# EFFECT OF TILLAGE ON RECRUITMENT DEPTH OF FIVE WEED SPECIES MEASURED *IN SITU* IN ZERO AND CONVENTIONAL TILLAGE FIELDS IN MANITOBA

BY

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**FACULTY OF GRADUATE STUDIES**

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

**of**

**Master of Science**

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**ABSTRACT**

du Croix Sissons, Michelle Jacklin. M.Sc., The University of Manitoba, July, 1999. Effect of Tillage on Recruitment Depth of Five Weed Species Measured *in situ* in Zero and Conventional Tillage Fields in Manitoba. Major Professor; Rene Van Acker.

Knowing the depth of weed seedling recruitment and how tillage affects the depth of recruitment can help in the development of improved weed control methods. Weed seedling recruitment depth is a better measure of seed placement than weed seedbank counts. Depth of recruitment of wild oats (*Avena fatua* L.), volunteer wheat (*Triticum aestivum* L.), green foxtail (*Setaria viridis* L. Beauv), wild buckwheat (*Polygonum convolvulus* L.) and barnyard grass (*Echinochloa crus-galli* L. Beauv) seedlings were measured in 1997 and 1998. The survey included 44 zero tillage and 44 conventional tillage fields over the two field seasons. Detailed information for each field was collected from farmers involved in the survey, to allow for the development of a tillage index. A morphological marker was identified on wild buckwheat so recruitment depth of this weed could be measured in the field.

Weed seedling recruitment was shallower at pre-seeding sampling than at pre-spray sampling. Spring tillage or seeding disturbs the soil, exposing seeds to conditions that stimulate weed seedling recruitment. Weed seedling recruitment was shallower in zero tillage fields versus conventional tillage fields. The mean depth of recruitment in zero tillage fields, at the pre-seeding sampling period, for wild oats, volunteer wheat and wild buckwheat was 1.92, 0.75 and 1.64 cm, respectively. At the pre-spray sampling period in zero tillage, the mean depth of recruitment for wild oats, volunteer wheat, wild buckwheat and barnyard grass was 2.42, 2.11, 2.18 and 1.59 cm, respectively. The mean

depth of recruitment for green foxtail at the pre-spray sampling period was 2.45 and 1.86 cm for 1997 and 1998 respectively. In conventional tillage the mean recruitment depth at the pre-seeding sampling period for wild oats, volunteer wheat and wild buckwheat was 3.25, 2.79 and 2.5 cm, respectively. At the pre-spray sampling period the mean depth of weed seedling recruitment for wild oats, volunteer wheat, wild buckwheat and barnyard grass was 4.15, 3.74, 3.47 and 2.97 cm, respectively. The mean depth of recruitment for green foxtail at the pre-spray sampling period was 3.8 and 3.11 cm for 1997 and 1998 respectively. The lack of tillage in zero tillage fields results in the majority of weed seeds occurring near the soil surface. Dormant seeds deep in the soil profile are not brought up to the surface in zero tillage.

The amount of soil disturbance is the main factor that determines the depth from which weeds will be recruited. High tillage levels directly corresponded with increased depth of weed seedling recruitment. Other factors such as soil type and environment need to be examined more closely to determine to what extent they affect the depth of weed seedling recruitment. Determining the depth of weed seedling recruitment in zero and conventional tillage fields is the first step in the development of predictive recruitment models. Before the models are developed, farmers can determine the depth of weed seedling recruitment in their own fields and concentrate weed control at that depth.

# CHAPTER 1

## General Introduction

One of the greatest concerns of farmers is soil erosion and preserving soil quality for the future (Domitruk *et al*, 1997). Since the mid-1970's, farmers have been adopting zero tillage in Manitoba and North Dakota to help prevent soil loss and to regenerate soil organic matter (Coutts and Smith, 1991). The only soil disturbance that occurs with zero tillage is during seeding, harrowing or application of fertilizer (Brandt, 1992). Zero tillage does not only reduce erosion, it also increases water infiltration and conserves moisture by reducing evaporation (Brandt, 1992; Domitruk *et al.*, 1997; Buhler, 1995). In some soils, organic matter does not increase greatly, even after years of zero tillage. These soils, generally, already have high organic matter or have a high turnover of organic matter (Domitruk *et al.*, 1997). Other studies have shown that organic residues accumulate on the soil surface instead of in the soil profile in zero tillage (Brandt, 1992). Brandt (1992) indicated that there has been no conclusive data to-date that demonstrates an overall increase in soil organic matter as a result of zero tillage. Soil nitrogen levels in the first few years of zero tillage may decrease or fluctuate until an equilibrium is reached (Domitruk *et al.*, 1997). It has been reported in several long term tillage studies that differences in soil nitrogen levels due to tillage tend to disappear after several years (Brandt, 1992). The advantages of adopting zero tillage include reduced soil erosion, increased organic matter, more earthworms and better soil tilth (Domitruk *et al.*, 1997).

Tillage, in agricultural production has been used for several reasons: to prepare a crop seedbed, eliminate stubble that may harbour disease or interfere with seeding and harvest machinery, dry out and warm up seed beds in the spring, and to control weeds. Reduced levels of weed control has been a major concern preventing farmers from adopting reduced or zero tillage systems. There are several types of tillage that affect weed seed distribution in the seed bank. Most conventional tillage systems result in little plant residue being left on the soil surface. Generally, with reduced or minimum tillage systems at least 30% of the soil surface is left covered with plant residue. In Manitoba, reduced or minimum tillage typically involves only primary tillage with a chisel plough. In zero tillage, also know as no tillage or conservation tillage, soil disturbance is limited to the planting operation and in some cases fertilizer application and/or harrowing to distribute stubble.

Weed seedling recruitment is the successful germination and emergence of weed seedlings in a field (Harper, 1977). Successfully recruited seedlings have overcome all of the obstacles that would prevent seeds from recruiting and their populations are easier to measure than seeds in the seedbank. Weed seedling recruitment is affected by many factors in the field besides tillage, but many of these factors are the result of tillage. Weed seed dormancy is affected by depth of weed seed placement and the microclimate around the seed. Light is important in the recruitment of weed seeds, dormancy can be broken by light flashes that occur during tillage. Factors such as tillage, seeding practice, weed species, soil type and soil applied herbicides can affect depth of weed seedling recruitment (de la Cruz, 1974). Many experiments determining the depth of weed seedling recruitment have been conducted where the weed seeds were placed at specific depths in the soil, and natural weed populations were not used (Dawson and Bruns, 1975;

Wiese and Davis, 1966; Stoller and Wax, 1973). These experiments give an idea of the maximum depth of emergence of the weeds. In general there is decreased emergence percentages with increased depth of planting (Dawson and Bruns, 1975; Wiese and Davis, 1966). The major limitation of these experiments is the lack of knowledge of the effects of different management practices on seed movement. A few experiments have determined the depth of weed seedling recruitment in the field (de la Cruz, 1974; Chancellor, 1964b; Buhler and Mester, 1991). In these experiments the depth of recruitment was generally shallower in a minimum or zero tillage system than in a conventional tillage system.

Weed population changes occur at the species level, while weed community changes refer to changes that include all weed species (Derksen, 1996). Weed community and population changes between different tillage practices are important in the adoption of conservation tillage practices. Farmers will not adopt new tillage practices unless they are profitable. Understanding the influence of reduced tillage on weed communities and populations will allow new and better management of weeds. Crop rotation, tillage and herbicide selection can have a large impact on weed communities. If producers carefully plan varied crop rotations and consistently use herbicides from different chemical families, adoption of conservation tillage may be more successful (Blackshaw *et al.*, 1994). Knowing specific microsite requirements of weed species and the impact that agricultural practices have on microsites could help explain varied weed species responses to management practices employed (Derksen *et al.*, 1994).

Determining the depth of recruitment of several economically important weeds in Manitoba and how different management strategies affect the depth of recruitment could help in the development of improved weed control strategies.

# CHAPTER 2

## Literature Review

### Introduction

Weed seedbanks, and the effect of tillage and the environment on weed seedbanks has been extensively documented. Understanding how different factors affect the weed seedbank is an important link to the development of improved weed control. The weed seedbank dictates that weed seedlings will be recruited to compete with crop plants for space, nutrients and moisture. The problem with measuring weed seedbanks is that they do not provide the best measure of future weed seedling populations. Weed seedling populations are easier to measure and provide a more accurate account of future weed competition. Attempts have been made to document the affects of management and the environment on seedling populations. Changes in weed communities, the length of seed dormancy and maximum depths of weed seedling emergence have all been investigated. Information is lacking for the depth of weed seedling recruitment under actual field conditions. In this study I investigated *in situ* the effects of different field management on the depth of weed seedling recruitment.

### Seedbanks

A seedbank is all the seeds in the soil profile (Cavers, 1995). Thompson and Grime (1979) defined the seedbank as all detached viable seeds of a species at a specific time. This includes all individual seeds present both above and below ground. The seedbank accounts for the largest segment of many plant populations. For most wild type species, only a very small number of the viable seeds in the seedbank will germinate in one year (Harper, 1977). Many investigators have shown that large reserves of seeds can accumulate in arable soils (Baskin and Baskin, 1985).

Seedbanks are studied to further our understanding of plant dynamics. They reflect the effects of factors such as tillage, seeding practices, moisture and temperature changes. Researchers assume that seedbanks are the most comprehensive measure of weed communities. If this were true, the information derived from seedbank research could be used to predict the future year's weed seedling populations (Derksen *et al.*, 1998). Yet comparisons of seedbank numbers over time indicate that seedbanks are not good predictors of future weed problems. Procedures used to estimate the seedbank tend to over or under estimate seedbank densities and the number of seedlings that will be recruited (Ball and Miller, 1989). The germination method, allowing seeds to germinate under controlled conditions, results in under estimations of seedbank densities because it only accounts for non-dormant seed (Ball and Miller, 1989). This procedure can be made more precise if samples are allowed to sit for two or more years. The Malone extraction count, a procedure developed by Malone (1967), over estimates the number of seedlings that will be recruited, because it measures all of the seeds in the seedbank, the dormant, non-dormant and non-viable but still intact seed, not just the active seedbank (Ball and Miller, 1989). A relationship exists between the seedbank and the subsequent seedling populations, but the relationship will vary from year to year due to environmental factors, weed species present, seed dormancy and the condition of the soil surface (Ball and Miller, 1989).

The percentage of seeds that are successfully recruited is often very low. One estimation is that only about six percent of viable seed in the top 10 cm are likely to produce seedlings (Roberts, 1984). Zhang *et al.* (1988) predicted that the percentage of seeds in the seedbank that will give rise to seedlings in one year is only three to seven percent. Green foxtail (*Setaria viridis* L. Beauv.) seed counts are poorly related to subsequent seedling populations. Green foxtail weed seed counts taken by Ball and Miller (1989) were not related to weed seedling counts. They concluded that seed count estimates were poor predictors of green foxtail seedling densities. The best predictors of future weed seedling populations are the past year's seedling populations (Derksen *et al.*, 1998). The seedling population is also easier and less labour intensive to measure and it is the seedlings, not weed seeds, that cause crop yield loss (Derksen *et al.*, 1998). More research comparing seedbank, seedling and mature weed populations in the context of weed community dynamics in agricultural production is needed before seedbanks can be used as predictors for future weed problems (Derksen *et al.*, 1998). Also, the processes of seedling recruitment need to be better understood before seedbank data can be useful. Once these processes are understood we can look at a seedbank population and be able to confidently predict the percentage of seeds that will be recruited as seedlings. Still, the seedbank is difficult and labour intensive to study because of its variability and it remains that the best measurement of seedling populations may be previous seedling populations (Derksen *et al.*, 1998).

The seedbank can be divided into two groups, the transient group lasts for less than one year and the persistent group lasts for more than one year (Thompson *et al.*, 1977). Cavers (1983) defined several important points about seedbanks. He indicated that there are enormous numbers of viable seeds in arable soil and wetlands, but there are fewer seeds present in other types of habitats. Most buried seeds become non-viable within a few years, but there still are a significant number of weed seeds left in the soil. These may survive for many years and successfully germinate and emerge if conditions become favourable. Seeds buried deep in the soil profile remain dormant longer than seeds buried near the surface, but deeply buried seeds do not germinate and establish as well as shallow seeds. Each species has a unique seedbank in terms of longevity and dormancy. In addition, a single species can have one type of seedbank in one habitat and another in a different habitat (Cavers, 1983). Cavers (1983) gives an example of dwarf snapdragon (*Chaenorrhinum minus* L.) which has a persistent seedbank on railway tracks in North America and a transient seedbank on gravel riversides that are flooded every year in London, Ontario. Weed populations in the soil are variable (vary from field to field and within a field) and are influenced by soil environment and farming practice (Buhler *et al.*, 1997; Wilson *et al.*, 1985).

Weed species and numbers of seeds are not uniformly distributed in the soil. In cultivated soil the seedbank is usually composed of a few dominant species that are present in high numbers and comprise 70-90% of the total seedbank. These species are primary pests and are present at high numbers because of resistance to control measures and adaptation to cropping systems (Buhler *et al.*, 1997; Wilson *et al.*, 1985). Weed species that are high in number in the seedbank are generally those that have similar germination and growth patterns to the crops being grown (Wilson *et al.*, 1985). A few weed species are present in moderate numbers and represent about 10-20% of the total seedbank. These species are generally adapted to the geographic area, but not to the current production practices. Finally, there are many weed species present in the seedbank at very low densities. These are usually seeds from hard to control weed species, newly introduced species and seed from the previous crop (Buhler *et al.*, 1997; Wilson *et al.*, 1985). Many factors contribute to this association of weeds with crops, these include; similarity of seed size, time of ripening, time of germination and time of tillage and cropping and harvest practices (Wilson *et al.*, 1985). Pre-plant tillage and soil environmental conditions at planting have been shown to influence weed seedling emergence (Wilson *et al.*, 1985). The recruitment of seeds at or near the soil surface are highly influenced by environmental conditions.

Conditions that affect seedling recruitment include daily cycles of temperature and moisture, and long term effects of hydration and dehydration due to precipitation patterns. Species respond differently to conditions experienced at the soil surface. Seeds in the seedbank do not germinate continuously and seed germination generally follows a cyclical pattern. A seed has germinated once the radical or another embryonic organ appears through the seed coat or other enclosing structures (Taylorson, 1987). The largest flushes of weed germination and emergence occur in the spring as the soil warms up.

Modern agriculture has selected for weed seeds that are dormant and, this has lead to the creation of a large weed seedbank. Dormancy prevents germination of seeds even under conditions that are favourable to successful germination and emergence. Initial dormancy is often termed innate or primary dormancy. Dormancy occurring because of unfavourable environmental conditions is termed secondary or induced dormancy (Taylorson, 1987). Dormancy is an adaptation to seasonally unfavourable environmental conditions. It also allows weeds to survive weed control measures (Taylorson, 1987). Continuous weed control has reduced the number of non-dormant weed seeds and has selected for dormancy in weed populations. At the same time we have selected against dormancy in crop seeds. Crop plants do not need dormancy because they are placed in the ground each year at times and locations optimal for germination and emergence (Baskin and Baskin, 1985). Weedy races of crop plants generally have higher levels of dormancy and a larger seedbank than their cropped counterparts (Cavers, 1995). Some weed species may remain dormant, but viable, for 50 to 100 years or more (Baskin and Baskin, 1985). Three of 21 species buried in 1879 by W.J. Beal were viable after 100 years and 36 of 107 species buried by Duvel in 1902 were viable after 39 years (Baskin and Baskin, 1985).

In the soil, a number of variables act on weed seeds to affect their viability and dormancy. These factors act simultaneously or separately and include changes in exposure to light, moisture, temperature and gaseous environment (Taylorson, 1970). Location in the soil profile can affect the extent to which each of these factors acts upon the seeds. Seeds close to the surface will be exposed to more extreme conditions and will lose viability faster than seeds deeper in the soil profile (Taylorson, 1970). Most likely, a decline in the number of seeds in the seedbank is due to germination of seeds while they are in the soil. Generally, non-dormant seeds lose viability faster than dormant seeds. Seeds deeper in the soil will remain dormant longer than seeds at the soil surface, and generally, seeds need to be brought to the soil surface to germinate (Baskin and Baskin, 1985).

In wild oats (*Avena fatua* L.), primary dormancy is probably responsible for persistence of this weed in the soil, secondary dormancy was not evident in the field (Banting, 1962). Banting (1962) determined that after 13 years of continuous cropping, a minimum of five years of summerfallow is needed to eliminate wild oats from a heavy clay soil. He also found that the percentage of highly dormant seeds is maintained or will increase over time due to natural selection. Conn (1990) found that after 4.7 years of burial, wild oat and foxtail barley (*Hordeum jubatum* L.) seeds in Alaska had less than one percent viability. Although, Conn (1990) did remark that even such a low percentage of viable seeds could cause an infestation of wild oats. Miller and Nalewaja (1990) conducted experiments on wild oat longevity in Fargo and Williston, North Dakota. They found that seed viability and dormancy was affected by length and duration of burial and by nitrogen fertilizer rate. Seeds had greater longevity with deep burial and low levels of nitrogen. They proposed that seed longevity would most likely be lower under a zero tillage or a conservation tillage system where the majority of the seeds reside near the surface (Miller and Nalewaja, 1990).

Dawson and Bruns (1975) placed green foxtail, barnyard grass (*Echinochloa crus-galli* L. Beauv.) and yellow foxtail (*Setaria glauca* L. Beauv.) seeds at 2.5, 10 and 20 cm soil depths to determine the longevity of the seeds for these species. The largest number of weeds emerged from the 2.5 cm depth for all species, only a few seedlings emerged from seeds placed at 10 cm and no seedlings emerged from seeds placed at the 20 cm depth. The seeds that had the greatest viability were those exhumed from the 10 and 20 cm depths and seeds remained viable longer at the 20 cm depth (Dawson and Bruns, 1975). Vanden Born (1971) had similar results with green foxtail seeds grown in soil conditions that resembled conventionally tilled fields in central Alberta with respect to moisture, compaction and aeration. A large number of seeds germinated from the 0.5 to 8 cm depth in well drained soil. The emergence from 10 cm took a few days longer, and the emergence percentage for seeds placed at 12 cm was only 7% (Vanden Born, 1971). Barnyard grass had the lowest levels of dormancy over time and yellow foxtail had the longest levels of dormancy of the three species (Dawson and Bruns, 1975). After 13 years of burial a few seeds, of each species tested were able to germinate. After 15 years of burial no viable seeds remained. Most of the seeds that became non-viable in the soil at the 10 and 20 cm depths did not germinate before becoming non-viable, so those seeds were actually prevented from even germinating (Dawson and Bruns, 1975).

Thomas (1986) tested the longevity of green foxtail seeds by burying packets of seeds at 1.0, 2.5, 5.0, 7.5, 10.0 and 15.0 cm. There were increasing levels of viability with increasing depths of green foxtail seed placement. After 17 years of burial no viable seeds remained. To prevent green foxtail seeds from becoming dormant and developing a persistent seedbank, fields should not be deep tilled. A shallow tillage of no more than 10 cm should be performed on Canadian prairie soils to promote a rapid depletion of the seedbank (Thomas, 1986; Vanden Born, 1971).

Wild buckwheat (*Polygonum convolvulus* L.) seeds have been reported to have a high level of longevity in an undisturbed soil. Lewis (1973) reported that wild buckwheat seeds were still viable after being buried for 32 years in a pasture. This was an undisturbed site and the longevity of viability may be reduced under a conventionally tilled field.

**Emergence of weed seeds as affected by environment**

**Light.** Light has a significant effect on the germination of weed seeds. It can either inhibit or promote germination (Taylorson, 1987). Phytochrome in seeds is a receptor for red and far-red light. Red-light can promote germination in weed seeds and far-red light can inhibit germination (Taylorson, 1987). Phytochrome is present in two forms in the seed, an inactive form and an active form (Taylorson, 1987). Gross evidence of this is the observation than in annual cropping systems the number of weeds appearing before cultivation are fewer than after cultivation (Wesson and Wareing, 1969a).

No more than 10% of the total number of seeds will germinate when disturbed in the dark. This suggests that light plays a major role in the germination of buried seeds (Wesson and Wareing, 1969a). Light is important for the stimulation of germination in any disturbed habitat. Seeds need to be exposed to light for a brief moment to stimulate germination (Scopel *et al.*, 1994; Tester and Morris, 1987). The exposure to a light flash can cause a significant increase in weed seedling numbers (Wesson and Wareing, 1969a). Greater germination of weeds has been shown to occur when daytime tillage was preformed with a moldboard plough; a form of tillage that effectively moves seeds between different layers in the soil (Scopel *et al.*, 1994). Wesson and Wareing (1969b) conducted a detailed study examining the effect of light on germination. The germination of *Papaver dubium* (L.), *Plantago lanceolata* (L.), and *Spergula arvensis* (L.) were unaffected or slightly inhibited by light exposure. Seeds of *Rumex crispus* (L.), *Senecio jacobaea* (L.) and *Sonchus asper* (L. Hill) were stimulated to germinate when exposed to light after a period of burial.

Germination of seeds buried deep in wet soil may be inhibited by more than just a lack of light. The lack of oxygen and other gases has an effect on germination of seeds. Some gases act as inhibitors of germination and are the product of seed metabolism (Wesson and Wareing, 1968b). It is assumed that germination is prevented initially by the presence of inhibitors, and when seeds are held imbibed in the dark they develop a light sensitivity (Wessing and Wareing, 1968b).

