EFFECT OF TILLAGE SYSTEM AND ECO-REGIONAL FIELD LOCATION CLUSTER ON THE EMERGENCE PERIODICITY OF WILD OAT AND GREEN FOXTAIL

BY

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Marginet, Anastasia Maria. M. Sc. The University of Manitoba, May, 2001. Effect of Tillage System and Eco-Regional Field Location Cluster on Emergence Periodicity of Wild Oat and Green Foxtail. Major Professor: Dr. Rene Van Acker.

Knowing the emergence periodicities of individual weed species and how tillage and eco-regional field location cluster affects them can assist producers in more accurately timing control methods. Emergence periodicities of wild oat (*Avena fatua* L.) and green foxtail (*Setaria viridis* L. Beauv.) were measured in 1999 and 2000. The survey examined 34 fields, which were under conventional- or zero-tillage. The fields were grouped into 4 eco-regional field location clusters based on field proximity to each other, soil type, soil moisture deficit and environmental conditions. Seedling emergence was tracked in the post-seeding (1999 and 2000) and pre- and post-seeding (2000) periods. Tillage system did not significantly affect wild oat emergence periodicity post-seeding in either year, but did significantly affect periodicity in the pre-and post-seeding period, due to more favourable moisture conditions in zero-till fields. Green foxtail emergence periodicity was not affected by tillage system post-seeding, but did significantly affected green foxtail emergence periodicity in the pre- and post-seeding period. Significant differences between tillage systems occurred in the pre- and post-seeding period due to soil moisture differences and recruitment depth. Eco-regional field location cluster significantly affected wild oat emergence periodicity both post-seeding and pre-and post-seeding. Significant differences in emergence periodicity between eco-regional field location clusters occurred in the post-seeding period due to an interaction between high precipitation and soil type. In the pre- and post-seeding period, significant differences

between eco-regional field location clusters occurred because of soil moisture differences. Presence of wild oat biotypes having different responses to environmental conditions between eco-regional field location clusters were also thought to have occurred, and contributed to significantly different emergence periodicities. Eco-regional field location cluster significantly affected green foxtail emergence periodicity post-seeding in 1999 and 2000, and pre- and post-seeding. Significant differences between eco-regional field location clusters post-seeding in 1999, was due to differences in soil moisture. In 2000, significant differences post-seeding, was due to differences in accumulated soil temperatures between field clusters, and biotype presence. Significant differences between eco-regional field location clusters occurred in the pre- and post-seeding period due to differences in total soil moisture throughout the sampling period. Determination of the variation of emergence periodicities in different weed species due to tillage system and eco-regional field location clusters effects is the first step in developing predictive emergence models. Simple environmental conditions such as air temperature and precipitation can be used to assist producers in determining more optimal timing for weed control or crop scouting.

FORWARD

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

GENERAL INTRODUCTION

The profit margin for producers in the agricultural sector is declining. Low commodity prices and steadily increasing input costs are forcing producers to try alternative production and pest control options. Additionally, producers are struggling with consumer demands for cheap food, environmental protection, and high food quality. Therefore, to achieve cost-effective, environmentally-friendly crop production, optimization of inputs is required (Gill et al. 1995).

Integrated weed management (IWM) fits these requirements. With IWM, farmers optimize their knowledge of their system, combining this with use of more cultural and less chemical controls. For successful IWM, knowledge of weed species emergence periodicity within a season is important (Stoller and Wax 1973; Roman et al. 2000), as well as knowledge of weed responses to production systems, and agronomic practices (Blackshaw et al. 1994).

Characteristic emergence periodicities for individual weed species have previously been observed by a number of researchers (Chepil 1946; Egley and Williams 1991; Mulugeta and Boerboom 1999; Ogg and Dawson 1984; Stoller and Wax 1973). They observed emergence periodicity to begin and end in a set pattern, dependent on soil temperature and soil moisture in the microsite, and that emergence periodicity varies between species, site and year of crop production (Forcella et al. 1997).

The intent of many studies examining emergence periodicity of weed species was to build predictive emergence models for use by farmers in IWM (Forcella 1993). Most species emergence datasets used in model creation were collected from experiments conducted under controlled environmental conditions or from limited field studies.

Therefore, these datasets may not accurately represent the species emergence periodicity occurring within real production fields. Collection of robust weed species emergence periodicity datasets from actual fields is more time-consuming, and may be logistically difficult, but the application would be tremendous. These datasets would be useful for parameterizing existing emergence periodicity models created under controlled conditions, or to create new, simple models, that are easily applicable by farmers.

Species emergence is controlled mainly by soil temperature and soil moisture (Blackshaw 1990, Stoller and Wax 1973). Agronomic practices and environmental conditions can impact soil temperature and soil moisture between fields (Spandl et al. 1998). Therefore, soil temperature and soil moisture measurements and how their correspondence with emergence patterns is essential to understand why differences between tillage systems and eco-regional field location clusters (clusters) occur.

Innate seed requirements for onset and completion of emergence are similar within populations of a specific species, but variations in environmental conditions between different tillage system and clusters can influence species emergence periodicities. Additionally, these factors can influence selection of species biotypes within clusters or under different tillage systems for increased species survival and or reproduction. For example, Anderson and Nielsen (1996) observed biotypes of weed species with altered emergence characteristics.

Tillage system may influence weed biotype selection. Tillage affects soil temperature, and moisture, whereas reduced tillage practices was observed to increase soil moisture and diminish rate of soil warming (Spandl et al. 1998). Additionally, weed seeds become more uniformly condensed at shallower depths. Buhler and Mester (1991) observed greater percentages of green foxtail emergence from the upper 1 cm of soil in reduced tillage systems.

The cluster effect strongly influences the emergence periodicity of weed species. Differences in soil types, and environmental conditions between clusters affect how quickly soil temperatures accumulate and soil moisture levels. In this project, fields studied were grouped into four main clusters, based on soil type, average precipitation accumulation and temperature accumulation (Agriculture Canada 1989; Environment Canada 1998; Smith et al. 1998).

In this study we examined the emergence periodicities of wild oat and green foxtail under two tillage systems and within four clusters. Wild oat and green foxtail were examined because they are the two most abundant weed species in field crops in Manitoba (Van Acker at al. 2000). In addition, green foxtail (Spandl et al. 1998) has been observed to increase in density under reduced-tillage systems. As well, herbicide resistant wild oat and green foxtail are common in Manitoba (Andrews and Morrison 1989; Bourgeois et al. 1997; Friesen et al. 2000; Jansieniuk et al. 1994; Morrison et al. 1989; Murray et al. 1995).

The intention of this study was to examine emergence periodicity of wild oat and green foxtail under un-manipulated field conditions across a broad arable area of Manitoba. From the dataset we were interested in discovering if statistical differences in emergence periodicity existed between tillage systems and clusters.

The uniqueness of this project is that all emergence data was collected from active production fields and so the dataset represent not only differences in tillage and clusters, but also a broad range of crop management practices. In this respect we were able to test whether tillage or cluster were robustly significant factors to consider in empirical emergence models.

Reliable, predictive models of weed emergence could be used alone or in conjunction with other weed management or crop-competition models. The ability to accurately predict when weeds will emerge could enable producers to better time herbicide applications or planting dates. Producers could determine from the model when (according to accumulated measures of climatic conditions) a given percentage of the total weed population would have emerged in a given field. Planting dates, burn-off applications, or tillage events could then be timed to eliminate a majority of the weeds before planting. Models could be used in conjunction with historical crop insurance data to indicate potential yields of crops when planted during certain weeks of the year. A combination of historical planting date effects on yield, and weed species emergence periodicity could result in timed seeding dates which maintained high potential yields, and allowed for reduced in-crop herbicide use.

Purpose and Objectives

The purpose of this project was to observe and characterize weed emergence periodicity in situ across 4 clusters in southern Manitoba, in both zero-tillage and conventional-tillage fields.

The objectives were,

(1) To determine tillage effects on wild oat, and green foxtail emergence periodicity;

(2) To determine cluster effects on wild oat and green foxtail emergence periodicity;

(3) To determine whether the tillage and cluster affect emergence periodicity of wild oat and green foxtail in a similar fashion if thermal time is measured as soil or air GDD.

LITERATURE REVIEW

Introduction

Seasonal emergence periodicity has been reported for a number of weed species (Chepil 1946; Egley and Williams 1991; Mulugeta and Boerboom 1999; Ogg and Dawson 1984; Stoller and Wax 1973). Knowledge of emergence periodicity for a weed species is valuable for improved control by facilitating more timely tillage operations (Forcella et al. 1992) and herbicide applications.

For accurate predictions of weed species periodicities, factors affecting emergence and germination must be quantified. Biotic factors such as soil temperature and soil moisture were observed to be influential in affecting emergence (Alex et al.1972; Blackshaw 1990; Dawson and Bruns 1962; Vanden Born 1971); where individual weed species required specific ranges in soil temperatures and moisture levels, to break dormancy and commence germination and emergence (Hunter and Erickson 1952). For example, temperature was observed to have a greater impact on green foxtail emergence onset versus germination onset (Vanden Born 1971; Blackshaw et al. 1981a).

Tillage type, frequency and depth significantly affected soil temperature and moisture availability, which can influence seedling emergence. For example, Gebhardt et al. (1985) observed delayed crop emergence due to lower soil temperatures in reduced tillage versus higher disturbance systems.

The effect of soil temperature and soil moisture on individual species is in response to innate seed characteristics controlling germination and emergence. In different geographic areas, and under different agronomic practices, species biotypes may be present due to selection by the ensuing abiotic conditions and this will affect how a population reacts to conditions present in the soil microsite (Norris and Schoner 1980).

For successful weed species emergence predictions, factors including agronomic practices, location and potential biotype differences need to be considered. Ultimate success in predicting weed emergence is dependent upon understanding interactions of species innate requirements for emergence, and the biotic and abiotic factors effect on processes.

Weed Emergence

Weed species emergences is influenced by biological, physical and environmental factors such as soil temperature, soil moisture, and seed depth (Blackshaw 1990, Roberts and Potter 1980, Stoller and Wax 1973, Zimdahl 1988). Seed dormancy (Baskin and Baskin 1985); light; and method, frequency and timing of soil disturbances were also observed to influenced emergence (Roberts 1981).

Precise studies were conducted to determine specific factors required for the onset, continuation and completion of emergence. A number of these were completed in labs or under controlled field conditions (Chepil 1946; Egley and Williams 1991; Mulugeta and Boerboom 1999; Ogg and Dawson 1984; Stoller and Wax 1973), and observed individual species exhibiting characteristic seasonal patterns of emergence, influenced by innate seed characteristics and favorable environmental conditions (Egley 1986). It was observed for successful emergence to occur, non-dormant seeds were required, and must be present within suitable environments, meeting innate species germination and emergence requirements. If conditions were not met, seeds reverted back to the dormant state until suitable conditions occurred (Karssen 1982).

The biological processes resulting in seedling emergence involve the breaking of seed dormancy, seed germination, radicle elongation, and shoot elongation (Fyfield and Gregory 1989). Each process has an optimal range of temperatures and moisture requirements which need to be satisfied before emergence occurs. For example, Blackshaw (1990) found round-leaf mallow emergence to be more sensitive to soil temperature fluctuations than germination. Fyfield and Gregory (1989) reported mungbean germination occurred only after a specific combination of soil temperature and moisture requirements were met, yet radicle and shoot elongation were primarily driven by temperature.

Temperature

Temperature is important in defining the time when individual species emergence patterns occur. Temperature provides stimulation for emergence onset, and is a dominant factor inhibiting emergence as the season progresses. The main periods of germination and emergence within a season were observed to be associated with the different temperature requirements the species has for germination (Fernandez-Quinantilla et al.1990). Sharma et al. (1976) observed wild oat to have an optimum temperature range that regulated germination and emergence. As temperatures increased outside the range, they became detrimental to seed germination and emergence.

Temperature is important for stimulating germination, emergence, and induction of seed dormancy. For example, Ervio (1981) found low daily maximum temperatures, stimulated emergence, whereas high maximum temperatures induced dormancy in *Chenopodium album* L., and *Polygonus spp.* L. As well, Blackshaw (1990) found temperatures exceeding the maximum optimal range, stimulated seed dormancy in round-leaf mallow. Ogg and Dawson (1984) and Roberts and Feast (1970) indicated the diurnal temperature variation in the soil, within a restricted temperature range was important for stimulating emergence and not just maximum temperature alone.

In the beginning of the growing season emergence is dependent on temperature, but as the season progresses Ervio (1981) suggested emergence flushes were the result of precipitation events.

Moisture

Moisture, is a factor limiting weed seed germination in soils across western Canada (Bibbey 1935), and is a dominant factor in influencing weed species germination and emergence periodicity. For example, when temperatures were within an acceptable range for green foxtail emergence, moisture became the factor influencing the length of time required to reach 50% emergence (Blackshaw et al. 1981a).

Moisture must be at adequate levels to break seed dormancy, stimulate germination, radicle growth, and allow for emergence from soil depths (Egley 1986). Individual species have optimal ranges of soil moisture required for emergence. Too little soil moisture delays emergence due to lack of embryo hydration (Blackshaw 1990; Harris et al. 1998), and excess soil moisture reduces emergence due to lack of soil available oxygen (Sharma et al. 1976).

In early spring, temperature is more important than moisture for stimulation of seed germination, but after the initial emergence onset, soil moisture was observed to be responsible for emergence continuation and determining how many round-leaf mallow seedlings emerged (Blackshaw 1990). In mid-summer, rain was found to significantly affect the total number of weeds emerging (Roberts 1984).

Variability in precipitation contributes to variations in emergence patterns within seasons and between years. Roberts (1984) found emergence occurred during or following wet periods, but stopped when dry weather occurred. Precipitation events that resulted in soil moisture being at or near field capacity influenced emergence within the season (Anderson 1994; Schnieder and Gupta 1985; Stoller and Wax 1973), as defined by the optimal temperature range of the species (Roberts 1964; Roberts and Potter 1980).

Soil moisture was observed to affect length of time after cultivation that weeds emerged (Bond and Baker 1990). When moisture was adequate, emergence occurred soon after cultivation events, if moisture was limiting, emergence was delayed or reduced (Roberts 1984).

The sigmodial shape of the common emergence periodicity curve is related to the rainfall pattern. The initial lag period in the curves represents time from germination onset to resulting emergence (Roberts 1984, Roberts and Potter 1980), where lag period length is controlled by soil moisture. Areas where emergence rate increased rapidly within the curve, result from soil moisture at the soil surface reaching field capacity, and remaining at or near field capacity for a number of days (Roberts and Potter 1980).

Temperature and Moisture Interactions

Separately, temperature and moisture affect emergence, but interactions between these factors have been observed to have a greater impact on percentages of seeds germinating and emerging. For example, round-leaf mallow (Blackshaw 1990), and wild oat (Sharma et al. 1976), were found to have a strong temperature-moisture interaction affecting germination and emergence.

Baskin and Baskin (1985) found soil temperature, soil moisture and seed dormancy status to have substantial effects on emergence period. Suitable conditions of all factors required for a given species, occurred only for short periods (Mulugeta and Boerboom 1999). Emergence periodicity duration was observed to increase or decrease, depending on soil moisture conditions. Egley and Williams (1991) observed in wet years, weed emergence occurred over a broad time period, beginning earlier in the season and lasting through to mid-season, but in dry years, weed emergence completion took less time.

Soil temperature and moisture change with soil depth. At the surface, tremendous fluctuations in daily temperature and moisture were recorded (Thompson and Grime 1979), but at greater depths, the magnitude of moisture fluctuation diminished because of decreased heat and water infiltration. As conditions in the soil layer containing viable weed seeds becomes increasingly favourable, more seedlings germinated and emerged.

Burial Depth

Burial depth of weed seeds affects weed population dynamics, by influencing both seed germination and seedling emergence in summer annuals (Buhler 1995).

Thompson and Grime (1979) observed temperature and moisture fluctuations to promote emergence for a number of species. For example, small seeded cereals and broadleaves germinate and emerge more successfully if seeds are placed closer to the soil surface (Buhler 1997; Froud-Williams et al. 1984). At the soil surface, seeds were observed to experience larger daily fluctuations in temperature and moisture, which may trigger emergence or induce dormancy, dependent on conditions (Stoller and Wax 1973).

Increased emergence of small seeded species, from shallower depths, may be due to the small energy reserves feeding the emerging radicle not being depleted before the radicle reaches the soil surface. Some soil cover of seeds is required for successful germination and emergence of most species. For example, Banting (1962) observed wild oat seeds not to germinate on the soil surface, but germination was successful when they were buried directly below the soil surface (Bibbey 1935).

Seeds are not evenly distributed throughout the soil, whereas tillage affects seed location. Tillage moves seeds within soil profiles, and burial depth was a function of the extent and depth of tillage (du Croix Sissons 1999; Buhler 1997; Froud-Williams et al. 1983). Mean depth of weed seedling emergence was observed to be significantly shallower under zero-tillage versus conventional-tillage and significantly shallower in the pre-seeding versus pre-spraying sampling period. Average wild oat seedling recruitment depth was 1.92cm (pre-seed), 2.42 cm (pre-spray) in zero-tillage versus 3.25 cm (pre-seed), and 4.15 cm (pre-spray) in conventional-tillage fields (du Croix Sissons et al. 2000).

Light

Light penetrates shallowly into soils, and transmittance is dependent on soil particle size, color, and roughness (Benvenuti 1985). Soils consisting of smaller particles and darker coloured soil particles reduce the amount of light infiltration, and soils rough from tillage increase penetration due to increased soil surface areas exposed (Tester and Morris 1987). In all soils, light is unable to penetrate below 4mm (Benvenuti 1985).

Light is important in triggering phytochrome in seeds. In plants, phytochrome is a family of photoreceptor proteins and is present in two forms, active and inactive. The signal triggering activation is light, where red light promotes germination and far red inhibits it. This process does not occur in all weed species, only those with light requirements for germination, such as green foxtail (Douglas et al. 1985). Therefore, for successful emergence, species exhibiting light requirements would require seeds to be located at shallower soil depths (Susko 1999) or exposed to light via tillage.

Tillage operations expose seeds to light for a long enough period to affect germination. Scopel et al. (1994) and Tester and Morris (1987) observed that tillage exposed seeds to sunlight from a μs up to one second, a long enough period to meet the triggering requirements for the seeds.

Light interacts with other factors that induce germination in weed seeds. Light is important for germination stimulation, but if other environmental factors are not suitable, such as extremes in temperature and moisture, germination and emergence will not occur (Buhler 1997; Pons 1991).

Influences of Non-Climatic Conditions on Emergence

Climatic factors are important for triggering, maintaining and inhibiting emergence, but their impact on weed seedling emergence is influenced by other factors including soil type, soil residue cover, tillage and soil disturbance timing.

<u>Soil Type</u>

Soil type affects soil warming and moisture retention capacity and can impact weed seedling emergence periodicity. Effects of soil type on emergence is species specific. Alex et al. (1972) did not find green foxtail emergence to be significantly affected in clay, loam or sandy loam soils, but Ghorbani et al. (1999) found redroot pigweed emergence was generally greater in sandier versus heavier soils.

Soil type cannot be altered by agronomic practices, since the soil formation was previously determined by type of original geologic material, by previous vegetation cover, and by the length of time the soil was weathered (Miller and Donahue 1990). Soil type within an area does impact soil temperature, soil moisture, and soil moisture deficit. Miller and Donahue (1990) observed soils with increased sand content, warmed faster, and had lower decreased soil moisture holding capacities versus soils with greater clay content. It seems likely then, soil type may influence weed seedling emergence periodicity, not necessarily from soil type alone, but the impact it has on soil temperature and moisture.

Soil Residues

Soil residues increase as tillage is reduced. Increased soil residues slow soil warming, and increase soil moisture (Spandl et al. 1998), possibly delaying emergence periodicities (Teasdale et al. 1991). Surface residues may create more favourable environments for emergence, for example, in dry springs, increased residues in reduced-till fields slowed soil drying, providing more moisture for seedling emergence (Buhler and Mester 1991)

Increased residues from decreased tillage operations can cause differences in soil moisture and temperature, possibly affecting weed emergence. Johnson and Lowery (1985) observed that differences in soil temperature between zero- and conventional-tillage systems were the greatest from the soil surface to 5 cm depth, which was also found to be the most common weed seedling recruitment zone (du Croix Sissons et al. 2000). But, Anderson and Nielson (1996) and Egley and Williams (1991) observed individual species emergence patterns not to be affected by tillage, even though soil temperature and soil moisture were affected. Instead, reduced tillage was observed to affect the magnitude of weed emergence, resulting in increased total weed density. For example Roberts (1964) observed the magnitude of emergence flushes for some annual weeds to be reflective of the timing of cultivation and environmental conditions occurring at that time. In dry periods tillage caused emergence delays due to lack of soil moisture near the soil surface.

Soil Disturbance Timing

Soil disturbance timing is linked to the time when soil and environmental conditions are suitable for tillage or seeding operations, and for mechanical weed control. Timing of soil disturbance in relation to weed seedling emergence periodicity can influence weed seedling density. Harvey and Forcella (1993) observed delayed seeding reduced in-crop densities of early emerging wild oat and wild mustard.

Disturbance date may not, however affect emergence periodicity. For example, Egley and Williams (1991) found tillage did not significantly affect the shape of the emergence period curve, but did alter the pattern within the environmentally suitable periods, governed by temperature and moisture. Periodicity of species emergence is important for planning control decisions because it can influence weed competition (Bond and Baker 1990). Therefore knowledge of the temperature, and moisture factors controlling the seasonal emergence periodicity for an individual species can be used to plan the timing of tillage operations or seeding to achieve control of the greatest proportion of a given weed infestation.

Species Requirements

Wild Oat

Emergence of wild oat in the Canadian prairies is typically restricted to spring, and early summer, mainly due to optimum soil temperatures and soil moisture requirements being met during these times (Sharma et al.1976). Populations of wild oat have been observed to proliferate in areas with cool climates and constant moisture (Fernandez-Quintallia et al.1990).

In spring months, rising soil temperature promotes wild oat germination and causes the characteristic emergence periodicity for an area (Friesen and Shebeski 1961; Sharma and Vanden Born 1978; Thurston 1951, 1961). Various reports of temperature requirements for wild oat germination and emergence are found in table 2.1. A study done previously at the University of Manitoba using wild oat seeds collected from outside Winnipeg, Manitoba found the greatest number of seeds germinated at 15°C to 21°C, and temperatures beyond the 15°C to 32°C range were detrimental for normal germination (Friesen and Shebeski 1961). Emergence was observed to occur only when soil moisture was adequate (Friesen and Shebeski 1961), whereas Sharma et al. (1976) observed maximum emergence occurred when the soil was maintained at 50 to 70% of field capacity. When soil moisture was at field capacity, no wild oat emergence occurred.

Table 2.1. Temperature requirements for germination and emergence of wild oat.

	Temperature (°C)			
	Min.	Max.	Optimum	Reference
Germination	-0.8	20	10 – 30	Fernandez-Quinantila et al. (1990)
	4.5	32	15 – 21	Friesen and Shebeski (1961)
			15 – 26.5	Sharma et al. (1976)
Emergence	2	30		Fernandez-Quinantila et al. (1990)
	10	32	10 – 21	Sharma et al. (1976)

Wild oat germination is influenced more by inherent seed properties than varying environmental or agronomic factors. Unfavourable weather delays germination within normal periods for wild oat (Thurston 1961), and if conditions remain unfavourable for long periods, non-dormant seeds can go into secondary dormancy (Hay and Cummings 1959) and will remain dormant until conditions become favourable again for germination.

Wild oat seeds distributed throughout the soil, are in various states of dormancy. Seed dormancy was found to be the main factor leading to wild oat seed longevity in cultivated soil (Cousens et al.1992). Wild oat seed was observed to remain viable in cultivated soil for 3 to 6 years, and seeds were found to survive longer if buried in undisturbed soil (Thurston 1961).

Emergence of wild oat seed from depths of up to 20cm was previously observed, but depths of 2 to 8 cm were found to be optimum (Sharma and Vanden Born 1976; Thurston 1961). du Croix Sissons et al. (2000) observed mean depth of wild oat recruitment in southern Manitoba to be shallower in zero-tillage fields versus conventional-tillage fields, and recruitment was shallower in the pre-seed versus pre-spray sampling period. The mean depth of recruitment for the wild oat seeds under zero-tillage was 1.92cm (pre-seed), and 2.42 cm (pre-spray), and under conventional-tillage it was 3.25 cm (pre-seed), and 4.15 cm (pre-spray).

In the 2000 weed survey for cereal and oilseeds in Manitoba, wild oat ranked second for relative abundance (Van Acker et al. 2000). It was estimated by Leggett (1950) that a badly infested field in western Canada had up to 70 bu./ac. wild oat seed contained in the soil. A number of methods for wild oat control have been suggested including delayed seeding (Banting 1962) and herbicide use, but wild oat remains the second most abundant weed in cultivated fields in Manitoba, Saskatchewan and Alberta (Thomas et al. 1998).

Green Foxtail

In the 1997 weed survey for cereal and oilseeds in Manitoba, green foxtail ranked first for relative abundance (Thomas et al. 1998, Van Acker et al. 2000).

Green foxtail is a summer annual, emerging from mid-spring into the summer (Chepil 1946), therefore emergence onset begins later than wild oat, which is likely due to higher temperatures requirements for germination and emergence versus wild oat (Vanden Born 1971). The temperature requirements for germination and emergence of green foxtail are shown in table 2.2. The range of soil temperature was observed to have greater effects on emergence of green foxtail versus germination (Blackshaw et al. 1981a, Vanden Born 1971), indicating once green foxtail germination occurs, soil temperature in the driving factor leading to successful seedling emergence.

Table 2.2. Germination and emergence temperature requirements of green foxtail.

	Temperature (°C)			
	Min.	Max.	Optimum	Reference
Germination	7	40	20 –30	Lauer (1953)
			15 –35	Vanden Born (1971)
Emergence			10 – 24	Alex et al. (1972)
			20 –30	Vanden Born (1971)

Green foxtail emergence increased with rising temperature, but outside of the limited temperature range of 20°C to 30°C, emergence rate and final emergence percentages were reduced drastically (Vanden Born 1971).

Temperature was found to be the main factor driving the emergence periodicity of green foxtail (Banting 1962; Banting et al.1973), and soil moisture and seed depth in the soil modified the periodicity (Weaver et al.1988). The effect of soil moisture on green foxtail germination was more pronounced when soil temperatures were within the suitable range for emergence, but as soil moisture declined below the required range for germination, temperature became the most important factor determining green foxtail emergence (Blackshaw et al. 1981a). This is in agreement with the observation that emergence flushes of green foxtail were identified after periods of high rainfall (Banting et al.1973; Douglas et al.1985).

The germination and emergence of green foxtail seeds was affected by burial depth (Alex et al. 1972; Dawson and Bruns 1962; Vanden Born 1971), where emergence decreased, as seeds were located at greater soil depths. This may be due to lack of light exposure since green foxtail seeds require some light exposure for germination (Douglas et al. 1985). Maximum depths of emergence recorded for the species were 12 cm (Dawson and Bruns 1962; Vanden Born 1971). Alex et al. (1962) observed optimum emergence in all soil types to range from the surface to 5.1 cm.

Tillage practices have been observed to affect seed placement in the soil (Zimdahl et al.1988), and this can influence weed infestation levels in fields (Spandl et al. 1998; Stahl et al. 1999). Increased proportional emergence occurs with reduced tillage because seeds stayed at or near the surface, where conditions were more conducive for germination in the spring (Blackshaw et al. 1981a; Spandl et al. 1998). Stahl et al. (1999) found an increased seedbank density at shallower depths in no-tillage systems versus molboard and chisel plough systems. In Manitoba, du Croix Sissons et al. (2000) observed *in situ* in conventional- and zero-tillage production fields that green foxtail emergence occurred from shallower depths in zero-tillage fields. Under zero-tillage, green foxtail mean emergence occurred from between 1.2 cm and 2.7 cm in 1997, and 0.6 cm and 1.6 cm in

1998. In conventional-till fields, the mean emergence depth was between 2.2 cm and 4.2 cm in 1997, and 1.2 cm and 3.5 cm in 1998.

