Mann and Cavers, 1979), and size of vegetative fragments (Khan, 1969).

Table 4.1.1. Parameter estimates for models of the relationship between dandelion emergence from rootstock and accumulated growing degree days. Standard errors are in parentheses. For model see materials and methods.

| | Parameter Estimates | | | |
|---|---|---|---|---|
| Site-Year | a | b | c | Overall model $R^{2a}$ |
| Oak Bluff 1 | 99.1 (1.33) | 8.8 (1.44) | 0.006 (0.0005) | 0.95 |
| Oak Bluff 2 | ----------same regression as Oak Bluff 1---------- | | | |
| Carman | 99.1 (1.33) | 8.8 (1.44) | 0.004 (0.0003) | |
| Roland | ----------same regression as Oak Bluff 1---------- | | | |
| Carman UM | 99.1 (1.33) | 179977 (714463) | 0.030 (0.0101) | |

[a] One $R^2$ value is determined for the model fit for each site-year.

Among site-years there were order of magnitude differences in the mean number of dandelion plants per $m^{-2}$ from rootstock which emerged during the season

(ranging from 3.3 to 27.7 plants per $m^{-2}$). However, these differences were not statistically significant because of the high level of variability among plots within each site-year (Table 4.1.2).

Table 4.1.2. Mean number of dandelion plants (plants $m^{-2}$) from rootstock present on the first sampling date of the growing season and number of dandelion plants from rootstock (plants $m^{-2}$) which emerged during the remainder of the growing season (standard errors in parentheses)[a].

| Site | Year | Present at start of season[b] | Number emerged during growing season[c] |
|---|---|---|---|
| | | —— plants $m^{-2}$—— | —— plants $m^{-2}$—— |
| Oak Bluff 1 | 2003 | 30.3 (8.4) | 16.0 (4.1) |
| Oak Bluff 2 | 2003 | 37.0 (10.9) | 27.7 (12.8) |
| Carman | 2003 | 59.7 (22.1) | 22.3 (9.2) |
| Roland | 2004 | 20.0 (1.4) | 3.3 (1.5) |
| Carman UM | 2004 | 37.7 (12.0) | 6.7 (2.4) |
| $LSD_{0.05}$ | | ns | ns |

[a] First sampling date approximately at the end of April.
[b] Represents number of dandelion plants from rootstock per $m^{-2}$ present on the first sampling date of the growing season.
[c] Number of dandelion plants from rootstock emerged throughout the growing season after the first sampling date.

The majority of dandelion plants originating from rootstock were present on the first sampling date of the season (mid April) when GDD accumulation was under 100 GDD (Table 7.5). Approximately 65 to 83% of the dandelion plants from rootstock had over-wintered from the previous fall with 20 to nearly 60 dandelion plants per $m^{-2}$ (on average) present at sites on the first sampling date (Table 4.1.2). The number of dandelion plants emerging from rootstock during the season (except those already present in the spring) were relatively low. This may be related to the lack of spring tillage at all site-years. Tillage acts to fragment dandelion tap roots, and Mann and

Cavers (1979) found that dandelion (originating from rootstock) abundance in fields rises when the frequency of tillage operations are increased. However, Hudson (1955) noted that dandelion root pieces which exist below the depth of tillage and remain unfragmented will also regenerate freely provided that they are large enough.

### 4.1.2 SEEDLING EMERGENCE

Based on soil thermal time (soil GDD) the emergence period of dandelion plants originating from seed at all 5 site-years occurred later than for plants originating from rootstock. The emergence of dandelion plants originating from seed commenced at 650 GDD (Figure 4.2), or the first week of June (Table 7.5). In some instances, emergence periods were determined to be statistically different between site-years based on the Lack-of-fit *F* test at $P \leq 0.05$. At the Carman UM site in 2004, seedling emergence commenced at approximately 500 GDD (beginning of June) which was consistent with the observed onset of dandelion seedling emergence at all site-years in 2003. Seedling emergence at the Roland site in 2004 did not commence until 900 GDD. Differences in flowering patterns and peak flowering periods at Roland may be responsible for the delay in dandelion seedling emergence at this site-year (Figure 4.3).

The peak flowering period at Roland occurred late in comparison to the other site-years (e.g. peak flowering at Roland and Carman UM site-years were 650 and 350 GDD's, respectively) (Figure 4.3). Fluctuating environmental conditions and differences among dandelion biotypes can result in differences in flowering periodicity (Sterk and Luteijn, 1984), and the interaction of precipitation, day length, and temperature also influence flowering rhythms (Gray et al., 1973).

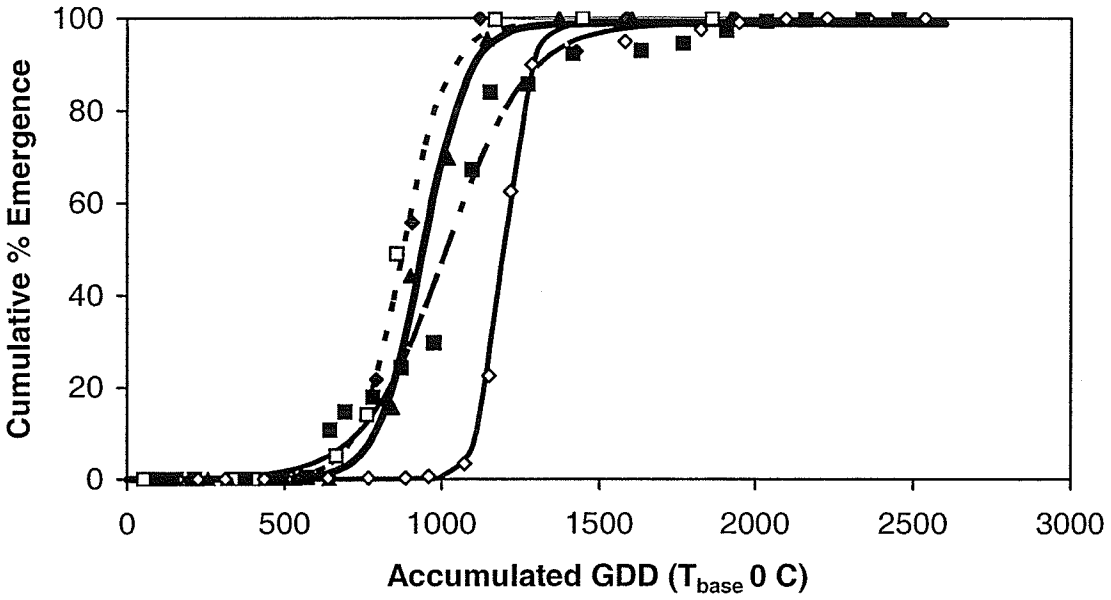



Figure 4.2. Emergence period of dandelion from seed as related to soil growing degree days (accumulated GDD). Markers represent field data points for Oak Bluff 1 (♦), Oak Bluff 2 (■), Carman (▲), Roland (◇), and Carman UM (□). Lines represent fitted regression equations for Oak Bluff 1 and Oak Bluff 2 ( - - -), Carman (——), Roland (———), and Carman UM (-·-·-). Based on the Lack-of-fit *F* test, a common regression curve was fitted for Oak Bluff 1 and Oak Bluff 2. For model see materials and methods. For parameter values see Table 4.1.3.

Table 4.1.3. Parameter estimates for models of the relationship between dandelion emergence from seed and accumulated growing degree days. Standard errors are in parentheses. For model see materials and methods.

| | Parameter Estimates | | | |
|---|---|---|---|---|
| Site-Year | a | b | c | Overall model $R^{2a}$ |
| Oak Bluff 1 | 98.9 (0.62) | 347370 (265957) | 0.015 (0.0009) | 0.99 |
| Oak Bluff 2 | ----------same regression as Oak Bluff 1 ---------- | | | |
| Carman | 98.9 (0.62) | 850491 (709508) | 0.015 (0.0009) | |
| Roland | 98.9 (0.62) | $2.24 \times 10^{13}$ ($6.33 \times 10^{13}$) | 0.026 (0.0024) | |
| Carman UM | 98.9 (0.62) | 2934 (1370) | 0.007 (0.0004) | |

[a] One $R^2$ value is determined for the model fit for each site-year.

Temperatures were below normal and precipitation levels were above average in May and June of 2004 (the normal flowering period for dandelion) (Table 7.3) and flowering at the 2004 site-years extended over a longer period (Figure 4.3), as cooler temperatures intensify the frequency and duration of flowering (Litsowki and Jackowska, 1965).

Among the 5 site-years the $E_{50}$ value for dandelion seedlings ranged from 878 to 1195 GDD with a mean $E_{50}$ value of 980 GDD (end of June). The thermal time required to achieve $E_{50}$ was greater in 2004 than 2003 (Figure 4.2), regardless of the timing of the onset of seedling emergence. This may have been a direct result of dandelion plants flowering over a longer period in 2004 (and hence producing more available seed throughout the season) versus 2003 (Figure 4.3). The optimum temperature for dandelion seed germination is approximately 23 C (Watson et al., 2001) and seeds tend to germinate when temperatures are high and light is not a limiting factor (Letchamo and Gosselin, 1996). Sub-optimal air temperatures experienced early in the 2004 growing season (Table 7.3) could have hampered seed germination and resulted in delayed seedling emergence.

The total number of dandelion seedlings that emerged at each site-year was high (ranging from 1055.7 to 2862.4 plants per $m^{-2}$) with site-year greatly influencing the total number of seedlings per $m^{-2}$ ($P \leq 0.05$) (Table 4.1.4). The 2003 site-years had significantly lower populations of dandelion seedlings when compared to the 2004 site-years with the exception of Oak Bluff 1 in 2003 and Roland in 2004 (Table 4.1.4).

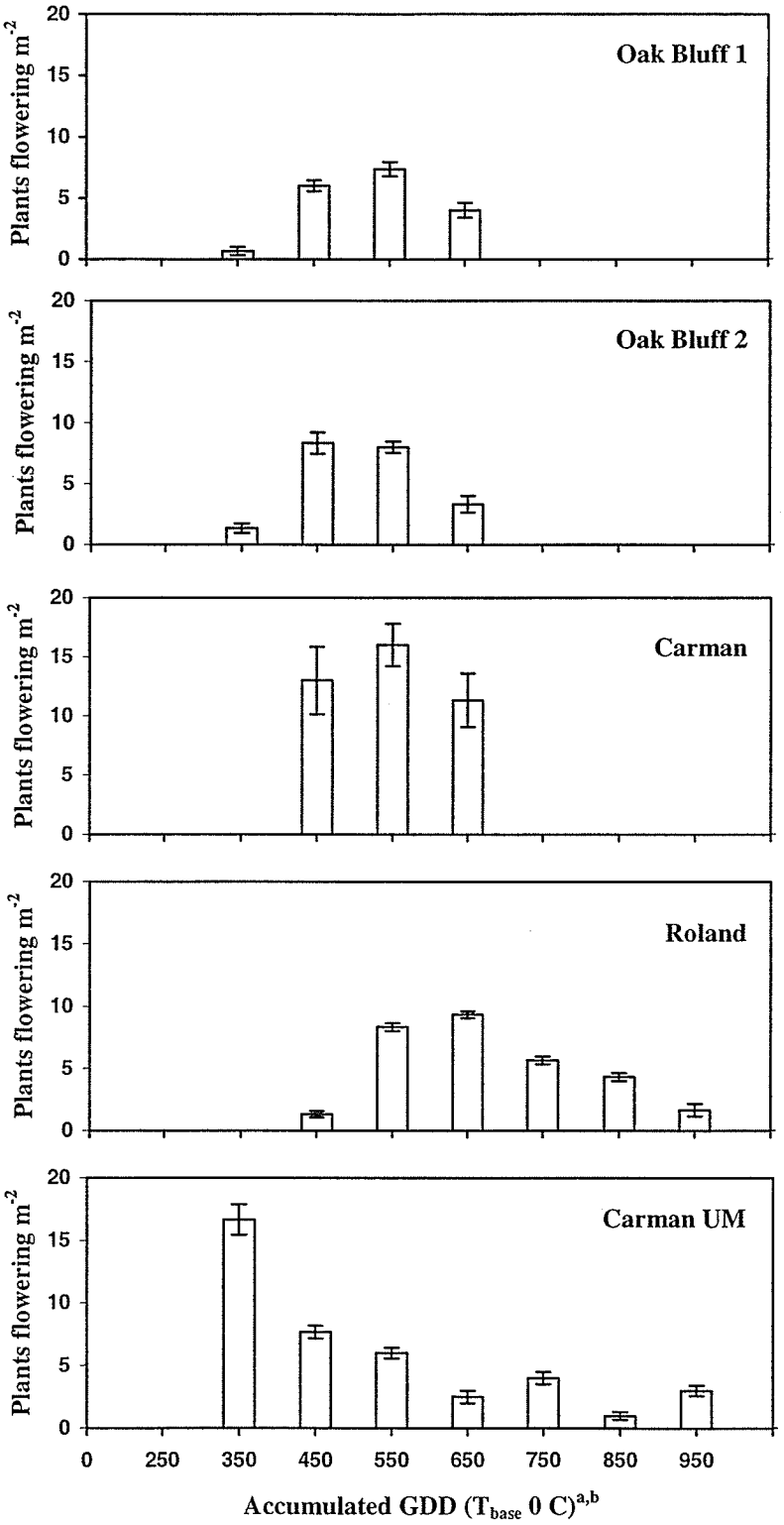



Figure 4.3. Mean number of dandelion plants flowering (plants per $m^{-2}$) for each site-year.

[a] GDD's arbitrarily divided into classes to represent dandelion flowering period.

[b] Number of plants flowering beyond 950 GDD were less than 1 dandelion plant per $m^{-2}$ and are not shown.

Table 4.1.4. Mean total density of dandelion seedlings (plants $m^{-2}$) which emerged during the growing season and percent dandelion seedling survivorship as assessed at the end of the growing season (standard errors in parentheses).

| Site | Year | Total seedlings[a] | End of season seedling survivorship[b] |
|---|---|---|---|
| | | plants $m^{-2}$ | % |
| Oak Bluff 1 | 2003 | 1545.7 (443.6) | 0.0 |
| Oak Bluff 2 | 2003 | 1083.3 (179.4) | 0.7 (0.3) |
| Carman | 2003 | 1055.7 (201.8) | 0.1 (0.1) |
| Roland | 2004 | 1914.8 (94.3) | 49.3 (5.2) |
| Carman UM | 2004 | 2862.4 (243.9) | 91.5 (1.6) |
| $LSD_{0.05}$ | | 800.0 | 7.1 |

[a] Mean total dandelion seedling density is a measure of the total number of dandelion seedlings emerged throughout the entire growing season
[b] Dandelion seedling survivorship in 2003 was assessed in early September. Dandelion seedling survivorship in 2004 was assessed in early October.

The variation in seedling densities between years may be attributed to differences among site-years in environmental conditions, since above average rainfall (typical of 2004) and moist soil conditions favour dandelion seedling recruitment. Dandelion seedling emergence was greatest when soils were near field capacity (Figure 4.2, Table 7.4), which is consistent with the findings of Boyd and Van Acker (2003). Field capacity (% volume) for clay soils (typical of Oak Bluff 1 and Oak Bluff 2) is generally near 40% and for sandy loam soils (Carman, Roland, Carman UM) it ranges from 15 to 30% (Peter Haluschak, Pedologist, Manitoba Agriculture, Food and Rural Initiatives, Winnipeg, MB, personal communication, 2005). In 2003 the termination of seedling emergence coincided with a decline in soil moisture levels in early July, when the weather became so dry that volumetric soil sampling was discontinued (Table 7.4). In both 2003 and 2004, there were relatively high soil

moisture levels at all site-years early in the growing season immediately following snow-melt, but dandelion seedling emergence was not observed at this time of the year due to a lack of dandelion seeds and accumulated GDD's. Perhaps, integrated soil moisture over the 7.5 cm soil depth is not a good indicator of soil moisture driving recruitment patterns of surface germinating seeds.

Dandelion seed generally does not form a persistent soil seedbank (Martinkova and Honek, 1997). Seedbank samples from early spring sampling at both sites in 2004 show the presence of a small seedbank. The seedbank accounted for less than 4% of the total number of emerged dandelion seedlings at Roland and Carman UM (Tables 4.1.4 and 4.1.5). This result suggests that the vast majority of the dandelion seedlings observed arose from seed that was disseminated during the given growing season. This result also supports the observed delay in seedling emergence until after the peak flower time of dandelion rootstock plants.

Table 4.1.5. Mean total number of dandelion seedlings emerging from early spring seedbank samples at the 2004 sites-years (standard errors in parentheses).

| Site | Year | Total seedlings[a] |
|---|---|---|
| | | —— plants $m^{-2}$ —— |
| Roland | 2004 | 63.8 (63.8)[b] |
| Carman UM | 2004 | 63.8 (63.8)[b] |

[a] Mean total dandelion seedling density is a measure of total number of dandelion seedlings emerged in cycle 1 of the greenhouse study.
[b] Standard errors are high due to 87.5% of samples containing no dandelion seedlings.

The in-crop herbicide application timing (applied on average at 717 GDD; mid June), consistently did not coincide with peak seedling emergence. At the time of the in-crop herbicide application, less than 10% of dandelion seedlings (on

average) had emerged (Figure 4.2), with the great majority of dandelion seedlings emerging after the time when in-crop (post-emergent) herbicides were applied. Dandelion is a simple perennial and population spread depends on seed spread and successful seedling emergence and survival (Solbrig and Simpson, 1974). Therefore, controlling dandelion seedlings is crucial for limiting population spread. The timing of in-crop herbicide applications makes this herbicidal control strategy ineffective for limiting the spread of dandelion populations. In addition, the in-crop herbicide application was applied too late to control the source of seedlings (mature flowering rosettes) (Figure 4.3).

Dandelion seedling survivorship was markedly different between the 2003 and 2004 site-years with low and high survivorship levels in 2003 and 2004, respectively (Table 4.1.4). The Carman UM site had the highest density of dandelion seedlings and the highest percentage of seedling survivorship, suggesting that dandelion seedling survivorship is not necessarily a function of density, contrary to the findings of Ford (1981, 1985), who found that mortality rates were generally higher at increased dandelion seedling densities. Differences in seedling survivorship were likely related to the cool temperatures and high soil moisture levels in the mid- to late summer of 2004 compared to 2003 (Tables 7.3 and 7.4). These conditions favour the proliferation of dandelion (Jackson, 1982). Dandelions in annual cropping systems behave similar to annuals by producing enormous amounts of seedlings (Légère and Samson, 1999). High seedling production rates can offset high mortality in years when environmental conditions are not conducive to dandelion seedling survival, especially in disturbed environments (annual cropping systems) where

density independent seedling mortality is high and resources are diverted towards seed production to ensure population proliferation and persistence (Mølgaard, 1977; Welham and Setter, 1998).

### 4.1.3 SUMMARY DISCUSSION

Dandelion seedling densities were greater than dandelion rootstock densities at all of the site-years possibly because dandelion seed production and emergence is favoured in reduced tillage cropping systems (Blackshaw et al., 1994; Chancellor, 1964; Légère and Samson, 1999; Mann and Cavers, 1979) and seed production is favoured in disturbed (agricultural) environments (Mølgaard, 1977). The correlation between total dandelion seedling density and total dandelion rootstock density was very weak (Table 7.7). There was no statistical difference in rootstock densities between the five site-years but there were very significant differences between the site-years in seedling densities. This suggests that rootstock densities are not the sole determinant of seedling densities, considering that mature rootstock plants are the source of seed. A weak correlation was also observed between total seedling density and the greatest number of plants flowering per $m^{-2}$ at a given point during the growing season (Table 7.8 and Figure 7.1). The lack of correlation between these two variables may be impacted to a greater extent by the age distribution of the dandelion rootstock population. Dandelion plants must reach a certain age limit, associated with the differentiation of a certain number of leaves to render the process of flowering possible (Listowski and Jackowska, 1965). A high density of juvenile dandelion plants (that have over-wintered on a rootstock) may contribute very little to dandelion seedling densities in their first seasons of growth when only leaf production

occurs (Longyear, 1918). Dandelion biotype competitive ability (Froese and Van Acker 2003; Solbrig and Simpson, 1977) and seed production is variable (Bostock and Benton, 1979; Roberts, 1936), depending on the size and vigor of the plant (Longyear, 1918), and these variables interact to yield differences in seedling densities. Dandelion is a wind disseminated species, thus seeds could travel a substantial distance away from the parent plant, causing a lack of correlation between seedling density and number of flowering plants in a given area, but research in Germany showed that 99.5% of the seeds produced by dandelion plants land within 10 m of the parent plant while only 0.05% of seeds are dispersed greater than 100 m and 0.014% of seeds are dispersed at distances greater than 1 km (Tackenberg et al., 2003).

The onset of dandelion seedling emergence is preceded by the availability and production of seed, adequate soil moisture, and sufficient accumulation of growing degree days. Seedling emergence generally commenced after crop canopy closure, high humidity inside the crop canopy, high temperatures, and moist soil conditions. In both 2003 and 2004 the first flush of dandelion seedlings was observed immediately (one to two days) after a heavy rainfall.

An immense proportion of the literature with reference to the period of dandelion rootstock and seedling recruitment is almost always expressed in terms of calendar days (months) in which seedling emergence peaks. Expressing recruitment timing in this manner is vague considering that emergence is governed by the prevailing environmental conditions in a given year and thermal time is a much better indicator of dandelion emergence period. The critical period for dandelion rootstock

emergence is early in the growing season when GDD accumulation is minimal. The period of interest for seedling emergence is later in the growing season (end of spring and summer), when flowering patterns, seed production rates, temperature, and soil moisture interact to determine dandelion seedling emergence period and survival.

## 4.2 HERBICIDE EFFICACY EXPERIMENT

For the majority of dependent variables, site-year was found to be significant, and thus site-years were analyzed individually. The post-harvest assessment period is most representative of season long dandelion control (Froese et al., 2005) and it was therefore used as the primary indicator of herbicide efficacy in this study.

### 4.2.1 DANDELION ROOTSTOCK DENSITY

For all five site-years, the highest density of dandelion plants originating from rootstock (ranging from 18.7 to 31.7 plants $m^{-2}$) were generally found in the nontreated controls. Generally, herbicide treatments reduced dandelion rootstock density although these densities were not necessarily significantly different than those found in the herbicide treated plots (Table 4.2.1). Fall applications (even numbered treatments) tended to provide a greater reduction in rootstock density than spring applications (odd numbered treatments with the exception of treatment 1; Table 4.2.1). Similarly, Froese et al. (2005) found that post-harvest applications of glyphosate were more effective on dandelion than pre-seeding, in-crop, or mid-season applications. Since zero mean values were omitted from the analysis to prevent biasing the estimation of variance (Finney, 1989), treatments resulting in mean values of 0 plants $m^{-2}$ were deemed to be biologically significant (Deubreuil et al., 1996). Generally, the most efficacious treatments, including those which resulted in "zero"

values, were those treatments that included fall applied glyphosate + florasulam (treatments 8, 10, 12) or a fall applied high rate of glyphosate (treatment 6) (Table 4.2.1). The fall applied treatment of 675 g a.e. $ha^{-1}$ of glyphosate + 7.5 g a.e. $ha^{-1}$ of florasulam (treatment 10) resulted in a density of 0 plants $m^{-2}$ at 4 of 5 site-years and was therefore considered to be the most efficacious treatment in terms of reducing post-harvest dandelion rootstock densities. Reduced control was observed when these same treatments were spring applied. At Carman in 2003, all the spring applied treatments, regardless of the rate or product used, were statistically the same as the nontreated control ($P \leq 0.05$), with the exception of the spring applied glyphosate + tribenuron (treatment 15) (Table 4.2.1). In most instances, for the high rate of glyphosate + florasulam or tribenuron (treatments 8 to 15) and the high rate of glyphosate alone (treatments 6 and 7), there were no significant differences between fall or spring application timings ($P \leq 0.05$). The fall applied florasulam + glyphosate (treatments 8,10, and 12) and the high rate of glyphosate (treatment 6) provided excellent control, reducing dandelion rootstock density in at least two of the site-years to 0 plants $m^{-2}$. The late season visual assessments (Table 7.12) support the post-harvest dandelion rootstock density results, although the visual assessments tend to attenuate the differences between the herbicide treatments. Density counts are a good indicator of herbicide efficacy as re-growth of dandelion plants from rootstock and small dandelion rosettes are not always properly assessed (observed) during visual evaluations. Generally, for the late season visual assessment, the glyphosate + florasulam or tribenuron treatments (treatments 8 to 15) provided better control than either the 450 or 675 g a.e. $ha^{-1}$ glyphosate treatments (treatments 2 to 5), regardless of application timing.

