The effect of tillage and seeding dates on levels and periodicity of redroot pigweed (*Amaranthus retroflexus* L.) and green foxtail (*Setaria viridis* L. Beauv.) emergence.

BY

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A Thesis
Submitted to the Faculty of Graduate Studies
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ABSTRACT

Kabanyana, Anastasie. M.Sc., The University of Manitoba, April, 2004. The effect of tillage and seeding dates on levels and periodicity of redroot pigweed (*Amaranthus retroflexus* L.) and green foxtail (*Setaria viridis* L. Beauv.) emergence. Major Professor; Rene C. Van Acker.

Knowing the effect of farm management practices (tillage and seeding dates) on levels and periodicity of weed seedling emergence can assist producers to better time weed control techniques. Field experiments were conducted in spring of 2002 and 2003 at University of Manitoba research stations (Carman and Winnipeg) to determine the effect of tillage (FTST: fall tillage spring tillage, FTSNT: fall tillage spring no tillage, FNTST: fall no tillage spring tillage, FNTSNT: fall no tillage spring no tillage) and seeding dates (early and late seeding) on the levels and periodicity of green foxtail and redroot pigweed emergence. Generally, densities of green foxtail and redroot pigweed tended to increase as tillage intensity increased. This response was attributed to the relatively higher soil temperatures observed on tilled vs. no-tilled plots. Total densities of green foxtail and redroot pigweed were unaffected by seeding dates except at one site-year because emergence was measured both pre and post-seeding. Significant differences were observed between management periods (MP). High levels of emergence of both species were observed during management period 2 (MP2; post seeding and pre-in crop herbicide application) because this period corresponded to the period of the year where conditions required for seed germination and seedling emergence of green foxtail and redroot pigweed were favorable. The emergence periodicities of redroot pigweed and green foxtail were unaffected by tillage treatments in either 2002 or 2003 probably due to the fact that

tillage did not affect accumulated soil GDDs, soil moisture, or the location of the seedbank in the soil. Seeding date did not affect the emergence periodicity of green foxtail, but it did significantly influence the emergence periodicity of redroot pigweed. Our results suggest that tillage intensity, *perse* in a single year may not be an important factor for predicting the timing of green foxtail and redroot pigweed, but timing of tillage in the spring may, for species where recruitment is stimulated by tillage. In this respect, timing of tillage or seeding date may play a major role in planning weed control measures.

CHAPTER 1. GENERAL INTRODUCTION

The levels and periodicity of emergence of many weed species has been well documented (Chepil 1946a; Egley and Williams 1991; Mulutega and Boerboom 1999; Ogg and Dawson 1984; Stoller 1973), and several factors including seed dormancy, soil environmental conditions and crop management practices were reported to affect the magnitude and periodicity of weed emergence.

The ability of weed species to germinate and emerge is controlled by innate dormancy and by conditions required for germination and emergence (this could be considered "conditional" dormancy). Dormancy breaking may require the exposure of seeds to a constant level of a single factor such as chilling, elevated temperature, light, or it may require exposure to fluctuating environmental conditions, or exposure to given levels of two or more factors (Bradbeer, 1988). The presence of conditions that break innate (if present) and conditional dormancy lead to the germination of seeds. Beyond factors favoring germination, additional conditions are required to allow for successful seedling emergence. Successful seed germination and seedling emergence together constitute seedling recruitment.

Successful seedling recruitment requires exposure of viable seeds to the range of conditions necessary for the seeds to germinate and seedlings to emerge. Seedlings may emerge when abiotic and biotic factors directly surrounding the seed match with the germination and emergence requirements for a particular weed species. These conditions may vary both between eco-regions (as determined by climate and soil type [Dale et al. 1992]), and between fields due to differences in management practices and soil type

(Andreason et al. 1991; Mohler and Galeford, 1997). In agricultural environments, the conditions favoring weed seedling emergence are strongly linked to type and time of soil disturbance (Boström and Fogelfors 1999; Boström 1999; Mahli and O'Sullivan 1990; Wrucke and Arnold 1985; Bibbey 1935; Roberts and Potter 1980; Steiner 1989).

Tillage has been used by farmers as a primary method of weed control before the introduction of herbicides, and it is still a weed control technique widely used as part of an integrated weed control program on many Manitoba farms (Donaghy, 1985). In Manitoba, conventional, minimum and zero-tillage systems are used on 62.3%, 32% and 5.6 % of the land area, respectively (Thomas et al. 1999). Conventional-tillage systems usually include 2 to 3 tillage passes with a cultivator. Minimum-tillage systems usually include 1 or no-tillage pass before seeding. A typical zero-tillage system includes no soil disturbance other than that created with the seeding equipment. These various tillage approaches may either increase or decrease weed emergence levels.

There are many types of tillage regimes that farmers might practice in order to reduce weed infestation levels. Such practices could be a combination of type and timing of tillage operations. A shift from conventional-tillage to no-tillage or vice-versa may determine the size and composition of a weed population because there is an alteration of microsite conditions, which favor seed germination and seedling emergence. For example, Mulutega and Stoltenberg (1997) reported that secondary soil disturbance increased seedling emergence and seedbank. depletion of common lambsquaters (*Chenopodium album* L.), Giant foxtail (*Setaria faberi* L.), and redroot pigweed (*Amaranthus retroflexus* L.) in a long-term no-tillage corn (*Zea mays* L.) cropping system. This response was likely due to the increased exposure of seeds to favorable conditions for germination.

Most farmers in Manitoba till both in fall and spring (Thomas et al. 1999). Since repeated soil disturbance has been shown to favor the emergence of many weed species (Ogg and Dawson 1984; Chepil 1946 b; Roberts 1984), fall primary tillage followed by spring no-tillage may result in a reduction of spring weed seedling recruitment and subsequent weed populations. Tillage or soil disturbance may stimulate weed emergence by exposing buried seed to a changes in conditions including soil temperature, soil moisture level, and light and these can all affect seedling recruitment. This leads to the central question in this study "to what extent does tillage in a given year affect the emergence periodicity and emergence levels of common annual weed species in fields located on two distinct soil types in the Lake Manitoba Plain Ecoregion of Manitoba".

CHAPTER 2. LITERATURE REVIEUW

Environmental factors affecting weed seedling emergence

Temperature. Temperature is an important factor affecting seed germination and seedling emergence. Each weed species possesses a temperature range across which germination may occur and across which seedling emergence is possible. For example, Blackshaw (1990) observed the emergence of round-leaved mallow (*malva pusilla L.*) to occur from a minimum temperature of 5°C to a maximum temperature of 30°C. Similarly, Ghorbani et al.(1999) found that the minimum temperature for redroot pigweed germination was above 5°C whereas maximum germination occurred at temperatures between 35 and 40 °C. Seventy to 80 % of wild oat (*Avena fatua* L.) emergence occurred over a temperature range of 10 to 30°C, however, germination and emergence of sterile brome (*Avena sterilis* L.) was greater at lower temperatures, with optimum germination and emergence occurring at a temperature of 10°C (Fernandez-Quinantilla et al. 1990).

Temperature also has a great effect on the timing of emergence of individual weed species. Initial emergence timing as well as emergence magnitude of *Eriochloa villosa L.* and *amaranthus rudis L.* was affected by both growing degree day (GDD) accumulation and rainfall (Hartzler et al.1999). Conversely, Egley and Williams (1991) reported that warm soil temperatures stimulated the emergence of velvetleaf (*Abutilon theophrasti* L.), prickly sida (*Sida spinosa* L.) and hemp sesbania (*sesbania exaltata* L.). For these species flushes of seedlings observed in late April or early May appeared to be associated with a rise in soil temperatures (Roberts and Margaret 1980), but subsequent flushes were related to rainfall patterns (Roberts 1984).

Moisture. Soil moisture levels influence weed seedling emergence. There is growing evidence of the effect of soil moisture on the emergence of weed species (Blackshaw 1990; Ghorbani 1999; Fyfield and Gregory 1989; Blackshaw et al. 1981; Blackshaw 1990; Blackshaw 1991; Susko 1999; Roberts and Potter 1980; Harris et al. 1998; Roberts 1984; Leblanc et al. 2002).

In Western Canada, moisture was found to be a limiting factor for weed seed germination (Bibbey, 1935) and it was suggested as the most important factor regulating the germination and emergence of weed seedlings in the spring. For example, in a study conducted in Manitoba, Blackshaw et al. (1979) found that soil moisture had a greater effect than soil temperature on green foxtail germination. Blackshaw (1990) later confirmed this effect in Alberta and reported that soil moisture significantly affected the percent emergence of round-leaved-mallow more than did soil temperature. However, in Quebec Leblanc et al. (2002) showed that rainfall or irrigation had little or no influence on lambsquarters and barnyardgrass (*Echinochloa crusgalli* L.) emergence patterns and level, and this response was attributed to the fact that soil water content in the fields they were studying was at field capacity during the main period of weed emergence. Leblanc et al. (2002) hypothesized that in southwestern Quebec, temperature was the most significant factor influencing weed seed germination and subsequent seedling emergence.

Rainfall patterns resulting in high soil moisture can modify the time of weed seedling emergence.. Roberts and Potter (1980) related spring flush of seedlings to soil temperature, but subsequent flushes to rainfall patterns. Accordingly, Roberts (1984) reported a relationship between rainfall pattern and weed emergence periodicity.

Seedling emergence occurred during or after wet weather, and ended when dry conditions appeared.

Temperature and moisture interaction. Temperature and moisture may interact to affect weed emergence. Blackshaw (1991) found a significant interaction effect of temperature and moisture on the emergence of downy brome (*Bromus tectorum* L.). Soil temperatures of 5 to 30°C had little effect on total emergence of downy brome, but emergence was > 90% at higher moisture levels (-0.03 to -078 Mpa) throughout this range of temperatures. Sharma et al. (1978) reported a significant interactive effect of temperature and moisture on emergence of wild oat. Percent germination and emergence of wild oat was maximum at temperatures ranging from 10 to 21°C only when soil moisture was maintained at 50 to 75% of field capacity. At field capacity moisture level, the same ranges of temperature (10 to 21°C) did not stimulate the emergence of wild oat. Although temperature was the dominant factor influencing the rate of germination of mungbean (*Vigna radiata* L.), Fyfield and Gregory (1989) found that germination at favorable temperatures was most rapid when moisture was not limiting.

Light. Light breaks dormancy and stimulates seed germination for many weed species (Bouwmeester and Karseen 1989; Benvenuti 1995; Gallagher and Cardina 1997). The germination response of seeds to light is mediated by phytochrome with convertible forms. There is an active form (the far-red-absorbing form, PFR), and an inactive form (the red -absorbing form, PR) (Bradbeer 1998). Photoconversion of phytochrome may stimulate germination of some species, but it can also induce dormancy in others (Bouwmeester and Karseen 1989; Bartlet and Frankland 1985; Gallagher and Cardina 1997). Lambsquarters did not germinate in darkness, but in light, seed germination varied between 20-30% (Bouwmeester and Karseen 1989). Gallaghar and Cardina (1997) reported that light environment during tillage had a significant effect on the emergence of summer annual weeds. Emergence of giant foxtail, lambsquarters, and redroot pigweed averaged 30%, 36%, 55 %, higher, respectively, in plots disked during the day compared with plots disked at night. The germination of other species, such as common purslane (*Portulaca oleracea* L.) and common ragweed (*Ambrosia artemisiifolia* L.), was not affected by light environment changes resulting from tillage treatments.

Although the seed germination of many weed species is sensitive to light, only a small quantity of light penetrates the soil. In all types of soil, Benvenuti (1995) found that only 0.01% of light penetrated soils at a depth no greater than 4mm. Woolley and Stoller (1978) reported that less than 1% of incident radiation penetrated 2.2mm through a Drummer clay loam and Broomfield sand. It appears that light is more likely to induce germination and emergence of weed species located at or very near the soil surface. It is also possible that the flash of light received during and after tillage may break dormancy of buried seed and promote weed germination and emergence.

Some authors suggest that light perceived by buried seeds during soil cultivation is effective in triggering germination and emergence of some weed species. For example, Gallagher and Cardina (1998) reported that the emergence of pigweed species and giant foxtail was at most 30 to 55% higher following day versus night disking. Buhler (1997) found little emergence response to light environment during tillage for annual grasses and large-seeded broad leaf weed species. The emergence of small-seeded species was often lower with tillage conducted in darkness than when tillage was conducted in the light. In addition, large variations in response could be observed within a genus. Giant foxtail and yellow foxtail emergence levels were not influenced by light during tillage. However, green foxtail emergence levels were significantly affected by light environment (Buhler 1997). It appears that in many cases factors other than light determine weed emergence.

Effect of non-climatic conditions on weed seedling emergence

Seed Burial Depth. Depth of weed seed burial influences weed seedling recruitment for annual weeds. Froud-Williams et al. (1984) found that the emergence level of small-seeded weed species was reduced by increasing the depth of burial, whereas emergence level was improved for large-seeded species if the seeds were buried at a shallow depth. Similar results were reported by Ghorbani et al. (1999) who found that small seeds of redroot pigweed emerged mostly from depths shallower than 5cm probably due to low soil water potential at the soil surface. The lower rate of emergence was attributed to low soil water potential at the soil surface.

Depth of weed seed burial changes as tillage increases resulting in a shift in seedling recruitment depth. Emergence depths for many weed species is suggested to be shallower in no-tillage versus conventional-tillage systems. du Croix Sissons et al (2000) reported that for five common annual weed species the mean recruitment depth for more than 75 % of individual plants was no deeper than 4.5 cm for zero- and conventional-tillage fields. Deeper recruitment depths were observed in conventional-tillage fields versus zero tillage fields. In another study, Buhler and Mester (1991) observed that mean depths of emergence were influenced by tillage systems. Mean emergence depths were between 1.5 cm and 3.5 cm for no-tillage and conventional tillage, respectively. Tillage may move seeds deeper into the soil where germination and emergence conditions are less favorable (Egley and Williams 1990). Consequently, no-tillage systems should have higher weed populations whereas conventional tillage systems should have fewer weeds, but more seeds buried throughout the soil horizons. However, this is not always the case. The response of a weed population to a certain tillage system depends on the year, location and the species found in the viable weed seedbank. For example, Wilson and Cussans (1975) reported higher weed seedling densities after cultivation versus zero-tillage. In Saskatchewan, Campbell et al. (1998) found that the population of perennial weeds including foxtail barley was not significantly decreased by a pre-seeding tillage and there were higher green foxtail and broadleaved species densities in tillage versus zero-tillage treatments. Roberts and Feast (1973) found that total weed seedlings appearing after 6 years of the experiment was much higher in cultivated versus undisturbed plots, and of the total seedlings, almost half emerged during the first year. The numbers of viable seeds and weed seedling populations that appeared in successive years decreased exponentially regardless of tillage (Roberts 1963; Roberts and Feast 1973). They also found that distribution of weed seeds after one primary cultivation was not uniform between soil layers. On the undisturbed land, almost all seeds were found in the top 23cm with greatest proportion in the upper layer of soil (0-7.6cm). Shallow depths (0-7.6cm) of cultivated plots contained fewer seeds compared to deeper depths. In general, both deep and shallow plowing decreased the proportion of buried seeds in the surface horizons (0-7.6cm) and increased the proportion of seeds found below 15cm.

Soil type. Weed seedling emergence periodicity and density may be influenced by soil type. A study conducted by Chepil (1946b) showed higher levels of weed seedling emergence on heavy clay versus loam and fine sandy loam soils for a range types of tillage treatments. The higher levels of emergence on clay soils were suggested to be due to the existence of a finely granulated loose surface layer observed on clay plots. Chepil (1946 b) also argued that the reduction in emergence levels on loam and sandy loam soil resulted from a firm surface crust, which prevented emergence and caused death of some seedlings before they emerged. Marginet (2001) also showed that the emergence periodicity of wild oat and green foxtail could be significantly affected by soil type. She showed that the emergence of wild oat seedlings was delayed most in regions characterized by heavy clay soil while in a region characterized by a sandy loam soil the emergence periodicity of green foxtail was delayed. In contrast, Ghorbani et al. (1999) found higher emergence levels of redroot pigweed in lighter versus heavier soils and they attributed this response to poor gas exchange, poor light penetration and lower spring temperatures in heavier soils.

Other studies have shown no relationship between seedling emergence and soil type or soil texture. For example, Alex et al. (1972) observed no connection between groups of soil textures and densities of green foxtail when moisture level was maintained at field capacity. In laboratory tests, they found similarities between clay, loam and sandy loam soils with regard to the emergence of green foxtail. du Croix Sissons (1999) also showed no link between soil type and depth of emergence for any of the five weed species she studied.