Transmittance of light through the soil is affected by soil particle size, moisture content and colour (Benvenuti, 1995; Tester and Morris, 1987). A decrease in soil particle size causes a decrease in the amount of light transmittance. An increase in soil moisture content increases light transmittance in sandy soil, but decreases transmittance in a silty soil. Silts and loams tend to compact when wet and reflect low amounts of light. Light coloured soil particles allow light to penetrate further than dark coloured soil particles (Tester and Morris, 1987). The dark colour of organic soil greatly decreases the amount of light transmittance even in the thinnest of soil layers (Benvenuti, 1985). Because, light penetration through the soil is poor, the proportion of total seed in the seedbank receiving light after tillage is small (Scopel *et al.*, 1994; Tester and Morris, 1987). Light, in all types of soil, failed to penetrate effectively below 4 mm (Benvenuti, 1995). Germination levels in seed located below 4 mm of soil were almost identical to germination levels of seed kept in darkness.

The relative importance of light in stimulating germination in seed is dependent on the ecological niche in which the seed is found. Shading by vegetation or litter can affect light quality and quantity. Increased roughness in the soil surface increases the amount of light penetration, especially if the soil is highly disturbed. A greater surface area, exposed as a result of tillage, results in an increase in the number of seeds receiving light. Cracks in the soil surface also allow for greater penetration of light (Tester and Morris, 1987). Light is important in stimulating germination of weed seeds, but it is not the only environmental factor responsible for germination. Temperature and precipitation patterns also have a marked effect on germination. Weed seeds will not germinate and emerge under conditions of extreme soil temperature or soil moisture (Buhler, 1997; Pons, 1991). Tillage in the dark may prevent germination of weeds seeds that require a light flash, but it may select for weeds that do not require a light flash in order to germinate (Buhler, 1997).

Wild oat recruitment may be inhibited by exposure to light flashes, white, blue and far-red light may inhibit recruitment to the greatest extent (Sharma and Vanden Born, 1978). Covering wild oat seeds with soil may stimulate recruitment (Sharma and Vanden Born, 1978). Green foxtail recruitment was reported to be higher under natural light than under light filtered through plant canopies. This may be the effect of differing levels of far red to red light (Douglas *et al.*, 1985). Several studies have reported that light does not effect recruitment of wild buckwheat seeds (Hume, 1983).

**Temperature.** Weed seeds can germinate and emerge over a wide range of temperatures, from 5° C to greater than 40° C. A seed that is weakly dormant may be recruited over a wider range of temperatures than a seed that is highly dormant. A gradual loss of dormancy will occur with seeds stored at room temperature, prolonged viability of a seed is dependant on low temperatures. Temperatures of greater than 20° C may accelerate the process of after ripening (Taylorson, 1987). Some weeds have specific ranges of temperature over which recruitment is greatest. Green foxtail, for example, has optimum germination at 15 to 35° C, but maximum germination rate was achieved at 35° C (Vanden Born, 1971). Temperature has a great effect on the rate of induction of seeds that require light to germinate or dark dormancy of seeds. At low temperatures, dark dormancy in seeds will be induced at a very slow rate. A light flash in the winter may break dark dormancy, allowing seeds to germinate in the spring when the temperatures rises (Pons, 1991).

The optimum temperature for wild oat seedling recruitment has not been conclusively determined. Generally, wild oats prefer cooler temperatures, although recruitment may be limited below 15° C and above approximately 25°C (Sharma and Vanden Born, 1978). Maximum recruitment levels for green foxtail are between 20 to 30° C. If the temperature decreases to between 15 to 20° C time to 50% recruitment was increased significantly (Douglas *et al.*, 1985). Wild buckwheat is adapted to a wide range of environmental conditions and, therefore, recruitment can occur under a wide range of temperatures (Hume *et al.*, 1983). Barnyard grass has similar temperature requirements to green foxtail (Dawson and Bruns, 1962).

**Gaseous Environment.** Weed seeds need oxygen to meet metabolic requirements for germination, and in the process of germination carbon dioxide is released (Taylorson, 1987). It was previously thought that an increase in carbon dioxide levels inhibited germination, but the carbon dioxide levels in upper soil layers is seldom greater than 1% and an increase of 10% would be needed to affect germination (Baskin and Baskin, 1985; Taylorson, 1987). Oxygen levels would have to be reduced to 5 % or less in the soil to affect germination and the soil rarely contains less than 19% oxygen. Therefore, the oxygen to carbon dioxide ratios do not significantly impact germination rates of weed seedlings. As oxygen levels decrease in the soil, levels of acetaldehyde, ethanol, and acetone accumulate in amounts sufficient to inhibit germination (Baskin and Baskin, 1985; Taylorson, 1987).

**Moisture.** Moisture levels influence seed germination during initial imbibition and during extremes in moisture availability after imbibition. Unless seeds are tolerant to flooding, extreme amounts of water can cause anoxia which is detrimental to seed viability (Taylorson, 1987). When excessive moisture, in early spring or fall, causes periods of nearly anaerobic conditions, seed dormancy can either be broken or induced. The relationship between weed seeds and soil moisture and how dormancy is maintained or broken, is not completely understood (Taylorson, 1987).

Wild oat recruitment is highest under moist soil conditions (Sharma and Vanden Born, 1978). Soil moisture had a greater effect on green foxtail recruitment than temperature (Blackshaw *et al.*, 1981). Blackshaw *et al.*(1981) determined that green foxtail is more sensitive to changes in environmental conditions than wheat. Barnyard grass has been reported to have low levels of recruitment under dry conditions, especially where crusts form after a rainfall (Wiese and Davis, 1966).

**Response of the weed seedbank to tillage.**

Tillage has a significant effect on the density of weed seeds in the seedbank, species composition in the field, and location and distribution of seeds in the seedbank. A change in tillage system will change the composition, vertical distribution and density of weed seeds in agricultural soil (Buhler *et al.*, 1997). Fallowing land to control weeds has been practiced for many years and has been proven to be very successful. At Morris, Minnesota an experiment was conducted to determine how long it takes to eliminate wild mustard (*Brassica kaber* (D.C) L.C. Wheeler) seed from the seedbank using various tillage and chemical practices. In this experiment, moldboard ploughing was performed three times per year. After seven crop years, less than three percent of the original weed seeds in the viable seedbank remained (Warnes and Anderson, 1984). However, this level of tillage for weed control is impractical (Warnes and Anderson, 1984). In the same study, tillage and crop rotation, together, had intermediate effectiveness in reducing viable weed seed numbers. Continuous bromegrass and continuous chem-fallow were least effective in reducing viable weed seed numbers (Warnes and Anderson, 1984). Derksen *et al.* (1994) has indicated that, in Saskatchewan, competitive crops may be as successful as a crop-fallow rotation in controlling weeds.

Increased soil organic matter resulting from less tillage can also influence the weed seedbank via increased activity of soil borne organisms such as earthworms, bacteria, fungi, algae, protozoa, nematodes and insects (Cavers, 1995; Domitruk, 1997). Besides eating and destroying weed seeds, these organisms deposit waste around weed seeds. The increased nitrogen levels can break seed dormancy, causing a greater emergence of weed seeds (Cavers, 1995). Reduced tillage can also lead to an increase in soil borne pathogens because of increased residue levels. Some of these pathogens can kill weed seeds in the soil. Decreased soil temperature and the prevention of light penetration are also the result of increased levels of residue and these may reduce or delay emergence of weeds (Dyer, 1995). Harper (1959) demonstrated that there was a longer dormancy period in weed species as depth of seed placement increases. With zero-tillage there were no seeds buried so the numbers of weed seeds in the seedbank should decrease, although some weed species have higher dormancy at the soil surface. (Cavers, 1995).

Derksen *et al.* (1998) determined that the year of assessment had a greater effect than tillage on weed species community composition of seedbank and residual weed populations. For seedling (pre-spray) communities, the order of importance was reversed and tillage had a greater impact on the species composition than did the year of assessment. This indicates that weed management strategies could be based on tillage system, despite annual influences on weed community composition (Derksen *et al.*, 1998). Differences in total weed densities between tillage systems did not exist in the seedbank or the residual weed communities, but densities did differ in the seedling communities. This indicates that recruitment is delayed in zero-tillage. This may provide an explanation for greater crop yields in zero-tillage despite the presence of weeds (Derksen *et al.*, 1998).

The extent and depth of weed seed distribution is directly related to the amount of soil disturbance (Dyer, 1995). Tillage is the primary cause of vertical weed seed movement in soil (Buhler *et al.*, 1997). Inversion tillage, such as moldboard ploughing, tends to uniformly distribute seed throughout the soil profile (Ball, 1992; Buhler *et al.*, 1997; Dyer, 1995). Cousens and Moss (1990) tried to determine how tillage affected seed movement by monitoring coloured bead movement in the soil. The first year of moldboard ploughing moved seeds deep into the soil, during the second year, the beads were moved to the surface. It took five years to obtain a stable seed distribution in the soil. In soil that was ridge tine cultivated it took ten years to reach a stable bead distribution. After 20 years of tillage the two systems had similar bead distributions. Using beads to indicate what is happening with seeds is not always accurate because beads are added only once and weed seeds are added every year (Cousens and Moss, 1990). Seeds have been found at depths up to 32 cm after moldboard ploughing compared to depths of only 12 cm following chisel ploughing (Buhler *et al.*, 1997). Moldboard ploughing also moves older seed to the surface while burying young or freshly shed seed via soil inversion (Ball, 1992; Yenish *et al.*, 1992).

Minimal tillage systems in which the soil is not inverted (ie. chisel plough) cause a concentration of large portions of seed at or near the soil surface. Chisel ploughing may cause a more uniform seed age distribution in the soil compared to moldboard ploughing, because it does not result in an inversion the soil (Yenish *et al.*, 1992). In fields that were moldboard ploughed, fewer weed seeds were found in the upper 5 cm after five years compared to fields that were chisel ploughed or not tilled. In zero-tillage, 60% of seeds were found in the top 1 cm of the soil and few seeds were found below 10 cm. In comparison, fields that were chisel ploughed had about 30% of seeds in the top 1 cm of the soil (Ball, 1992; Buhler *et al.*, 1997; Dyer, 1995). Yenish *et al.* (1992) reported that chisel plough and zero-tillage plots had approximately 60% more seeds in the top 19 cm of soil than plots that were moldboard ploughed. In an undisturbed ley the majority of the seeds were found on or near the soil surface. Both the number of seeds and the number of species found decreased with increasing depth (Roberts, 1963). Pareja *et al.* (1985) recovered seeds from depths of 20 cm even if no tillage was performed. In reduced tillage 85% of the seed was in the upper 5 cm of the soil, only 25% was in the same layer under conventional tillage. Seeds closer to the soil surface have a greater chance of germinating and emerging successfully (Ball, 1992; Paraja *et al.*, 1985). Seeds on the surface of the soil, however, are more liable to be eaten by predators, or to decay (Yenish et al., 1992).

The potential for increased weed infestations in fields exists where tillage methods are practiced that leave the majority of the seed near the soil surface. As such, better management strategies are needed to prevent severe weed problems from developing (Ball, 1992; Yenish *et al.*, 1992). It is possible that chisel plough and crop rotations can be combined to accelerate the decline of weed seedbanks. Vertical seed distribution in seedbanks plays a more important role in weed community shifts among tillage systems than does the amount of surface residue (Buhler *et al.*, 1997). The effect that secondary tillage has on seed distribution in the seedbank is minimal compared to primary tillage (Staricka *et al.*, 1990). As more cultivation is performed a finer seed bed is created, through which tillage implements pass more easily and, therefore, causing less seed movement than in hard packed soil (Rew and Cussans, 1997).

Seed movement also depends on soil texture, structure, moisture and type, and speed of cultivation (Rew and Cussans, 1997). Where seeds are positioned in soil structural units also has effects on where seeds will be distributed in the soil profile after tillage. Paraja *et al.* (1985) found weed seeds in most soil fractions, even in the absence of tillage, however, greater numbers occurred in the unaggregated fraction in zero tillage fields. Weed seeds were distributed evenly among various soil aggregate size classes in conventional tillage fields. Tillage not only moves seeds deeper into the soil profile, but also, into larger soil aggregates. The seeds inside the soil aggregates are exposed to high moisture concentrations and low oxygen tensions that inhibits germination and promotes dormancy (Paraja *et al.,* 1985; Pareja and Staniforth, 1985). Cousens and Moss (1990) indicated that all seeds will move with the soil regardless of their size and shape, therefore, seed distribution should be similar among species. Fine seed beds provide better weed seed-soil contact and, therefore, a better chance for germination when compared to coarse seedbeds (Pareja and Staniforth, 1985). Soil structure creates a heterogeneity of soil environments that, in turn, creates a variety of microsites for weed seeds. There may be several sub-populations of weeds in different microsites. The requirements for germination may be similar among weed species but the time at which each microsite provides the optimum conditions for germination may differ (Pareja and Staniforth, 1985).

Weed species that can germinate and become established at the soil surface, such as small seeded grasses and broadleaf weeds, have the greatest potential to flourish under reduced tillage systems (Buhler *et al.*, 1997; Dyer, 1995). Moldboard ploughing buries these seeds at depths too great for successful germination and emergence so that seedling numbers would be expected to decline unless subsequent tillage occurs (Buhler *et al.*, 1997; Dyer, 1995; Yenish *et al.*, 1992). Large seeded weeds that remain near the surface in conservation tillage systems are inhibited from establishing. Large seeded weeds have seeds that are too large to fall into soil cracks in most soil types, preventing good soil to seed contact (Buhler *et al.*, 1997; Warnes and Anderson, 1984). Deeper burial of these species contributes to re-infestation following subsequent tillage (Buhler *et al.*, 1997).

Experiments in England have shown that after five years of zero tillage the number of seeds remaining in the seedbank is two to four times higher than in cultivated soil. In addition, seed number increased with increasing depth of burial (Dyer, 1995; Roberts and Feast, 1972; Yenish *et al.*, 1992). For many weed species, burial of seeds, even at a shallow depth is sufficient to suppress germination and favour the survival of weed seeds (Chepil, 1946; Chepil, 1949; Roberts and Feast, 1972). Roberts and Feast (1973b) reported that the loss of viable seeds was 34% per year in undisturbed soil. When the number of cultivation events increased to seven per year, loss of viable weed seed increased to 50% per year (Roberts and Feast, 1973b; Roberts and Dawkins, 1967). The number of viable seeds in the seedbank is greater in untilled soil because tillage promotes germination of seeds (Roberts and Dawkins, 1967). Viability levels of seeds of *Poa annua* (L.), *Stellaria media* (L.) Vill. and *Capsella bursa-pastoris* (L. Medicus) decreased at a rate of about 50% per year in tilled soil, while for *Chenopodium album* (L.) the rate was about 40% per year. *Avena fatua* (L.) seed survival decreased at a rate of 25% per year in undisturbed soil. This rate increased to 80% in the first year when the plots were moldboard ploughed, and the rate of viability decrease in a yearly moldboard ploughed system was 50 to 60% per year. The rate of decrease was significantly higher in plots that were moldboard ploughed four times per year compared to plots that were moldboard ploughed two times per year (Roberts and Dawkins, 1967). Thurston (1961) found that wild oat seeds could survive longer in undisturbed soil than in cultivated soil. A seed's ability to recruit from deep soil depths decreases with length of burial period. The spring flush of weeds may represent only four percent of the viable seeds in the soil, indicating that it would take several years to reduce weed seedbank populations (Roberts and Dawkins, 1967). Chepil (1946) found that wild oat seed had a maximum dormancy of three to four years. He found that 80% of viable seed germinated in the first year, 18% in the second, and 2% in the third year. By the fourth year, only two seeds out of several thousand germinated at Swift Current, Saskatchewan. Seeds produced at different points on the spikelet of wild oats had different levels of dormancy. The seeds from the secondary florets of the spikelet had greater dormancy than the larger seeds originating at the base of the spikelet (Chepil, 1946). Cultivation should induce the majority of these seeds to germinate in the first year. Since wild oat seeds will not geminate readily when lying on the soil surface, Chepil (1946) suggested that in order to better manage wild oats, soil should be tilled to bury seeds at a depth where they will readily germinate.

When weed seeds fall on the soil surface, shallow tillage may increase germination levels because shallow burial can stimulate germination. Inversion of soil by moldboard ploughing decreases emergence of some seeds that initially fall on the soil surface. It also increases seed survival by burying seeds beyond the reach of surface hazards such as predation and fluctuating temperature and moisture conditions. The soil environment is changed (decreasing temperature, increasing moisture and maintaining the seed in darkness) in a way that promotes seed survival (Chepil, 1946; Chepil, 1949; Mohler and Galeford, 1997). Mohler (1993) observed two types of germination patterns in response to tillage. A monotonic decrease in seedling emergence in response to increasing depth and a non-monotonic response, where shallow burial increased emergence levels but deep burial decreased the amount of seeds germinating. The effect of tillage on an entire seedbank depends on the initial vertical distribution of seeds in the soil profile and subsequent movement by tillage (Mohler and Galeford, 1997). If seed return is prevented, seed populations will decline more rapidly in cultivated soil than in undisturbed soil, but seedling populations will initially be greater in tilled fields (Froud-Williams *et al.*, 1983). It is almost impossible to prevent all seed return and freshly shed seed will always be a problem. If zero tillage is being practiced, any cultivation will exhume buried seed and reduce any benefit of weed control previously obtained (Froud-Williams *et al.*, 1983).

**Depth of weed seedling recruitment as affected by tillage.**

The amount of soil disturbance is an important factor in determining the depth of weed seedling recruitment (de la Cruz, 1974). In Arlington, Hancock and Janesville, Wisconsin giant (*Setaria faberi*) and green foxtail seedling emergence depths were found to be shallower in zero tillage treatments than in chisel plough treatments. The deepest recruitment depths were from moldboard plough plots (Buhler and Mester, 1991). In a study by de la Cruz (1974), 50% of weed recruitment in zero tillage occurred in the top 1 cm. Buhler and Mester (1991) reported that 40% of weeds emerged from depths of 0.5 to 1 cm in zero-tillage. In plots that were chisel ploughed, 16% of weeds emerged from this same depth range. Only 10% germinated from the 0.5 to 1 cm depth in conventional tillage plots. These measurements were made on natural weed seedling populations found in the field. Grassy weeds were removed from the sôil cores by Buhler and Mester (1991) and measured from the seed or seed scar to the soil surface. De la Cruz (1974) measured depth of weed seedling recruitment by taking soil cores as well. He measured grassy and broad leaf weeds because he was able to identify point of germination (morphological marker) on smartweed (*Polygonum pensylvanicum* L.) and velvetleaf (*Abutilon theophrasti* Medicus).

Yenish *et al.* (1992) found that recruitment of weed seeds was 9 to 10% higher in moldboard ploughed and chisel ploughed plots respectively, when compared to zero tillage plots. He found no differences in percent recruitment at different depths in zero tillage. In plots that were chisel ploughed there was a small decreases in percent recruitment with increasing depth of seed placement from around 30% close to the surface to 22% at 14 to 19 cm deep. Moldboard ploughing caused large increases in percent recruitment as depth of seed placement increased from the soil surface (19%) to 14 to 19 cm deep (38%) (Yenish *et al.*, 1992). Buhler and Mester (1991) found that overall, emergence depths were similar under conventional tillage and chisel plough treatments, but the emergence depths were shallower in zero tillage plots.

Dawson and Bruns (1962) placed green foxtail, barnyard grass and yellow foxtail seeds at 1.25 cm intervals from the soil surface to 12.5 cm deep to determine the depths at which these weeds could emerge. All three weeds could recruit from depths as deep as 10 cm, but the majority emerged from depths of less than 7.5 cm. Deep recruitment can cause unique weed problems, including the possibilities that they may escape pre-emergent herbicide applications via delayed emergence (Dawson and Bruns, 1962). The seeds that successfully emerged from deeper in the soil were usually larger and had greater food reserves (Dawson and Bruns, 1962).

Chancellor (1964b) has indicated that different species can germinate from different depths. Some weed species, such as *Matricaria recutita* (L.) and *Papaver rhoeas* (L.), can only recruit from depths of less than 3 cm. Species such as *Polygonom convolvulus* (L.) and *Veronica hederifolia* (L.), however, can recruit from as deep as 13 cm. The majority of weed species have a moderate range of recruitment depths (from the soil surface to 7 cm) (Chancellor, 1964b; Zhang *et al.*, 1998).

Seeds that are able to recruit from deep in the soil may be able to do so because of larger seed size and greater food reserves, or they are able to recruit under a wider range of environmental conditions (Chancellor, 1964b). Weed seedling recruitment in large groups can have deeper recruitment than weed seedlings that are recruited as individuals, because the combined force of the group allows them to push through greater depths of soil (Zhang *et al.*, 1998). This has been observed for *Seteria viridis*, *Seteria glauca*, *Seteria faberi* (Herrm.) and *Abutilon theophrasti* (Zhang *et al.*, 1998).

Fall or spring tillage may also create conditions that are favourable for deeper weed recruitment. It is not known if small seeded weeds positioned deep in the soil profile germinate but fail to emerge or if they remain dormant until they are moved closer to the soil surface. It is suspected that they do not germinate when deep in the soil, since, if this were the case, the viable seedbank for many species would be more quickly depleted then has been observed (Chancellor, 1964b).

Chancellor (1964a) comments that soil type is not important in determining from what depth seeds can recruit. This is contrary to findings from Dawson and Bruns (1962). Dawson and Bruns (1962) indicated that the deepest recruitment depths of barnyard grass, green foxtail and yellow foxtail seedlings would occur in a fine sandy loam. Recruitment was greater at deeper depths in light sandy soil compared to heavier soil types (Dawson and Bruns, 1962; Zhang *et al.*, 1998).