Table 4.2.1. Mean density of dandelion from rootstock (no. $m^{-2}$) assessed post-wheat harvest for each herbicide treatment and for each site year (standard errors in parentheses)[a].

| Trt. no. | Treatment[b] | Application dose | Application timing[c] | Site-years: Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
|---|---|---|---|---|---|---|---|---|
| | | g $ha^{-1}$[d] | | no. $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 31.7 (6.1) a | 23.6 (8.1) | 33.1 (12.3) a | 19.5 (2.7) a | 18.7 (2.0) a |
| 2 | Glyph | 450 | Fall | 11.4 (5.7) bc | 4.9 (4.9) | 1.6 (1.6) d | 4.9 (3.1) bc | 4.9 (2.1) cde |
| 3 | | | Spring | 11.4 (2.8) bc | 12.2 (3.6) | 22.0 (5.8) a | 5.7 (2.4) bc | 10.6 (3.4) bcd |
| 4 | Glyph | 675 | Fall | 0.0 | 6.5 (6.5) | 3.3 (3.3) d | 3.3 (2.3) bc | 1.6 (0.9) e |
| 5 | | | Spring | 16.3 (3.3) b | 15.5 (4.3) | 36.6 (13.5) a | 8.9 (1.6) b | 14.6 (6.0) ab |
| 6 | Glyph | 1350 | Fall | 0.0 | 0.0 | 0.0 | 2.4 (1.6) bc | 0.8 (0.8) e |
| 7 | | | Spring | 3.3 (2.3) cd | 9.8 (9.8) | 20.3 (10.2) abc | 1.6 (0.9) c | 7.3 (2.0) bcde |
| 8 | Glyph + Flor | 450 + 5 | Fall | 0.0 | 7.3 (7.3) | 0.0 | 5.7 (4.7) bc | 4.0 (2.4) cde |
| 9 | | | Spring | 7.3 (4.3) bcd | 8.9 (5.8) | 35.0 (9.2) a | 5.7 (3.6) bc | 13.8 (2.8) ab |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 0.0 | 0.0 | 0.0 | 0.8 (0.8) c | 0.0 |
| 11 | | | Spring | 8.1 (2.1) bcd | 8.1 (5.4) | 25.2 (7.9) a | 5.7 (1.6) bc | 11.4 (3.9) abc |
| 12 | Glyph + Flor | 900 + 5 | Fall | 0.8 (0.8) d | 0.0 | 0.0 | 2.4 (2.4) bc | 0.0 |
| 13 | | | Spring | 6.5 (4.0) bcd | 13.8 (5.5) | 22.8 (13.8) ab | 1.6 (0.9) c | 3.3 (1.3) de |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 1.6 (0.9) cd | 2.4 (2.4) | 2.4 (1.6) cd | 1.6 (0.9) c | 1.6 (1.6) e |
| 15 | | | Spring | 8.1 (4.3) bcd | 13.8 (5.0) | 9.8 (7.7) bcd | 5.7 (2.8) bc | 8.1 (2.8) bcde |

[a] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$.
[b] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[c] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[d] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

Table 4.2.2. Mean density of dandelion from rootstock (no. $m^{-2}$) assessed at the boot stage[a] of the wheat crop for each herbicide treatment and for each site year (standard errors in parentheses)[b].

| Trt. no. | Treatment[c] | Application dose | Application timing[d] | Site-years: Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
|---|---|---|---|---|---|---|---|---|
| | | g $ha^{-1}$[e] | | no. $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 24.4 (0.9) a | 34.2 (8.7) a | 18.7 (4.5) abc | 17.9 (2.8) | 38.2 (8.9) |
| 2 | Glyph | 450 | Fall | 10.6 (3.8) bc | 12.2 (5.7) abc | 18.7 (7.1) abc | 10.6 (4.9) | 9.8 (5.8) |
| 3 | | | Spring | 16.3 (4.8) b | 12.2 (3.4) abc | 33.4 (8.3) a | 8.1 (7.1) | 9.8 (4.8) |
| 4 | Glyph | 675 | Fall | 7.3 (2.8) cd | 2.4 (2.4) cd | 6.5 (6.5) bc | 4.1 (3.1) | 9.8 (4.6) |
| 5 | | | Spring | 4.9 (2.1) cd | 8.1 (2.8) abcd | 23.6 (8.3) ab | 6.5 (4.4) | 15.5 (7.4) |
| 6 | Glyph | 1350 | Fall | 0.0 | 6.5 (5.5) bcd | 10.6 (6.4) bc | 0.0 | 4.9 (3.1) |
| 7 | | | Spring | 4.9 (3.9) cd | 4.1 (3.1) bcd | 20.3 (7.4) ab | 2.4 (2.4) | 8.1 (4.9) |
| 8 | Glyph + Flor | 450 + 5 | Fall | 0.0 | 0.8 (0.8) d | 1.6 (1.6) c | 1.6 (1.6) | 10.6 (3.6) |
| 9 | | | Spring | 6.5 (3.0) cd | 4.1 (3.1) bcd | 21.2 (12.4) ab | 7.3 (6.3) | 9.8 (2.7) |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 0.0 | 0.8 (0.8) d | 0.0 | 4.9 (4.9) | 4.1 (3.1) |
| 11 | | | Spring | 6.5 (2.7) cd | 0.0 | 21.1 (7.8) ab | 4.1 (1.6) | 4.9 (1.6) |
| 12 | Glyph + Flor | 900 + 5 | Fall | 0.0 | 0.0 | 1.6 (1.6) c | 0.0 | 4.9 (2.8) |
| 13 | | | Spring | 2.4 (2.4) d | 4.9 (3.1) bcd | 8.1 (4.9) bc | 0.8 (0.8) | 5.7 (2.0) |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 1.6 (0.9) d | 0.0 | 0.8 (0.8) c | 0.0 | 1.6 (1.6) |
| 15 | | | Spring | 1.6 (1.6) d | 2.4 (2.4) cd | 9.8 (6.2) bc | 0.0 | 8.9 (5.2) |

[a] Assessed approximately at the boot stage of the wheat crop (according to Zadock's growth stages for cereal crops).
[b] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$.
[c] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[d] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[e] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

For dandelion rootstock density assessed mid-season (at the boot stage of the wheat crop) the fall treatments of glyphosate in combination with florasulam or tribenuron (treatments 8, 10, 12, 14) and the high rate of fall applied glyphosate (treatment 6) eliminated dandelion plants originating from rootstock (0 plants $m^{-2}$) in at least one of the five site-years (Table 4.2.2). In some instances the spring applied treatments also reduced dandelion density to 0 plants $m^{-2}$, specifically the 675 g a.e. $ha^{-1}$ glyphosate + 7.5 g a.i. $ha^{-1}$ florasulam (treatment 11) at Oak Bluff 2, and the 450 g a.e. $ha^{-1}$ glyphosate + 5 g a.i. $ha^{-1}$ tribenuron (treatment 15) at Roland (Table 4.2.2). At Oak Bluff 1 in 2003, all herbicide treated plots were statistically different ($P \leq 0.05$) from the nontreated control, which is consistent with observations made post-harvest at this site-year. This trend was also observed at Oak Bluff 2 with the exception of the 450 g a.e. $ha^{-1}$ of glyphosate applied in the fall and spring (treatments 2 and 3) and the 675 g a.e. $ha^{-1}$ rate of glyphosate applied in the spring only (treatment 5). At Roland in 2004, treatments 6, 12, 14, and 15 reduced rootstock density to 0 plants $m^{-2}$ (Table 4.2.2).

Under ideal conditions (temperatures near 20 C and weeds actively growing), glyphosate + florasulam injury symptoms generally occur within 7 to 10 days after the herbicide application but under non-ideal conditions (temperatures near 0 C, frost conditions), control may only be visible after a period of 6 to 8 weeks (DowAgro Sciences, 2004). Likewise, injury symptoms with tribenuron usually appear over one to two weeks after the initial application (WSSA, 1994). Environmental conditions preceding and following both the fall and spring herbicide application periods were not ideal, with cool temperatures and above average precipitation at these times

(Table 7.3). Given these conditions, the length of time from spring herbicide application to the mid-season assessment (6 to 8 weeks) may have been insufficient to allow for visually distinct differences in control between the spring treatments. Dandelion rootstock density assessed post harvest was positively correlated to dandelion rootstock density at the mid-season assessment time in both 2003 (0.63) and 2004 (0.53) (Tables 7.9 and 7.10), as would be expected since dandelion emergence from rootstock had ended by mid summer (boot stage of the wheat crop) (section 4.1.1).

### 4.2.2 DANDELION SEEDLING DENSITY

For all five site-years, herbicide treatment did not significantly affect dandelion seedling densities as assessed post-harvest (Table 4.2.3). Site-year itself had the most significant effect on seedling densities. In 2003, conditions were extremely hot and dry while in 2004 conditions were cool and moist throughout the entire growing season (Tables 7.3 and 7.4). The conditions in 2004 seemed to favour seedling survival (see Table 4.1.4). In 2003, dandelion seedlings were generally not present post-harvest (Table 4.2.3). Higher densities of dandelion seedlings were present at Oak Bluff 2 (ranging from 8.1 to 53.7 seedlings $m^{-2}$) than at the other sites in 2003 (Table 4.2.3). Substantial amounts of crop residue present on the soil surface throughout the entire growing season at this site may have maintained a moist, cool soil surface which would have been more favourable for seedling survival. At this site, the highest seedling densities were found in the herbicide treatments and the lowest densities in the nontreated control. Untreated strips of mature dandelion plants, adjacent to the plots, flowered freely and set seed during the growing season.

Dandelion is a wind disseminated species with seeds traveling distances of 2.5 m (Sheldon and Burrows, 1973) to 1 km (Tackenberg et al., 2003). Therefore, the influence of the herbicide treatments on controlling seedlings and the source of those seedlings (mature flowering plants) may have been masked by the untreated strips and the wind disseminated nature of this species. Dandelion seedling density, assessed post-harvest at the 2004 site-years, was prolific with densities at Roland ranging from 95.8 to 209.2 seedlings $m^{-2}$ and Carman UM averaging between 237.5 to 722.9 seedlings $m^{-2}$ (Table 4.2.3). The higher densities at Carman UM may have also been due to higher residue levels (visual observation). The consistency of flowering mature dandelion plants during the entire growing season (Tables 7.13, 7.14, 7.15, 7.16, and 7.17), and a greater number of plants flowering in the nontreated control plots (Figure 4.3) may have also contributed to the high seedling densities at Carman UM. It is interesting to note that the greatest number of plants flowering at Carman UM were those located in the spring herbicide treatments (Tables 7.13, 7.14, 7.15, 7.16, and 7.17) but because dandelion seed is so effectively dispersed by wind, high numbers of flowering plants did not necessarily translate into higher seedling densities within those treatments (Table 4.2.3). At both sites in 2004, the highest post-harvest seedling densities were found in the nontreated control.

For 3 of 5 site–years, herbicide treatment had no significant effect on dandelion seedling density assessed mid-season (Table 4.2.4). At Oak Bluff 1 and Roland, where herbicide treatment did significantly affect dandelion seedling densities, the seedling densities in the majority of the herbicide treatments were statistically similar.

Table 4.2.3. Mean dandelion seedling density (no. $m^{-2}$) assessed post-wheat harvest for each herbicide treatment and for each site year (standard errors in parentheses)[a].

| Trt. no. | Treatment[b] | Application dose | Application timing[c] | Site-years | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
| | | g $ha^{-1}$[d] | | no. $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 0.0 | 8.1 (3.1) | 0.8 (0.8) | 209.2 (31.2) | 722.9 (312.0) |
| 2 | Glyph | 450 | Fall | 0.8 (0.8) | 20.3 (12.1) | 0.8 (0.8) | 116.5 (26.4) | 237.5 (77.5) |
| 3 | | | Spring | 0.0 | 23.6 (12.8) | 0.8 (0.8) | 139.0 (41.7) | 291.7 (82.6) |
| 4 | Glyph | 675 | Fall | 0.0 | 11.4 (4.7) | 0.0 | 100.8 (35.7) | 385.4 (34.6) |
| 5 | | | Spring | 0.0 | 9.8 (7.7) | 4.0 (3.0) | 156.4 (19.5) | 320.8 (28.2) |
| 6 | Glyph | 1350 | Fall | 0.0 | 16.3 (9.8) | 0.8 (0.8) | 155.4 (53.0) | 329.2 (31.6) |
| 7 | | | Spring | 0.0 | 34.2 (26.6) | 0.0 | 128.4 (46.9) | 318.8 (40.0) |
| 8 | Glyph + Flor | 450 + 5 | Fall | 0.0 | 17.0 (5.8) | 0.8 (0.8) | 118.0 (37.5) | 300.0 (41.8) |
| 9 | | | Spring | 0.0 | 21.5 (10.7) | 0.0 | 138.3 (22.0) | 339.6 (31.25) |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 0.0 | 14.6 (6.6) | 0.0 | 109.9 (43.2) | 404.2 (92.5) |
| 11 | | | Spring | 0.0 | 17.9 (2.8) | 0.8 (0.8) | 158.7 (41.4) | 402.1 (89.0) |
| 12 | Glyph + Flor | 900 + 5 | Fall | 0.0 | 27.6 (3.9) | 2.4 (0.8) | 128.8 (29.4) | 354.2 (99.9) |
| 13 | | | Spring | 0.0 | 53.7 (20.2) | 0.0 | 198.8 (42.4) | 360.4 (110.2) |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 0.0 | 33.3 (17.3) | 2.4 (1.6) | 95.8 (21.7) | 412.5 (132.0) |
| 15 | | | Spring | 0.0 | 35.8 (17.7) | 0.8 (0.8) | 158.3 (57.6) | 252.1 (45.3) |

[a] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$.
[b] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[c] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[d] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

Table 4.2.4. Mean dandelion seedling density (no. $m^{-2}$) assessed at the boot stage[a] of the wheat crop for each herbicide treatment and for each site year (standard errors in parentheses)[b].

| Trt. no. | Treatment[c] | Application dose | Application timing[d] | Site-years: Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
|---|---|---|---|---|---|---|---|---|
| | | g $ha^{-1}$[e] | | no. $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 640.1 (273.8) a | 244.0 (166.1) | 21.2 (6.6) | 63.1 (21.4) a | 1006.7 (442.6) |
| 2 | Glyph | 450 | Fall | 109.0 (7.6) b | 116.3 (27.7) | 12.2 (2.8) | 20.0 (11.6) bc | 558.8 (292.3) |
| 3 | | | Spring | 95.2 (20.2) bcd | 144.8 (39.2) | 12.8 (5.5) | 16.2 (4.4) bc | 818.2 (282.9) |
| 4 | Glyph | 675 | Fall | 137.5 (51.6) bc | 136.6 (44.3) | 25.0 (5.9) | 7.3 (1.0) cd | 930.5 (177.9) |
| 5 | | | Spring | 88.7 (30.2) bcdef | 78.9 (36.0) | 17.9 (6.3) | 9.7 (2.7) bcd | 614.9 (103.3) |
| 6 | Glyph | 1350 | Fall | 91.9 (29.2) bcde | 125.3 (75.3) | 11.7 (2.3) | 13.7 (2.0) bc | 849.1 (242.1) |
| 7 | | | Spring | 41.5 (11.1) bcdef | 151.3 (104.8) | 13.2 (5.8) | 11.7 (1.6) bcd | 713.3 (171.7) |
| 8 | Glyph + Flor | 450 + 5 | Fall | 38.9 (11.3) cdef | 104.9 (28.8) | 22.5 (4.4) | 8.7 (1.2) bcd | 1001.2 (224.8) |
| 9 | | | Spring | 32.5 (14.1) f | 158.6 (55.2) | 20.7 (4.9) | 14.8 (1.1) bc | 659.6 (118.9) |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 29.3 (4.8) ef | 122.0 (53.8) | 18.2 (4.5) | 6.7 (2.2) d | 890.6 (52.3) |
| 11 | | | Spring | 29.3 (8.8) ef | 97.6 (16.5) | 15.4 (6.1) | 11.7 (1.9) bcd | 732.8 (191.0) |
| 12 | Glyph + Flor | 900 + 5 | Fall | 35.8 (13.1) def | 122.4 (58.3) | 15.5 (3.3) | 11.8 (3.5) bcd | 504.3 (147.7) |
| 13 | | | Spring | 83.0 (30.0) bcdef | 136.6 (67.4) | 27.2 (5.5) | 21.4 (5.4) ab | 471.7 (157.4) |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 48.0 (10.4) bcdef | 192.8 (67.3) | 17.3 (4.2) | 9.7 (3.0) bcd | 1192.4 (213.0) |
| 15 | | | Spring | 86.2 (36.9) bcdef | 167.5 (45.6) | 14.9 (5.4) | 8.8 (1.0) bcd | 558.8 (147.9) |

[a] Assessed approximately at the boot stage of the wheat crop (according to Zadock's growth stages for cereal crops).
[b] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$.
[c] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[d] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[e] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

However, at Oak Bluff 1 and Roland, all herbicide treatments, with the exception of the spring applied 900 g a.e. $ha^{-1}$ glyphosate + 5 g a.i. $ha^{-1}$ florasulam (treatment 13) at Roland, resulted in a significant decline in seedling densities versus the nontreated controls (Table 4.2.4).

There was an overall reduction in dandelion seedling density from the mid-season assessment timing to the post-harvest assessment date at all sites with the exception of Roland (Table 4.2.3 and 4.2.4). The lag in flowering period at this site-year, as observed in the nontreated control (Figure 4.3), may be responsible for this result. The mid-season assessment date occurred on July 13 (JDay 195) which corresponds to approximately 1200 GDD (Table 7.5). Mature dandelion plants at Roland were still flowering at 950 GDD. The time for seed maturation ranges from 8 to 12 days (Beach, 1939; Gray et al., 1973) and germination of dandelion seed generally occurs within one and a half months after dispersal (Ogawa, 1978). Therefore, seed from dandelion plants that were flowering in early June at Roland (peak flowering at 650 GDD) may have only germinated and emerged in early August (2 months later), after the mid-season assessment time.

The residual effect of the spring applied florasulam + glyphosate treatments (treatments 9, 11, and 13) was insufficient to provide dandelion seedling control as measured at both assessment periods. Florasulam has a half life of only 2 to 18 days (depending upon the prevailing environmental conditions) (Alberta Agriculture, Food, and Rural Development, 2004) and the peak emergence of dandelion seedlings seems to occur long after the dissipation of florasulam residue in the soil. The in-crop

herbicide application (applied in mid June) consistently took place before dandelion seedling emergence, and hence had no effect on dandelion seedling density. In 2004 a substantial portion of the dandelion seedlings observed within the growing season went on to produce fall rosettes that had the ability to over-winter and produce dandelion plants that could flower, set seed, and contribute to population spread in the following year.

### 4.2.3 DANDELION ROOTSTOCK ABOVEGROUND BIOMASS

For all site-years, dandelion rootstock aboveground biomass assessed post-harvest was greatest in the nontreated controls (ranging from 9.2 g $m^{-2}$ at Carman to 141.6 g $m^{-2}$ at Carman UM) (Table 4.2.5). Among site-years, rootstock aboveground biomass was greatest at Carman UM, perhaps because the cool wet summer in 2004 was conducive to dandelion survival and aboveground biomass production. The summer of 2003 was hot and dry (Tables 7.3 and 7.4), resulting in the senesce of dandelion leaves (visual observation). These hot and dry conditions may have masked the influence of herbicide treatment on dandelion aboveground biomass production at the post-harvest assessment period. All herbicide treatments significantly reduced dandelion aboveground biomass when compared to the nontreated controls at Roland, and Carman UM. For 4 of the 5 site-years, 675 g a.e. $ha^{-1}$ of glyphosate + 7.5 g a.i. $ha^{-1}$ of florasulam applied in the fall (treatment 10) provided superior efficacy, reducing dandelion aboveground biomass to 0 g $m^{-2}$ (Table 4.2.5). At Oak Bluff 1 and Carman UM the fall applied herbicide treatments significantly reduced dandelion aboveground biomass when compared to their spring applications ($P \leq 0.05$), with the exception of the 450 g a.e. $ha^{-1}$ glyphosate treatments (treatments 2 and 3) and the tribenuron +glyphosate treatments (treatments 14 and 15) at Carman UM (Table 4.2.5).