Soil residues (Killed residues). Crop residues can alter the physical conditions in the environment surrounding weed seeds, thereby affecting weed seed germination and seedling emergence. An experiment conducted to determine light transmittance, temperature, and moisture conditions under hairy vetch (*Vicia villosa* Roth) and rye

(*Secale cereale* L.) residues showed these factors to be affected by cover crops (Teasdale and Mohler, 1993). Light transmittance declined as residue biomass and, soil maximum temperatures were reduced, but minimum soil temperatures were only slightly affected. Biomass of residue for both species prevented decline in the moisture content of the soil surface during drought conditions. Consequently, the changes observed in seed environment due to soil residues might have a great effect on weed emergence levels.

In general, greater coverage of soil surface by crop residues can negatively affect seed germination and the emergence of weed seedlings (Teasdale et al. 1991). Teasdale et al. (1991) reported that within no-tillage systems, hairy vetch and rye residues decreased total weed density compared to treatments without crop residues, and no-tillage had higher total weed densities versus conventional-tillage after the first year of their experiment. The greater weed densities were also observed after two years of conventional-tillage. These results suggest and confirm the hypothesis that seeds shed during the first year of an experiment remain on or near the soil surface in the no-tillage treatments while conventional-tillage using moldboard plow inverts soil and brings buried seeds to the soil surface where conditions are more favorable for seedling recruitment.

Effect of tillage on factors affecting weed seedling recruitment

Residue levels (Killed residues). The amount of crop surface residues is an important difference between conservation and conventional-tillage systems (Johnson and Lowery 1985). As tillage intensity decreases, the proportion of the soil surface covered by residues increases. Kladivko and al. (1986) reported that the percentage of soil surface covered by residues was 97% and 2% for no-tillage and conventional-tillage, respectively, in corn fields, while it was 88% and 1 % in soybeans fields. Van Acker et al. (2003) showed that percentage of residue cover remaining on the soil surface after tillage events was considerably related to type of tillage implement. They found that tillage index based on estimates of post tillage surface residue levels was inversely proportional to percentage of residue cover. Tillage index was higher for moldboard plow and disks, and lower for cultivators and harrows.

The higher proportion of residues cover observed in no-tillage systems has been suggested as a factor influencing the emergence of some weed species. Spandl et al. (1998) attributed the slow rate of foxtail emergence to lower soil temperatures caused by greater soil residues in no-tillage systems. High surface residue levels have also been shown to increase the emergence levels of foxtail species in no-tillage systems (Spandl et al. 1998; Stahl et al. 1999; Mester and Buhler 1991). Because tillage affects residue cover, it is likely to alter the microsite conditions required for successful weed seedling emergence.

Soil temperature. The type of tillage that leaves more crop residues on the soil surface has a great influence on soil temperatures. For example, conservation or no-tillage resulted in lower soil temperature than conventional tillage at depths no greater than 6cm (Kladivko et al. 1986; Mahli and O'Sullivan 1990). Similarly, Bidlake et al. (1992) observed lower soil temperature to occur at 6cm depth under no-tillage versus conventional-tillage and this response was related to decreased absorption of short wave and net radiation in the no-tillage system. The same argument was supported by Johnson and Lowery (1985) who found reduced soil temperatures at 5cm below the surface in no-tillage versus conventional-tillage to be due to differences in heat flux and total heat inputs. In Manitoba, Reid (2003) found that tillage in a given year significantly affected soil temperatures at 4cm, but the differences between tillage treatments were very small (less than 1°C). The differences were considerably greater when soil temperature was compared between depths (1 and 4 cm).

Since temperature exerts a considerable influence on weed seedling recruitment (Roberts 1984; Roberts and Potter 1980; Blackshaw 1990; Ghorbani et al. 1999; Fernandez-Quinantilla et al. 1990; Hartzler et al. 1999; Egley and Williams 1991), a difference in weed seed germination and seedling emergence might be expected between zero-tillage and conventional-tillage cropping systems. Because zero-tillage is reported to lower soil temperatures (Kladivko et al. 1986; Mahli and O'Sullivan 1990; Bidlake et al. 1992; Johnson and Lowery 1985), and increase soil surface residue levels (Spandl et al. 1998; Stahl et al. 1999; Mester and Buhler 1991) spring and summer annuals such as lambsquarters and redroot pigweed (Baskin and Baskin 1998) may recruit more in conventional-tillage system versus no-tillage.

Soil moisture. Conservation of soil moisture is one of the major advantages of no-tillage crop production systems. The moisture content of the soil may be altered by tillage practices. Johnsons et al. (1984) reported higher soil moisture in no-tillage treatments throughout the growing season. Volumetric water content in the 0-25cm zone were 0.320, 0.309, 0.300, and 0.297 m3/m3 for no-tillage, chisel-plowing, conventional moldboard plowing and fall till-plant, respectively. Marginet (2001) found significant differences between zero-tillage versus conventional-tillage fields with respect to soil moisture from 0 to 2.5cm. In contrast, gravimetric (at 5cm) or volumetric soil moisture (at 6cm) was not affected by tillage treatments in a short-term study (Reid, 2003).

In long-term tillage experiments, Blevins et al. (1983) and Grevers et al. (1986) found greater soil moisture under no-tillage versus conventional-tillage. The higher residue levels observed at the soil surface in no-tillage treatments directly affects soil moisture by reducing soil water evaporation, slowing runoff and increasing infiltration (Blevins et al. 1983). The same conclusions were drawn by Hussain at al. (1999) who found more soil water at 20 cm depth in no-tillage systems versus conventional-tillage. They attributed this difference to differences in residue levels on the soil surface, which resulted in suppression of evaporation and more water infiltration.

Tillage also indirectly affects moisture content by modifying the physical properties of the soil. Maurya (1986) reported higher porosity in no-tillage plots with surface residue than in conventionally tilled plots. The no tilled plots had a 50% higher infiltration rate (6.6 cm/h) than the tilled plots (4.4cm/h). Consequently, soil water storage was higher in the no-tillage systems compared to conventional-tillage. Conversely, Azooz and Arshad (1996) and Logsdon et al. (1989) found that no-tillage plots had more macrospores than conventional-tillage plots. They also found that saturated hydraulic conductivity was significantly greater in no-tillage plots (ranging from 0.36 to 3 cm/h) than in conventional-tillage plots (ranging from 0.26 and 1.06 cm/h). Soil moisture levels also differ within a given tillage type with surface layers having lower moisture levels than deeper zones in conventional-tillage versus zero-tillage. Therefore, weed seeds will germinate and emerge according to the location of microsites.

Characterization of the weed seedling recruitment environment (the recruitment microsite) is essential for a better understanding of the response of weed species to tillage systems. Although studies on the effect of tillage on the general zone of seedling recruitment weed exist, not many researchers have made measurements of soil temperature and soil moisture in the true weed seedling recruitment zone. For example, Mahli and O'Sullivan (1990) measured soil temperature and soil moisture under zero-tillage and conventional-tillage from depths ranging from 0-15cm, 15-30cm, and 30-60cm. Similarly, Hussain et al. (1999) reported that soil moisture and soil temperature measurements were taken from 20cm depth. In Manitoba, du Croix Sissons (2000) showed that the weed seedling recruitment zone in most fields is generally shallower and it varies with time (pre-seed versus pre-spray) and with tillage. Therefore, research is needed in order to describe the accurate zone from which weeds emerge.

Weed seed placement. The location of weed species in soil profile varies among tillage regimes. In many studies, tillage has been found to affect the vertical distribution of weed seeds (Hoffman et al. 1998; Mulutega and Stoltenberg 1997; Clements et al. 1996; Webster et al. 1998; Staricka et al. 1990; Pareja et al. 1985; Yenish et al. 1996; Roberts 1963). Roberts (1963) found that 37% of all weed seeds were in the 0 to 7.6 cm depth layer in undisturbed soil, whereas plowed soil had only 24% of seeds in that layer. Pareja et al. (1985) reported that 85 % of weed seeds were located in the upper 5cm of reduced-tillage plots, but only 28% were found at the same depth in conventional-tillage plots. In conventional-tillage where moldboard ploughing inverted the soil, weed seeds were uniformly distributed among sampling depths (Yenish et al.1996). However, seeds were concentrated near the soil surface in reduced and no tillage plots because soil was not disturbed by tillage (Hoffman et al. 1998). Hoffman et al. (1998) also demonstrated that the total number of weed seeds found in the soil was rarely influenced by tillage practices. They suggested that in cases where seed numbers differed among tillage treatments, factors such as predation and decay might have increased weed seed decline at the soil surface in reduced-tillage treatments. The reduction in numbers of weed seeds at the soil surface may also result from increased levels of seedlings emergence since seeds concentrated at shallow depths are likely to experience the conditions required for successful germination and subsequent emergence.

Not only does tillage influence the location and numbers of weed seeds in different horizons of the soil profile, it also affects weed seed return and the seedbank composition. Clements et al. (1996) demonstrated that seedbank populations of common lambsquarters were greater with moldboard plow treatments than with chisel, ridge-tillage or no-tillage treatments. Although seed production per plant was equivalent among the four tillage systems, estimated seed production per unit area was greater in moldboard plow and chisel plow systems than other two systems. This study indicates that some weed species may produce more seeds per unit area in moldboard plow and chisel plow systems and fewer seeds per unit area in no-tillage and ridge-tillage. Consequently, the emergence levels of these species could be higher in conventional versus no-tillage systems.

Influence of cultural practices on weed seedling recruitment

Tillage. Agronomic practices such as tillage operations and time of planting may affect the periodicity and emergence level of weed seedlings. These practices stimulate weed seedlings emergence and by altering the microsite conditions required for seedling recruitment.

Intensity of tillage affects the emergence of weed seedlings in various ways. Depending on the type of implement used in the tillage system, tillage type may increase or decrease weed seedling emergence levels. For example, Stahl et al. (1999) found that no-tillage plots contained a greater number of foxtail species than moldboard or chisel plowed plots. They reported a greater than 90% increase in foxtail species emergence in no tillage plots three to four weeks after planting. Significant emergence did not occur past five to six weeks after planting. Cumulative emergence at the end of the experiment was higher in no-tillage versus moldboard plow and chisel-tillage, but little difference between moldboard plow and chisel treatments was observed. Similar results were obtained by Spandl et al. (1998) who found that total foxtail emergence was greater in no-tillage and chisel plow plots versus moldboard plow plots and it was greater in no tillage versus chisel plowed plots. Factors such as seed placement, seed density and higher surface residue contributed to the increased emergence level of foxtail species in no-tillage plots. Mohler and Calloway (1992) reported substantial differences in seedling emergence between tillage and no tillage treatments. Redroot pigweed, lambsquarters, purslane (*Portulaca oleracea* L.) and large crabgrass (*Digitaria sanguinalis* L. Scop.) showed significantly lower emergence levels in tilled versus untilled plots. In contrast, Ogg and Dawson (1984) found that shallow tillage using a rotary hoe increased the emergence level of common lambsquarters and redroot pigweed, decreased the emergence of barnyard grass and had no effect on the emergence level of Russian thistle

(*Salsola pestifer* A. NELS.). The reason for these differences is not well explained, but it is probably related to differences in environmental factors including soil temperature.

Secondary tillage using implements such as a chisel plow can stimulate weed emergence. In a long-term no-tillage cropping system, Mulutega and Stoltenberg (1997) found that soil disturbance increased the emergence level of giant foxtail and redroot pigweed. The response for lambsquarters was similar but more independent of rainfall. They concluded that soil disturbance using secondary tillage implements increased seedling emergence and seedbank depletion of the predominant species in their long-term no-tillage system. Buhler (1997) investigated the effect of secondary tillage on the emergence of 13 summer annual weed species and found that elimination of secondary spring soil disturbance following a fall moldboard tillage often affected the spring density of most weed species. In his study, the densities of annual grass and broadleaf species were both reduced when secondary tillage using disk in the spring was eliminated. Eliminating secondary tillage may have reduced the penetration of light in the soil, which in turn may have decreased the emergence of buried weed seeds that were sensitive to light.

Frequent soil disturbance favors the recruitment of most weed species by exposing buried seeds to the conditions suitable for germination and emergence. However, primary tillage incorporates freshly shed seeds deep into the soil profile. As the number of tillage passes increases, the densities of emerged seedlings increases as well. Roberts and Potter (1980) found that the total number of seedlings which emerged on undisturbed plots was lower compared with those where the soil was cultivated at intervals of two weeks throughout the growing season. Popay et al. (1994) reported similar trends. They found that cultivations at one month intervals resulted in more weeds seedlings in deep cultivated plots versus undisturbed plots. After 7 years of this experiment, 28,000 weed seedlings per m^2 emerged from deep cultivated tillage treatments, while less than 11,000 seedlings emerged in the shallow tilled plots and just over 4,000 emerged in the uncultivated plots. Since shallow tillage as compared to deep tillage reduced seedling numbers, Popay et al. (1994) concluded that minimal or zero-cultivation techniques coupled with herbicide applications should replace the use of regular deep soil tillage to control weeds.

The application of herbicides will depend not only on weather and stage of crops but also on the time of maximum emergence, which is a function of the timing of tillage operations. The time of the year at which tillage takes place can have a strong effect on the weed seedling emergence levels. Roberts (1984) found that *Polygonum aviculare* L. emergence was greatest when the soil was tilled in early April and decreased progressively with later cultivations. He also found that most seedlings of lambsquarters appeared after spring cultivations, but some seedlings emerged even after cultivations in early autumn (Roberts 1980, Roberts 1984). Bibbey (1935) argued that fall tillage increased the spring emergence of wild oats while stinkweed emerged better from plots not tilled in the fall, but wild mustard (*Brasica kaber* D.C. L.C. Wheeler) emergence in the spring did not show any response to fall tillage. The number of wild mustard seedlings that had emerged from fall-tilled plots was equal to that which emerged from fall-untilled plots.

Although the type and time of tillage significantly affects the numbers of weed seedlings emerging in a given year, the periodicity of seedling emergence has been shown to be unrelated to tillage practice (Roberts 1984). Oryokot et al. (1997) demonstrated that tillage did not affect the emergence periodicity of pigweed seedlings except during severe drought. They attributed this result to the fact tillage did not affect soil temperature and moisture at the 2.5 cm depth. Similarly, Ogg and Dawson (1984) found that shallow tillage at monthly intervals did not affect the emergence periodicity of redroot pigweed but it changed the magnitude of the peaks. Egley and Williams (1991) also showed that the emergence periodicity of six annual weeds was not affected by early tillage to depths of 5, 10, or 15 cm with the light cultivator, disc, and deep cutting disc, respectively. They suggested that the lack of differences between these types of tillage was due to the fact that type and depth of tillage were not sufficiently different to produce consistent differences in emergence. In fact, spring tooth cultivator and discs penetrated the soil layers near the surface. Also, tillage was performed only at one time (early March) during the season.

The patterns of weed emergence are usually linked to differences in environmental conditions such as temperature and moisture rather than tillage systems. Egley and Williams (1991), Ogg and Dawson (1984) and Spandl et al. (1998) reported that the lower temperatures in early season stimulated the flushes of annual weeds that were able to recruit at cooler temperatures, whereas higher temperatures promoted the germination and emergence of weed species requiring warmer soil temperatures for successful recruitment. Therefore, weed management practices aimed at varying planting dates may affect the magnitude and periodicity of weed emergence and the emergence response of weeds to seeding date changes may be due to differences in soil temperature and soil moisture occurring between different planting dates.

Seeding dates. Planting date affects the competition between weed species and crop, and strategies of planting are generally adopted in order to increase the competitive ability of the crop. Farmers may use two main strategies to manage weeds emerging in the spring. The first strategy consists of planting the crop early in the season before weeds emerge. The second is to seed the crop later to allow one or more flushes of weed emergence prior to seeing. These strategies may influence the periodicity and number of weed seedlings emerging in the crop.

Seeding dates affect the recruitment of weed seedlings by modifying the seed microsite, which in turn influences the period and levels of emergence. For example, Spandl et al. (1998) found that earlier seeding generally resulted in a greater percent of foxtail emergence until mid season. But, at 22 days after planting, later planting increased the percent of foxtail emergence. The explanation for this difference in emergence among planting dates is related to recruitment environment (microsite). Spandl et al. (1998) argued that delayed planting pushed the germination of green foxtail further into the spring where environmental conditions including soil and air temperatures were higher. Delayed plantings also increased the rate of foxtail emergence, but decreased seedling emergence densities. The decrease in foxtail emergence densities may have been the result of induced dormancy and death of seedlings with late seedbed preparation. Similarly, Robinson and Dunham (1956) reported that weed emergence was significantly reduced when cultivations occurred late in the season on both tilled and untilled plots. When tillage was delayed in late May, weed emergence was 61% less without tillage than with tillage (Buhler 1997). Early tillage increased green foxtail density only on no tilled plots. By late May, as many as

500 green foxtail and 300 yellow foxtail plants/m² had emerged prior to tillage. This emergence alters both the nature of the seedbank and the temperature and moisture conditions near weed seeds.