De la Cruz (1974) determined the depth of weed seedling recruitment of velvetleaf (*Abutilon theophrasti*), smartweed (*Polygonum pensylvanicum*) and three species of foxtail (*Setaria glauca, Setaria viridis* and *Setaria faberi*). Soil cores of weed seedlings in the field were taken, to determine *in situ* recruitment depth. Several fields were sampled to determine the effect of different soil types on depth of recruitment. De la Cruz (1974) determined that the majority of seedlings germinated at 1.0 to 2.5 cm depths in the soil under field conditions. A clear trend of shallower emergence occurred under zero tillage. The average depth of weed seedling recruitment in tilled plots was nearly twice what was measured in zero tillage plots. Species buried in lighter soil under conventional tillage had a better chance of germinating from greater depths than in a heavier soil (de la Cruz, 1974). Grassy weeds were able to germinate and emerge from deeper soil depths than broadleaf weeds. This is because the soil creates more resistance to the expanding cotyledons of broadleaf weeds than it does to the narrow coleoptile of grassy weeds (de la Cruz, 1974). Overall, de la Cruz (1974) concluded that weed seeds germinate and emerge from relatively shallow depths in the soil. In zero tillage, seeds tended to germinate from extremely shallow depths, 50% of seedlings recruited from shallower than 1 cm.

A seedbed that was smooth and even, promoted maximum herbicide efficacy of soil applied herbicides. Tillage methods used had a significant effect on recruitment depths but there was no significant effect associated with herbicides used. The depth of weed seedling recruitment in plots treated with trifluralin was similar to weed recruitment depth in untreated plots. The recruitment depth for weed seedling when other herbicides were used was slightly shallower (De la Cruz, 1974).

**Effect of tillage on weed seedling communities.**

The ecological theory predicts greater species diversity at low levels of soil disturbance (Clements *et al.*, 1996). This is supported by data of Clements *et al.* (1996) who reported that moldboard ploughing resulted in the fewest weed species while zero tillage resulted in the greatest number of different weed species. Moldboard ploughing actually prevents the establishment of a diverse weed community. Disk and chisel ploughing promote the establishment of a more diverse weed community because stubble and soil clods left on the surface provide a greater diversity of microsites (Feldman *et al.*, 1998). Anderson (1994) indicated that tilling the soil increased the number of seedlings emerging within the weed community, but the community emergence patterns were not affected, in other word the same species were present in each system. The response of individual weed species was the same, where tillage increases the magnitude of emergence, but not the emergence pattern (Anderson, 1994). Clements *et al.* (1996) attributed greater weed species diversity in zero tillage and chisel tillage systems to an increase in the number of perennial weed species. Derksen *et al.* (1993) and Frick and Thomas (1992) found that most species present were not associated with any specific tillage system. In fact, Frick and Thomas (1992) discovered that the top five most prevalent weeds were the same for each tillage system in Ontario. Differences in weed recruitment found between tillage systems may be due to high occurrences of a particular weed in one or two fields and Frick and Thomas (1992) indicated that the differences among tillage systems could be chance events. The same study indicated that the influence of tillage is less than that of the crop grown or the year in which the survey or experiment was conducted (Thomas and Frick, 1993). Thomas *et al.* (1994) compared zero and conventional tillage systems in Manitoba. They determined that tillage had a significant impact on 17 out of 23 weed species that were included in the survey. The Manitoba survey, indicated that some weed species had greater densities in zero tillage fields while other had greater densities in conventional tillage fields. The Manitoba study measured seedling populations and the Ontario study measured residual weeds. Differences in weed populations between tillage systems do not exist in the residual weed populations (Derksen *et al.*, 1998).

Foxtail barley (*Hordeum jubatum*), a perennial bunch grass, was difficult to control in zero tillage in Saskatchewan (Derksen *et al.*, 1993). Derksen *et al.* (1994) and Hume *et al.*, (1991) reported that foxtail barley was strongly associated with zero tillage continuous cropping. Effective control for perennial native species needs to be developed for zero tillage to continue in Saskatchewan (Derksen *et al.*, 1994).

Canada thistle (*Cirsium arvense* L. Scop.) and perennial sow-thistle (*Sonchus arvensis* L.) were present in both zero tillage and conventional tillage plots (Blackshaw *et al.*, 1994). Of all the perennial weed species found, dandelion (*Taraxacum officinale* Weber in Wiggers) was most commonly associated with zero tillage (Blackshaw *et al.*, 1994; Derksen *et al.*, 1993; Thomas and Frick, 1993). Thomas and Frick (1993) reported that fragmenting perennials such as field bindweed (*Convolvulus arvensis* L.), common milkweed (*Asclepias syriaca* L.) and Canada thistle, may be expected to decrease in zero tillage systems because regenerating structures would not be broken up and moved around. This is contrary to the Manitoba weed survey by Thomas *et al.* (1994), where dandelion, perennial sow thistle, quack grass (*Agropyron repens* (L.) Beauv.) and Canada thistle had higher densities in zero tillage fields versus conventional tillage fields. Some studies indicated that perennial weeds increased in zero tillage, but Blackshaw *et al.* (1994), Derksen *et al.* (1993) and Derksen *et al.* (1994) did not find this to be true.

Annual grassy weeds have often been reported to be associated with zero tillage, but this was not the case in a study by Derksen *et al.* (1993). Wild oats were associated with zero tillage in three of seven site years in Saskatchewan, but green foxtail was not associated with any one tillage system (Derksen *et al.*, 1993; Derksen *et al.*, 1994). Thomas *et al.* (1994) also reported higher densities of wild oats in zero tillage versus conventional tillage in Manitoba. Froud-Williams (1981) indicated that wild oats decreased in zero tillage due to a greater loss of seeds on the soil surface. Green foxtail densities were higher in conventional tillage fields versus zero tillage fields in a survey by Thomas *et al.* (1994). Buhler (1992) found that green foxtail control was often poorer in chisel ploughed plots and zero tillage plots than in conventional tillage plots where soil applied herbicides were used. Soil applied herbicides are not always as effective when used in minimal or zero tillage systems because of interception of herbicide by soil residue (Buhler, 1992). Hume *et al.* (1991) indicated that the most important factor affecting the presence of green foxtail was crop rotation. There were very high densities of green foxtail under continuous cropping with much lower densities when one year of fallow was included.

Wind disseminated species, along with winter annuals, were highly associated with zero-tillage (Derksen *et al.*, 1993). Volunteer crop species were generally associated with zero or minimal tillage, but this was not consistent (Derksen *et al.*, 1993; Thomas *et al.*, 1994).

Annual dicot species have been associated with conventional tillage systems Derksen *et al.* (1993). Weed communities often fluctuate and are dependant on environmental conditions and location, and may be affected by relative timing of management (Derksen *et al.*, 1993). Blackshaw *et al.* (1994) and Cardina *et al.*, (1991) found that the annual dicot, redroot pigweed (*Amaranthus retroflexus* L.), sometimes increased in zero tillage plots versus minimal or conventional tillage plots. The germination of redroot pigweed is stimulated by light. It's hard seed coat allows it to survive the harsh conditions found at the soil surface and, therefore, it is well adapted to zero tillage systems (Blackshaw *et al.*, 1994; Buhler, 1992; Hume *et al.*, 1991). Oryokot *et al.* (1997) reported that at Elora and Woodstock, Ontario, redroot pigweed was not affected by tillage system, at all sites except in 1994 at Elora, where recruitment was delayed in the moldboard system because of a lack of moisture. Thomas *et al.* (1994) found increased densities of redroot pigweed in conventional tillage fields versus zero tillage fields in Manitoba. He stated that warmer temperatures in conventional tillage may stimulate the growth of redroot pigweed in Manitoba. Lamb's quarters (*Chenopodium album*) densities were not greatly effected by tillage systems (Blackshaw *et al.*, 1994), but densities were greater under chisel ploughing in Buhler's (1992) study. In studies by Teasdale *et al.* (1991) and Thomas *et al.* (1994) lamb's quarters seedling populations grew faster in conventional tillage compared to zero tillage plots. The reason for this is not understood because lamb's quarters seedling recruitment can occur at low temperatures and on the soil surface, therefore, tillage should not affect recruitment patterns (Teasdale *et al.*, 1991).

A study by Froud-Williams *et al.* (1984), found that the recruitment of small seeded species was reduced by burial. The establishment and emergence of large seeded species was improved by shallow burial (Froud-Williams *et al.*, 1984). Poor establishment of large seeded species from the surface indicates that surface recruitment for these species was generally unsuccessful because of inadequate moisture availability (Froud-Williams *et al.*, 1984).

**Effect of tillage on weed seedling populations.**

Wilson and Cussans (1975) reported that the greatest increase in seedling populations followed cultivation, and there was a lower number of seedlings in zero tillage plots. Chancellor (1964a) found the same response for arable weed seeds following a reasonable number of cultivations. He also found an inverse response between the number of weeds recruited and the number of cultivation events. A third response outlined was an intermediate response, where weed species respond to an intermediate number of cultivation events or to a specific timing of cultivation (Chancellor, 1964a). In contrast, Derksen *et al.* (1994) observed that, in Saskatchewan, there was no apparent trend between total weed density and tillage treatments. Weed communities were more similar within the continuous cropping treatments than in the crop fallow treatments. Growers already practicing continuous cropping may experience less of a change in weed communities when switching to zero tillage than when switching from fallow to zero tillage (Derksen *et al.*, 1994). In continuous wheat and a wheat-canola rotation, zero tillage plots in Alberta often had more weeds than minimal tillage or conventional till plots (Blackshaw *et al.*, 1994). Wrucke and Arnold (1985) determined that total grass yield was significantly greater in zero tillage than in systems where either disk or plough were used, but yields for broad leaf weeds were not different.

Egley and Williams (1990) reported a decrease in the number of weeds recruiting in the first year in tilled plots compared to zero tillage plots in Stoneville, MS. Higher emergence in the second year in the tilled plots compared to the zero tillage plots, offset this difference. In the subsequent three years no differences were found in levels of weed emergence between tillage systems when weed seed return was prevented. Teasdale *et al.* (1991) had similar results, where total weed density increased after one year of zero tillage but it took two years of conventional tillage to produce a similar increase in weed numbers. This trend was explained by the fact that moldboard ploughing moves seeds deep in the soil during the first year brings them back up to the surface in the second year. Popay *et al.* (1994) suggest that because tillage stimulated germination, shallow cultivation reduces seedling numbers over time when no seeds are allowed to be replaced. If seed return could be prevented, seeds should be buried deep into the soil profile where they remain dormant or germinate but are prevented from emerging (Popay *et al.*, 1994) A control method recommended by Egley and Williams (1990) was to eliminate tillage for one or more years to ensure maximum emergence of seeds on the surface. This would prevent seeds from being incorporated into the soil profile and obtaining long term persistence through imposed dormancy. Hume *et al.* (1991) indicated that total elimination of tillage in Saskatchewan may not yet be feasible depending on the weed species present, since continuous cropping of wheat can build up green foxtail populations. On the other hand, in Akron, CO, Anderson and Nielson (1996) reported that in a 20 year rotation, green foxtail densities were not affected by tillage. Campbell *et al.* (1998) determined that a pre-seeding tillage event in Saskatchewan did not significantly decrease perennial weed populations of foxtail barley. The populations of green foxtail and broadleaved plants were found to be higher in the plots that were tilled compared to the zero tillage plots.

**Summary**

More diverse weed communities occur in reduced and zero tillage systems for several reasons. Availability of favourable recruitment microsites generally increases because of increased stubble and soil clods on the soil surface. Seedbanks are reduced in zero tillage fields because weed seeds are not incorporated into the soil each year by tillage, and loss of seed viability is greater at the soil surface than within the soil profile. Seed movement in zero tillage fields due to soil borne organisms, freeze-thaw cycles creating cracks in the soil, and seeding of contaminated crops, does not seem to build up soil seed populations to significant levels. More research is needed to determine the effects of changes in tillage system on weed seedbanks, seedling communities and seedling populations. At this time, changes in weed communities cannot be predicted. Knowing future weed problems could give an advantage to producers when they are choosing cropping practices. Seedling populations tend to be greater in zero tillage fields, but research to-date has not reported consistent results, and often weeds can be managed using diverse crop rotations and the rotation of herbicides. To fully understand what is happening in weed communities when tillage practices are changed requires more than presence-absence data or a record of the level of weed infestation. Determining from where in the soil profile weeds are successfully recruited could improve management by optimizing different types of weed control methods. Knowing the depth of weed seedling recruitment indicates the position of the microsite. The factors that allow dormancy to be broken and recruitment can be quantified at the microsite. These conditions can be simulated in the lab and allow for increased accuracy of seedbank measurements. Identifying the management factors that affect seed movement and consequently affect the depth of seedling recruitment can improve understanding and control of weeds. If depth of seedling recruitment can be confidently predicted under certain management practices, farmers can optimize weed control. This information can also be used in the development of a model to predict when weed seedlings will recruit.

**Objectives**

The objectives of this project were:

1) To determine the depth of wild oats, volunteer wheat, green foxtail, wild buckwheat and barnyard grass seedling recruitment under zero and conventional tillage fields across Manitoba.

2) To develop a model to predict depth of weed seedling recruitment based on management factors.

# Chapter 3

## Identification of morphological markers of root/shoot interface in broad leaf weeds to allow for *in situ* measurement of recruitment depth.

### Introduction

Weed seedbanks have been extensively studied in order to get a better understanding of weed seedling populations in subsequent years (Derksen *et al.*, 1998). Derksen *et al.* (1998) has shown, however, that seedbanks are not good predictors of future weed problems. Methods used to estimate the seedbank tend to over or underestimate seed densities and the number of seedlings that will be recruited (Ball and Miller, 1989). Pre-spray seedling counts give a more accurate account of the seedling populations that will be present and compete with crops the next year (Derksen *et al.*, 1998). Measuring the depth of weed seedling recruitment allows us to determine where weeds are coming from and how different management factors affect seed movement.

The depth of weed seedling recruitment is measured differently in grassy versus broadleaf weeds. For grassy weeds, the distance between the seed present on the seedling, or the seed scar, to the soil surface indicates the depth of recruitment (de la Cruz, 1974; Buhler and Mester, 1991). Most common broadleaf weeds bring their cotyledons and seed coats to the soil surface leaving no obvious means for measuring depth of seedling recruitment. What is needed to identify broadleaf seedling recruitment depth *in* situ is a morphological marker at the root/shoot interface, where the vascular systems of the root and shoot meet. This marker would be indicative of the point of germination. This point has been identified in some species by a kink or a bending and at times a darker colouration at the interface (de la Cruz, 1974). De la Cruz (1974) found these indicators on two species, velvetleaf (*Abutilon theophrasti* Medicus.) and smart weed (*Polygonym pensylvanicum* L.). He also found that the root/shoot interface was easier to identify and measure when weed seedlings were at the cotyledon to the second true leaf stage because weed seedlings at this stage had not yet developed secondary roots and the shoots were easy to distinguish from the roots.

Our objective, therefore, was to determine if morphological markers of the root/shoot interface were present on several economically important broadleaf weed species present in Manitoba. We wanted to be able to measure, *in situ*, depth of recruitment for broadleaf weeds as well grassy weeds because they are equally as problematic to producers in Manitoba.

**Materials and Methods**

**Weed Species.** Weed species initially included in this experiment were wild buckwheat (*Polygonum convolvulus* L.), redroot pigweed (*Amaranthus retroflexus* L.), lamb's quarters (*Chenopodium album* L.), stinkweed (*Thlaspi arvense* L.), volunteer canola (*Brassica napus* L.) and wild mustard (*Brassica kaber* (D.C.) L.C. Wheeler). A second experiment was conducted on wild buckwheat, redroot pigweed and wild mustard in order to provide confirmation of a marker on wild buckwheat and to have another, more intensive, look at redroot pigweed and wild mustard.

These species represent a range of economically important weeds in Manitoba (Thomas and Donaghy, 1991; Thomas *et al.*, 1998).

**Soil Preparation and Planting.** Experiments were conducted in a growth room with a day/night temperature of 21 /15°C respectively and 16 hours light. A 2:1 clay-loam:sand mixture was used for planting. Soil was sterilised using a type EA Dillon Automatic Soil Pasteurizer (E200A) to kill any weed seeds present in the soil before planting. Plastic pots (10 cm diameter) were lined with a shallow layer of peat moss to prevent soil from falling out the bottom. Seeds were placed on a four-centimetre thick layer of soil and the appropriate thickness of soil was placed on top of the seeds to simulate planting depths of 0 (soil surface), 2.5, 5, 7.5 and 10 cm. Pots were watered as required to keep the soil moist. In the first experiment, four reps at each planting depth were seeded for each weed species. Weed seedlings were excavated at the cotyledon and four leaf stages. The soil surface was marked on the weeds in one pot with a permanent marker before any soil was removed. Soil was washed from the roots by running them under water. In the second experiment, eight reps at each planting depth were seeded for each weed species. Weeds in this experiment were excavated between the cotyledon and the six-leaf stage. In both experiments, the depth of planting and the soil surface was known, so it was known where to look for a marker of the root/shoot interface. Plants were initially examined to see if there was an obvious morphological marker at this point, as described by de la Cruz (1974). If one was found, the distance between that point and the soil surface was measured to see if it coincided with the depth of planting. If one was not found, the distance from the soil surface to the known point of germination was measured and the seedling was examined for the presence of any morphological indicator of the root/shoot interface.

**Results and Discussion**

A definite morphological marker of the root/shoot interface was found only on wild buckwheat seedlings. There did not seem to be any other obvious indicators of germination points on seedlings of the other weed species. This does not, however, indicate that they do not exist for these species. Wild buckwheat seedlings had an obvious and stable morphological marker present at the point of germination (Figure 3.1). The marker was in the form of a kink or displacement at the root/shoot interface. In most cases, as well, the root/shoot interface was darker than the surrounding portions of the stem and root. The darkened area usually began at a distinct point and then gradually faded out. These observations are similar to those found by de la Cruz (1974). One of the species for which he found a morphological marker of the root/shoot interface, was smartweed, which is in the same family as wild buckwheat. This may indicate that the marker is easier to find in the Polygonaceae family or that it is more common in this family. De la Cruz (1974) did find a morphological marker of the root/shoot interface for velvetleaf, indicating that the marker is present on weed species in more than one family. Finding the morphological marker on wild buckwheat allowed a broadleaf weed species to be added to the large-scale survey identifying the depth of weed seedling recruitment in

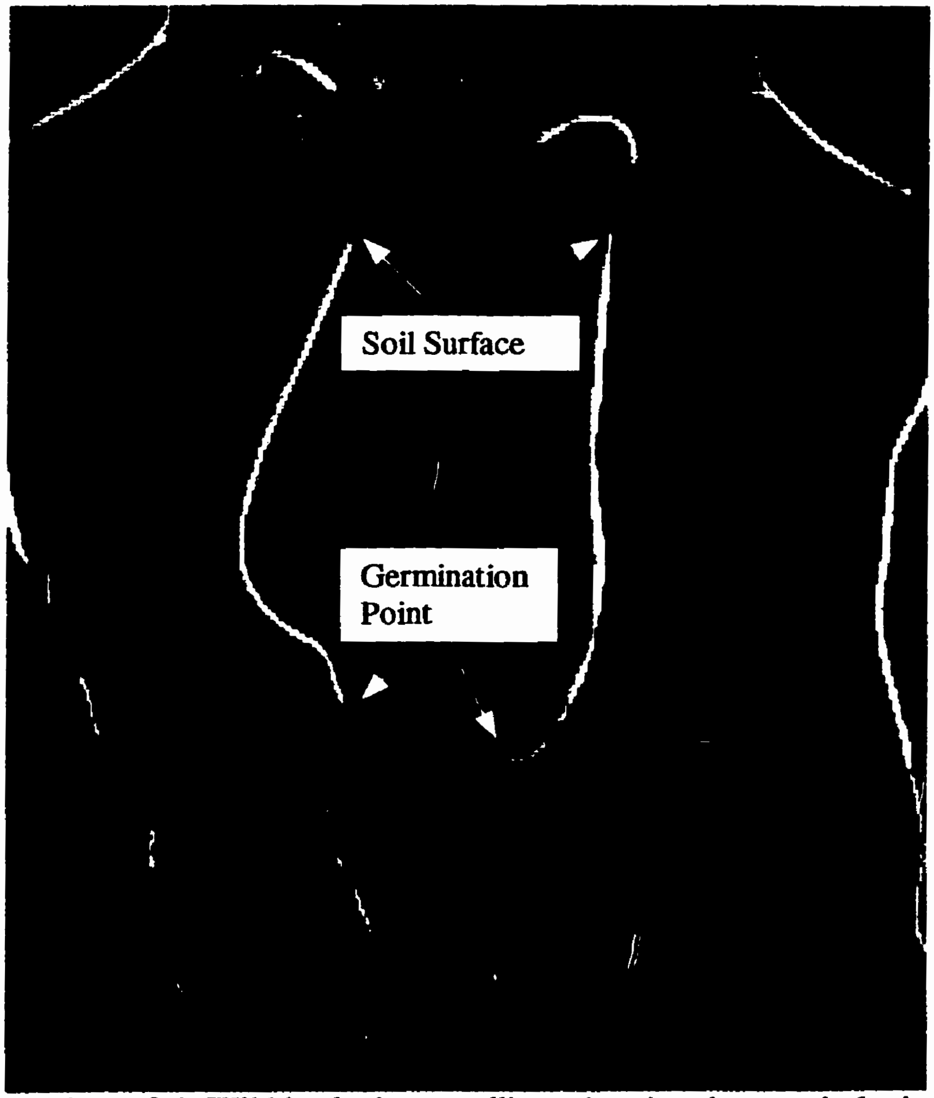



Figure 3.1. Wild buckwheat seedlings showing the morphological marker which was used to determine depth of recruitment.

two different tillage systems. These experiments were not exhaustive in the search for morphological markers for the root/shoot interface and although they allowed us to add one species to our recruitment depth survey, there are many other important broadleaf species for which recruitment depth should be investigated.