Reduced tillage may result in later emergence of green foxtail in time. Spandl et al. (1998) observed green foxtail emergence to be delayed in reduced tillage systems because of cooler soil temperatures. Anderson and Neilsen (1996) found emergence periodicity of green foxtail to be unaffected by tillage, even though populations of emerged green foxtail increased.

Delayed planting may affect the rate of emergence in green foxtail. Spandl et al. (1998) found green foxtail emergence rates to increase with later planting dates. They reasoned that germination was pushed later into spring where soil temperatures were increased, and conditions more favourable for germination. The effect of late seeding on green foxtail emergence was visible in late seeded crops where green foxtail has been found to be a primary weed problem (Douglas et al. 1985). Therefore, strategies of delayed planting to control wild oat, may be ineffective to control green foxtail, and would instead favour emergence and establishment relative to crop emergence (Banting 1962).

Biotype Effects on Weed Emergence Periodicity

For a weed species to be successful and widely dispersed, it must adapt to diverse environmental conditions. Interactions occur between environment and soil type, providing conditions needed for germination and emergence of a species. Soil type influences the water holding capacity of the soil (clay>sand), and contributes to soil warming (sand>clay), and the environment contributes to available moisture and temperature accumulation in the area (Miller and Donahue 1990). In combination, soil type and the environment provide available soil moisture and temperatures required by specific species to meet their emergence requirements. Depending upon the particular soil type and environmental conditions in an area, a species population may develope physiological adaptions to the area to guarantee success (Norris and Schroner 1980)

Long term average environmental conditions and farming practices cause selection pressure on weed species populations. For example, collected yellow foxtail seeds from different sites in the United States (Norris and Schoner 1980) displayed germination differences between a California biotype and four eastern biotypes. The differences were thought to reflect the adaptations through selection of the California biotype to high soil temperatures normally experienced in that area. The California biotype emerged 1 to 3 days earlier than the eastern biotypes over the entire temperature range used to test the biotypes. Additionally, O'Donovan et al. (1999) observed wild oat biotypes resistant to triallate/difenzoquat emerged one day earlier than susceptible biotypes.

Norris and Schnoer (1980) also observed that the dormancy characteristics, and germination requirements within species populations vary substantially. Agronomic practices such as seeding date and timing of tillage could cause selection for biotypes with particular emergence periodicities. For example, Naylor and Jana (1976) observed large differences in germination behaviour of local populations and indicated differences occurred to selection pressures from genetic adaptation to local environmental conditions and farming practices.

Methods of Studying Weed Emergence Periodicity

Many studies on emergence periodicity of weed species, where most have been carried out under greenhouse or controlled field conditions (Banting et al. 1973;

Blackshaw 1990; Chepil 1946; Ogg and Dawson 1984; Roberts 1984), and very few have been done with natural populations in un-manipulated fields. The information from controlled condition studies has aided in our understanding of the germination and emergence requirements for individual species, and has contributed to the creation of predictive emergence models (Forcella 1993; Harvey and Forcella 1993). Under field conditions, emergence is more easily measured than germination (Weaver et al. 1988).

Due to the lack of species emergence information from natural populations in un-manipulated field conditions, it is uncertain whether that the results obtained from controlled studies will actually occur under real conditions. Emergence periodicity information for a number of species under a variety of agronomic and environmental conditions would be beneficial for testing against predictive emergence models to determine their accuracy.

When measuring factors that affect emergence, the practicality of measurements must be considered. For example, temperature was found to be one of the driving factors initiating, regulating, and stopping emergence (Blackshaw 1990; Lafond and Baker 1986). Measurements of temperature though can be done a number of ways; including growing degree days (GDD) of air or soil, diurnal fluctuations and maximum temperatures recorded.

Air GDD is easily accessible for researchers and farmers, but the temperature found in the seed zone more accurately relates to emergence (Cutforth and Shaykewich 1989). There is a relationship between air temperature and seed zone temperature, but this is affected by soil management practices (Swan et al. 1987). For each field, soil and management practice interact to create unique relationships to air temperature. Therefore it is preferable to measure temperatures in the seed zone to determine the amount of GDD needed for emergence in a range of soil and tillage systems (Schneider and Gupta 1985).

The study undertaken in 1999 and 2000 examined emergence in 36 fields across a farm area of approximately one million hectares. The study was done with producers practicing a range of agronomic systems including different tillage systems and seeding dates. The study sites also represent a range of soil types and environmental conditions.

Emergence Periodicity Modeling

Models are useful for the validation and testing of biological systems. The advantages of mathematical modeling is that they are testable, they can describe large, separate observations in a concise form, they can identify where knowledge in the area is lacking, and they can be used to predict biological system behaviours in untried combinations and conditions. Yet, biological systems are complex and it is not often that a complete mathematical description or model of what is occurring can be found. Therefore, starting with simple assumptions about the systems behaviour is required (Jones 1983).

There are different types of modeling approaches that can be taken, and the choice of the model being used is dependent on the research objectives. What we focused on in this study was empirical and mechanistic modeling. The empirical model uses simple inputs in the creation of the model, and minimal information in its development. Mechanistic models use knowledge from previous work in attempts to explain what is occurring in greater detail (Jones 1983). A continuum exists between the models such that the approaches are not completely distinct, and empirical models can develop into mechanistic models as they are refined.

Figure 2.1. Diagram of inputs needed, continuum between empirical and mechanistic models, and potential end-users of the models.

Model:	**Empirical Model** (simple) Air temperature + Precipitation	$\longrightarrow$	**Mechanistic Model** (complex) Incorporation of other models into present model
	$\downarrow$		$\downarrow$
End User:	Farmers		Scientists

EMERGENCE PERIODICITY OF WILD OAT AS AFFECTED BY TILLAGE AND ECO-REGIONAL FIELD LOCATION CLUSTER

Introduction

Wild oat was observed to be the second most abundant weed, by relative abundance in cereal and oilseed fields in Manitoba (Thomas et al. 1998), and it was estimated by Leggett (1950) that an infested area of a field in western Canada contained 70 bu/ac of wild oat seed. Wild oat prevalence in Manitoba may be explained by the observation that mature wild oat plants shed seed before field crops reach maturity, allowing for re-infestations (Sharma and Vanden Born 1978). Therefore, control methods need to be implemented within the growing season, before wild oat plants reach maturity.

One of the most effective mechanical control methods for weed control is the use of tillage (Arshad 1992), but due to increasing concerns about soil conservation, moisture retention and reducing input costs, tillage is less frequently used. Tillage reductions have been observed to shift weed population dynamics to favour certain weeds over long periods of time. For example, Gill and Arshad (1995) observed wild oat to have highest mean densities under zero-till versus conventional-tilled. In reduced-tillage systems, herbicides become more important factors in controlling weed populations. In Manitoba, a number of reported cases of herbicide resistance for single or multiple herbicide groups in wild oat have been confirmed (Bourgeois et al. 1997; Friesen et al. 2000; Murray et al. 1995). With the apparent diminishing control options for wild oat, alternative management methods are required. A better understanding of factors controlling wild oat emergence and the emergence periodicity will aid in the development of new management methods.

Characteristic seasonal emergence periodicities for individual weed species have been observed (Chepil 1946; Egley 1991; Mulugeta and Boerboom 1999; Ogg and Dawson 1984; Stoller and Wax 1973). Generally, these authors found emergence of an individual species begins and ends in a set pattern, dependent on temperature and moisture levels in the microsite.

The intent of many studies of species emergence periodicity is to build predictive emergence models (Alm et al. 1993; Forcella 1993). Datasets used to build these models, in general, have either come from controlled environmental experiments or limited field studies. The intentions of this study was to examine the emergence periodicity of weed species under unmanipulated field conditions across a broad area in Manitoba. From the dataset we were interested in discovering if any statistical empirical difference in emergence periodicity existed between conventional and zero-tillage fields and between fields in different ecodistricts.

The uniqueness of this project is the fact that emergence data was collected from so many fields. The dataset therefore, not only represents differences in tillage and ecodistrict, but also a broad range of agronomic practices. In this respect we were able to test whether tillage or ecodistrict are robustly significant factors affecting wild oat emergence periodicity.

Differences in wild oat emergence periodicity between tillage systems and ecodistricts were examined both post-seeding and pre- and post-seeding. The two sampling periods were chosen because we wanted to determine if tillage and ecodistrict affected wild oat emergence periodicity differently when periodicity monitoring began at soil-thaw, versus after crop planting.

Materials and Methods

Field Selection

Fields were selected on the basis of tillage system, (zero- or conventional-tillage) and weed spectrum. Potential fields were chosen by contacting a zero-tillage farmer in pre-determined areas and requesting a referral to a nearby conventional-tillage farmer. Zero-tillage fields were subjected to one or less soil disturbance operation (including seeding) from harvest of the previous year to seeding in the year of observation. One pass with harrows was allowed in zero-tillage fields. Conventional-tillage fields were subjected to more than one soil disturbance operation, besides seeding, from harvest of the previous year to seeding in the year of observation. For fields to qualify, tillage systems must have been practiced in that field for at least three years prior to the year of study.

Medium infestations of wild oat must have been previously observed within selected fields and no soil residual herbicides could have been used in selected fields within the past twelve months. All fields were seeded to canola, and had a spring cereal crop (excluding rye) as the previous crop.

Classification of Tillage System and Eco-Regional Field Location Cluster

Weed emergence periodicity was tracked in fourteen and twenty fields in 1999 and 2000, respectively. Fields were located across a one million hectare area of southern Manitoba. Both zero- and conventional-tillage fields were examined (seventeen conventional-tillage and seventeen zero-tillage fields) and they were located in four distinct eco-regional field location clusters (cluster). Each cluster contained a number of fields within close geographic proximity to one another. Clusters included either one ecodistrict or two ecodistricts (Table 3.1). The clusters were characterized according to average precipitation and air growing degree days (base temperature 5°C) from April to June, average soil moisture deficits, and soil type (Table 3.1).

Table 3.1. Characteristics of eco-regional field location clusters (cluster).

Cluster	Ecodistrict	Soil Texture[a]	Soil Moisture Deficit (mm)[b]	30 year average April to June[c] GDD>5[d]	Rainfall (mm)
1	Gladstone/Winnipeg	Clay	190	625	170
2	Pembina Hills	Clay Loam	150	610	185
3	Stockton/Shilo	Sandy Loam	230	615	165
4	St.Lazare/Hamiota	Clay Loam	200	570	155

[a]Agriculture Canada 1989
[b]Smith et al. 1998
[c]Environment Canada 1998
[d]GDD>5, growing degree days calculated using a 5°C base

<u>In-Field Sampling</u>

Observation of weed emergence in fields occurred ever two to four days. Four permanent ¼ m^2 quadrats were placed in each field in areas generally representative of the field. At each visit, all newly emerged seedlings in the quadrats were tagged with coloured rings, and seedling populations and identities were recorded. No seedlings were removed from the quadrats until the end of the sampling period. In 1999, sampling occurred from time of crop seeding to canola bolting, and in 2000, sampling occurred from the first week of April to canola bolting. The time of sampling was divided into two sampling periods. All sampling occurring after crop seeding was labeled as the post-seeding sampling period (PS). Emergence was tracked during this period in both 1999 and 2000. Sampling from soil thaw to crop bolting was labeled as the pre- and post-seeding sampling period (PPS). Emergence was tracked during this period in 2000 only.

At the time of each field visit, gravimetric soil moisture samples were taken to a 2.5 cm depth and accumulated precipitation in the field was recorded from rain-gauges placed in each field. Soil temperatures were recorded continuously throughout the sampling period using Stow Away® TidbiT™ temperature recorders (Onset Computer Corporation, Box 3450, 536 MacArthur Blvd., Pocasset, MA 02559-3450). TidbiTs™ were removed during seeding and tillage events, and soil temperatures for these times were interpolated from air temperature. Air temperature and precipitation data was obtained from Environmental Canada weather stations located closest to the fields where sampling occurred.

To protect seedlings from herbicide damage within the sampling period, all quadrats were covered with a white, non-permeable plastic barrier sheet during pre-seed and in-crop herbicide applications. At weed harvest, all plants were removed from the quadrats by cutting plants off at the soil surface, and individual plants were sorted by date of emergence (ring colour), species and phenological stage.

Thermal Time Measurements

Daily air temperature, from the nearest Environment Canada weather station, and soil temperature, from field TidbiTs placed at 2.5cm depth, were collected for each site and the accumulated growing degree days (GDDs) calculated. The equation used to calculate accumulated GDDs was,

$$\text{GDD} = \frac{\text{Maximum + Minimum Daily Temperature}}{2} - \text{Base temperature.} \qquad [1]$$

The PROC CORR function of the SAS (version 8.0) statistical package (SAS Institute, Raleigh, N.C.) was used to find the correlation coefficient between accumulated soil and air GDD for the pre- and post-seeding periods (base temperature of 0°C). 0°C was used as the base temperature when calculating thermal time for wild oat because it makes for a simpler calculation (which would be useful if producers are calculating their own GDD). Soil and air GDD had a correlation coefficient of 0.98 (Figure 3.1). The close relationship of air to soil GDD concurred with the findings of Alessi and Power (1971).

Data analysis proceeded therefore, using only a single measurement of thermal time, soil GDD. Soil GDD, represents the temperature where emergence is occurring, and the measurements were unique for each field. Soil temperature also reflects to a greater extent, moisture by temperature interactions, as well as the influences of tillage and soil type on individual field soil temperatures.

Statistical Analysis

Estimating Wild Oat Emergence Periodicity.

Statistical analysis closely followed the procedures outlined by Friesen et al. (1992). A logistic model was fitted to the emergence periodicity data. The model chosen was used because of its accuracy and simplicity and because the parameters have biological meaning (Friesen et al. 1992). The model fitted was,

$$y = a/(1 + be^{-cx}) \qquad [2]$$

where y is the dependent variable (species emergence), x is the emergence percentage expressed in soil growing degree days (base 0°C, measured 2.5 cm below soil surface) e is the base of the natural logarithm, and a, b, and c are the nonlinear parameter estimates.

Specifically, a, is the estimated value of the upper asymptote, and $a/(1+b)$ 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 inflection point. After the a, b, and c parameters were obtained, lack-of-fit *F* tests, as outlined by Seefeldt et al. (1995), were used to test significance between models fitted to apriori groups of data (i.e. tillage systems, cluster) (Tables A.3.3, A.3.4, A.3.5 for 1999 and 2000 PS, and 2000 PPS periods respectively). Coefficients of determination (R^2) were calculated as described by Kvalseth (1985) using the residual sum of squares value from the SAS output. As outlined by Seefeldt et al. (1995), SAS provides only one residual sum of squares value for the model as a whole, even though parameters for several functions are estimated simultaneously.

Data sets only included sites where observed wild oat emergence was greater than 5 plants/m^{-2} in the sampling period, and emergence was expressed as a cumulative percentage of total. The estimated parameters for the logistic model for different tillage systems and for different clusters were compared and considered to be significantly different statistically at the 5% level (Steel et al. 1997).

Wild oat emergence periodicity models fitted to data for 1999 and 2000 PS were compared to determine if datasets could be combined over years (Figure 3.2). The results from PROC NLIN and the lack-of-fit *F* test showed cumulative wild oat emergence periodicity to be significantly different between years (Table 3.2). Years were therefore analyzed separately.

Table 3.2. *F* test[a] results for comparing significance of parameter estimates of post-seeding (PS) cumulative percent of wild oat emergence models. Comparisons made between year models for 1999 and 2000.

	a	*b*	*c*	R^2
Years	NS[b]	NS	*[c]	0.86

[a]Statistical differences between parameter estimates were determined using the lack-of-fit *F* test at the 5% level of significance
[b]NS means not significant at 5% level
[c]* means significant at 5% level

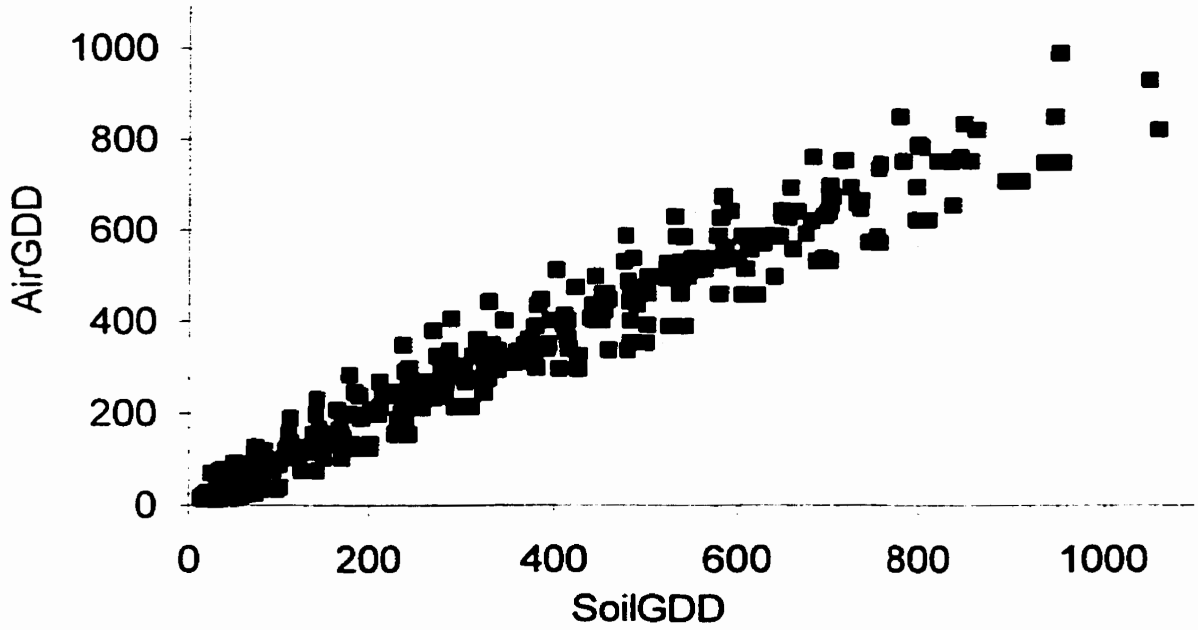

Figure 3.1. Relation of soil growing degree days (GDD, base 0°C, 2.5 cm from the soil surface) and air growing degree days (GDD, base 0°C) in the pre- and post-seeding period of 2000 (■).

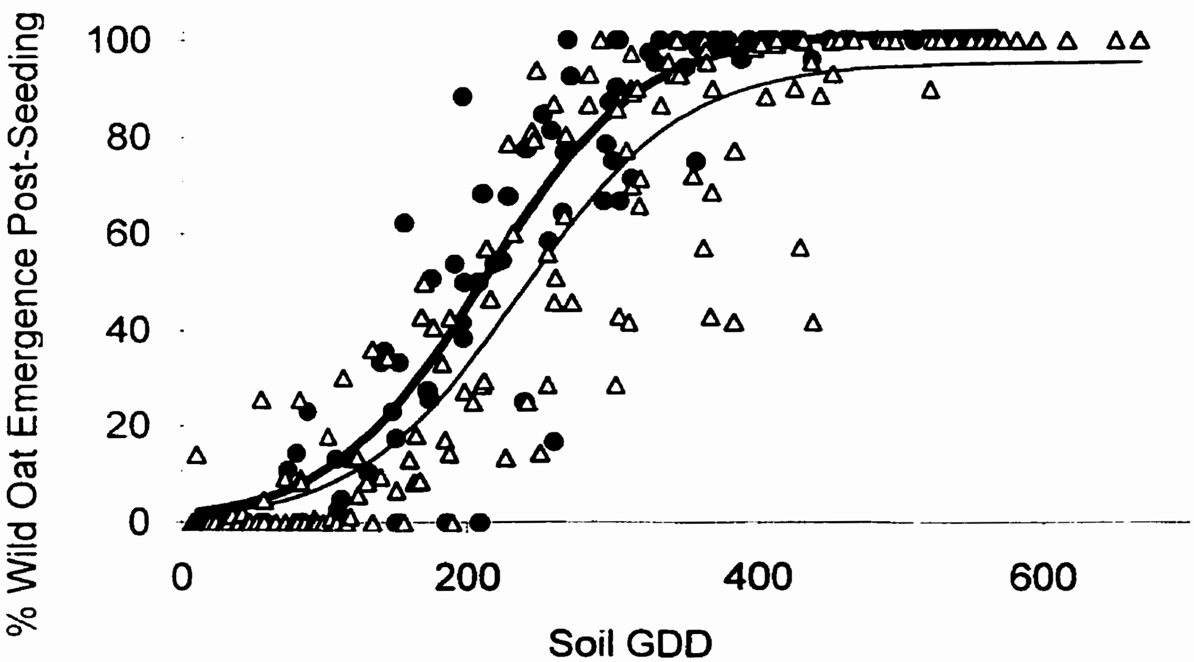

Figure 3.2. Wild oat emergence periodicity as related to soil growing degree days (GDD, base 0°C, 2.5 cm from the soil surface), measured post-seeding (PS) in 1999 (●), and 2000 (△). Markers represent field data and lines represent models. Refer to table A.3.2. for parameter estimates of models.

Soil Temperature Analysis.

Temperature is a major factor driving the periodicity of wild oat emergence. Therefore differences in soil temperature between tillage systems and clusters within sampling periods and years by Julian date were required. The same sites used in estimating the wild oat emergence periodicity were used in the soil temperature analysis to avoid confounding data.

The PROC LNIN function of SAS was used to run a linear regression on the accumulated soil GDD versus Julian days under different tillage systems and clusters. The regression equation used was,

$$y = a + bx \qquad [3]$$

where y was the accumulated soil GDD (base 0°C) for the sampling period, a was the y-axis intercept, b was the linear regression coefficient, and x was the julian day on which the accumulated soil GDD occurred (Steel et al. 1997). After the a, and b parameters were obtained, lack-of-fit F tests, as outlined by Seefeldt et al. (1995), were used to test for significant differences between apriori data groupings (i.e. tillage systems, clusters) (Tables A.3.7, A.3.8 and A.3.9 for parameters; significance testing in PS 1999 and 2000, and PPS periods respectively).

Comparisons of mean diurnal soil temperature fluctuations between tillage systems were made using the PROC GLM function of SAS where diurnal soil temperature fluctuations were sorted by weeks after April, or weeks after seeding (Table 3.7).

Gravimetric Soil Moisture Analysis.

To avoid confounding data, the same sites in which wild oat emergence periodicity was tracked were used for examining gravimetric soil moisture. Gravimetric soil moisture was determined from soil samples collected at each site at each sampling date. The equation used to determine gravimetric soil moisture was,

$$Y = \frac{Sw - Sd}{Sd} \qquad [4]$$

where y is the percent of gravimetric soil moisture (w/w) in the soil sample, Sw is the wet weight of the soil in grams collected from the field, and Sd is the dry weight of the soil after being dried for 48 hours at 80°C.

Comparisons of mean gravimetric soil moisture between tillage systems or clusters were made using the PROC GLM function of SAS where gravimetric soil moisture for the PPS period, was sorted by weeks after April 1 (Table 3.8), and by weeks after seeding in the PS period (Table 3.11 and 3.12).

Results and Discussion

The model determining predictive cumulative wild oat emergence for all sites was a good fit to the data. For all sites and sampling periods (Figure 3.3a, 3.4a and 3.5a) data points were evenly scattered around the models, and standard errors for the estimated parameters were relatively small.

A simple model fitted to field observation may not accurately represent wild oat emergence over a large geographic area or under different tillage systems, therefore the models were tested to see if they were statistically different when datasets were separated on the basis of these factors.

<u>Effect of Tillage on Emergence Periodicity</u>

Emergence Post-Seeding

Wild oat emergence periodicity PS of the crop was not significantly different between zero-tillage (ZT) and conventional-tillage (CT) fields in 1999 and 2000

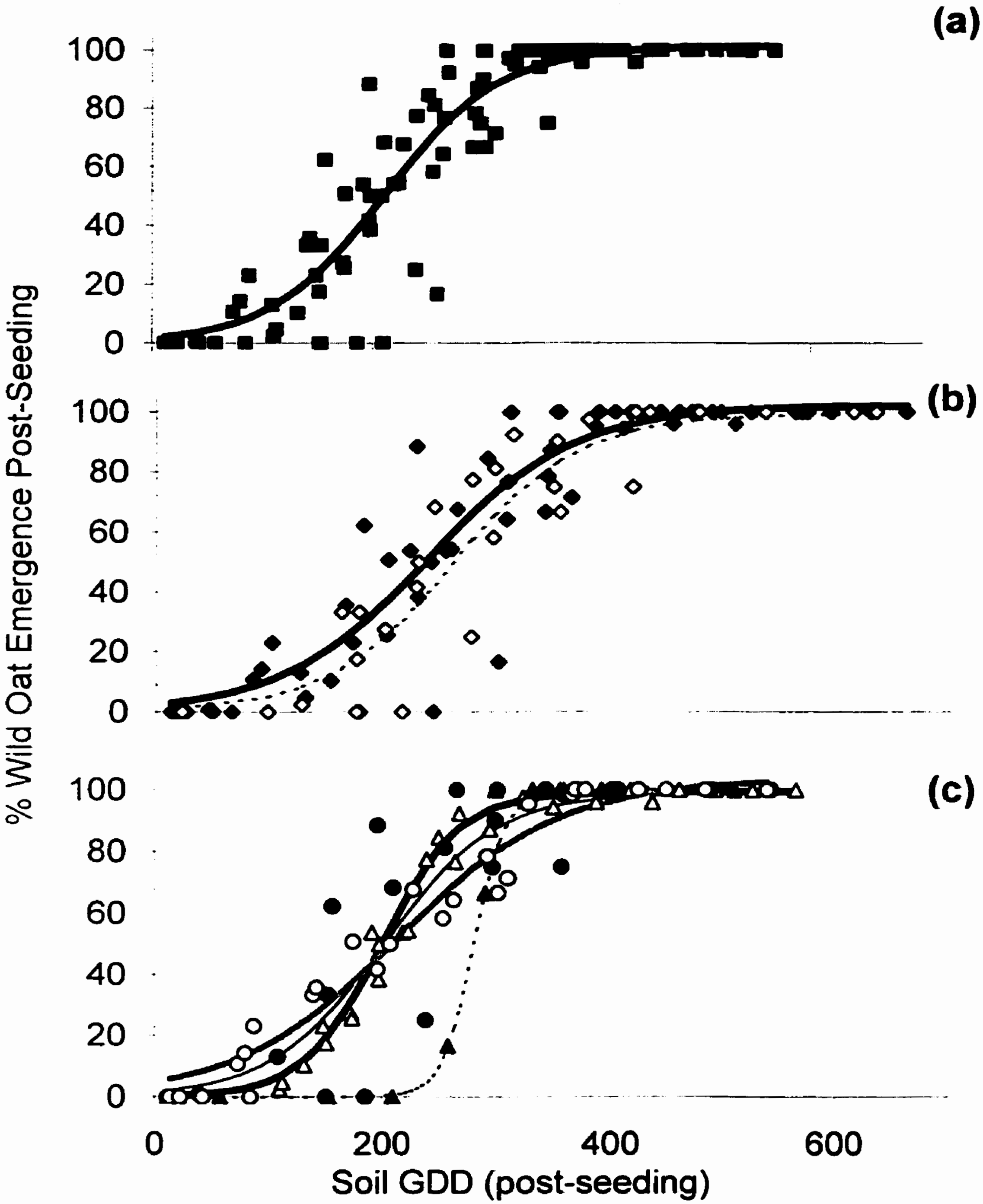

Figure 3.3. Wild oat emergence periodicity as related to soil growing degree days (GDD, base 0°C, 2.5 cm from the soil surface), in post-seeding (PS) period of 1999, for (a) all sites (—■), (b) conventional-tillage (---◇), and zero-tillage—◆) fields, and (c) cluster 1 (--▲), cluster 2 (—△), cluster 3 (—●), and cluster 4 (—○). Markers represent field data and lines represent models. Refer to table 3.5 for parameter estimates of models.