Timing of crop planting also has a considerable influence on the proportions of the viable seedbank that are potentially destroyed by seedbed preparations. Forcella et al. (1993) demonstrated that late plantings increased significantly the percentages of seedlings emerging before seedbed preparation, but this trend was reversed when soybean and corn were planted early. In the absence of herbicides, seedbed preparation dates had a significant effect on weed seedling emergence and subsequent weed population levels (Forcella et al. 1993). Early plantings resulted in 74, 38, and 13 plants/m² of giant foxtail, redroot pigweed and lambsquarters, respectively. In contrast, densities of the same species were 18,14 and 2-plants/ m² when soybeans were planted late. Not only did date of planting cause differences in emergence levels between species, large variations in emergence levels also occurred within species. Variation was more pronounced in lambsquarters. It is suggested that the apparent differences were probably due to variation in the extent of seedling emergence at the times seedbed preparations occurred at different sites or during different years. Although late planting decreases the levels of weed emergence, this practice may not be a viable option because it can reduce crop yield.

Summary.

Tillage and seeding date may affect the periodicity and levels of weed seedling emergence by altering the conditions required for successful weed seedling emergence. Higher surface residues observed under zero-tillage tend to lower soil temperature and increase levels of soil moisture. These conditions may favor the recruitment of some weed species while decreasing the emergence levels of others. Tillage may also affect the placement of weed seeds in the soil profile thereby causing differences in seedling emergence between zero-tillage and conventional tillage systems. The strategy of changing seeding dates can influence weed seedling emergence. Late planting may cause a delay in the periodicity of emergence and a reduction in levels of weed seedling emergence because late seeding allows more emerged weed seedlings to be killed by late seedbed preparations.

Studies on the effect of tillage and planting date on weed seedling emergence exist, but results from these investigations are conflicting. Although the influence of tillage systems on weed seedling emergence is well documented, there is little information on the influence of type and timing of tillage in interaction with seeding dates on the periodicity and levels of weed seedling emergence. In addition, not many studies have measured variables causing differences between tillage systems in the true weed seedling recruitment zone. Therefore, research is needed in order to investigate how time and type of tillage within a given year affect the potential microsite for weed seedling recruitment and subsequent weed emergence. Such studies will allow a better understanding and accurate prediction of the periodicity and levels of weed seedling emergence. Knowing how tillage and planting date affects the periodicity and levels of weed emergence could help producers to better time weed control measures so that they can reduce herbicide applications.

This study will focus on the emergence of two prominent weed species in Manitoba, green foxtail and redroot pigweed. These species were chosen because they are common troublesome species in the province and because they are the most common weed species at our two research sites.

Recruitment biology of green foxtail and redroot pigweed

Green foxtail. Green foxtail is the most abundant weed in the province with a relative abundance of 75.8 (Leeson et al.2002). Alex et al. (1972) observed that in Manitoba green foxtail occurred on all soils regardless of textures. Green foxtail is a summer annual weed and has the C_4 pathway of photosynthesis (Douglas et al. 1985). Green foxtail possesses a short period of seed dormancy (Chepil 1946a). Chepil (1946a) observed that the majority of green foxtail seedlings emerge usually in mid-spring Green foxtail requires high temperatures for seed germination and successful seedling emergence. Studies have shown that maximum germination for green foxtail seeds occurred at temperature ranges of 20 to 30 °C (Vanden Born 1971, Banting et al. 1973). Reductions in soil temperatures from 20 to 15 °C caused a delay in time to reach 50% emergence of green foxtail (Blackshaw et al.1981).

Soil moisture is another critical factor affecting the germination and emergence of green foxtail. Bibbey (1935) found that moisture was a limiting factor for weed seed germination in Western Canada, and it was suggested to be the most important factor regulating the germination of seeds of this species and subsequent seedling emergence in the spring. It has been observed that flushes of green foxtail emerged after periods of rainfall (Banting et al. 1973). In Manitoba, Blackshaw et al. (1981) found that soil moisture had a greater effect than soil temperature on green foxtail germination. The germination percentage of green foxtail was reported to decline to zero at water potential of –6.5 Mpa (Blackshaw et al. 1981). The placement of weed seeds in the soil profile has also been reported to influence the recruitment of green foxtail. Chepil (1946 a) found that the majority of green foxtail (98%) germinated and emerged from shallow depth. In a green house, Boyd and Van Acker (2003) found less emergence of green foxtail from seeds placed on the surface than seeds buried below the soil surface (1 to 2, 3 to 4, and 6 to 7 cm). In a field, the effect of depth on weed emergence may vary depending on tillage systems.

The position of weed seeds in the soil changes as tillage systems vary resulting in a shift in seedling recruitment depth. Emergence depths for many weed species are suggested to be shallower in no-tillage versus conventional-tillage systems. In Manitoba, du Croix Sissons et al (2000) reported that green foxtail emerged from shallow depths in zero- versus conventional-tillage fields. Similarly, Buhler and Mester (1991) observed that mean emergence depths of green and giant foxtail were shallower in no-tillage treatments, followed by chisel plow and conventional tillage treatments. Emergence percentage of foxtail species from 1cm averaged 40%, 25% and 15% for no-tillage, chisel plow and conventional tillage, respectively. It is suggested that the increased emergence from shallow depths depends on favorable environmental conditions near the soil surface (Pareja et al. 1985).

Redroot pigweed. Redroot pigweed is among the most troublesome weeds in Manitoba. It appears as one of the top ten most abundant species in the province with a frequency of 27.9 % (Leeson et al.2002). It is a summer annual species of cultivated fields and has the C_4 pathway of photosynthesis (Weaver and McWilliams, 1980). Redroot pigweed possesses very long (maximum length of dormancy exceeding 3 years) seed dormancy

(Chepil 1946a). The peak recruitment of redroot pigweed occurs between late spring and mid summer because it requires high temperature and relatively low soil moisture content for seed germination and seedling emergence (Chepil 1946a). The minimum temperature for seed germination is less than 5 °C and maximum germination occurs between 35-40 °C (Weaver and McWilliams 1980; Ghorbani et al. 1999).

Light is also a major factor stimulating the recruitment of redroot pigweed. Buhler (1997) showed that the emergence of redroot pigweed was reduced by 50% when tillage was conducted without light versus when it was conducted with light. Similarly, Gallagher and Cardina (1998) found that redroot pigweed was the only weed species for which emergence was significantly affected by light during tillage. Therefore, buried seeds of redroot pigweed may not germinate and emerge until they are exposed to light.

Deeper burial depth may both reduce and delay the emergence of redroot pigweed. Weise and Davis (1967) found little emergence of redroot pigweed from seeds buried below 2.5 cm. Also, percent emergence of redroot pigweed was higher when redroot pigweed seeds were placed below 0.5-3cm than when seeds were located on the soil surface or below 4cm (Ghorbani et al. 1999). The main explanation for the reduction of emergence is related to the photodormancy of pigweed seeds buried deep in the soil profile.

The recruitment of redroot pigweed is affected by tillage. Tillage may stimulate the germination and emergence of redroot pigweed either by changing the conditions of the microsite or by placing the seeds at various soil depths. The growing evidence of the effect of tillage on the recruitment of weed species suggests that tillage systems that warm up the soil (Blevins et al 1983; Azooz and Arshad 1996; Maurya 1986) or expose seeds to the light environment (Buhler 1997; Gallagher and Cardina 1998) increase the germination and emergence of redroot pigweed (Chepil 1946b; Buhler 1997; Gallagher and Cardina 1998; Mulutega and Stoltenberg 1997; Ogg and Dawson 1984).

Objectives

The global objective of this study is to determine the effect of various combinations of soil disturbance and time of planting on the periodicity and levels of green foxtail and redroot pigweed seedling emergence in a given season.

The specific objectives are:

- To observe and characterize green foxtail and redroot pigweed seedling emergence levels and periodicity in untilled and tilled plots
- To determine the influence of secondary tillage on green foxtail and redroot pigweed seedling emergence level and periodicity
- To document soil temperature and soil moisture (volumetric) in the weed seedling recruitment microsite in order to explain the influence of tillage on green foxtail and redroot pigweed seedling emergence levels and periodicity

Hypotheses

- Tillage does not stimulate green foxtail or redroot pigweed emergence. Given the minimum level of depth and intensity of tillage commonly practiced in Western Canada, green foxtail and redroot pigweed will emerge equally in-levels and timing regardless of tillage applied.

- Planting time has a large effect on green foxtail and redroot pigweed emergence. In all treatments, early seeding will reduce seedling emergence while late seeding will increase seedling emergence.
- Spring tillage in a fall no-tillage system increases the levels of seedling emergence.
- Tillage has no impact on timing of green foxtail or redroot pigweed seedling emergence. These species will emerge according to thermal time.

CHAPTER 3. MATERIALS AND METHODS

Experimental site description

Field experiments were conducted in 2002 and 2003 at the University of Manitoba research stations located at Winnipeg and Carman. The soil type at Winnipeg was a Riverdale silty clay and at Carman the soil type was a fine sandy loam (Orthic Black) with 4.1-5% organic matter and pH was strongly acid (5.1-5.5) (Mills and Haluschak, 1993). The trials at both sites were established on untilled wheat stubble from 2001 and 2002. Both Winnipeg and Carman research station plots had been under conventional-tillage continuously for many years. Conventional-tillage consisted of one tillage pass with medium duty cultivator to depth of 7-9cm once each in fall and spring and seeding with hoe opener drill (hoe with of 2.5cm) followed by finger harrows. Therefore, the tillage treatments in our study, especially the no-tillage treatment do not represent typical long-term no-tillage treatments.

The experimental design was a randomized complete block (RCBD) with a split plot arrangement. The main plot size was 4m wide and 9m long at Carman, and 4m wide and 8m long at Winnipeg. The main plot treatments were tillage treatments. The subplots treatments were seeding dates, and subplot size was 1.8mx9m at Carman and 1.8mx8m at Winnipeg. In total, 4 tillage treatments and 2 seeding dates were replicated 8 times resulting in 64 subplots at each site. The experiment in each year was established on plots with approximately similar soil characteristics. All treatments are summarized in Table 3.1.

Soil preparation and field operations

In the fall of each year, 4 cultivated and 4 uncultivated strips were established at each site. Cultivation was with a sweep cultivator (7 inch sweeps or 5 inch spacing) done in south-north direction. Tillage was always to a depth of only 7-9cm. Prior to fall tillage for the 2003 trial, a mixture of weed seeds (green foxtail and redroot pigweed) and sand were hand spread on the whole plot area at both sites in order to increase the size of the weed seedbank. The additional weed seeds included green foxtail applied at (0.2g/m²) and redroot pigweed applied at (0.06g/m²) in order to achieve additional emergence levels for each of these species of 20 plants/m² (assuming 20% germination). Spring tillage or secondary tillage using a sweep cultivator was done in a direction perpendicular to fall tillage treatments and occurred on the same day or a day before seeding operations.

Barley (cv McGwire) was seeded into plots using a 12 row (6" raw spacing) double disk press drill (with no harrows attached: very low disturbance seeder) at two different dates (early and late) spaced 16 days apart on average (Table 3.2). The early seeding date (SD1) was May 16 and May 17 in 2002 and May 7 and May 6 2003 in Carman and Winnipeg, respectively. Late seeding (SD2) was conducted June 4 and June 5 in 2002 and May 21 and May 22 in 2003 at Carman and Winnipeg, respectively. Calendar dates for seeding and data collection are summarized in Table 3.2. Barley was seeded at rate of 126 kg/ha and fertilizer (23-10-5-5) was mixed with barley seeds at a rate of 200 kg/ha and applied in the seed row at seeding time. Due to the heavy infestation of dandelion at the Winnipeg site in 2002, glyphosate at recommended rate (1350 g ai/ha) was sprayed on May 20, before the emergence of barley using a bicycle sprayer (275 kpa and application volume of 110 L/ha). Because the recommended rate did not effectively control dandelion, it was decided to increase the rate of glyphosate to 2250 g ai/ha and respraying occurred on June 1, 2002. The Winnipeg trial was seeded on June 5 and hence, there was only one seeding date for this site-year corresponding to the late planting date. In-crop herbicide treatments included a mixture of fenoxaprop-p-ethyl (92g ai/ha), thifensulfuron and thibenuron (2:1) (10g ai/ha: 5g ai./ha) and MCPA amine (550 ai g/ha) (Guide to crop protection, 2002) and in-crop herbicide was applied approximately one month after seeding when barley was in the 4 leaf stage. All herbicide application was done using an ATV sprayer equipped with a 3m wide boom and 6 standard 11001VS TeeJet nozzles calibrated to deliver 110 l/ha total spray solution at 275 Kpa. Prior to in-crop herbicide application, weed and crop aboveground biomass was harvested in each plot from a 0.25 square meter quadrat, packed in paper bags and frozen at –20°C for 3weeks. Weeds and barley were separated and weeds were sorted by species, dried at 105°C for 48 hours. Weed and crop dry biomass was then determined by weighing dried samples.

Table 3.1: Tillage and seeding date treatments.

Treatments	Code
Tillage	
1. Fall tillage spring tillage	FTST
2. Fall tillage spring no-tillage	FTSNT
3. Fall no-tillage spring tillage	FNTST
4. Fall no-tillage spring no-tillage	FNTSNT
Seeding date	
1. Early seeding	SD1
2. Late seeding	SD2

Table 3.2: Calendar dates for barley seeding date, in-crop herbicide applications and management periods at Winnipeg 2002 and 2003, and Carman 2002 and 2003.

	Winnipeg 2002	Winnipeg 2003	Carman 2002	Carman 2003
Seeding dates				
SD1	-	May 6	May 16	May 7
SD2	June 5	May 22	June 4	May 22
Spraying dates				
SD1	-	June 13	June 18	June 10
SD2	July 3	June 24	July 2	June 23
Management periods	*Emergence sampling dates*			
MP1: Prior to seeding				
SD1	-	April 23,29 May 2	-	April 24 May 1,5,7
SD2	May 19,24,31	April 23,29 May 2,15,20	May 27, 30 June 3	April 24 May 1,5,7,13,20
MP2: Post- seeding, prior to in-crop herbicide application				
SD1	-	May 15,20,27 June 2	May 27,30 June 3,7	May 13,20,26,30 June 3,6
SD2	June 21,25,28	May 27 June 2,16,19,23	June 14,20,24,28	May 26,30 June 3,6,13,18,23
MP3: Post in-crop herbicide application				
SD1	-	June 16,19,23,27 July 3	June 20,24,28 July 2,10	June 13,18,23,26 July 2
SD2	July 3,11	June 27, July 3	July 2,10	June 26, July 2

Measurements

Weed seedling emergence. The levels of weed emergence were determined twice per week at each site starting at initial weed emergence prior to spring tillage (April) and continuing until emergence ended in early-July. Two permanent 0.25-m^2 quadrats were placed randomly in each subplot at the onset of weed emergence. At each sampling date, newly emerged weeds were identified, counted and tagged with colored plastic rings coded by date. Weeds were not removed from the quadrats until biomass was harvested. Weed emergence periodicity was expressed as cumulative percentage of emerged seedlings and was calculated as the number of seedlings emerged at a given time relative to the total number of seedlings emerged from the initial to the final weed count. Barley grain yield from each subplot was harvested using a plot combine (Wintersteiger-Hege, Salt Lake city, Utah). All data for the cumulative percentages and densities of seedling emergence were converted to a m^2 basis.

Soil moisture. Volumetric soil moisture content was determined weekly using a copper ring with a known volume. Soil moisture samples were taken from 3 depths (0-2.5cm; 2.5-5cm; and 5-7.5cm). The cut face technique was used for soil sample collection. This method consisted of cutting the soil profile in each subplot using a shovel. The soil surface was considered to be the soil not the residue surface. Loose residue was removed to find the soil surface for temperature, soil moisture and soil seedbank measurements. The sampling ring was then placed on the surface close to the edge of the soil profile. The ring was pushed into the soil and a sharp knife was used to remove the ring. Six soil rings were taken randomly from each subplot (2 rings per depth). Soil samples from the same depth were pooled in a plastic jar, which was then hermetically sealed. Wet soil samples were weighed and oven dried at 105 °C for 48 hours. After soil dry weight was obtained, soil samples were discarded. Volumetric water content was calculated as follows (McKeague, 1978):

Water content (volume basis) Pv = Pw x Dbm [1]

Where Pv = water content (volume basis); Pw = water content (weight basis); and Dbm =bulk density at field water content (W/V g/cm^3) (W: oven-dry weight of sample; V: volume of sample).