# CHAPTER 4

## Depth of weed seedling recruitment in zero and conventional tillage fields in Manitoba.

### Introduction

The distribution and number of weed seeds in seedbanks has been extensively studied (Soriano *et al.*, 1968; Mohler, 1993; Ball, 1992; Cavers, 1995; Yenish *et al.*, 1992; Wrucke and Arnold, 1985; Staricka *et al.*, 1990). Many researchers have used data obtained from weed seedbanks to try to predict future weed problems and improve weed control (Buhler *et al.*, 1997; Cardina and Sparrow, 1996; Forcella, 1992; Wilson *et al.*, 1985). Not all researchers agree that the answer to weed control can be found by investigating the seedbank. Derksen *et al.* (1998) found that the seedbank population was not the best indicator of subsequent years weed seedling populations. He also found that the best predictor of future weed seedling populations was the previous years seedling population.

It is very labour intensive to try to characterize seedbanks and many samples need to be taken to do this because of the inherent variability of seed placement in the seedbank. In addition, the sample may or may not represent seeds ready to germinate and emerge because the sampling does not account for external factors (moisture, temperature, light) and dormancy acting on seeds, preventing them from germinating (Baskin and Baskin, 1985; Cardina *et al.*, 1996; Taylorson, 1987).

Cardina and Sparrow (1996) considered several methods of predicting weed seedling populations from the soil seedbank. They found that seedling population characteristics drawn from seedling emergence from soil trays, emergence from intact cores and seed extraction, all correlated poorly with subsequent *in situ* seedling populations. This does not mean that seedbanks should not be studied. Zhang *et al.* (1998) found that using the active soil seedbank to predict future seedling populations could be more dependable and less time consuming than using the total seedbank. Seedbanks are important because they are the physical and genetic source of weed seedling populations. Factors, such as temperature, moisture, seed rain and seed mortality, affect seedbanks and regulate seedling populations by either promoting or preventing seedling recruitment (Buhler *et al.*, 1997).

The seedbank also provides important information about the effects of different types of tillage and weed management on weed populations. Understanding how different management factors affect weed seedbanks could lead to better weed control strategies (Buhler *et al.*, 1997). Examining seedling populations instead of the seedbank may provide the answer to understanding seedbanks and seed dynamics.

Weed seedling recruitment is the successful germination and emergence of weed seedlings in a field (Harper, 1977). Successfully recruited seedlings have overcome all of the obstacles that would prevent seeds from recruiting and their populations are easier to measure than seeds in the seedbank. Measuring the depth of seedling recruitment will increase our understanding of how tillage affects active weed seed movement without having to take soil core measurements. Measuring successfully recruited weed seedlings allows for rapid quantification of how changes in management affect the active weed seedbank.

Factors such as tillage, seeding practice, weed species, soil type and soil applied herbicides can affect depth of weed seedling recruitment (de la Cruz, 1974). Many experiments determining the depth of weed seedling recruitment have been conducted where the weed seeds were placed at specific depths in the soil, and natural weed populations were not used (Dawson and Bruns, 1975; Wiese and Davis, 1966; Stoller and Wax, 1973). These experiments give an estimation of the maximum depth of emergence of the weeds that were tested. In general emergence decreased with increased depth of planting (Dawson and Bruns, 1975; Wiese and Davis, 1966). The major limitations of these experiments were the lack of knowledge of the effects of different management practices on seed movement and the fact that natural seedbanks were not studied. A few experiments have been conducted to determine the depth of weed seedling recruitment from natural weed seedbanks in the field (de la Cruz, 1974; Chancellor, 1964b; Buhler and Mester, 1991). In these experiments, the depth of recruitment was generally shallower in a minimum or zero tillage system than in a conventional tillage system. It is important to know the depth of weed seedling recruitment and how it is affected by different management strategies to aid in the development of improved weed control strategies.

The objective of this study was to determine the depth of recruitment of several economically important weeds in Manitoba under zero and conventional tillage systems.

**Materials and Methods**

A field survey of 88 fields was conducted over two years, that included 44 zero tillage and 44 conventional tillage fields. Each field was surveyed twice, once pre-seeding (pre-seed) and once before post emergent herbicide application (pre-spray). These two sampling dates were chosen because this is when weeds have the greatest economic impact on crop yield, and when most farmers choose to implement weed control measures (Derksen *et al.*, 1998). Fields were chosen by contacting zero tillage farmers in pre-determined areas and requesting a referral to a nearby conventional tillage farmer.

Certain criteria for both zero and conventional tillage fields needed to be fulfilled before they could be included in the survey. Zero tillage fields were required to have had a minimum of three years without tillage to ensure that the weed seedbank had time to adapt to this system and were, therefore, reflective of the system. In selecting zero tillage systems, narrow seed openers were preferred to minimise the amount of disturbance that occurred. Fields that had a harrowing, and/or a separate application of fertilizer with narrow openers were accepted as zero tillage. This helped ensure that enough zero tillage fields could be found. Conventional tillage fields had to have been tilled at least twice before seeding, either in the fall or spring. In some cases a fertilizer application with a cultivator was considered a tillage operation. All fields included in the survey had to be free of soil applied herbicides for at least one year to ensure the presence of weeds at sampling. As well, stubble type for all of the fields was limited to wheat or canola to minimize variation among fields.

A large area of south western Manitoba was surveyed in this study. Fields were located in the vicinity of each of the following locations: Altona (N49'06.204" W097'34.010"), Carman (N49'30.264" W097'39.883"), Homewood (N49'30.264" W097'49.171"), Portage la Prairie (N49'58.938" W098'15.705"), Brandon (N49'54.324" W099'36.722"), Souris (N49'37.350" W100'16.333"), Hartney (N49'28.781" W100'31.494"), Crystal City (N49'07.687" W098'57.067"), Mather (N49'05.642" W099'12.130"), Arden (N50'16.736" W099'16.512"), Brookdale (N50'02.563" W099'33.816"), Minnedosa (N50'14.758" W099'49.801") and Newdale (N50'21.696" W100'12.245"), Manitoba. Up to six fields were surveyed near each location.

In 1997, wild oats (*Avena fatua* L.), volunteer wheat (*Triticum aestivum* L.) and green foxtail (*Setaria viridis* L. Beauv.) were surveyed. In 1998, wild buckwheat (*Polygonum convolvulus* L.) and barnyard grass (*Echinochola crusgalli* L. Beauv.) were added to the survey. Wild buckwheat was added when a morphological marker of the root/shoot interface was identified in the winter of 1997/98 (Chapter 3). This marker allowed for *in situ* measurement of recruitment depth. Barnyard grass was added to increase the number of species sampled in 1998.

Depth of recruitment for grassy weeds was measured from the seed, that remained at the point of germination, to the soil surface. Depth of recruitment for wild buckwheat was measured from the morphological marker to the soil surface. Before weeds were removed from the soil, the soil surface was marked on the stem of the plant with a permanent marker. Grassy weeds were measured in the field to the nearest 0.5 cm in

1997 and the nearest 0.1 cm in 1998. Wild buckwheat plants were removed along with a large portion of soil and placed in plastic bags intact. The bags were then stored on ice until they could be put in a cold room. In the lab, soil was removed from wild buckwheat plants in a root-washing sink. Each plant was then carefully examined to identify the presence of the morphological marker. For all species, seedlings were chosen arbitrarily in each field.

Sampling did not occur in a set pattern, each field was scouted until weeds were found. No more than five weeds of one species were taken from any single weed patch in a given field. In 1997, a maximum of 20 individuals from each weed species was taken from each field (if that many weeds could be found within a field). The number of individuals of each species sampled per field was increased to 30 in 1998, to increase the accuracy of measurement. This sampling method resulted in a large portion of each field being included in the study.

Wild oat and volunteer wheat data for 1997 and 1998 were combined upon confirmation of homogeneity of variances because mean recruitment depths were found not to be significantly different between years (see appendix 4.1.1 to 4.1.2). A significant difference occurred between years for green foxtail, therefore, each year had to be analysed separately (see appendix 4.1.3). Wild buckwheat and barnyard grass depth of weed seedling recruitment, was only measured in 1998, therefore, there was only one year of data to analyse. Data was analysed as a completely randomized design using analysis of variance (ANOVA) to separate treatment means and to test for significant interactions with the SAS (version 6.12) statistical package (SAS Institute, Raleigh, NC). Tillage system and time of sampling were the main effects.

## Results and Discussion

**Numbers of seedlings sampled.** The total number of weeds sampled in both years is indicated in Tables 4.1 and 4.2.

Table 4.1. The number of individual weeds sampled pre-seeding in 1997 and 1998, combined.

| | Zero Tillage | Conventional Tillage |
|---|---|---|
| Volunteer wheat | 751 | 651 |
| Wild oats | 665 | 663 |
| Green foxtail | 57 | 66 |
| Wild buckwheat | 434 | 447 |

Table 4.2. The number of individual weeds sampled pre-spray in 1997 and 1998, combined.

| | Zero Tillage | Conventional Tillage |
|---|---|---|
| Volunteer wheat | 331 | 447 |
| Wild oats | 946 | 784 |
| Green foxtail | 904 | 941 |
| Wild buckwheat | 654 | 645 |
| Barnyard grass | 70 | 128 |

A decrease in the number of volunteer wheat seedlings in the pre-spray sampling period occurred in both zero tillage and conventional tillage fields. It is likely that a large portion of the volunteer wheat seedlings that were close to, or on the soil surface, had germinated or were controlled by pre-seeding herbicide application (burn-off), tillage or seeding operations before the pre-spray sampling. Because crop plants have been selected not to have dormancy, volunteer wheat has a very small seed bank compared to the other weed species sampled (Baskin and Baskin, 1985; Cavers, 1995). Consequently, volunteer wheat seedlings were found in fewer fields and in lower numbers during the pre-spray sampling period. Green foxtail seedlings were found in very low numbers during the pre-seeding sampling period in 1998 and not at all in the pre-seeding sampling period in 1997. Green foxtail is a $C_4$ plant that requires warm temperatures to germinate (Douglas *et al.*, 1985). At the time of the first sampling period, temperatures may not have reached the level needed for green foxtail recruitment.

Barnyard grass was not found, at all, in the pre-seeding sampling period in 1998. Barrett and Wilson (1983) noted that barnyard grass takes longer to germinate under cool conditions and germination rates are much greater at warm temperatures. The barnyard grass plants that were surveyed in 1998, in the pre-spray sampling period, were found in a very limited number of fields. The barnyard grass seedlings surveyed in the zero tillage system were from one field only. In the conventional tillage system the barnyard grass seedlings were surveyed in only four fields. It is not clear why more barnyard grass was not found in 1998. Wild oats, green foxtail and wild buckwheat seedling numbers increased in the pre-spray sampling period. Increased soil temperature and soil disturbance caused by tillage and seeding may have stimulated seedling recruitment, making is easier to find individuals of these species to sample in the pre-spray versus the pre-seeding sampling period.

**General trends in weed seedling recruitment.** Recruitment depths were affected by time of year and by tillage system. Mean recruitment depth for all species in both tillage systems was generally shallow, not deeper than 4.5 cm. Deeper recruitment depths were observed in conventional tillage fields versus zero tillage fields (Table 4.3 to 4.7). These results are similar to those reported by de la Cruz (1974) who found that the majority of weed seedlings recruited from shallow depths (upper 4 cm) and that weed seedlings in zero tillage fields recruited from shallower depths than weed seedlings in conventional tillage fields.

**Effect of tillage on depth of recruitment.** Mean recruitment depth was shallower in zero tillage versus conventional tillage fields for all weed species, in both pre-seeding and pre-spray sampling periods. This difference was significant for all weed species at both sampling periods (Tables 4.3 to 4.7).

Recruitment from greater depths in conventional tillage fields was likely the result of many factors. Tillage exposes seeds to light, for example, which stimulates seedling germination, even if the light flash is brief (Scopel *et al.*, 1994; Taylorson, 1987; Tester and Morris, 1997; Wesson and Wareing, 1969a).

Table 4.3. Effect of tillage on mean recruitment depth (cm) of volunteer wheat in 1997 and 1998 (data for years combined).

| | Time of Sampling | | |
|---|---|---|---|
| Tillage | Pre-Seeding | Pre-Spray | $LSD_{0.05}$ |
| Conventional | 2.79 | 3.74 | 0.70 |
| Zero | 0.75 | 2.11 | 0.42 |
| $LSD_{0.05}$ | 0.46 | 0.73 | |

Table 4.4. Effect of tillage on mean recruitment depth (cm) of wild oats in 1997 and 1998 (data for years combined).

| Tillage | Time of Sampling<br>Pre-Seeding | Pre-Spray | $LSD_{0.05}$ |
|---|---|---|---|
| Conventional | 3.25 | 4.15 | 0.58 |
| Zero | 1.92 | 2.42 | 0.39 |
| $LSD_{0.05}$ | 0.55 | 0.43 | |

Table 4.5. Effect of tillage on mean recruitment depth (cm) of green foxtail in 1997 and 1998.

| Tillage | Year of Sampling<br>1997 | 1998 | $LSD_{0.05}$ |
|---|---|---|---|
| Conventional | 3.80 | 3.11 | 0.62 |
| Zero | 2.45 | 1.86 | 0.45 |
| $LSD_{0.05}$ | 0.69 | 0.44 | |

Table 4.6. Effect of tillage on mean recruitment depth (cm) of wild buckwheat in 1998.

| Tillage | Time of Sampling<br>Pre-Seeding | Pre-Spray | $LSD_{0.05}$ |
|---|---|---|---|
| Conventional | 2.50 | 3.47 | 0.51 |
| Zero | 1.64 | 2.18 | 0.42 |
| $LSD_{0.05}$ | 0.53 | 0.40 | |

Table 4.7. Effect of tillage on mean recruitment depth (cm) of barnyard grass in 1998.

| Tillage | Pre-Spray |
|---|---|
| Conventional | 2.97 |
| Zero | 1.59 |
| $LSD_{0.05}$ | 1.29 |

Tillage also changes the vertical distribution of seeds in the soil, the extent and depth of which is determined by the amount of soil disturbance (Buhler et al., 1997, Dyer, 1995).

Some studies have indicated that soil bulk density in zero tillage was higher than in conventional tillage and this was detrimental to crop emergence (Buhler and Mester, 1991). Therefore, higher bulk density in zero tillage fields could restrict weed seedling recruitment from deeper depths in the soil. Buhler and Mester (1991) attributed reduced depth of weed seedling recruitment in zero tillage fields to greater bulk density. Blevins *et al.* (1983) reported differing results, they found that soil bulk density in zero and conventional tillage fields was, generally, very similar, and this would therefore, have no affect on recruitment depth of weed seedlings.

Most of the tillage performed in Manitoba is chisel tillage or non-inversion tillage. Although most weed seeds are concentrated near the soil surface in chisel plough tillage, seeds in zero tillage fields are generally found even closer to the surface (Ball, 1992; Buhler *et al.*, 1997; Dyer, 1995; Yenish *et al.*, 1992). The recruitment depth for both zero tillage fields and conventional tillage fields was deeper during the pre-spray sampling period versus the pre-seeding sampling period. This difference between sampling times in depth of recruitment was likely caused by seeding and tillage operations occurring after the pre-seeding sampling, moving weed seeds deeper into the soil profile. Warming of the soil as the season progressed, which can be accelerated by tillage, was also a probable contributor to increased depth of recruitment at the later sampling time. Weed seeds can germinate at a variety of temperatures, but will germinate faster at optimum temperatures (Taylorson, 1987; Vanden born, 1971). As thermal time passes the emergence zone expands permitting deeper recruitment prior to the pre-spray sampling period.

Mean recruitment depths for all weed species in both tillage systems were shallower than 4.5 cm during both sampling periods. Therefore, seeds located deeper than 4.5 cm in the soil profile are less likely to be recruited and recruitment of those seedlings may be delayed. Deep tillage will not prevent weed seedling recruitment since it will bring up new seeds at the same time that it is burying seeds shed on the soil surface. If seed return is prevented, seed and seedling populations will decline more rapidly in conventional tillage versus zero tillage systems (Froud-Williams *et al.*, 1983). It is, however, very difficult to prevent all seed return. Seeds shed on the soil surface are incorporated into the soil, replenishing the seed bank every year.

Knowing where weed seedlings are recruiting from allows for the development of improved weed control methods. Based on observations in the present study, in conventional tillage systems, for example, soil applied herbicides may not have to be incorporated below 5 cm in the soil and tillage for weed control can be concentrated at the depth of weed seedling recruitment. Optimising the effectiveness of tillage for weed control may lead to a reduction in the amount of tillage needed to control weeds. This may enable farmers to switch from intensive cultivation to minimum amounts of cultivation and still benefit from the tillage based weed control. In zero tillage systems, soil applied herbicides could be applied between 1.0 and 2.5 cm, in the band where weed seedling recruitment occurs. Although, this would improve the effectiveness of soil applied herbicides in zero tillage and give zero tillage farmers another option for weed control, it may be difficult to do. Currently, there is no technology that would deliver herbicides at a specific depth in the soil while still maintaining uniform field coverage, especially if low disturbance is required.

Seed longevity may play an important role in the depth of seedling recruitment for species that have seeds that can remain viable and dormant for many years. Seedlings recruiting from deeper in the soil profile in zero tillage, for example, may still be remnants of seeds moved by tillage before zero tillage was implemented.

**Effect of time of sampling on recruitment depth.** Seedling recruitment was deeper and more variable during the pre-spray sampling period for all of the weed species sampled (Tables 4.3 to 4.7). In the zero and conventional tillage fields the first sampling date was performed before any field operations took place. The second sampling period occurred after tillage and seeding had been performed. The soil disturbance may have caused seeds to be moved deeper into the soil profile and could have also stimulated germination of deeply buried dormant seeds. This would have resulted in the more variable recruitment depth profile witnessed in the pre-spray sampling period versus the pre-seeding sampling period (Figures 4.1 to 4.5). The box plots indicate the distribution of weed seedling recruitment in zero and conventional tillage fields. The upper and lower lines indicate the upper and lower quartiles respectively or the $75^{th}$ and the $25^{th}$ percentiles. The middle line indicates the median of the data and the whiskers indicate 1.5 times inter-quartile range. Data points outside of this range or outliers were not plotted.

**Recruitment depths for individual weed species.** Wild oats had a deeper and wider range of recruitment than the other weed species. The depth of wild oat seedling recruitment ranged from the soil surface to as deep as 14.5 cm (outlier not plotted) in the soil (Figure 4.1). The extreme recruitment depth example was found in a pre-spray, conventional tillage field. Wild oat seed is able to bury itself into the ground due to a long awn that twists under wetting and drying conditions. The larger seed size and the ability of the first internode to elongate allows wild oats to recruit from greater depths in the soil compared to most other grassy species (Sharma and Vanden Born, 1978). Wild oats recruitment can occur from up to 20 cm in the soil if the conditions are favourable (Sharma and Vanden Born, 1978). The ability of wild oat seed to remain dormant longer under an undisturbed site (> 3-6 years) than a cultivated one (3-6 years) will help to maintain a supply of deep emerging wild oat seedlings for the first several years of zero tillage (Sharma and Vanden Born, 1978). Mean recruitment depth for wild oats were significantly different between conventional and zero tillage fields, during both sampling periods (Table 4.3). Mean recruitment depths were significantly different between the pre-seeding and pre-spray periods, in zero and conventional tillage (Table 4.3).

The majority of volunteer wheat seed recruited on the soil surface, especially in zero tillage fields (Figure 4.2). Crop plants do not have a persistent seedbank, therefore, volunteers are primarily the result of the previous year's seed rain. As such, the seeds do not have a chance to become incorporated into the soil. The mean recruitment depth of volunteer wheat was shallower than wild oats because, in wheat, the first internode does not elongate to the same length that it does in wild oat (Sharma and Vanden Born, 1978). Mean recruitment depths for volunteer wheat were significantly deeper in conventional tillage fields than in zero tillage fields at both pre-seeding and pre-spray sampling periods. Mean recruitment depths were also deeper in the pre-spray versus the pre-seeding sampling period in both tillage systems (Table 4.4).