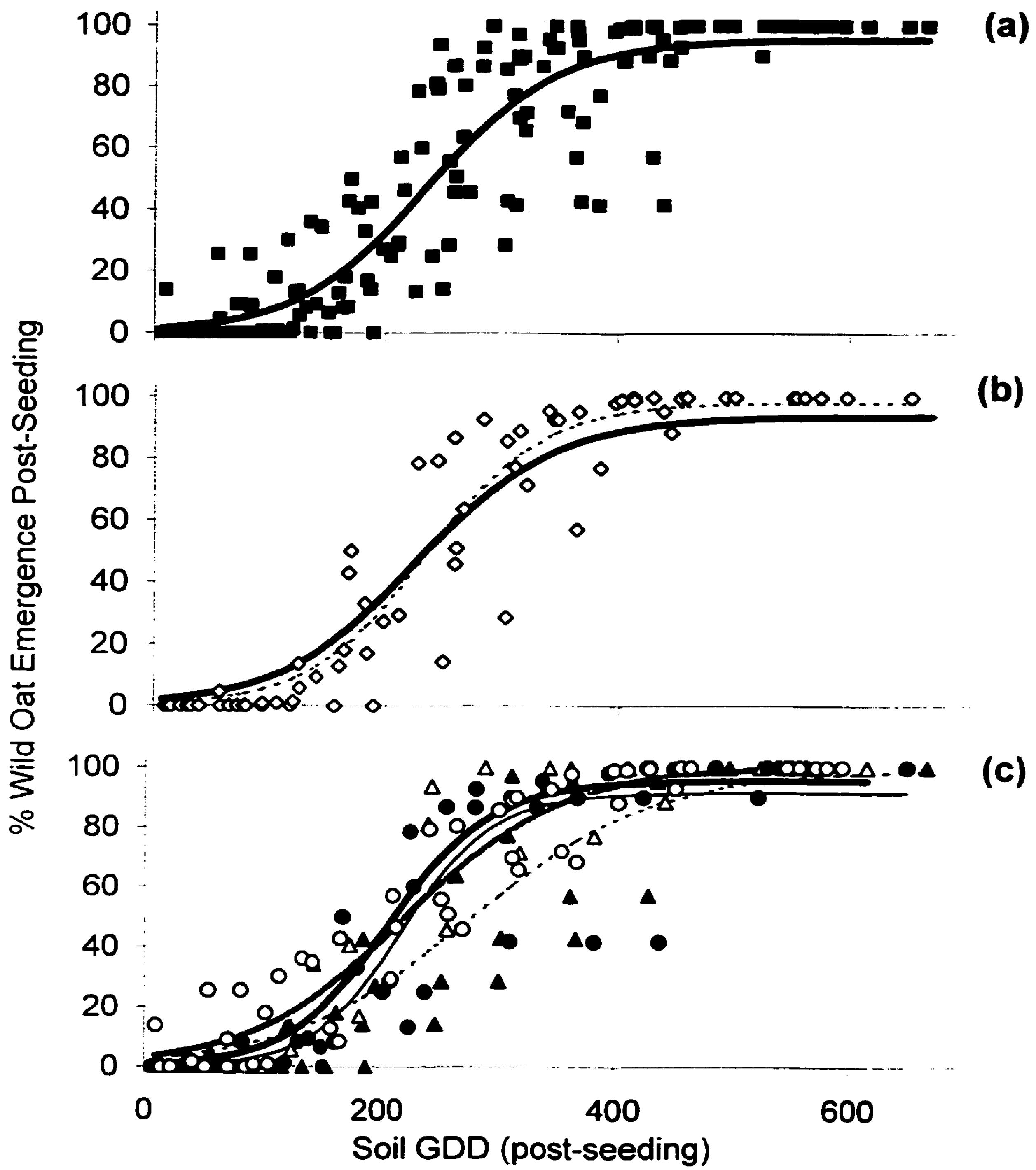

Figure 3.4. Wild oat emergence periodicity as related to soil growing degree days (GDD, base 0°C, measured at 2.5 cm under the soil surface) in post-seeding (PS) period of 2000, for (a) all sites (_■), (b) conventional-tillage (--- ◇), and zero-tillage (_◆) fields, and (c) cluster 1(---▲), cluster 2 (_△), cluster 3 (_●), and cluster 4 (_○). Markers represent field data and lines represent models. Refer to table 3.5 for parameter estimates of models.

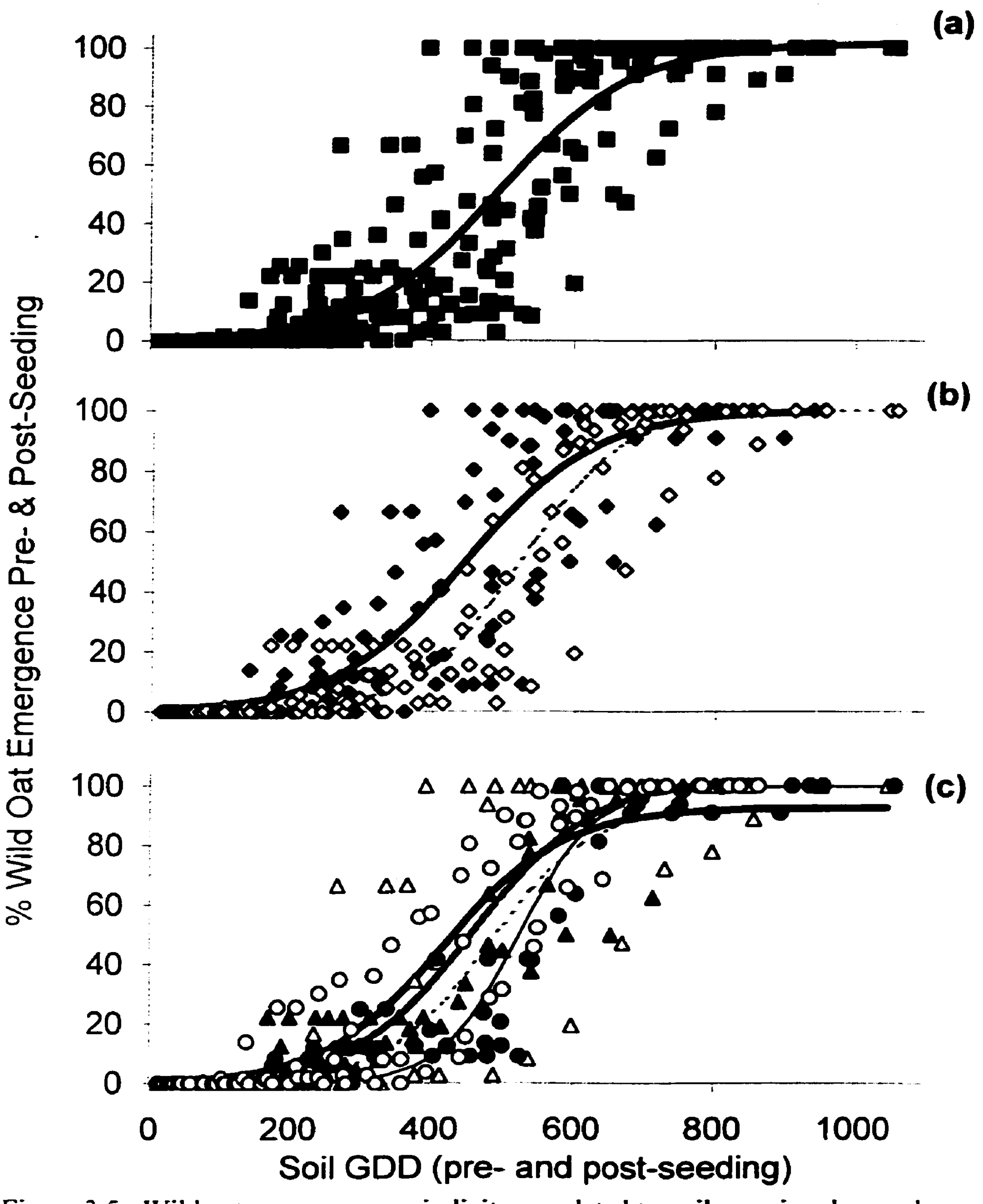

Figure 3.5. Wild oat emergence periodicity as related to soil growing degree days GDD, base 0°C, 2.5 cm form the soil surface), in the pre- and post-seeding (PPS) period of 2000, for (a) all sites (–■), (b) conventional-tillage (--◇), and zero-tillage (–◆) fields, and (c) cluster 1 (--▲), cluster 2 (–△), cluster 3 (–●), and cluster 4 (–○). Markers represent field data and lines represent models. Refer to table 3.5 for parameter estimates of models.

(Table 3.3, Figures 3.3b, 3.4b). This concurs with Thurston (1961) and Froud-Williams et al. (1984) who observed that tillage had no affect on wild oat emergence.

Table 3.3. *F* test[a] results for comparing significance of parameter estimates of post-seeding (PS) cumulative percent of wild oat emergence models. Comparisons made between tillage system models and eco-regional field location clusters (cluster) models in 1999 and 2000.

	1999				2000			
	a	*b*	*c*	R^2	*a*	*b*	*c*	R^2
Tillage	NS	NS[b]	NS	0.87	NS	NS	NS	0.86
Cluster 1,2,3,4	NS	*[c]	*	0.91	NS	NS	*	0.86
Cluster 1,2	NS	*	*	0.98	NS	NS	*	0.84
Cluster 1,3	NS	*	NS	0.83	NS	NS	*	0.84
Cluster 1,4	NS	*	*	0.94	NS	NS	*	0.87
Cluster 2,3	NS	NS	NS	0.89	NS	NS	NS	0.87
Cluster 2,4	NS	*	*	0.96	NS	NS	NS	0.91
Cluster 3,4	NS	NS	NS	0.87	NS	NS	NS	0.88

[a]Statistical differences between parameter estimates were determined using the lack-of-fit *F* test at the 5% level of significance
[b]NS means not significant at 5% level
[c]* means significant at 5% level

Emergence Pre- and Post-Seeding

Wild oat emergence periodicity pre- plus post-seeding (PPS) of the crop was significantly different between ZT and CT in 2000 (Table 3.4, Figures 3.5b). The findings were contrary to those of Thurston (1961) and Froud-Williams et al. (1984) who observed that tillage had no affect on wild oat emergence. This may be because the observations of Thurston (1961) and Froud-Williams et al. (1984) were made after tillage occurred, they did not use natural weed populations, and they did not consider differences in systems that had been under long-term tillage practices. In our study we observed wild oat emergence prior to and post-seeding, and examined natural weed populations in fields experiencing tillage practices over the long-term.

Table 3.4. F test[a] results for comparing significance of parameter estimates of pre- and post-seeding (PPS) cumulative percent of wild oat emergence models. Comparisons made between tillage system models and eco-regional field location clusters (cluster) models in 2000.

	a	b	c	R^2
Tillage	NS	* [a]	NS	0.84
Cluster 1,2,3,4	NS	NS [b]	*	0.82
Cluster 1,2	NS	NS	NS	0.77
Cluster 1,3	NS	NS	NS	0.89
Cluster 1,4	NS	NS	NS	0.86
Cluster 2,3	NS	NS	*	0.79
Cluster 2,4	NS	NS	NS	0.79
Cluster 3,4	NS	NS	*	0.87

[a]Statistical differences between parameter estimates were determined using the lack-of-fit F test at the 5% level of significance
[b]NS means not significant at 5% level
[c]* means significant at 5% level

The fitted emergence models representing wild oat emergence in tillage systems PPS (Figure 3.5b) had an even scatter of data points around them. The b parameter was high in the CT system, and the standard error of b was high under both tillage systems, but much higher in CT (Table 3.5). The same was true for the PS data set in both years (Table 3.6). The b parameter affects both the value of the y-axis intercept, and the value of x at the inflection point. A higher b value indicates that the emergence periodicity will be delayed, but the time taken to reach the inflection point will be shorter. The high standard error of the b parameter in CT versus ZT indicates that the onset of emergence periodicity under CT was more variable than in ZT, and that the amount of time taken to reach the inflection point was more variable among sites under CT versus ZT. Increased variability among sites in wild oat emergence periodicity may be due to greater diurnal temperature fluctuations experienced in CT versus ZT fields. We observed that CT had greater diurnal soil temperature fluctuations than ZT fields, (Table 3.7) for 12 of 13 weeks in the PPS period, 4 of 8 weeks in PS period of 2000, and 3 of 6 weeks in PS period of 1999. Significance in the diurnal temperature range in PPS period occurred a majority of the time (3 of 5 weeks) prior to crop seeding.

Table 3.5. Parameters estimates for cumulative percentage wild oat emergence models pre- plus post-seeding (PPS) as affected by tillage system (conventional-tillage (CT) and zero-tillage (ZT)) and eco-regional field location clusters (cluster) in 2000 only. Values in parentheses are standard errors.

	a	*b*	*c*
All Sites	101.7 (3.7)	183.3 (73.29)	.011 (.001)
Tillage			
CT	100.2 (4.7)	1481.7 (1466.7)	.014 (.002)
ZT	100.1 (4.5)	133.8 (60.1)	.011 (.001)
Cluster			
1	93.6 (14.8)	852.2 (1641.3)	.014 (.005)
2	92.8 (7.0)	154.7 (205.1)	.012 (.003)
3	99.8 (6.7)	21512.8 (57768.3)	.019 (.005)
4	102.5 (10.3)	255.3 (279.2)	.012 (.003)

Table 3.6. Parameter estimates for cumulative percent wild oat emergence models post-seeding (PS) as affected by tillage system (conventional-tillage (CT) and zero-tillage (ZT)) and eco-regional field location clusters (cluster) in 1999 and 2000. Values in parentheses are standard errors.

	1999			2000		
	a	*b*	*c*	*a*	*b*	*c*
All Sites	101.6 (3.6)	55.7 (26.6)	.019 (.002)	95.5 (2.6)	70.2 (27.6)	.018 (.002)
Tillage						
CT	99.5 (5.6)	110.6 (101.5)	.021 (.005)	98.4 (4.1)	109.0 (74.3)	.020 (.003)
ZT	102.3 (4.4)	40.2 (21.0)	.018 (.003)	93.9 (3.7)	47.6 (22.3)	.017 (.002)
Cluster						
1	100.9 (7.2)	3.9E8 (3.2E9)	.070 (.03)	99.3 (8.5)	37.3 (24.2)	.013 (.003)
2	99.5 (3.5)	330.6 (324.0)	.029 (.005)	95.7 (5.6)	125.1 (164.0)	.023 (.007)
3	99.5 (5.1)	56.2 (44.1)	.020 (.004)	91.6 (3.7)	313.7 (364.9)	.026 (.005)
4	103.7 (6.7)	20.1 (8.9)	.014 (.002)	100.8 (5.4)	28.9 (13.8)	.015 (.002)

Table 3.7. Mean daily maximum and minimum temperature soil temperature fluctuations, measured 2.5cm below the soil surface in conventional-till (CT) and zero-till (ZT) fields separated into weeks. For post-seeding (PS) weeks represent weeks after planting, for pre- and post-seeding (PPS) weeks represent weeks after April 1, 2000. Values in parentheses are standard errors.

Weeks	Post-Seeding 1999			Post-Seeding 2000			Pre- and Post-Seeding 2000		
	CT	ZT	LSD	CT	ZT	LSD	CT	ZT	LSD
1	9.7 (7.1) a[a]	6.6 (4.2) a	5.27	7.6 (2.7) a	7.3 (2.5) a	1.28	7.8 (3.2) a	5.6 (2.8) b	1.99
2	7.3 (3.8) a	8.8 (4.0) a	1.62	7.8 (3.2) a	8.0 (3.4) a	1.19	6.9 (3.8) a	4.3 (3.0) b	1.31
3	8.0 (3.8) b	9.7 (4.3) a	1.60	9.6 (3.4) a	7.8 (3.0) b	1.14	13.2 (4.1) a	10.9 (4.5) b	1.55
4	10.5 (4.8) a	8.6 (3.3) b	1.93	7.1 (3.4) a	8.0 (3.5) a	1.22	12.2 (4.1) a	11.1 (5.6) a	1.78
5	10.1 (4.5) a	7.3 (3.8) a	3.21	8.2 (4.1) a	7.1 (3.7) a	1.37	10.0 (3.0) a	9.6 (4.9) a	1.37
6	6.2 (1.8) b	9.2 (2.5) a	2.53	7.2 (3.9) a	5.7 (3.9) b	1.43	7.4 (3.0) a	7.2 (2.8) a	1.03
7				4.2 (1.9) a	5.8 (2.6) a	2.43	9.7 (2.5) a	8.6 (2.9) b	0.98
8				--- (---)	5.7 (3.0)	---	7.9 (3.0) a	7.5 (3.1) a	1.07
9							10.0 (3.9) a	8.6 (3.7) b	1.34
10							6.9 (3.5) a	6.5 (3.3) a	1.21
11							6.8 (4.0) a	5.3 (2.8) b	1.38
12							8.0 (4.3) a	6.1 (4.9) a	2.67
13							6.7 (3.0) a	7.5 (1.8) a	3.65

[a]Comparisons are between tillage systems or between eco-regional field location clusters within weeks; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).

Emergence of wild oat when sampled over the PPS period was delayed in CT versus ZT fields. This observation is opposite to the findings of Gebhardt (1985) who reported that crop emergence was delayed in reduced-tillage systems due to reduced soil temperatures. ZT fields in our study displayed earlier wild oat emergence, even though soil temperatures were significantly cooler in ZT versus CT fields (Table 3.8, Figure 3.6). The earlier wild oat emergence in ZT versus CT fields in the PPS period was probably due to greater soil moisture (Table 3.9) and shallower weed seedling recruitment depths in ZT versus CT fields (du Croix Sissons et al. 2000). If emergence is occurring from greater depths, a longer 'emergence lag period' will be produced in the sigmoidal emergence periodicity curve. A 'lag' was defined by Roberts (1984) as the time from seed germination to emergence, where the duration of the lag period was controlled by soil moisture. A 'lag' was present in curves for both the ZT and CT fields, but it was longer for the CT curve, reflective perhaps of the fact that wild oat seeds are being recruited from greater depths in CT fields, and that seeds in CT fields may be experiencing limited soil moisture conditions versus ZT fields.

In 2000, all sites experienced very dry conditions prior to the second week of May (Table 3.10), and soil moisture may have been limiting for seed germination. Buhler and Mester (1991) observed that decreased soil disturbance and the removal of surface residues slowed soil drying in reduced tillage systems. Therefore, any disturbance potentially reduces soil moisture in the weed seedling recruitment zone more so in CT versus ZT fields and causes delayed weed emergence. Roberts (1984) also observed that soil disturbances under dry conditions can delay weed emergence.

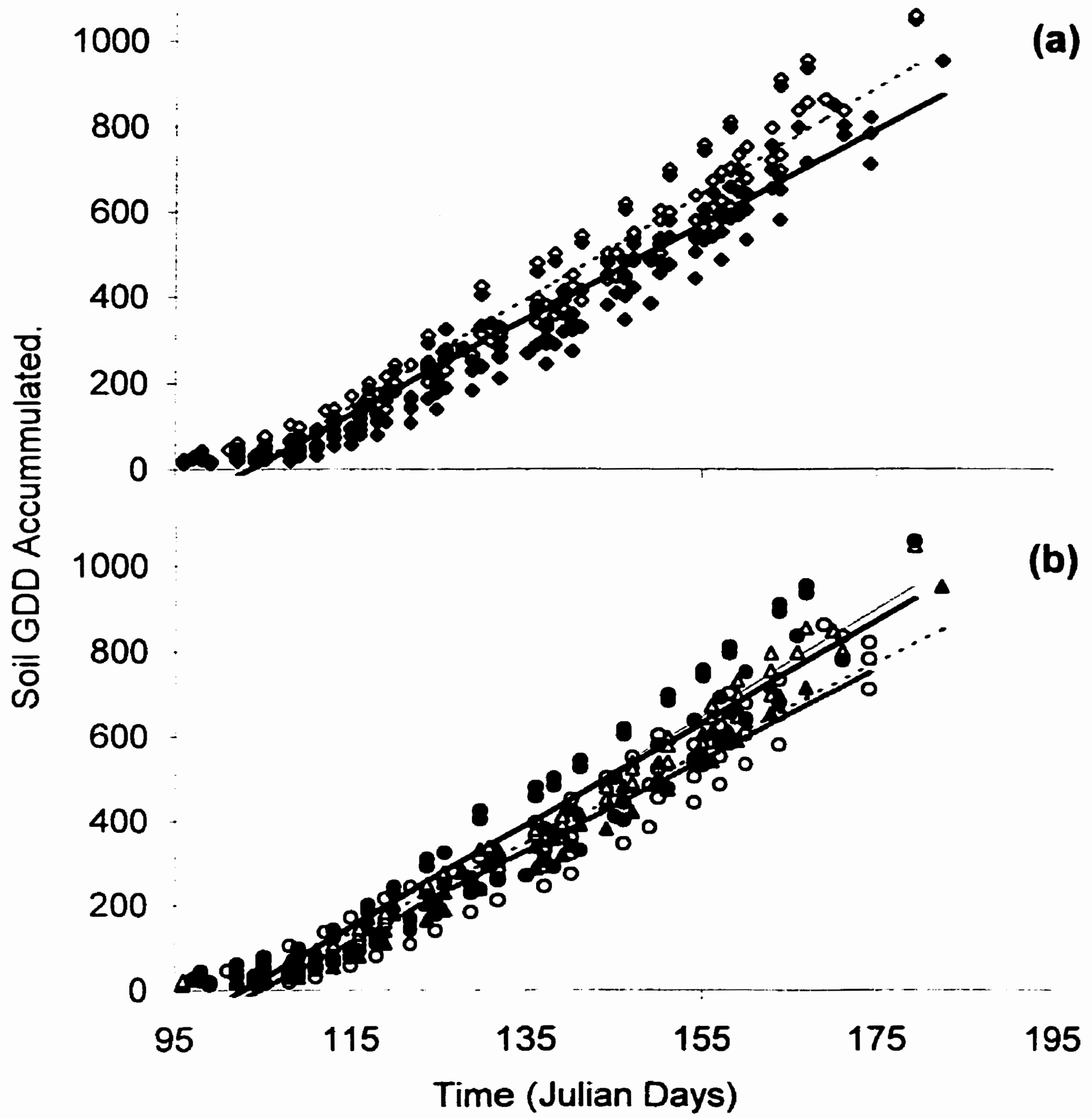

Figure 3.6. Measured accumulated soil growing degree days (GDD, base 0°C, at 2.5 cm below soil surface) as related to Julian day in the pre- and post-seeding (PPS) period of 2000 for wild oat emergence in (a) conventional-tillage (--◇) and zero-tillage (—◆) fields, and (b) cluster 1 (---▲), cluster 2 (—△), cluster 3 (—●), and cluster 4 (—○). Markers represent field data and lines represent models. Refer to Table A.3.9 for parameter estimates of models.

Table 3.8. *F* test results[a] for comparing significance of parameter estimates of post-seeding (PS) and pre- and post-seeding (PPS) accumulated soil growing degree days (GDD, base 0C, 2.5 cm from soil surface) models. Comparisons between tillage system models and eco-regional field location clusters (cluster) models in 1999 and 2000.

	Post-Seeding						Pre and Post-Seeding		
	1999			2000			2000		
	a	*b*	R^2	*a*	*b*	R^2	*a*	*b*	R^2
Tillage	NS[b]	*[c]	0.87	NS	*	0.96	*	*	0.92
Cluster 1,2,3,4	NS	*	0.88	NS	*	0.96	*	*	0.92
Cluster 1,2	NS	*	0.88	NS	*	0.96	*	*	0.96
Cluster 1,3	NS	NS	0.94	NS	*	0.95	*	*	0.92
Cluster 1,4	NS	*	1.00	NS	NS	0.97	NS	*	0.95
Cluster 2,3	NS	*	0.85	NS	NS	0.96	NS	NS	0.93
Cluster 2,4	*	*	1.00	*	*	1.00	*	*	1.00
Cluster 3,4	NS	NS	0.96	NS	*	0.96	*	*	0.91

[a]Statistical differences between parameter estimates were determined using the lack-of-fit *F* test at the 5% level of significance
[b]NS means not significant at 5% level
[c]*means significant at 5% level

The time it took for wild oat cumulative emergence to progress from 25% of total emergence (E_{25}) to 80% of total emergence (E_{80}) was greater in ZT versus CT fields (Table 3.11). The increased time for wild oat to reach E_{80} under ZT may be reflective of greater soil moisture present in ZT versus CT fields (Table 3.9). Egley and Williams (1991) observed that under moist conditions, weed emergence occurred over a broader time period, but under dry conditions less time was taken to reach total emergence. Gravimetric moisture samples from ZT and CT fields in our study indicated that soil moisture from the soil surface to 2.5 cm was significantly greater under ZT versus CT systems in 5 of 13 weeks (Table 3.9). Therefore, the greater time taken to reach E_{80} in ZT could have been a result of greater soil moisture available to germinating seeds.

Table 3.9. Average percent gravimetric soil moisture (w/w) sorted by week for wild oat emergence between tillage system (conventional-tillage (CT) and zero-tillage (ZT)) and eco-regional field location clusters (cluster) in pre- and post-seeding (PPS) in 2000.

		Tillage System			Cluster				
Days	Weeks	CT	ZT	LSD	1	2	3	4	LSD
		---% gravimetric soil moisture (w/w) ---							
92-100	1	16.5 (5.6) a[a]	26.9 (6.5) a	16.4	26.0 (5.2) a	23.2 (15.1)a	21.4 (5.5) a	22.7 (5.1) a	22.6
100-107	2	17.3 (4.0) b	24.5 (4.8) a	5.3	24.0 (5.0) a	17.9 (9.7) a	20.4 (6.0) a	22.7 (5.1) a	8.1
107-114	3	13.0 (4.1) b	21.2 (6.3) a	3.8	19.4 (6.6) a	17.9 (10.4)a	15.5 (7.1) a	20.6 (5.5) a	5.5
114-121	4	11.5 (4.6) b	18.2 (5.8) a	3.9	17.5 (6.3) a	13.8 (7.5) a	13.5 (6.8) a	18.7 (3.9) a	5.5
121-129	5	12.5 (8.4) a	17.1 (6.4) a	5.1	15.9 (8.3) a	16.4 (9.4) a	13.1 (6.9) a	15.5 (5.0) a	7.2
129-136	6	12.7 (7.9) a	21.0 (9.1) a	8.5	23.0 (11.6)a	21.3 (16.0)a	14.5 (8.0) a	16.1 (6.7) a	12.5
136-143	7	15.1 (5.8) b	19.5 (5.9) a	3.3	22.9 (3.8) a	19.5 (6.3) a	12.9 (4.6) b	18.0 (7.1) a	4.8
143-150	8	11.2 (6.9) b	19.3 (5.9) a	15.5	17.0 (5.1) a	14.1 (7.2) a	12.3 (7.5) a	18.6 (5.9) a	7.7
150-157	9	13.6 (6.2) a	17.0 (7.6) a	5.4	15.6 (6.9) a	11.8 (4.8) a	15.5 (7.5) a	19.0 (8.6) a	7.7
157-164	10	9.7 (5.2) a	14.5 (6.9) a	5.1	14.2 (8.4) a	13.8 (6.5) a	10.7 (7.3) a	19.1 (8.1) a	7.2
164-171	11	7.5 (4.7) a	19.2 (6.0) a	4.6	17.0 (11.3)a	16.6 (5.9) a	18.3 (3.0) a	12.3 (5.6) a	7.1
171-178	12	1.0 (--)	23.5 (5.0) a	25.0	--- (---)	23.5 (---)	29.2 (---)	20.8 (6.2) a	28.0
178-185	13	2.3 (3.4)	20.9 (--)	---	20.9 (--)	14.7 (---)	9.9 (---)	19.0 (6.9) a	---

[a]Comparisons are between tillage systems or between eco-regional field location clusters within weeks; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).

Table 3.10. Environmental characteristics of eco-regional field location clusters 1 (Gladstone and Winnipeg ecodistricts), 2 (Pembina Hills ecodistrict), 3 (Stockton and Shilo ecodistricts), 4 (St. Lazare and Hamiota ecodistricts) in 1999, 2000 and over 30 year average.