Soil temperature. Soil temperature measurements were monitored hourly throughout the sampling period using Stow Away® TidbiT™ temperature loggers (Onset Computer

Corporation, Box 3450, 536 MacArthur Blvd., Pocasset, MA 02559-3450). Prior to spring tillage, TidbiTs were placed between crop rows in selected plots and buried at two depths (0-2.5 cm and 2.5-5 cm) in order to determine the influence of tillage on soil temperature. The selected plots represented 2 replicates of each of the 4 tillage treatments and the 2 seeding dates in 2003. In 2002, TidbiTs were placed only in the 4 tillage treatments. TidbiTs were removed at each spring tillage operation and were replaced right after crop planting. Soil temperatures for these periods were correlated with air temperature taken from local weather stations. Daily soil temperatures from TidbiTs placed at 0-2.5 cm were converted to heat units expressed in growing degree days (GDD) using the basic equation:

$$GDD=[(T\ max + T\ min)/2] - T\ base \qquad [2]$$

(McMaster and Wilhelm, 1997), where Tmax and Tmin are daily maximum and minimum soil temperature, respectively, and Tbase (0°C) is the base temperature.

Weed seeds location in the soil seedbank. To determine how tillage affected the placement of weed seeds in the soil profile, soil samples were taken post spring tillage at two depths (0-2.5 cm; 2.5-5 cm) using a 5 cm diameter and 2.5 cm height cooper ring. Soil samples were taken from each of 4 replicates of selected subplots (See below). Soil sampling for the seedbank followed the same method as per the procedure used for volumetric soil sampling. The sampling technique and estimation of weed seedling densities from viable buried seeds followed, generally, the methods described by Forcella (1992). Twelve soil rings were systematically sampled from each tillage treatment. Soil samples from the same depth and subplot were pooled in a plastic bag, stored in a freezer room (-20°C) until emergence experiments begun. In 2003, the total number of soil cores represented a surface area of approximately 235 cm^2 per treatment, and this should permit a reliable estimate of the size of the seedbank. Forcella (1984) observed that a soil surface area of about 200 cm^2 was required to obtain a representative individual sample of the number of species in the seedbank.

The assessment of viable weed seeds from buried seedbank was based on the greenhouse grow-out procedure. We chose this procedure because it appeared to be more consistent than other techniques in terms of correlation of results with field seedling densities (Forcella 1992; Cardina and Sparrow 1996).

In early-July, frozen soil samples were spread and allowed to thaw on trays (10 cm x 12 cm x 5 cm) in a greenhouse (30/20 °C day/night) and kept moist continuously for 1 month. Emerging seedlings were identified, counted, and removed from the trays. At the end of one month, in order to allow further germination and emergence, soil samples were dried for one day. Soil samples were periodically stirred and watered. At the end of each emergence run, soil samples were re-frozen (-20 °C) for about 30 days. This process was repeated 3 times and emergence data for the 3 runs was pooled by species.

Statistical analysis.

Statistical analysis for measured and derived variables was conducted using SAS 8.2 statistical software (SAS, 1990). Data sets included only plots in which emerged weed species exceeded 6 plants per m^2 for a given site-year. Data of densities (plants/m^2) of emerged seedlings were analyzed using analysis of variance (ANOVA) (PROC GLM procedures) and emergence periodicities (% cumulative emergence) data were analyzed using analysis of variance (PROC GLM) and nonlinear regression (PROC NLIN) procedures. Where main factors or interactions were found to be non-significant in ANOVA or GLM analysis the sums of squares for these factors were added to the error sums of squares and the analyses re-run.

Densities of emerged weed seedlings as well as volumetric soil moisture were analyzed as a randomized complete block designed experiment (RCBD) with a split plot arrangement. Mean separation was performed using Fisher's Protected LSD test for comparing differences between tillage, seeding date and management periods. Seeding date was not included in the analysis for Winnipeg 2002 because both levels of seeding date were not represented for this site-year. Since the analysis of variance (ANOVA) showed significant differences between year and location, data were analyzed separately for year and location. Where significant interactions ($P<0.05$) between main factors occurred, analysis of combination of factors was conducted to determine differences between interactive variables.

Weed emergence periodicity was determined as cumulative percentage of total emergence. Periodicity of emergence was analyzed with nonlinear regression as a function of cumulative soil GDD using the PROC NLIN procedures with iterations derived by the Gauss-Newton algorithm (SAS, 1990). A logistic model was fitted to the emergence periodicity data. The logistic model was chosen for its simplicity and biological meaning (Friesen et al. 1992). The model fitted was

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

where y is the dependent variable (species emergence), x is the emergence percentage expressed in soil growing degree days (base temperature 0°C), and *e* is the base of the natural logarithm. The parameters *a*, *b*, and *c* are the nonlinear parameter estimates where *a* is the estimated value of the upper asymptote, *a*/(1+*b*) is the y axis intercept, *ac*/4 is the slope at the inflection point and (ln*b*)/*c* and *a*/*c* are the values of x and y respectively at the inflexion point. After *a*, *b* and *c* parameter estimates were determined individual curves for years, tillage and seeding date and were statistically tested for common *a*, *ab*, *abc* and *ac* using the lack-of-fit F test at the 0.05 level of significance, as outlined by Seefeldt et al. (1995). Coefficients of determination (R^2) were calculated as described by Kvalseth (1985) using the residual sum of squares value from the SAS output.

CHAPTER 4. RESULTS AND DISCUSSION

Green foxtail seedling emergence

Effect of tillage system, seeding date and management period on green foxtail densities

Effect of tillage on green foxtail densities. Analysis of variance (ANOVA) showed that site and year were significant factors (Appendix 4.1) affecting densities of green foxtail, and subsequently, each site-year was analyzed separately for the effect of tillage, seeding date and management period on densities of green foxtail. Significant interactions occurred between tillage and management period in 2003 at both sites. Therefore, combinations of tillage and management period were analyzed separately for 2003 (Table 4.2)

Green foxtail densities (absolute number of seedlings per m^2) were significantly different between tillage systems (Table 4.1). Tillage caused an increase in densities of foxtail in three of 4 site-years (Winnipeg 2003, Carman 2002 and 2003). This response may be the result of higher soil temperatures observed on tilled versus untilled plots (Figure 4.1). In contrast, in 2002 at Winnipeg (Table 4.1), tillage reduced green foxtail density. This may have been due to the relatively low soil moisture content observed in the tilled treatment in this site-year (Table 4.3). The position of weed seeds in the soil may also have explained the high number of green foxtail seedlings in no-tillage treatments at this particular site-year. Anderson and Nielsen (1996) and Spandl et al. (1998) found higher densities of green foxtail in reduced-tillage treatments and they attributed this to the location of seeds nearer the soil surface. In general, no-tillage systems tend to concentrate seeds near the soil surface (du Croîx Sissons et al. 2000).

Table 4.1. Green foxtail densities as affected by tillage (FTST: fall till and spring till; FTSNT: fall till and spring no till; FNTST: fall no till and spring till; FNTSNT: fall no till and spring no till), seeding date (SD1: early seeding; SD2: late seeding) and management period (MP1: prior to spring tillage; MP2: post spring tillage and prior in-crop herbicide application; MP3: post in-crop herbicide application) at Winnipeg and Carman, MB in 2002 and 2003.

Factor	Winnipeg 2002	Winnipeg 2003	Carman 2002	Carman 2003
Tillage	Seedlings/m²			
FTST	73.5b [a]	249.8a	10.7a	50.4a
FTSNT	49.1b	139.8b	7.5ab	24.0b
FNTST	157.5a	181.8ab	5.5ab	63.5a
FNTSNT	162.6a	35.2c	2.5c	23.1b
LSD	56.8	96.7	5.4	47.7
Seeding date				
SD1	- [b]	178.5a	8.8a	39.6a
SD2	-	123.8a	4.2a	40.7a
LSD		68.4	3.8	14.7
Management period				
MP1	-	8.32b	2.2b	19.8b
MP2	-	443.5a	12.3a	92.8a
MP3	-	1.7b	5.1b	7.3b
LSD		83.8	4.6	18.0

[a] Means within a column followed by the same letter are not significantly different according to the Fisher Protected LSD test ($\alpha = 0.05$)
[b] No seeding date treatment at Winnipeg in 2002

In 2003, there were interactions between tillage system and management period (Appendix 4.1), but the interactions were driven by the differences in MP2 (post seeding and prior to in crop herbicide applications). During this period, spring tillage seemed to cause an increase in green foxtail density (Table 4.2). This may have been related to the higher soil temperature on tilled compared to no-tilled plots. The same interaction was not apparent for management periods 1 (MP1) or 3 (MP3), but densities were much lower during these periods versus management period 2 (MP2).

Effect of seeding date on green foxtail densities

The effect of seeding date on green foxtail densities was significant only at Carman in 2002 (Table 4.1), with higher green foxtail densities with early seeding at that site. Although Forcella et al. (1993) and Spandl et al. (1998) found that delayed seeding resulted in lower foxtail densities it was because of the greater proportion of green foxtail emerging prior to seeding in delayed seeding treatments. Their results were for in-crop (after seeding) densities only whereas our results are for total (both prior to and after seeding) densities. In the present study, significant effects, generally, of seeding date on total emergence density were due to the fact that densities were measured both pre- and post-seeding. Any effect we did see was likely a tillage effect because the time of spring tillage corresponded to planting time and no weeds were allowed to emerge between soil preparation and planting operations.

Effect of management period on green foxtail densities

Sampling dates for weed emergence were grouped into three management periods (MP) (Table 3.2). Management period significantly affected green foxtail densities (Table 4.1) in all site-years. MP2 was the management period during which most green foxtail seedlings emerged in all site-years. In Winnipeg 2002, and Carman 2002 and 2003, 97.8 %, 62.7 % and 77.5 %, respectively, of green foxtail seedlings emerged during this period. High levels of green foxtail emergence during MP2 can be attributed to favorable environmental conditions for emergence during this period. In fact, MP 2 included mid-May through to the end of June (Table 2.2), which corresponded to the period of the year where temperature and precipitation (Table 4.4) are favorable for green foxtail seed germination and subsequent seedling emergence (Bullied et al. 2003; Blackshaw et al. 1981).

Table 4.2. Effect of tillage (FTST: fall till and spring till; FTSNT: fall till and spring no till; FNTST: fall no till and spring till; FNTSNT: fall no till and spring no till) and management period ((MP1: prior to spring tillage; MP2: post spring tillage and prior in-crop herbicide application; MP3: post in-crop herbicide application) on green foxtail densities at Winnipeg and Carman, MB in 2003[b].

	Winnipeg 2003	Carman 2003
Treatments	Seedlings/m^2	
FTST MP1	16.0 c[a]	19.0bcd
FTSNT MP1	17.0 c	14.8cd
FNTST MP1	0.0 c	29.1bcd
FNTSNT MP1	0.1 c	16.5cd
FTST MP2	726.0 a	121.8a
FTSNT MP2	401.3 b	53.5b
FNTST MP2	542.0 b	149.1a
FNTSNT MP2	104.8 c	46.7bc
FTST MP3	1.6 c	10.3d
FTSNT MP3	1.1 c	3.8d
FNTST MP3	3.4 c	9.0d
FNTSNT MP3	0.6 c	6.2d
LSD	171.57	15.9

[a] Means within a column followed by the same letter are not significantly different according to the Fisher Protected LSD test ($\alpha = 0.05$)
[b] Interaction between MP and tillage was not significant in 2002

Effect of spring tillage and depth on the quantity and location of green foxtail seeds in the soil

Analysis of variance (Appendix 4.5) showed that site and depth were the only factor affecting the quantity of green foxtail seeds in the soil and so data were combined over tillage and seeding date treatments. The greatest proportion of green foxtail was located at or near the soil surface (0-2.5cm) (Table 4.7). The total proportion of seeds found in the soil averaged 87.1 % and 12.8 % for depth 1 (0-2.5cm) and depth 2 (2.5-5cm), respectively. This response suggests that the type of tillage (field cultivator) used in this study was not sufficient to bury green foxtail seeds deeper into the soil profile. Contrary to moldboard tillage that tends to move freshly shed seeds deeper in the soil (Ball 1992; Buhler et al. 1997; Dyer 1995), chisel plow or field cultivator tillage concentrate seeds closer to the soil surface (Ball 1992, Buhler et al. 1997 and Dyer 1995). Therefore, in Manitoba, where the most popular tillage systems include only cultivators with minimum or no soil inversion (Thomas et al. 1999), it would not be surprising to find an increase in the number of weed seeds located near the soil surface. Chepil (1946a) reported that 98% of green foxtail seeds germinated from shallow depth in the field during the first year. In addition, seeds of most annual weed species have been found near the soil surface in reduced and no-tillage systems (Hoffman et al. 1998). It has been shown that even though chisel plowing tends to distribute weed seeds evenly in the soil profile, a large portion of seeds remain at or near the soil surface due to lack of soil inversion (Yenish et al. 1992).

Although both sites contained higher number of seeds at shallow depth, more green foxtail seeds were found in the soil at Winnipeg. Winnipeg was a clay soil site while Carman was a sandy soil. Even though some studies have shown a significant effect of soil type on seedbank populations and levels of seedling emergence (Chepil 1946b; Ghorbani et al. 1999), others have shown no connection between soil characteristics and densities of seeds or levels of seedling emergence. Several other factors, including cropping history (crop and weed management) (Hoffman et al. 1998) and the initial distribution and quantity of seeds in the soil profile (Mohler and Galeford, 1997) may explain the differences between two distinct soil types (or locations) in the size and the location of seedbank in the soil.

Effect of year, tillage system and seeding date on green foxtail emergence periodicity

Analysis of variance [(General linear model (GLM)] was used to determine the effect of year, site, tillage, and seeding date on the emergence percentage of green foxtail. The ANOVA showed significant differences between years, but no significant differences between sites, tillage treatments or seeding dates. Details for the analysis of variance are summarized in Appendix 4.2. Although percentage emergence of green foxtail was not significantly influenced by seeding date according to ANOVA, according to non-linear regression analysis there was a slight influence of seeding date on emergence periodicity (Table 4.5). Tillage and site remained non-significant factors affecting green foxtail emergence periodicity according to non-linear regression analysis (Table 4.5 and Appendix 4.4. a, b). Because the results from PROC NLIN and the lack-of-fit F-test showed that emergence periodicity of green foxtail was significantly different between years (Figure 4.2. and Table 4.6) and not significant between sites, tillage treatments and seeding date, data for the latter treatments were pooled within year.

Effect of year on periodicity of green foxtail emergence

Based on Figure 4.2, green foxtail emerged earlier and at higher proportion at the start of the year in 2002 versus 2003. In 2003, emergence was delayed and proceeded at a low level, in comparison to 2002, until the inflection point when emergence of green foxtail become more rapid in 2003 vs. 2002. This result was surprising because one would expect the faster GDD accumulation observed in 2003 to increase the rate of green foxtail emergence. The delay in emergence early in the season in 2003 may have been the result of very low soil moisture levels at shallow depth (0-2.5cm) (Table 4.3). Marginet (2001) found that in most cases where green foxtail emergence was delayed, soil moisture was the major limiting factor. Similarly, when soil moisture was limiting, Blackshaw et al. (1981) observed a delay in green foxtail emergence.

In 2003, once cumulative emergence levels reached approximately 40%, it may be that all green foxtail seeds near the surface would have emerged. Subsequent emergence would come from seeds located deeper in the soil profile (du Croîx Sissons et al. 2000). This subsequent emergence was rapid and occurred at a higher rate compared to the emergence at the beginning of the season. This result could be attributed to the combined effect of the rapid GDD accumulation observed in 2003 versus 2002 (Figure 4.3) and the adequate moisture content in the soil at 2.5-5 and 5-7.5 cm depths (Table 4.3). These results emphasize the importance of knowing microsite location when trying to explain the periodicity of green foxtail emergence.

Table 4.3. Mean volumetric soil moisture (%) as affected by tillage (FTST: fall till and spring till; FTSNT: fall till and spring no till; FNTST: fall no till and spring till; FNTSNT: fall no till and spring no till) and depth at Winnipeg and Carman, MB in 2002 and 2003. Note: tillage treatment values are means over depth and depth treatments are means over tillage treatments.