Table 4.2.5. Mean biomass of dandelion from rootstock (g $m^{-2}$) assessed post-wheat harvest for each herbicide treatment and for each site year (standard errors in parentheses)[a].

| Trt. no. | Treatment[b] | Application dose | Application timing[c] | Site-years: Oak Bluff 1 2003 | Oak Bluff 2[d] 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
|---|---|---|---|---|---|---|---|---|
| | | g $ha^{-1}$[e] | | g. $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 27.0 (3.5) a | 32.0 (9.4) a | 9.2 (3.3) a | 48.4 (6.3) a | 141.6 (28.4) a |
| 2 | Glyph | 450 | Fall | 3.6 (2.2) cd | 2.0 (2.0) b | 0.1 (0.1) d | 3.9 (2.8) bcde | 9.5 (3.8) ef |
| 3 | | | Spring | 9.6 (1.5) ab | 5.3 (2.1) b | 4.5 (1.3) ab | 8.5 (3.8) bc | 31.4 (14.8) bcde |
| 4 | Glyph | 675 | Fall | 0.0 | 2.2 (2.2) b | 0.5 (0.5) cd | 2.3 (2.0) bcde | 1.5 (1.1) ef |
| 5 | | | Spring | 10.2 (3.0) ab | 6.1 (3.0) b | 3.2 (0.7) ab | 8.3 (3.4) bc | 48.7 (19.1) bc |
| 6 | Glyph | 1350 | Fall | 0.0 | 0.0 | 0.0 | 1.1 (0.6) bcde | 0.4 (0.4) f |
| 7 | | | Spring | 1.9 (1.2) cd | 1.0 (1.0) b | 0.0 | 2.6 (1.5) bcde | 43.4 (15.6) bc |
| 8 | Glyph + Flor | 450 + 5 | Fall | 0.0 | 2.6 (2.6) b | 0.0 | 0.1 (0.1) e | 12.8 (7.4) ef |
| 9 | | | Spring | 8.6 (6.3) bc | 5.6 (3.1) b | 1.7 (0.7) bc | 4.9 (2.1) bc | 56.6 (12.3) b |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 0.0 | 0.0 | 0.0 | 0.4 (0.4) de | 0.0 |
| 11 | | | Spring | 7.5 (3.4) bc | 2.1 (1.7) b | 3.0 (0.8) ab | 4.9 (2.1) bcd | 46.7 (6.7) bc |
| 12 | Glyph + Flor | 900 + 5 | Fall | 0.2 (0.2) d | 0.0 | 0.0 | 1.2 (1.2) cde | 0.0 |
| 13 | | | Spring | 9.2 (5.3) bc | 7.7 (3.5) ab | 0.3 (0.2) d | 1.7 (1.1) bcde | 13.6 (7.5) def |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 0.2 (0.1) d | 1.0 (1.0) b | 0.1 (0.1) d | 3.7 (2.2) bcde | 3.0 (3.0) ef |
| 15 | | | Spring | 7.2 (3.4) bc | 7.2 (2.9) ab | 0.5 (0.5) cd | 10.4 (8.9) bc | 20.4 (7.8) cdef |

[a] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$.
[b] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[c] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[d] Data did not quite meet Fisher's Protected LSD criteria ($P \leq 0.05$). LSD rankings still presented as P-value for treatment was 0.0565.
[e] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

Table 4.2.6. Mean biomass of dandelion from rootstock (g $m^{-2}$) assessed at the boot stage[a] of the wheat crop for each herbicide treatment and for each site year (standard errors in parentheses)[b].

| Trt. no. | Treatment[c] | Application dose | Application timing[d] | Site-years: Oak Bluff 1[e] 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland[e] 2004 | Carman UM 2004 |
|---|---|---|---|---|---|---|---|---|
| | | g $ha^{-1}$[f] | | g $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 100.8 (12.1) a | 240.0 (90.1) a | 145.2 (29.6) a | 109.7 (14.6) a | 243.1 (44.6) a |
| 2 | Glyph | 450 | Fall | 2.0 (1.1) b | 1.9 (1.2) cd | 7.6 (2.2) bc | 14.3 (7.4) b | 13.0 (9.3) b |
| 3 | | | Spring | 11.3 (6.3) b | 14.3 (7.3) b | 36.0 (18.6) b | 4.7 (4.5) bc | 10.0 (6.0) b |
| 4 | Glyph | 675 | Fall | 5.6 (3.0) b | 0.8 (0.8) d | 1.4 (1.4) bc | 5.3 (5.3) bc | 9.6 (2.4) b |
| 5 | | | Spring | 0.7 (0.4) b | 8.6 (4.0) bc | 14.7 (7.1) bc | 7.6 (7.6) bc | 20.4 (9.5) b |
| 6 | Glyph | 1350 | Fall | 0.0 | 4.0 (4.0) cd | 7.4 (6.7) bc | 0.0 | 4.9 (4.8) bc |
| 7 | | | Spring | 6.9 (6.6) b | 0.4 (0.2) d | 6.2 (2.5) bc | 0.8 (0.8) bc | 24.8 (16.7) b |
| 8 | Glyph + Flor | 450 + 5 | Fall | 0.0 | 0.1 (0.1) d | 0.5 (0.5) c | 1.1 (1.1) bc | 6.1 (3.5) bc |
| 9 | | | Spring | 0.6 (0.3) b | 6.4 (5.4) bcd | 5.6 (2.0) bc | 3.3 (2.7) bc | 19.0 (12.7) b |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 0.0 | 0.2 (0.2) d | 0.0 | 7.0 (7.0) bc | 0.1 (0.1) c |
| 11 | | | Spring | 0.7 (0.4) b | 0.0 | 29.5 (25.3) bc | 1.6 (0.9) bc | 31.1 (19.2) b |
| 12 | Glyph + Flor | 900 + 5 | Fall | 0.0 | 0.0 | 0.2 (0.2) c | 0.0 | 1.6 (1.2) bc |
| 13 | | | Spring | 0.4 (0.4) b | 1.8 (1.4) cd | 0.7 (0.5) c | 0.1 (0.1) c | 8.6 (6.1) bc |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 0.1 (0.1) b | 0.0 | 0.5 (0.5) c | 0.0 | 0.0 |
| 15 | | | Spring | 1.5 (1.5) | 0.2 (0.2) d | 10.0 (7.6) bc | 0.0 | 24.9 (15.1) b |

[a] Assessed approximately at the boot stage of the wheat crop (according to Zadock's growth stages for cereal crops).
[b] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$.
[c] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[d] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[e] A $\log_{10}(x+1)$ transformation was used.
[f] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

Generally, for all site-years the fall applied glyphosate + florasulam treatments (treatments 8, 10, and 12) and the high rate fall applied glyphosate treatment (treatment 6) reduced aboveground biomass to 0 g $m^{-2}$. The biggest differences in effect between fall and spring treatments were seen at Carman UM where, for example, the fall applied rate of 675 g a.i. $ha^{-1}$ of glyphosate (treatment 4) resulted in a 40 fold greater reduction in dandelion aboveground biomass compared to the same rate applied in the spring (treatment 5) (Table 4.2.5).

Plots that were treated with herbicide, regardless of the rate or product used, significantly reduced dandelion aboveground biomass production (assessed mid-season) compared to the nontreated controls at all site-years (Table 4.2.6). The reductions in dandelion aboveground biomass in the herbicide treated plots versus the nontreated controls were quite substantial. For example, at Oak Bluff 2 there was over a hundred-fold difference observed in dandelion aboveground biomass production between the fall applied low rate of glyphosate (treatment 2) versus the nontreated control. Overall, the fall applied herbicide treatments decreased dandelion aboveground biomass to a greater degree than the spring applied treatments. For the mid-season assessment, the fall applied 900 g a.e. $ha^{-1}$ glyphosate + 5 g a.i. $ha^{-1}$ florasulam (treatment 12) and the fall applied 450 g a.e. $ha^{-1}$ glyphosate + 7.5 g a.i. $ha^{-1}$ tribenuron (treatment 14) were the most efficacious treatments reducing dandelion aboveground biomass to 0 g $m^{-2}$ at 3 out of the 5 site-years (Table 4.2.6). There were differences in dandelion aboveground biomass production between the sites in the nontreated controls (range of 100.8 g $m^{-2}$ to 243.1 g $m^{-2}$) (Table 4.2.6). These differences could be attributed to many factors which affect dandelion biomass

production levels including differences between sites in mean dandelion age and the proportion of older versus younger dandelion plants (Froese and Van Acker, 2003).

In general, herbicide treatments that provided good control according to mid-season assessments, also provided good control according to post-harvest assessments. However, this was not the case at Carman UM where, for the most part, dandelion aboveground biomass in the herbicide treatments, specifically the spring herbicide plots, was higher post-harvest versus mid-season (Tables 4.2.5 and 4.2.6), although there was a reduction between sampling dates for the nontreated control. Spring herbicide applications and crop seeding operations at the Carman UM site occurred within less than 24 hours of each other and this lack of time between the two operations may have affected the efficacy of the spring treatments. At both herbicide application timings there was a substantial amount of crop residue present on the soil surface (visual observation) at Carman UM. These residues covered many mature (rosette) dandelion plants and may have affected herbicide coverage on the dandelions. At the other four site-years aboveground biomass was generally lower post-harvest versus mid-season. This may be due to the fact that the leaves of dandelion tend to senesce as accumulated temperature (degree days) increases following the floral bud stage (Calvière and Duru, 1995).

### 4.2.4 DANDELION SEEDLING ABOVEGROUND BIOMASS

Only in 2004 was there sufficient aboveground dandelion seedling biomass post-harvest to allow for measurement. In 2003, conditions were not conducive to dandelion seedling survival (as was observed in the dandelion emergence period study) and most dandelion plants originating from seed died prior to the post-harvest

Table 4.2.7. Mean biomass of dandelion plants from seed (g $m^{-2}$) assessed post-wheat harvest[a] for each herbicide treatment and for each site year (standard errors in parentheses).

| Trt. no. | Treatment[b] | Application dose | Application timing[c] | Site-years | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Oak Bluff 1 2003[d] | Oak Bluff 2 2003[d] | Carman 2003[d] | Roland 2004 | Carman UM 2004 |
| | | g $ha^{-1}$[e] | | g $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | --- | --- | --- | 1.2 (0.6) | 1.4 (0.8) |
| 2 | Glyph | 450 | Fall | --- | --- | --- | 2.9 (1.5) | 9.5 (2.7) |
| 3 | | | Spring | --- | --- | --- | 3.8 (1.5) | 9.8 (4.3) |
| 4 | Glyph | 675 | Fall | --- | --- | --- | 2.7 (1.4) | 15.3 (4.8) |
| 5 | | | Spring | --- | --- | --- | 4.4 (1.5) | 9.3 (2.0) |
| 6 | Glyph | 1350 | Fall | --- | --- | --- | 5.3 (1.9) | 17.1 (3.5) |
| 7 | | | Spring | --- | --- | --- | 2.0 (0.9) | 8.7 (2.2) |
| 8 | Glyph + Flor | 450 + 5 | Fall | --- | --- | --- | 6.0 (2.5) | 12.9 (2.0) |
| 9 | | | Spring | --- | --- | --- | 5.2 (1.5) | 11.2 (3.4) |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | --- | --- | --- | 5.2 (2.6) | 11.4 (2.9) |
| 11 | | | Spring | --- | --- | --- | 5.7 (2.1) | 11.6 (0.7) |
| 12 | Glyph + Flor | 900 + 5 | Fall | --- | --- | --- | 4.8 (1.5) | 11.6 (2.9) |
| 13 | | | Spring | --- | --- | --- | 3.7 (1.1) | 11.3 (2.1) |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | --- | --- | --- | 4.5 (1.8) | 12.1 (2.8) |
| 15 | | | Spring | --- | --- | --- | 5.5 (2.7) | 10.9 (2.7) |

[a] Only 2004 site-years were assessed for post-harvest dandelion seedling biomass
[b] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[c] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[d] In 2003 few seedling survived to the post-harvest assessment period and those that did survive were too small to harvest.
[e] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

assessment period. At both sites in 2004, herbicide treatment had no significant effect on dandelion seedling biomass post-harvest (Table 4.2.7), but there was a tendency for treatments that included both glyphosate and florasulam (treatments 8 to 13) to have slightly higher seedling densities when compared to the nontreated controls. The highest densities of mature dandelion plants (Table 4.2.1) which produced the greatest amount of aboveground rootstock biomass (Table 4.2.5) were found in the nontreated controls. The proliferance of these large dandelion rosettes in the nontreated controls may have limited seedling biomass production. In the nontreated controls there were high post-harvest seedling densities (Table 4.2.3) but these seedlings were generally small (cotyledon to 1 to 2 leaf), yielding little aboveground biomass (Table 4.2.7). It was in treatments where dandelions from rootstock were affected by herbicides that dandelion seedlings grew to produce plants yielding measurable aboveground biomass.

### 4.2.5 WHEAT ABOVEGROUND BIOMASS

For all five site-years, the aboveground biomass of wheat was significantly higher in the herbicide treated plots versus the nontreated plots, regardless of the rate or product used, suggesting that all herbicide treatments in this study significantly reduced dandelion competitive ability in wheat (Table 4.2.8). All other weeds present in the plots were negligible. There were only a few significant differences in wheat biomass between herbicide treatments. For example, at Oak Bluff 1 wheat aboveground biomass in the fall herbicide treated plots (even numbered treatments) tended to be greater than in the spring herbicide treated plots (odd numbered treatments, with the exception of treatment 1). This effect was not observed at the

other four site-years. As herbicide rate increased and glyphosate was tank mixed with either florasulam or tribenuron the differences in wheat aboveground biomass in the fall versus the spring applied herbicide treatments were attenuated. There was a strong relationship between dandelion biomass and wheat biomass at both the mid-season and post-harvest assessment periods in 2004, but not in 2003. The Pearson correlation coefficients in 2004 were -0.60 and -0.61, respectively (Table 7.10). The unpredictability of dandelion competitive ability (Froese and Van Acker, 2003) may be responsible for the lack of relationship in 2003 between measurements of dandelion aboveground biomass and wheat biomass. Froese and Van Acker (2003) found no reliable measures for predicting canola yield loss due to dandelion interference. Dandelion is an apomictic species (Mann and Cavers, 1979; Richardson, 1985; Solbrig, 1971; Solbrig and Simpson, 1974; Stewart-Wade et al., 2002) and differences in biotype competitive ability and the age structure of a dandelion infestation (Froese and Van Acker, 2003) may have a greater impact on yield than aboveground biomass production alone. For example, a dandelion infestation characterized by low diversity and a juvenile age structure may interfere less with crop yield than a diversified, older dandelion population.

Table 4.2.8. Mean wheat biomass (g $m^{-2}$) assessed at the boot stage[a] of the wheat crop for each herbicide treatment and for each site year (standard errors in parentheses)[b].

| Trt. no. | Treatment[c] | Application dose | Application timing[d] | Site-years | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
| | | g $ha^{-1}$[e] | | g $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 213.6 (36.4) e | 127.9 (29.3) c | 218.2 (17.4) c | 229.3 (29.7) d | 111.4 (34.4) d |
| 2 | Glyph | 450 | Fall | 364.7 (30.8) ab | 297.6 (31.0) ab | 423.2 (41.7) ab | 399.5 (33.9) abc | 447.1 (69.5) ab |
| 3 | | | Spring | 306.1 (12.7) bcd | 231.8 (21.8) b | 370.1 (56.0) b | 390.9 (44.0) bc | 336.9 (38.2) a-c |
| 4 | Glyph | 675 | Fall | 351.6 (17.1) abc | 291.6 (33.3) ab | 426.6 (8.3) ab | 445.5 (16.7) abc | 451.6 (48.5) a |
| 5 | | | Spring | 345.9 (5.9) abc | 271.8 (22.0) ab | 447.5 (17.4) ab | 400.9 (45.9) abc | 305.1 (73.9) c |
| 6 | Glyph | 1350 | Fall | 360.8 (15.6) ab | 315.0 (42.2) a | 423.3 (36.2) ab | 375.9 (23.6) c | 422.7 (62.5) a-c |
| 7 | | | Spring | 320.8 (17.6) abcd | 267.8 (32.3) ab | 438.7 (32.5) ab | 389.7 (26.9) bc | 356.9 (54.3) a-c |
| 8 | Glyph + Flor | 450 + 5 | Fall | 365.7 (24.9) a | 282.6 (16.3) ab | 486.5 (19.9) a | 472.2 (18.6) ab | 383.9 (45.1) a-c |
| 9 | | | Spring | 318.3 (15.8) abcd | 246.9 (15.2) ab | 425.8 (8.1) ab | 408.8 (49.7) abc | 314.3 (44.4) bc |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 348.4 (7.2) abc | 260.6 (24.6) ab | 492.3 (36.7) a | 421.4 (41.3) abc | 430.1 (59.8) a-c |
| 11 | | | Spring | 272.7 (29.7) d | 255.4 (8.4) ab | 357.8 (64.5) b | 439.2 (24.0) abc | 342.8 (38.8) a-c |
| 12 | Glyph + Flor | 900 + 5 | Fall | 340.7 (18.6) abc | 282.9 (13.3) ab | 472.2 (41.5) a | 482.6 (20.2) a | 356.4 (28.9) a-c |
| 13 | | | Spring | 317.1 (13.4) abcd | 271.9 (13.5) ab | 507.4 (32.1) a | 437.6 (27.3) abc | 309.0 (51.5) c |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 365.1 (21.9) a | 280.0 (13.8) ab | 422.3 (34.8) ab | 463.7 (38.4) abc | 410.4 (40.1) abc |
| 15 | | | Spring | 299.0 (20.6) cd | 245.4 (40.4) ab | 422.1 (70.1) ab | 473.7 (17.2) ab | 307.7 (75.9) c |

[a] Assessed approximately at the boot stage of the wheat crop (according to Zadock's growth stages for cereal crops).
[b] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$.
[c] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[d] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[e] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

### 4.2.6 WHEAT GRAIN YIELD

For all site-years, the wheat crop grew normally throughout the season and appeared to be of normal competitiveness. The wheat crop at all site-years was observed to be of normal density and height and matured evenly. There were few significant differences in wheat yield between the various herbicide treatments (Table 4.2.9). For each site-year, mean wheat yields in all herbicide treatments were significantly greater than in the nontreated control ($P \leq 0.05$). In 2003 the highest wheat yields tended to occur in the fall applied herbicide treatments that included glyphosate and florasulam (treatments 8, 10, and 12) (Table 4.2.9). There were no statistical differences between any of the herbicide treatments at either site in 2004 (Table 4.2.9). The 2003 site-years had slightly higher wheat yields overall (>300 g $m^{-2}$) in some plots, which may be a function of the cool, wet conditions experienced in 2004, which caused a delay in wheat maturation and harvest, and the increased wheat seeding rate, due to drill calibration error, at the 2003 site-years. In 2003 and 2004, there was a strong relationship between wheat yield and dandelion aboveground biomass assessed post-harvest. The statistically significant Pearson correlation coefficients were -0.62 and -0.54 in 2003 and 2004 respectively. This suggests that dandelion aboveground biomass measured post-harvest had a significant impact on wheat yield in both years of the experimental study.

Table 4.2.9. Mean wheat grain yield (g $m^{-2}$) for each herbicide treatment and for each site year (standard errors in parentheses)[a].

| Trt. no. | Treatment[b] | Application dose | Application timing[c] | Site-years | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
| | | g $ha^{-1}$[d] | | g $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 124.6 (13.3) e | 109.7 (37.1) c | 204.6 (43.8) d | 108.0 (10.2) b | 87.3 (27.8) b |
| 2 | Glyph | 450 | Fall | 260.5 (18.9) abc | 274.4 (31.5) b | 331.2 (20.1) abc | 258.6 (19.6) a | 244.8 (41.5) a |
| 3 | | | Spring | 226.6 (9.1) d | 291.6 (14.5) ab | 298.0 (9.0) c | 275.0 (33.1) a | 234.3 (21.1) a |
| 4 | Glyph | 675 | Fall | 262.1 (23.6) a | 323.2 (7.8) a | 312.4 (9.2) abc | 267.1 (26.6) a | 278.8 (10.1) a |
| 5 | | | Spring | 231.6 (16.3) bcd | 294.3 (19.7) ab | 309.2 (11.3) bc | 274.0 (13.1) a | 277.9 (12.7) a |
| 6 | Glyph | 1350 | Fall | 262.3 (11.5) a | 333.0 (8.2) a | 331.9 (7.9) abc | 249.4 (13.6) a | 253.9 (16.4) a |
| 7 | | | Spring | 231.5 (24.0) bcd | 299.4 (18.4) ab | 319.3 (8.8) abc | 264.3 (19.3) a | 261.8 (4.6) a |
| 8 | Glyph + Flor | 450 + 5 | Fall | 263.0 (19.4) a | 332.6 (14.6) a | 357.7 (16.8) a | 273.2 (14.2) a | 277.0 (16.0) a |
| 9 | | | Spring | 238.8 (15.6) abcd | 318.8 (16.4) ab | 320.9 (14.5) abc | 265.4 (13.8) a | 264.2 (6.9) a |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 264.4 (17.9) a | 328.3 (15.0) a | 318.4 (12.2) abc | 244.4 (13.4) a | 252.4 (18.6) a |
| 11 | | | Spring | 247.1 (16.2) abcd | 303.7 (24.6) ab | 330.6 (10.7) abc | 255.0 (11.9) a | 277.6 (9.1) a |
| 12 | Glyph + Flor | 900 + 5 | Fall | 253.2 (12.6) abcd | 292.6 (25.8) ab | 344.4 (10.7) ab | 282.8 (16.5) a | 274.7 (21.3) a |
| 13 | | | Spring | 228.6 (11.3) d | 295.5 (19.0) ab | 340.3 (4.2) abc | 278.9 (11.7) a | 253.7 (6.9) a |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 250.0 (24.3) abcd | 301.1 (11.6) ab | 318.0 (20.0) abc | 275.5 (31.4) a | 283.1 (13.1) a |
| 15 | | | Spring | 230.6 (15.2) cd | 290.3 (30.5) ab | 337.3 (9.1) abc | 284.0 (12.0) a | 269.2 (16.7) a |

[a] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD test at $P \leq 0.05$.
[b] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[c] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[d] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

### 4.2.7 SUMMARY DISCUSSION

The results of this study indicate that fall herbicide treatments (post-harvest) can be an effective method of reducing dandelion rootstock density and aboveground biomass, as assessed mid-season and post harvest in a wheat crop. In contrast, the effect of herbicide treatment in reducing dandelion seedling densities and seedling aboveground biomass was not statistically significant in this study when plots were assessed post-harvest. In 2004, dandelion seedling densities were highest in the nontreated controls but seedling aboveground biomass was also lowest in the nontreated controls due to the presence of large dandelion rosettes in these plots. Treatments that included glyphosate + florasulam, glyphosate + tribenuron, or a high rate of glyphosate, provided the greatest level of dandelion control.

Dandelion is a simple perennial species that spreads via seed alone (Solbrig and Simpson, 1974). Controlling the seedlings and the large established dandelion plants is crucial for managing infestations. In this study the in-crop herbicide application (applied at the 3 to 4 leaf stage of the wheat crop) provided no control of dandelion seedlings because they emerged after the in-crop herbicide application. The fall herbicide applications generally restricted the spread of dandelion to a greater extent than the spring herbicide applications, as the fall treatments controlled large dandelion rosettes (which are the source of seed) and the seedlings themselves (source of population spread). There is evidence that late season applications of herbicides to perennial weeds, such as dandelion and Canada thistle [*Cirsium arvense* (L.) Scop.], may provide enhanced control possibly because of enhanced

translocation of herbicides at this time to underground (root) storage organs along the photoassimilate stream (Stewart Wade et al., 2002; Wilson and Michiels, 2003).

**Sources of Materials**

[1] Florasulam + Glyphosate, Vanatge Plus. Dow AgroSciences Canada Inc. 210, 1144 29 Avenue East, Calgary, AB T2E 7P1 Canada.

[2] Tribenuron methyl ester, Express. E. I. du Pont Canada Company. P.O. Box 2200 Streetsville, Mississauga, ON L5M 2H3, Canada.

[3] Teejet flat fan nozzle tips. Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189-7900.

[4] Valmar Airflo Inc., P.O. Box 100, Elie, MB R0H 0H0, Canada.

[5] R-Tech Industries Ltd., P.O. Box 27, Homewood, MB R0G 0Y0, Canada.

[6] Score, adjuvant. Syngenta Crop Protection Canada Inc., 140 Research Lane, Research Park, Guelph, ON N1G 4Z3, Canada.

[7] StowAway TidbiT® temperature loggers, Onset Computer Corporation, Box 3450, 536 MacArthur Boulevard, Pocasset, MA, 02559-3450.

[8] Hege Maschinen GmbH. Domäne Hohebuch, D-74638, Waldenburg, Germany.

[9] Wintersteiger Nursery Master, Wintersteiger Inc. 217 Wright Brothers Drive, Salt Lake City, UT, 84116.

[10] SAS v.8.2, Statistical Analysis Systems, SAS Institute Inc., SAS Campus Drive, Box 8000, Cary, NC 25712-8000.

# 5.0 GENERAL DISCUSSION

## 5.1 DANDELION BIOLOGY AND ECOLOGY

Most literature regarding dandelion behaviour and emergence from either seed or rootstock has been documented, to some degree, for dandelion populations in undisturbed ecosystems, such as meadows (Vavrek et al., 1997), grassland areas (Ford, 1981; Solbrig and Simpson, 1974); alfalfa fields (Ominski et al., 1999), and sand dunes (Ford, 1985). Only in recent years has dandelion been studied as a weed in annual cropping systems (Derksen et al., 1996; Légère and Samson, 1999; Légère and Stevenson, 2002), including Manitoba canola fields (Froese and Van Acker, 2003). The behaviour of dandelion in annual cropping systems remains relatively unknown and there is a need for research into the biology, ecology, and population demography of dandelion under varying tillage regimes, in complex crop rotations, and in a variety of agroecoregions across North America.

Traditionally, the emergence period of dandelion has been expressed as a function of calendar days and not thermal time. Ghersa and Holt (1995) stated that variability within plant populations is often minimized when stages of development are expressed in terms of accumulated environmental conditions rather than chronological (calendar) time. In this study, if calendar day had been used to monitor the emergence period of dandelion instead of thermal time, the results between site-years would have been even greater different due to the immense variability in climatic conditions between the two years of the study. The use of growing degree days rather than calendar days leads to a recognition of ecophysiological similarities and differences among given dandelion infestations that otherwise would be

confounded by temperature responses to varying experimental conditions (Ghersa and Holt, 1995). Despite differences in soil type, previous management practices, and environmental conditions between all five site-years, dandelion emergence period based on thermal time remained relatively constant for both rootstock and seedlings. In the literature, dandelion rootstock emergence has not generally been documented and there has been some debate regarding dandelion seedling emergence period as a function of chronological time. Based on calendar day, it is difficult to reconcile the dandelion recruitment period debate, considering that dandelion germination and emergence is primarily a function of the prevailing environmental conditions in a given year and the availability of viable seed. For example, in this study, dandelion seedling recruitment was greatest in the summer, but given the appropriate environmental conditions, as in 2004, seedling recruitment also occurred (although to a lesser extent) in the early fall. Generally, the more rapid the accumulation of heat units the earlier the onset of dandelion emergence.