		April			May			June		
Cluster	Measurement	1999	2000	30yr	1999	2000	30yr	1999	2000	30yr
1	GDD>5[a]	82.2	68.5	50.9	212.6	202.5	217.9	413.6	287.8	354.9
	Precip (mm)[b]	15.0	12.5	40.5	142.0	53.9	54.4	74.0	129.6	76.0
2	GDD>5	95.3	74.6	53.3	222.7	219.1	210.6	437.3	288.9	348.5
	Precip (mm)	35.7	8.0	42.5	170.9	60.2	60.0	67.0	114.8	83.6
3	GDD>5	85.7	69.2	56.5	201.2	208.1	211.9	409.8	276.5	349.1
	Precip (mm)	17.8	9.3	38.0	180.9	66.9	54.4	54.9	90.9	74.1
4	GDD>5	81.1	60.1	46.2	187.9	198.7	192.6	383.9	252.8	333.8
	Precip (mm)	20.0	9.6	33.9	201.4	65.1	48.4	46.2	58.0	72.1

[a] growing degree days calculated using 5°C base temperature
[b] cumulative precipitation

Table 3.11. Soil growing degree days (GDD, base 0°C) required to reach 25 (E_{25}) and 80% (E_{80}) cumulative emergence in wild oat in the post-seeding (PS) and pre- plus post-seeding (PPS) sampling periods of 1999 and 2000.

	Post-seeding						Pre- and Post-Seeding		
	1999			2000			2000		
	E_{25}	E_{80}	E_{80}-E_{25}	E_{25}	E_{80}	E_{80}-E_{25}	E_{25}	E_{80}	E_{80}-E_{25}
All Sites	153	281	128	179	332	153	387	616	229
Conventional-till	172	292	120	181	308	127	464	630	166
Zero-till	142	277	135	168	331	163	360	587	227
Cluster 1	267	302	35	195	388	193	410	609	199
Cluster 2	163	249	86	165	281	116	337	573	236
Cluster 3	147	273	126	184	296	112	468	599	131
Cluster 4	133	302	169	151	315	164	368	568	200

Sampling Period Effect on Influences of Tillage on Emergence Periodicity

Time to reach E_{80} from E_{25} was greater for ZT versus CT fields in both the PS periods of 1999 and 2000, as well as in the PPS period (Table 3.11). Mean gravimetric soil moisture PPS was found to be greater in ZT versus CT fields (Table 3.9), significantly so in 5 of 13 weeks, the majority of the significant differences occurred prior to May 1st. In the PS period, gravimetric soil moisture was also greater in ZT versus CT fields, 2 of 8 weeks in 1999, and 2 of 9 weeks in 2000 (Table 3.12, Table 3.13). This again suggests that greater soil moisture in ZT systems may have contributed to the increased duration of the wild oat emergence period.

Tillage system significantly affected emergence periodicity in the PPS sampling period but not in the PS period. This may be due to the fact that in the PS period, only a portion of the entire emergence curve is being examined and the portion examined begins after crop seeding when the soil microsite is suitable for seedling emergence in both ZT and CT fields. Seeding date is chosen by producers to coincide with optimal soil temperature and moisture conditions for germination and emergence of crops, and these conditions are likely also to be optimal for weed emergence, and this would be true for either tillage system. Therefore, at time of crop planting the soil moisture and temperature is probably adequate for wild oat emergence in both systems. The emergence period 'lag' time, therefore, will be shorter between the two tillage systems because moisture is less likely to be limiting.

Observation of the emergence curve over a longer time period (PPS versus PS) amplifies the differences in seedling microsite conditions between the tillage systems and the effects of tillage system on emergence, therefore showing significance in emergence periodicity due to tillage PPS, but not PS. Over the entire PPS period, soil temperatures were cooler in ZT versus CT (Figure 3.6), and soil moisture was greater in ZT versus CT (Table 3.9). With the relatively dry early season conditions in 2000 (table 3.6), conditions in ZT were more favorable than CT for wild oat emergence, due to greater soil moisture availability.

Effect of Eco-Regional Field Location Cluster on Emergence Periodicity

Emergence Post-Seeding

Wild oat emergence periodicity post-seeding of the crop was significantly different between clusters 1 (Gladstone/Winnipeg ecodistrict) and 2 (Pembina Hills ecodistrict), 1 and 3 (Stockton/Shilo ecodistrict), 1 and 4 (St.Lazare/Hamiota ecodistrict), in 1999 (Figure 3.3c) and between clusters 1 and 2, 1 and 3, 1 and 4, and 2 and 4 in 2000 (Figure 3.4c).

In 1999, wild oat emergence data points were scattered evenly around the models for clusters 2, 3 and 4, and in 2000, the data points were evenly scattered around the models for clusters 1, 2, 3 and 4, indicating that the models were a good representation of the emergence periodicity in these clusters in each of these years. For cluster 1 in 1999, there was no scatter of wild oat emergence data points around the model, all actual wild oat emergence points were contained in the model. The lack of scatter of the data points around the model for cluster 1 in 1999, was the result of only one site fitting the criteria for the cluster. The standard errors for the b parameter was very high (table 3.6), indicating that the b parameter for wild oat emergence in cluster 1 in 1999, was not well estimated due to lack of data.

In 1999 and 2000, the model in cluster 1 was significantly different than the models in clusters 2, 3 and 4. In both years, wild oat emergence periodicity was delayed when compared to the emergence periodicity in clusters 2, 3, and 4. Delayed wild oat emergence in cluster 1 was a function of the particular conditions experienced in the sites representing this cluster. This cluster is categorized as having clay to heavy clay soil (Agriculture Canada 1989, Smith et al. 1998), which can contribute to poor drainage. In

1999 and 2000, a large amount of precipitation fell in this cluster (Environment Canada 1999, 2000), which could have kept the soils at field capacity for long periods. High levels of gravimetric soil moisture were observed for cluster 1 in 1999 and 2000 (Table 3.12, 3.13). Cluster 1 had the highest gravimetric soil moisture content 3 of 5 weeks in 1999 (Table 3.12), and 4 of 8 weeks in 2000 (Table 3.13). Soils kept at field capacity were observed to inhibit wild oat emergence due to lack of oxygen. Sharma et al. (1976) observed wild oat seeds to begin to rot if soils were maintained at field capacity for 11 days or more.

Cluster 1 is usually very warm (Table 3.9), and in normal years, if wild oats emerged under cooler conditions in this cluster, they would be killed by early season tillage and planting. Therefore, normal environmental conditions, combined with normal agronomic practices may have caused selection in this cluster for wild oat biotypes emerging only at warmer temperatures, or in soils with high daily temperature peaks. Biotype selection of emergence timing in wild oat was observed by O'Donovan et al. (1999) who found that wild oat biotypes resistant to triallate/difenzoquat emerged one day earlier than susceptible biotypes.

May and June 2000 were much cooler than normal in cluster 1 (table 3.9). If there had been biotype selection in this cluster for wild oat biotypes that emerged under only warm conditions, then the cooler than normal conditions in May and June 2000 would have led to delayed wild oat emergence in this cluster.

In the PS period, a significance difference was observed in wild oat emergence periodicity between clusters 2 and 4 in 1999. Emergence began earlier in cluster 4, but

Table 3.12. Average percent gravimetric soil moisture (w/w) sorted by days after seeding (DAS) and grouped into weeks after seeding (WAS) for wild oat emergence between tillage system (conventional-tillage (CT) and zero-tillage (ZT)) and eco-regional field location clusters (cluster) in post-seeding in 1999.

		Tillage System			Cluster				
DAS	WAS	CT	ZT	LSD	1	2	3	4	LSD
-------------------------------------% gravimetric soil moisture (w/w) --------------------------------------									
0-7	1	5.6 (---) b[a]	22.8 (11.5) a	11.7	29.9 (---) a	24.9 (---) a	9.7 (2.6) b	26.0 (14.2) a	12.5
7-14	2	12.9 (8.3) a	24.5 (9.8) a	8.8	34.7 (6.5) a	22.6 (1.7) ab	10.8 (4.6) b	16.3 (1.1) b	12.3
14-21	3	19.9 (5.7) a	19.6 (11.3) a	5.0	30.1 (6.3) a	25.3 (5.1) a	10.9 (8.0) b	17.7 (6.4) b	7.5
21-28	4	16.6 (5.5) a	18.9 (10.4) a	8.4	17.7 (10.0) a	24.2 (5.8) a	13.7 (4.8) a	14.1 (10.5) a	12.6
28-35	5	24.5 (6.0) a	21.5 (5.06) a	16.6	--- (---)	22.7 (5.2)	--- (---)	--- (---)	---
35-42	6	--- (---)	24.2 (---)	---	--- (---)	24.2 (---)	--- (---)	--- (---)	---

[a]Comparisons are between tillage systems or between eco-regional field location clusters within weeks after seeding; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).

Table 3.13. Average percent gravimetric soil moisture (w/w) sorted by days after seeding (DAS) and grouped into weeks after seeding (WAS) for wild oat emergence between tillage system (conventional-tillage (CT) and zero-tillage (ZT)) and eco-regional field location cluster (cluster) in post-seeding in 2000.

		Tillage System			Cluster				
DAS	WAS	CT	ZT	LSD	1	2	3	4	LSD
		--------------------% gravimetric soil moisture (w/w)							--------------------
0-7	1	7.1 (3.9) b[a]	16.9 (6.8) a	4.7	13.4 (9.1) ab	10.3 (4.3) b	9.9 (6.7) b	18.1 (7.0) a	6.6
7-14	2	14.6 (7.3) b	19.4 (5.4) a	3.5	23.1 (5.0) a	10.1(7.4) c	13.5 (3.4) bc	18.4 (6.4) ab	5.5
14-21	3	12.9 (7.2) b	19.6 (6.6) a	5.3	18.0 (8.0) a	12.7 (7.1) a	14.8 (7.2) a	19.0 (7.9) a	7.9
21-28	4	13.8 (5.6) a	15.9 (6.9) a	4.7	13.7 (4.7) ab	11.5 (1.7) b	12.9 (5.4) b	19.8 (7.5) a	6.8
28-35	5	12.8 (6.1) a	15.0 (8.0) a	7.4	16.8 (6.8) a	13.9 (---) a	14.5 (10.9) a	11.9 (5.9) c	14.0
35-42	6	13.6 (4.9) b	20.3 (7.5) a	6.1	10.1 (2.3) b	13.0 (2.1) ab	20.8 (6.8) a	17.9 (7.9) ab	9.8
42-49	7	25.0 (---) a	16.1 (7.2) a	29.0	17.0 (11.3) a	19.3 (5.3) a	7.6 (---) a	20.6 (7.1) a	30.0
49-56		--- (---)	23.7 (---)	---	--- (---)	--- (---)	--- (---)	23.7 (---)	---

[a]Comparisons are between tillage systems or between ecoregional field location clusters within weeks after seeding; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).

finished earlier with a much steeper emergence slope in cluster 2 versus 4. The emergence in cluster 4 versus 2 began earlier due to warmer initial conditions in cluster 4 in June (Table 3.10). June conditions were examined because the average crop planting date in 1999 was May 27th (Table 3.14). In 1999, 50 more air GDD accumulated in cluster 4 for the month of June, versus cluster 2 (base temperature 5°C, where base 5°C used in table 3.10 for comparison sake of temperatures calculated from the 30 year environmental normal by Environment Canada). Precipitation for 1999 was similar between the two clusters (Table 3.10).

Cooler air temperatures in cluster 4 probably contributed to delayed emergence (Figure 3.3c) versus cluster 2. As well, the average crop seeding date in cluster 4 was approximately 27 days later than in cluster 2 (Table 3.15). Therefore, it is possible that a greater proportion of wild oat seedlings emerged in cluster 4 versus 2 prior to seeding and that the emergence periodicity observed PS in cluster 4 represents a more advanced portion of the wild oats emergence periodicity curve in the season versus cluster 2.

Table 3.14. Average crop planting date (Julian day) for sampled fields containing wild oats in 1999 and 2000 for all sites. Standard deviations of mean planting dates in parentheses.

	1999	2000	LSD
	---------------Average Planting Date--------------		
All Sites	147.2 (16.2) a[a]	129.9 (6.6) b	9.1

[a]Comparisons are between years; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).

Table 3.15. Average crop planting date (Julian day) for sampled fields containing wild oats in 1999 and 2000 for between tillage systems (conventional-tillage (CT) and zero-tillage (ZT)) and among eco-regional field location clusters (cluster). Standard deviations of mean planting dates in parentheses.

	1999	LSD	2000	LSD
	Average Planting Date			
Tillage		25.9		7.7
CT	144.8 (20.2) a[b]		131.7 (8.3) a	
ZT	148.8 (14.8) a		128.6 (5.2) a	
Cluster		40.1		11.0
1	151.0 (--)[a] a[c]		127.8 (7.3) a	
2	132.7 (19.3) a		131.3 (8.7) a	
3	148.3 (12.7) a		129.8 (7.7) a	
4	159.3 (9.8) a		130.8 (5.5) a	

[a]Only one field in cluster 1 in 1999
[b]Comparisons are between tillage systems or are between eco-regional field location clusters within weeks after seeding; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).
[b]LSD for comparisons between tillage systems within sampling period and year.
[c]LSD for comparisons between cluster within sampling period and year.

No significant differences were found in wild oat emergence periodicity between clusters 2 and 4 in 2000. In 2000, the average planting was early May (Table 3.14), indicating weather in May and June were important for triggering emergence. The accumulated temperatures in 2000 for May and June were similar between clusters 2 and 4, and the average planting dates for these two clusters were only 0.5 days apart (Table 3.15). This helps to explain why there were no differences in emergence periodicity of wild oat between these two clusters PS in 2000 versus 1999. It also supports the idea that crop seeding date affects wild oat emergence periodicity (Egley and Williams 1991).

Emergence Pre- and Post-Seeding

Wild oat emergence periodicity post-seeding of the crop was significantly different between clusters 2 and 3, and 3 and 4 (Figure 3.5c). The wild oat emergence data points were scattered evenly around the fitted model of clusters 1, 2, 3 and 4, indicating that the models were a good representation of wild oat emergence in these clusters in 2000. For cluster 3, the b parameter had very high standard error, indicating it the parameter was not well estimated and that wild oat emergence periodicity in this cluster as related to soil temperature was variable among sites (Table 3.5).

In 2000, environmental conditions in both May and June in cluster 3 were very similar to those for clusters 2 and 4, and the average crop seeding date for cluster 3 was within 2 days of the average crop seeding date for both cluster 2 and cluster 4 (Table 3.14). Accumulated air GDD above 5°C, accumulated precipitation in May and the average crop seeding dates in cluster 3 were all between those of clusters 2 and 4. This indicates that something besides environmental conditions and planting date was affecting the wild oat emergence in the PPS period in cluster 3 causing the emergence periodicity of wild oat in this cluster to be significantly different from the wild oat emergence periodicity in clusters 2 and 4.

Differences in wild oat emergence periodicity between clusters 2 and 3, and 3 and 4, were probably due to differences in soil type between the clusters, and perhaps due to wild oat biotype differences between clusters. In cluster 3, the soil had a higher sand content (sandy loam) versus either cluster 2 and 4 (clay loam), and average soil moisture deficit was much higher in cluster 3 versus clusters 2 and 4 (Table 3.1). In the early part of 2000, conditions were dry in cluster 3 (Table 3.9), and remained dry until the second week of May (Environment Canada 2000). In cluster 3, where soil moisture deficit is high under normal conditions, the drier than normal conditions (Table 3.10) may have contributed to soil moisture limitations for germination of wild oat.

Typical warm and dry conditions (Table 3.10) experienced in cluster 3, may have caused selection in this cluster for wild oat biotypes that react differently to temperature and moisture, than biotypes found in the other clusters. The biotypes in cluster 3 may have heightened soil moisture sensitivity, causing emergence to occur only when soil moisture is high for long periods of time. When this does occur, seeds may germinate, emerge, and rapidly establish themselves to take advantage of the soil moisture before it disappears. Norris and Schoner (1980) observed a California biotype of yellow foxtail that had adapted to germinate and establish rapidly in response to ephemeral soil moisture conditions. This may be what is occurring at 450 soil GDD in the PPS emergence curve of cluster 3 (Figure 3.5c). In cluster 3, in 2000, 450 soil GDD (base temperature 0°C) corresponds to late May, a time in this cluster when frequent precipitation events began to occur (Environment Canada 2000).

Sampling Period Effect on Cluster Influences on Emergence Periodicity

In the PS period, significance in emergence periodicity between clusters appeared to occur due to large differences in environmental conditions between clusters (Table 3.3). High gravimetric soil moisture in cluster 1 PS, in both 1999 and 2000 (Tables 3.11, 3.12) are thought to have contributed to the lag in emergence periodicity versus the other three clusters, as well as the significant differences in wild oat emergence periodicity between cluster 1 and all the other clusters.

In the PPS period, significant differences in emergence periodicity were observed when wild oat emergence periodicity in cluster 3 was compared to clusters 2 and 4. Environmental conditions in cluster 2, 3 and 4 (Table 3.5) were very similar in the PPS, but when gravimetric soil moisture was examined, cluster 3, on average, had the lowest gravimetric soil moisture versus the other clusters in 8 of 11 weeks (Table 3.11). The Stockton/Shilo ecodistricts (cluster 3) tend to have had a higher soil moisture deficit than the other ecodistricts (Smith et al. 1998). It is thought that the significant differences in wild oat emergence periodicities between clusters in the PPS period were due to a combination of soil moisture deficit differences and differential selection for emergence periodicities characteristics for wild oat biotypes among clusters.

Summary

The PPS period showed the complete emergence periodicity of wild oats from the time when the soil temperature was adequate to stimulate emergence, to the time when the crop canopy closed in. Significant differences in wild oat emergence periodicity between tillage systems and clusters in the PPS period could be exploited for weed management measures. For example, weed management strategies such as delayed seeding could be made for specific tillage systems and used to control percentages of total wild oat populations. This would reduce in-crop wild oat pressures and could improve in crop herbicide efficacy, or could favor tame oat production (where no wild oat herbicides can be used) to help producers successfully use pesticide-free production or organic systems.

Little difference in wild oat emergence periodicity was observed in PS period in either year between tillage systems or clusters. Perhaps, a simple model would be good enough to estimate emergence periodicity PS, for predicting herbicide application timing.

Differences in emergence periodicity among clusters were apparent for both PPS and PS periods, indicating that cluster should be considered when determining wild oat emergence periodicity. In the PS period, soil type and environment had a greater influence on emergence periodicity than environment alone. In the PPS period environmental factors alone could not explain emergence periodicity significance between clusters, therefore it was assumed that differences were due to the presence of biotypes within the clusters, and they had different emergence requirements from each other.

GREEN FOXTAIL EMERGENCE PERIODICITY AS AFFECTED BY TILLAGE AND ECO-REGIONAL FIELD LOCATION CLUSTER

Introduction

Green foxtail has been observed to be the most abundant weed in cereal and oilseed fields in Manitoba for a number of years (Thomas et al. 1998; Thomas and Wise 1984; Thomas and Wise 1988; Van Acker at al. 2000).

Increased green foxtail prevalence in Manitoba may have initially occurred due to the increased control of wild oat and broadleaf weeds by herbicides, allowing green foxtail to occupy the niche previously held by other weed species (Blackshaw et al. 1981b). The prolific seed producing nature of green foxtail and it's ability to germinate over a broad range of conditions may have allowed it to increase it's distribution and density, making it so widely abundant in Manitoba (Douglas et al. 1985; Van Acker et al. 2000). Seeds of green foxtail were found to be the second most frequent weed seed in wheat, barley, flax and rapeseed crops, and they represent a major portion of dockage in these crops (Chow and Lapka 1975).

One of the most effective mechanical green foxtail control methods is tillage (Arshad 1992), but due to increasing concerns about soil conservation, moisture retention and reducing input costs, tillage is less frequently used as a method of weed control. Tillage reductions have been observed to shift weed communities over long periods of time. For example, Buhler (1992) observed green foxtail plant densities to be greater in no-till and chisel plow versus conventional or ridge-tillage systems. Buhler and Mester (1991) attributed increased green foxtail densities in reduced tillage systems to the favourable environments created by increased residues on the soil surface and the positions of the weed seeds in the soil.

In reduced-tillage systems, herbicides become a more important factor in controlling weed populations. In Manitoba, a number of reported cases of herbicide resistance in green foxtail have been confirmed (Andrews and Morrison 1989; Jansieniuk et al. 1994; Morrison et al. 1989)). With the reduced control options for green foxtail, alternative management tools are required. A better understanding of factors controlling wild oat emergence and the emergence periodicity will aid in the development of new management tools.

Characteristic seasonal emergence periodicities for individual weed species have been observed (Chepil 1946; Egley and Williams 1991; Mulugeta and Boerboom 1999; Ogg and Dawson 1984; Stoller and Wax 1973). Generally, these authors found emergence of an individual species begins and ends in a set pattern, dependent on temperature and soil moisture levels in the microsite.

The intent of many studies of species emergence periodicity is to build predictive emergence models (Alm et al. 1993; Forcella 1993). Datasets used to build these models, in general, have either come from controlled environmental experiments or limited field studies. The intention of this study was to examine the emergence periodicity of weed species under un-manipulated field conditions across a broad area in Manitoba. From the dataset we were interested in discovering if any statistical empirical difference in emergence periodicity existed between conventional and zero-tillage fields and between fields in different eco-regional field location clusters (cluster).

The uniqueness of this project is the fact that emergence data was collected from so many fields. The dataset therefore, not only represents differences in tillage and clusters, but differences in all agronomic practices. In this respect we were able to test whether tillage or clusters are robustly significant factors affecting wild oat emergence periodicity.

Differences in green foxtail emergence periodicity between tillage systems and clusters were examined both post-seeding and pre- and post-seeding. The two sampling periods were chosen because we wanted to determine if tillage and cluster affected green foxtail emergence periodicity differently when periodicity was tracked from the time of soil-thaw, or from the time directly after crop planting occurred. The emergence periodicity information for both sampling periods could aid in the refinement of weed management tools such as delayed seeding.

Materials and Methods

Field Selection

Fields were selected on the basis of tillage system, (zero- or conventional-tillage) and weed spectrum. Potential fields were chosen by contacting a zero-tillage farmer in pre-determined areas and requesting a referral to a nearby conventional-tillage farmer. Zero-tillage fields were subjected to one or less soil disturbance operation (including seeding) from harvest of the previous year to seeding in the year of observation. One pass with harrows was allowed in zero-tillage fields. Conventional-tillage fields were subjected to more than one soil disturbance operation, besides seeding, from harvest of the previous year to seeding in the year of observation. For fields to qualify, tillage systems must have been practiced in that field for at least three years prior to the year of study.

Medium infestations of green foxtail must have been previously observed within selected fields and no soil residual herbicides could have been used in selected fields within the past twelve months. All fields were seeded to canola, and had a spring cereal crop (excluding rye) as the previous crop.

Classification of Tillage System and Field Location Cluster

Weed emergence periodicity was tracked in fourteen and twenty fields in 1999 and 2000, respectively. Fields were located across a one million hectare area of southern Manitoba. Both zero- and conventional-tillage fields were examined (eighteen conventional-tillage and seventeen zero-tillage fields) and they were located in four distinct clusters. Each cluster contained a number of fields within close geographic proximity to one another. Clusters included either one ecodistrict or two ecodistricts (Table 4.1). The clusters were characterized according to average precipitation and air growing degree days (base temperature 5°C) from April to June, average soil moisture deficits, and soil type (Table 4.1).

Table 4.1. Characteristics of eco-regional field location clusters (cluster).

Cluster	Ecodistrict	Soil Type[a]	Soil Moisture Deficit (mm)[b]	30 year average April to June[c] GDD>5[d]	30 year average April to June[c] Rainfall (mm)
1	Gladstone/Winnipeg	Clay	190	625	170
2	Pembina Hills	Clay Loam	150	610	185
3	Stockton/Shilo	Sandy Loam	230	615	165
4	St.Lazare/Hamiota	Clay Loam	200	570	155

[a]Agriculture Canada 1989
[b]Smith et al. 1998
[c]Environment Canada 1998
[d]GDD>5, growing degree days calculated using a 5°C base

In-Field Sampling

Observation of weed emergence in fields occurred ever two to four days. Four permanent ¼ m^2 quadrats were placed in each field in areas generally representative of the field. At each visit, all newly emerged seedlings in the quadrats were tagged with coloured rings, and seedling populations and identities were recorded. No seedlings were removed from the quadrats until the end of the sampling period. In 1999, sampling occurred from time of crop seeding to canola bolting, and in 2000, sampling occurred from the first week of April to canola bolting. The time of sampling was divided into two sampling periods. All sampling occurring after crop seeding was labeled as the post-seeding sampling period (PS). Emergence was tracked during this period in both 1999 and 2000. Sampling from soil thaw to crop bolting was labeled as the pre- and post-seeding sampling period (PPS). Emergence was tracked during this period in 2000 only.

At the time of each field visit, gravimetric soil moisture samples were taken to a 2.5 cm depth and accumulated precipitation in the field was recorded from rain-gauges placed in each field. Soil temperatures were recorded continuously throughout the sampling period using Stow Away® TidbiT™ temperature recorders (Onset Computer Corporation, Box 3450, 536 MacArthur Blvd., Pocasset, MA 02559-3450). TidbiTs™ were removed during seeding and tillage events, and soil temperatures for these times were interpolated from air temperature. Air temperature and precipitation data was obtained from Environmental Canada weather stations located closest to the fields where sampling occurred.

To protect seedlings from herbicide damage within the sampling period, all quadrats were covered with a white, non-permeable plastic barrier sheet during pre-seed and in-crop herbicide applications. At weed harvest, all plants were removed from the quadrats by cutting plants off at the soil surface, and individual plants were sorted by date of emergence (ring colour), species and phenological stage.

Thermal Time Measurements

Daily air temperatures, from the nearest Environment Canada weather station, and soil temperatures, from field TidbiTs placed at 2.5cm depth, were collected for each site and the accumulated growing degree days (GDDs) calculated. The equation used to calculate accumulated GDDs was,

$$GDD = \frac{\text{Maximum + Minimum Daily Temperature}}{2} - \text{Base temperature.} \qquad [1]$$

The PROC CORR function of the SAS (version 8.0) statistical package (SAS Institute, Raleigh, N.C.) was used to find the correlation coefficient between accumulated soil and air GDD for the pre- and post-seeding periods (base temperature of 0°C). 0°C was used as the base temperature when calculating thermal time for green foxtail because it makes for a simpler calculation (which would be useful if producers are calculating their own GDD). Soil and air GDD had a correlation coefficient of 0.98 (Figure 4.1). The close relationship of air to soil GDD concurred with the findings of Alessi and Power (1971).

Data analysis proceeded therefore, using only a single measurement of thermal time, soil GDD. Soil GDD, represents the temperature where emergence is occurring, and the measurements were unique for each field. Soil temperature also reflects to a greater extent, moisture by temperature interactions, as well as the influences of tillage and soil type on individual field soil temperatures.

Statistical Analysis

Estimating Green Foxtail Emergence Periodicity

Statistical analysis closely followed the procedures outlined by Friesen et al. (1992). A logistic model was fitted to the emergence periodicity data. The model chosen was used because of its accuracy and simplicity and because the parameters have biological meaning (Friesen et al. 1992). The model fitted was,

$$y \quad = \quad a/(1 + be^{-cx}) \qquad [2]$$

where y is the dependent variable (species emergence), x is the emergence percentage expressed in soil growing degree days (base 0°C, measured 2.5 cm below soil surface) e is the base of the natural logarithm, and a, b, and c are the nonlinear parameter estimates. Specifically, a, is the estimated value of the upper asymptote, and $a/(1+b)$ 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 inflection point. After the a, b, and c parameters were obtained, lack-of-fit F tests, as outlined by Seefeldt et al. (1995), were used to test significance between models fitted to apriori groups of data (i.e. tillage systems, clusters) (Tables A.4.2, A.4.3 and A.4.4 for 1999, 2000 PS and 2000 PPS respectively). Coefficients of determination (R^2) were calculated as described by Kvalseth (1985) using the residual sum of squares value from the SAS output. As outlined by Seefeldt et al. (1995), SAS provides only one residual sum of squares value for the model as a whole, even though parameters for several functions are estimated simultaneously.