Factor	Winnipeg		Carman	
Tillage	2002	2003	2002	2003
FTST	23.0a [a]	29.3a	25.3a	14.9a
FTSNT	31.3a	29.3a	22.2a	16.9a
FNTST	36.1a	29.3a	27.7a	17.0a
FNTSNT	29.9a	28.7a	21.9a	14.9a
LSD	13.1	1.3	5.5	2.6
Depth (cm)				
0-2.5	27.1a	16.3a	18.8a	13.0a
2.5-5	31.1b	32.6b	26.6b	16.9b
5-7.5	38.2c	38.5c	28.3b	18.3b
LSD	3.3	1.1	2.1	2.2

[a] Means within a column followed by the same letter are not significantly different according to the Fisher Protected LSD test ($\alpha = 0.05$)

Table 4.4. Monthly actual and normal mean temperatures (°C) and precipitation (mm) at Winnipeg and Carman, MB in 2002 and 2003.

	Winnipeg		Carman		Winnipeg
	2002	2003	2002	2003	
	Actual				Normal [b]
Temperature (°C)					
April	1.9[a]	5.7[c]	-	5.5 [d]	4
May	8.0	13.4	8.1 [d]	12.2	12
June	17.8	17.7	17.8	16.6	17
July	20.8	20.4	20.2	19.1	19.5
August	18.2	21.8	17.7	20.6	18.5
Precipitation (mm)					
April	38.8	14.4	-	14.4	31.9
May	54.8	70.3	41.4	80.2	58.8
June	76.4	74.4	141	90	89.5
July	81.2	41.1	49.4	56.2	70.6
August	91.5	68.3	129.2	71	75.1

[a] Source: Environmental Canada
[b]Source: Environmental Canada 30years average, 1971-2000
http://www.climate.weatheroffice.ec.gc.ca/climate_normals
[c] source: University of Manitoba, The Point weather station.
http://home.cc.umanitoba.ca/~adam/home/
[d] source: University of Manitoba, Carman weather station

Table 4.6. F test results comparing parameter estimates of green foxtail emergence periodicity models for years 2002 and 2003. See materials and methods for models. Values in parentheses are standard errors.

Year	Parameter estimates a	b	c	R^2
				0.81
2002	99.8 (1.7)	46.1 (21.6)	0.007 (0.0008)	
2003	99.8(1.7)	571.4 (376.6)	0.01 (0.001)	
P values	NS[a]	<0.0001	<0.0001	

[a]NS Means not significant at 5% level

Table 4.5. Green foxtail emergence periodicity (sites combined within years) as affected by tillage (FTST: fall till and spring till; FTSNT: fall till and spring no till; FNTST: fall no till and spring till; FNTSNT: fall no till and spring no till) and seeding date (SD1: early seeding; SD2: late seeding) in 2002 and 2003. See materials and methods for models. Values in parentheses are standard errors.

	2002				2003			
Tillage	a	b	c	R^2	a	b	c	R^2
				0.88				0.87
FTST	94.9 (2.3)	630.6 (465.5)	0.014 (0.001)		97.2 (1.5)	362.6 (185.2)	0.013 (0.001)	
FTSNT	94.9 (2.3)	630.6 (465.5)	0.014 (0.001)		97.2 (1.5)	362.6 (185.2)	0.013 (0.001)	
FNTST	94.9 (2.3)	630.6 (465.5)	0.014 (0.001)		97.2 (1.5)	362.6 (185.2)	0.013 (0.001)	
NTSNT	94.9 (2.3)	630.6 (465.5)	0.014 (0.001)		97.2 (1.5)	362.6 (185.2)	0.013 (0.001)	
P values	NS [a]	NS	NS		NS	NS	NS	
Seeding date								
				0.76				0.82
SD1	99.7 (4.2)	88.7 (59.5)	0.01 (0.001)		99.6 (1.6)	77.5 (32.7)	0.01 (0.001)	
SD2	99.7 (4.2)	88.7 (59.5)	0.007 (0.0001)		99.6 (1.6)	77.5 (32.7)	0.009 (0.009)	
P values	NS	NS	<0.0001)		NS	NS	<0.0001	

[a] NS Means not significant at 5% level

a)

b)

c)

d)

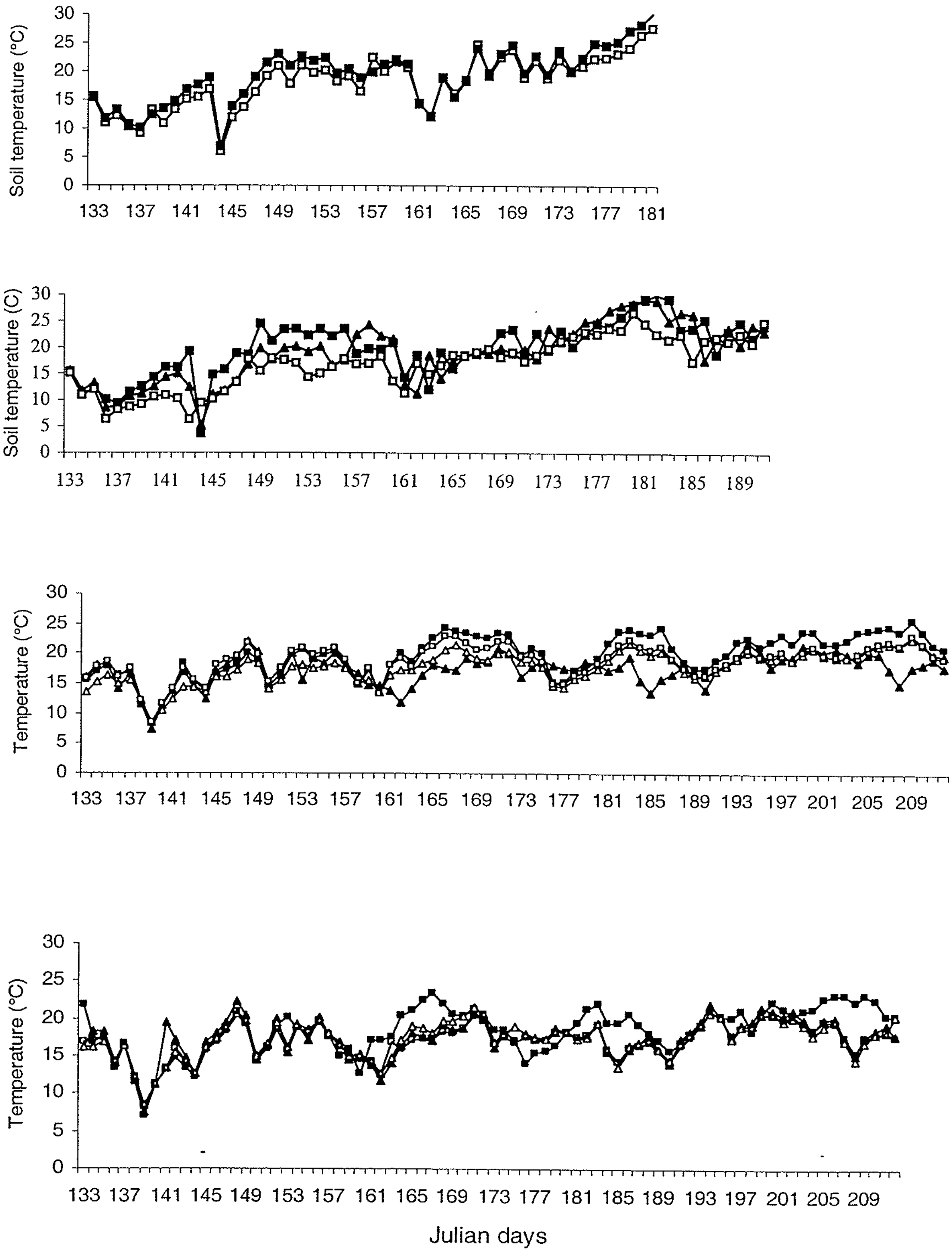


Figure 4.1. Average daily mean soil temperature (°C) measured at 2.5 cm below the soil surface on fall till spring till (FTST, ■), fall till spring no-till (FTSNT, ▲), fall no-till spring till (FNTST, Δ) and fall no-till spring no-till (FNTSNT, □) treatments, at a) Winnipeg 2002 b) Carman 2002 c) Winnipeg 2003 and d) Carman 2003, MB. In 2002 at both sites, soil temperatures were not determined in all tillage treatments.

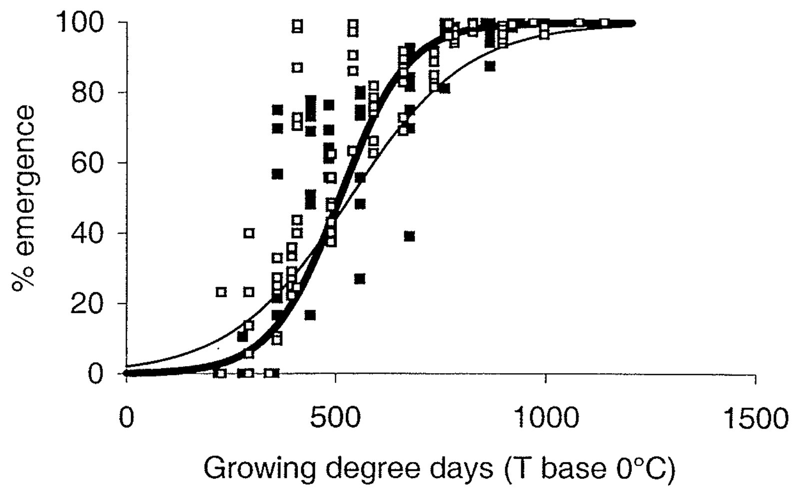


Figure 4.2. Green foxtail emergence periodicity as affected by years. (□, —) 2002 and (■, ━) 2003. (Sites, seeding dates and tillage treatments combined) Markers represent field data and lines represent models. See materials and methods for models and table 4.6 for model parameter estimates.

Table 4.7: Average number of green foxtail seeds in the soil profile post seeding in 2003 at Winnipeg and Carman, MB as affected by depth (0-2.5cm; 2.5-5cm).

Depth	Winnipeg	Carman
	Seeds/m^2	
0-2.5 cm	3537.9 a	778.9 a
2.5-5 cm	662.6 b	201.4 b
LSD	3602.1	910.4

Effect of tillage on the periodicity of green foxtail emergence

Based on NLIN analysis procedures and lack-of-fit F-test, the periodicity of green foxtail emergence was not significantly affected by tillage treatments in either 2002 and 2003 (Table 4.5, Appendix 4.4.a,b). The lack of response of green foxtail emergence periodicity to tillage system could be explained by the fact that tillage did not generally affect soil temperature and the accumulation of soil growing degree days (Appendix 4.3). Anderson and Nielson (1996) found similar results, observing that tillage did not influence the timing of green foxtail emergence.

Although tillage system did not affect the periodicity of green foxtail in the present study, Bullied et al. (2003) reported that conventional compared to conservation tillage delayed the emergence periodicity of green foxtail. They attributed the emergence delay in part to higher gravimetric soil moisture levels in conservation versus conventional tillage fields. They also suggested that because soil moisture and soil temperature were rarely influenced by tillage, the differences in green foxtail emergence periodicity might be attributed to shallower recruitment depths in conservation vs. conventional tillage fields, and that these differences were likely due to differences between tillage systems in the vertical position of seeds in the seedbank. The difference between our study and that of Bullied et al. (2003) emphasizes the significance of considering the influence of the duration of practices when trying to explain the influence of these practices.

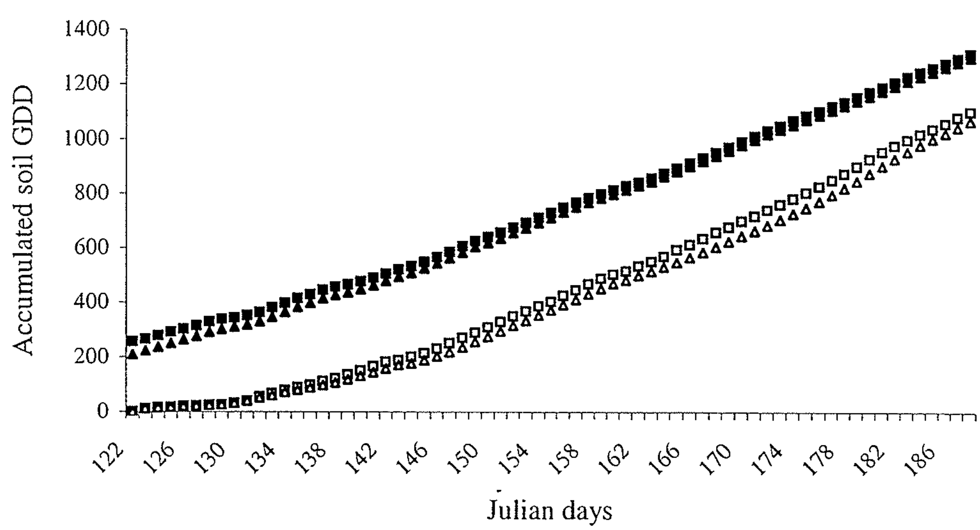
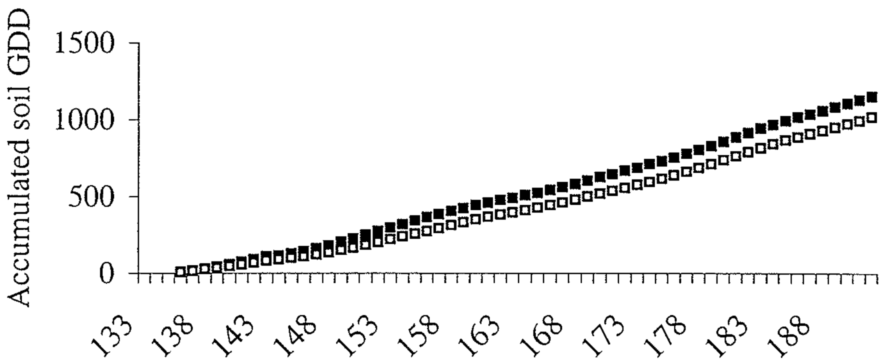


Figure 4.3. Accumulated soil GDD (Base 0°C) measured at 2.5 cm below the soil surface at Carman 2003(■), Winnipeg 2003 (▲), Carman 2002 (□) and Winnipeg 2002 (Δ).

Effect of seeding date on green foxtail emergence periodicity

Periodicity of green foxtail emergence was not influenced by seeding date according to ANOVA (Appendix 4.2), but very small differences were observed when periodicity was analyzed using non-linear regression (Table 4.5.). The a and b model parameters were similar for seeding date models and only the c parameter differed significantly between models for seeding date (Table 4.5), indicating that seeding date was not strongly affecting the periodicity of green foxtail. The similarity in emergence periodicity between seeding dates may be attributed partly to the lack of significant differences in accumulated GDDs between early and late seeding dates (Figure 4.4.). Also, the similarity in vertical location of the seedbank in the soil profile may have minimized differences in emergence timing between seeding dates. For example, a large green foxtail seedbank was located close to the surface at 0-2.5 cm at Winnipeg and Carman in 2003 (84% and 79% of seeds), respectively (Table 4.7). In a controlled environment, Froud-Williams et al. (1984) found that the emergence of small seeded species was improved by shallow burial. They suggested that deeper burial retarded and decreased the germination of seeds. Therefore, in our study, because the green foxtail seedbank was found near the surface (81.5% of green foxtail seeds were found at 0-2.5 cm), this shallow seed placement may have diminished the emergence differences between early and late seeding. The majority of seedlings would have emerged from the top 2.5 cm and only a very small proportion would recruit from deeper depths or would have been stimulated by tillage to recruit from deeper depths.

a)



b)

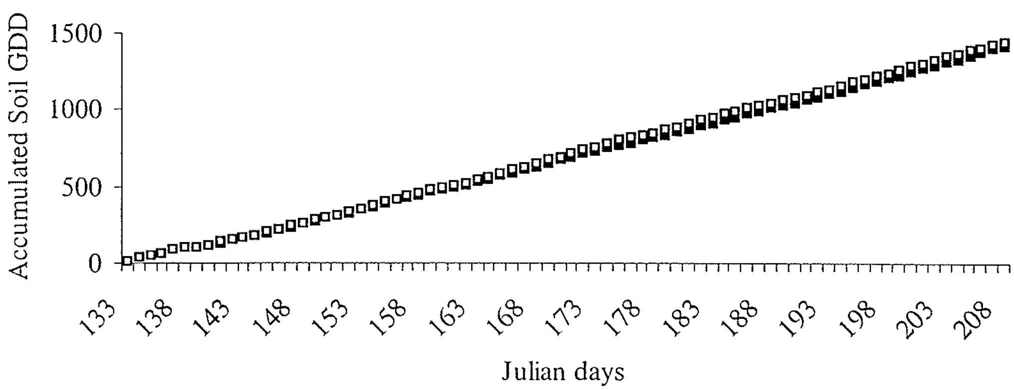


Figure 4.4: Accumulated soil GDD (base 0°C) measured at 2.5 cm below the soil surface for early (■) and late seeding (□) dates in a) 2002 and b) 2003 at Winnipeg and Carman MB.