Dandelion rootstock emergence began early in spring and was completed by the time seedling emergence started. Dandelion seedling emergence is a function of available soil moisture, specifically near the soil surface, heat accumulation (GDD's), and the availability of viable seed (from nearby flowering plants). Environmental conditions in the two years of this study were extremely dissimilar which led to a broadened understanding of the influence of environment on dandelion emergence period, flowering patterns, and seedling survivorship. Environmental conditions strongly affected flowering period which consequently influenced seed availability and hence, dandelion seedling recruitment period. Mature dandelion rosettes present

in the first year of the study (2003) flowered for a period of two to four weeks on average, beginning in late May. In 2004, mature rosettes flowered throughout the entire growing season, with peak flower production occurring in mid-June and July. The main flowering period of dandelion may vary depending upon year, plant, and population, due to inconsistencies in microclimate, but also due to genetically controlled differences between dandelion biotypes (Sterk and Luteijn, 1984). Not all mature dandelion rosettes flower within a given year. Dandelion plants must reach a certain age associated with the attainment of a particular number of leaves to render the process of flowering possible (Listowski and Jackowska, 1965). Dandelion plants that flowered in a given season were large rosettes, generally greater than 15 cm in diameter (personal observation), and had accumulated substantial aboveground biomass. In this study, the population demography of the majority of the dandelion infestations located at the experimental sites in mid-summer consisted of an assortment of mature flowering rosettes, juvenile (non-flowering) rosettes, and small seedlings. It is for the reasons listed above that dandelion rootstock densities (mature rosettes) are not a suitable indicator of dandelion seedling densities. If an infestation is composed of a high proportion of juvenile rosettes that do not produce flowering heads, correlating dandelion rootstock densities to seedling densities is difficult. Dandelion is also a wind dispersed species, therefore mature rosette densities in a given area may not be strongly related to seedling densities located in the same vicinity, although Tackenberg et al. (2003) found that 99.5% of dandelion seeds land within 10 m of the parent plant and only 0.014% of seeds are dispersed at distances greater than 1 km. The proportion of seeds dispersed at distances greater than 1 km

may appear insignificant, but dandelion is a prolific seed producer. Roberts (1936) found that over 246 million dandelion seeds could be produced in a one acre grassy field per year. Given these seed production rates and dispersal proportions, over 34,000 seeds could travel a distance of 1 km from one single acre of land. The seed dispersal ability of dandelion offers it an ecological advantage since seedlings can colonize areas that lack parent plants. The dispersal ability of dandelion allows for populations to persist and infestations to spread. Unfortunately, in annual cropping systems there is no accurate measurement of dandelion seed production rates, perhaps due to the unpredictability of dandelion infestations in annually disturbed areas.

Dandelion seed is considered short-lived, averaging two to three years of longevity (Holm et al., 1997a). In this study, dandelion seedling emergence never occurred in the absence of seed shed. Dandelion seedling emergence at all five site-years consistently coincided with seed shed, suggesting that the seedbank, if it existed, did not significantly contribute to the overall number of seedlings observed in a given year. Further research, in terms of dandelion seedbank studies and seed production rates, is required to confirm these results.

In North America, dandelion is considered an apomictic species, regenerating in the absence of embryo fertilization. There is evidence of sexual species of dandelions on the European continent but presently there are no documented cases of sexually reproducing dandelions in North America. Given that there are 50 to 60 biotypes of dandelion present in North America it seems unlikely that random genetic mutations are exclusively responsible for population variability. Does phenotypic plasticity alone account for the presence of multiple dandelion biotypes within given

populations? It appears logical that pollen flow and sexual reproduction do occur, given that genetic mutations in selfing species are naturally occurring random events. Further research into the genetic composition of dandelion biotypes is necessary. If dandelions in North America are truly asexual species, what are the implications of this mode of reproduction? Parent plants can produce clones which exhibit superior fitness and reproduction is not limited by pollen flow. Some disadvantages of this ability would include a reduction in genetic diversity within populations in an area, which may limit population adaptation to changing environmental and ecological conditions, and increased susceptibility to attack by pathogens. In terms of herbicide resistance, in asexually reproducing species, such as dandelion, there is no method by which a resistance allele could be obtained from a neighbouring plant, and the chance of spreading resistance in a population would be reduced due to the lack of pollen flow. The heritability of genetic mutations in future generations is dependent upon the presence of the mutation in germ cells (male and female gametes). However, if there were herbicide resistant dandelion populations, limiting the spread of these populations via wind dispersed seed would be challenging, and given the obvious nature of spread, legal liability for spread could be an issue.

## 5.2 DANDELION MANAGEMENT

Devising weed management strategies requires knowledge of the life cycle of the target species. Dandelion is a simple perennial species whose sole mode of population spread is via seed, even though it is capable of regenerating from both seed and rootstock (vegetative fragments). Controlling population spread requires the control of dandelion seedlings and the source of those seedlings, namely mature

rosettes that have the potential to flower and produce seed. In this study, fall herbicide applications were most effective for controlling the source of seedlings (rosettes) and the seedlings themselves. Fall herbicide applications on dandelion are considered more efficacious than spring applications due to the increased translocation of herbicides, along with carbohydrates, towards the roots as plants prepare to over winter on rootstocks. Fall applications generally target dandelion seedlings at the cotyledon to one to four leaf stage when vulnerability to herbicides is greatest. Spring applications controlled mature rosettes present at the start of the growing season and the previous year's seedlings but had no effect on seedlings that emerged during the year of application. Delaying the control of seedlings almost one year (until the next spring) could result in a dandelion infestation composed of highly competitive plants. The longer a farmer waits to control a dandelion infestation, the more difficult that infestation will be to control.

The spring herbicide applications that included florasulam provided early-season control of wild buckwheat and volunteer canola, which emerged approximately two weeks after the spring herbicide applications (personal observation; data not shown), especially in 2004. However, the residual activity of florasulam varies depending upon environmental conditions within a given year, but residual activity generally ranges from 2 to 18 days. Florasulam is degraded microbially with warm, wet conditions enhancing degradation. The cool conditions in 2004 may have prolonged the residual activity of florasulam. The residual nature of both florasulam and tribenuron was insufficient to provide control of dandelion

seedlings because these seedlings emerged one and half to two and a half months after the spring herbicide applications.

Dandelion populations were quite remarkable considering that at all of the site-years, with the exception of Roland, there was an application of glyphosate in at least one of the past five years leading up to the initiation of our field study (see Appendix 7.1). At Oak Bluff 1, Oak Bluff 2, and Carman, farmers applied glyphosate prior to seeding in the spring. For all of these farmers, dandelion was a persistent problem in the following growing season. These "real world" examples confirm that fall (post-harvest) is the premium time to control dandelion to achieve long-term control. In typical rotations in Western Canada, consisting of annual crops, the time to control dandelion is in the fall after crop harvest. According to this study, applying glyphosate at rates $\geq$ 675 g a.e. $ha^{-1}$ or applying glyphosate + florasulam in the fall was very efficacious on dandelion. However, Froese (2001) found that a single application of glyphosate at 900 g a.e. $ha^{-1}$ offered sufficient dandelion control. The benefit of adding florasulam is the residual activity it provides for weeds such as wild buckwheat and volunteer canola (including the herbicide tolerant varieties) and its broadened spectrum of control, but these benefits do not exist for fall applications.

Tillage is frequently cited as a means of controlling dandelion infestations. Froese (2001) found that even a single spring tillage pass could greatly reduce dandelion biomass, but could not significantly reduce dandelion density as assessed 12 months after the tillage treatment. Similarly, Mann (1981) reported that dandelion percentage survival was not greatly affected by cutting roots 2 cm below the crown and removing the shoot. But does tillage control population spread? Spring tillage

controls only dandelion rosettes, not the seedlings emerging in a given year. Failing to control summer seedlings allows for population persistence and further production of seed. Fall tillage is effective for controlling small summer seedlings and some large rosettes. Tillage also acts to fragment and spread dandelion roots which have the ability to regenerate and establish new populations. Tillage can be effectively used to control infestations, depending on the intensity and timing, but with the increased adoption of minimum tillage practices, herbicidal control of dandelion is required.

## 5.3 OUTLOOK FOR DANDELION INFESTATIONS FOR THE 2005 SEASON

The 2005 growing season could go on record as one of the worst years for dandelion infestations in annual cropping systems in Manitoba. Dandelion plants thrive and proliferate in cool, moist climatic conditions, like the conditions seen in Manitoba during the summer of 2004. In the fall of 2004, seedlings that emerged in early to mid-summer went on to produce small rosettes that have the capacity to over-winter on rootstocks. One of the most constraining factors in controlling dandelion in 2004 was the environment. Cool and wet conditions delayed harvest operations, and many fields in southern Manitoba, particularly in the Red River Valley, were left un-harvested. Consequently, the frequency of post-harvest herbicide applications in 2004 was reduced due to the late growing season and time constraints. Given these conditions, dandelion populations may be extremely large and problematic in the spring of 2005, especially if farmers cannot apply a pre-seed or pre-emergent burn-off herbicide. Recommendations to farmers for this upcoming spring would be to apply a pre-seed burn-off herbicide and increase the application rate to control mature

rosettes that were not controlled the previous fall. If using glyphosate alone, it is recommended to apply it at a rate greater than 675 g a.e. $ha^{-1}$, according to this study. The results of the our study also indicate that applying glyphosate at a rate of 1350 g a.e. $ha^{-1}$ in the spring will provide adequate dandelion control. Applying a pre-seed treatment of glyphosate + florasulam may be advantageous in terms of volunteer canola control, especially if canola swaths were left un-harvested in fields in the fall of 2004. In our study, the differences between the spring applied glyphosate + florasulam treatments were often insignificant, but it seems that in order to maintain a reasonable level of spring control a high rate of glyphosate (900 g a.e. $ha^{-1}$) + florasulam (5 g a.i. $ha^{-1}$) should be applied.

## 5.4 FUTURE RESEARCH

Considering the significant impact of moisture and heat on seedling recruitment timing, research to improve the prediction of dandelion seedling emergence should focus on hydrothermal time. Temperature and water potential, accounted for in the hydrothermal model, are the main factors regulating seed germination (Alvarado and Bradford, 2002). Constraints in employing this type of model are that currently the osmotic potential threshold at which dandelion seeds do not germinate is unknown. There is also no reliable method available to obtain continuous measurements of soil moisture.

Assessing herbicide efficacy is often a difficult and somewhat subjective process. Efficacy of various herbicidal treatments is measured via weed counts, biomass production, and visual evaluations, the later being the most subjective. Density counts (plants $m^{-2}$) are not always indicative of control as counts do not

account for the size of the weed species being controlled and re-growth of suppressed plants. Dandelion is a perennial species that is hard to kill, is frequently suppressed by herbicides, but not completely controlled, it is prone to re-growth after herbicide application, and populations are comprised of a variety of distinct biotypes which also vary in their response to herbicides. For example, a herbicide treatment may provide suppression of a high number of large dandelion plants, but in terms of absolute density counts these suppressed plants are still regarded as living and uncontrolled. Another herbicide treatment may control the majority of dandelion plants in an area but leave a few large rosettes uncontrolled. It is not clear which treatment is more efficacious. Measuring biomass production is more indicative of perennial weed control and provides for a truer evaluation of weed suppression. When herbicides are applied to a population of annual weeds, such as wild oat, all of the individuals within the population are at approximately the same developmental stage at the time of application, and these individuals (except for herbicide resistant biotypes) generally respond similarly to the applied herbicide. The variability associated with perennial weed populations hold implications for control methods. The demography of dandelion plants being targeted at any time during the course of the growing season can range from seedlings (cotyledon) to large mature rosettes, making control timing difficult. For example, a strong relationship was found in 2004 between measures of dandelion aboveground biomass and dandelion density, while in 2003 there was no significant relationship between these two measurements. If an infestation cannot be accurately quantified then how can effective control be recommended?

In weed science there is a need for further integration of weed life history information with management strategies in order to enhance control methods. Herbicide efficacy information and weed population biology studies complement each other. This study integrated the biological and ecological aspects of dandelion with the timing of management practices to determine the most efficacious timing for dandelion control. It is important to identify when in their lifecycle given weed species are most susceptible to a wide range of control measures. In this respect, an understanding of weed species, especially apomictic simple perennial weed species, is essential for implementing effective control strategies. By targeting weeds at appropriate stages within their life cycle farmers can increase herbicide use efficiency and perhaps reduce herbicide use. Instead of spraying dandelion infestations in the spring and again in the fall, a single fall application may result in only one herbicide application per year or one every two years. Altieri and Liebman (1988) summed the current agricultural situation fittingly by stating "where traditional approaches in weed science have failed (chemicals), plant population biology studies are needed in order to improve weed management and further develop integrated pest management strategies".

## 6.0 LITERATURE CITED


Alberta Agriculture, Food, and Rural Development. 2004. The Herbicide Selector: Florasulam. Available: www.agric.gov.ab.ca/app23/pesticides/herbicides/getweeds.jsp (accessed 23 September 2004).

Altieri, M.A. and M. Liebman. 1988. Weed Management in Agroecosystems: Ecological Approaches. CRC Press Inc., Boca Raton, Florida. 354 p.

Alvarado, V. and K.J. Bradford. 2002. A hydrothermal time model explains the cardinal temperatures for seed germination. Plant, Cell, and Environ. 25: 1061-1069.

Anderson, W.P. 1999. Perennial Weeds: Characteristics and Identification of Selected Herbaceous Species. Iowa State University Press, Ames, Iowa. Pp. 828-842.

Beach, F. 1939. The dandelion. Am Bee J. 79:238-239.

Bingaman, B.R. and N.E. Christians. 1995. Greenhouse screenings of corn gluten meal as a natural control product for broadleaf and grass weeds. HortScience. 30(6):1256-1259.

Blackshaw, R.E., F.O. Larney, C.W. Lindwall, and G.C. Kozub. 1994. Crop rotation and tillage effects on weed populations on the semi-arid Canadian prairies. Weed Technol. 8:231-237.

Blackshaw, R.E., L.J. Molnar, and H.H. Janzen. 2004. Nitrogen fertilizer timing and application method affect weed growth and competition with spring wheat. Weed Sci. 52:614-622.

Bostock S .J. 1978. Seed germination strategies of five perennial weeds. Oecologia. 36:113-126.

Bostock, S.J. and R.A. Benton. 1979. The reproductive strategies of five perennial compositae. J. Ecol. 67:91-107.

Boyd, N.S. and R.C. Van Acker. 2003. The effects of depth and fluctuating soil moisture on the emergence of eight annual and six perennial plant species. Weed Sci. 51:725-730.

Brainard, D.C., R.R. Bellinder, and A.J. Miller. 2004. Cultivation and interseeding for weed control in transplanted cabbage. Weed Technol. 18:704-710.

Buhler, D. D. and J. C. Mercurio. 1988. Vegetation management and corn growth and yield in untilled mixed-species perennial sod. Agron. J. 80:454-462.

Buhler, D.D., D.E. Stoltenberg, R.L. Becker, and J.L. Gunsolus. 1994. Perennial weed populations after 14 years of variable tillage and cropping practices. Weed Sci. 42:205-209.

Bullied, W.J., A.M. Marginet, and R.C. Van Acker. 2003. Conventional- and conservation-tillage systems influence emergence periodicity of annual weed species in canola. Weed Sci. 51:886-897.

Burpee, L.L. 1992. A method for assessing the efficacy of a biocontrol agent on dandelion (*Taraxacum officinale*). Weed Technol. 6:401-403.

Calivière, I. and M. Duru. 1995. Leaf appearance and senescence patterns of some pasture species. Grass Forage Sci. 50:447-451.

Cardina, J. and D.H. Sparrow. 1996. A comparison of methods to predict weed seedling populations from the soil seedbank. Weed Sci. 44:46-51.

Chancellor, R.J. 1964. Emergence of weed seedlings in the field and the effects of different frequencies of cultivation. Proc. of the Seventh British Weed Control Conference, Brighton UK. Pp. 599-606.

Corbett, J.L., S.D. Askew, W.E. Thomas, and J.W. Wilcut. 2004. Weed efficacy evaluations for bromoxynil, glufosinate, glyphosate, pyrithiobac, and sulfosate. Weed Technol. 18:443-453.

Cox, C. 1998. Glyphosate (Roundup). J. Pestic. Reform. 18 (3):3-16.

Darwent, A.L. and J.C. Drabble. 1995. Control of quackgrass and wild oats with glyphosate in glyphosate tolerant canola. ECW/HERB-95W. Experiment Number 9551250.

de la Fuente, E.B., S.A Suàrez, C.M. Ghersa, and R.J.C. León. 1999. Soybean weed communities: relationships with cultural history and crop yield. Agron. J. 91:234-241.

Derksen, D.A., G.P. Lafond, A.G. Thomas, H.A. Loeppky, and C.J. Swanton. 1993. Impact of agronomic practices on weed communities: tillage systems. Weed Sci. 41:409-417.

Derksen, D.A., R.E. Balckshaw, and S.M. Boyetchko. 1996. Sustainability, conservation tillage and weeds in Canada. Can. J. Plant Sci. 76:651-659.

Derksen, D.A., C. Grant, and B. Irvine. 2002. New weed management strategies for conservation tillage. Land Resource Management Research Program Research Highlights 2002. Agriculture and Agri-Food Canada, Brandon Research Center, Brandon, Manitoba, Canada. Pp. 28-31.

Deubreuil, D.J., L.F. Friesen, and I.N. Morrision. 1996. Growth and seed return of auxin-type herbicide resistant wild mustard (*Brassica kaber*) in wheat. Weed Sci. 44:871-878.

Devine, M.D., S.O. Duke, and C. Fedtke. 1993. Inhibition of amino acid biosynthesis. Chapter 13. Pages 251-294 *in* Physiology of Herbicide Action. PTR Prentice Hall. Englewood Cliffs, New Jersey.

Doll, J.D. 1978. A survey of perennial weed problems in Wisconsin. Proc. North Cent. Weed Control Conf. Volume 33. Pp. 72.

Dow AgroSciences. 2002. Label Specimen: Florasulam Suspension Concentrate Herbicide [Online]. Available: www.dowagro.com. (accessed 23 September 2004).

Dow AgroSciences. 2004. PrePass™ Technical Bulletin 0203-441-009. 2004. [Online]. Available: www.dowagro.com. (accessed 23 September 2004).

Dunn, R. and J. Moyer. 1999. Dandelion control in direct seeding systems. [Online] Available: http://www.agric.gov.ab.ca/agdex/500/519-26.html. (accessed 2 February 2003).

Fay, P.K. 1990. A brief overview of the biology and distribution of weeds in wheat. Chapter 3. Pages 33-49 *in* Systems of Weed Control in Wheat in North America. W. W. Donald (ed.). Monograph of the Weed Science Society of America. Champaign Illinois.

Finney, D.J. 1989. Was this in your statistic textbook? V. Transformation of data. Expl. Agric. 25:165-175.

Forcella, F. 1992. Prediction of weed seedling densities from buried seed reserves. Weed Res. 32:29-38.

Ford, H. 1981. The demography of three populations of dandelion. Biol. J. Linn. Soc. 15:1-11.

Ford, H. 1985. Life history strategies in two coexisting agamospecies of dandelion. Biol. J. Linn. Soc. 25:169-186.

Froese, N.T. 2001. Dandelion's (Taraxacum officinale) distribution, interference, and control in Roundup Ready™ canola. M.Sc. Thesis. The University of Manitoba,Winnipeg, Canada. 136 p.

Froese, N.T. and R.C. Van Acker. 2003. Distribution and interference of dandelion (*Taraxacum officinale*) in spring canola. Weed Sci. 51:435-442.

Froese, N.T., R.C. Van Acker, and L.F. Friesen. 2005. Influence of spring tillage and glyphosate treatment on dandelion (*Taraxacum officinale*) control in glyphosate-resistant canola. Weed Technol. 19:[In Press, accepted].

Froud-Williams, R.J., R.J. Chancellor, and D.S.H. Drennan. 1981. Potential changes in weed floras associated with reduced-cultivation systems for cereal production in temperate regions. Weed Res. 21:99-109.

Friesen, L.F., K.P. Nickel., and I.N. Morrison. 1992. Round-leaved mallow (*Malva pusilla*) growth and interference in spring wheat (*Triticum aestivum*) and flax (*Linum usitatissimum*). Weed Science. 40:448-454.

Georgia, A.E. 1933. A Manual of Weeds. The McMillan Company, New York. 535 p.

Ghersa, C.M. and J.S. Holt. 1995. Using phenology prediction in weed management: a review. Weed Res. 35: 461-470.

Gomez, K.A., and A.A. Gomez. 1984. Pages 187-207 *in* Statistical Procedures for Agricultural Research. 2nd ed. John Wiley & Sons, New York.

Government of Canada. 1994. Note to CAPCO: 2,4-D Re-evaluation Update and Label Improvement Program. Plant Industry Directorate. Agriculture and Agri-Food Canada. Nepean, Ontario, Canada. C94-08.

Gray, E., E.M. McGhee, and D.F. Carlisle. 1973. Seasonal variation in flowering of common dandelion. Weed Sci. 21:230-232.

Holm, L., J. Doll, E. Holm, J. Panco, and J. Herberger. 1997a. World Weeds: Natural Histories and Distribution. John Wiley and Sons, New York. Pp. 81-86.

Holm, F.A., G.R. Stuber, and C.A. Brenzil. 1997b. Efficacy of pre-seeding treatments for direct seeded crops in clay/sandy loam soil. ECW/HERB-97W. Experiment Number 9752340.

Hudson, J.P. 1955. Propagation of plants by root cuttings. II. Seasonal fluctuation of capacity to regenerate from roots. J. Hortic. Sci.30:242-251.

Jackson, B.S. 1982. The lowly dandelion deserves more respect. Can. Geogr. 102: 54-59.

Jackson, R., G. Dipankar, and G. Paterson. 2000. The soil degradation of the herbicide florasulam. Pest Manag. Sci. 56:1065-1072.

Jenniskens, M.J.P.J., P.C.J. Wetzels, and A.A. Sterk. 1984. Aspects of the flowering ecology of taxa of *Taraxacum* sect. *Taraxacum*. Bot. Jahrb. Syst. 104:369-400.

Khan, M.I. 1969. Regeneration in relation to root size in *Taraxacum officinale* Web. Pak. J. Sci. Ind. Res. 12: 310-311.

Klingman, D.L. 1946. Dandelion control with 2,4-dichlorophenoxyacetic acid (2,4-D). University of Wyoming Experimental Station Bulletin No. 274. 12 p.

Kotoula-Skya, E., and K.K. Hatzios. 1996. Interactions of tribenuron with four safeners and piperonyl butoxide on corn (*Zea mays*). Weed Sci. 44:215-218.

Krieger, M.S., R.N. Yoder, and R. Gibson. 2000a. Photolytic degradation of florasulam on soil and in water. J.Agric. Food Chem. 48:3710-3717.

Krieger, M.S., F. Pillar, and J.A. Ostrander. 2000b. Effect of temperature and moisture on the degradation and sorption of florasulam and 5-hydroxyflorasulam in soil. J. Agric. Food Chem. 48:4757-4766.

Kvalseth, T. O. 1985. Cautionary note about $R^2$. Am. Stat. 39:279-285.

LeBaron, H.M. and J. Gressel. 1982. Herbicide resistance in plants. John Wiley and Sons, New York. 353 p.

Leeson, J.Y., A.G. Thomas, T. Andrews, K.R. Brown, and R.C. Van Acker. Manitoba Weed Survey: Cereal and Oilseed Crops. 2002. Agriculture and Agri-Food Canada Weed Survey Series Publication 02-2. Saskatoon, Saskatchewan. 191 p.

Légère, A. and N. Samson. 1999. Relative influence of crop rotation, tillage, and weed management on weed associations in spring barley cropping systems. Weed Sci. 47:112-122.

Légère, A. and F.C. Stevenson. 2002. Residual effects of crop rotation and weed management on a wheat test crop and weeds. Weed Sci. 50:101-111.

Letchamo, W. and A. Gosselin. 1996. Light, temperature and duration of storage govern the germination and emergence of *Taraxacum officinale* seed. J. Hort. Sci. 71:373-377.

Litowksi, A. and I. Jackowska. 1965. Observations on plant development XI: on the rhythm of flowering of *Taraxaum officinale*. Act. Soc. Botanicorum Poloniae. 34 (3):549-561.