Mean recruitment depth for green foxtail seedlings in 1997 and 1998 were significantly different (Appendix 4.1.3) and, therefore, the data for each year could not be

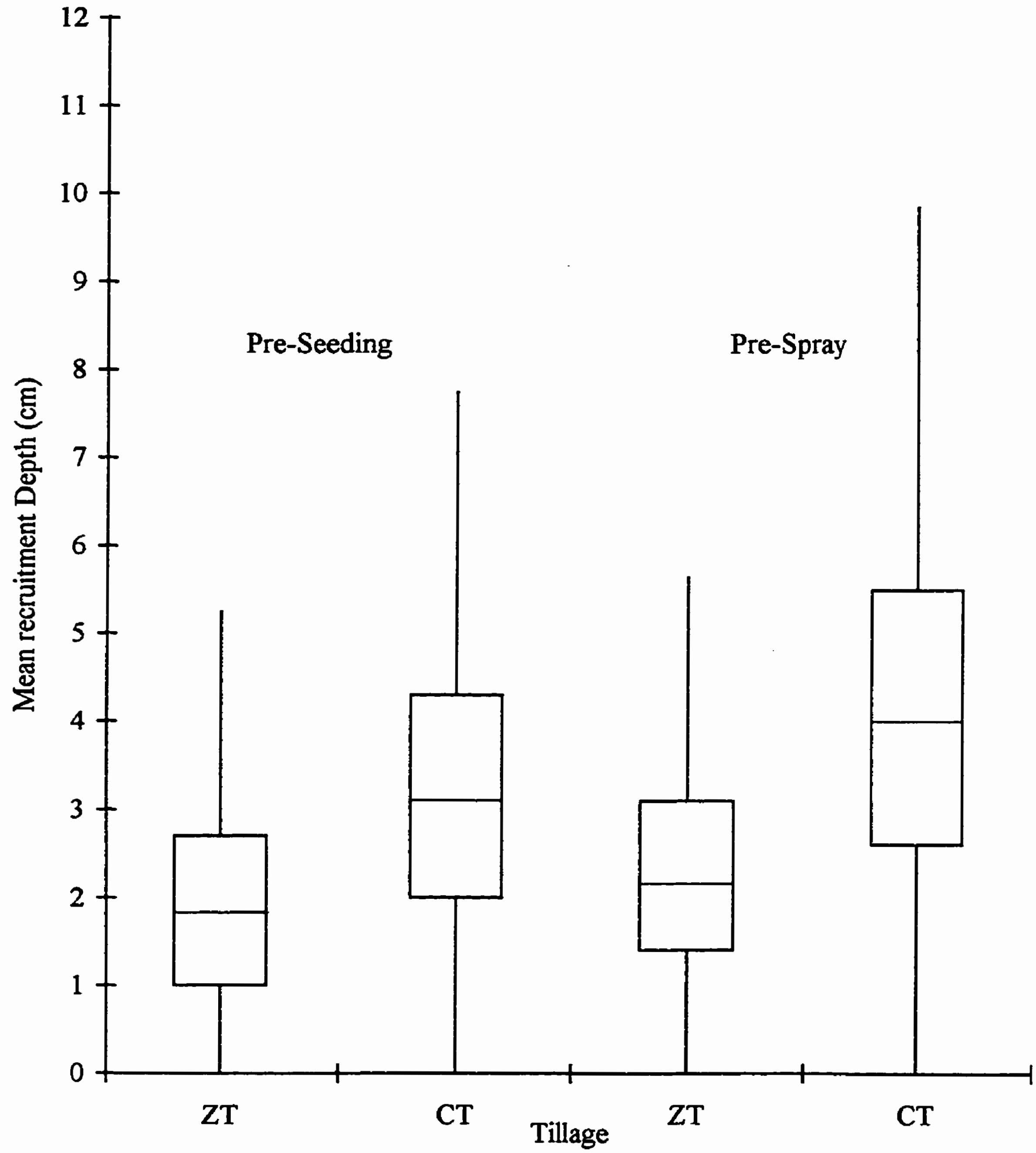



Figure 4.1. Box plots showing the range of wild oat recruitment depth in zero and conventional tillage fields sampled during 1997 and 1998 (years combined).

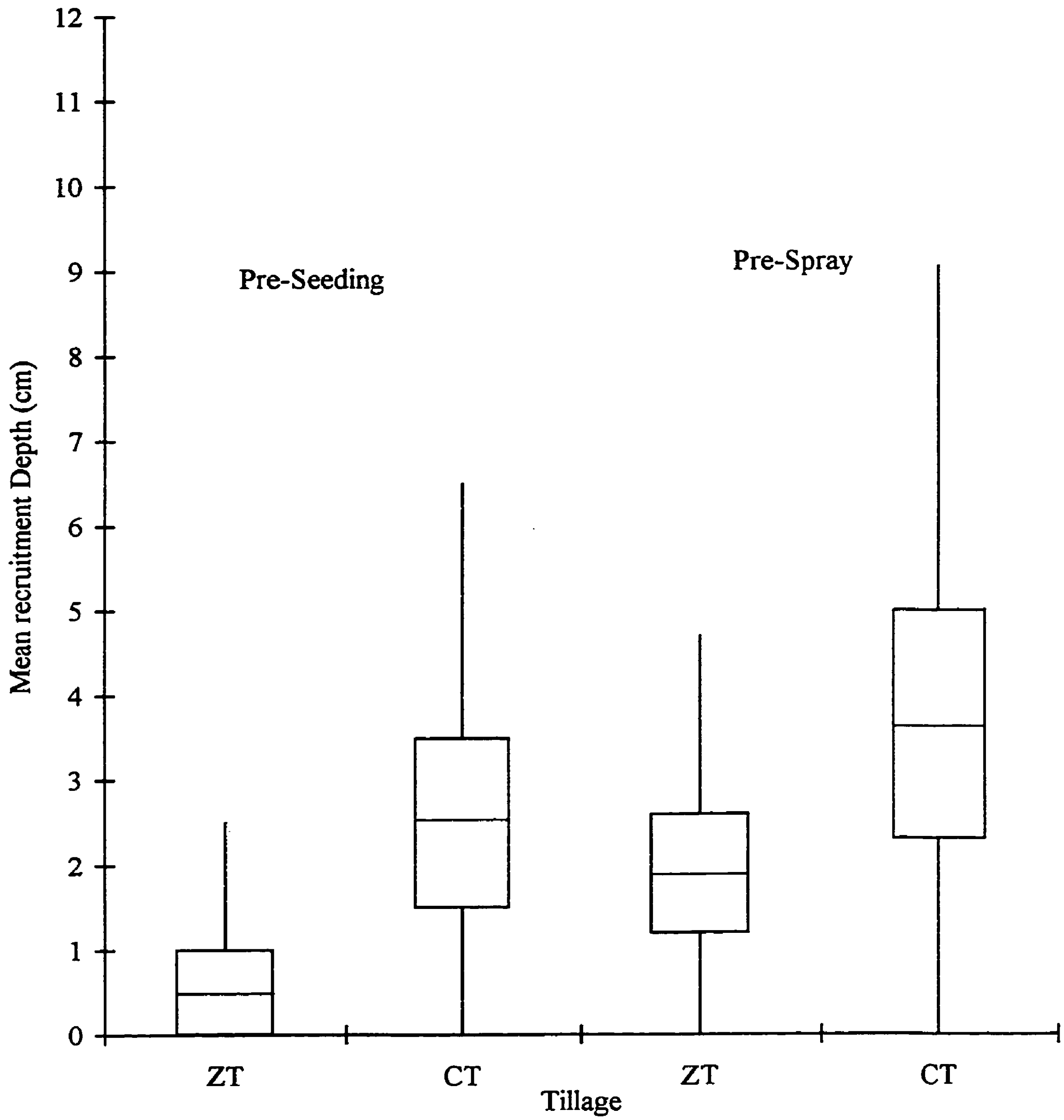



Figure 4.2. Box plots showing the range of volunteer wheat recruitment depth in zero and conventional tillage fields sampled during 1997 and 1998 (years combined).

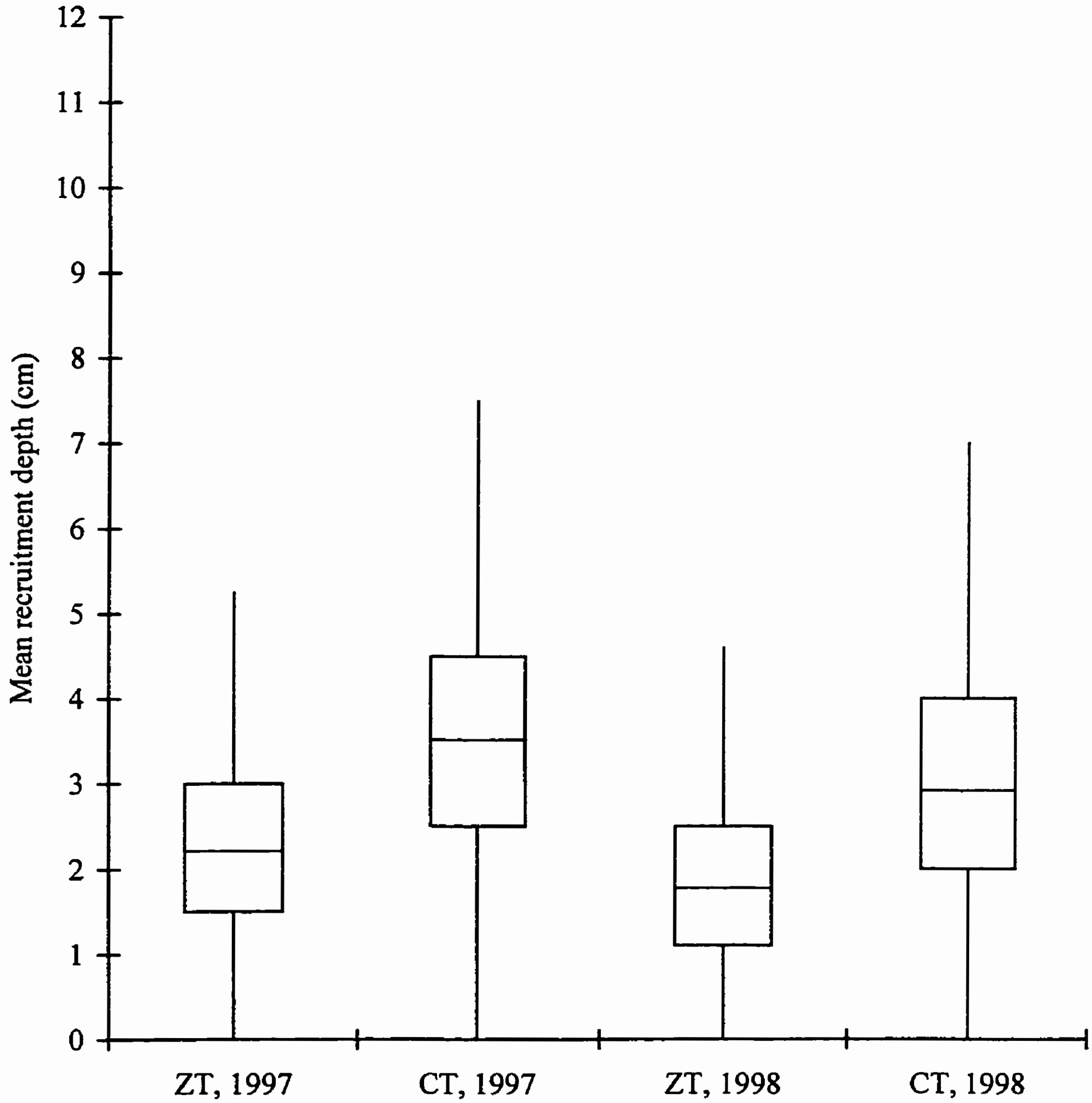



Figure 4.3. Box plots showing the range of green foxtail recruitment depth in zero and conventional tillage fields sampled during 1997 and 1998.

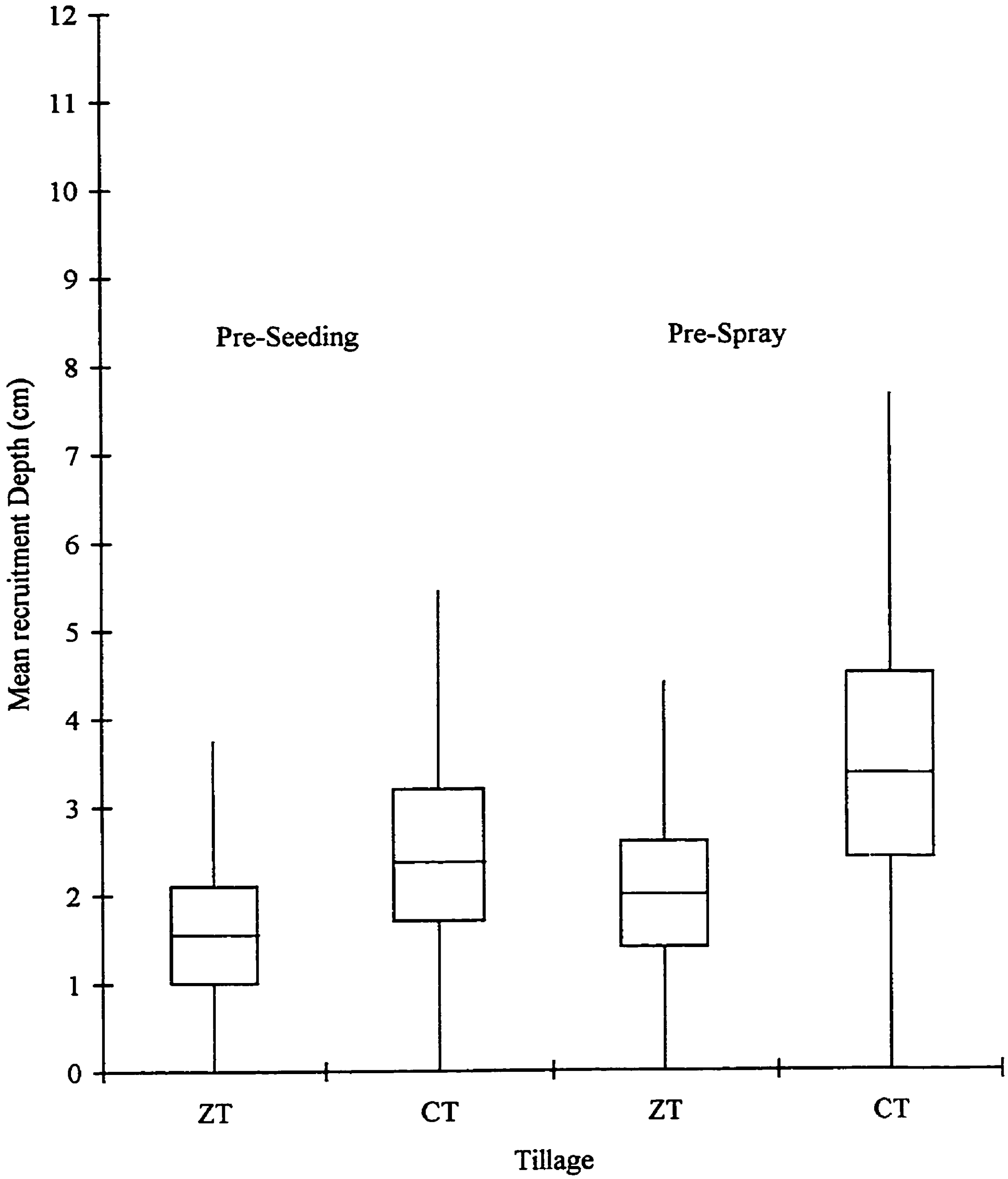



Figure 4.4. Box plots showing the range of wild buckwheat recruitment depth in zero and conventional tillage fields sampled during 1998.

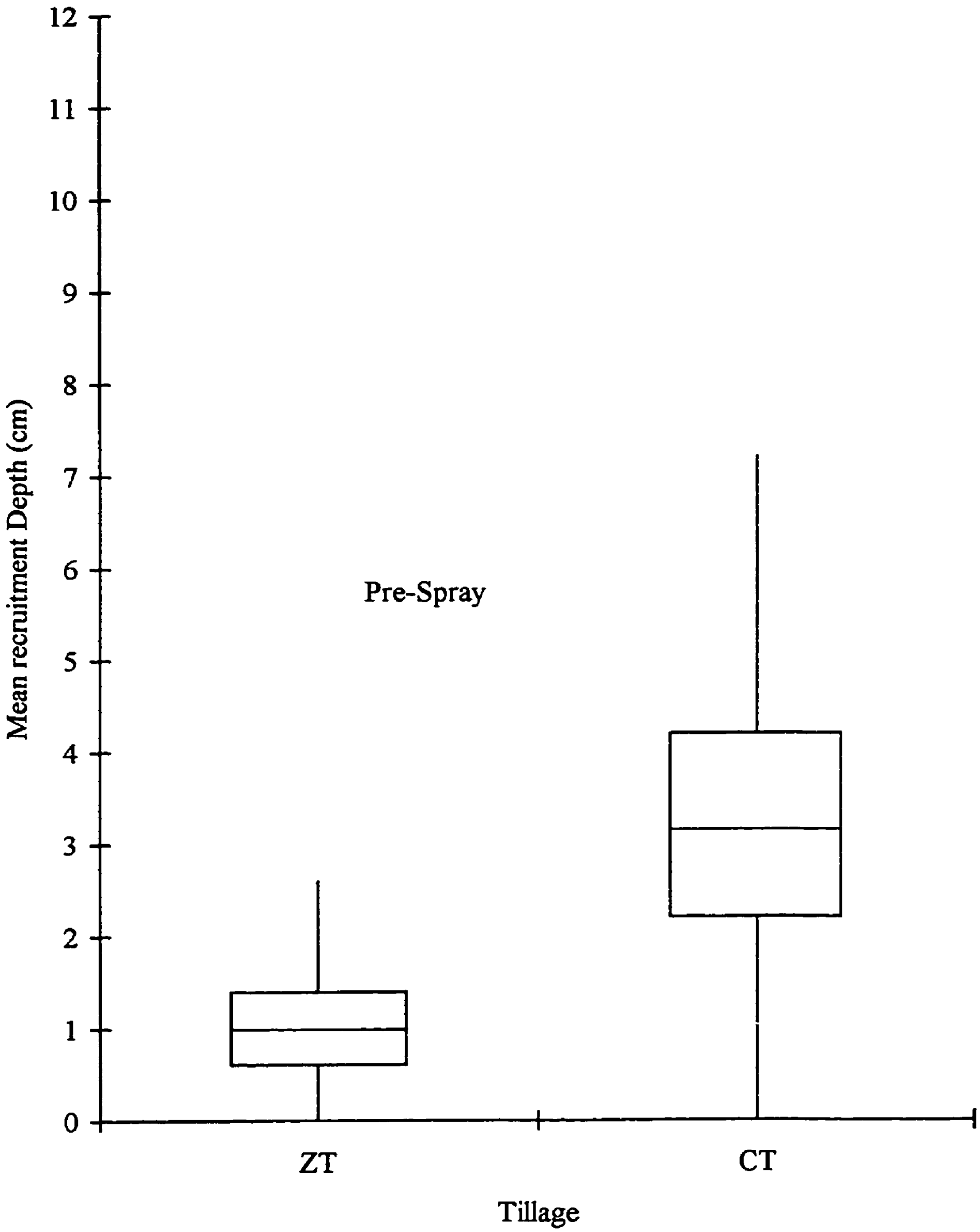



Figure 4.5. Box plots showing the range of barnyard grass recruitment depth in zero and conventional tillage fields sampled during 1998.

combined in the analysis. The average depth of recruitment for green foxtail was deeper in 1997 than in 1998 (Table 4.5). Mean recruitment depth was also significantly deeper in conventional tillage fields than in zero tillage fields for both 1997 and 1998 (Table 4.5).

Since green foxtail is a $C_4$ plant, recruitment will be greatly affected by soil temperature. In 1998, a cold period occurred during the pre-spray sampling period, which may have limited recruitment depth more so than in 1997 (appendix 4.2). Green foxtail recruitment, was generally, from shallower depths and over a narrower range than either wild oats or volunteer wheat in both years (Figure 4.3). It has been reported that green foxtail recruitment can occur from 12 cm deep in the soil, but the majority of seedling recruitment was from the soil surface to 7.5 cm deep (Dawson and Bruns, 1962). Vanden Born (1971) also found that green foxtail could recruit from as deep as 12 cm, but the majority of seedlings were recruiting from 0.5 to 8 cm in the soil. Douglas *et al.* (1985) reported maximum recruitment depth for green foxtail to be between 7.6 and 10 cm with fewer seedlings recruiting from deep in the soil profile. This may be due to the small seed size of green foxtail, relative to volunteer wheat or wild oats, that would restrict the depth from which it can recruit since smaller seed size indicates reduced food storage (Dawson and Bruns, 1962).

In this study, the deepest recruitment depths for green foxtail were 7.5 cm and 9.0 cm in zero and conventional tillage fields, respectively. Unlike wild oats, the coleoptile of green foxtail seedlings is quite short, which also restricts it's potential depth of recruitment (Douglas *et al.*, 1985). Green foxtail recruited from greater depths in conventional tillage fields versus zero tillage fields, suggesting that seed movement caused by soil disturbance from tillage operations plays an important role in determining depth of seedling recruitment.

Green foxtail requires warm temperatures for recruitment. Maximum recruitment levels reported by Douglas *et al.* (1985) were not reached until temperatures of 20-30° C occurred. They reported that a decrease in temperature from 20° C to 15° C decreased the time needed for recruitment by 50%. Johnson and Lowery (1985) compared temperature differences in various zero tillage and conservation tillage methods to conventional tillage. They found that in early spring, zero tillage fields were cooler than minimum tillage fields (chisel plough and till-plant) or conventional tillage fields. The warmer temperatures in conventional tillage fields may have allowed deeper recruitment of green foxtail, which is a heat-loving weed (Douglas *et al.*, 1985).

Wild buckwheat recruitment depth patterns were similar to those of green foxtail (Figure 4.4). This may have been due to similar seed sizes between green foxtail and wild buckwheat. The achenes of wild buckwheat have been reported to be recruited from as deep as 19 cm, but the majority of recruitment occurs between 1.25 to 5 cm (Hume *et al.*, 1983). The maximum recruitment depths in this study were 7 cm and 10 cm (not plotted) for zero and conventional tillage fields, respectively. The mean depths of recruitment of wild buckwheat for zero tillage pre-seeding and pre-spray, (1.64 and 2.18 cm, respectively) and conventional tillage pre-seeding and pre-spray, (2.5 and 3.47 cm, respectively) fall into the range described by Hume *et al.* (1983). The expanding cotyledons of wild buckwheat may provide more resistance to recruitment through the soil than grassy weeds, therefore, limiting maximum recruitment depth. Hume *et al.* (1983) indicates, however, that soil compaction should not affect the depth of wild buckwheat recruitment. Depth of weed seedling recruitment in conventional tillage fields was significantly deeper that in zero tillage fields at the pre-seeding and the pre-spray sampling period (Table 4.6). In conventional and zero tillage fields, the depth of recruitment for the pre-spray sampling period was significantly deeper than the pre-spray mean recruitment depth (Table 4.6).