Summary

All factors considered in this study including year, site, tillage, seeding date and management period significantly affected the density of green foxtail. Generally, densities of green foxtail tended to increase with more tillage. We suggested that this response might be the result of relatively higher soil temperatures observed on tilled versus no-tilled plots. Total density of green foxtail was unaffected by seeding date except at one site-year. The similarity between seeding dates was likely related to the fact that emergence density was measured both pre and post-seeding. Significant differences in density were observed between management periods (MP) in all site-years. High levels of green foxtail emergence were observed during MP2 because this period corresponded to the period of the year where conditions required for seed germination and seedling emergence of green foxtail were favorable.

The emergence periodicity (% cumulative emergence) of green foxtail was comparable between site, tillage and seeding date, because these factors did not strongly affect soil moisture, soil GDD and the location of the seedbank in the soil. Year was the only factor significantly affecting the emergence periodicity of green foxtail. The combined effect of differences between years in accumulated GDD and soil moisture content at different soil depths may help to explain the impact of year on the emergence periodicity of green foxtail.

Redroot pigweed seedling emergence

Effect of tillage system, seeding date and management period on redroot pigweed densities

Effect of tillage on redroot pigweed densities. Analysis of variance (ANOVA) showed that site and year were significant factors (Appendix 4.6) affecting redroot pigweed density, and subsequently, each site-year was analyzed separately for the effect of tillage, seeding date and management period on densities of redroot pigweed. There were significant interactions between tillage and management period in 2002 at Carman and in 2003 at both sites. Therefore, combinations of tillage and management period effects on the emergence density of redroot pigweed were analyzed separately for Winnipeg 2003, Carman 2002 and Carman 2003.

Densities of redroot pigweed were significantly affected by tillage treatments for all site-years (Table 4.8). Except for Winnipeg in 2002, there were higher densities of redroot pigweed on tilled (FTST) versus no-tilled (FNTSNT) treatments. The observed differences may be the result of elevated soil temperatures on tilled compared to no tilled plots (Figure 4.1) since other factors including soil moisture (Table 4.3) and vertical location of seedbank were similar between tillage treatments (Appendix 4.9). Similarly, Mulutega and Stoltenberg (1997) observed that in a long-term no-tillage system, soil disturbance increased emergence of redroot pigweed relative to the undisturbed soil and they attributed this result to the exposure of seeds to favorable conditions for germination. Soil temperature is reported as one of the major factors affecting weed germination and weed seedling recruitment generally (Roberts 1984; Roberts and Potter 1980; Blackshaw 1990; Ghorbani et al. 1999; Fernandez-Quinantilla et al. 1990; Hartzler et al.1999; Egley and Williams 1991) and it often differs between zero and conventional-tillage fields (Kladivko et al. 1986; Mahli and O'Sullivan 1990; Bidlake et al. 1992; Johnson and Lowery 1985). For this reason, a difference in weed seed germination and seedling emergence might be expected between zero-tillage and conventional-tillage cropping systems. Most studies report that in zero-tillage fields soil temperatures are lower (Kladivko et al. 1986; Mahli and O'Sullivan 1990; Bidlake et al. 1992; Johnson and Lowery 1985; Ogg and Dawson 1984) and consequently, spring and summer annuals such as lambsquarters and redroot pigweed (Baskin and Baskin 1998) may recruit preferentially in conventional versus zero-tillage fields.

Contrary to these studies and to our research, Oryokot et al. (1997) and Mohler and Calloway (1992) found that emergence levels of redroot pigweed were lower on tilled versus untilled plots. They associated the increased number of pigweed seedlings on no-tillage treatments to the fact that no-tillage practices often concentrate weed seeds in the top 5 cm of soil. This is true because the type of tillage implement they used (moldboard or chisel plow) may have inverted the soil to a depth of 20 to 25 cm, and weed seeds could have been buried very deep in the soil profile, perhaps beyond the depth from which redroot pigweed can emerge (Froud-Williams et al. 1984). In our study however, the tillage implement we used disturbed the soil to a depth of approximately only 7 to 8 cm. This minimum soil disturbance may not have buried weed seeds, but rather stimulated seed germination and seedling emergence by enhancing soil environmental conditions surrounding the seeds.

The majority of redroot pigweed emerged during MP2. At Winnipeg 2003, regardless of tillage, 6.3%, 93.4% and 0.29% of redroot pigweed emerge during MP1, MP2, and MP3, respectively; at Carman 2002 redroot pigweed emergence averaged 1.7%, 86.3% and 11.9 % for MP1, MP2, and MP3, respectively, and at Carman 2003 redroot pigweed emergence averaged 6.7 %, 91.3% and 1.9% for MP1, MP2 and MP3, respectively. The greater redroot pigweed emergence in MP2 may have been a result of environmental and soil conditions including soil temperature and soil moisture being very favorable for germination and emergence during this period. In fact, MP2 is the time of the year where conditions favoring weed seed germination and subsequent weed seedling emergence are optimum (Spandl et al.1998; Blackshaw et al.1981).

Interactions between tillage treatments and management periods were observed in 2002 and 2003 at Carman and in 2002 at Winnipeg and were driven by differences in management period 2 (post seeding and prior to in crop herbicide applications) (Table

4.9). In this period, tillage resulted in an increase in redroot pigweed density. This may have been related to higher soil temperatures in tilled versus to no-tilled plots (Figure 4.1).

Effect of seeding date on redroot pigweed densities

Within site-year, average total density of redroot pigweed was not significantly different between early and late seeding dates (Table 4.8). The lack of significant differences in term of densities of redroot pigweed between seeding dates may be explained in part by the limited differences in soil environmental conditions including soil temperatures between early versus late seeded treatments (Figure 4.5). In contrast to our study, Robinson and Dunham (1946) found considerable differences in levels of weed emergence among 3 seeding dates. They reported that very late seeding significantly reduced weed infestation due to late seedbed preparation, which controlled emerged weed seedlings prior to seeding.

Management period effect on density of redroot pigweed

Sampling dates for weed emergence were grouped into three management periods (MP) (Table 3.2); Management periods significantly affected densities of redroot pigweed (Table 4.8) at all site years. Most redroot pigweed seedlings emerged in MP2. The proportions of redroot pigweed seedlings that emerged in MP2 were 95.9 %, 86.3 % and 91.9 % in Winnipeg 2002, Carman 2002 and 2003, respectively (Table 4.8). High levels of redroot pigweed emergence in MP2 could be attributed to good environmental conditions for emergence during that period. In fact, MP2 includes mid May to the end of June (Table 2.2) which correspond to period of the year where temperatures and precipitation (Table 4.4) are favorable for weed seed germination and subsequent seedling emergence.

Table 4.8. Redroot pigweed densities (number of emerged seedling per m²) as affected by tillage (FTST: fall till and spring till; FTSNT: fall till and spring no-till; FNTST: fall no-till and spring till; FNTSNT: fall no-till and spring no-till), seeding date (SD1: early seeding; SD2: late seeding) and management period (MP1: prior to spring tillage; MP2: post spring tillage and prior in-crop herbicide application; MP3: post in-crop herbicide application) at Winnipeg and Carman, MB in 2002 and 2003.

	Winnipeg		Carman	
Factor	2002	2003	2002	2003
Tillage				
FTST	156.8ab[a]	69.6a	57.1a	21.3a
FTSNT	108.1b	54.4a	33.4b	24.3a
FNTST	128.5ab	13.08b	38.7ab	10.2b
FNTSNT	176.5a	2.58b	12.67c	5.2b
LSD	55.5	34.52	20.7	10.4
Seeding date				
SD1	-[b]	36.7a	35.8a	14.2a
SD2	-	33.1a	35.1a	16.3a
LSD		24.4	14.6	7.3
Management period				
MP1	-	3.94b	1.8b	3.1b
MP2	-	100.6a	91.9a	42a
MP3	-	0.31b	12.7b	0.6b
LSD		29.8	17.9	9.0

[a] Means within a column followed by the same letter are not significantly different according to the Fisher Protected LSD test ($\alpha = 0.05$)
[b] No seeding date treatment at Winnipeg in 2002

Effect of year, tillage system and seeding date on the emergence periodicity of redroot pigweed

Analysis of variance [(General linear model (GLM)] was used to determine the effect of year, site, tillage, and seeding date on the emergence periodicity of redroot pigweed. ANOVA showed significant differences between years and seeding dates, but not between sites or tillage treatments. Details for the analysis of variance are summarized in appendix 4.7. Similar results were obtained for non-linear regression analysis (Table 4.11).

Because the results from PROC NLIN and the lack-of-fit F-test showed that emergence periodicity of redroot pigweed was significantly different between years (Figure 4.6. and Table 4.10) and not significant between sites and tillage treatments, data were pooled over sites and tillage treatments, and data for years and seeding dates were analyzed separately.

Table 4.9. Effect of tillage (FTST: fall till and spring till; FTSNT: fall till and spring no-till; FNTST: fall no-till and spring till; FNTSNT: fall no-till and spring no-till) and management period (MP1: prior to spring tillage; MP2: post spring tillage and prior in-crop herbicide application; MP3: post in-crop herbicide application) on densities of redroot pigweed at Winnipeg and Carman, MB in 2003.

Treatments	Winnipeg 2003	Carman 2002	Carman 2003
	Seedlings/m²		
FTST MP1	11.5 b[a]	2.8 c	3.0 c
FTSNT MP1	4.2 b	2.8 c	7.2 c
FNTST MP1	0.0 b	1.3 c	0.7 c
FNTSNT MP1	0.0 b	0.5 c	1.5 c
FTST MP2	197.4 a	155.6 a	60.3 a
FTSNT MP2	159.1 a	77.3 b	65.1 a
FNTST MP2	38.1 b	99.6 b	28.8 b
FNTSNT MP2	7.7 b	35.0 c	13.6 bc
FTST MP3	0.1 b	13.0 c	0.6 c
FTSNT MP3	0.0 b	20.1 c	0.6 c
FNTST MP3	1.1 b	15.3 c	0.5 c
FNTSNT MP3	0.0 b	2.5 c	0.6 c
LSD	59.6	36.4	15.9

[a] Means within a column followed by the same letter are not significantly different according to the Fisher Protected LSD test ($\alpha = 0.05$)

Effect of year on the periodicity of redroot pigweed emergence

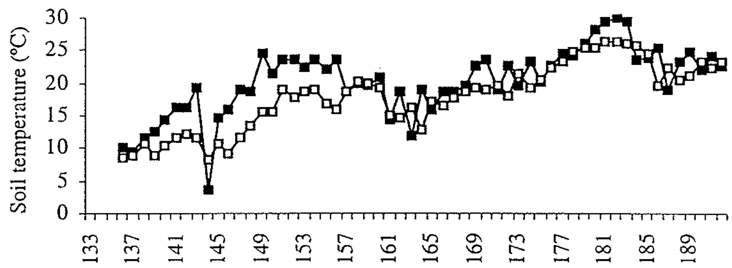
At the start of the experiment, redroot pigweed emerged at a similar rate in 2002 and 2003 (Figure 4.6) until approximately 12% emergence. After this point, emergence response to GDD was stronger in 2003 versus 2002. Growing degree days accumulation was much more rapid in 2003 versus 2002 (Figure 4.3), but this could not provide a simple explanation for the difference in emergence periods between years because the periods were normalized for GDD. It may be that the addition of seed in 2003 created a shallower seedbank in 2003 versus 2002. This would have appeared as earlier emergence even when logged versus GDD, because GDD was measured at one depth only. We did not, however measure differences in seedbank depth between years. It was also unexpected that redroot pigweed emergence did not start earlier in 2003 vs. 2002. This did not occur because soil moisture early in the season in 2003 was lower near the surface (0-2.5cm) compared to 2002 (Table 4.3) and low moisture might have limited the emergence during this particular period. Ghorbani et al. (1999) concluded that low initial rates of redroot pigweed emergence could be attributed to low soil water potential at the soil surface. Weed germination and emergence at favorable temperatures is most rapid when moisture is not limiting (Fyfield and Gregory, 1989).

Table 4.10. F test result comparing parameter estimates of redroot pigweed emergence periodicity models for years 2002 and 2003. See materials and methods for models. Values in parentheses are standard errors.

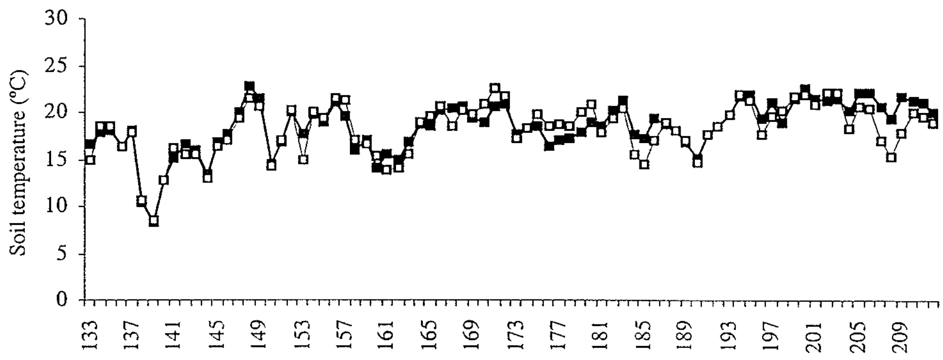
	Parameter estimates			R^2
Year	a	b	c	
				0.76
2002	99.1 (2.15)	243.8 (132.5)	0.009 (0.0009)	
2003	99.1 (2.15)	243.8 (132.5)	0.01 (0.001)	
P values	NS[a]	NS	<0.0001	

[a] NS Means not significant at 5% level

a)



b)



c)

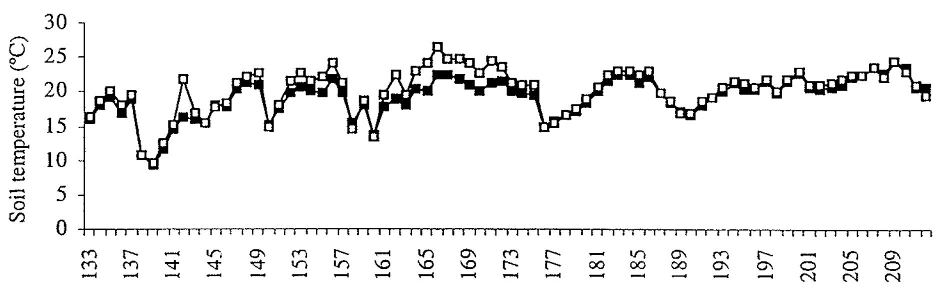


Figure 4.5: Average soil temperature (°C) measured at 2.5 cm below the soil surface for early (—■—) and late (—□—) seeding dates at a) Carman 2002, b) Carman 2003 and c) Winnipeg 2003.

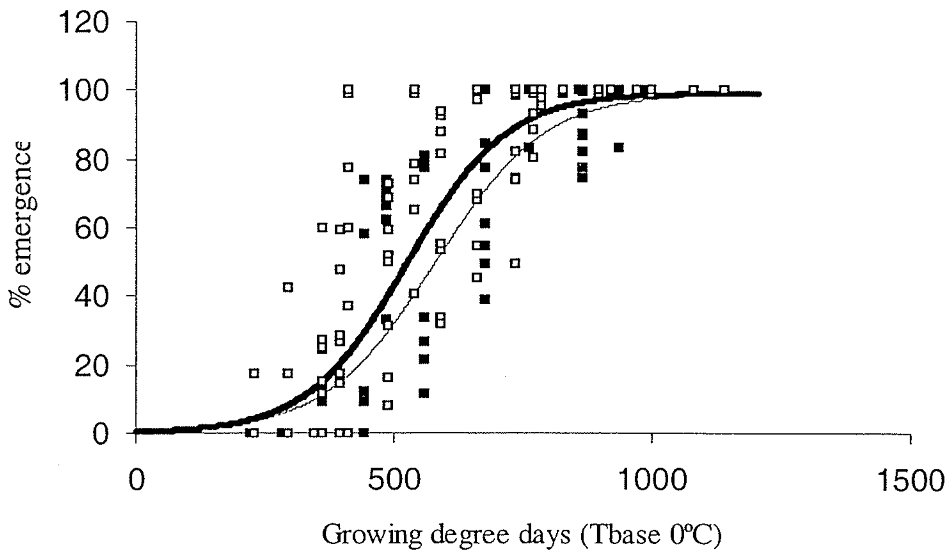


Figure 4.6. Redroot pigweed emergence periodicity as affected by year (□, —) 2002 and (■, ━) 2003. (Sites, tillage treatments and seeding dates combined within year). Markers represent field data and lines represent models. See materials and methods for models and Table 4.9 for model parameter estimates.