Liu, D.L. and N.E. Christians. 1997. Inhibitory activity of corn gluten hydrolysate on monocotyledonous and dicotyledonous species. HortScience. 32:243-245.

Longyear, B.O. 1918. The dandelion in Colorado. Agric. Exp. Sta. Agric. Coll. Colorado Bull. 236:1-35.

Lyman, J.C. and N.C. Ellstrand. 1984. Clonal diversity in *Taraxacum officinale* (Compositae), an apomict. Heredity. 53:1-10.

Manitoba Agriculture. 2000. Soil Fertility Guide. 13 p.

Manitoba Agriculture, Food and Rural Initiatives. 2004. Guide to Crop Protection 2004. 354 p.

Manitoba Agriculture, Food and Rural Initiatives. 2005. Guide to Crop Protection 2005. 354 p.

Mann, H. and P.B.Cavers. 1979. The regenerative capacity of root cuttings of *Taraxacum officinale* under natural conditions. Can. J. Bot. 57:1783-1791.

Mann, H. 1981. Common dandelion (*Taraxacum officinale*) control with 2,4-D and mechanical treatments. Weed Sci. 29:704-708.

Martinkova, Z. and A. Honek. 1997. Germination and seed viability in a dandelion, *Taraxacum officinale Agg.* Ochr. Rostl. 33 (2):125-133.

McKeague, J.A. (ed). 1978. Manual on Soil Sampling and Method of Analysis. 2nd edition. Canadian Society of Soil Science. Ottawa, ON. Pp. 29-31.

McMaster, G.S. and W.W. Wilhelm. 1997. Growing degree-days: one equation, two Interpretations. Agric. For. Meterol. 87:291-300.

Mertens King, L.M. and B.A. Schaal. 1990. Genotypic variation within asexual lineages of Taraxacum officinale. Proc. Natl. Acad. Sci. USA. Volume 87. Pp.998-1002.

Mitich, L.W. 1989. Common dandelion – the lion's tooth. Weed Technol. 3:537-539.

Mølgaard, P. 1977. Competitive effect of grass on establishment and performance of *Taraxacum officinale*. Oikos. 29:376-382.

Moyer, J.R. 1984. Yield and nutrient composition of orchardgrass hay as affected by dandelion control. Can. J. Plant Sci. 64:295-302.

Moyer, J.R., R. Hironaka, G.C. Kozub, and P. Bergen. 1990. Effect of herbicide treatments on dandelion, alfalfa and sainfoin yields and quality. Can. J. Plant Sci. 70:1105-1113.

Neal, J.C. 1990. Non-phenoxy herbicides for perennial broadleaf weed control in cool-season turf. Weed Technol. 4:555-559.

Neuwmann, S. and G.J. Boland. 1999. Influence of selected adjuvants on disease severity by *Phoma herbarum* on dandelion (*Taraxacum officinale*). Weed Technol. 13:675-679.

Ogawa, K. 1978. The germination pattern of a native dandelion (*Taraxacum platycarpum*) as compared with introduced dandelions. Jap. J. Ecol. 28:9-15.

Ominski, P.D., M.H. Entz, and N. Kenkel. 1999. Weed suppression by *Medicago sativa* in subsequent cereal crops: a comparative survey. Weed Sci. 47:282-290.

Raven, P.H., R.F. Evert, and S.E. Eichhorn. 1999. Biology of Seed Plants 6th Edition. W.H. Freeman and Company, New York. 944 p.

Reimer, A. and C.F. Shaykewich. 1980. Estimation of Manitoba soil temperatures from atmospheric meteorological measurements. Cdn. J. Soil Sci. 60:299-309.

Richards, A.J. 1970. Hybridization in *Taraxacum*. New Phytol. 69:1103-1121.

Richards, A.J. 1973. The origins of *Taraxacum* agamospecies. Biol. J. Linn. Soc. 66: 189-211.

Richardson, J. 1985. In praise of the archenemy. Audubon. 87:36-39.

Riddle, G.E., L.L. Burpee, and G.J. Boland. 1991. Virulence of *Sclerotinia sclerotiorum* and *S. minor* on dandelion (*Taraxacum officinale*). Weed Sci. 39:109-118.

Rijckaert, G. and Lepeice D. 2001. Selectivity of florasulam in 4 grass species during the seed harvest year. Med. Fac. Landbouww. Univ. Gent. 66:747-752.

Roberts, H. F. 1936. Seed reproduction in the dandelion. Scient. Agric. 27:235 242.

Roberts, H.A. and J.E. Neilson. 1981. Seed survival and periodicity of seedling emergence in twelve weedy species of compositae. Ann. Appl. Biol. 97:325-334.

Roggenbuck, F.C. and D. Penner. 1986. Susceptibility of common dandelion (*Taraxacum officinale* Weber) to glyphosate and related compounds. Proc. North Cent. Weed Control Conf. Vol. 41. Pp. 96.

Ross, M.A. and C.A. Lembi. 1999. Applied Weed Science. Second Edition. Upper Saddle River: Prentice Hall. 452 p.

Royer, F. and R. Dickinson. 1999. Weeds of Canada and the Northern United States. The University of Alberta Press, Edmonton, Alberta, Canada. Pp. 60-61.

Rutherford, P. P. and A. C. Deacon. 1974. Seasonal variation in dandelion in dandelion roots of fructosan composition, metabolism, and response to treatment with 2,4-dichloropehnoxyacetic acid. Ann. Bot. 38:251-260.

Salisbury, F.B. and C.W. Ross. 1992. Plant Physiology 4$^{th}$ Edition. Wadsworth Publishing Company. Belmont, California. Pp. 409-411.

Sawada, S., Y. Kasaishi, and Y. Nakamura. 1982. Difference in adaptive strategy of production process between indigenous and naturalized dandelions under artificial disturbance. Jap. J. Ecol. 32:347-355.

Schmidt, M. 1979. The delightful dandelion. Organic Living. 26:112-117.

Seefeldt, S. S., J. E. Jensen, and E. P. Fuerst. 1995. Log-logistic analysis of herbicide dose-response relationships. Weed Technol. 9:218-227.

Sheaffer, C.C. and D.L. Wyse. 1982. Common dandelion (*Taraxacum officinale*) control in alfalfa (*Medicago sativa*). Weed Sci. 30:216-220.

Sheldon, J.C. 1974. The behaviour of seeds in soil: the influence of seed morphology and the behaviour of seedlings on the establishment of plants from surface lying seeds. J. Ecol. 62:47-66.

Sheldon, J.C. and F.M. Burrows. 1973. The dispersal effectiveness of the achene-pappus units of selected Compositae in steady winds with convection. New Phytol. 72:665-675.

Silversides, W.H. 1938. A study of the eradication and ecology of the dandelion. M.Sc. Thesis. The University of Manitoba, Winnipeg, Manitoba, Canada. 58 p.

Solbrig, O.T. 1971. The population biology of dandelions. Am. Sci. 59:686-694.

Solbrig, O.T. and B.B. Simpson. 1974. Components of regulation of a population of dandelions in Michigan. J. Ecol. 62:473-486.

Solbrig, O.T. and B.B. Simpson. 1977. A garden experiment on competition between biotypes of the common dandelion (*Taraxacum officinale*). J. Ecol. 65:427-430.

Spandl, E., J.J. Kells, and O.B. Hesterman. 1999. Weed invasion in new stands of alfalfa seeded with perennial forage grasses and an oat companion crop. Crop Sci. 39:1120-1124.

Steel, R.G.D, J.H. Torrie, and D.A. Dickey. 1997. Principles and Procedures of Statistics: A Biometrical Approach. 3rd ed. New York: McGraw-Hill. Pp. 178-183.

Stendlund, J. and N. Alkali. 1989. Express 75 DF (DPX L5300) – a new herbicide in cereals. 30th Swedish Crop Protection Conf. Uppsala, Sweden. Pp. 138-144.

Sterk, A.A., M.C. Groenhart, and J.F.A. Mooren. 1983. Aspects of the ecology of some microspecies of Taraxacum in the Netherlands. Acta. Bot. Neerl. 32:385-415.

Sterk, A.A. and M.M. Luteijn. 1984. A study of the flowering phenology of Taraxacum microspecies in some biotypes in the Netherlands as observed during three successive years. Acta. Bot. Neerl. 33(1):39-59.

Stevenson, F.C. and A.M. Johnston. 1999. Annual broadleaf crop frequency and residual weed populations in Saskatchewan Parkland. Weed Sci. 47:208-214.

Stewart-Wade, S.M., S. Neumann, L.L. Collins, and G.J. Boland. 2002. The biology of Canadian weeds.117.*Taraxacum officinale* G.H. Weber ex Wiggers. Can. J. Plant Sci. 82:825-853.

Tackenberg, O., P. Poschlod, and S. Kahmen. 2003. Dandelion seed dispersal: the horizontal wind speed does not matter for long distance dispersal – it is updraft. Plant Biol. 5:451-454.

Taylor, R.J. 1987. Populational variation and biosystematic interpretations in weedy dandelions. Bull. Torrey Bot. Club. 114:109-120.

Thompson, A.R., A.M. McReath, C.M. Carson, R.J. Her, and G.J. deBoer. 1999. Florasulam: a new, low dose herbicide for broadleaf control in cereals. Brighton Crop Protection Conf.—Weeds. Surrey, U.K.: British Crop Protection Council. Pp. 73-80.

Tilman, E.A., D. Tilman, M.J. Crawley, and A.E. Johnston. 1999. Biological weed control via nutrient competition: potassium limitation of dandelions. Ecol. Appl. 9:103-111.

Triplette, G.B. Jr. and G.D. Lytle. 1972. Control and ecology of weeds in continuous corn grown without tillage. Weed Sci. 20:453-457.

Van Acker, R.C., A.G. Thomas, J.Y. Leeson, T. Andrews, and K. Brown. 2002. What's up? Preliminary results from the 2002 Manitoba survey of weeds in cereal and oilseed crops. Proceedings from the 2002 Manitoba Agronomists Conference. Pp. 109-105.

Vavrek, M.C., J.B. McGraw, and H.S. Yang. 1996. Within-population variation in demography of *Taraxacum officinale*: maintenance of genetic diversity. Ecology. 77:2098-2107.

Vavrek, M.C., J.B. McGraw, and H.S. Yang. 1997. Within-population variation in demography of *Taraxacum officinale*: season- and size-dependent survival, growth, and reproduction. J. Ecol. 85:277-287.

Waddington, J. 1980. Chemical control of dandelion (*Taraxacum officinale*) and perennial sowthistle (*Sonchus arvensis*) in alfalfa (*Medicago sativa*) grown for seed. Weed Sci. 28:164-167.

Watson, G.A. and H.P. Allen. 1985. Limited Tillage Around the World. Chapter 12. Pages 26-40 *in* Weed Control in Limited Tillage Systems. A. F. Wiese (ed). Weed Science Society of America. Champaign, Illinois.

Watson, P.R., D.A. Derksen, A.G. Thomas, G.C. Turnbull, R.E. Blackshaw, J.Y. Leeson, A. Légère, R.C. Van Acker, S.A. Brandt, A.M. Johnston, G.P. Lafond, and B.G. McConkey. 2001. Weed management and ecology in conservation tillage systems: determination of weed community changes in conservation-tillage systems. Weed Community Analysis Series, Publication Dow-2001-01. Brandon, Manitoba: Agriculture and Agri-Food Canada. 229 p.

Whelham, C.V.J. and R.A. Setter. 1998. Comparison of size-dependent reproductive effort in two dandelion (*Taraxacum officinale*) populations. Can. J. Bot. 76:166-173.

Whitson, T.D., L.C. Burril, S.A. Dewey, D.W. Cudney, B.E. Nelson, R.E. Lee, and R. Parker. 1996. Weeds of the West. Pioneer of Jackson Hole, Jackson, Wyoming. Pp. 186-187.

Wilson, R.G. and A. Michiels. 2003. Fall herbicide treatments affect carbohydrate content in roots of Canada thistle (*Cirsium arvense*) and dandelion (*Taraxacum officinale*). Weed Sci. 51:299-304.

Witt, W.W., 1984. Response of weeds and herbicides under no-tillage conditions. Chapter 7. Pages 153-170. *in* No-Tillage Agriculture. Phillips, R. E. and S. H. Phillips (ed). Van Nostrand Reinhold Company, New York.

Wrucke, M.A. and W.E. Arnold. 1985. Weed species distribution as influenced by tillage and herbicides. Weed Sci. 33:853-856.

[WSSA] Weed Science Society of America. 1994. Herbicide Handbook of the Weed Science Society of America. 7th ed. 1508 West University Avenue. Champaign, Illinois. 61821-3133.

Zollinger, R.K., D. Penner, and J. J. Kells. 1992. Absorption, translocation, and foliar activity of clopyralid and tribenuron in perennial sowthistle (*Sonchus arvensis*). Weed Sci. 40:528-533.

## 7.0 APPENDICES

Table 7.1 Field histories for the 2003 and 2004 site-years.

| Year | Crop | Tillage | Herbicide |
|---|---|---|---|
| **Oak Bluff 1 and Oak Bluff 2** | | | |
| 2002 | Sunflowers | Disk[a], In-crop[b] | Glyphosate[c] |
| 2001 | Oats | Sweeps[d], Harrow[e] | Bromoxynil, MCPA ester |
| 2000 | Canola | Sweeps | Glufosinate ammonium, Clethodim |
| 1999 | Wheat | Sweeps, Harrow | Bromoxynil, MCPA ester, Fenoxyprop, |
| 1998 | Flax | Sweeps | Bromoxynil, MCPA ester, Sethoxydim, Lontrel |
| **Carman** | | | |
| 2002 | Wheat | Harrow[e] | Florasulam[f], Glyphosate[c], Bromoxynil, MCPA ester, Sethoxydim |
| 2001 | Canola | Harrow | Glyphosate[g], Sethoxydim, Ethametasulfuron-methyl |
| 2000 | Wheat | Harrow | Glyphosate[h], Sethoxydim, Thifensulfuron, Tribenuron |
| 1999 | Oats | Harrow | Glyphosate[h],Bromoxynil, MCPA ester |
| 1998 | Flax | Harrow | Glyphosate[h],Bromoxynil, MCPA ester, Sethoxydim, Lontrel |
| **Roland** | | | |
| 2003 | Oats | Sweeps[i], Harrow[j] | Clopyralid, MCPA ester, Fluoxypyr, Popanil |
| 2002 | Wheat | Sweeps, Harrow | Flucarbazone-sodium, Dichloroprop, 2,4-D ester |
| 2001 | Flax | Sweeps, Harrow | Sethoxydim, Lontrel, MCPA ester |
| 2000 | Wheat | Sweeps, Harrow | 2,4-D ester, Fluoxypyr |
| 1999 | Flax | Sweeps, Harrow | Bromoxynil, MCPA ester, Sethoxydim, Lontrel |
| **Carman U of M** | | | |
| 2003 | Wheat | Sweeps[k] | Clodinafop-propargyl, MCPA ester, Mecaprop, Dicamba |
| 2002 | Wheat[l] | Sweeps | Glyphosate[h], Imazamox, Imazethapyr |
| 2001 | Winter Wheat | Sweeps | Bromoxynil, MCPA ester |
| 2000 | Oats | None | Diquat[m] |
| 1999 | Alfalfa[n] | Disk | Glyphosate[o] |

[a] Field was double disked once in the fall.
[b] In-crop tillage due to row cropped sunflowers.
[c] Glyphosate applied pre-seed at a rate of 450 g a.i. $ha^{-1}$.
[d] Field was cultivated twice in the fall using 13 inch sweeps.
[e] Field harrowed once in the fall using medium weight tine harrows.
[f] Florasulam applied pre-seed at a rate of 5 g a.e. $ha^{-1}$.
[g] Glyphosate applied pre-seed at a rate of 1350 g a.i. $ha^{-1}$.
[h] Glyphosate applied pre-seed at a rate of 900 g a.i. $ha^{-1}$.
[i] Field was cultivated twice in the fall using 9 inch sweeps.
[j] Field harrowed using diamond harrows once in the spring.
[k] Field was cultivated once in the fall using 9 inch wide sweeps and once in the spring using 6 inch sweeps.

[l] Wheat intercropped with peas and canola.
[m] Diquat applied post-harvest at a rate of 296.5 g a.e. $ha^{-1}$.
[n] Alfalfa stand terminated in the fall of 1999 after 6 years.
[o] Glyphosate applied post-harvest at a rate of 1800 g a.i. $ha^{-1}$.

Table 7.2. Meteorological conditions at the time of the post-harvest and pre-seed herbicide applications for each of the 5 site-years.[a]

| Application Timing | Site-years | | | | |
|---|---|---|---|---|---|
| | Oak Bluff 1[b] 2003 | Oak Bluff 2[b] 2003 | Carman[c] 2003 | Roland[c] 2004 | Carman UM[c] 2004 |
| Post-harvest | | | | | |
| Air temperature (C) | 10 | 14 | 19 | 11 | 12 |
| Relative humidity (%) | 47 | 73 | 53 | 77 | 70 |
| Wind speed (kph) | 19 | 9 | 19 | 6 | 6 |
| Wind direction | SW | W | W | N | N |
| Pre-seed | | | | | |
| Air temperature (C) | 9 | 16 | 10 | 13 | 13 |
| Relative humidity | 34 | 60 | 67 | 62 | 47 |
| Wind speed (kph) | 7 | 22 | 13 | 13 | 4 |
| Wind direction | N | SE | SE | SW | N |

[a] Weather data provided by Environment Canada. Available at: www.climate.weatheroffice.ec.gc.ca; accessed November 15, 2004.
[b] Data taken from Environment Canada station at Winnipeg International Airport, Winnipeg, Manitoba.
[c] Data taken from Environment Canada station at the University of Manitoba Research Station, Carman, Manitoba.

Table 7.3. Monthly mean temperature and precipitation at Winnipeg, Manitoba and Carman, Manitoba during the 2003 and 2004 growing seasons, and the 30-year norm (1971 – 2000).[a]

| | April | May | June | July | August | September | October |
|---|---|---|---|---|---|---|---|
| **Winnipeg** | | | | | | | |
| Temperature (C): | | | | | | | |
| 2003 | 5.4 | 12.6 | 16.7 | 19.4 | 21.6 | 12.6 | 6.6 |
| 2004 | 3.6 | 7.4 | 14.1 | 18.2 | 14.3 | 14.6 | 6.0 |
| 30-yr norm[b] | 4.0 | 12.0 | 17.0 | 19.5 | 18.5 | 12.3 | 5.3 |
| Precipitation (mm): | | | | | | | |
| 2003 | 33.0 | 78.5 | 42.5 | 44.5 | 72.0 | 38.5 | 18.5 |
| 2004 | 23.3 | 134.0 | 35.0 | 67.0 | 127.5 | 84.6 | 50.5 |
| 30-yr norm[b] | 31.9 | 58.8 | 89.5 | 70.6 | 75.1 | 52.3 | 36.0 |
| **Carman** | | | | | | | |
| Temperature (C): | | | | | | | |
| 2003 | 5.5 | 12.3 | 16.6 | 19.2 | 20.7 | 12.4 | 7.0 |
| 2004 | 4.2 | 7.8 | 14.6 | 18.0 | 14.0 | 14.1 | 6.0 |
| 30-yr norm[c] | 4.2 | 12.5 | 16.9 | 19.4 | 18.2 | 12.3 | 5.5 |
| Precipitation (mm): | | | | | | | |
| 2003 | 32.2 | 80.2 | 81.0 | 56.4 | 70.8 | 36.2 | 24.1 |
| 2004 | 21.0 | 166.6 | 32.4 | 50.2 | 76.6 | 87.0 | 35.2 |
| 30-yr norm[c] | 33.4 | 53.4 | 81.0 | 71.1 | 70.0 | 57.7 | 38.4 |

[a] Weather data provided by Environment Canada . Available at: www.climate.weatheroffice.ec.gc.ca; accessed January 31, 2005.
[b] 30-year normal based on years 1971-2000 at Winnipeg International Airport, Winnipeg, Manitoba, Canada.
[c] 30-year normal based on years 1971-2000 at Elm Creek, Manitoba, Canada.

Table 7.4. Volumetric soil moisture (Pv) and corresponding accumulated growing degree days (AccGDD) for permanent quadrat sampling for each site-year (standards errors in parentheses)[a].

| Site-years | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oak Bluff 1[b] 2003 | | Oak Bluff 2[b] 2003 | | Carman[b] 2003 | | Roland 2004 | | Carman UM[c] 2004 | |
| AccGDD | Pv | AccGDD | Pv | AccGDD | Pv | AccGDD | Pv | AccGDD | Pv |
| 213 | 33.8 (0.7) ed | 215 | 35.4 (0.6) bcd | 320 | 27.4 (0.7) abc | 100 | 23.8 (0.4) ef | 98 | 27.2 (0.7) abcd |
| 357 | 33.3 (0.8) ed | 336 | 34.2 (0.9) cd | 448 | 26.9 (0.6) abc | 162 | 24.7 (1.3) cdef | 145 | 23.9 (0.7) ef |
| 423 | 34.8 (0.7) cde | 401 | 37.4 (0.6) a | 533 | 25.8 (0.7) c | 226 | 23.5 (1.4) ef | 378 | 25.9 (0.5) bcde |
| 551 | 35.4 (1.2) bcd | 514 | 35.4 (0.7) bc | 644 | 23.7 (0.8) d | 313 | 27.6 (0.9) ab | 492 | 27.3 (0.7) abcd |
| 647 | 37.7 (1.5) abc | 667 | 36.8 (0.7) ab | 847 | 27.6 (0.7) ab | 436 | 26.5 (0.6) abcd | 574 | 25.0 (0.5) de |
| 796 | 40.6 (0.7) a | 776 | 35.8 (0.9) abc | 904 | 28.0 (0.6) a | 507 | 26.7 (0.6) abc | 674 | 25.5 (0.8) cde |
| 908 | 38.0 (0.6) ab | 861 | 33.5 (0.6) d | 1021 | 26.1 (0.8) bc | 640 | 28.5 (1.3) a | 695 | 24.5 (1.1) ef |
| 1120 | 31.9 (1.4) e | 1169 | 28.4 (0.5) e | 1142 | 22.5 (0.5) de | 770 | 26.8 (0.8) abc | 785 | 25.0 (1.2) de |
| 1586 | 26.5 (1.7) f | | | 1372 | 21.2 (0.4) e | 888 | 17.6 (0.7) h | 875 | 18.9 (1.1) g |
| | | | | | | 961 | 18.9 (0.7) gh | 976 | 16.6 (0.8) g |
| | | | | | | 1072 | 22.4 (0.9) f | 1096 | 27.0 (0.6) abcd |
| | | | | | | 1149 | 26.6 (0.9) abcd | 1153 | 18.8 (0.8) g |
| | | | | | | 1218 | 27.3 (0.7) ab | 1272 | 10.0 (1.1) h |
| | | | | | | 1285 | 20.0 (1.0) g | 1416 | 17.8 (1.1) g |
| | | | | | | 1426 | 13.4 (0.6) i | 1633 | 27.1 (0.9) abcd |
| | | | | | | 1581 | 17.8 (0.9) gh | 1768 | 22.3 (1.1) f |
| | | | | | | 1825 | 28.4 (0.6) a | 1908 | 27.8 (0.7) abc |
| | | | | | | 1948 | 18.7 (0.6) gh | 2035 | 27.7 (1.1) abc |
| | | | | | | 2096 | 26.3 (0.5) abcd | 2159 | 28.0 (0.7) ab |
| | | | | | | 2226 | 25.3 (0.7) bcde | 2340 | 29.0 (0.4) a |
| | | | | | | 2355 | 26.8 (0.6) abc | 2454 | 18.0 (1.2) g |
| | | | | | | 2538 | 24.3 (0.5) def | | |

[a] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at $P \leq 0.05$.
[b] Volumetric soil moisture sampling terminated in mid July at the 2003 site-years due to extremely dry soil conditions rendering sampling impossible.
[c] At Carman UM depth was a significant factor but only accounted for 2.8% of the model sum of squares, therefore data was pooled over depth.