Data sets only included sites where observed wild oat emergence was greater than 5 plants/m^{-2} in the sampling period, and emergence was expressed as a cumulative percentage of total. The estimated parameters for the logistic model for different tillage systems and for different clusters were compared and considered to be significantly different statistically at the 5% level (Steel et al. 1997).

Green foxtail emergence periodicity models fitted to data for 1999 and 2000 post-seeding were compared to determine if datasets could be combined over years (Figure 4.2). The results from PROC NLIN and the lack-of-fit *F* test showed cumulative green foxtail emergence periodicity to be significantly different between years (Table 4.2). Years were analyzed separately for the effects of tillage system and clusters on wild oat emergence periodicity post-seeding.

Table 4.2. *F* test[a] results for comparing significance of parameter estimates of post-seeding (PS) cumulative percent of green foxtail emergence models. Comparisons made between year models for 1999 and 2000.

	a	*b*	*c*	R^2
Years	NS[b]	*[c]	NS	0.83

[a]Statistical differences between parameter estimates were determined using the lack-of-fit *F* test at the 5% level of significance
[b]NS means not significant at 5% level
[c]* means significant at 5% level

Soil Temperature Analysis

Temperature is a major factor driving the periodicity of wild oat emergence. Therefore differences in soil temperature between tillage systems and clusters within sampling periods and years by Julian date were required. The same sites used in estimating the wild oat emergence periodicity were used in the soil temperature analysis to avoid confounding data.

The PROC LNIN function of SAS was used to run a linear regression on the accumulated soil GDD versus Julian days under different tillage systems and clusters. The regression equation used was,

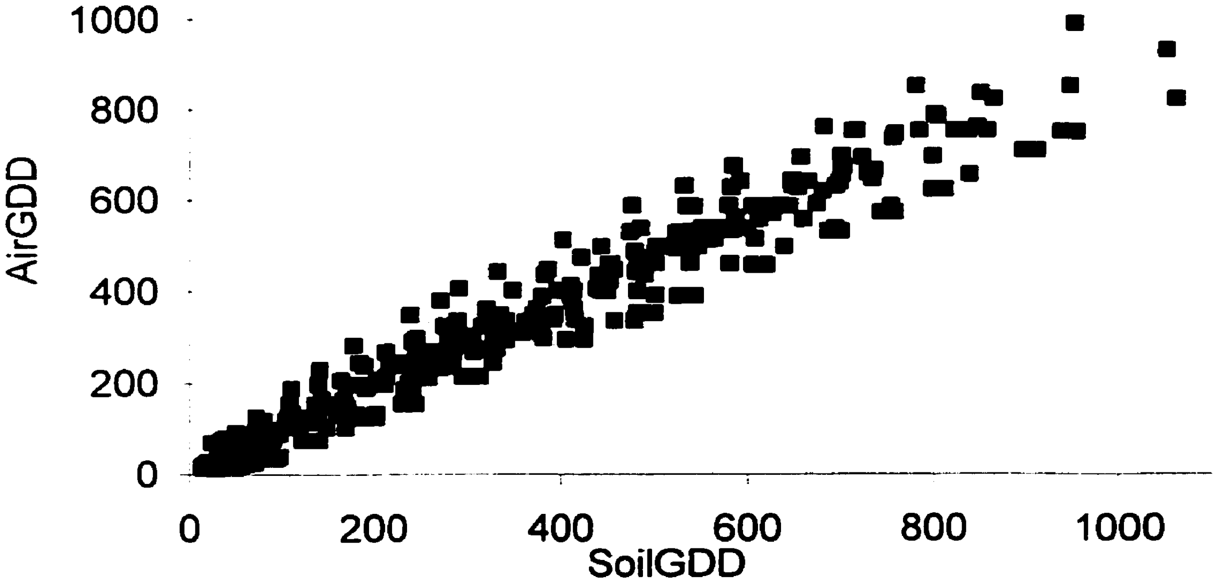

Figure 4.1. Relation of soil growing degree days (GDD, base 0 C, 2.5 cm from the soil surface) and air growing degree days (GDD, base 0°C) in the pre- and post-seeding period of 2000 (—■).

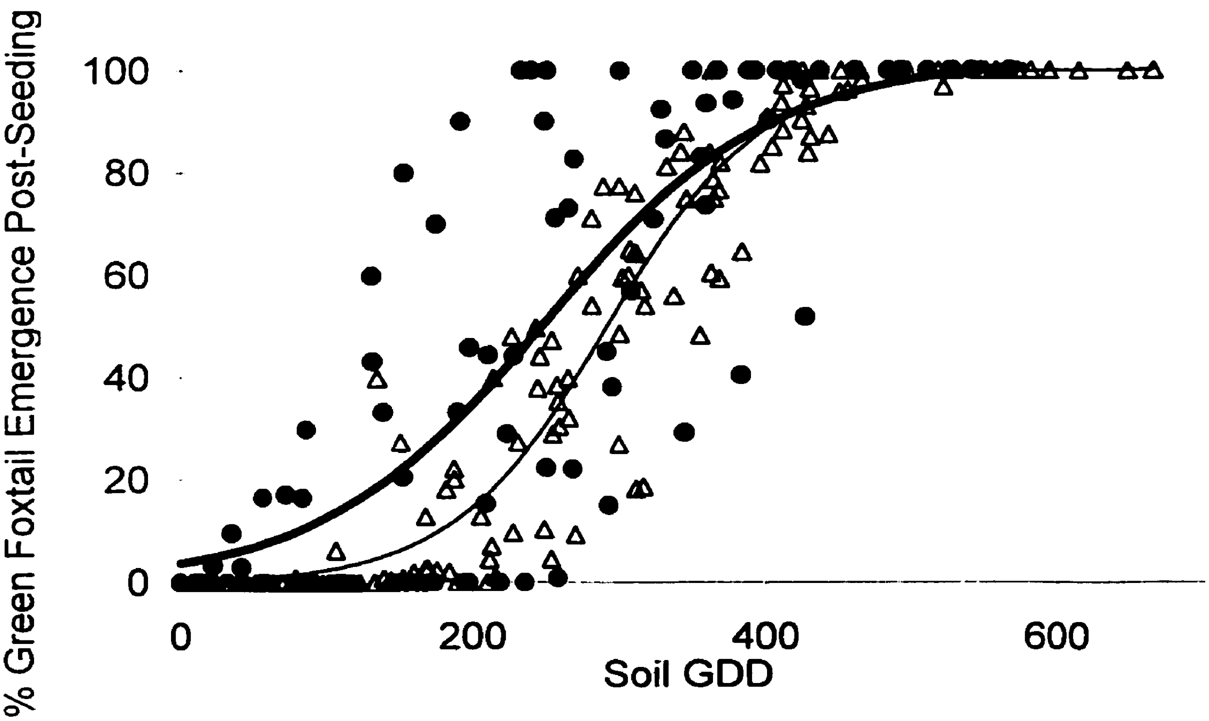

Figure 4.2. Green foxtail emergence periodicity as related to soil growing degree days (GDD, base 0°C, 2.5 cm from the soil surface), measured post-seeding (PS) in 1999(—●), and 2000 (—△). Markers represent field data and lines represent models. Refer to table A.4.1. for parameter estimates of models.

$$y = a + bx \qquad [3]$$

where y was the accumulated soil GDD (base 0°C) for the sampling period, a was the y-axis intercept, b was the linear regression coefficient, and x was the julian day on which the accumulated soil GDD occurred (Steel et al. 1997). After the a, and b parameters were obtained, lack-of-fit F tests, as outlined by Seefeldt et al. (1995), were used to test for significance between apriori data groupings (i.e. tillage systems, clusters) (Tables A.4.5, A.4.6 and A.4.7 for parameters; significance testing in PS 1999 and 2000, and PPS periods respectively). PROC NLIN function of SAS was run on soil temperatures sorted by weeks after April 1, 2000 in the PPS period, or weeks after seeding in the PS periods of 1999 and 2000 (Table 4.7).

Gravimetric Soil Moisture Analysis

To avoid confounding data the same sites in which green foxtail emergence periodicity was tracked were used for examining gravimetric soil moisture. Gravimetric soil moisture was determined from soil samples collected at each site at each sampling date. The equation used to determine gravimetric soil moisture was,

$$\mathrm{Y} = \frac{\mathrm{Sw} - \mathrm{Sd}}{\mathrm{Sd}} \qquad [4]$$

where y is the percent of gravimetric soil moisture (w/w) in the soil sample, Sw is the wet weight of the soil in grams collected from the field, and Sd is the dry weight of the soil after being dried for 48 hours at 80°C.

Comparisons of mean gravimetric soil moisture between tillage systems or clusters were made using the PROC GLM function of SAS, where gravimetric soil moisture for the PPS period, was sorted by weeks after April 1 (Table 4.10), and by weeks after seeding in the PS period (Table 4.4 and 4.12) or averaged over the entire sampling period (Table 4.14).

Results and Discussion

The cumulative green foxtail emergence model for all sites was a good fit to the data. Data points were evenly scattered around the models for all sites and sampling periods (Figures 4.3a, 4.4a and 4.5a), and standard errors for estimated parameters were relatively small.

A single model from field observations may not accurately represent green foxtail emergence over large geographic areas or under different tillage systems, therefore, models were tested to see if they were statistically different when datasets were separated on the basis of these factors.

Effect of Tillage System on Emergence Periodicity

Emergence Post-Seeding

Green foxtail emergence periodicity post-seeding (PS) of the crop was not significantly different between zero-tillage (ZT) and conventional-tillage (CT) fields in either 1999 and 2000 (Table 4.3, Figures 4.3b, 4.4b).

Even though emergence periodicity of green foxtail was not significantly different between tillage systems, density of green foxtail plants was observed to be higher in ZT versus CT fields PS in both 1999 and 2000 (Table 4.4). This concurs with Anderson and Nielsen (1996) who found tillage to not affect green foxtail emergence periodicity, but they did find that green foxtail density increased under zero-till.

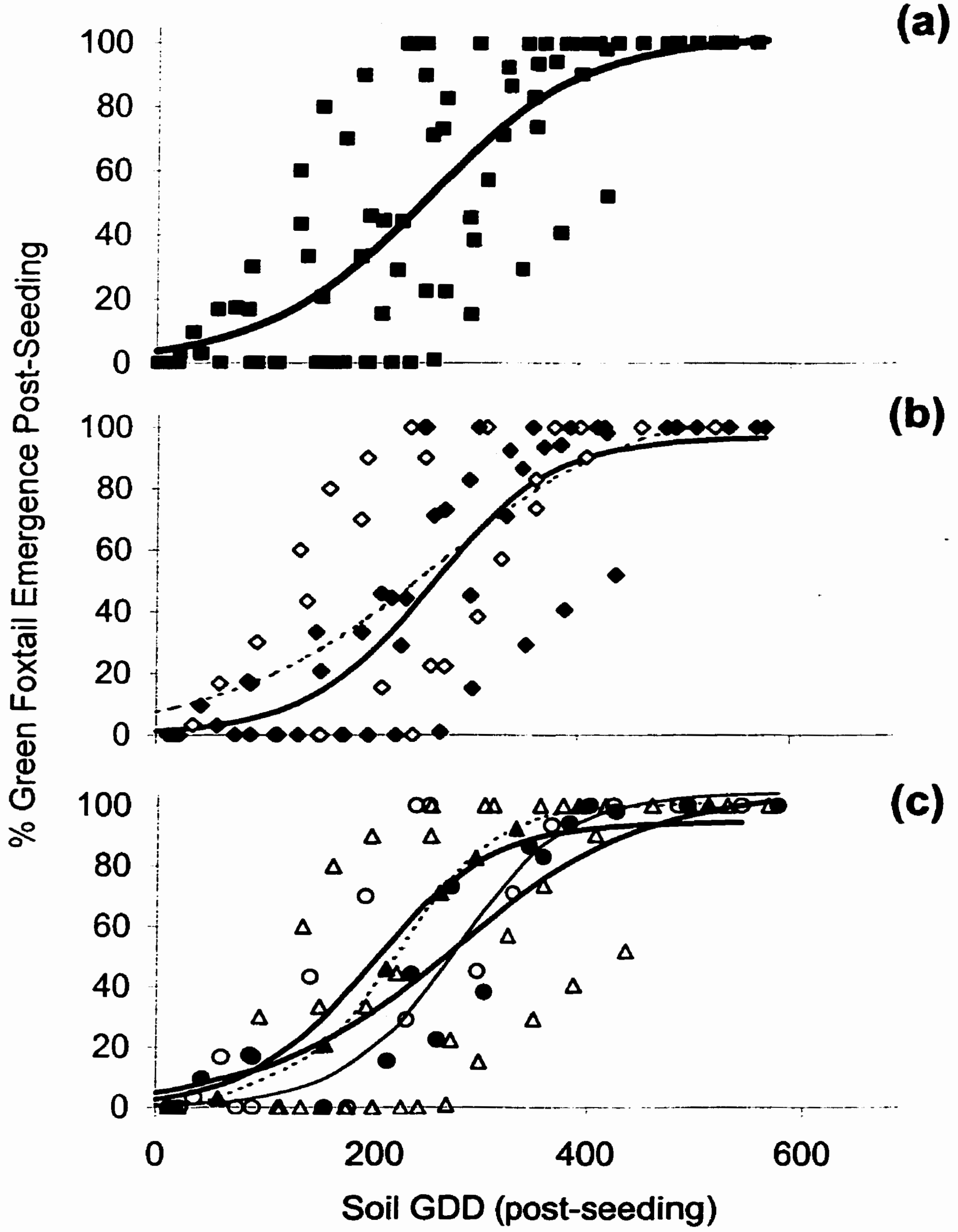

Figure 4.4. Green foxtail emergence periodicity as related to soil growing degree days (GDD, base 0°C, 2.5 cm from the soil surface), in post-seeding (PS) period of 2000, for (a) all sites (— ■), (b) conventional-tillage (---◇), and zero-tillage (— ◆) fields, and (c) cluster 1(--▲), cluster 2 (—△), cluster 3 (—●), and cluster 4 (—○). Markers represent field data and lines represent models. Refer to table 4.3 for parameter estimates of models.

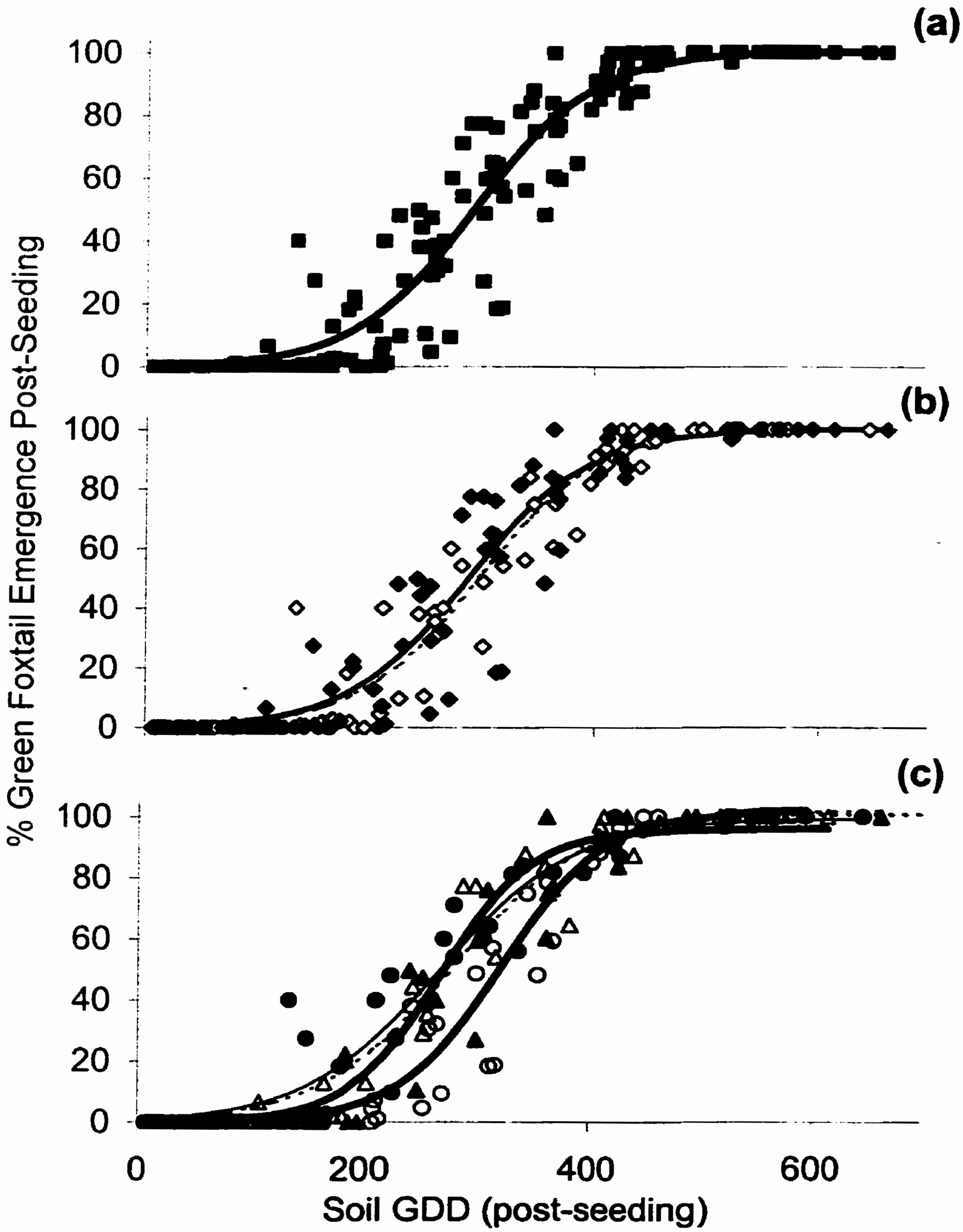

Figure 4.3. Green foxtail emergence periodicity as related to soil growing degree days (GDD, base 0°C, 2.5 cm from the soil surface), in post-seeding (PS) period of 1999, for (a) all sites (— ■), (b) conventional-tillage (---◇), and zero-tillage (— ◆) fields, and (c) cluster 1(--▲), cluster 2 (—△), cluster 3 (—●), and cluster 4 (—○). Markers represent field data and lines represent models. Refer to table 4.3 for parameter estimates of models.

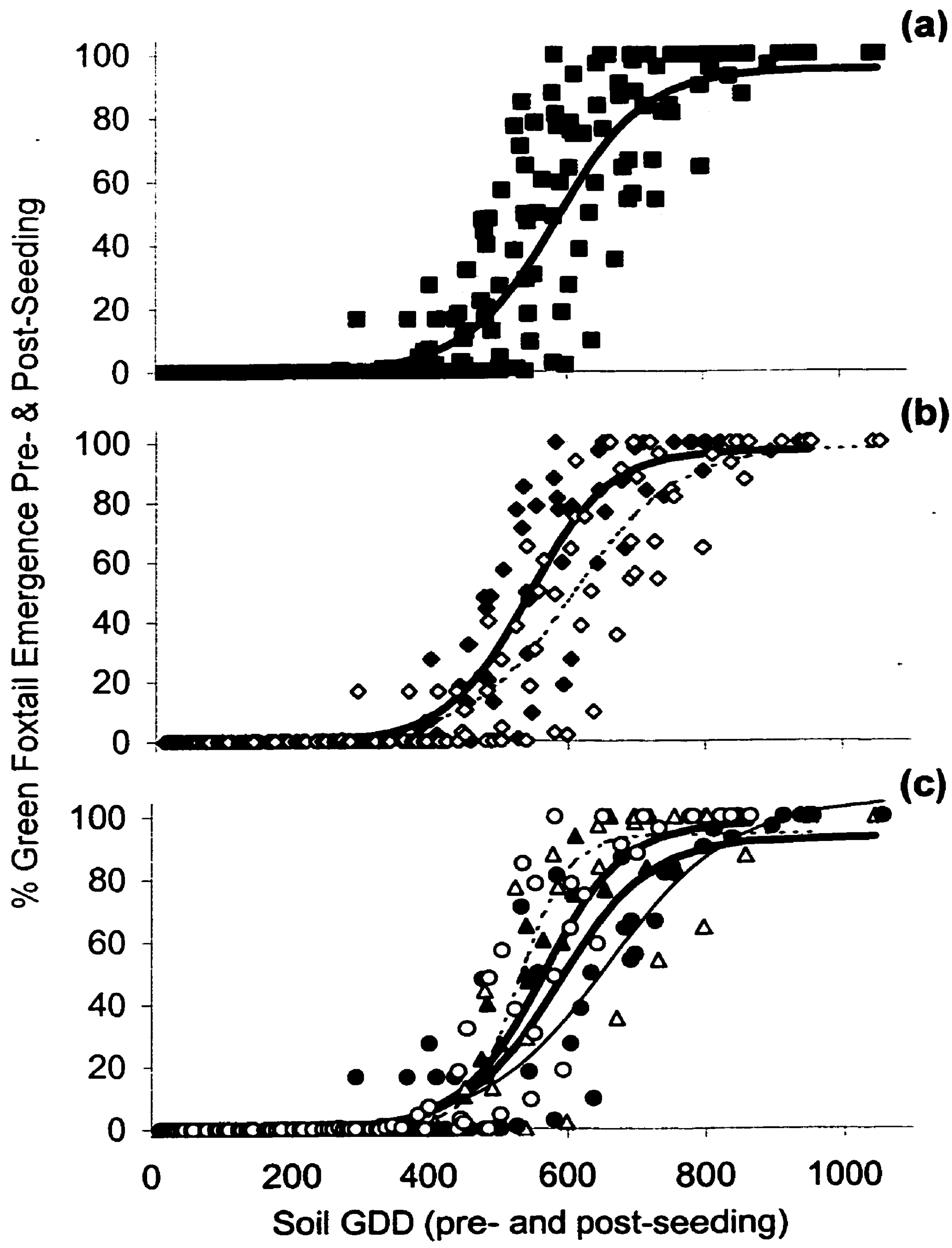

Figure 4.5. Green foxtail emergence periodicity as related to soil growing degree days (GDD,base 0°C, 2.5 cm form the soil surface), in the pre- and post-seeding (PPS) period of 2000, for (a) all sites (— ■), (b) conventional-tillage (---◇), and zero-tillage (— ◆) fields, and (c) cluster 1(--▲), cluster 2 (—△), cluster 3 (—●), and cluster 4 (—○). Markers represent field data and lines represent models. Refer to table 4.5 for parameter estimates of models.

Table 4.3. F test[a] results for comparing significance of parameter estimates of post-seeding (PS) cumulative percent of green foxtail emergence models. Comparisons made between tillage system models and eco-regional field location clusters (cluster) models in 1999 and 2000.

	1999				2000			
	a	*b*	*c*	R^2	*a*	*b*	*c*	R^2
Tillage	NS	NS[a]	NS	0.64	NS	NS	NS	0.93
Cluster 1,2,3,4	NS	NS	NS	0.60	NS	*	NS	0.95
Cluster 1,2	NS	NS	NS	0.55	NS	NS	NS	0.95
Cluster 1,3	NS	NS	*[b]	0.90	NS	NS	NS	0.95
Cluster 1,4	NS	NS	NS	0.83	NS	*	NS	0.94
Cluster 2,3	NS	NS	NS	0.60	NS	NS	NS	0.95
Cluster 2,4	NS	NS	NS	0.55	NS	NS	*	0.93
Cluster 3,4	NS	NS	*	0.79	NS	*	*	0.95

[a]Statistical differences between parameter estimates were determined using the lack-of-fit F test at the 5% level of significance
[b]NS means not significant at 5% level
[c]* means significant at 5% level

Table 4.4. Comparison of numbers of emerged green foxtail plants (plants m^{-2}) between tillage systems (conventional-tillage (CT) and zero-tillage (ZT)) and eco-regional field location clusters (cluster) in the post-seeding period of 1999 and 2000, and the pre- and post-seeding period (PPS) of 2000.

	Post-seeding				Pre- and Post-Seeding	
	1999	LSD	2000	LSD	2000	LSD
	---------no. m^{-2}---------					
Tillage		21.8[b]		52.2		41.0
CT	76.8 b[a]		107.9 b		107.2 b	
ZT	94.0 a		224.5 a		227.3 a	
Cluster		68.4[c]		74.8		58.7
1	291.0 a		251.0 a		263.5 a	
2	54.3 c		185.0 ab		161.9 b	
3	124.4 b		173.8 b		178.2 b	
4	25.1 c		98.2 c		99.1 c	

[a]Comparisons are between tillage systems or between eco-regional field location clusters, within years; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).
[b]LSD for comparisons between tillage systems within sampling period and year.
[c]LSD for comparisons between cluster within sampling period and year.

Emergence Pre- and Post-Seeding

Green foxtail emergence periodicity in the pre- and post-seeding (PPS) period was significantly different between zero-tillage (ZT) and conventional-tillage (CT) fields (Table 4.5, Figures 4.5c).

An even scatter of data points was observed around the models representing green foxtail emergence periodicities for tillage systems in the PPS period (Figure 4.5b). High b parameters were observed for both ZT and CT systems (Table 4.6). A high b value indicates a long initial lag in the emergence model, which was expected in PPS versus PS, but the b parameter for the ZT model was much greater than for the CT model. Relative standard errors of the b parameter were similar between tillage systems, indicating a similar level of variability in green foxtail emergence periodicity among both CT and ZT fields (Table 4.6).

Table 4.5. *F* test[a] results for comparing significance of parameter estimates of pre- and post-seeding (PPS) cumulative percent of green foxtail emergence models. Comparisons made between tillage system models and eco-regional field location clusters (cluster) models in 2000.

	a	*b*	*c*	R^2
Tillage	NS	NS	*	0.83
Cluster 1,2,3,4	NS	NS	*	0.87
Cluster 1,2	NS	NS[b]	*	0.89
Cluster 1,3	NS	*[c]	*	0.91
Cluster 1,4	NS	NS	NS	0.92
Cluster 2,3	NS	NS	NS	0.87
Cluster 2,4	NS	NS	NS	0.87
Cluster 3,4	NS	NS	*	0.86

[a]Statistical differences between parameter estimates were determined using the lack-of-fit *F* test at the 5% level of significance
[b]NS means not significant at 5% level
[c]* means significant at 5% level

Table 4.6. Parameters estimates for cumulative percent green foxtail emergence models pre- and post-seeding (PPS) as affected by tillage system (conventional-tillage (CT) and zero-tillage (ZT)) and eco-regional field location clusters (cluster) in 2000. Values in parentheses are standard errors.

	a	*b*	*c*
All Sites	95.4 (2.8)	6401.8 (4626.6)	.017 (.002)
Tillage			
CT	98.4 (5.7)	2667.8 (3138.0)	.013 (.002)
ZT	97.3 (4.4)	10011.4 (12671.6)	.017 (.003)
Cluster			
1	94.4 (7.8)	2.7E6 (1.2E7)	.028 (.009)
2	93.5 (6.6)	6619.0 (13722)	.015 (.004)
3	105.7 (9.4)	1425.2 (1749.8)	.011 (.002)
4	98.3 (7.8)	14526.0 (27828.6)	.017 (.004)

Significant differences in green foxtail emergence periodicity PPS between ZT and CT in 2000 (Table 4.5, Figures 4.5b) were likely due to significant differences in soil GDD accumulations (Table 4.7, Figure 4.6), soil moisture levels (Table 4.8), and seedling recruitment depths between tillage systems.

Delayed emergence of green foxtail in CT versus ZT fields in the PPS period may be explained by significantly higher measured gravimetric soil moisture levels in ZT versus CT fields for 7 of 13 weeks PPS (Table 4.8). Significant differences occurred mostly in the early part of the season when rainfall events were less frequent in 2000 (Environment Canada 2000), and the chances of soils drying out were good. Soil moisture, therefore, may have been limiting for seed germination and was probably more adequate for green foxtail emergence in ZT, therefore delaying the emergence onset in CT fields. Blackshaw et al. (1981a) observed that when soil moisture was limiting, green foxtail took longer to emerge. Additionally, earlier onset of green foxtail emergence and the resulting periodicity is thought to be affected more by soil moisture, because soil temperatures were found to be significantly cooler in ZT versus CT fields (Table 4.7, Figure 4.6). We would have expected a warm season grass such as green foxtail (Douglas et al. 1985) to emerge sooner under the warmer soil conditions in CT fields. Earlier emergence in ZT versus CT was probably also due to shallower recruitment depths in ZT versus CT (du Croix Sissons et al. 2000).