Effect of tillage on redroot pigweed emergence periodicity

Based on NLIN procedures and lack-of-fit F-test, the periodicity of redroot pigweed emergence throughout the entire season was not significantly affected by tillage treatments in either 2002 or 2003 (Table 4.11, Appendix 4.8 a, b). The lack of response of redroot pigweed emergence periodicity to tillage treatments could be explained by the fact that tillage did not affect the density or vertical position of seeds in the soil (Appendix 4.9), or soil temperature and soil GDD (Figure 4.1, Appendix 4.3). Oryokot et al. (1997) found no effect of tillage practices on the phenology (emergence periodicity) of redroot pigweed. Bullied et al. (2003) reported similar results for redroot pigweed observing that tillage system (conventional versus conservation tillage) did not influence the periodicity of redroot pigweed emergence. They attributed their results to the lack of soil moisture or soil temperature differences between tillage systems. Our results suggest that tillage may not be a key factor to consider when predicting the emergence timing of redroot pigweed.

Most studies have reported that tillage systems affect soil temperature (Kladivko et al. 1986; Mahli and O'Sullivan 1990; Bidlake 1992; Johnson and Lowery 1985) and soil moisture (Johnsons et al. 1984; Blevins et al. 1983; Grevers et al. 1986; Hussain 1999). In most studies, however, soil temperature and soil moisture measurements are taken at depths of 10 cm or more. In our experiments, we measured soil temperature and soil moisture at depths of 0-2.5cm because most annual weeds emerge successfully when they are located on or near the soil surface, regardless of tillage system (Pareja et al. 1985; du Croîx Sissons 2000). In our study, because tillage did not influence primary microsite conditions, the periodicity of redroot pigweed was not affected by tillage treatments as they were applied in our study. We hesitate, however, to claim that tillage does not stimulate the emergence of redroot pigweed (as has been found by other researchers e.g. Gallagher and Cardina 1998 a, b). In our study, timing of spring tillage was linked to time of seeding and therefore it is time of tillage that would have influenced emergence periodicity. This effect is seen in the seeding date treatments, not in the tillage treatments.

Effect of seeding date on redroot pigweed emergence periodicity

The emergence periodicity of redroot pigweed was influenced by seeding date according to both ANOVA (Appendix 4.7) and non-linear regression (Table 4.11; Figure 4.7). Late seeding delayed pigweed emergence in both 2002 and 2003, but the differences were more pronounced after emergence reached 25% and 10% in 2002 and 2003, respectively (Figure 4.7). Differences between years may be explained in part by the rapid accumulation of soil GDD very early in 2003 versus 2002 (Figure 4.3). In both years, late seeding delayed the emergence of redroot pigweed (Figure 4.7) probably because a large proportion of the redroot pigweed seedbank was located relatively deep in the soil profile (Appendix 4.9). This is in contrast to results for green foxtail, because green foxtail seeds were shallower.

Froud-Williams et al. (1984) found that deep burial delayed the emergence periodicity of small seeded species. Accordingly, Weise and Davis (1967) found little emergence of pigweed seeds buried below 2.5cm in the soil. In our study, soil disturbance caused by tillage and seeding may have stimulated the germination of more deeply buried seeds of redroot pigweed by exposing these seeds to light, higher soil temperature and adequate gas exchange; conditions which favor the germination and subsequent emergence of this species (Chepil 1946b; Froud-Williams et al. 1984; Gallagher and Cardina 1998a,b). Gallagher and Cardina (1998a) found redroot pigweed to be the only species for which germination was consistently affected by the light environment during tillage. Flashes of light received during tillage have been shown to stimulate the emergence levels of buried seeds of redroot pigweed (Buhler 1997; Gallagher and Cardina, 1998b). So, if buried seeds of redroot pigweed are exposed to favorable conditions for germination late rather than early in the season and if time of tillage is linked to seeding date, it is reasonable to expect a delay in timing of redroot pigweed emergence with delayed seeding.

Table 4.11. Redroot pigweed emergence periodicity (sites combined within years) as affected by tillage (FTST: fall till and spring till; FTSNT: fall till and spring no till; FNTST: fall no till and spring till; FNTSNT: fall no till and spring no till) and seeding date (SD1: early seeding; SD2: late seeding) in 2002 and 2003. See materials and methods for models. Values in parentheses are standard errors.

	2002				2003			
Tillage	a	b	c	R^2	a	b	c	R^2
				0.85				0.80
FTST	95.9 (3.1)	388.3 (297.3)	0.01 (0.001)		99.3 (2.4)	187.2 (107.7)	0.01 (0.001)	
FTSNT	95.9 (3.1)	388.3 (297.3)	0.01 (0.001)		99.3 (2.4)	187.2 (107.7)	0.01 (0.001)	
FNTST	95.9 (3.1)	388.3 (297.3)	0.01 (0.001)		99.3 (2.4)	187.2 (107.7)	0.01 (0.001)	
NTSNT	95.9 (3.1)	388.3 (297.3)	0.01 (0.001)		99.3 (2.4)	187.2 (107.7)	0.01 (0.001)	
P values	NS	NS	NS		NS	NS	NS	
Seeding date				0.87				0.80
SD1	103.5 (6.1)	173.0 (286.3)	0.01 (0.003)		102.1 (2.01)	87.5 (73.8)	0.01 (0.001)	
SD2	103.5 (6.1)	33.8 (23.13)	0.006 (0.001)		102.1 (2.01)	80.9 (40.6)	0.007 (0.0008)	
P values	NS	<0.0001	<0.0001		NS	<0.0001	<0.0001	

[a] NS Means not significant at 5% level

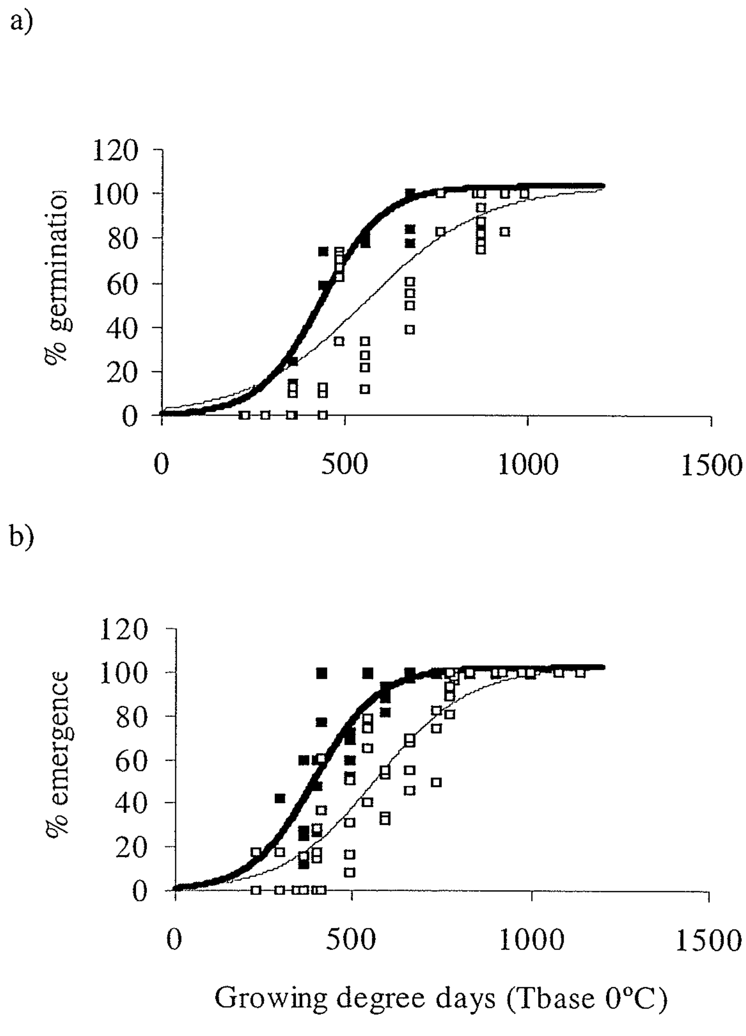


Figure 4.7. Redroot pigweed emergence periodicity as affected by seeding dates (Early seeding —■; Late seeding —□) in a) 2002 and b) 2003. Sites and tillage treatments are combined within year and seeding date. Markers represent field data and lines represent models. See materials and methods for models and table 4.11. for model parameter estimates.

Summary

All factors studied including year, site, tillage, seeding date and management period had a significant influence on the density of redroot pigweed. Generally, densities of redroot pigweed tended to increase with more tillage. This might be the result of relatively higher soil temperatures observed on tilled versus no-tilled plots. Total density of redroot pigweed was unaffected by seeding date across all site-years, probably because seedling emergence was measured both pre and post-seeding. Significant differences in redroot pigweed densities were observed between management periods (MP) in all site-years. High levels of redroot pigweed emergence were observed during MP2 because this period corresponded to the period of the year where factors favoring seed germination and seedling emergence of redroot pigweed were optimum.

The emergence periodicity of redroot pigweed was unaffected by site or tillage in either 2002 or 2003. The lack of significant differences between tillage treatments could be attributed to the fact that tillage did not affect soil GDD, soil moisture, and the location of the seedbank in the soil. Seeding date was a significant factor affecting the emergence periodicity of redroot pigweed, and this was attributed to the fact that tillage influence pigweed density and time of tillage was linked to seeding date. In this respect, time of tillage affected redroot pigweed emergence periodicity.

CHAPTER 5. GENERAL DISCUSSION

The main objective of this study was to determine the effect of different combinations of tillage treatments and seeding dates on the levels and periodicities of green foxtail and redroot pigweed emergence. Because there were interactions between tillage and seeding dates in some cases, only the main effect of these factors were evaluated. Furthermore, the impact of other factors including management periods and the location of weed seeds in the soil were also assessed. The significant findings of this study are discussed in the following sections:

The levels of green foxtail emergence were significantly increased with tillage and generally, higher densities of both redroot pigweed and green foxtail were observed on tilled versus no-tilled plots at three of 4 site-years. This observation was attributed to higher soil temperatures observed on till versus no-till treatments. The other explanation for the increase in the number of green foxtail and redroot pigweed seedlings on tilled plots would have been related to the size and location of the seedbank. In fact, although the greenhouse germination experiment conducted in 2003 did not result in significant differences between tillage treatments in term of levels of seedling emergence, there was a trend to higher densities of green foxtail and redroot pigweed seedlings on tilled versus no-tilled plots. Some studies have suggested that seed predation, poor seed-soil contact or residue cover and placement of seeds in the soil horizons may contribute to lower levels of weed seedling emergence in no-tillage systems. In the future, it would be interesting to investigate the impact of these factors on the emergence of green foxtail and redroot pigweed in different tillage systems in order to achieve a more complete understanding of the recruitment behavior of these weeds in a wider range of particular tillage and seedbank situations.

It may be possible to reduce green foxtail and redroot pigweed populations by occasionally including no-tillage in a conventional-tillage system, a practice recently termed "strategic tillage" (Byron I., personnel communication). In our study, we found that plots that were tilled in the fall and left untilled the following spring generally had lower densities of both redroot pigweed and green foxtail compared to plots tilled both in fall and spring. The reduction was even more pronounced when plots were left untilled in both fall and spring. Although conversion of conventional-tillage fields to no-tillage, on occasion, may decrease the densities of green foxtail and redroot pigweed, this shift may increase densities of others weed species. For example, wind disseminated species, (e.g. dandelion and Canada thistle), and fall germinating species requiring cool temperatures for germination and emergence have the potential to increase under zero-tillage systems (Derksen et al.1994; Thomas et al. 1994; Derksen et al.1996). Thus, converting from conventional to no-tillage practices may require some changes to a farmers weed control tactics and an emphasis on integrated weed management systems. Integrated weed management systems including cultural weed control techniques such as crop rotation, altering time of tillage and seeding dates in combination with herbicide rotation can lead both to improved weed management and a reduction in the use of herbicide for weed control, the later of which also helps to slow the evolution of herbicide resistant weed populations.

The influence of seeding date on levels of weed seedling emergence was also evaluated in our study. The results showed that densities of green foxtail and redroot pigweed were not significantly affected by seeding date, though in some cases early seeding increased emergence levels. The lack of significant differences between seeding dates was related to the fact that in our study emergence counts were done throughout the entire field season. Our results suggest that seeding date manipulation may not be an effective strategy for weed management in the sense that it does not affect total seedling densities. On the other hand, the significant effect of seeding date can be seen if emergence is observed during different management periods. For example, in our study, we observed that the proportion of seedlings that emerged in MP1 (prior to spring tillage) were higher with late seeding. But, in MP3 (post in crop herbicide application) seedling emergence was significantly reduced when seeding was delayed. These observations suggest that prior to spring tillage, the higher proportion of emergence may be controlled by delaying spring tillage in a conventional-tillage system, or using herbicide for weed control in a no-tillage system. In MP3, the reduction of emergence with late seeding implies that the need for herbicide application post harvest may not be necessary. However early vs. late seeding seems to result in increased seedling emergence even after in-crop weed control has been applied and these seedlings may set seed to produce problems in subsequent years.

A significant effect of management period on quantity of green foxtail and redroot pigweed was found for all site-years. The vast majority of seedlings emerged in management period 2 (post-seeding and prior to in crop herbicide application) simply because at this time of the season conditions required for green foxtail and redroot pigweed germination and emergence are optimum. It may be useful to study the interaction of management period with the emergence timing of other weed species, especially those germinating and emerging very early in the season when soil temperatures are cool. For example, knowing the levels of emergence of wild oat and volunteer crops, in comparison to summer annual species such as green foxtail and redroot pigweed within specific management periods could allow for an effective improvement in control of these species. For example, if maximum emergence of wild oat or volunteer wheat occurs very early (in MP1, prior to spring tillage), delaying seeding (which corresponds to a delay in tillage) may result in a reduction in seedling emergence levels. This reduction may not occur for all species as was shown in our study. In order to increase the efficacy of weed management strategies, farmers need to know not only which weed species are present in a field, but also the emergence periodicity of the most troublesome species.

In 2003, the placement and size of green foxtail and redroot pigweed seedbanks was evaluated. We found that tillage did not affect the total number of green foxtail or redroot pigweed seeds in the seedbank, but seedbank size varied significantly by depth for green foxtail. The majority of green foxtail seeds were located at the shallowest depth (0-2.5 cm), whereas redroot pigweed seeds were more evenly distributed between the 0-2.5cm and the 2.5-5cm depths. It is not clear why the placement of green foxtail was not comparable to that of redroot pigweed. Since these weeds are classified as small seeded-species, we expected similar trends in the placement of their seedbanks.

Although the characterization of weed seed placement in the seedbank was difficult and time consuming due to the absence of an effective method for assessment this part of the study was of great importance. By knowing the location of weed seeds at different soil depths and the conditions in the microsite at various scales, we were better able to understand and explain the factors leading to the observed differences between treatments. In the future, it would be essential to develop more appropriate and efficient methods to allow accurate microsite and seedbank measurements. Because weeds emerge from shallow depths (less than 4.5cm) (du Croîx Sissons et al. 2000), it would be essential to characterize microsite conditions (soil temperature and soil moisture) and seedbank location in the near surface layers, and most importantly measurements made at different scales could allow for detection of differences between treatments.

Tillage did not affect the periodicity of either green foxtail or redroot pigweed in either 2002 or 2003. Tillage also did not affect accumulated soil growing degree-days, volumetric soil moisture, and the size of green foxtail and redroot pigweed seedbanks. This confirms our hypothesis that the intensity of tillage in a given year does not affect the periodicity of weed seedling emergence. This result also suggests that tillage intensity (without soil inversion) may not be a key factor in predicting the recruitment timing of green foxtail and redroot pigweed in short-term cropping systems. However, the timing of tillage could be considered as an important factor influencing the periodicity of redroot pigweed emergence (and to a lesser extent green foxtail emergence).

Time of tillage (seeding date) did have a significant effect on the emergence periodicity of redroot pigweed. If time of spring tillage changes, then the timing of tillage related stimulation of emergence changes and this can influence emergence periodicity. In our study, seeding the crop late in the season delayed the emergence of redroot pigweed. However, this was not true to the same extent for green foxtail, because a greater proportion of the redroot pigweed seedbank was located deeper in the soil profile for pigweed vs. green foxtail and pigweed seeds had a greater requirement perhaps of tillage for the stimulation of recruitment. In the literature, it has been shown that pigweed recruitment is relatively sensitive to depth. Wiese and Davis (1966) and Oryokot et al. (1997) found less pigweed emergence from seeds buried below 2.5 cm in the soil. Also, Ghorbani et al. (1999) observed an increase in pigweed emergence from seed placed between 0.5 and 3 cm. This result emphasizes again the importance of knowing the placement of the weed seedbank in the soil horizons.