Table 7.5. Julian days (JDay) and corresponding accumulated growing degree days (AccGDD) for permanent quadrat sampling for each site-year.

| Site-years | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Oak Bluff 1 2003 | | Oak Bluff 2 2003 | | Carman 2003 | | Roland 2004 | | Carman UM 2004 | |
| JDay | AccGDD | JDay | AccGDD | JDay | AccGDD | JDay | AccGDD | JDay | AccGDD |
| 106 | 53 | 106 | 53 | 111 | 53 | 113 | 100 | 113 | 98 |
| 114 | 96 | 114 | 104 | 118 | 204 | 120 | 162 | 120 | 145 |
| 121 | 150 | 121 | 157 | 126 | 258 | 127 | 226 | 148 | 378 |
| 129 | 213 | 129 | 215 | 133 | 320 | 138 | 313 | 156 | 492 |
| 141 | 347 | 141 | 336 | 143 | 448 | 149 | 436 | 161 | 574 |
| 147 | 423 | 147 | 401 | 149 | 533 | 154 | 507 | 166 | 647 |
| 155 | 551 | 155 | 514 | 156 | 644 | 161 | 640 | 169 | 695 |
| 161 | 647 | 161 | 667 | 168 | 847 | 169 | 770 | 175 | 785 |
| 169 | 796 | 169 | 766 | 171 | 904 | 177 | 888 | 181 | 875 |
| 175 | 908 | 175 | 861 | 178 | 1021 | 181 | 961 | 187 | 976 |
| 187 | 1120 | 187 | 1169 | 185 | 1142 | 187 | 1072 | 194 | 1096 |
| 210 | 1586 | 210 | 1447 | 198 | 1372 | 191 | 1149 | 197 | 1153 |
| 226 | 1934 | 226 | 1863 | 210 | 1603 | 194 | 1218 | 203 | 1272 |
| | | | | 226 | 1922 | 197 | 1285 | 211 | 1416 |
| | | | | | | 203 | 1426 | 224 | 1633 |
| | | | | | | 211 | 1581 | 233 | 1768 |
| | | | | | | 225 | 1825 | 243 | 1908 |
| | | | | | | 233 | 1948 | 251 | 2035 |
| | | | | | | 243 | 2096 | 260 | 2159 |
| | | | | | | 251 | 2226 | 273 | 2340 |
| | | | | | | 260 | 2355 | 285 | 2454 |
| | | | | | | 273 | 2538 | | |

Table 7.6. Mean total number of dandelion seedlings that emerged from greenhouse trays for each site-year (standard errors in parentheses).

| Site | Year | Total seedlings[a] |
|---|---|---|
| | | —— plants $m^{-2}$—— |
| Oak Bluff 1 | 2003 | 382.7 (143.6) |
| Oak Bluff 2 | 2003 | 1148.0 (669.3) |
| Carman | 2003 | 223.2 (113.8) |
| Roland | 2004 | 63.8 (63.8) |
| Carman UM | 2004 | 63.8 (63.8) |

[a] Mean total dandelion seedling density is a measure of total number of dandelion seedlings emerged in cycle 1 of the greenhouse study.

Table 7.7. Correlation among total number of dandelion seedlings and total number of dandelion plants from rootstock per $m^{-2}$. P values occur in parentheses below the correlation coefficients. Site-years have been combined.

| | Rootstock | Seedlings |
|---|---|---|
| Rootstock | 1.00 | |
| Seedlings | -0.1<br>(0.6893) | 1.00 |

Table 7.8. Correlation among total number of dandelion seedlings and greatest number of dandelion plants flowering per $m^{-2}$. P values occur in parentheses below the correlation coefficients. Site-years have been combined.

| | Flowering | Seedlings |
|---|---|---|
| Flowering | 1.00 | |
| Seedlings | 0.30<br>(0.1985) | 1.00 |

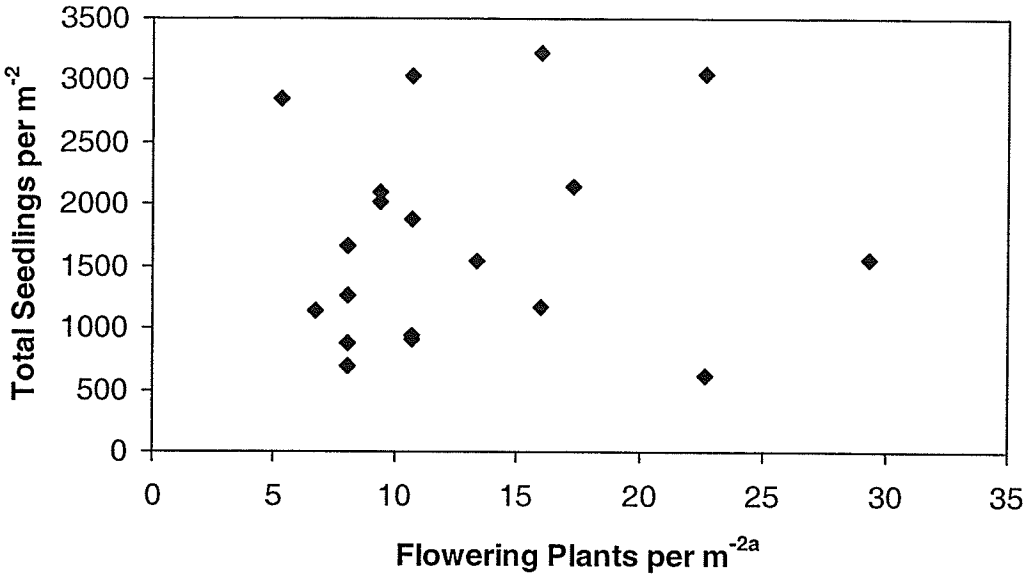



Figure 7.1. Relationship of the greatest number of flowering dandelion plants per $m^{-2}$ and the total number of dandelion seedlings emerged throughout the growing season.
[a] Flowering plants per $m^{-2}$ refers to the greatest number of dandelion plants flowering at a point in time.

Table 7.9. Correlation among measured variables in 2003. P values occur in parentheses below the correlation coefficients. 2003 site-years have been combined.

| | CDbio[a] | PDbio[b] | Whtbio[c] | WhtYld[d] | CDnoR[e] | CDnoS[f] | PDnoR[g] | PDnoS[h] |
|---|---|---|---|---|---|---|---|---|
| CDbio | 1.00 | | | | | | | |
| PDbio | **0.63**[i] | 1.00 | | | | | | |
| | (<0.0001) | | | | | | | |
| Whtbio | -0.39 | -0.43 | 1.00 | | | | | |
| | (<0.0001) | (<0.0001) | | | | | | |
| WhtYld | -0.46 | **-0.62** | 0.46 | 1.00 | | | | |
| | (<0.0001) | (<0.0001) | (<0.0001) | | | | | |
| CDnoR | 0.40 | 0.34 | -0.1 | -0.25 | 1.00 | | | |
| | (<0.0001) | (<0.0001) | (0.1898) | (0.0007) | | | | |
| CDnoS | 0.20 | 0.25 | -0.12 | -0.18 | 0.22 | 1.00 | | |
| | (0.0080) | (0.0007) | (0.1022) | (0.0159) | (0.0032) | | | |
| PDnoR | 0.31 | 0.44 | -0.14 | -0.27 | **0.63** | 0.32 | 1.00 | |
| | (<0.0001) | (<0.0001) | (0.0539) | (0.0002) | (<0.0001) | (<0.0001) | | |
| PDnoS | -0.07 | -0.02 | -0.36 | 0.08 | -0.09 | 0.17 | 0.02 | 1.00 |
| | (0.3289) | (0.8222) | (<0.0001) | (0.2873) | (0.2275) | (0.0226) | (0.7841) | |

[a] CDbio represents dandelion biomass assessed at the boot stage of the wheat crop.
[b] PDbio represents dandelion biomass assessed post-harvest.
[c] Whtbio represents wheat biomass assessed at the boot stage of the wheat crop.
[d] WhtYld represents wheat grain yield.
[e] CDnoR represents dandelion rootstock density assessed at the boot stage of the wheat crop.
[f] CDnoS represents dandelion seedling density assessed at the boot stage of the wheat crop.
[g] PDnoR represents dandelion rootstock density assessed post-harvest.
[h] PDnoS represents dandelion seedling density assessed post-harvest.
[i] All variables with a correlation coefficient of (+/-) 0.50 or greater is highlighted in bold. The number of observations used in calculating the correlation coefficients for 2003 was 180.

Table 7.10. Correlation among measured variables in 2004. P values occur in parentheses below the correlation coefficients. 2004 site-years have been combined.

| | CDbio[a] | PDbio[b] | Whtbio[c] | WhtYld[d] | CDnoR[e] | CDnoS[f] | PDnoR[g] | PDnoS[h] |
|---|---|---|---|---|---|---|---|---|
| CDbio | 1.00 | | | | | | | |
| PDbio | **0.72**[i] | 1.00 | | | | | | |
| | (<0.0001) | | | | | | | |
| Whtbio | **-0.60** | **-0.61** | 1.00 | | | | | |
| | (<0.0001) | (<0.0001) | | | | | | |
| WhtYld | **-0.63** | **-0.54** | 0.43 | 1.00 | | | | |
| | (<0.0001) | (<0.0001) | (<0.0001) | | | | | |
| CDnoR | **0.61** | **0.62** | **-0.67** | -0.47 | 1.00 | | | |
| | (<0.0001) | (<0.0001) | (<0.0001) | (<0.0001) | | | | |
| CDnoS | 0.17 | 0.38 | -0.22 | -0.05 | 0.27 | 1.00 | | |
| | (0.0684) | (<0.0001) | (0.0165) | (0.6065) | (0.0024) | | | |
| PDnoR | **0.52** | **0.72** | -0.45 | -0.38 | **0.53** | 0.15 | 1.00 | |
| | (<0.0001) | (<0.0001) | (<0.0001) | (<0.0001) | (<0.0001) | (0.1072) | | |
| PDnoS | -0.47 | 0.45 | -0.45 | -0.18 | -0.38 | 0.47 | 0.25 | 1.00 |
| | (<0.0001) | (<0.0001) | (<0.0001) | (0.0501) | (<0.0001) | (<0.0001) | (0.0063) | |

[a] CDbio represents dandelion biomass assessed at the boot stage of the wheat crop.
[b] PDbio represents dandelion biomass assessed post-harvest.
[c] Whtbio represents wheat biomass assessed at the boot stage of the wheat crop.
[d] WhtYld represents wheat grain yield.
[e] CDnoR represents dandelion rootstock density assessed at the boot stage of the wheat crop.
[f] CDnoS represents dandelion seedling density assessed at the boot stage of the wheat crop.
[g] PDnoR represents dandelion rootstock density assessed post-harvest.
[h] PDnoS represents dandelion seedling density assessed post-harvest.
[i] All variables with a correlation coefficient of (+/-) 0.50 or greater is highlighted in bold. The number of observations used in calculating the correlation coefficients for 2004 was 120.

Table 7.11. Visually estimated early season control of herbicides applied either in the fall or spring on dandelion originating from rootstock for each site-year[a] (standard errors in parentheses)[b].

| Trt. no. | Treatment[c] | Application dose | Application timing[d] | Site-years | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | | Carman UM 2004 |
| | | g ha$^{-1}$[e] | | % | | | | | |
| 1 | NTC | --- | --- | 0 | 0 | 0 | 0 | | 0 |
| 2 | Glyph | 450 | Fall | 84 (3.1) c | 85 (6.8) bc | 75 ( 3.3) de | 69 | (10.1) d | 73 (3.3) cd |
| 3 | | | Spring | 64 (3.1) f | 65 (2.0) f | 60 (7.1) f | 70 | (4.1) d | 72 (1.7) de |
| 4 | Glyph | 675 | Fall | 91 (2.4) b | 93 (2.5) ab | 91 (2.4) abc | 83 | (1.4) bc | 78 (3.4) bc |
| 5 | | | Spring | 71 (1.3) e | 66 (1.3) ef | 78 (5.0) de | 76 | (3.6) cd | 68 (1.2) e |
| 6 | Glyph | 1350 | Fall | 97 (0.8) a | 95 (3.3) a | 92 (1.2) a | 90 | (0.8) ab | 92 (1.2) a |
| 7 | | | Spring | 79 (1.5) cd | 84 (3.8) bcd | 88 (3.8) abcd | 89 | (2.4) ab | 78 (1.8) bc |
| 8 | Glyph + Flor | 450 + 5 | Fall | 98 (0.0) a | 97 (0.8) a | 96 (0.8) ab | 90 | (2.0) ab | 94 (0.8) a |
| 9 | | | Spring | 75 (1.7) de | 73 (1.4) ef | 82 (3.4) bcd | 84 | (0.8) bc | 74 (1.3) cd |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 98 (0.3) a | 98 (0.0) a | 97 (0.9) a | 94 | (0.8) a | 95 (0.0) a |
| 11 | | | Spring | 81 (0.5) c | 76 (1.3) cdef | 81 (1.5) cd | 88 | (2.5) ab | 75 (1.7) cd |
| 12 | Glyph + Flor | 900 + 5 | Fall | 98 (0.9) a | 97 (0.8) a | 94 (2.1) abc | 95 | (0.0) a | 97 (1.5) a |
| 13 | | | Spring | 82 (1.2) c | 75 (1.2) def | 86 (1.3) abcd | 91 | (1.5) ab | 81 (0.7) b |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 93 (1.2) b | 90 (4.6) ab | 93 (2.9) abc | 89 | (1.3) ab | 94 (1.3) a |
| 15 | | | Spring | 71 (2.4) e | 77 (6.6) cde | 66 (12.5) ef | 81 | (2.4) bc | 77 (2.9) bc |

[a] Visually assessed approximately 1 month after the spring herbicide application.
[b] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05.
[c] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[d] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[e] Dosage of glyphosate expressed as g a.e. ha$^{-1}$; dosage of florasulam expressed as g a.i. ha$^{-1}$; dosage of tribenuron expressed as g a.i. ha$^{-1}$.

Table 7.12. Visually estimated late season control of herbicides applied either in the fall or spring on dandelion originating from rootstock for each site-year[a] (standard errors in parentheses)[b].

| Trt. no. | Treatment[c] | Application dose | Application timing[d] | Site-years | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
| | | g ha$^{-1}$[e] | | % | | | | |
| 1 | NTC | --- | --- | 0 | 0 | 0 | 0 | 0 |
| 2 | Glyph | 450 | Fall | 91 (2.5) de | 76 (6.0) gh | 93 (2.5) de | 79 (3.8) ef | 73 (1.7) cde |
| 3 | | | Spring | 85 (1.9) f | 74 (4.3) h | 89 (1.5) e | 69 (4.3) f | 62 (1.7) f |
| 4 | Glyph | 675 | Fall | 95 (1.7) bcd | 90 (2.0) cdef | 95 (0.0) cd | 81 (3.8) de | 86 (1.8) ab |
| 5 | | | Spring | 89 (2.5) e | 85 (2.0) efg | 90 (0.8) e | 69 (3.8) f | 66 (6.8) ef |
| 6 | Glyph | 1350 | Fall | 97 (0.8) ab | 95 (2.4) abc | 98 (0.0) ab | 94 (0.8) ab | 94 (1.3) a |
| 7 | | | Spring | 97 (0.8) ab | 91 (3.8) bcde | 97 (1.5) abc | 89 (1.3) bcd | 81 (6.1) bcd |
| 8 | Glyph + Flor | 450 + 5 | Fall | 96 (1.6) ab | 96 (1.4) ab | 98 (0.0) ab | 89 (2.4) bcd | 86 (5.1) ab |
| 9 | | | Spring | 93 (1.2) cde | 91 (1.3) ab | 95 (1.7) bcd | 76 (4.3) ef | 73 (4.3) de |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 98 (4.8) ab | 98 (0.3) a | 98 (0.0) ab | 92 (2.4) abc | 93 (1.8) a |
| 11 | | | Spring | 97 (0.9) abc | 94 (2.1) abcd | 96 (1.4) bcd | 85 (2.1) cde | 81 (2.4) bcd |
| 12 | Glyph + Flor | 900 + 5 | Fall | 99 (0.3) a | 98 (0.0) a | 99 (0.3) a | 97 (0.9) a | 95 (0.0) a |
| 13 | | | Spring | 96 (2.0) abc | 97 (0.9) ab | 97 (1.7) abc | 92 (2.0) abc | 82 (1.5) bc |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 97 (0.9) abc | 88 (2.7) def | 98 (0.0) ab | 91 (2.4) abc | 93 (1.4) a |
| 15 | | | Spring | 94 (1.4) bcd | 82 (4.6) gh | 95 (1.7) bcd | 80 (6.5) de | 80 (3.5) bcd |

[a] Visually assessed post crop harvest.
[b] Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD at P≤0.05.
[c] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[d] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[e] Dosage of glyphosate expressed as g a.e. ha$^{-1}$; dosage of florasulam expressed as g a.i. ha$^{-1}$; dosage of tribenuron expressed as g a.i. ha$^{-1}$.

Table 7.13. Mean density of dandelion plants from rootstock flowering (no. $m^{-2}$) assessed prior to the spring herbicide application for each herbicide treatment and for each site year (standard errors in parentheses).

| Trt. no. | Treatment[a] | Application dose | Application timing[b] | Site-years | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
| | | g $ha^{-1}$[c] | | no. $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 0.00 | 0.00 | 0.00 | 0.00 | 10.0 (1.6) |
| 2 | Glyph | 450 | Fall | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 |
| 3 | | | Spring | 0.00 | 0.00 | 0.00 | 0.00 | 10.3 (3.9) |
| 4 | Glyph | 675 | Fall | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 |
| 5 | | | Spring | 0.00 | 0.00 | 0.00 | 0.00 | 19.0 (5.8) |
| 6 | Glyph | 1350 | Fall | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 |
| 7 | | | Spring | 0.00 | 0.00 | 0.00 | 0.00 | 12.3 (2.3) |
| 8 | Glyph + Flor | 450 + 5 | Fall | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 |
| 9 | | | Spring | 0.00 | 0.00 | 0.00 | 0.00 | 17.7 (4.3) |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 |
| 11 | | | Spring | 0.00 | 0.00 | 0.00 | 0.00 | 19.0 (3.4) |
| 12 | Glyph + Flor | 900 + 5 | Fall | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 |
| 13 | | | Spring | 0.00 | 0.00 | 0.00 | 0.00 | 10.3 (3.5) |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 0.00 | 0.00 | 0.00 | 0.00 | 0.0 |
| 15 | | | Spring | 0.00 | 0.00 | 0.00 | 0.00 | 8.3 (1.4) |

[a] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[b] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[c] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

Table 7.14. Mean density of dandelion plants from rootstock flowering (no. $m^{-2}$) assessed prior to the in-crop herbicide application[a] for each herbicide treatment and for each site year (standard errors in parentheses).

| Trt. no. | Treatment[b] | Application dose | Application timing[c] | Site-years: Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
|---|---|---|---|---|---|---|---|---|
| | | g $ha^{-1}$[d] | | no. $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 11.3 (1.6) | 10.0 (1.3) | 15.3 (3.6) | 7.3 (1.8) | 4.3 (1.6) |
| 2 | Glyph | 450 | Fall | 1.7 (1.7) | 0.3 (0.3) | 2.3 (2.3) | 1.0 (1.0) | 0.3 (0.3) |
| 3 | | | Spring | 1.3 (1.3) | 0.0 | 7.0 (4.1) | 0.0 | 0.0 |
| 4 | Glyph | 675 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 (0.3) |
| 5 | | | Spring | 0.0 | 0.0 | 0.3 (0.3) | 0.0 | 0.0 |
| 6 | Glyph | 1350 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 8 | Glyph + Flor | 450 + 5 | Fall | 0.0 | 0.0 | 0.3 (0.3) | 0.3 (0.3) | 0.0 |
| 9 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 0.0 | 0.3 (0.3) | 0.3 (0.3) | 0.0 | 0.0 |
| 11 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12 | Glyph + Flor | 900 + 5 | Fall | 0.3 (0.3) | 0.0 | 0.7 (0.7) | 0.0 | 0.0 |
| 13 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 15 | | | Spring | 0.0 | 0.0 | 4.3 (4.3) | 0.0 | 0.0 |

[a] Measured approximately in mid June.
[b] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[c] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[d] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

Table 7.15. Mean density of dandelion plants from rootstock flowering (no. $m^{-2}$) assessed at the boot stage of the wheat crop[a] for each herbicide treatment and for each site year (standard errors in parentheses).

| Trt. no. | Treatment[b] | Application dose | Application timing[c] | Site-years | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
| | | g $ha^{-1}$[d] | | no. $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 0.0 | 0.0 | 0.0 | 0.1 (0.1) | 6.5 (0.6) |
| 2 | Glyph | 450 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | Glyph | 675 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6 | Glyph | 1350 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 8 | Glyph + Flor | 450 + 5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 9 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12 | Glyph + Flor | 900 + 5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13 | | | Spring | 0.0 | 0.0 | 0.0 | 0.4 (0.4) | 0.0 |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 15 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

[a] Measured at the boot stage of the wheat crop (according to Zadok's growth stages for cereal crops).
[b] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[c] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[d] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

Table 7.16. Mean density of dandelion plants from rootstock flowering (no. $m^{-2}$) assessed prior to wheat harvest[a] for each herbicide treatment and for each site year (standard errors in parentheses).

| Trt. no. | Treatment[b] | Application dose | Application timing[c] | Site-years | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
| | | g $ha^{-1}$[d] | | no. $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 0.0 | 0.0 | 0.0 | 0.0 | 4.1 (3.1) |
| 2 | Glyph | 450 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 1.6 (0.9) |
| 4 | Glyph | 675 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 (0.8) |
| 5 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 2.4 (1.6) |
| 6 | Glyph | 1350 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 (0.8) |
| 8 | Glyph + Flor | 450 + 5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 9 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 (0.8) |
| 12 | Glyph + Flor | 900 + 5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 15 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

[a] 2003 sites assessed approximately at the beginning of August. 2004 sites assessed at the beginning of September.
[b] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[c] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[d] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

Table 7.17. Mean density of dandelion plants from rootstock flowering (no. $m^{-2}$) assessed post-wheat harvest[a] for each herbicide treatment and for each site year (standard errors in parentheses).

| Trt. no. | Treatment[b] | Application dose | Application timing[c] | Site-years | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Oak Bluff 1 2003 | Oak Bluff 2 2003 | Carman 2003 | Roland 2004 | Carman UM 2004 |
| | | g $ha^{-1}$[d] | | no. $m^{-2}$ | | | | |
| 1 | NTC | --- | --- | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | Glyph | 450 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | Glyph | 675 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 (0.8) |
| 6 | Glyph | 1350 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 (0.8) |
| 8 | Glyph + Flor | 450 + 5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 9 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | Glyph + Flor | 675 + 7.5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 11 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12 | Glyph + Flor | 900 + 5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 14 | Glyph + Triben | 450 + 7.5 | Fall | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 15 | | | Spring | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

[a] 2003 sites assessed approximately at the beginning of September. 2004 sites assessed at the beginning of October.
[b] Abbreviations: NTC, nontreated control; Glyph, glyphosate; Flor, florasulam; Triben, tribenuron.
[c] Fall applications made post crop harvest. Spring applications made prior to crop seeding.
[d] Dosage of glyphosate expressed as g a.e. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$; dosage of tribenuron expressed as g a.i. $ha^{-1}$.