The sample size was very small for barnyard grass in both zero tillage and conventional tillage fields (Table 4.2); therefore, the patterns seen in barnyard grass recruitment may not be wholly representative of what is happening across Manitoba (Figure 4.5). Recruitment depths in barnyard grass were shallower and had a smaller range of distribution than wild oat or volunteer wheat. The zero tillage recruitment depths for barnyard grass were shallower than green foxtail recruitment depths but the conventional tillage recruitment depths were similar to those of green foxtail.

Dawson and Bruns (1962) compared recruitment depths of barnyard grass, yellow foxtail and green foxtail. All weeds were able to recruit from as deep as 12.5 cm, but the majority of seedlings recruitment was in the range from the soil surface to 7.5 cm. They indicated that yellow foxtail and barnyard grass recruited from deeper depths than green foxtail because of their greater seed size. In this study barnyard grass was found to have similar recruitment patterns to green foxtail (Figure 4.3 and 4.5). Dawson and Bruns (1975) also studied the longevity of seeds of these weeds in soil. They found that barnyard grass remained viable longer when the seeds were buried deeper in the soil. Out of the three weeds tested barnyard grass had the shortest length of viability, and yellow foxtail had the longest length of viability. Since barnyard grass and green foxtail have similar heat requirements for recruitment (Dawson and Bruns, 1962) and have similar patterns of recruitment in this study, it may be that the two weeds would act similarly under similar conditions. Barnyard grass was only sampled in 1998 and in that year it was found only during the pre-spray sampling period. The mean recruitment depth of barnyard grass seedlings was deeper in conventional versus zero tillage fields (Table 4.7).

**Conclusions**

All of the weeds surveyed in this study were recruited from shallower depths in zero tillage fields versus conventional tillage fields and recruitment was from shallower depths in the pre-seeding versus the pre-spray sampling period. These results are similar to those obtained by de la Cruz (1974) and Buhler and Mester (1991) who also measured depth of recruitment for natural weed seedling populations in the field. The significance of this study is that the data represents a large number of fields from a wide range of geographic areas in Manitoba and that the recruitment measurements were taken in producers fields under commonly practised field conditions. The multiple sites represent varied soil types, climate and management factors, all of which have an impact on the depth of seedling recruitment.

Conventional tillage fields have a wider range of recruitment depth than zero tillage fields. Soil mixing caused by tillage moves seeds deeper into the soil profile (Ball, 1992; Buhler *et al.*, 1997; Dyer, 1995; Yenish *et al.*, 1992). Tillage also causes the soil to warm to a deeper depth versus zero tillage fields, thus facilitating deeper recruitment. In zero tillage, recruitment was concentrated near the soil surface. There was some variation in recruitment depths and there was deeper recruitment than expected for some individuals in some fields, which may be the result of seed movement caused by seeding and fertilizer operations.

Knowing the depth of weed seedling recruitment can aid in the development of improved weed control strategies. Even now, soil applied herbicides are being placed on the soil surface of zero tillage fields in the fall and early spring with good weed control results (G. Turnbull, personal communication). The concentration of seedling recruitment near the surface in zero tillage allows this practice to be successful. Being able to place herbicides at the point of recruitment may allow farmers to reduce herbicide rates or increase the efficacy of herbicides.

Weeds will always be a problem since seeds can never be economically eliminated from fields. Escapes from control measures will replenish the seed bank. Weed control can be optimised by understanding more about weed ecology and biology. Knowing where weeds come from in the soil profile is one step in that direction.

# CHAPTER 5

## Tillage index as a predictor of mean weed seedling recruitment depth.

### Introduction

Tillage has a significant impact on weed seedbanks, position of seeds within the soil profile and subsequent seedling populations (Ball, 1992; Buhler, 1997; Cardina *et al.*, 1991; Chancellor, 1964a; Chepil, 1946; Chepil, 1949; Cousens and Moss, 1990; Dyer, 1995; Froud-Williams *et al.*, 1983; Soriano *et al.*, 1968; Yenish *et al.*, 1992). One of the major impacts of tillage on weeds is seed movement and placement in the soil profile, which is dependant on the intensity and frequency of tillage. A change in tillage systems will change the composition, vertical distribution and density of weed seeds in the soil (Buhler *et al.*, 1997). The extent and depth of weed distribution is directly related to the amount of disturbance, it is the primary cause of vertical weed seed movement in the soil (Buhler *et al.*, 1997; Dyer, 1995).

The effect of tillage on an entire seedbank depends on the initial vertical distribution of seeds in the soil profile and subsequent movement by tillage (Mohler and Galeford, 1997). Fields in which chisel ploughing is performed tend to have a more uniform seed age than fields in which moldboard ploughing is performed. Large portions of weed seed remain at or near the soil surface because there is no soil inversion (Yenish *et al.*, 1992). Furthermore, zero tillage fields tend to have seed on the soil surface or very close to the soil surface (Roberts, 1963). In zero tillage fields, 60% of seeds were found in the top 1 cm of the soil compared to chisel ploughed fields, which had 30% of seeds in the top 1 cm of the soil (Ball, 1992; Buhler *et al.*, 1997; Dyer, 1995).

Secondary tillage has a minor effect on seed movement compared to primary tillage (Staricka *et al.*, 1990). As more cultivation is performed a finer seed bed is created, through which tillage implements pass more easily, therefore, causing less seed movement than in hard packed soil (Rew and Cussans, 1997). Seed movement in the soil also depends on soil texture, structure, moisture and type and speed of cultivation (Rew and Cussans, 1997). Where seeds are positioned in soil structural units also influences where seeds will be distributed in the soil profile after tillage. Although, Paraja *et al.* (1985) found weed seeds in most soil fractions even in the absence of tillage, weed seeds were found in greater numbers in the unaggregated fraction in zero tillage fields. In conventional tillage fields weed seed was distributed evenly among various soil aggregate size (Paraja *et al.*, 1985). Seed size and shape should not have an effect on movement because of tillage; therefore, seed distribution should be similar among species (Cousens and Moss, 1990).

Seedling recruitment depths have been found to be shallower in zero tillage plots than in chisel plough plots (Buhler and Mester, 1991). In a study by de la Cruz (1974), 50% of weed seedling recruitment in zero tillage fields occurred in the top 1 cm of soil. Buhler and Mester (1991) reported that 40% of weeds emerged from depths of 0.5 to 1 cm in zero tillage plots. Chisel plough plots had only 16% of weeds recruiting from this same range.

Weed seedling recruitment was generally deeper in a sandy soil than a clay soil (Dawson and Bruns, 1962; de la Cruz, 1974; Zhang *et al.*, 1998). On the other hand Chancellor (1964b) comments that soil type is not important in determining from what depth weed seedlings can recruit from.

Determining the depth of weed seedling recruitment based on tillage intensity is difficult because of the variety of tillage implements and seeders available. The development of a method for estimating depth of weed seedling recruitment based on a standardized scale of soil disturbance would allow any piece of equipment to be easily incorporated into the scale. A tillage index could be based on implement size, speed and depth of tillage, amount of stubble removed or soil disturbance.

The objective of this study was to create a tillage index, based on levels of crop residues removed. We also wanted to determine if this tillage index could be used as a predictor of depth of weed seedling recruitment.

**Materials and Methods**

A field survey of 88 fields over two years was conducted to determine the depth of weed seedling recruitment in zero and conventional tillage fields (Chapter 4). Each farmer participating in the field survey provided information on the management of each field that was surveyed. Information was gathered on seeding, fertilizing, soil type, legal land description, and harrowing for zero and conventional tillage farmers (appendix 5.1). In addition, the amount and type of tillage that occurred on each field was collected from each conventional tillage farmer. The total number of years in zero tillage for fields surveyed was also received from each zero tillage farmer.

A matrix was developed using this information and the mean depth of recruitment for each weed species in each field (appendix 5.1). A tillage index was created from the data collected on tillage and seeding. The tillage index was based on estimations of percentage stubble left after specific field operations. The best indicator of soil disturbance and movement is the amount of stubble that remains after a field operation (Dr. David Lobb, Department of Soil Science, University of Manitoba, personal communication). The amount of stubble remaining on the soil surface after a tillage operation is dependent on the percentage of stubble before the tillage operation. Since, the speed and depth of a tillage or seeding operation can be variable and the condition of the soil and the residue before field operations is often unknown, the percent stubble removed by a particular implement is the best measure of soil disturbance. True depth and speed of tillage and seeding can vary by as much as 40-60% compared to what the farmer reports (Dr. David Lobb, personal communication). In-field measurement would be required to obtain accurate estimates of these parameters; therefore, we did not use farmer's estimates of speed and depth of tillage in our tillage index estimation. Instead, data on the percent residue remaining after a single implement pass were used to develop a tillage index (Siemens *et al.*, 1993). The value used in Table 1 was calculated by converting the percent stubble remaining to the percent stubble removed. The stubble density data presented by Siemens *et al.* (1993) were separated between fragile and non-fragile stubble and were presented in ranges (wheat is non-fragile and canola is fragile stubble). The mean of each range was calculated and divided by ten to present the value in whole numbers. The mean of the calculated value for fragile and non-fragile stubble was then determined and used as the values for the tillage index (Table 1). Stubble types were combined because stubble type did not seem to affect weed seedling recruitment depth (data not shown). The tillage index is a quantification of the amount of soil disturbance.

For each field, each operation was given a value based on Table 5.1. Because narrow hoe type openers were not rated all hoe openers with a width of one inch or less were considered to provide an equivalent tillage index to a semi deep furrow drill or a press drill. All hoe openers, that were wider than one inch, were given a tillage index of a hoe opener drill. The value for each operation in one field for each sampling period by summing the individual values to give a total tillage index for that field. The mean depth of recruitment for each weed was plotted against the tillage index of that particular field. Pre-seeding and pre-spray sampling periods were calculated separately. The pre-seeding sampling period only included operations that occurred before the sampling period. A tillage index of zero indicates that no tillage or seeding had taken place since the previous spring. The pre-spray tillage index included all operations from the previous fall. A farmer calculating a tillage index for his field would use Table 5.1 and choose the values for the implements that were closest to his own and sum each individual tillage event to reach a total tillage index. The tillage index and the mean depth of weed seedling recruitment for each weed in each field were plotted and regression analysis was used to test for relationships between depth of weed seedling recruitment and tillage index.

Table 5.1. Tillage index values for different field implements (Based on values given in Siemens *et al.*, 1993).

| **Implement** | **Tillage index** |
|---|---|
| Chisel Plough with | |
| Sweeps | 3.375 |
| Straight Points | 4.0 |
| Twisted points or shovels | 5.25 |
| Disks | |
| Offset – heavy ploughing | 7.25 |
| Primary cutting | 6.25 |
| Finishing | 5.625 |
| Tandom – heavy ploughing > 10" spacing | 7.25 |
| Primary cutting > 9" spacing | 6.25 |
| Finishing 7-9" spacing | 5.625 |
| Light after harvest but before tillage | 4 |
| One way disc – 12-16" blades | 6.25 |
| 18-30" blades | 7.5 |
| Field cultivators (as primary tillage operation) | |
| Sweeps 12-20" | 3.5 |
| Sweeps or shovels 6-12" | 4.25 |
| duckfoot points | 5.0 |
| Field cultivators (as secondary tillage operation) | |
| sweeps 12-20" | 2.375 |
| sweeps or shovels 6-12" | 3.5 |
| duckfoot points | 4.625 |
| Harrows | |
| spring tooth | 3.5 |
| spike tooth | 2.5 |
| flextine tooth | 2.0 |
| roller harrow | 2.5 |
| packer harrow | 0.75 |
| Rod weeder | |
| Plain | 3.0 |
| with semi chisels or shovels | 3.0 |
| Drills | |
| hoe opener drill | 4.0 |
| semi deep furrow drill or press drill 7-12" spacing | 2.75 |
| deep furrow drill with 12" spacing | 3.25 |
| single disc opener drill | 1.375 |
| double disc opener drill | 2.0 |

Air seeders refer to field cultivator or chisel plough
Air drill refer to drill opener

The regression was accomplished using the PROCREG procedure in the SAS system for windows (Version 6.12) statistical package (SAS Institute, Raleigh, NC). Pre-seeding and pre-spray sampling periods were analyzed separately for wild oats (*Avena fatua* L.), volunteer wheat (*Triticum aestivum* L.) and wild buckwheat (*Polygonum convolvulus* L.). Years for green foxtail (*Setaria viridis* L. Beauv.) were analyzed separately and only for the pre-spray sampling period. Barnyard grass (*Echinichola curs-galli* L. Beauv.) was only sampled in 1998 in the pre-spray sampling period. A tillage index of zero in the pre-seeding sampling period indicates that no soil disturbance occurred in that field prior to sampling. The large number of fields sampled in this study ensured a continuum of soil disturbances, from a single low disturbance pass to up to six separate disturbance operations in one field.

The effect of soil type on mean depth of weed seeding recruitment was determined by plotting soil type against mean depth of weed seedling recruitment depth for each field (Appendix 5.2.1 to 5.2.8). Soil types were determined by using Reconnaissance Soil Survey Reports. Fields were located on the map using legal land descriptions and the soil was determined to be clay, clay loam, loam, loam, clay-loam, sandy loam or a loamy sand.

The effect of number of years in zero tillage on weed seedling recruitment was determined by plotting years in zero tillage against mean weed seedling recruitment depth for each field (Appendix 5.3.1 to 5.3.5).

**Results and Discussion**

**Effect of tillage index on weed seedling recruitment depth.** In both sampling periods the depth of weed seedling recruitment, generally, increased with increasing amounts of tillage (Figures 5.1 to 5.9 and Table5.2). Soil disturbance caused by tillage and seeding had a significant impact in determining the depth of weed seedling recruitment. For all of the weed species, the relationships between tillage index and depth of recruitment were linear. Except for a few outliers, increased tillage did not increase depth of weed seedling recruitment beyond 5 cm. This may be related to the fact that chisel type tillage is most common in Manitoba (there was no moldboard tillage in this study). Moldboard tillage tends to uniformly distribute seed throughout the soil profile up to depths of 32 cm (Ball, 1992; Buhler *et al.*, 1997; Dyer, 1995). Chisel plough systems concentrate seeds closer to the soil surface, resulting in maximum depths of recruitment of 12 cm (Ball, 1992; Buhler *et al.*, 1997; Dyer, 1995).

Higher tillage indexes may not increase depth of weed seedling recruitment for two main reasons. Cousens and Moss (1990) found that it took 10 years of ridge tine cultivation to reach a stable distribution of beads within a field. After a number of cultivation passes weed seeds may not be moved any deeper into the soil profile. Staricka *et al.* (1990) and Rew and Cussans (1997) determined that only primary tillage has a significant effect on weed seed movement. As more tillage is performed a finer seed bed is created, through which tillage implements pass more easily, therefore, causing less seed movement than in hard packed soil.

The $R^2$ value associated with the regressions was higher for all weed species for the pre-spray sampling period versus the pre-seeding sampling period (Table 5.2).

Table 5.2. Results and parameter values from linear regression analysis of the effect of tillage index on mean depths of weed seedling recruitment.

| Weed Species | Time | Slope | Y-Intercept | $R^2$ | F Value |
|---|---|---|---|---|---|
| Wild oats | Pre-Seed | 0.200<br>(0.0346) | 1.772<br>(0.1899) | 0.38 | 33.51** |
| Wild oats | Pre-Spray | 0.162<br>(0.0186) | 1.821<br>(0.1934) | 0.54 | 76.05** |
| Volunteer wheat | Pre-Seed | 0.278<br>(0.0260) | 0.649<br>(0.1346) | 0.66 | 114.88** |
| Volunteer wheat | Pre-Spray | 0.197<br>(0.0302) | 1.232<br>(0.3214) | 0.58 | 42.46** |
| Green foxtail | 1997<br>Pre-spray | 0.108<br>(0.0278) | 2.164<br>(0.3089) | 0.33 | 15.02** |
| Green foxtail | 1998<br>Pre-spray | 0.110<br>(0.0203) | 1.518<br>(0.2147) | 0.42 | 29.13** |
| Wild buckwheat | 1998<br>Pre-seed | 0.118<br>(0.0255) | 1.504<br>(0.1599) | 0.40 | 21.58** |
| Wild buckwheat | 1998<br>Pre-spray | 0.116<br>(0.0188) | 1.768<br>(0.1956) | 0.47 | 38.14** |
| Barnyard grass | 1998<br>Pre-spray | 0.160<br>(0.0467) | 0.689<br>(0.5385) | 0.56 | 11.80** |

Values in parentheses are standard errors.
** - significant at the 1% level

Tillage generally occurred in the spring. Spring tillage may have more of an effect on depth of recruitment because it stimulates recruitment through exposure of weed seeds to light flashes and warmer temperature. Recruitment response to fall tillage is possible because seeds exposed to a light flash in fall may respond and recruit in the spring when temperatures rise (Pons, 1991). All of the relationships between tillage index and mean recruitment depth for all of the weed species were significant at the 1% level, therefore, tillage had a significant effect on depth of weed seedling recruitment.

The only soil disturbance that occurred before the pre-seeding sampling period was fall tillage or fall harrowing. Sampling in conventional and zero tillage fields was done before any spring tillage operations had occurred. During the pre-spray sampling period, weed seedling recruitment depth was affected by both spring and fall tillage and soil disturbance caused by seeding. Increased soil disturbance, caused by tillage and seeding operations, may have moved weed seeds deeper into the soil profile, and weed seeds that were already deeper in the soil profile were stimulated to recruit, because of soil warming and exposure to light flashes (Pons, 1991; Taylorson, 1987). During the pre-seeding sampling period, weed seeds that were positioned deeper in the soil profile may still have been dormant and did not, therefore, recruit, regardless of how much tillage was performed the previous fall. Therefore, only those seeds that were close enough to the soil surface to receive a light flash or those seeds that were in soil which was warm enough would have recruited at the pre-seeding sampling period (Pons, 1991; Taylorson, 1987).

**Factors other than tillage affecting depth of weed seedling recruitment.** The strongest relationship between tillage index and mean recruitment depth for any of the weed species provided an $R^2$ value of 0.66 (this was for volunteer wheat in the pre-seeding sampling period). This indicates that 66% of the variation in recruitment depth was accounted for by the tillage index (Table 5.2). The other 34% of variation must be related to other factors, such as soil type and speed and depth of tillage and seeding (de la Cruz, 1974). Data on soil type were collected and plotted versus mean weed seedling recruitment depth. The relationship between soil type and depth of weed seedling recruitment for any of the weed species was inconsistent (appendix 5.2.1 to 5.2.8). This compares with Chancellor (1964b) who concluded that soil type was not important in determining from what depth weed seeds could recruit. Dawson and Bruns (1962) and De la Cruz (1974) found, however, that weed seeds could consistently recruit from deeper depths in lighter soil types.

Speed and depth of tillage and seeding can impact depth of weed seedling recruitment but they are difficult to measure (Dr. David Lobb, personal communication; Siemens *et al.*, 1993).

Environmental conditions such as moisture and temperature and the exposure of seeds to a light flash can also affect the depth of weed seedling recruitment (Baskin and Baskin, 1985; Taylorson, 1987). Light is important for the stimulation of germination in any disturbed habitat (Scopel *et al.*, 1994; Tester and Morris, 1987). Light penetration through soil is poor, therefore, the proportion of total seed in the seedbank receiving light after tillage is small (Scopel *et al.*, 1994; Tester and Morris, 1987). Effective penetration of light into the soil is not greater than 4 mm (Benvenuti, 1985). Increased roughness in the soil surface increases the amount of light penetration, especially if the soil is highly disturbed by tillage (Tester and Morris, 1987). Although light is important in the recruitment of weed seedlings it is not the only environmental factor responsible for stimulating germination. Weed seeds will not germinate under extreme conditions of moisture or temperature (Buhler, 1997; Pons, 1991). These factors are important in limiting the depth of recruitment, especially at the pre-seeding sampling period.

The initial distribution of weed seeds in the seedbank before tillage will also affect the depth of weed seedling recruitment (Rew and Cussans, 1997). The seedbank is difficult and time consuming to quantify (Baskin and Baskin, 1985; Cardina *et al.*, 1996).

The number of years any field is in zero tillage (which ranged from 3 to 24 in this study) did not seem to affect depth of recruitment of any of the weed species considered (appendix 5.3.1 to 5.3.5). Perhaps length of seed dormancy is not a factor that strongly affects depth of weed seedling recruitment. If it did, there would be shallower weed seedling recruitment in fields that had been in zero tillage longer. Seed placed deeper in the soil profile would have been exhausted, and there would not have been any tillage to replace those seeds. Therefore, weed seedlings may not be recruiting as deep in zero tillage as in conventional tillage because the conditions necessary for recruitment are not being met at deeper depths in zero tillage. There may be other environmental factors such as decreased soil temperature and prevention of light penetration which may prevent weed seedling recruitment from deeper depths (Dyer, 1995). Harper (1959) demonstrated that the length of seed dormancy increases as depth of seed placement increases. Therefore, if a zero tillage field is cultivated, dormant seed will be exhumed and reduce any benefits of weed control previously obtained (Froud-Williams *et al.*, 1983).