In our study, the time of tillage coincided with the time of seeding. It would be interesting, in subsequent studies, to separate these two periods in order to determine the effect of varying time of tillage vs. time of seeding on the levels and periodicity of weed seedling. Knowing the effect of changing time of tillage and seeding date may help producers to effectively plan tillage and seeding events as a means of weed management. For example, if spring tillage occurs early in the season and seeding is delayed, there would be a higher proportion of seedlings emerging prior to seeding, resulting in reduced levels of emergence in-crop. This response would depend, however, on how much soil disturbance the seeding equipment created. Reid (2002) (personal communication) found that even seeding equipment with minor soil disturbance might stimulate cleavers (*Galium ssp.*) recruitment. Thus, emergence reduction resulting from delaying seeding may be offset by further recruitment caused by the seeding equipment. In addition, delaying seeding for weed management may also result in yield reductions.

Recommendations for future studies

Although our results are in part conclusive, the study was conducted at research stations and over a short period of time. The research station sites do not necessarily represent real farmers' fields. For example, the effect of tillage treatments referred to in this study represented the effect of a single season and our results could be different in many ways from the results obtained on long-term tillage systems trials conducted over multiple seasons. For example, in our study, tillage did not affect the periodicity of green foxtail emergence because of the lack of significant differences between tillage treatments in terms of soil moisture, soil temperature and seedbank placement. But, tillage has been shown to significantly affect the emergence periodicity of green foxtail in long-term tillage systems (Bullied et al. 2003). Long-term no-tillage vs. conventional-tillage has been found to concentrate weed seed close to the surface (Stahl et al. 1999; Cardina et al. 2002) and this can result in earlier seedling emergence. Differences between long-term vs. short-term cropping systems may also be seen in soil moisture, soil temperatures and other soil properties. For example, tillage systems in our study did not affect soil temperature or soil moisture. However, in long-term tillage systems, higher soil moisture and lower temperatures were generally found in no-tillage vs. conventional tillage systems (Blevins et al 1983; Azooz and Arshad 1996; Maurya 1986). Therefore, in order to confirm and extrapolate our results to farmers' fields, further research on the long-term effect of tillage and seeding date on weed seedling emergence is needed. Long-term studies could allow for a better understanding of the dynamics of weed seedling recruitment and better predictions of weed seedling emergence timing.

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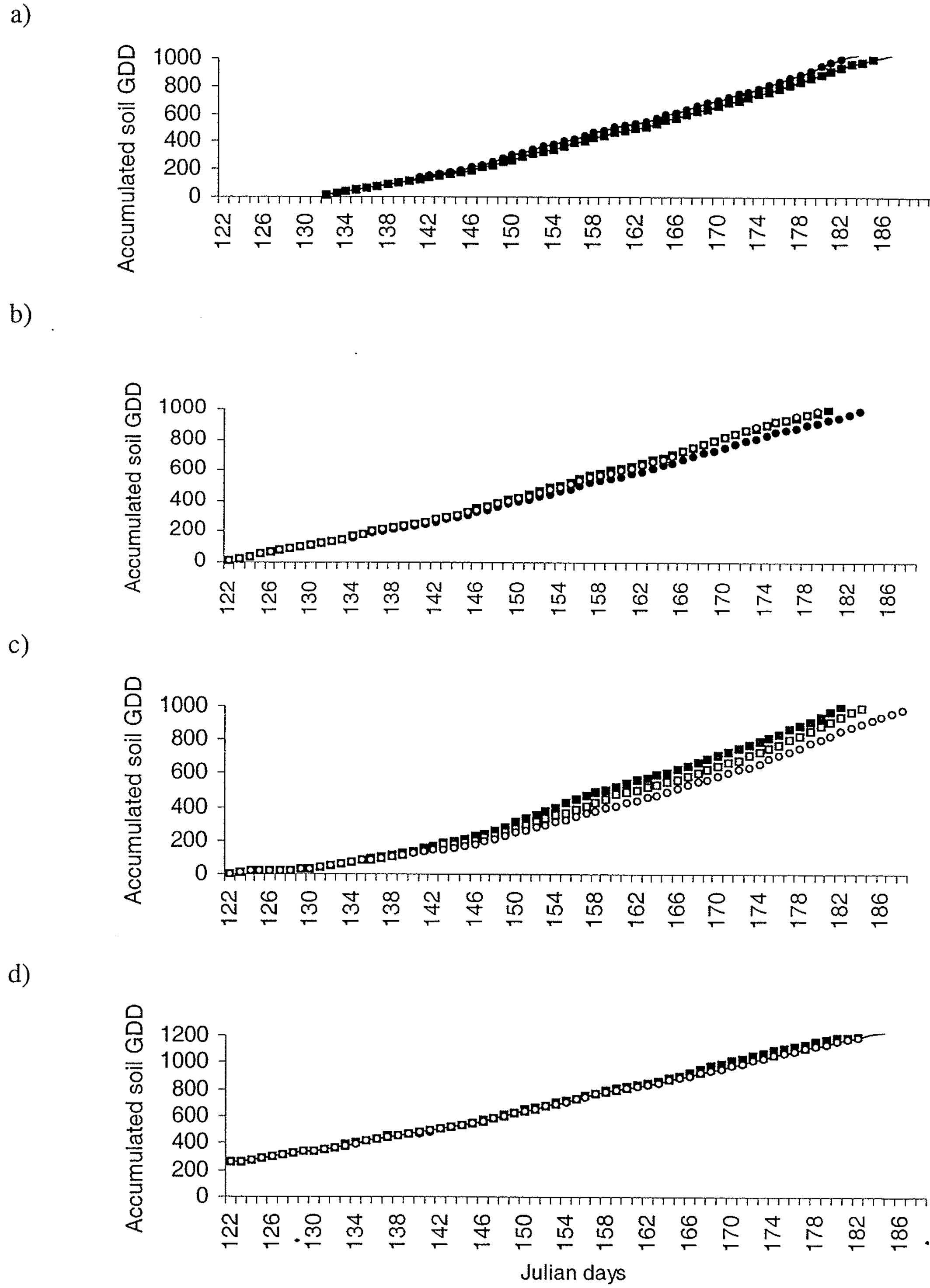
APPENDIX

Appendix 4.1. Analysis of variance of density of green foxtail as affected by year, site, tillage, seeding date and management periods.

Source	DF	Type III SS	Mean square	F value	Pr>F
Year	1	7587.15	7587.15	9.22	0.0025
Site	1	355657.12	355657.12	43.23	<.0001
Rep	7	226389.47	32341.35	3.93	0.0004
Tillage (T)	3	81799.04	27266.34	3.31	0.0200
SD	1	0.33	0.33	0.00	0.9949
MP	2	1024586.11	512293.05	62.27	<.0001
T*SD	3	22544.03	7514.68	0.91	0.4344
T*MP	6	162011.63	27001.93	3.28	0.0037
SD*MP	2	1368.71	684.35	0.08	0.9202
T*SD*MP	6	38902.82	6483.80	0.79	0.5796
Error	398				
Total	430				

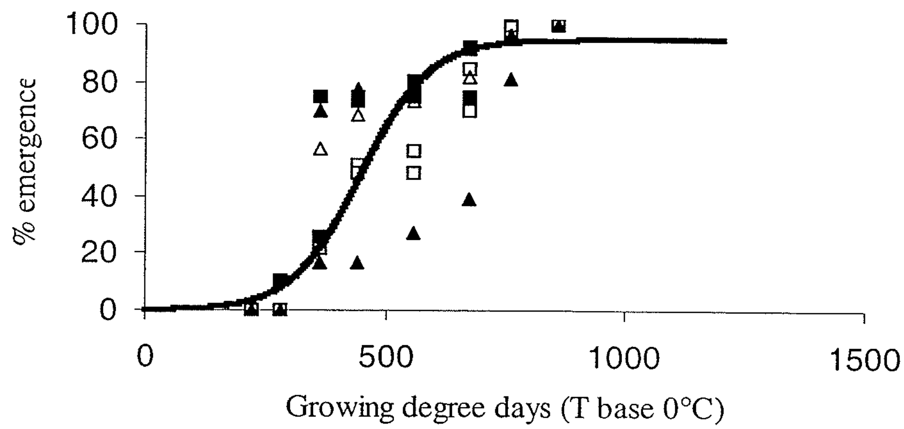
Appendix 4.2. Analysis of variance of green foxatil emergence periodicity as affected by year, site, tillage and seeding date.

Source of variation	DF	Type III SS	Mean square	F value	Pr >F
Year	1	15050.1	15050.1	9.50	0.002
Site	1	1037.5	1037.5	0.6	0.419
Tillage (T)	3	113.8	37.9	0.02	0.995
Seeding date (SD)	1	1546.7	1546.7	0.98	0.323
T*SD	3	532.8	117.6	0.11	0.952
Error	262				
Total	271				

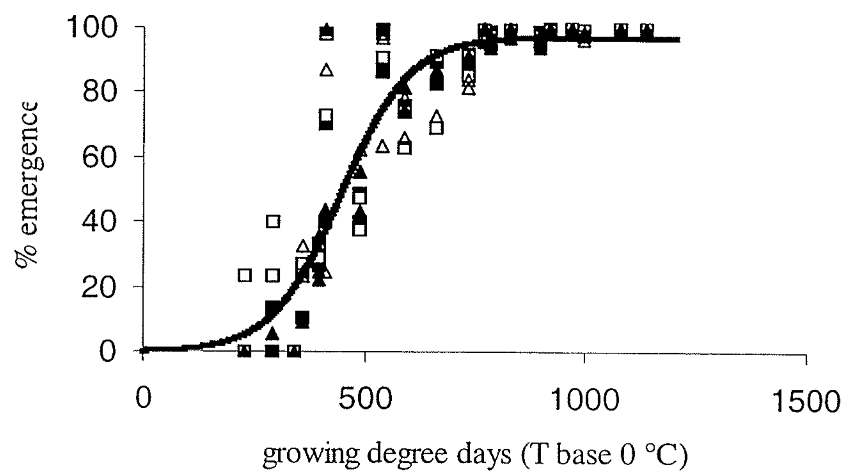


Appendix 4.3. Accumulated soil GDD (Base 0°C) measured at 2.5 cm below the soil surface in fall till spring till (FTST, ■), fall till spring no till (FTSNT, □), fall no till spring till (FNTST, •) and fall no till spring no till (FNTSNT, ○), at a) Winnipeg 2002, b) Winnipeg 2003, c) Carman 2002 and d) Carman 2003, MB.

a) 2002



b) 2003



Appendix 4.4. Green foxtail emergence periodicity as affected by tillage treatments. (fall till spring till (FTST, ■), fall till spring no till (FTSNT, □), fall no till spring till (FNTST, ▲) and fall no till spring no till (FNTSNT, Δ) in a) 2002 and b) 2003. Markers represent field data and line represent model. See materials and methods for models.

Appendix 4.5. Analysis of variance of density of green foxtail seeds in the soil profile as affected tillage, seeding date and depth in 2003.

Source	DF	Type III SS	Mean square	F value	Pr>F
Site	1	82674183.68	82674183.68	16.04	0.0001
Rep	3	21799704.96	7266568.32	1.41	0.2453
Tillage	3	10117240.32	3372413.97	0.65	0.5823
SD	1	6318374.97	6318374.97	1.23	0.2712
Depth	1	69387542.73	69387542.73	13.47	0.0004
Error	86				
Total	95				

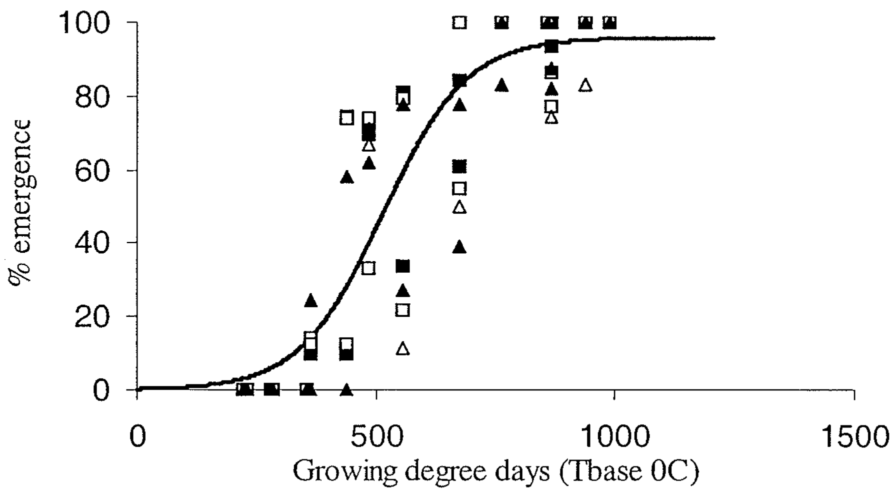
Appendix 4.6. Analysis of variance of density of redroot pigweed as affected by year, site, tillage, seeding date and management periods.

Source	DF	Type III SS	Mean square	F value	Pr>F
Year	1	109907.94	109907.94	23.41	<.0001
Site	1	85379.10	85379.10	18.18	<.0001
Rep	7	127384.92	18197.84	3.88	0.0004
Tillage (T)	3	87158.61	29052.87	6.19	0.0004
SD	1	54.35	54.35	0.01	0.9144
MP	2	547383.51	273691.75	58.29	<.0001
T*SD	3	6858.17	2286.05	0.49	0.6916
T*MP	6	176329.18	29388.19	6.26	<.0001
SD*MP	2	3973.96	1986.98	0.42	0.6552
T*SD*MP	6	18989.79	3164.96	0.67	0.6707
Error	398				
Total	430				

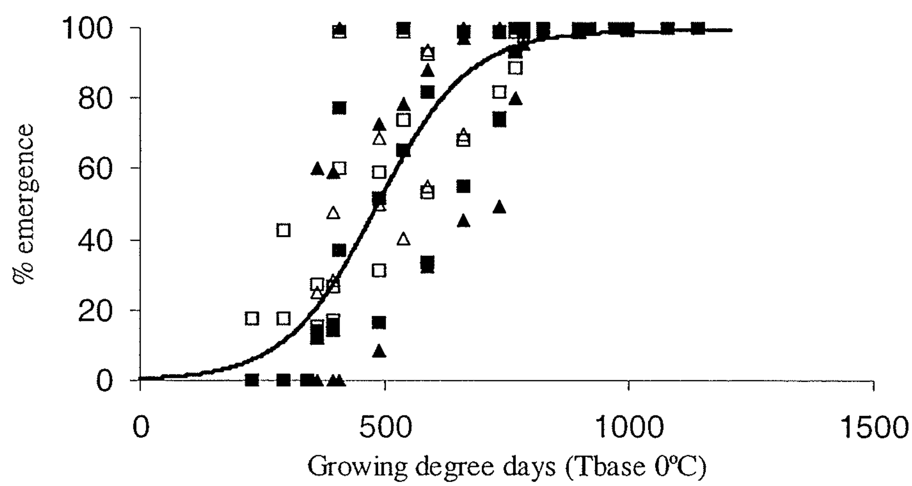
Appendix 4.7. Analysis of variance of the effect of year, site, tillage and seeding date on the emergence periodicity of redroot pigweed.

Source of variation	DF	Type III SS	Mean square	F value	Pr >F
Year	1	16693.8	16693.8	9.82	0.001
Site	1	5543.0	5543.0	3.26	0.072
Tillage (T)	3	454.1	151.3	0.09	0.966
Seeding date (SD)	1	13844.4	13844.4	8.15	0.004
T*SD	3	931.6	310.5	0.18	0.908
Error	253				
Total	262				

a) 2002



b) 2003



Appendix 4.8. Redroot pigweed emergence periodicity as affected by tillage treatments (fall till spring till (FTST, ■), fall till spring no till (FTSNT, □), fall no till spring till (FNTST, ▲) and fall no till spring no till (FNTSNT, Δ) in a) 2002 and b) 2003. Markers represent field data and line represent model. See materials and methods for models.

Appendix 4.9. Average number of redroot pigweed seeds in the soil profile post seeding in 2003 (combined sites), as affected by tillage (FTST: fall till and spring till; FTSNT: fall till and spring no till; FNTST: fall no till and spring till; FNTSNT: fall no till and spring no till) and depth (0-2.5cm; 2.5-5cm). There was no analysis for seedbank in 2002 due to very low germination.

	2003
Factor	
Tillage	
FTST	736.7a[a]
FTSNT	296.8a
FNTST	400.2a
FNTSNT	254.4a
LSD	21.33
Depth	
0-2.5cm	401.0a
2.5-5cm	540.6a
LSD	660.9

[a] Means within a column followed by the same letter are not significantly different according to the Fisher Protected LSD test ($\alpha = 0.05$)