Table 4.7. *F* test results[a] for comparing significance of parameter estimates of post-seeding (PS) and pre- and post-seeding (PPS) accumulated soil growing degree days (GDD, base 0C, 2.5 cm from soil surface) models. Comparisons made between tillage system models and eco-regional field location clusters (cluster) models in 1999 and 2000.

	Post-Seeding 1999			Post-Seeding 2000			Pre and Post-Seeding 2000		
	a	*b*	R^2	*a*	*b*	R^2	*a*	*b*	R^2
Tillage	NS[b]	*[c]	0.88	NS	*	0.95	*	*	0.93
Cluster 1,2,3,4	NS	*	0.88	NS	*	0.95	*	*	0.93
Cluster 1,2	NS	*	0.88	NS	NS	0.96	*	*	0.96
Cluster 1,3	NS	NS	0.96	NS	*	0.95	*	*	0.93
Cluster 1,4	NS	*	0.99	NS	NS	0.97	NS	*	0.95
Cluster 2,3	NS	*	0.86	NS	*	0.96	NS	*	0.95
Cluster 2,4	*	*	1.00	*	*	1.00	*	*	1.00
Cluster 3,4	NS	NS	0.97	NS	*	0.96	*	*	0.91

[a]Statistical differences between parameter estimates were determined using the lack-of-fit *F* test at the 5% level of significance
[b]NS means not significant at 5% level
[c]*means significant at 5% level

Emergence lag period is dependent on seedling recruitment depth, where the greater the recruitment depth, the longer the lag period in emergence periodicity curves. The emergence lag represents the time from seed germination to emergence, where duration is controlled by soil moisture (Roberts 1984). The lag was present in both the ZT and CT curves, but was longer for CT fields, reflecting perhaps that green foxtail seeds are being

Table 4.8. Average percentage gravimetric soil moisture (w/w) sorted by weeks after the week of April 1st, 2000 for green foxtail emergence between tillage system (conventional-tillage (CT) and zero-tillage (ZT)) and among eco-regional field location clusters (cluster) pre- and post-seeding (PPS) in 2000. Values in parentheses are standard errors.

Julian Days	Week	Tillage System CT	Tillage System ZT	Tillage System LSD	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster LSD
		% gravimetric soil moisture (w/w)							
92-100	1	17.7 (5.5) a[a]	27.0 (7.1) a	16.5	26.0 (5.2) a	23.2 (15.1) a	20.2 (4.2) a	22.7 (5.1) a	23.7
100-107	2	17.8 (4.0) b	24.5 (4.8) a	2.3	24.1 (5.0) a	17.9 (9.7) a	20.8 (4.9) a	20.6 (5.5) a	7.2
107-114	3	13.0 (3.9) b	20.9 (6.7) a	3.6	9.4 (6.6) c	17.9 (10.4) ab	13.4 (5.7) b	18.7 (3.9) a	5.3
114-121	4	11.4 (4.4) b	18.3 (6.0) a	3.8	7.5 (6.3) a	13.8 (7.5) a	12.7 (6.7) a	15.5 (5.0) a	5.5
121-129	5	11.9 (8.0) b	17.0 (6.7) a	4.9	25.9 (8.3) a	16.4 (9.4) a	10.6 (6.1) a	16.1 (6.7) a	7.1
129-136	6	12.4 (7.1) b	20.6 (9.6) a	7.6	23.0 (11.6) a	21.3 (16.0) a	11.6 (5.7) a	18.0 (7.1) a	11.7
136-143	7	14.3 (5.8) b	19.9 (5.4) a	2.9	22.9 (3.4) a	19.5 (6.3) ab	11.8 (3.3) c	18.6 (5.9) b	4.3
143-150	8	10.5 (6.9) b	19.0 (6.0) a	5.2	17.0 (5.1) a	14.1 (7.2) ab	8.6 (5.7) b	19.0 (8.6) a	7.4
150-157	9	12.4 (6.6) a	15.6 (6.9) a	4.8	15.6 (6.9) ab	11.8 (4.8) b	11.0 (5.1) b	19.1 (8.2) a	6.9
157-164	10	9.6 (5.0) a	14.3 (6.5) a	4.7	14.2 (8.4) a	13.8 (6.5) a	8.5 (4.0) a	12.3 (5.6) a	6.7
164-171	11	17.5 (4.3) a	19.2 (6.0) a	2.3	17.0 (11.3) a	16.6 (5.9) a	18.2 (2.7) a	20.8 (6.2) a	6.4
171-178	12	8.0 (11.2) a	23.5 (5.0) a	19.1	--- (---)	23.5 (---)	28.1 (1.6) a	19.0 (6.9) a	24.7
178-185	13	12.3 (3.4)	20.9 (---)	---	20.9 (---)	14.7 (---)	9.9 (---)	--- (---)	---

[a]Comparisons are between tillage systems within weeks, or between eco-regional field location clusters within weeks; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).

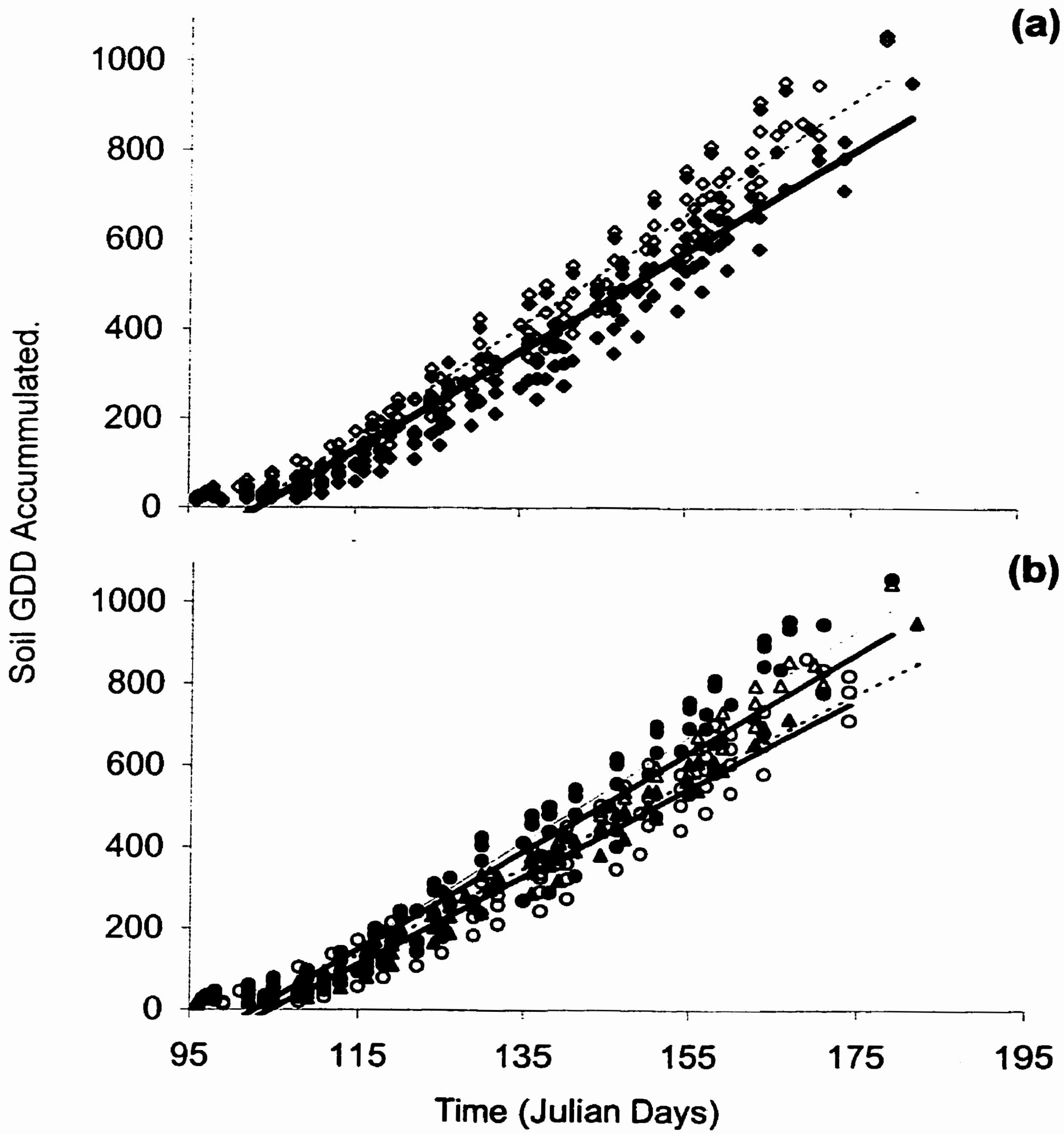

Figure 4.6. Measured accumulated soil growing degree days (GDD, base 0°C, at 2.5 cm below the soil surface) as related to Julian day in the pre- and post-seeding (PPS) period of 2000 in (a) conventional-tillage (---◇) and zero-tillage (—◆) fields, and (b) cluster 1 (--▲), cluster 2 (—△), cluster 3 (—●), and cluster 4 (—○). Markers represent field data and lines represent models. Refer to table A.4.5 for parameter estimates.

recruited from greater and more variable depths in CT fields (du Croix Sissons et al. 2000), and that seeds may be experiencing limited soil moisture conditions compared to ZT fields. In 2000, all sites experienced very dry conditions prior to the second week of May (Environment Canada 2000) and soil moisture may have been limiting for green foxtail seed germination. Buhler and Mester (1991) observed reduced soil disturbances to slow soil drying in reduced tillage systems, therefore, any disturbance could have reduced soil moisture, potentially causing green foxtail emergence delays in 2000.

In the PPS period of 2000, the time taken for green foxtail emergence to progress from E_{25} to E_{80} was greater for CT versus ZT fields (Table 4.9). The slower rate of green foxtail emergence under CT versus ZT may once again being attributed to deeper green foxtail recruitment depths in CT versus ZT systems. We would then expect a greater density of green foxtail plants to emerge in ZT versus CT fields, because green foxtail recruits more successfully from shallow depths (Buhler and Mester 1991; Boyd and Van Acker 2001 (unpublished data)). Density of emerged green foxtail plants was significantly greater in ZT versus CT fields (Table 4.4). Anderson and Nielsen (1996) and Spandl et al. (1998) observed increased proportional green foxtail emergence occurring under reduced tillage, because seeds remained at or near the soil surface where conditions are more conducive for germination.

Sampling Period Effects on Influence of Tillage on Emergence Periodicity

Tillage system significantly affected emergence periodicity in the PPS sampling period but not in the PS period. This may be due to the fact that in the PS period, only a portion of the entire emergence curve was considered, and the portion considered begins after crop seeding when the soil microsite is becoming suitable for green foxtail emergence in either ZT or CT fields. Seeding date is chosen by producers to coincide with optimal soil temperature and moisture conditions for germination and emergence of crops, and these conditions are likely also to be optimal for weed emergence. Therefore, soon after crop planting, soil moisture and temperatures will probably be adequate for green foxtail emergence in both tillage systems.

Table 4.9. Soil growing degree days (GDD, base 0°C) required to reach 25% (E_{25}) and 80% (E_{80}) cumulative emergence in green foxtail in the post-seeding (PS) and pre- plus post-seeding (PPS) sampling periods of 1999 and 2000.

	Post-seeding						Pre- and Post-Seeding		
	1999			2000			2000		
	E_{25}	E_{80}	E_{80}-E_{25}	E_{25}	E_{80}	E_{80}-E_{25}	E_{25}	E_{80}	E_{80}-E_{25}
All Sites	165	350	185	235	365	130	516	695	179
Conventional-tillage	139	360	221	239	369	130	525	721	196
Zero-tillage	195	348	153	230	361	131	480	632	152
Cluster 1	165	282	117	215	358	143	493	590	97
Cluster 2	168	378	210	228	334	119	520	706	186
Cluster 3	214	337	123	205	353	148	554	764	210
Cluster 4	138	290	152	273	382	109	500	651	151

Observation of the emergence curve over a longer time period (PPS versus PS) amplifies the soil temperature and soil moisture differences between the tillage systems. Over the entire PPS period, soil temperatures were cooler in ZT versus CT (Figure 4.7), and soil moisture was greater in ZT versus CT (Table 4.8). With the relatively dry early season in 2000 (table 4.10), conditions for green foxtail emergence in ZT may have been more favorable than CT from earlier on in the season (i.e. prior to planting), due to greater soil moisture levels.

Table 4.10. Environmental characteristics of eco-regional field location clusters (cluster) 1 (Gladstone and Winnipeg ecodistricts), 2 (Pembina Hills ecodistrict), 3 (Stockton and Shilo ecodistricts), and 4 (St. Lazare and Hamiota ecodistricts) in 1999, 2000 and over 30 year average.

		April			May			June		
Cluster	Measurement	1999	2000	30yr	1999	2000	30yr	1999	2000	30yr
1	GDD>5[a]	82.2	68.5	50.9	212.6	202.5	217.9	413.6	287.8	354.9
	Precip (mm)[b]	15.0	12.5	40.5	142.0	53.9	54.4	74.0	129.6	76.0
2	GDD>5	95.3	74.6	53.3	222.7	219.1	210.6	437.3	288.9	348.5
	Precip (mm)	35.7	8.0	42.5	170.9	60.2	60.0	67.0	114.8	83.6
3	GDD>5	85.7	69.2	56.5	201.2	208.1	211.9	409.8	276.5	349.1
	Precip (mm)	17.8	9.3	38.0	180.9	66.9	54.4	54.9	90.9	74.1
4	GDD>5	81.1	60.1	46.2	187.9	198.7	192.6	383.9	252.8	333.8
	Precip (mm)	20.0	9.6	33.9	201.4	65.1	48.4	46.2	58.0	72.1

[a]GDD>5, growing degree days calculated using a base of 5°C, from air temperature measurements collected by Environment Canada weather stations.
[b]Precip (mm), measurement of accumulated precipitation, in millimeters, collected from Environment Canada weather stations.

We also suggested that significant differences in green foxtail emergence periodicity PPS between tillage systems was due to differences in seedling recruitment depths. We believe this occurred in our study, based on differences in the shape of the emergence periodicity models between tillage systems PPS. For example, green foxtail reached E_{80} from E_{25} in 152 and 196 soil GDD in ZT and CT fields, respectively (Table 4.9). This suggests that green foxtail seedlings in ZT were emerging more uniformly, most likely from a similar, shallow depth versus CT.

Effect of Eco-Regional Field Location Cluster on Emergence Periodicity

Emergence Post-Seeding

Green foxtail emergence periodicity PS was significantly different (Table 4.3) between eco-regional field location clusters (clusters) 1 (Gladstone/Winnipeg ecodistrict) and 3 (Stockton/Shilo ecodistrict), and 3 and 4 (St. Lazare/Hamiota ecodistrict), in 1999

(Figure 4.3c), and between clusters 1 and 4, 2 (Pembina Hills ecodistrict) and 4, and 3 and 4, in 2000 (Figure 4.4c).

In 1999, green foxtail emergence data points were scattered evenly around the models for clusters 2, 3 and 4, and clusters 1, 2, 3 and 4 in 2000, indicating that the models were a good representation of the emergence periodicity data in these clusters in each of these years. For cluster 1 in 1999, there was no scatter of data points around the model, all data points were contained in the model. The lack of scatter of the data points around the model for cluster 1 in 1999, was the result of only one site fitting the criteria for the cluster. The standard error for the *b* parameter was very high (table 4.11), indicating that the *b* parameter for green foxtail emergence in cluster 1 in 1999, was not well estimated.

In 1999, significant differences in green foxtail emergence periodicity were observed between clusters 1 and 3 and, 3 and 4, where emergence periodicity in cluster 3 was delayed in comparison to clusters 1 and 4 (Figure 4.3c). Delayed emergence onset and the unique emergence periodicity for cluster 3 may be the result of lower soil moisture in cluster 3 versus clusters 1 and 4 (Table 4.12).

No significant differences in soil temperature accumulation (Table 4.7) were observed between clusters 1 and 3 or 3 and 4 PS in 1999, again indicating soil moisture level differences between clusters were causing periodicity differences. Cluster 1 had higher soil moisture in 4 of 6 weeks after seeding versus cluster 3, and cluster 4 had higher soil moisture in 3 of 6 weeks after seeding versus cluster 3. Limited soil moisture levels may have contributed to the delayed green foxtail emergence in cluster 3.

Blackshaw et al. (1981a) observed that when soil moisture was limiting, green foxtail took longer to emerge.

Table 4.11. Parameter estimates for cumulative percent green foxtail emergence models post-seeding (PS) as affected by tillage system (zero-tillage (ZT) and conventional-tillage (CT)) and eco-regional field location cluster (cluster) in 1999 and 2000. Values in parentheses are standard errors.

	1999			2000		
	a	*b*	*c*	*a*	*b*	*c*
All Sites	102.2 (6.8)	25.9 (10.3)	.013 (.002)	100.3 (3.5)	259.8 (154.6)	.019 (.002)
Tillage						
CT	109.2 (26.2)	13.4 (8.4)	.010 (.004)	100.4 (3.5)	282.6 (164.1)	.019 (.002)
ZT	97.0 (9.4)	78.0 (95.1)	.017 (.005)	100.3 (3.0)	239.6 (121.2)	.019 (.002)
Cluster						
1	101.1 (19.1)	96.7 (306.1)	.021 (.015)	102.0 (5.1)	119.0 (80.2)	.017 (.003)
2	105.4 (22.4)	20.3 (14.6)	.011 (.004)	96.0 (3.5)	841.7 (909.3)	.025 (.004)
3	104.3 (17.7)	182.2 (465.7)	.019 (.010)	99.4 (3.3)	96.7 (47.4)	.017 (.002)
4	94.6 (13.4)	33.4 (50.6)	.018 (.008)	102.3 (3.9)	1237.0 (1011)	.028 (.003)

In 2000, significant differences in green foxtail emergence periodicity were observed between cluster 4 and all other clusters, where emergence periodicity in cluster 4 was delayed in comparison to the other clusters (Figure 4.5c). Delayed emergence onset and the unique emergence periodicity for cluster 4 may have been the result of the slower accumulation of soil GDDs (Table 4.7, Figure. 4.7) and higher soil moisture levels in cluster 4 versus the other clusters (Table 4.13).

Significant difference in emergence periodicity between cluster 4 and cluster 2 and cluster 3 are thought to have occurred due to the significantly higher rate of soil GDD accumulation in clusters 2 and 3 versus cluster 4 (Table 4.7, Figure 4.7). This would support the why more rapid emergence occurred in clusters 2 and 3 versus cluster 4.

Table 4.12. Average percent gravimetric soil moisture (w/w), measured 0 to 2.5 cm below the soil surface, sorted by days after seeding (DAS) and grouped into weeks after seeding (WAS) compared between tillage systems (conventional-tillage (CT) and zero-tillage (ZT)) and eco-regional field location clusters (cluster) post-seeding (PS) in 1999. Values in parentheses are standard errors.

		Tillage System			Cluster				
DAS	WAS	CT	ZT	LSD	1	2	3	4	LSD
		---% gravimetric soil moisture (w/w) ---							
0-7	1	19.2 (6.1) a[a]	24.8 (7.0) a	3.2	29.9 (---) a	19.0 (8.3) a	14.8 (---) a	23.2 (6.1) a	17.5
7-14	2	19.3 (7.5) a	24.7 (7.5) a	6.2	34.7 (6.5) a	19.3 (6.1) bc	12.7 (---) c	25.3 (2.9) ab	11.3
14-21	3	19.3 (5.0) a	20.6 (10.5) a	5.9	30.1 (6.3) a	23.2 (6.7) a	12.7 (6.4) b	13.6 (4.3) b	9.3
21-28	4	17.4 (6.6) a	14.9 (10.3) a	8.1	17.7 (10.0) ab	24.3 (5.8) a	9.3 (6.5) b	9.0 (3.0) b	11.6
28-35	5	24.5 (6.0) a	21.5 (5.6) a	16.6	--- (---)	22.7 (5.2)	--- (---)	--- (---)	---
35-42	6	--- (---)	24.2 (---)	---	--- (---)	22.4 (---)	--- (---)	--- (---)	---

[a]Comparisons are between tillage systems within weeks after seeding, or between eco-regional field location clusters within weeks after seeding; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).

In 2000, environmental conditions were not significantly different between clusters 1 and 4, but green foxtail emergence periodicity was still statistically different between these two clusters. No significant differences between rate of soil GDD accumulation (Table 4.7) or measured gravimetric soil moisture levels (Table 4.13) were found between cluster 1 and 4, therefore we speculated that differences in emergence periodicity were due to differences in green foxtail biotypes between the two clusters.

Cluster 4 is usually cooler and drier than the other clusters (Table 4.10). Producers usually apply herbicides based on calendar date, and when they see the presence of any weeds (such as wild oat), that have emerged earlier in the season. The in-crop herbicide application probably occurs, on average, therefore, early in the green foxtail emergence period. This may have resulted in selection in some clusters for green foxtail biotypes that would emerge at warmer temperatures (i.e. later in the season), escaping control by herbicide applications. Anderson and Nielsen (1996) found biotypes of weed species with altered emergence characteristics among locations, and Forcella et al. (1993) found that under identical conditions a green foxtail biotype, originally form a warmer site (Colorado), emerged one month later than one that originated at a cooler site (Minnesota).

Emergence Pre- and Post-Seeding

Data points were scattered evenly around the green foxtail emergence periodicity models for clusters 1, 2, 3 and 4, indicating the models were a good representation of green foxtail emergence data in these clusters in 2000.

Green foxtail emergence periodicity in the PPS period was significantly different between clusters 1 and 2, 1 and 3, and 3 and 4 (Figure 4.5c). Significant differences in

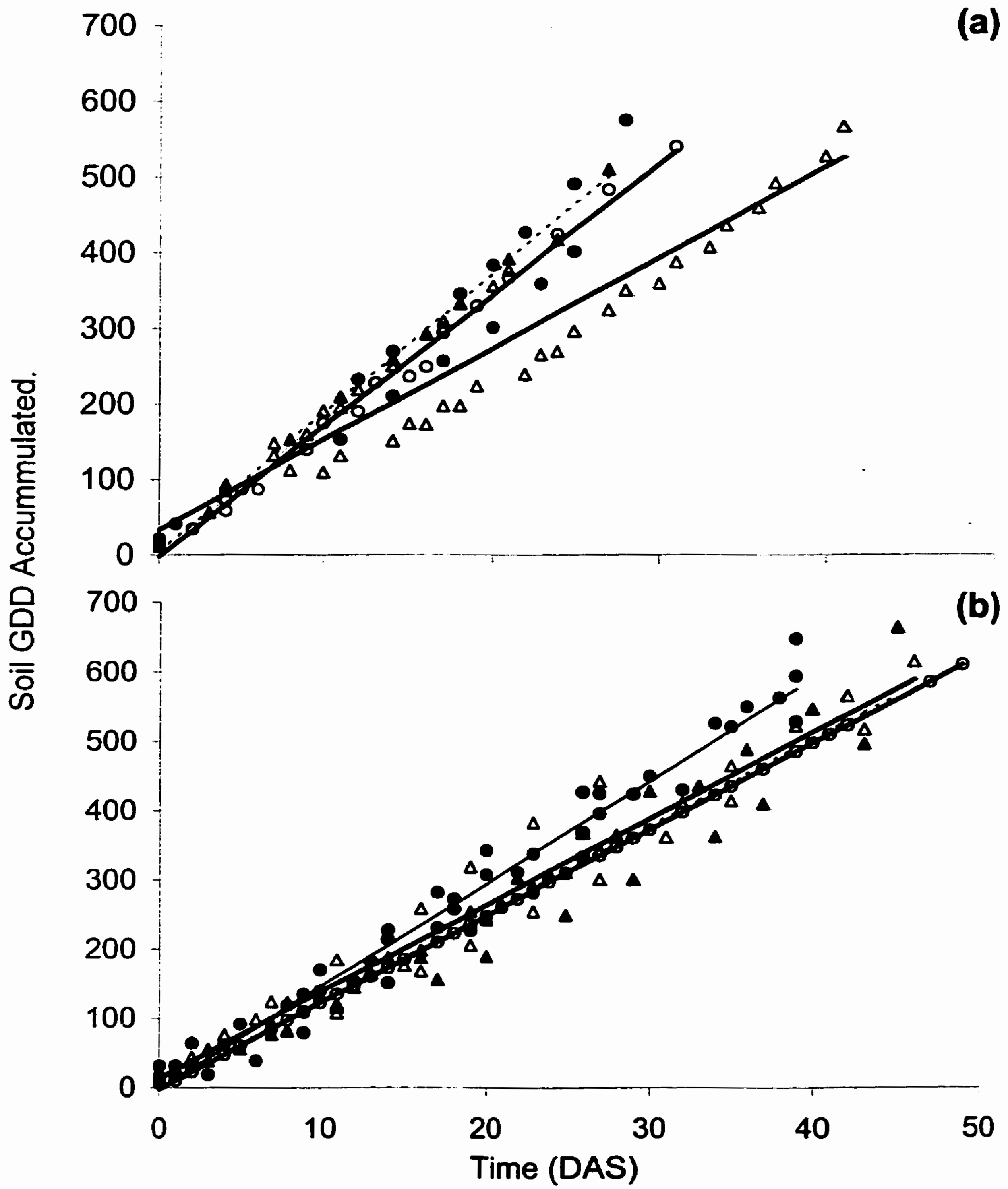

Figure 4.7. Measured accummulated soil growing degree days (GDD, base 0°C, at 2.5 cm below the soil surface) as related to days after seeding (DAS) in the post-seeding (PS) period between cluster 1 (--▲), cluster 2 (–△), cluster 3 (—●), and cluster 4 (–○) in (a) 1999 and (b) 2000. Markers represent field data and lines represent models. Refer to table A.4.5 for parameter estimates.

Table 4.13. Average percent gravimetric soil moisture (w/w), measured 0 to 2.5 cm below the soil surface, sorted by days after seeding (DAS) and grouped into weeks after seeding (WAS) compared between tillage system (conventional-tillage (CT) and zero-tillage (ZT)) and eco-regional field location clusters (cluster) post-seeding (PS) in 2000. Values in parentheses are standard errors.

		Tillage System			Cluster				
DAS	WAS	CT	ZT	LSD	1	2	3	4	LSD
		-----% gravimetric soil moisture (w/w)-----							
0-7	1	7.5 (3.6) b[a]	18.2 (8.9) a	6.0	13.4 (9.1) ab	16.2 (13.5) ab	8.3 (4.2) b	18.1 (7.0) a	8.5
7-14	2	13.9 (7.6) b	20.2 (5.9) a	3.9	23.1 (5.0) a	16.0 (10.2) bc	11.3 (3.5) c	18.4 (6.4) ab	5.7
14-22	3	11.7 (7.0) b	18.9 (6.2) a	4.6	18.0 (8.0) a	15.1 (6.8) ab	10.2 (5.0) b	19.0 (7.9) a	6.6
21-29	4	14.1 (5.4) a	16.0 (6.5) a	4.3	13.7 (4.7) b	12.8 (3.3) b	13.0 (4.4) b	19.8 (7.5) a	6.1
28-36	5	14.3 (7.4) a	14.4 (7.3) a	7.3	16.8 (6.8) a	16.3 (3.3) a	14.8 (11.4) a	11.9 (5.9) a	11.7
35-43	6	13.6 (4.9) a	19.2 (7.1) a	6.7	10.1 (2.3) a	16.5 (6.2) a	18.7 (6.5) a	17.9 (7.9) a	9.9
42-49	7	25.0 (---) a	18.7 (6.4) a	18.8	17.0 (11.3) a	20.7 (4.5) a	--- (---)	20.6 (7.1) a	16.4
49-56	8	--- (---)	23.7 (---)	---	--- (---)	--- (---)	--- (---)	23.7 (---)	---

[a]Comparisons are between tillage systems within weeks after seeding, or between eco-regional field location clusters, within weeks after seeding; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).

emergence periodicity in the PPS period between clusters was due to differences in rate of soil GDD accumulation between clusters, recruitment depths, and soil moisture availability. By cluster, form earliest to latest, ranking of the time to reach E_{80} was cluster 1>4>2>3 (Table 4.9). This mirrored the ranking of average measured gravimetric soil moisture levels among clusters (Table 4.14), where the ranking from greatest to least was 1>4>2>3. Weaver et al. (1988) observed that temperature accumulation drove green foxtail emergence, but that soil moisture modified it. Differences in soil moisture levels among cluster may have created differences in emergence periodicities between clusters. For example, the onset of green foxtail emergence was similar for all clusters (started around 350 GDD) (Figure 4.5c). After the onset of emergence, however, the model for each cluster separated on the basis of highest to lowest soil moisture levels (Table 4.14).