**The relationship of tillage index to the recruitment depth of individual weed species.** Wild oat weed seedling recruitment depth was weakly associated with tillage index in the pre-seedling sampling period, 38% of the variation was explained by tillage index (Table 5.2). At the pre-spray sampling period, depth of wild oat seedling recruitment had a stronger association with tillage index, tillage index explained 54% of the variation in recruitment depth (Figures 5.1 and 5.2, and Table 5.2). Although the $R^2$ values were lower in the pre-seeding versus the pre-spray sampling period the relationship of recruitment depth to tillage index was highly significant at both sampling periods (Table 5.2). The higher slope value at the pre-seeding sampling period indicates that with each increase in tillage index, recruitment depth will be affected more than in the pre-spray sampling period. This was true for volunteer wheat and wild buckwheat as well. Rew and Cussans (1997) noted that if little tillage has been performed, any additional tillage would have a great affect on weed seed movement as is shown in the results from the pre-seeding sampling period. Seed movement within the soil profile would be affected less as more tillage was performed. This can be seen in the results from the pre-spray sampling period.

These data suggest that factors other than tillage affect recruitment depth because tillage does not account for all the variation around the mean. At the pre-seeding sampling period the soil had not been disturbed since fall, and in some cases not at all since seeding the previous year. Soil temperature, moisture and the absence of a light flash may have prevented recruitment from deeper in the soil profile and, therefore, had more of an affect on recruitment depth than tillage index. The relationship between tillage index and recruitment depth was much stronger for the pre-spray sampling period (Figure 5.2, Table 5.2). This indicates that tillage was a very important factor driving weed seedling recruitment depth during this period. Tillage before the pre-spray sampling period exposed (shallow and deeply buried) seeds to light, that is necessary to break dormancy (Taylorson, 1987). Tillage would have also warmed up the soil to deeper depths promoting recruitment of deeply buried seed. Deeper tillage would have stimulated recruitment of deeply buried weed seeds.

The relationship between recruitment depth and tillage index was strongest for volunteer wheat compared to all of the other weed species sampled at either the pre-seeding or the pre-spray sampling period (Table 5.2). The tillage index accounted for 66% and 58% of the variation in volunteer wheat seedling recruitment in the pre-seeding sampling period and the pre-spray sampling period, respectively (Table 5.2). The slopes for pre-seeding and the pre-spray sampling periods were 0.278 and 0.197, respectively. Increases in tillage index pre-seeding will affect recruitment depth more so than during the pre-spray period. The number of volunteer wheat seedlings sampled pre-seeding was greater than during the pre-spray period, which may be the reason for a stronger relationship at the pre-seeding sampling period. Volunteer wheat does not have a persistent seedbank, therefore, volunteers are primarily the result of the previous year's seed rain. As such, recruitment depth will be largely affected by the amount of soil disturbance caused by tillage and seeding. In the pre-seeding sampling period, the majority of the fields having a tillage index of zero had volunteer wheat recruitment depths of less than 1 cm deep (Figure 5.3). As tillage index increased so did the depth of

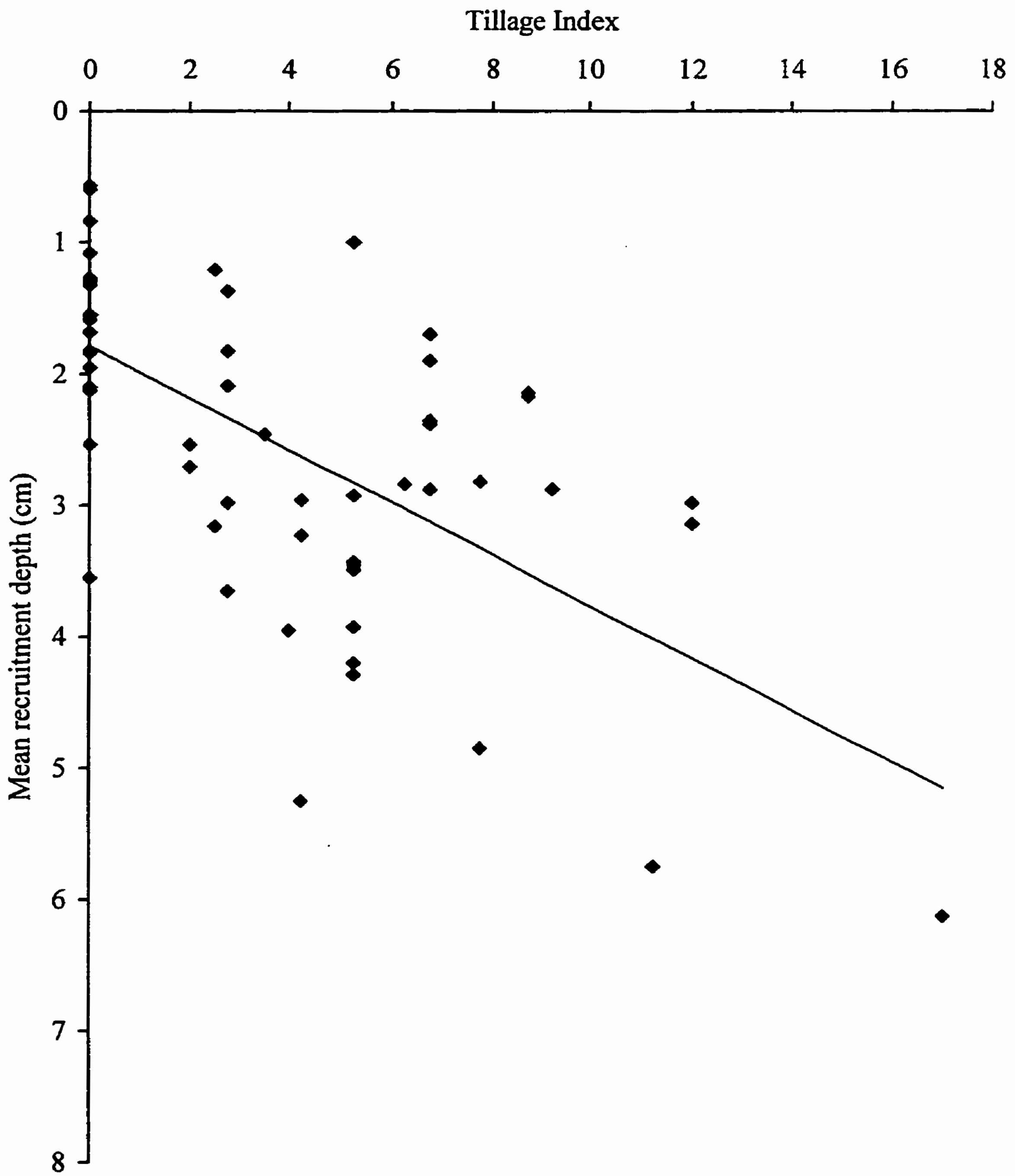



Figure 5.1. Relationship of tillage index to mean recruitment depth of wild oats seedlings for the pre-seeding sampling period (1997 and 1998 combined).

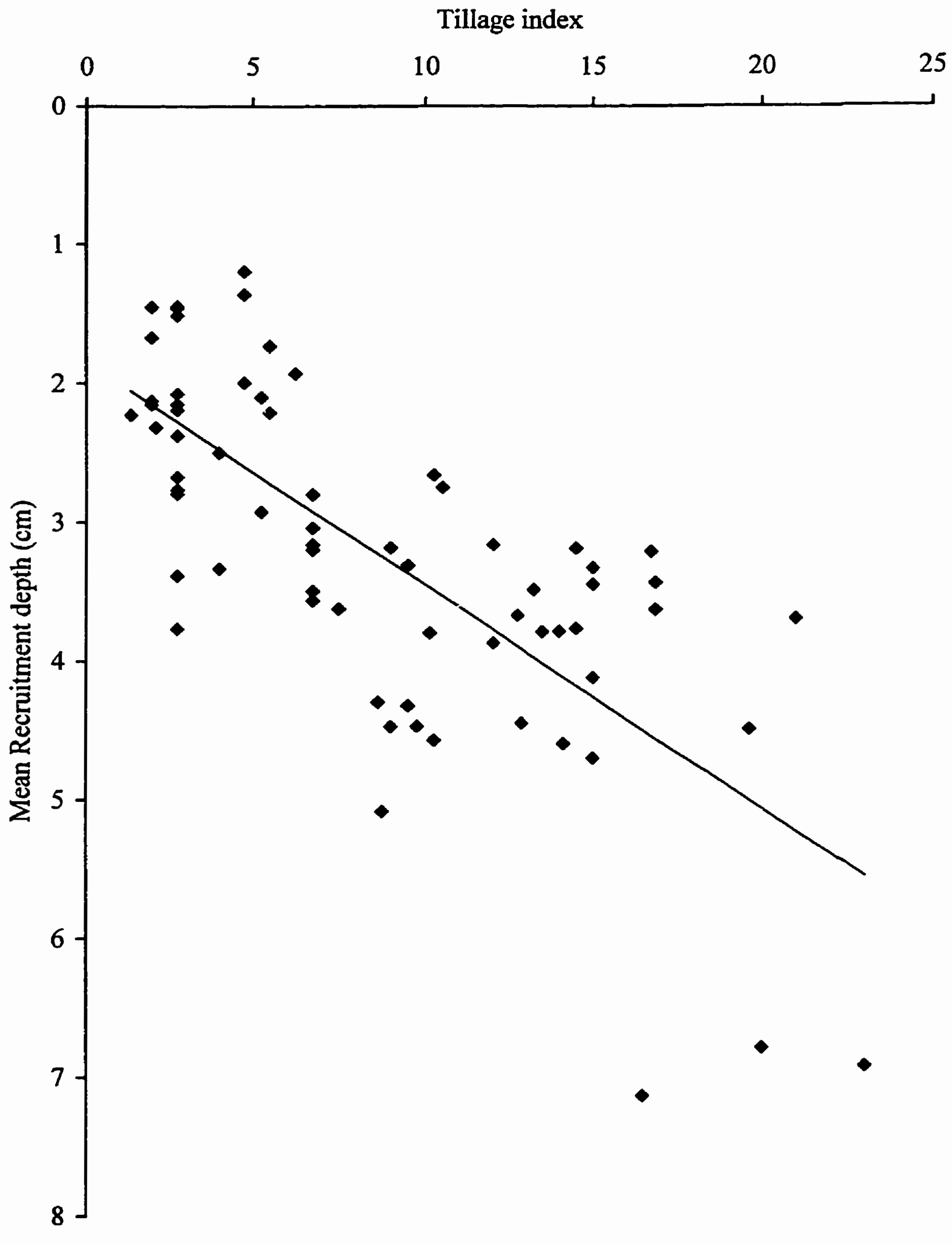



Figure 5.2. Relationship of tillage index to mean recruitment depth of wild oats seedlings for the pre-spray sampling period (1997 and 1998 combined).

volunteer wheat recruitment. At the pre-spray sampling period recruitment depth was even more strongly related to the tillage index (Figure 5.4 and Table 5.2).

Green foxtail recruitment depths were only analyzed for the pre-spray sampling period. In addition, mean recruitment depths were significantly different between years and data for each year was, therefore, analyzed separately (Chapter 4). Green foxtail seedlings were found in almost every field in 1997 and 1998, an increased number of fields in 1998 increased the number of data points. For 1997, the tillage index explained 33% of the variation in mean recruitment depth of green foxtail. In 1998, the tillage index explained 42% of the variation in mean recruitment depth (Table 5.2). The higher $R^2$ in 1998 may have been due to the increased number of fields sampled and the increased number of data points giving a stronger indication of the relationship between recruitment depth and tillage index. The relationship between tillage index and recruitment depth was weaker for green foxtail in both years than for either wild oats or volunteer wheat (Figures 5.5 and 5.6, and Table 5.2). This may be because, with a relatively smaller seed size, green foxtail seeds are not moved as much by tillage as are wild oats and volunteer wheat seeds. Although, according to Cousens and Moss (1990), seed size and shape should have no affect on how seeds will move within the soil; therefore, seed distribution should be similar among weed species. Recruitment depth was shallower for green foxtail versus wild oat and volunteer wheat (Chapter 4), perhaps because green foxtail seeds are smaller and have less energy reserves. It may be for this same reason that tillage index was not as strongly related to recruitment depth for green foxtail as compared to wild oats or volunteer wheat. Lower slope values for green foxtail

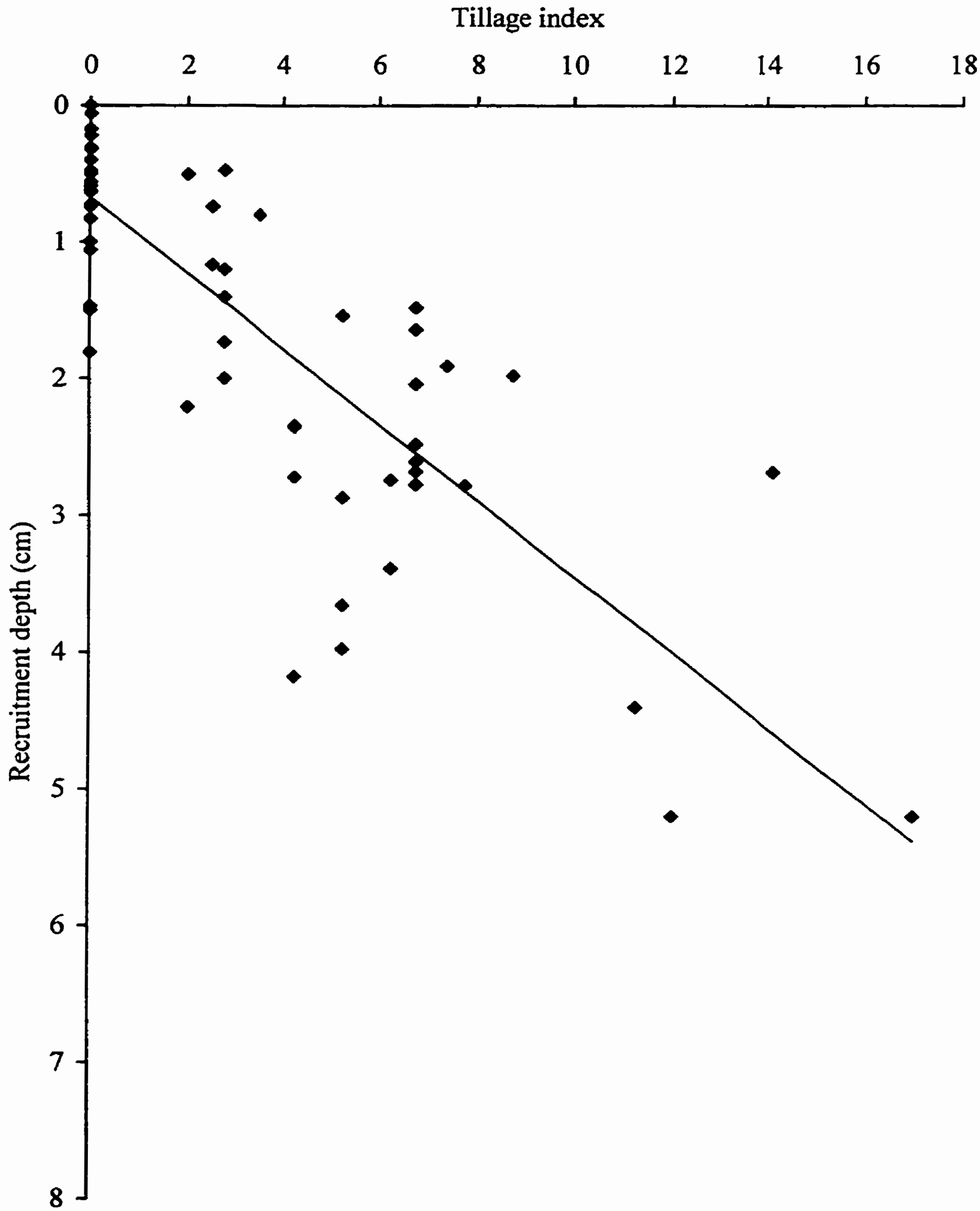



Figure 5.3. Relationship of tillage index to mean recruitment depth of volunteer wheat seedlings for the pre-seeding sampling period (1997 and 1998 combined).

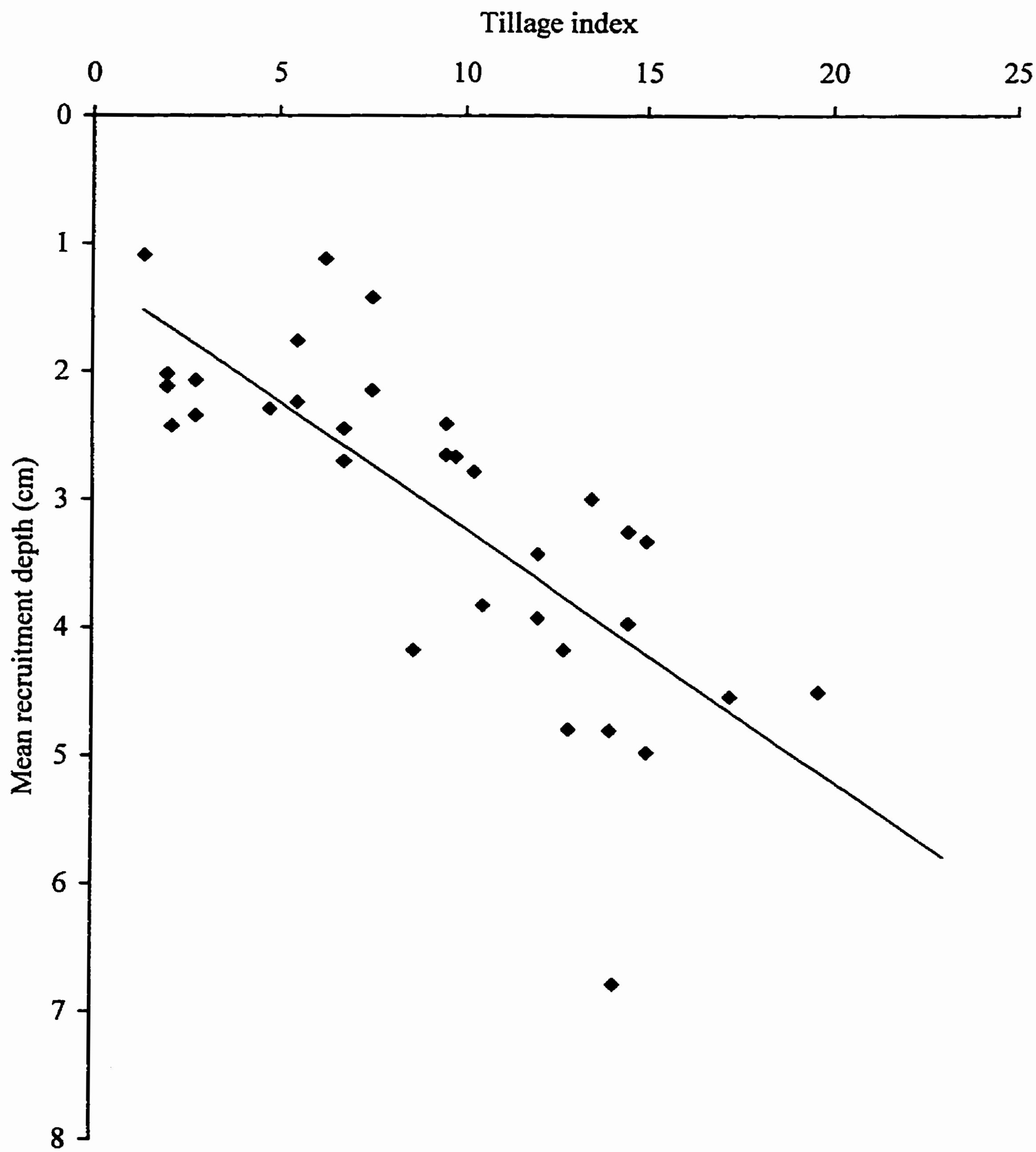



Figure 5.4. Relationship of tillage index to mean recruitment depth of volunteer wheat seedlings for the pre-spray sampling period (1997 and 1998 combined).