Table 7.18. Results of ANOVA for number of dandelion plants originating from rootstock (no. $m^{-2}$) emerged on the first sampling date of the growing season.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Site-year | 4 | 3390.66 | 847.67 | 0.86 | 0.5174 |
| Rep | 3 | 997.34 | 332.45 | 0.34 | 0.8000 |
| Error | 12 | 11889.21 | 990.77 | | |

Table 7.19. Results of ANOVA for total number of dandelion plants originating from seed (no. $m^{-2}$) emerged throughout the entire growing season.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Site-year | 4 | 8865376.47 | 2216344.12 | 8.22 | 0.0020 |
| Rep | 3 | 821363.20 | 273787.73 | 1.02 | 0.4199 |
| Error | 12 | 3235360.98 | 269613.41 | | |

Table 7.20. Results of ANOVA for dandelion seedling survival (%) as assessed at the end of the growing season.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Site-year | 4 | 27152.80 | 6788.20 | 321.51 | <0.0001 |
| Rep | 3 | 102.66 | 34.22 | 1.62 | 0.2365 |
| Error | 12 | 253.36 | 21.11 | | |

Table 7.21. Results of ANOVA for dandelion rootstock density at Oak Bluff 1 assessed at the boot stage of the wheat crop.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 10 | 1921.65 | 192.17 | 6.85 | <0.0001 |
| Rep | 3 | 250.96 | 83.65 | 2.98 | 0.0470 |
| Error | 30 | 842.14 | 28.07 | | |

Table 7.22. Results of ANOVA for dandelion rootstock density at Oak Bluff 2 assessed at the boot stage of the wheat crop[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 11 | 10.58 | 0.96 | 3.05 | 0.0064 |
| Rep | 3 | 2.93 | 0.98 | 3.09 | 0.0402 |
| Error | 33 | 10.41 | 0.32 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.23. Results of ANOVA for dandelion rootstock density at Carman assessed at the boot stage of the wheat crop.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 5012.30 | 385.56 | 2.30 | 0.0223 |
| Rep | 3 | 1031.92 | 343.97 | 2.05 | 0.1220 |
| Error | 39 | 6528.12 | 167.39 | | |

Table 7.24. Results of ANOVA for dandelion rootstock density at Roland assessed at the boot stage of the wheat crop[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 10 | 5.99 | 0.60 | 1.64 | 0.1440 |
| Rep | 3 | 2.91 | 0.97 | 2.65 | 0.0667 |
| Error | 30 | 10.98 | 0.37 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.25. Results of ANOVA for dandelion rootstock density at Carman UM assessed at the boot stage of the wheat crop[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 7.44 | 0.53 | 1.84 | 0.0644 |
| Rep | 3 | 7.93 | 2.64 | 9.15 | <0.0001 |
| Error | 42 | 12.13 | 0.29 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.26. Results of ANOVA for dandelion seedling density at Oak Bluff 1 assessed at the boot stage of the wheat crop[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 6.33 | 0.45 | 3.91 | 0.0003 |
| Rep | 3 | 0.11 | 0.04 | 0.32 | 0.8083 |
| Error | 42 | 4.85 | 0.12 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.27. Results of ANOVA for dandelion seedling density at Oak Bluff 2 assessed at the boot stage of the wheat crop[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 0.88 | 0.06 | 0.53 | 0.8982 |
| Rep | 3 | 1.24 | 0.41 | 3.50 | 0.0236 |
| Error | 42 | 4.96 | 0.12 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.28. Results of ANOVA for dandelion seedling density at Carman assessed at the boot stage of the wheat crop.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 121169.95 | 8655.00 | 0.94 | 0.5305 |
| Rep | 3 | 50567.49 | 16855.83 | 1.82 | 0.1577 |
| Error | 42 | 388453.77 | 9248.90 | | |

Table 7.29. Results of ANOVA for dandelion seedling density at Roland assessed at the boot stage of the wheat crop[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 2.71 | 0.19 | 2.76 | 0.0056 |
| Rep | 3 | 0.58 | 0.19 | 2.74 | 0.0551 |
| Error | 42 | 2.95 | 0.07 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.30. Results of ANOVA for dandelion seedling density at Carman UM assessed at the boot stage of the wheat crop.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 2628772.49 | 187769.46 | 1.46 | 0.1680 |
| Rep | 3 | 3123356.45 | 1041118.82 | 8.11 | 0.0002 |
| Error | 42 | 5390252.01 | 128339.33 | | |

Table 7.31. Results of ANOVA for dandelion aboveground biomass at Oak Bluff 1 assessed at the boot stage of the wheat crop[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 10 | 12.62 | 1.26 | 9.32 | <0.0001 |
| Rep | 3 | 0.56 | 0.19 | 1.38 | 0.2665 |
| Error | 30 | 4.06 | 0.14 | | |

[a] Data was $\log_{10}$ (x+1) transformed.

Table 7.32. Results of ANOVA for dandelion aboveground biomass at Oak Bluff 2 assessed at the boot stage of the wheat crop[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 11 | 25.49 | 2.31 | 7.98 | <0.0001 |
| Rep | 3 | 0.60 | 0.20 | 0.69 | 0.5621 |
| Error | 33 | 9.58 | 0.29 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.33. Results of ANOVA for dandelion aboveground biomass at Carman assessed at the boot stage of the wheat crop[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 24.52 | 1.89 | 7.57 | <0.0001 |
| Rep | 3 | 1.56 | 0.52 | 2.09 | 0.1170 |
| Error | 39 | 9.72 | 0.25 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.34. Results of ANOVA for dandelion aboveground biomass at Roland assessed at the boot stage of the wheat crop[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 10 | 12.21 | 1.22 | 4.66 | 0.0005 |
| Rep | 3 | 1.30 | 0.43 | 1.65 | 0.1991 |
| Error | 30 | 7.87 | 0.26 | | |

[a] Data was $\log_{10}$ (x+1) transformed.

Table 7.35. Results of ANOVA for dandelion aboveground biomass at Carman UM assessed at the boot stage of the wheat crop[a]

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 22.64 | 1.74 | 3.22 | 0.0023 |
| Rep | 3 | 8.05 | 2.68 | 4.96 | 0.0052 |
| Error | 39 | 21.09 | 0.54 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.36. Results of ANOVA for dandelion rootstock density at Oak Bluff 1 assessed post-wheat harvest.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 10 | 2960.35 | 296.04 | 5.63 | 0.0001 |
| Rep | 3 | 256.74 | 85.58 | 1.63 | 0.2037 |
| Error | 30 | 1577.03 | 52.57 | | |

Table 7.37. Results of ANOVA for dandelion rootstock density at Oak Bluff 2 assessed post-wheat harvest.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 11 | 1407.64 | 127.97 | 1.64 | 0.1344 |
| Rep | 3 | 2667.09 | 889.03 | 11.36 | <0.0001 |
| Error | 33 | 2582.82 | 78.27 | | |

Table 7.38. Results of ANOVA for dandelion rootstock density at Carman assessed post-wheat harvest[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 10 | 14.68 | 1.47 | 4.32 | 0.0009 |
| Rep | 3 | 0.14 | 0.05 | 0.14 | 0.9354 |
| Error | 30 | 10.20 | 0.34 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.39. Results of ANOVA for dandelion rootstock density at Roland assessed post-wheat harvest.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 1186.65 | 84.76 | 3.63 | 0.0006 |
| Rep | 3 | 65.42 | 21.81 | 0.93 | 0.4324 |
| Error | 42 | 979.82 | 23.33 | | |

Table 7.40. Results of ANOVA for dandelion rootstock density at Carman UM assessed post-wheat harvest.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 12 | 1564.41 | 130.37 | 5.00 | <0.0001 |
| Rep | 3 | 294.80 | 98.27 | 3.77 | 0.0188 |
| Error | 36 | 938.17 | 26.06 | | |

Table 7.41. Results of ANOVA for dandelion seedling density at Oak Bluff 1 assessed post-wheat harvest.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 0 | --- | --- | --- | --- |
| Rep | 3 | 7.92 | 2.64 | --- | --- |
| Error | 0 | --- | --- | | |

Table 7.42. Results of ANOVA for dandelion seedling density at Oak Bluff 2 assessed post-wheat harvest[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 5.49 | 0.39 | 1.36 | 0.2158 |
| Rep | 3 | 1.57 | 0.52 | 1.81 | 0.1597 |
| Error | 42 | 12.13 | 0.29 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.43. Results of ANOVA for dandelion seedling density at Carman assessed post-wheat harvest[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 9 | 1.04 | 0.12 | 0.64 | 0.7552 |
| Rep | 3 | 1.47 | 0.49 | 2.70 | 0.0657 |
| Error | 27 | 4.90 | 0.18 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.44. Results of ANOVA for dandelion seedling density at Roland assessed post-wheat harvest.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 60549.70 | 4324.98 | 1.45 | 0.1727 |
| Rep | 3 | 138918.36 | 46306.12 | 15.54 | <0.0001 |
| Error | 42 | 125116.16 | 2978.96 | | |

Table 7.45. Results of ANOVA for dandelion seedling density at Carman UM assessed post-wheat harvest[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 0.59 | 0.04 | 0.86 | 0.6053 |
| Rep | 3 | 0.61 | 0.20 | 4.12 | 0.0120 |
| Error | 42 | 2.07 | 0.05 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.46. Results of ANOVA for dandelion aboveground biomass at Oak Bluff 1 assessed post-wheat harvest[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 10 | 11.89 | 1.19 | 4.98 | 0.0003 |
| Rep | 3 | 2.86 | 0.96 | 4.00 | 0.0165 |
| Error | 30 | 7.16 | 0.24 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.47. Results of ANOVA for dandelion aboveground biomass at Oak Bluff 2 assessed post-wheat harvest[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 11 | 8.31 | 0.76 | 2.04 | 0.0565 |
| Rep | 3 | 1.60 | 0.54 | 1.44 | 0.2481 |
| Error | 33 | 12.24 | 0.37 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.48. Results of ANOVA for dandelion aboveground biomass at Carman assessed post-wheat harvest[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 9 | 6.93 | 0.77 | 6.67 | <0.0001 |
| Rep | 3 | 0.32 | 0.11 | 0.91 | 0.4494 |
| Error | 27 | 3.12 | 0.12 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.49. Results of ANOVA for dandelion aboveground biomass at Roland assessed post-wheat harvest[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 12.84 | 0.92 | 3.47 | 0.0009 |
| Rep | 3 | 1.25 | 0.42 | 1.58 | 0.2094 |
| Error | 42 | 11.12 | 0.27 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.50. Results of ANOVA for dandelion aboveground biomass at Carman UM assessed post-wheat harvest.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 12 | 69373.96 | 5781.16 | 13.12 | <0.0001 |
| Rep | 3 | 8451.89 | 2817.30 | 6.39 | 0.0014 |
| Error | 36 | 15863.92 | 440.66 | | |

Table 7.51. Results of ANOVA for dandelion aboveground seedling biomass at Roland assessed post-harvest.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 116.34 | 8.31 | 1.47 | 0.1652 |
| Rep | 3 | 325.26 | 108.42 | 19.18 | <0.0001 |
| Error | 42 | 237.45 | 5.65 | | |

Table 7.52. Results of ANOVA for dandelion aboveground seedling biomass at Carman UM assessed post-harvest.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 658.61 | 47.04 | 1.36 | 0.2137 |
| Rep | 3 | 11.14 | 3.71 | 0.11 | 0.9552 |
| Error | 42 | 1449.12 | 34.50 | | |

Table 7.53. Results of ANOVA for wheat aboveground biomass at Oak Bluff 1 assessed at the boot stage of the wheat crop.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 97403.68 | 6957.41 | 4.10 | 0.0002 |
| Rep | 3 | 7348.82 | 2449.61 | 1.44 | 0.2440 |
| Error | 42 | 71916.79 | 1698.02 | | |

Table 7.54. Results of ANOVA for wheat aboveground biomass at Oak Bluff 2 assessed at the boot stage of the wheat crop[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 0.53 | 0.04 | 5.21 | <0.0001 |
| Rep | 3 | 0.11 | 0.04 | 4.85 | 0.0055 |
| Error | 42 | 0.31 | 0.01 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.55. Results of ANOVA for wheat aboveground biomass at Carman assessed at the boot stage of the wheat crop.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 272660.54 | 19475.75 | 4.07 | 0.0002 |
| Rep | 3 | 72161.60 | 24053.87 | 5.02 | 0.0046 |
| Error | 42 | 201121.07 | 4788.60 | | |

Table 7.56. Results of ANOVA for wheat aboveground biomass at Roland assessed at the boot stage of the wheat crop[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 0.36 | 0.03 | 6.30 | <0.0001 |
| Rep | 3 | 0.07 | 0.02 | 5.48 | 0.0029 |
| Error | 42 | 0.17 | 0.004 | | |

[a] Data was $\log_{10}$ transformed.

Table 7.57. Results of ANOVA for wheat aboveground biomass at Carman UM assessed at the boot stage of the wheat crop.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 400596.12 | 28614.01 | 3.26 | 0.0015 |
| Rep | 3 | 136295.88 | 45431.96 | 5.17 | 0.0039 |
| Error | 42 | 368823.27 | 8781.51 | | |

Table 7.58. Results of ANOVA for wheat grain yield at Oak Bluff 1.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 66669.25 | 4762.09 | 10.36 | <0.0001 |
| Rep | 3 | 34170.47 | 11390.16 | 24.79 | <0.0001 |
| Error | 42 | 19297.99 | 459.48 | | |

Table 7.59. Results of ANOVA for wheat grain yield at Oak Bluff 2.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 160679.79 | 11477.13 | 9.82 | <0.0001 |
| Rep | 3 | 32945.83 | 10981.94 | 9.40 | <0.0001 |
| Error | 42 | 49084.61 | 1168.68 | | |

Table 7.60. Results of ANOVA for wheat grain yield at Carman.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 68184.98 | 4870.36 | 4.64 | <0.0001 |
| Rep | 3 | 5424.98 | 1808.33 | 1.72 | 0.1770 |
| Error | 42 | 44091.17 | 1049.79 | | |

Table 7.61. Results of ANOVA for wheat grain yield at Roland.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 102930.28 | 7352.16 | 5.58 | <0.0001 |
| Rep | 3 | 7829.33 | 2609.78 | 1.98 | 0.1317 |
| Error | 42 | 55382.74 | 1318.64 | | |

Table 7.62. Results of ANOVA for wheat grain yield at Carman UM.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 14 | 128662.84 | 9190.20 | 6.49 | <0.0001 |
| Rep | 3 | 2678.20 | 892.73 | 0.63 | 0.5993 |
| Error | 42 | 59444.11 | 1415.34 | | |

Table 7.63. Results of ANOVA for visually estimated early season dandelion control at Oak Bluff 1.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 5489.44 | 422.26 | 52.52 | <0.0001 |
| Rep | 3 | 9.91 | 3.30 | 0.41 | 0.7461 |
| Error | 39 | 313.59 | 8.04 | | |

Table 7.64. Results of ANOVA for visually estimated early season dandelion control at Oak Bluff 2[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 5268.98 | 405.31 | 11.84 | <0.0001 |
| Rep | 3 | 39.78 | 13.26 | 0.39 | 0.7626 |
| Error | 39 | 1334.76 | 34.22 | | |

[a] Data was arcsine square root transformed (expressed in degrees).

Table 7.65. Results of ANOVA for visually estimated early season dandelion control at Carman.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 7081.36 | 544.72 | 5.77 | <0.0001 |
| Rep | 3 | 332.93 | 110.98 | 1.18 | 0.3314 |
| Error | 39 | 3681.07 | 94.39 | | |

Table 7.66. Results of ANOVA for visually estimated early season dandelion control at Roland[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 2159.17 | 166.09 | 7.81 | <0.0001 |
| Rep | 3 | 89.92 | 29.98 | 1.41 | 0.2546 |
| Error | 39 | 829.52 | 21.27 | | |

[a] Data was arcsine square root transformed (expressed in degrees).

Table 7.67. Results of ANOVA for visually estimated early season dandelion control at Carman UM.

| Source | DF | Sum of Squares[a] | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 5107.01 | 389.87 | 36.17 | <0.0001 |
| Rep | 3 | 114.46 | 38.15 | 3.54 | 0.0241 |
| Error | 36 | 388.04 | 10.78 | | |

[a] Type III Sum of Squares.

Table 7.68. Results of ANOVA for visually estimated late season dandelion control at Oak Bluff 1[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 1058.10 | 81.39 | 8.00 | <0.0001 |
| Rep | 3 | 184.81 | 61.60 | 6.06 | 0.0017 |
| Error | 39 | 396.71 | 10.17 | | |

[a] Data was arcsine square root transformed (expressed in degrees).

Table 7.69. Results of ANOVA for visually estimated late season dandelion control at Oak Bluff 2[a].

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 2756.77 | 212.06 | 9.67 | <0.0001 |
| Rep | 3 | 133.00 | 44.33 | 2.02 | 0.1268 |
| Error | 39 | 855.49 | 21.94 | | |

[a] Data was arcsine square root transformed (expressed in degrees).

Table 7.70. Results of ANOVA for visually estimated late season dandelion control at Carman.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 497.59 | 38.28 | 5.72 | <0.0001 |
| Rep | 3 | 7.48 | 2.50 | 0.37 | 0.7729 |
| Error | 39 | 260.77 | 6.69 | | |

Table 7.71. Results of ANOVA for visually estimated late season dandelion control at Roland.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 4200.36 | 323.10 | 7.44 | <0.0001 |
| Rep | 3 | 88.29 | 29.43 | 0.68 | 0.5711 |
| Error | 39 | 1694.21 | 43.44 | | |

Table 7.72. Results of ANOVA for visually estimated late season dandelion control at Carman UM[a].

| Source | DF | Sum of Squares[b] | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Treatment | 13 | 2937.72 | 225.98 | 9.22 | <0.0001 |
| Rep | 3 | 221.08 | 73.69 | 3.01 | 0.0429 |
| Error | 39 | 882.56 | 24.52 | | |

[a] Data was arcsine square root transformed (expressed in degrees).
[b] Type III Sum of Squares.

Table 7.73. Results of ANOVA for volumetric soil moisture at Oak Bluff 1

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| AccGDD[a] | 8 | 1596.09 | 199.51 | 14.03 | <0.0001 |
| Rep | 3 | 9.15 | 3.05 | 0.21 | 0.8862 |
| Depth | 2 | 61.65 | 30.83 | 2.17 | 0.1202 |
| Error | 94 | 1337.05 | 14.22 | | |

[a] Abbreviation: AccGDD, Accumulated Growing Degree Days.

Table 7.74. Results of ANOVA for volumetric soil moisture at Oak Bluff 2

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| AccGDD[a] | 7 | 672.18 | 96.03 | 17.84 | <0.0001 |
| Rep | 3 | 21.13 | 7.04 | 1.31 | 0.2770 |
| Depth | 2 | 33.86 | 16.93 | 3.15 | 0.0482 |
| Error | 83 | 446.68 | 5.38 | | |

[a] Abbreviation: AccGDD, Accumulated Growing Degree Days.

Table 7.75. Results of ANOVA for volumetric soil moisture at Carman.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| AccGDD[a] | 8 | 570.08 | 71.26 | 13.96 | <0.0001 |
| Rep | 3 | 6.87 | 2.29 | 0.45 | 0.7187 |
| Depth | 2 | 15.87 | 7.93 | 1.55 | 0.2166 |
| Error | 94 | 479.78 | 5.10 | | |

[a] Abbreviation: AccGDD, Accumulated Growing Degree Days.

Table 7.76. Results of ANOVA for volumetric soil moisture at Roland.

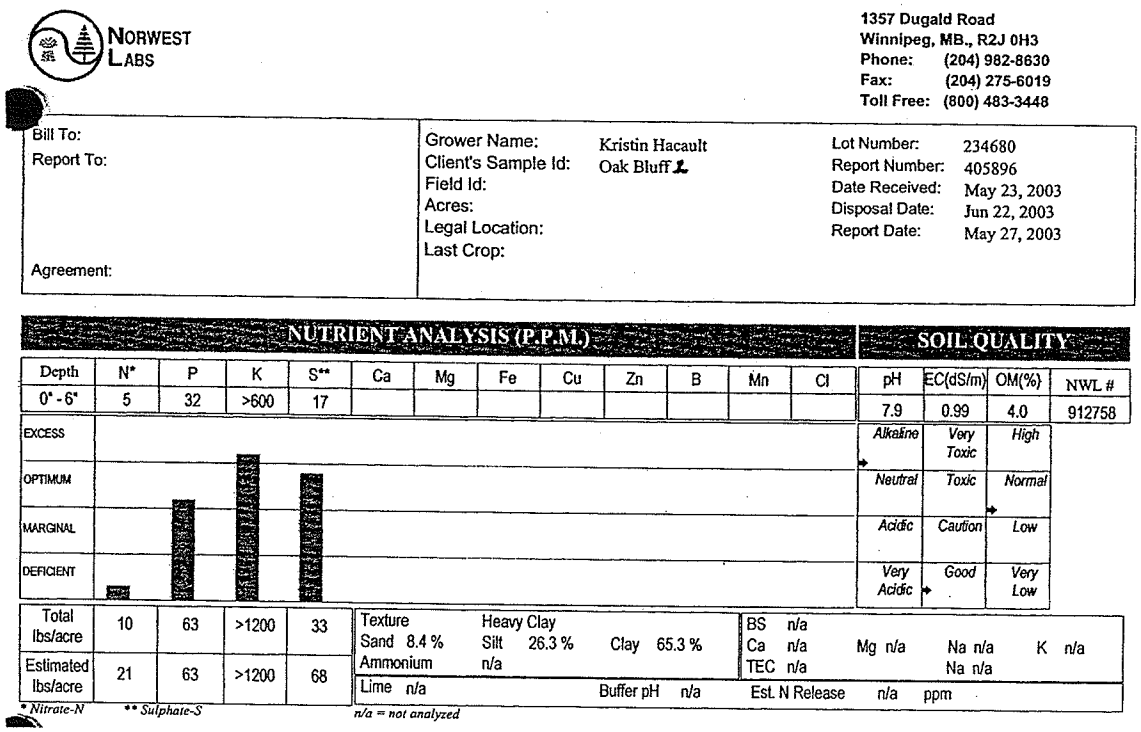
| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| AccGDD[a] | 21 | 4455.65 | 212.17 | 26.30 | <0.0001 |
| Rep | 3 | 48.78 | 16.26 | 2.02 | 0.1125 |
| Depth | 2 | 41.51 | 20.76 | 2.57 | 0.0785 |
| Error | 237 | 1912.09 | 8.07 | | |

[a] Abbreviation: AccGDD, Accumulated Growing Degree Days.

Table 7.77. Results of ANOVA for volumetric soil moisture at Carman UM.

| Source | DF | Sum of Squares | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| AccGDD[a] | 20 | 5941.85 | 297.09 | 35.03 | <0.0001 |
| Rep | 3 | 96.64 | 32.22 | 3.80 | 0.0110 |
| Depth | 2 | 173.15 | 86.58 | 10.21 | <0.0001 |
| Error | 226 | 1916.68 | 8.48 | | |

[a] Abbreviation: AccGDD, Accumulated Growing Degree Days.