Time to reach E_{80} from E_{25}, was greater in clusters with finer soil textures (clay). Time to E_{80} was greatest in cluster 1 (Table 4.9), which is characterized as having a heavy clay soil type versus the clay loam or sandy loam soil types in clusters 2, 3 and 4 (Table 4.1). Dawson and Bruns (1962) speculated that seedlings would emerge from greater depths in coarse textured soils, but Chepil (1946) observed that soil texture had little effect on green foxtail emergence, and du Croix Sissons (1999), found in similar sampled fields in southern Manitoba, that no consistent effect of soil type on green foxtail recruitment depth could be determined.

Table 4.14. Percent gravimetric soil moisture (w/w), measured 2.5cm below soil surface, tillage systems (conventional-tillage (CT) and zero-tillage (ZT)) and eco-regional field location clusters (cluster), averaged for the entire sampling period in the post-seeding (PS) period of 1999 and 2000, and the pre- and post-seeding (PPS) period of 2000.

	Post-seeding				Pre- and Post-Seeding	
	1999	LSD	2000	LSD	2000	LSD
	------------% gravimetric soil moisture (w/w) ------------					
Tillage		3.5[b]		2.1		1.5
CT	19.3 a[a]		12.6 b		13.1 b	
ZT	20.8 a		18.0 a		19.1 a	
Cluster		5.4[c]		2.9		2.1
1	28.1 a		16.8 a		18.6 a	
2	22.1 b		15.7 a		16.3 b	
3	18.7 b		12.1 b		13.0 c	
4	11.7 c		17.8 a		17.8 ab	

[a]Comparisons are tillage systems or eco-regional field location clusters within years; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).
[b]LSD for comparisons between tillage systems within sampling period and year.
[c]LSD for comparisons between cluster within sampling period and year.

Sampling Period Effects on Influence of Eco-Regional Field Location Cluster on Emergence Periodicity

In the PS period, significant differences in emergence periodicity between clusters appeared to occur due to soil moisture differences between clusters in 1999, and differences in soil moisture and soil temperature accumulation rate in 2000. Between cluster 1 and 4, in the PS period of 2000, green foxtail emergence periodicity could not be accounted for by differences in rate of soil GDD accumulation and soil moisture levels, and significance was thought to be due to differences in biotypes between the clusters.

Observation of the emergence curve over a longer time period (PPS versus PS) amplifies the soil temperature and soil moisture differences between clusters. In the PPS period, significant differences in emergence periodicity occurred between clusters 1 and 2, 2 and 3, and 3 and 4. Difference in emergence periodicity appear to be due to differences in total measured soil moisture levels between clusters over the entire sampling period. With the relatively dry early season in 2000 (table 4.10), conditions for green foxtail emergence in different clusters was probably influenced early on by differences in soil moisture availability between clusters. As the sampling period progressed, those differences were probably amplified, influencing the rate of time taken to reach E_{80} from E_{25}.

Summary

In the PS period, differences in emergence periodicity were not observed in either year between tillage systems, therefore, a single model may be sufficient to explain the emergence periodicity of green foxtail PS, and to help predict herbicide application timing.

Differences in emergence periodicity in both PPS and PS periods occurred among clusters, indicating that eco-regional field location cluster should be considered when determining green foxtail emergence periodicity. Clusters should be considered separately in particular, when there are differences in soil types between clusters. This is because soil type influences soil moisture holding capacity, and soil moisture deficits between clusters, which can contribute to unique emergence patterns in certain clusters depending on the environmental conditions (e.g. clay soils in wet year, versus clay soils in very dry year).

GENERAL DISCUSSION

General Summary

Within the study examining effects of tillage system and eco-regional field location clusters (cluster) on emergence periodicity of wild oat and green foxtail, the major findings were as follows,

- Tillage system did not affect wild oat emergence periodicity in the post-seeding (PS) period, but did in the pre- and post-seeding (PPS) period. We suggested that this was due to differences in soil moisture between tillage systems.
- Tillage system did not affect green foxtail emergence periodicity in the PS period, but did in the PPS period. We suggest that this was due to differences in soil moisture and seedling recruitment depths between tillage systems.
- Cluster significantly affected wild oat emergence periodicity PS. We believe this was due to extreme weather conditions and different soil type in one cluster versus others. Cluster also affected wild oat emergence periodicity in the PPS period. We suggested this was due to differences in soil moisture between clusters, and possible wild oat biotype differences among clusters.
- Cluster significantly affected green foxtail emergence periodicity PS. We suggest that in 1999, this was due to differences in soil moisture between clusters and that in 2000, this was due to differences soil moisture, and differences in rate of soil temperatures accumulation between clusters, and possibly green foxtail biotype differences. Cluster also affected green foxtail emergence periodicity in the PPS period. We suggested that this was due to differences in soil moisture levels between clusters.

Emergence Periodicity Modeling

The creation of models for predicting percentages of weed species emergence by specific field and environment information would be valuable in to assist in accurate timing of crop-scouting and weed control measures. Weed emergence periodicity tracking between tillage systems and clusters plays an integral part of creating models that are adaptable and accurate over large areas, but collection of such information, can be difficult to decipher when determining why difference in emergence periodicities are occurring between fields.

Soil microsites created by different tillage practices will lead to altered timing of species emergence periodicity within a season. Most of the differences will occur from a combination of soil moisture and temperature differences occurring between systems. The unique soil moisture and temperatures conditions in individual fields needs to be accounted for and the response of individual species emergence periodicity to conditions must be quantified.

For example, early spring of 2000 was very dry across all sites, yet emergence periodicity of green foxtail occurred more rapidly in ZT versus CT fields (Figure 4.5b). This was attributed to the greater soil moisture available to the germinating and emerging seedling under ZT conditions, but would this also occur in a wet spring? Further tracking and examination is required under more environmental conditions, before clear conclusions on the effects of tillage system on emergence periodicity occurs. Additional weed species emergence tracking in conditions outside those sampled in this thesis is necessary if wide applicability of the model in different areas of the province, country or continent is desired.

Datasets containing weed species emergence periodicities from different soil types in combination with different environmental conditions and management practices would be useful in locating where variations in weed emergence periodicity occur. In addition to focusing on why individual weed species emergence periodicities vary under different field conditions, it would be useful to examine how individual weed species emergence periodicities differ from each other. The comparisons and the incorporation of multi-species weed emergence periodicities into a single model would be utilized greatly by producers trying to accurately time when to implement control measures that would affect the largest diversity and density of weed species in their field.

Differences Between Wild Oat and Green Foxtail Emergence

Wild oat and green foxtail emergence periodicities were significantly different in the PPS period (Table 5.1). Wild oat emergence onset was much earlier than that of green foxtail (Figure 5.1). This was expected because of the lower germination and emergence temperature requirements for wild oat versus green foxtail (Fernandez-Quinantila et al. 1990; Sharma et al. 1976). Lag time to emergence onset was longer for green foxtail versus wild oat (Table 5.2). Roberts (1984) found lag time to be the time from seed germination to seedling emergence. Differences in time of emergence onset, also, reflect the differences in germination and emergence temperature requirements between these species. Wild oat took longer than green foxtail to reach E_{80} from E_{25}. This difference may reflect the fact that wild oat recruitment occurs from deeper depths versus green foxtail (du Croix Sissons et al. 2000). It may also reflect the fact that the optimal temperature range for germination and emergence occurs over a over a broader time period in the season for wild oat versus green foxtail.

Table 5.1. *F* test[a] results for comparing significance of parameter estimates of cumulative percent of wild oat and green foxtail emergence models. Comparisons made between post-seeding (PS) in 1999 and 2000 and pre- and post-seeding (PPS) in 2000 sampling periods.

	Wild Oat versus Green Foxtail			
Sampling Period	*a*	*b*	*c*	R^2
Pre- and Post-Seeding	NS[a]	*[b]	*	0.72
Post-Seeding 1999	NS	NS	*	0.90
Post-Seeding 2000	NS	*	NS	0.84

[a]NS means not significant at 5% level
[b]* means significant at 5% level

Table 5.2. Soil growing degree days (GDD, base 0°C) required to reach 25% (E_{25}) and 80% (E_{80}) cumulative emergence of wild oat or green foxtail in the post-seeding (PS) period of 1999 and 2000 and pre- plus post-seeding (PPS) period of 2000.

	Wild Oat			Green Foxtail		
Sampling	E_{25}	E_{80}	Difference	E_{25}	E_{80}	Difference
PPS	387	616	229	516	695	179
PS 1999	153	281	128	165	350	185
PS 2000	179	332	153	235	365	130

Examining wild oat and green foxtail emergence periodicities together in the PPS period would be useful for examining the practicality of delayed seeding measures. Because of emergence lag time differences between species, delayed seeding measures would probably not be successful in eliminating a large proportion of the population of both species. Green foxtail emergence is delayed versus wild oat. Green foxtail does not reach E_{25} until 129 soil GDDs after wild oat reaches E_{25} (Table 5.2). If planting dates was delayed to control wild oat, on average, only a small proportion of the total green foxtail population would be controlled. Banting et al. (1973) expressed the same idea. At the point in the PPS period when green foxtail reached E_{25} (516 soil GDD), 55% of wild oats had already emerged, and by calendar date, it was the third week of May. On the basis of thirty year crop insurance records, seeding at this time in May, has been observed to contribute to crop yield potential declines (Figure 5.2). As well, Blackshaw et al. (1981b) observed that if green foxtail emerged at the same time as the crop, it is very efficient competitor for nutrients, and soil moisture, leading to decreased crop yields. If our models are to be used to plan delayed seeding measures producers should first determine whether wild oat or green foxtail is the main weed problem in the field and how late in the season they would be willing to seed, and how much crop yield would they be willing to lose to save money by not applying an in-crop graminicide.

Emergence periodicity of wild oat and green foxtail were significantly different in the post-seeding periods of both 1999 and 2000 (Table 5.1). In the PS period of 1999 (Figure 5.3a), green foxtail emergence onset occurred sooner than that of wild oat. This was unusual and unexpected because one might expect that at the time of seeding, soil temperatures would be too cool for green foxtail emergence to occur. But, average crop planting dates in 1999 were delayed two weeks versus 2000 (Table 5.3), so that crop planting dates in 1999 occurred when soil temperatures were higher and soil GDDs were accumulating at a faster rate. In 2000, emergence onset of wild oat occurred before green foxtail, and emergence onset of green foxtail lagged behind that of wild oat (Figure 5.3b). This was because average planting date in 2000 was the first week of May, and at this time in the spring, soil temperatures are usually too cool for green foxtail emergence.

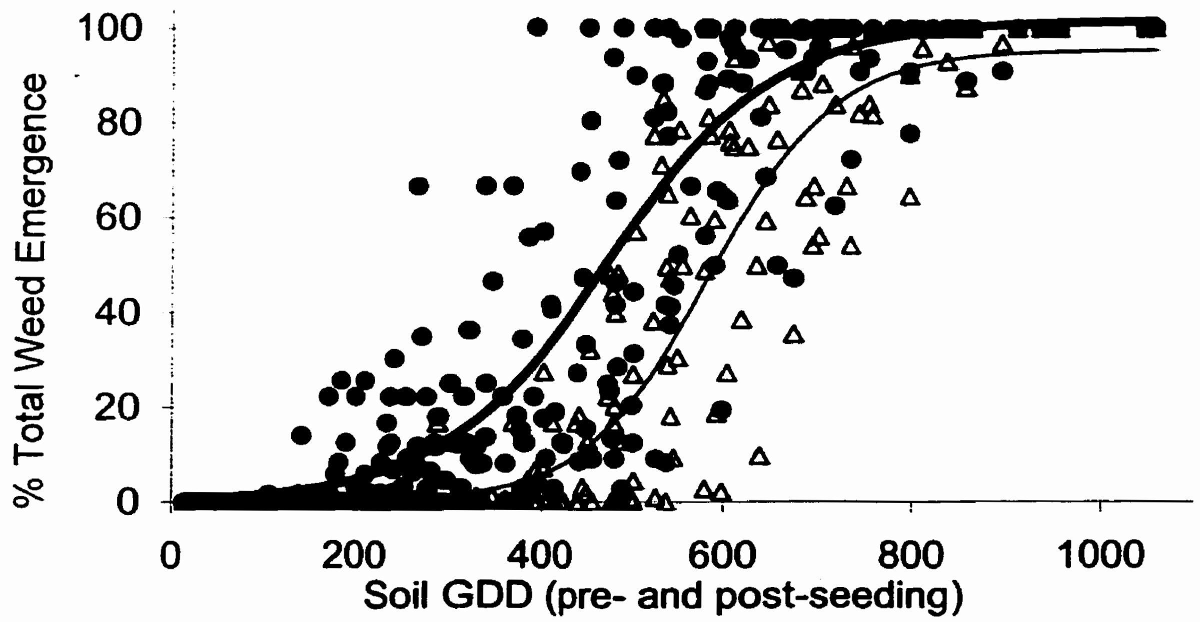

Figure 5.1. Wild oat (—●) and green foxtail (—△) emergence periodicity as related to soil growing degree days (GDD, base temperature 0°C, 2.5 cm from the soil surface), in pre- and post-seeding (PPS) period 2000. Markers represent field data and lines represent models. Refer to table A.5.2 for parameter estimates of model.

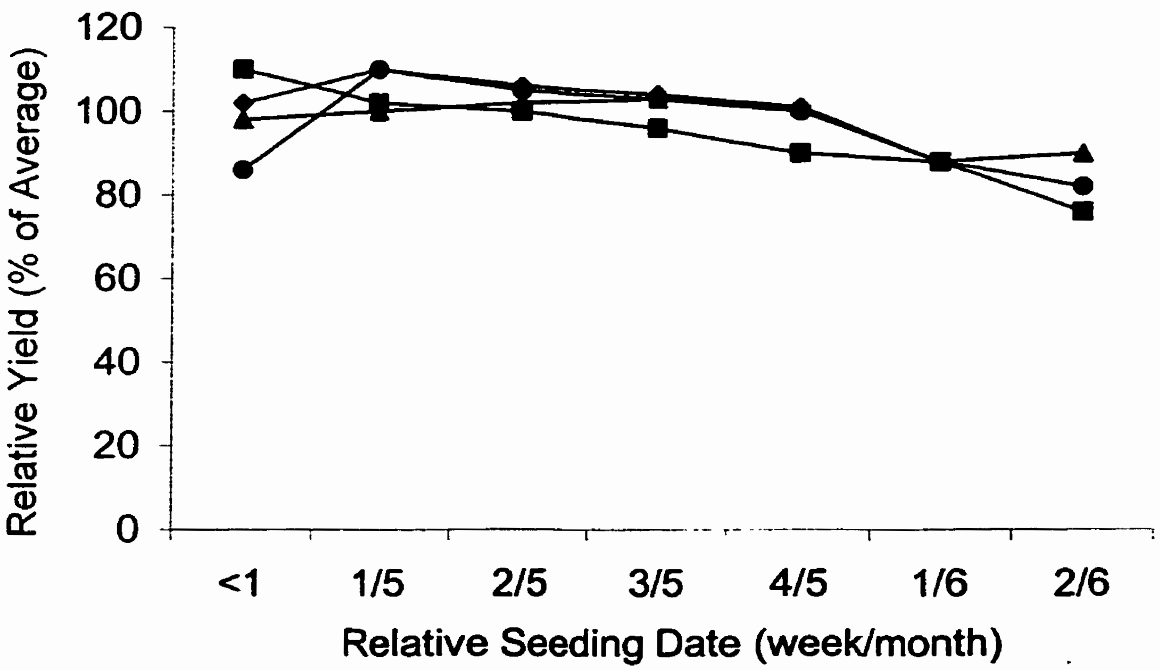

Figure 5.2. Seeding date effects on crop yield for spring wheat (■), barley (◆), argentine canola (▲) and flax (●). Data from historical Manitoba Crop Insurance Corporation records available on World Wide Web: <URL:http://www.mmpp.com>.

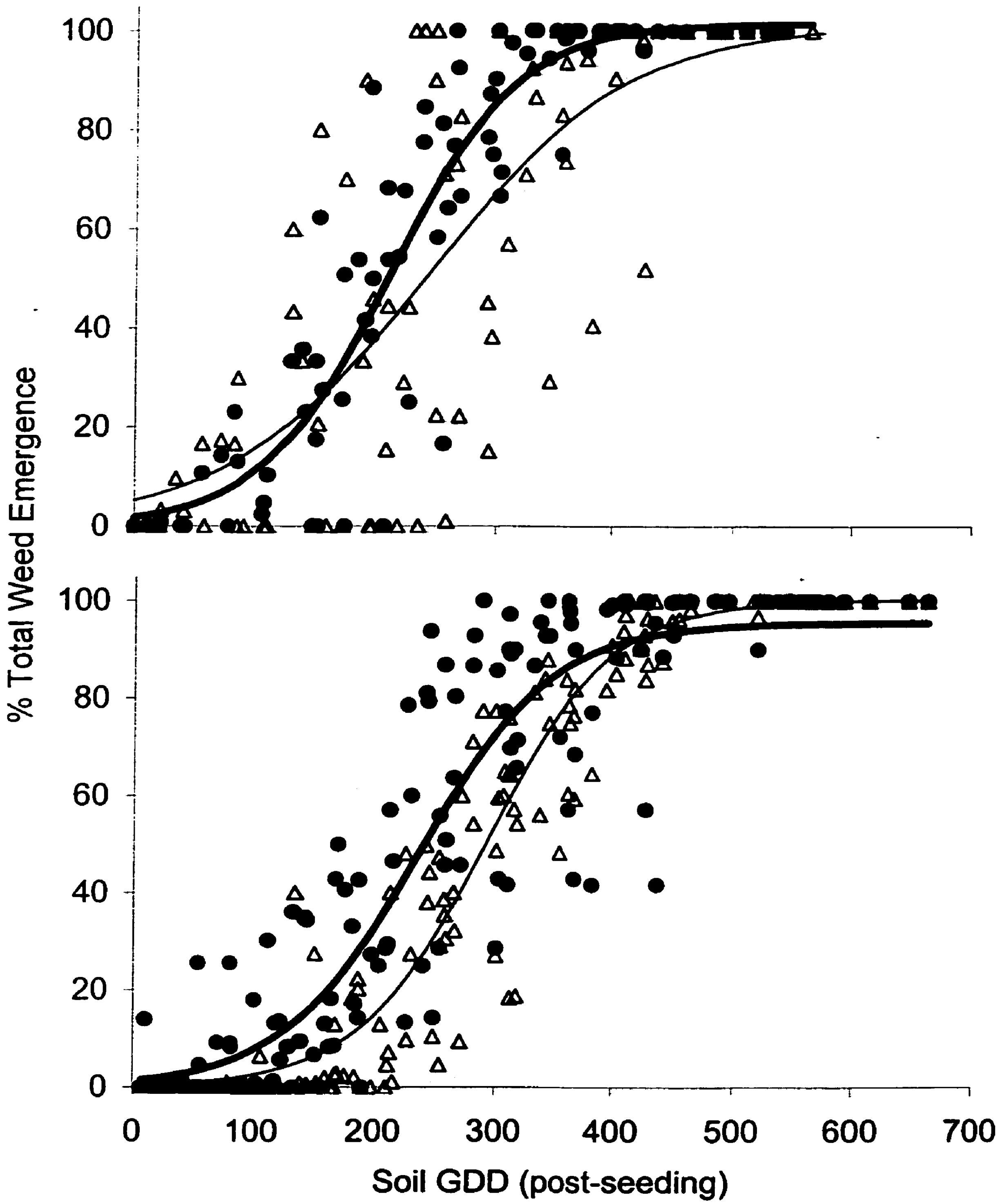

Figure 5.3. Wild oat (–●) and green foxtail (–Δ) emergence periodicity as related to soil growing degree days (GDD, base temperature 0°C, 2.5 cm from the soil surface), in post-seeding (PS) periods of (a) 1999 and (b) 2000. Markers represent field data and lines represent models. Refer to table A.5.2 for parameter estimates of model.

Table 5.3. Comparison between years of average crop planting date (Julian days) for fields containing wild oat and green foxtail. Values in parentheses are standard errors.

	1999	2000	LSD
	---------------Average Planting Date-------------		
All Sites	148.1 (14.3) a[a]	130.3 (6.6) b	7.8

[a] Means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).

Time to each E_{25} was very similar between species in 1999, but not in 2000, this again reflects the impact that seeding date has on species emergence periodicities. In general, with earlier seeding dates, there will be a greater lag in emergence onset, especially for species such as green foxtail that typically emerge later in the season because of higher temperature requirements for germination and emergence. When crop planting is delayed, the lag in emergence onset becomes shorter, but the time to reach E_{80} is also reduced. With delayed crop planting, therefore, there is a shorter time period during which control measures can be implemented. Spandl et al. (1998) also observed this phenomenon, and found that delayed crop planting produced more phenologically uniform seedling populations, because the emergence period was shorter. The time required for green foxtail to reach E_{80} from E_{25} was, however, longer in 1999 versus 2000, this probably being due to significantly greater soil moisture levels in 1999 versus 2000 (Table 4.12). Egley and Williams (1991) also found that for summer annual species, higher soil moisture levels produced a broader emergence period.

Anomalies in Experimental Results and Future Research

Significant differences between emergence periodicities in both wild oat and green foxtail were observed to occur between clusters, even when in some cases no significant differences in environmental conditions occurred between clusters. These observations resulted in the speculation that biotype selection of wild oat and green foxtail had occurred in certain clusters and biotype differences caused the differences in emergence periodicities. This occurred for the emergence periodicities of wild oat in cluster 3 versus clusters 2 and 4 in the PPS period, and for green foxtail in cluster 3 versus clusters 1 and 4 in 1999, and between cluster 4 and cluster 1 in the PS period of 2000. To confirm or reject this speculation, the clusters where these differences occurred should be re-visited and seed collected. Using these samples, we could determine, under controlled conditions, the emergence condition requirements of the biotypes and whether these requirements are significantly different versus biotypes from other clusters. Successful modeling of emergence periodicities of wild oat and green foxtail is dependent on understanding the individual species reactions to varying soil temperatures and soil moisture. If different biotypes of the same species are occurring in different areas, then the responses of all biotypes to environmental conditions, needs to be quantified for wider applicability and accuracy of emergence periodicity prediction models.

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APPENDIX

Table A.1. Information on site location, soil type and agronomy practices for sites sampled in 1999 and 2000.

Year	Location	Cluster	Tillage	Legal Descrip	Soil Texture[b]	Rotation	Seeding Date	Spray Date
1999	Carman	1	zero	NE 36-6-4W	clay	wh-canola[a]	31-May	18-Jun
1999	Carman	1	conv	NE 23-6-5	clay	brly-canola	26-May	N/A
1999	Altamont	2	zero	SE 3-5-8	clay loam	wh-canola	4-Jun	19-Jun
1999	Altamont	2	conv	SW 2-5-8	clay loam	brly-canola	7-Jun	N/A
1999	Mariapolis	2	zero	NW 14-4-12	clay loam	wh-canola	1-May	2-Jun
1999	Mariapolis	2	conv	NW 26-4-12	clay loam	wh-canola	2-May	27-May
1999	Justice	3	conv	SE 26-11-18	loamy sand	wh-canola	16-Jun	N/A
1999	Justice	3	conv	NW 20-11-17	loamy sand	wh-canola	9-Jun	N/A
1999	Holland	3	zero	NW 21-8-11	sandy loam	wh-canola	27-May	11-Jun
1999	Holland	3	zero	NE 22-8-11	sandy loam	oats-canola	2-Jun	14-Jun
1999	Holland	3	conv	SE 27-8-11	sandy loam	wh-canola	14-May	6-Jun
1999	ManDak	4	zero	NE 31-12-18	clay loam	wh-canola	14-Jun	N/A
1999	Mandak	4	conv	NW 32-12-18	clay loam	wh-canola	29-May	13-Jun
1999	Kenton	4	zero	NE1/4 33-11-23	clay loam	brly-canola	28-May	21-Jun
1999	Kenton	4	conv	E 4-12-23	clay loam	wh-canola	14-Jun	N/A
2000	Carman	1	zero	NW 29-5-4	clay	wh-canola	15-May	N/A
2000	Carman	1	conv	NE 30-5-4	clay	wh-canola	2-May	29-May
2000	Gladstone	1	zero	W 34-14-11	clay	oats-canola	9-May	3-Jun
2000	Gladstone	1	conv	SW 36-14-11	clay	canola-brly	29-Apr	30-May
2000	Altamont	2	zero	NW 3-5-8	clay loam	wh-canola	6-May	19-Jun
2000	Altamont	2	conv	SE 21-8-11	clay loam	wh-canola	22-May	N/A
2000	Bruxelles	2	zero	SE 1/4 14-6-11	clay loam	wh-canola	2-May	30-May
2000	Bruxelles	2	conv	SW 14-6-11	clay loam	wh-canola	19-May	N/A
2000	Holland	3	zero	SE 21-8-11	sandy loam	wh-canola	7-May	31-May
2000	Holland	3	conv	NE 28-8-11	sandy loam	brly-canola	6-May	3-Jun
2000	Glenboro	3	zero	NW 1/4 7-7-14	sandy loam	wh-canola	10-May	31-May
2000	Glenboro	3	conv	NW 1/4 13-7-15	sandy loam	oats-canola	15-May	5-Jun
2000	Brandon	3	zero	SE 30-10-18	clay loam	wh-canola	26-Apr	26-May
2000	Brandon	3	conv	NE 34-10-19	sandy loam	brly-canola	18-May	7-Jun
2000	ManDak	4	zero	SW 31-12-8	clay loam	oats-canola	10-May	N/A
2000	ManDak	4	conv	NE 28-12-18	clay loam	SF-brly	2-May	3-Jun
2000	Forrest	4	zero	NW 7-13-18	clay loam	wh-canola	5-May	2-Jun
2000	Forrest	4	conv	W 1/2 20-12-18	clay loam	wh-canola	17-May	7-Jun
2000	Rapid City	4	zero	SW 12-14-19	clay loam	wh-canola	3-May	2-Jun
2000	Virden	4	conv	SW 7-11-26	loam	SF-canola	9-May	7-Jun

[a]wh=wheat, brly=barley, SF=summer fallow
[b]Agriculture Canada 1989

Table A.3.1. Correlation between air growing degree days (GDD, base 0°C) and soil growing degree days (GDD, base 0°C, measured at 2.5 cm).

Pearson Correlation Coefficients, N = 181
Prob > |r| under H0: Rho=0

	Soil GDD	Air GDD
Soil GDD	1.00000	0.97714 p<.0001
Air GDD	0.97714 p<.0001	1.00000

Table A.3.2. Partial lack-of-fit F test summary for post-seeding (PS) wild oat emergence models between years in 1999 and 2000.

	Parameters held constant				
	a	*ab*	*abc*	*ac*	F value[a]
Years	1.80 (1,256)[b]	0.04 (1,257)	14.50 (1,258)	----	3.84

[a]Tabular F value statistic used to judge significance between parameters.
[b]Numbers in parentheses represent degrees of freedom used to judge the F statistic

Table A.3.3. Partial lack-of-fit F test summary for post-seeding (PS) wild oat emergence models between tillage system and eco-regional field location clusters (cluster) in 1999.