NORWEST LABS

1357 Dugald Road
Winnipeg, MB., R2J 0H3
Phone: (204) 982-8630
Fax: (204) 275-6019
Toll Free: (800) 483-3448

Bill To:
Report To:

Agreement:

Grower Name: Kristin Hacault
Client's Sample Id: Oak Bluff 1
Field Id:
Acres:
Legal Location:
Last Crop:

Lot Number: 234680
Report Number: 405896
Date Received: May 23, 2003
Disposal Date: Jun 22, 2003
Report Date: May 27, 2003

NUTRIENT ANALYSIS (P.P.M.)

| Depth | N* | P | K | S** | Ca | Mg | Fe | Cu | Zn | B | Mn | Cl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0" - 6" | 5 | 32 | >600 | 17 | | | | | | | | |
| Total lbs/acre | 10 | 63 | >1200 | 33 | | | | | | | | |
| Estimated lbs/acre | 21 | 63 | >1200 | 68 | | | | | | | | |

EXCESS / OPTIMUM / MARGINAL / DEFICIENT

Texture Heavy Clay
Sand 8.4 % Silt 26.3 % Clay 65.3 %
Ammonium n/a
Lime n/a Buffer pH n/a

SOIL QUALITY

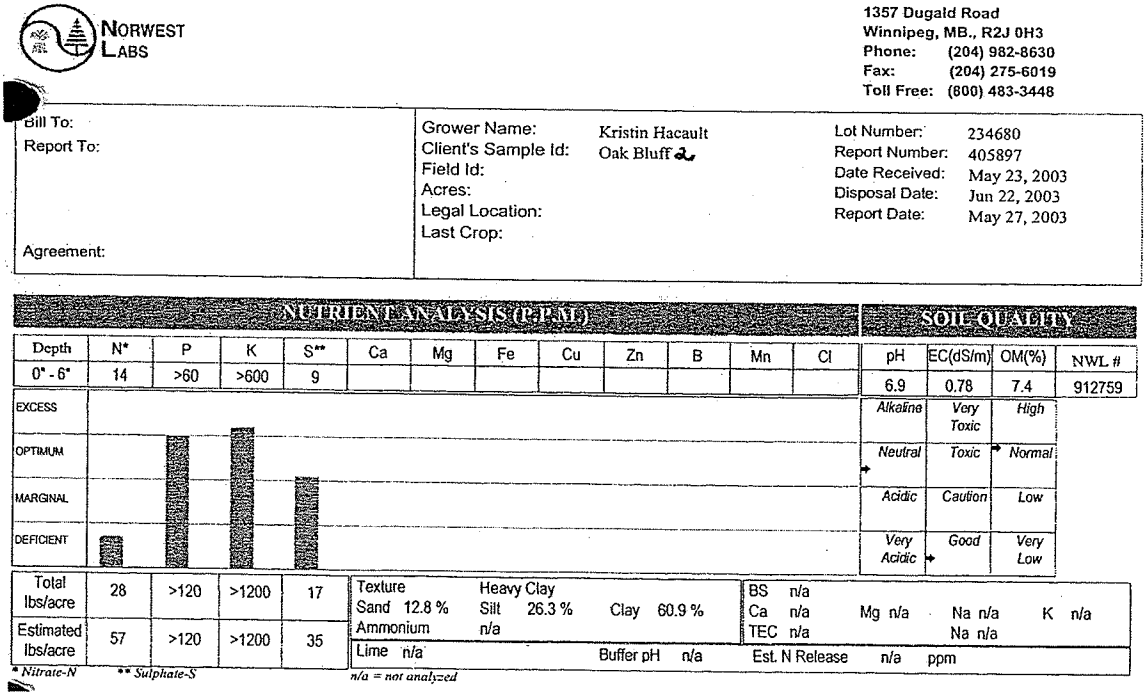
| pH | EC(dS/m) | OM(%) | NWL # |
|---|---|---|---|
| 7.9 | 0.99 | 4.0 | 912758 |

| pH | EC(dS/m) | OM(%) |
|---|---|---|
| Alkaline | Very Toxic | High |
| Neutral | Toxic | Normal |
| Acidic | Caution | Low |
| Very Acidic | Good | Very Low |

BS n/a
Ca n/a Mg n/a Na n/a K n/a
TEC n/a Na n/a
Est. N Release n/a ppm

* Nitrate-N ** Sulphate-S n/a = not analyzed

Figure 7.2. Soil analysis for Oak Bluff 1 at the 0 to 6" depth.



NORWEST LABS

1357 Dugald Road
Winnipeg, MB., R2J 0H3
Phone: (204) 982-8630
Fax: (204) 275-6019
Toll Free: (800) 483-3448

Bill To:
Report To:

Agreement:

Grower Name: Kristin Hacault
Client's Sample Id: Oak Bluff 2
Field Id:
Acres:
Legal Location:
Last Crop:

Lot Number: 234680
Report Number: 405897
Date Received: May 23, 2003
Disposal Date: Jun 22, 2003
Report Date: May 27, 2003

NUTRIENT ANALYSIS (P.P.M.)

| Depth | N* | P | K | S** | Ca | Mg | Fe | Cu | Zn | B | Mn | Cl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0" - 6" | 14 | >60 | >600 | 9 | | | | | | | | |
| Total lbs/acre | 28 | >120 | >1200 | 17 | | | | | | | | |
| Estimated lbs/acre | 57 | >120 | >1200 | 35 | | | | | | | | |

EXCESS / OPTIMUM / MARGINAL / DEFICIENT

Texture Heavy Clay
Sand 12.8 % Silt 26.3 % Clay 60.9 %
Ammonium n/a
Lime n/a Buffer pH n/a

SOIL QUALITY

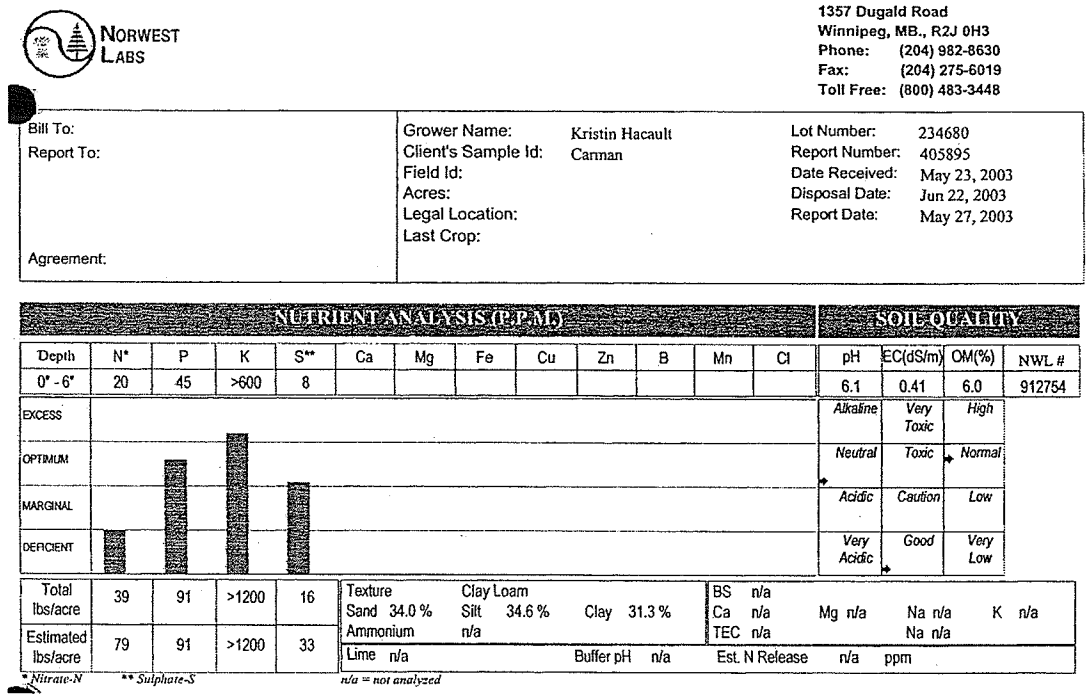
| pH | EC(dS/m) | OM(%) | NWL # |
|---|---|---|---|
| 6.9 | 0.78 | 7.4 | 912759 |

| pH | EC(dS/m) | OM(%) |
|---|---|---|
| Alkaline | Very Toxic | High |
| Neutral | Toxic | Normal |
| Acidic | Caution | Low |
| Very Acidic | Good | Very Low |

BS n/a
Ca n/a Mg n/a Na n/a K n/a
TEC n/a Na n/a
Est. N Release n/a ppm

* Nitrate-N ** Sulphate-S n/a = not analyzed

Figure 7.3. Soil analysis for Oak Bluff 2 at the 0 to 6" depth.



NORWEST LABS

1357 Dugald Road
Winnipeg, MB., R2J 0H3
Phone: (204) 982-8630
Fax: (204) 275-6019
Toll Free: (800) 483-3448

Bill To:
Report To:
Agreement:

Grower Name: Kristin Hacault
Client's Sample Id: Carman
Field Id:
Acres:
Legal Location:
Last Crop:

Lot Number: 234680
Report Number: 405895
Date Received: May 23, 2003
Disposal Date: Jun 22, 2003
Report Date: May 27, 2003

NUTRIENT ANALYSIS (P.P.M.)

| Depth | N* | P | K | S** | Ca | Mg | Fe | Cu | Zn | B | Mn | Cl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0" - 6" | 20 | 45 | >600 | 8 | | | | | | | | |
| Total lbs/acre | 39 | 91 | >1200 | 16 | | | | | | | | |
| Estimated lbs/acre | 79 | 91 | >1200 | 33 | | | | | | | | |

EXCESS / OPTIMUM / MARGINAL / DEFICIENT

SOIL QUALITY

| pH | EC(dS/m) | OM(%) | NWL # |
|---|---|---|---|
| 6.1 | 0.41 | 6.0 | 912754 |

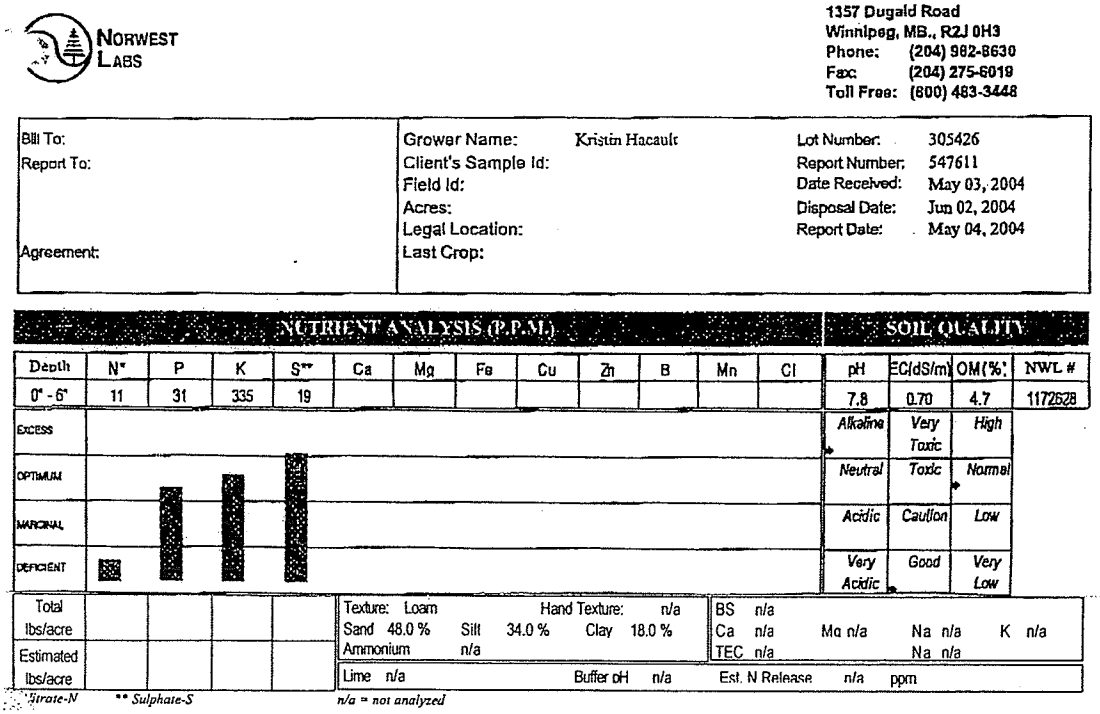
| | | |
|---|---|---|
| Alkaline | Very Toxic | High |
| Neutral | Toxic | Normal |
| Acidic | Caution | Low |
| Very Acidic | Good | Very Low |

Texture Clay Loam
Sand 34.0 % Silt 34.6 % Clay 31.3 %
Ammonium n/a
Lime n/a Buffer pH n/a

BS n/a
Ca n/a Mg n/a Na n/a K n/a
TEC n/a Na n/a
Est. N Release n/a ppm

* Nitrate-N ** Sulphate-S n/a = not analyzed

Figure 7.4. Soil analysis for Carman at the 0 to 6" depth.



NORWEST LABS

1357 Dugald Road
Winnipeg, MB., R2J 0H3
Phone: (204) 982-8630
Fax: (204) 275-6019
Toll Free: (800) 483-3448

Bill To:
Report To:
Agreement:

Grower Name: Kristin Hacault
Client's Sample Id:
Field Id:
Acres:
Legal Location:
Last Crop:

Lot Number: 305426
Report Number: 547611
Date Received: May 03, 2004
Disposal Date: Jun 02, 2004
Report Date: May 04, 2004

NUTRIENT ANALYSIS (P.P.M.)

| Depth | N* | P | K | S** | Ca | Mg | Fe | Cu | Zn | B | Mn | Cl |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0" - 6" | 11 | 31 | 335 | 19 | | | | | | | | |
| Total lbs/acre | | | | | | | | | | | | |
| Estimated lbs/acre | | | | | | | | | | | | |

EXCESS / OPTIMUM / MARGINAL / DEFICIENT

SOIL QUALITY

| pH | EC(dS/m) | OM(%) | NWL # |
|---|---|---|---|
| 7.8 | 0.70 | 4.7 | 1172628 |

| | | |
|---|---|---|
| Alkaline | Very Toxic | High |
| Neutral | Toxic | Normal |
| Acidic | Caution | Low |
| Very Acidic | Good | Very Low |

Texture: Loam Hand Texture: n/a
Sand 48.0 % Silt 34.0 % Clay 18.0 %
Ammonium n/a
Lime n/a Buffer pH n/a

BS n/a
Ca n/a Mg n/a Na n/a K n/a
TEC n/a Na n/a
Est. N Release n/a ppm

* Nitrate-N ** Sulphate-S n/a = not analyzed

Figure 7.5. Soil analysis for Roland at the 0 to 6" depth.

NORWEST LABS

1357 Dugald Road
Winnipeg, MB., R2J 0H3
Phone: (204) 982-8630
Fax: (204) 275-5019
Toll Free: (800) 483-3448

| | | | | | |
|---|---|---|---|---|---|
| Bill To: | | Grower Name: | Kristin Hacault | Lot Number: | 305426 |
| Report To: | | Client's Sample Id: | | Report Number: | 547610 |
| | | Field Id: | Carman UM | Date Received: | May 03, 2004 |
| | | Acres: | | Disposal Date: | Jun 02, 2004 |
| | | Legal Location: | | Report Date: | May 04, 2004 |
| Agreement: | | Last Crop: | Crop not provided | | |

**NUTRIENT ANALYSIS (PPM)** | **SOIL QUALITY**

| Depth | N* | P | K | S** | Ca | Mg | Fe | Cu | Zn | B | Mn | Cl | pH | EC(dS/m) | OM(%) | NWL # |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0" - 6" | 13 | 16 | 314 | 4 | | | | | | | | | 7.3 | 0.41 | 5.3 | 1172626 |
| EXCESS | | | | | | | | | | | | | Alkaline | Very Toxic | High | |
| OPTIMUM | | | | | | | | | | | | | Neutral | Toxic | Normal | |
| MARGINAL | | | | | | | | | | | | | Acidic | Caution | Low | |
| DEFICIENT | | | | | | | | | | | | | Very Acidic | Good | Very Low | |

| | | | | |
|---|---|---|---|---|
| Total lbs/acre | | | | |
| Estimated lbs/acre | | | | |

Texture: Loam — Hand Texture: n/a
Sand 41.4 % Silt 34.5 % Clay 24.1 %
Ammonium n/a

BS n/a
Ca n/a Mg n/a Na n/a K n/a
TEC n/a Na n/a

Lime n/a — Buffer pH n/a — Est. N Release n/a ppm

* Nitrate-N ** Sulphate-S n/a = not analyzed

Figure 7.6. Soil analysis for Carman UM at the 0 to 6" depth.

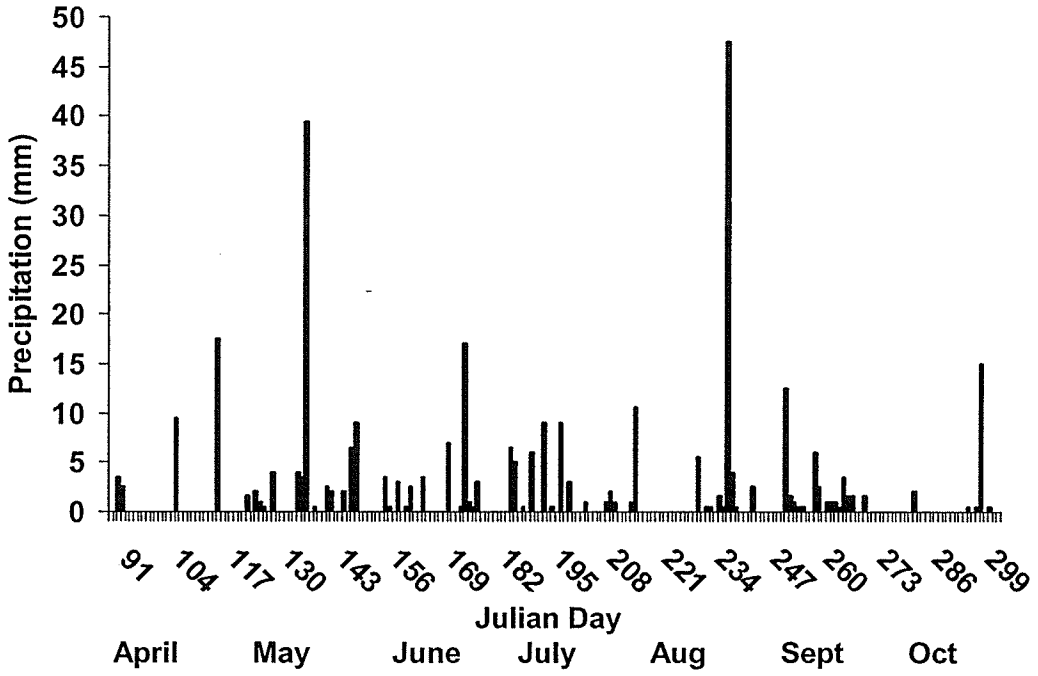



Figure7.7. Precipitation (mm) received at Winnipeg International Airport from April 1, 2003 to October 31, 2003.

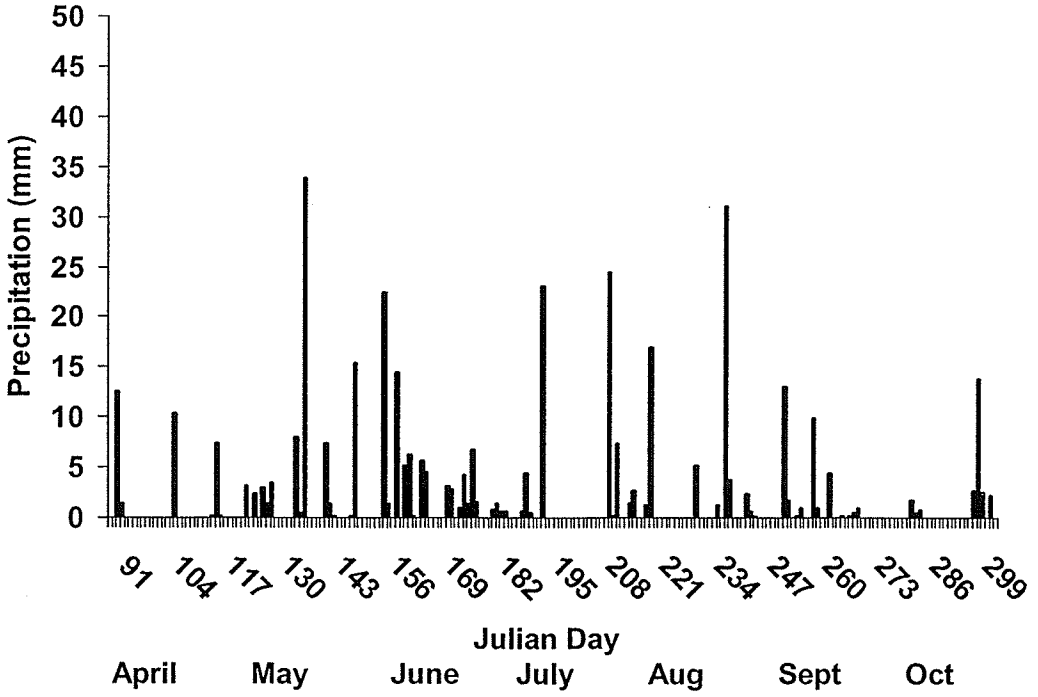



Figure 7.8. Precipitation received at Carman, Manitoba from April 1, 2003 to October 31, 2003.

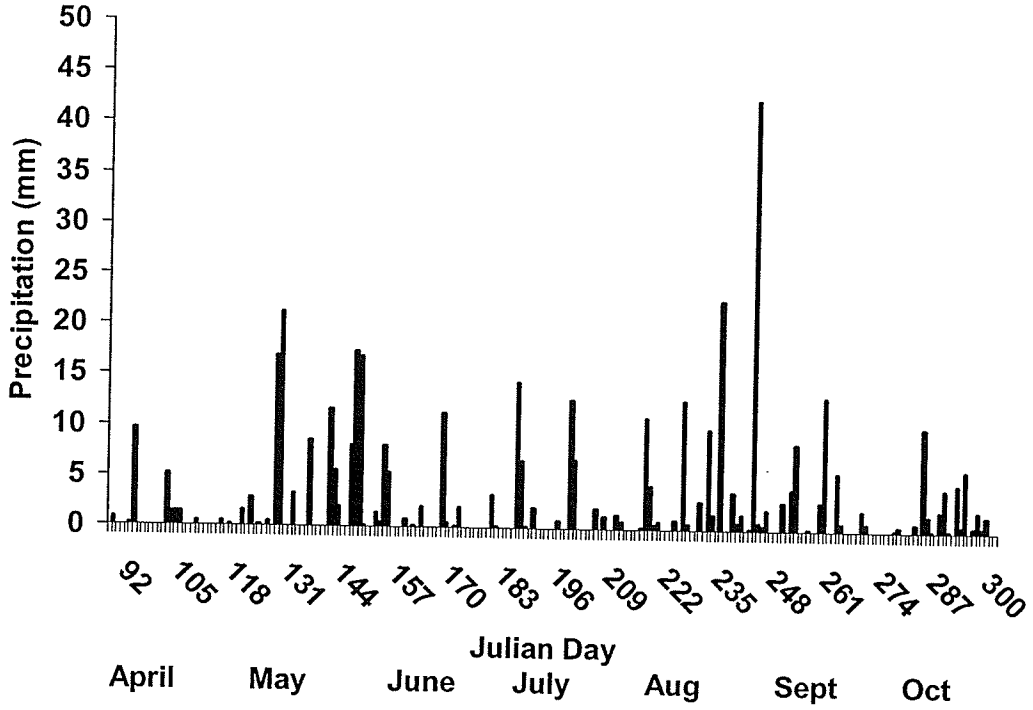



Figure 7.9. Precipitation received at Carman, Manitoba from April 1, 2004 to October 31, 2004.

Table 7.78. Mean density of dandelion plants from rootstock assessed throughout the course of the growing season at Roland for 2,4-D amine and 2,4-D ester + florasulam treatments applied in the fall (standard errors in parentheses).

| Treatment | Application dose | Application timing | Pre-Seed | Pre In-Crop | Post In-Crop | Pre-Harvest | Post-Harvest |
|---|---|---|---|---|---|---|---|
| | | | ---------- no. $m^{-2}$ ---------- | | | | |
| | g $ha^{-1}$[b] | | | | | | |
| 2,4-D Amine[a] | 560 | Fall | 21.0 (2.5) | 8.0 (2.3) | 5.7 (2.4) | 11.4 (4.4) | 5.7 (4.1) |
| 2,4-D LV Ester + Flor[c] | 560 + 5 | Fall | 4.3 (0.7) | 0.7 (0.3) | 0.0 | 3.6 (2.0) | 0.0 |

[a] 2,4-D Amine 600 SL.
[b] Dosage of 2,4-D expressed as g a.i. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$.
[c] 2,4-D LV Ester (564 g/L EC). Flor, florasulam.

Table 7.79. Mean biomass of dandelion plants from rootstock assessed throughout the course of the growing season at Roland for 2,4-D amine and 2,4-D ester + florasulam treatments applied in fall (standard errors in parentheses).

| Treatment | Application dose | Application timing | Post In-Crop | Post-Harvest |
|---|---|---|---|---|
| | | | ---------- g $m^{-2}$ ---------- | |
| | g $ha^{-1}$[b] | | | |
| 2,4-D Amine[a] | 560 | Fall | 2.1 (1.7) | 17.9 (11.4) |
| 2,4-D LV Ester + Flor[c] | 560 + 5 | Fall | 0.0 | 0.0 |

[a] 2,4-D Amine 600 SL.
[b] Dosage of 2,4-D expressed as g a.i. $ha^{-1}$; dosage of florasulam expressed as g a.i. $ha^{-1}$.
[c] 2,4-D LV Ester (564 g/L EC). Flor, florasulam.