	Parameters held constant				
	a	*ab*	*abc*	*ac*	F value[a]
Tillage	0.14 (1,89)[b]	0.95 (1,90)	0.74 (1,91)	----	3.92
Cluster 1, 2, 3, 4	0.12 (3,83)	7.85 (3,86)	----	6.99 (3,86)	3.92
Cluster 1, 2	0.20 (1,35)	55.86 (1,36)	----	33.14 (1,36)	4.08
Cluster 1, 3	0.01 (1,27)	5.36 (1,28)	----	3.75 (1,28)	4.20
Cluster 1, 4	0.21 (1,29)	42.17 (1,30)	----	34.56 (1,30)	4.17
Cluster 2, 3	0.00 (1,53)	1.98 (1,54)	0.01 (1,55)	----	4.00
Cluster 2, 4	1.10 (1,55)	31.82 (1,56)	----	35.33 (1,56)	4.00
Cluster 3, 4	0.16 (1,47)	0.09 (1,48)	0.53 (1,49)	----	4.08

[a]Tabular F value statistic used to judge significance between parameters.
[b]Numbers in parentheses represent degrees of freedom used to judge the F statistic

Table A.3.4. Partial lack-of-fit F test summary for post-seeding (PS) wild oat emergence models between tillage system and eco-regional field location clusters (cluster) in 2000.

	Parameters held constant				
	a	*ab*	*abc*	*ac*	F value[a]
Tillage	0.61 (1,162)[b]	2.25 (1,163)	0.11 (1,64)	----	3.84
Cluster 1, 2, 3, 4	0.77 (3,153)	1.24 (3,156)	4.17 (3,159)	----	2.60
Cluster 1, 2	0.11 (1,53)	0.61 (1,54)	8.48 (1,55)	----	4.00
Cluster 1, 3	0.57 (1,84)	1.73 (1,85)	4.73 (1,86)	----	3.92
Cluster 1, 4	0.33 (1,68)	0.10 (1,85)	8.80 (1,86)	----	3.91
Cluster 2, 3	0.02 (1,84)	0.08 (1,69)	1.54 (1,70)	----	4.00
Cluster 2, 4	0.66 (1,68)	1.68 (1,69)	1.48 (1,70)	----	4.00
Cluster 3, 4	2.30 (1,99)	3.26 (1,100)	0.15 (1,101)	----	3.92

[a]Tabular F value statistic used to judge significance between parameters.
[b]Numbers in parentheses represent degrees of freedom used to judge the F statistic

Table A.3.5. Partial lack-of-fit F test summary for pre- and post-seeding (PPS) wild oat emergence models between tillage system and eco-regional field location clusters (cluster).

	Parameters held constant				
	a	*ab*	*abc*	*ac*	F value[a]
Tillage	0.00 (1,305)[b]	7.00 (1,306)	----	2.52 (1,306)	3.84
Cluster 1, 2, 3, 4	0.27 (3,147)	1.59 (3,150)	3.93 (3,153)	----	2.60
Cluster 1, 2	0.00 (1,62)	0.45 (1,63)	3.27 (1,64)	----	4.00
Cluster 1, 3	0.28 (1,76)	2.74 (1,77)	2.62 (1,78)	----	4.00
Cluster 1, 4	0.36 (1,77)	0.09 (1,78)	2.58 (1,79)	----	4.00
Cluster 2, 3	0.35 (1,69)	3.15 (1,70)	7.01 (1,71)	----	4.00
Cluster 2, 4	0.41 (1,70)	0.36 (1,71)	0.59 (1,72)	----	4.00
Cluster 3, 4	0.07 (1,84)	3.37 (1,85)	9.00 (1,86)	----	4.00

[a]Tabular F value statistic used to judge significance between parameters.
[b]Numbers in parentheses represent degrees of freedom used to judge the F statistic

Table A.3.6. Table of ANOVA outputs for mean weekly average soil temperature measurements at 2.5cm below the soil surface, combined between conventional-till and zero-till fields. For post-seeding (PS) weeks represent weeks after planting, for pre- and post-seeding (PPS) weeks represent weeks after April 1, 2000.

Weeks	Post-Seeding 1999		Post-Seeding 2000		Pre- and Post-Seeding 2000	
	df[a]	F value	df	F value	df	F value
1	1,19	1.51	1,65	0.22	1,35	4.89
2	1,90	3.66	1,121	0.07	1,104	15.24
3	1,99	4.51	1,124	9.95	1,122	8.74
4	1,68	4.02	1,124	2.26	1,124	1.36
5	1,28	3.41	1,124	2.67	1,142	0.24
6	1,12	6.87	1,116	3.95	1,124	0.10
7			1,42	1.81	1,124	1.15
8			1,5	---	1,124	0.73
9					1,124	4.22
10					1,121	0.58
11					1,93	4.55
12					1,48	2.03
13					1,14	0.17

[a] df represents degrees of freedom used to judge the F statistic.

Table A.3.7. Parameter estimates for accumulated soil temperature models for wild oat emergence for tillage systems and eco-regional field location clusters (cluster) in the post-seeding (PS) period of 1999 and 2000 and the pre- and post-seeding (PPS) period of 2000.

	Post-Seeding 1999		Post-Seeding 2000		Pre- and Post-Seeding 2000	
	a	*b*	*a*	*b*	*a*	*b*
Tillage						
CT	29.6 (17.0)	12.8 (0.9)	11.1 (7.2)	13.2 (0.3)	-1277.7 (35.7)	12.4 (0.3)
ZT	41.1 (11.7)	14.2 (0.7)	-6.4 (6.2)	12.9 (0.3)	-1148.5 (29.2)	11.1 (0.2)
Cluster						
1	4.3 (21.4)	18.4 (1.4)	-0.7 (8.7)	12.6 (0.4)	-1096.0 (45.1)	10.7 (0.3)
2	20.1 (12.0)	12.3 (0.5)	22.8 (12.7)	13.0 (0.5)	-1242.9 (47.8)	12.1 (0.6)
3	28.0 (12.7)	16.2 (0.8)	-1.4 (8.2)	13.9 (0.4)	-1320.3 (42.2)	12.7 (0.3)
4	14.0 (11.4)	17.1 (0.7)	-2.4 (8.2)	12.5 (0.3)	-1129.3 (41.0)	10.8 (0.3)

Table A.3.8. Partial lack-of-fit F test summary for post-seeding (PS) accumulated soil temperature models for wild oat emergence between tillage systems and eco-regional field location clusters (cluster).

	1999			2000		
	Parameters held constant					
	a	*ab*	F value[a]	*a*	*ab*	F value
Tillage	0.31 (1,91)[b]	9.97 (1,92)	3.92	3.39 (1,164)	14.36 (1,165)	3.84
Cluster 1, 2, 3, 4	0.39 (3,89)	48.41 (3,92)	2.68	1.08 (3,162)	11.32 (3,165)	2.60
Cluster 1, 2	0.32 (1,39)	36.37 (1,40)	4.08	2.35 (1,60)	9.14 (1,61)	4.00
Cluster 1, 3	0.77 (1,31)	1.02 (1,32)	4.17	0.00 (1,91)	14.45 (1,92)	3.92
Cluster 1, 4	2.85 (1,33)	14.69 (1,34)	4.17	0.02 (1,91)	0.17 (1,92)	3.92
Cluster 2, 3	0.13 (1,55)	47.47 (1,56)	4.00	2.11 (1,70)	0.09 (1,71)	4.00
Cluster 2, 4	37.01 (1,57)	1185.31 (1,58)	4.00	297.56 (1,70)	8.24 (1,71)	4.00
Cluster 3, 4	0.87 (1,49)	0.09 (1,50)	4.08	0.01 (1,101)	25.01 (1,102)	3.92

[a]Tabular F value statistic used to judge significance between parameters.
[b]Numbers in parentheses represent degrees of freedom used to judge the F statistic

Table A.3.9. Partial lack-of-fit F test summary for pre- and post-seeding (PPS) accumulated soil temperature models for wild oat emergence between tillage systems and eco-regional field location clusters (cluster).

	Parameters held constant		
	a	*ab*	F value[a]
Tillage	7.85 (1,307)[b]	44.02 (1,308)	3.84
Cluster 1, 2, 3, 4	5.73 (3,305)	20.41 (3,308)	2.60
Cluster 1, 2	10.75 (1,129)	30.24 (1,130)	3.92
Cluster 1, 3	10.86 (1,158)	16.31 (1,159)	3.84
Cluster 1, 4	0.40 (1,160)	4.07 (1,161)	3.84
Cluster 2, 3	1.14 (1,144)	0.15 (1,145)	3.84
Cluster 2, 4	46.82 (1,146)	11.23 (1,147)	3.84
Cluster 3, 4	7.55 (1,175)	33.72 (1,176)	3.84

[a]Tabular F value statistic used to judge significance between parameters.
[b]Numbers in parentheses represent degrees of freedom used to judge the F statistic

Table A.3.10. Table of ANOVA outputs for average weekly percent gravimetric soil moisture (w/w), measured 2.5 cm below the soil surface, for wild oat emergence for comparisons between tillage systems or between eco-regional field location clusters (cluster). For pre- and post-seeding (PPS) weeks represent weeks after April 1, 2000.

Weeks	Tillage		Cluster	
	df[a]	*F* value	df	*F* value
1	1,3	4.20	3,3	0.27
2	1,7	9.07	3,7	1.03
3	1,25	23.98	3,25	1.83
4	1,23	15.29	3,23	1.46
5	1,27	2.24	3,27	0.62
6	1,15	5.87	3,15	0.94
7	1,27	8.96	3,27	7.80
8	1,17	10.79	3,17	1.78
9	1,22	1.79	3,22	1.59
10	1,20	4.94	3,20	0.44
11	1,7	0.04	3,7	1.18
12	1,2	3.01	3,2	0.76
13	1,0	---	3,0	---

[a] df represents degrees of freedom used to judge the *F* statistic.

Table A.3.11. Table of ANOVA outputs for average weekly percent gravimetric soil moisture (w/w) and grouped into weeks after seeding (WAS) for wild oat emergence for comparisons between tillage system or between eco-regional field location clusters (cluster) in post-seeding (PS) in 1999 and 2000.

	1999				2000			
Weeks	Tillage		Cluster		Tillage		Cluster	
	df[a]	*F* value	df	*F* value	df	*F* value	df	*F* value
1	1,4	35.15	3,4	18.31	1,19	17.64	3,19	2.71
2	1,12	0.84	3,12	3.84	1,25	7.99	3,25	8.97
3	1,21	5.91	3,21	13.75	1,23	6.62	3,23	1.07
4	1,10	1.85	3,10	2.53	1,23	0.42	3,23	2.86
5	1,3	0.32	3,3	---	1,14	1.02	3,14	0.70
6	1,0	---	3,0	---	1,13	3.51	3,13	2.01
7					1,2	3.28	3,2	1.56
8					1,0	---	3,0	---

[a] df represents degrees of freedom used to judge the *F* statistic.

Table A.3.13. Table of ANOVA outputs for average crop planting date (Julian days) for sampled fields containing wild oats in 1999 and 2000 for all sites, conventional- and zero-tillage systems and for eco-regional field location clusters (cluster).

	All Sites		1999		2000	
	df[a]	*F* value	df[a]	*F* value	df	*F* value
Years	1,25	15.47	N/A	N/A	N/A	N/A
Tillage	N/A	N/A	1,5	0.19	1,12	0.93
Cluster	N/A	N/A	3,5	1.51	3,12	0.24

[a] df represents degrees of freedom used to judge the *F* statistic.

Table A.4.1. Partial lack-of-fit *F* test summary for post-seeding (PS) green foxtail emergence models between years in 1999 and 2000.

	------------------------Parameters held constant-------------------				
	a	*ab*	*abc*	*ac*	*F* value[a]
Years	0.06 (1,256)[b]	13.30 (1,257)	----	3.31 (1,258)	3.84

[a]Tabular *F* value statistic used to judge significance between parameters.
[b]Numbers in parentheseis represent degrees of freedom used to judge the *F* statistic

Table A.4.2. Partial lack-of-fit *F* test summary for post-seeding (PS) green foxtail emergence models between tillage system and eco-regional field location clusters (cluster) in 1999.

	------------------------Parameters held constant--------------------				
	a	*ab*	*abc*	*ac*	*F* value[a]
Tillage	0.24 (1,81)[b]	1.84 (1,82)	1.25 (1,83)	----	4.00
Cluster 1, 2, 3, 4	0.08 (3,77)	0.56 (3,80)	2.38 (3,83)	----	2.76
Cluster 1, 2	0.02 (1,45)	0.28 (1,46)	2.68 (1,47)	----	4.08
Cluster 1, 3	0.09 (1,21)	0.33 (1,22)	14.37 (1,23)	----	4.28
Cluster 1, 4	0.13 (1,23)	0.42 (1,24)	0.08 (1,25)	----	4.24
Cluster 2, 3	0.00 (1,53)	1.11 (1,54)	0.22 (1,55)	----	4.00
Cluster 2, 4	0.13 (1,55)	0.01 (1,56)	3.32 (1,57)	----	4.00
Cluster 3, 4	0.34 (1,31)	1.46 (1,32)	5.61 (1,33)	----	4.17

[a]Tabular *F* value statistic used to judge significance between parameters.
[b]Numbers in parentheseis represent degrees of freedom used to judge the *F* statistic

Table A.4.3. Partial lack-of-fit F test summary for post-seeding (PS) green foxtail emergence models between tillage system and eco-regional field location clusters (cluster) in 2000.

	Parameters held constant				
	a	*ab*	*abc*	*ac*	F value[a]
Tillage	0.00 (1,170)[b]	0.07 (1,171)	0.62 (1,172)	----	3.84
Cluster 1, 2, 3, 4	0.54 (3,158)	4.58 (3,161)	----	2.28 (3,161)	2.60
Cluster 1, 2	0.89 (1,61)	1.63 (1,62)	1.59 (1,63)	----	4.00
Cluster 1, 3	0.18 (1,78)	0.24 (1,79)	2.31 (1,80)	----	4.00
Cluster 1, 4	0.00 (1,81)	6.31 (1,82)	0.22 (1,78)	----	4.00
Cluster 2, 3	0.47 (1,76)	3.99 (1,77)	----	3.21 (1,82)	4.00
Cluster 2, 4	1.47 (1,79)	0.94 (1,80)	34.13 (1,81)	----	4.00
Cluster 3, 4	0.35 (1,96)	12.21(1,97)	----	4.87 (1,97)	3.92

[a]Tabular F value statistic used to judge significance between parameters.
[b]Numbers in parentheses represent degrees of freedom used to judge the F statistic

Table A.4.4. Partial lack-of-fit F test summary for pre- and post-seeding (PPS) green foxtail emergence models between tillage system and eco-regional field location clusters (cluster).

	Parameters held constant				
	a	*ab*	*abc*	*ac*	F value[a]
Tillage	0.02 (1,185)[b]	0.73 (1,186)	31.01 (1,187)	----	3.84
Cluster 1, 2, 3, 4	0.46 (3,148)	1.97 (3,151)	10.55 (3,154)	----	2.60
Cluster 1, 2	0.01 (1,62)	3.25 (1,63)	4.28 (1,64)	----	4.00
Cluster 1, 3	1.28 (1,77)	7.18 (1,78)	----	12.15 (1,78)	4.00
Cluster 1, 4	0.82 (1,70)	2.97 (1,71)	2.09 (1,79)	----	4.00
Cluster 2, 3	0.18 (1,77)	0.00 (1,78)	3.21 (1,72)	----	4.00
Cluster 2, 4	0.15 (1,70)	0.29 (1,71)	1.48 (1,72)	----	4.00
Cluster 3, 4	0.36 (1,85)	0.76 (1,86)	18.89 (1,87)	----	4.00

[a]Tabular F value statistic used to judge significance between parameters.
[b]Numbers in parentheses represent degrees of freedom used to judge the F statistic

Table A.4.5. Parameter estimates for accumulated soil temperature models for green foxtail emergence for tillage systems and eco-regional field location clusters (cluster) in the post-seeding (PS) period of 1999 and 2000 and the pre- and post-seeding (PPS) period of 2000.

	Post-Seeding 1999		Post-Seeding 2000		Pre- and Post-Seeding 2000	
	a	*b*	*a*	*b*	*a*	*b*
Tillage						
CT	27.3 (14.7)	12.4 (0.8)	10.9 (6.8)	13.4 (0.3)	-1280.8 (33.3)	12.5 (0.3)
ZT	32.7 (13.0)	14.5 (0.7)	-6.2 (6.3)	12.9 (1.3)	-1147.0 (30.2)	11.1 (0.2)
Cluster						
1	4.3 (23.2)	18.4 (1.5)	-0.7 (8.3)	12.6 (0.4)	-1096.0 (42.6)	10.7 (0.3)
2	33.2 (11.0)	12.0 (0.5)	13.3 (9.9)	12.5 (0.4)	-1242.9 (45.1)	12.1 (0.3)
3	2.9 (17.4)	17.7 (1.0)	-2.1 (7.8)	14.8 (0.4)	-1326.7 (38.3)	12.9 (0.3)
4	-2.2 (14.3)	17.3 (0.9)	-2.4 (7.8)	12.5 (0.3)	-1129.3 (38.7)	10.8 (0.3)

Table A.4.6. Partial lack-of-fit *F* test summary for post-seeding (PS) accumulated soil temperature models for green foxtail emergence between tillage systems and eco-regional field location clusters (cluster).

	1999			2000		
	----Parameters held constant----					
	a	*ab*	*F* value[a]	*a*	*ab*	*F* value
Tillage	0.07 (1,83)[b]	17.08 (1,84)	4.00	3.42 (1,172)	21.22 (1,165)	3.84
Cluster 1, 2, 3, 4	1.63 (3,81)	21.12 (3,84)	2.76	0.65 (3,170)	24.40 (3,165)	2.60
Cluster 1, 2	1.03 (1,47)	27.18 (1,48)	4.08	0.94 (1,71)	1.41 (1,61)	4.00
Cluster 1, 3	0.00 (1,23)	0.80 (1,24)	4.26	0.02 (1,88)	47.85 (1,92)	4.00
Cluster 1, 4	0.52 (1,25)	21.40 (1,26)	4.23	0.02 (1,91)	0.17 (1,92)	4.00
Cluster 2, 3	1.56 (1,55)	38.81 (1,56)	4.00	1.41 (1,78)	25.71(1,71)	4.00
Cluster 2, 4	52.27 (1,57)	198.52 (1,58)	4.00	268.39 (1,81)	81.00 (1,71)	4.00
Cluster 3, 4	0.08 (1,33)	1.27 (1,34)	4.17	0.00 (1,98)	78.67 (1,102)	3.92

[a]Tabular *F* value statistic used to judge significance between parameters.
[b]Numbers in parentheses represent degrees of freedom used to judge the *F* statistic

Table A.4.7. Partial lack-of-fit F test summary for pre- and post-seeding (PPS) accumulated soil temperature models for green foxtail emergence between tillage systems and eco-regional field location clusters (cluster).

	---------Parameters held constant------		
	a	*ab*	F value[a]
Tillage	8.87 (1,309)[b]	49.47 (1,310)	3.84
Cluster 1, 2, 3, 4	7.05 (3,307)	36.56 (3,310)	2.60
Cluster 1, 2	10.75 (1,129)	30.24 (1,130)	3.92
Cluster 1, 3	14.47 (1,160)	42.16 (1,161)	3.84
Cluster 1, 4	0.40 (1,146)	6.13 (1,147)	3.84
Cluster 2, 3	1.70 (1,160)	4.07 (1,161)	3.84
Cluster 2, 4	45.79 (1,146)	11.23 (1,147)	3.84
Cluster 3, 4	9.76 (1,177)	70.12 (1,178)	3.84

[a]Tablular F value statistic used to judge significance between parameters.
[b]Numbers in parentheses represent degrees of freedom used to judge the F statistic

Table A.4.8. Table of ANOVA outputs for average weekly percent gravimetric soil moisture (w/w), measured 2.5 cm below the soil surface, for green foxtail emergence for comparisons between tillage systems or between eco-regional field location clusters (cluster) separated into weeks. For pre- and post-seeding (PPS) weeks represent weeks after April 1, 2000.

Weeks	Tillage		Cluster	
	df[a]	F value	df	F value
1	1,7	2.93	3,7	0.22
2	1,20	10.96	3,20	1.15
3	1,26	21.77	3,26	2.43
4	1,24	14.75	3,24	1.56
5	1,27	1.99	3,27	1.26
6	1,15	5.22	3,15	1.56
7	1,28	11.31	3,28	11.05
8	1,17	10.33	3,17	2.79
9	1,23	1.51	3,23	2.83
10	1,19	4.12	3,19	0.74
11	1,8	0.05	3,8	1.35
12	1,2	1.78	3,2	2.93
13	1,0	---	3,0	---

[a] df represents degrees of freedom used to judge the F statistic.

Table A.4.9. Table of ANOVA outputs for average weekly percent gravimetric soil moisture (w/w) grouped into weeks after seeding (WAS) for green foxtail emergence for comparisons between tillage systems or between eco-regional field location clusters (cluster) in post-seeding (PS) in 1999 and 2000.

	1999				2000			
Weeks	Tillage		Cluster		Tillage		Cluster	
	df[a]	*F* value	df	*F* value	df	*F* value	df	*F* value
1	1,3	5.30	3,3	2.91	1,21	8.86	3,21	0.86
2	1,10	1.77	3,10	5.47	1,26	9.54	3,26	6.83
3	1,18	0.19	3,18	6.79	1,26	7.25	3,26	2.52
4	1,9	0.20	3,9	5.27	1,24	0.34	3,24	2.85
5	1,3	0.32	3,3	---	1,15	0.04	3,15	0.55
6	1,0	---	3,0	---	1,12	1.64	3,12	0.80
7					1,3	4.26	3,3	1.88
8					1,0	---	3,0	---

[a] df represents degrees of freedom used to judge the *F* statistic.

Table A.4.10. Comparison of numbers of emerged green foxtail plants (m^{-2}) from all sites, between 1999 and 2000 post-seeding (PS).

	1999	2000	LSD
	---no. m^{-2}---		
Year	86.9 b[a]	171.9 a	43.1

[a]Comparisons are between years; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).

Table A.4.11. Table of ANOVA outputs for comparison of numbers of emerged green foxtail plants (plants m^{-2}) between years, between tillage systems (conventional-tillage (CT) and zero-tillage (ZT)) and among eco-regional field location clusters (cluster) in the post-seeding period of 1999 and 2000, and the pre- and post-seeding period (PPS) of 2000.

	Post-Seeding						Pre- and Post-Seeding	
	All Sites		1999		2000		2000	
	df[a]	*F* value	df	*F* value	df	*F* value	df	*F* value
Years	1,260	15.04	N/A	N/A	N/A	N/A	N/A	N/A
Tillage	N/A	N/A	1,82	4.72	1,170	26.62	1,307	41.62
Cluster	N/A	N/A	3,82	68.42	3,170	8.45	3,307	13.69

[a] df represents degrees of freedom used to judge the *F* statistic.

Table 4.12. Percent gravimetric soil moisture (w/w), measured 2.5cm below soil surface, for all sites post-seeding (PS) in 1999 and 2000.

	1999	2000	LSD
	---% gravimetric soil moisture (w/w)----		
Year	20.4 a[a]	15.6 b	2.1

[a]Comparisons are between years; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).

Table A.4.13. Table of ANOVA outputs for percent gravimetric soil moisture (w/w), measured 2.5cm below soil surface, for years, tillage systems (conventional-tillage (CT) and zero-tillage (ZT)) and eco-regional field location clusters (cluster), averaged for the entire sampling period in the post-seeding (PS) period of 1999 and 2000, and the pre- and post-seeding (PPS) period of 2000.

	Post-Seeding						Pre- and Post-Seeding	
	All Sites		1999		2000		2000	
	df[a]	*F* value	df	*F* value	df	*F* value	df	*F* value
Years	1,226	17.42	N/A	N/A	N/A	N/A	N/A	N/A
Tillage	N/A	N/A	1,61	0.00	1,157	21.83	1,287	54.91
Cluster	N/A	N/A	3,61	10.42	3,157	5.01	3,287	8.49

[a] df represents degrees of freedom used to judge the *F* statistic.

Table A.4.14. Table of ANOVA outputs for average crop planting date (Julian days) for sampled fields containing green foxtail in 1999 and 2000 for all sites, conventional- and zero-tillage systems and for eco-regional field location clusters (cluster).

	All Sites		1999		2000	
	df[a]	*F* value	df[a]	*F* value	df	*F* value
Years	1,24	15.47	N/A	N/A	N/A	N/A
Tillage	N/A	N/A	1,4	0.02	1,12	0.62
Cluster	N/A	N/A	3,4	1.51	3,12	0.52

[a] df represents degrees of freedom used to judge the *F* statistic.

Table A.4.15. Comparison of average crop planting date (Julian days) for fields containing green foxtail in 1999 and 2000 for between years. Values in parentheses are standard errors.

	1999	2000	LSD
	---------------Average Planting Date--------------		
All Sites	147.2 (16.2) a[a]	129.9 (6.6) b	9.1

[a]Comparisons are between years; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).

Table A.4.16. Comparison of average crop planting date (Julian days) for fields containing green foxtail in 1999 and 2000 for between tillage systems (conventional-tillage (CT) and zero-tillage (ZT)) and among eco-regional field location clusters (clusters). Values in parentheses are standard errors.

	1999	LSD	2000	LSD
	------------------Average Planting Date-----------------			
Tillage		25.9		6.9
CT	144.8 (20.2) a[b]		132.4 (7.9) a	
ZT	148.8 (14.8) a		129.7 (4.2) a	
Cluster		40.1		10.0
1	151.0 (--)[a] a[c]		127.8 (7.3) a	
2	132.7 (19.3) a		131.3 (8.7) a	
3	148.3 (12.7) a		133.4 (5.1) a	
4	159.3 (9.8) a		130.8 (5.5) a	

[a]only one field in cluster 1 in 1999.
[b]Comparisons are between tillage systems or between clusters within years; means followed by the same letter are not significantly different at the 5% level as determined by LSD (0.05).
[b]LSD for comparisons between tillage systems within sampling period and year.
[c]LSD for comparisons between cluster within sampling period and year.

Table A.5.1. Partial lack-of-fit *F* test summary for post-seeding (PS) pre- and post-seeding (PPS) comparison of emergence models between wild oat and green foxtail species.

	Parameters held constant				
	a	*ab*	*abc*	*ac*	*F* value[a]
PS 1999	0.00 (1,181)[b]	2.68 (1,182)	6.46 (1,183)	----	3.84
PS 2000	1.65 (1,337)	10.01 (1,338)	----	1.58 (1,338)	3.84
PPS	1.74 (1,617)	19.95 (1,618)	----	7.50 (1,618)	3.84

[a]Tabular *F* value statistic used to judge significance between parameters.
[b]Numbers in parentheses represent degrees of freedom used to judge the *F* statistic

Table A.5.2. Parameters estimates for cumulative percent emergence models post-seeding (PS) in 1999 and 2000, pre- and post-seeding (PPS) of wild oat (WO) versus green foxtail (GF) species. Values in parentheses are standard errors.

	a	*b*	*c*
PS 1999			
WO	101.6 (5.2)	55.6 (37.8)	.019 (.003)
GF	101.5 (8.4)	18.5 (8.2)	.012 (.002)
PS 2000			
WO	95.5 (2.3)	70.2 (24.2)	.018 (.002)
GF	100.3 (2.8)	259.8 (121.3)	.018 (.002)
PPS			
WO	101.7 (3.4)	183.8 (66.2)	.011 (.001)
GF	95.4 (3.2)	6401.4 (5253.5)	.015 (.002)

Table A.5.3. Table of ANOVA outputs for average crop planting date (Julian days) for sampled fields containing wild oat and green foxtail in 1999 and 2000 for all sites.

	All Sites	
	df[a]	*F* value
Years	1,29	15.47

[a] df represents degrees of freedom used to judge the *F* statistic.