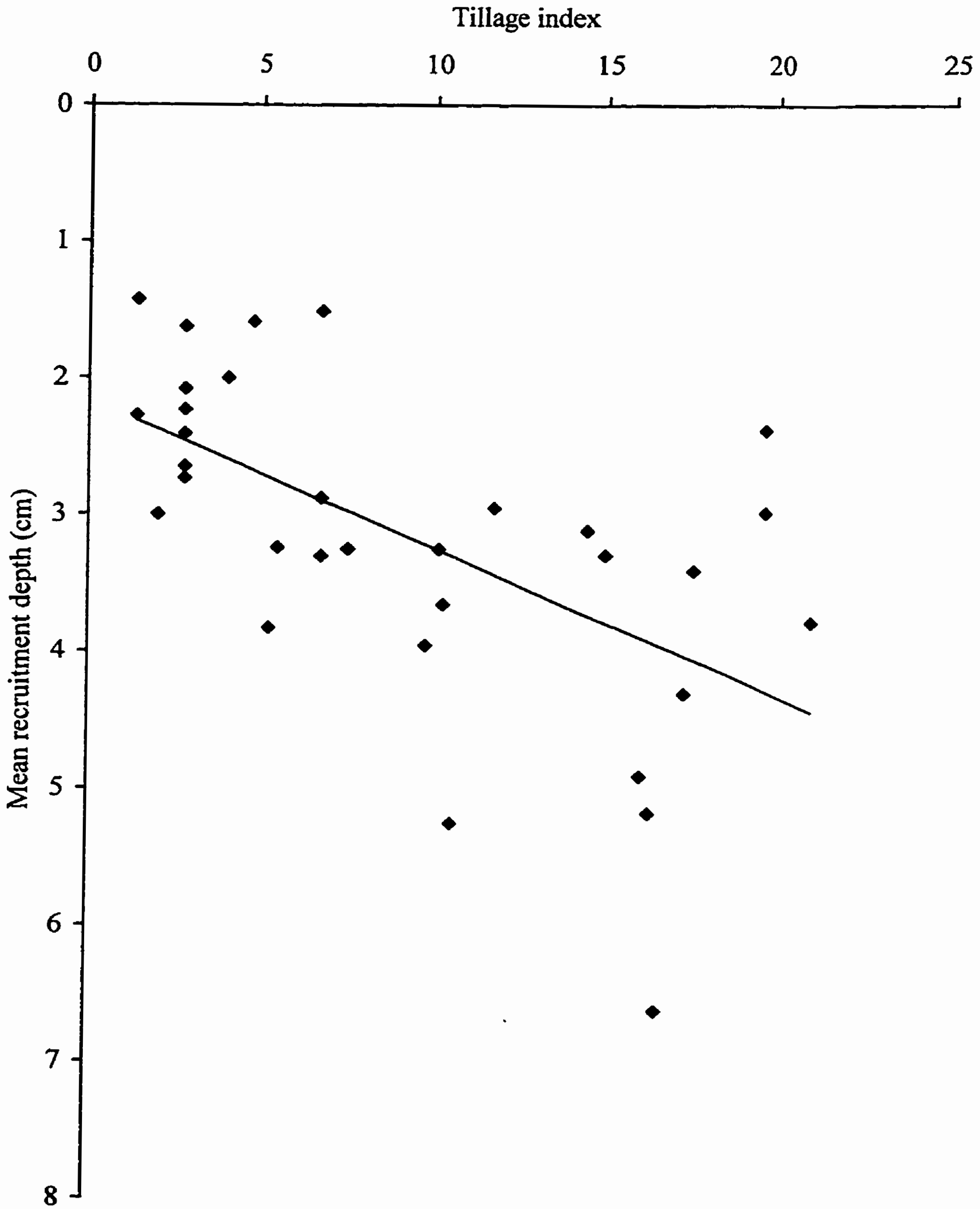



Figure 5.5. Relationship of tillage index to mean recruitment depth of green foxtail seedlings for the pre-spray sampling period (1997).

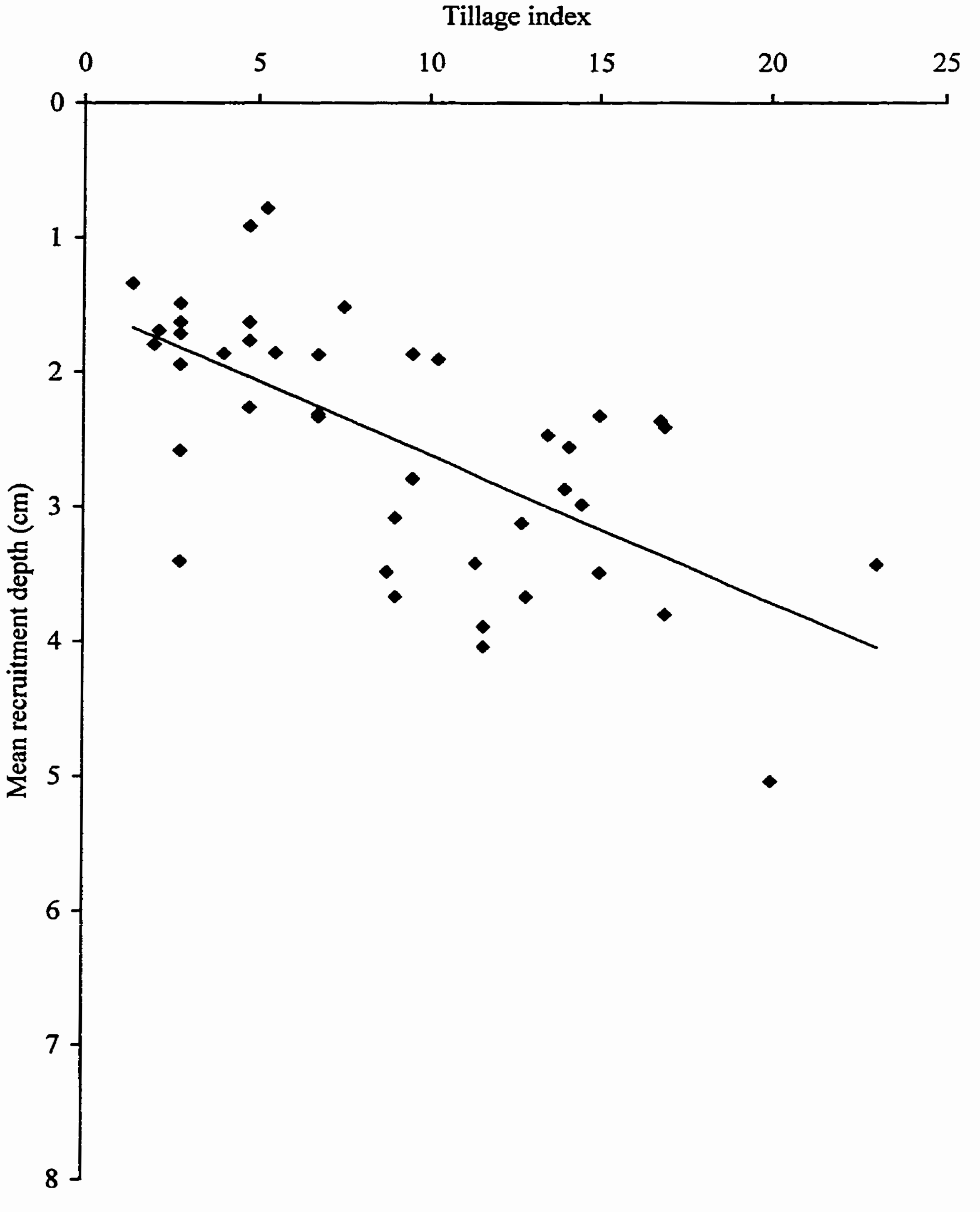



Figure 5.6. Relationship of tillage index to mean recruitment depth of green foxtail seedlings for the pre-spray sampling period (1998).

indicate that as tillage is increased recruitment depth of this weed would not change as much as would wild oat or volunteer wheat recruitment depth (Table 5.2).

The relationship between mean depth of recruitment and tillage index for wild buckwheat in the pre-seeding sampling period was weaker than volunteer wheat and similar to wild oats and green foxtail at the same sampling period. Tillage index explained 40% of the variation in recruitment depth (Table 5.2). This indicates that at this sampling time, tillage had a significant effect on the depth of recruitment of wild buckwheat (Figure 5.7). Wild buckwheat seed has very high levels of dormancy. The seeds need specific conditions to recruit. Early in the season, these conditions may only be met over a very narrow range of soil depths, thus preventing recruitment from any deeper in the soil before spring tillage. During the pre-spray sampling period, recruitment depth was more strongly related to tillage. The tillage index explained 47% of the variation in wild buckwheat recruitment depth (Figure 5.8 and Table 5.2). Spring tillage warms up the soil and exposes dormant seed to light flashes, breaking dormancy and allowing seeds deeper in the soil profile to recruit. The slopes for wild buckwheat support these conclusions. The slopes for the pre-seeding and pre-spray sampling periods were very similar at 0.118 and 0.116, respectively indicating that during the pre-spray sampling versus the pre-seeding sampling period recruitment depth of wild buckwheat seedlings would not change as much with changes in the tillage index (Table 5.2).

The sample size of barnyard grass was quite small but the relationship between tillage index and depth of recruitment was strong, with tillage index accounting for 56% of the variation associated with recruitment depth (Figure 5.9 and Table 5.2). The slope

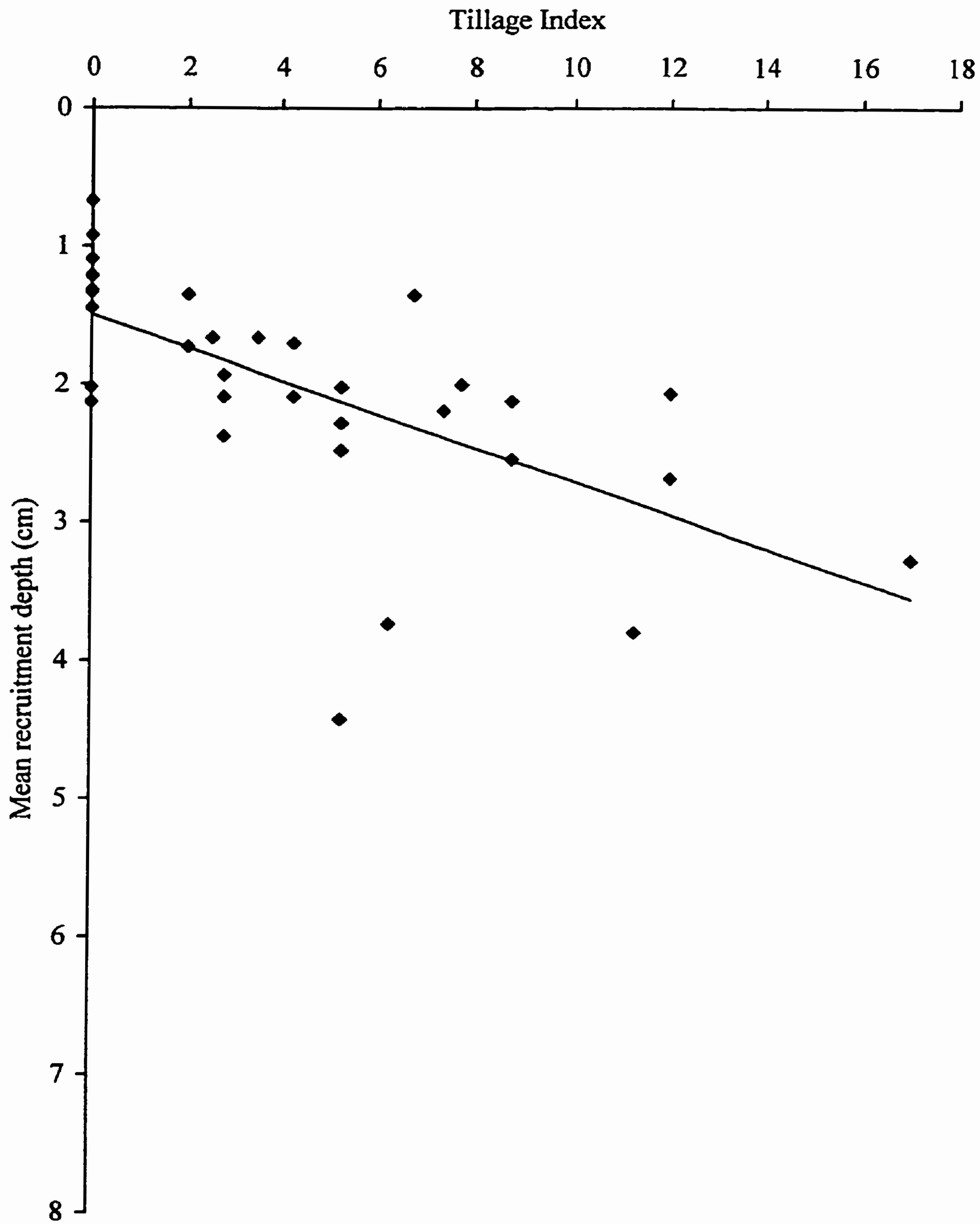



Figure 5.7. Relationship of tillage index to mean recruitment depth of wild buckwheat seedlings for the pre-seeding sampling period (1998).

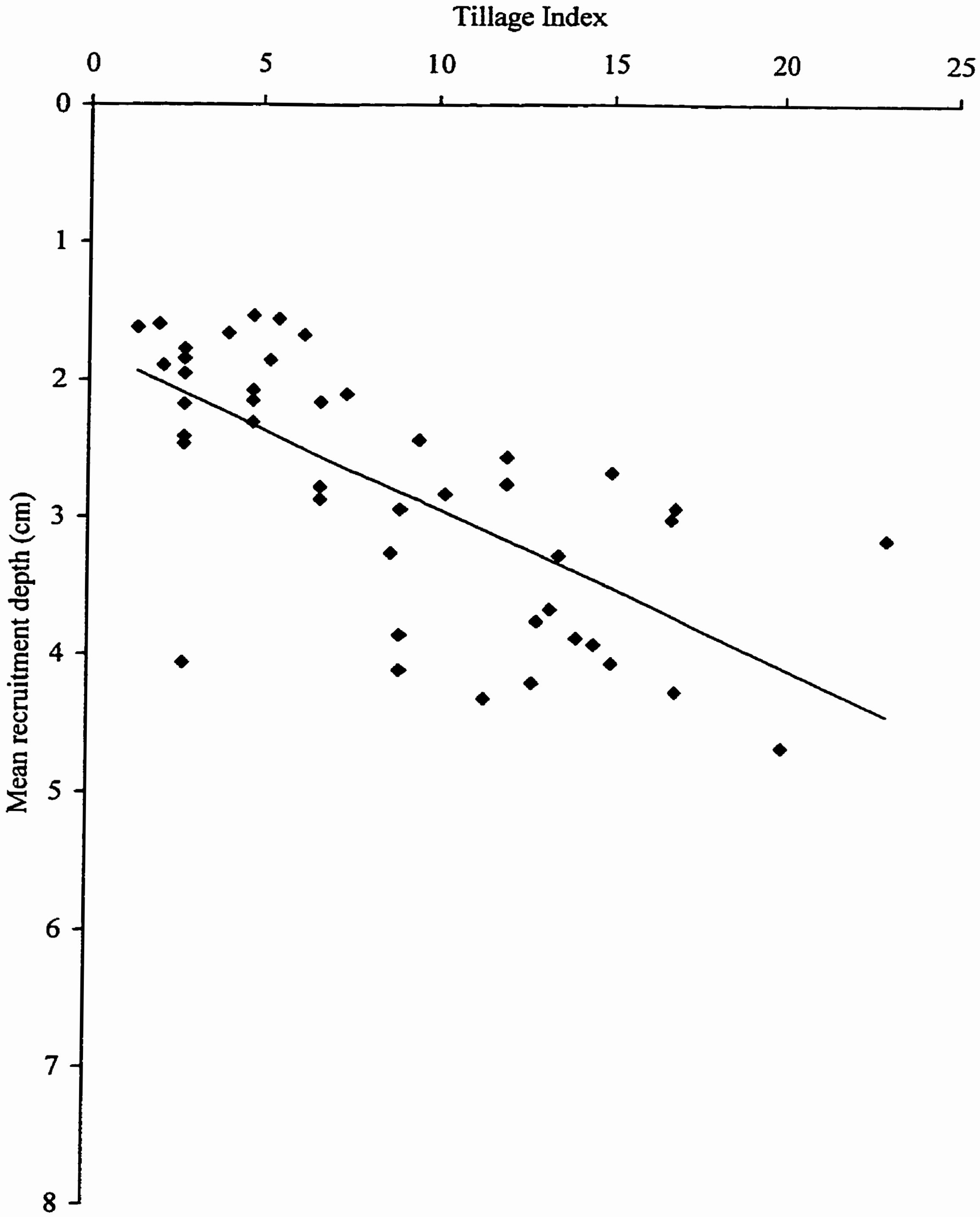



Figure 5.8. Relationship of tillage index to mean recruitment depth of wild buckwheat seedlings for the pre-spray sampling period (1998).

was 0.160 which indicated that increases in tillage index strongly affected recruitment depth of barnyard grass. Depth of barnyard grass recruitment, therefore, was greatly affected by the amount of soil disturbance caused by seeding and tillage. Barnyard grass seeds are slightly larger than green foxtail seed but it was not expected that tillage index would affect barnyard grass recruitment depth so much more than it did for green foxtail. This may be due to the small number of barnyard grass seedling sampled causing the data to be biased towards the management factors in only a few fields. Barnyard grass may be able to recruit from deeper depths in the soil than green foxtail but since barnyard grass was only sampled in 1998 more study is needed before more conclusions can be drawn (Chapter 4).

All of the relationships between tillage index and mean seedling recruitment depth were significant at the 1% level (Table 5.2). Although tillage index did not account for all of the variation associated with mean recruitment depths, tillage was a significant factor determining recruitment depth of the weed seedlings surveyed.

**Outliers in the data.**

The linear regression plots for wild oat pre-seeding and pre-spray, volunteer wheat pre-spray and both years of green foxtail pre-spray all had noticeable outliers, showing very deep recruitment at high levels of tillage index (Figures 5.1, 5.2, 5.4, 5.5 and 5.6). Out of eight obvious outliers, samples from one farmer's fields accounted for five of them. Trever McLeod is a conventional tillage farmer near the town of Brookdale, MB. In both sampling years, data from this farmer's fields produced outliers for wild oats at

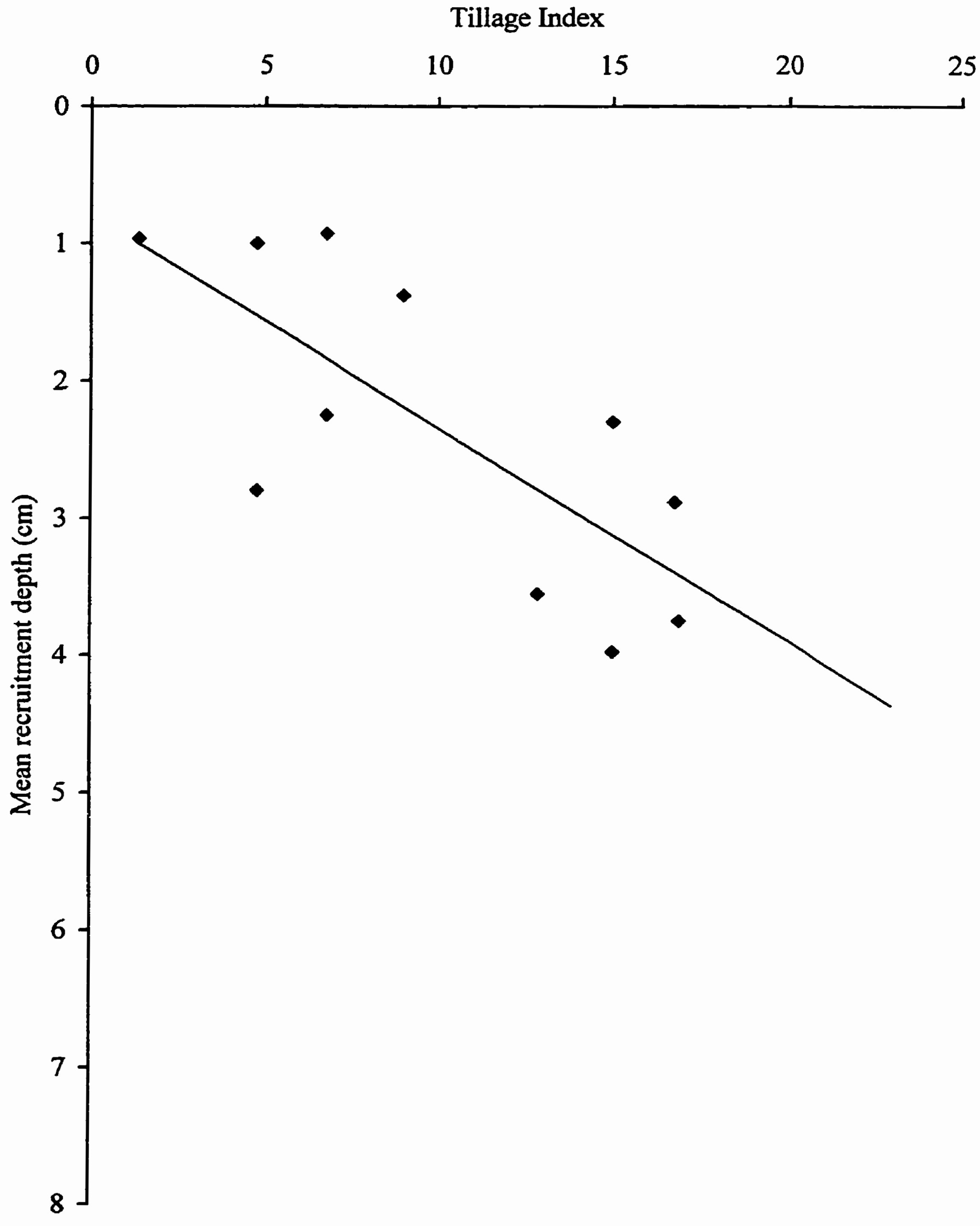



Figure 5.9. Relationship of tillage index to mean recruitment depth of barnyard grass seedlings for the pre-spray sampling period (1998).

the pre-seeding and the pre-spray sampling periods and green foxtail at the pre-spray sampling period (Figures 5.1, 5.2, 5.5 and 5.6). Over the course of one year he conducts six field passes, two cultivations in the fall, two in the spring, one anhydrous application and seeding. He pastures his cows on his fields over the winter and tills extensively to prepare the soil for seeding. His depth of tillage is similar to other conventional tillage farmers in this survey but he may have tilled deeper than he realized. His speed of tillage is in the upper range, but there are other farmers in the survey who performed tillage operations faster.

In 1998, outliers in both the pre-seeding and pre-spray sampling period for wild oats come from the fields of Doug Love, a conventional tillage farmer near the town of Portage la Prairie, MB (Figures 5.1 and 5.2). Over the course of one year this farmer has four field operations; two fall cultivations, one anhydrous application in the spring and seeding. The wild oat outlier during the pre-spray sampling period was in the same area as the outliers found in Trever McLeod's fields. Each of the fields for both Trever Mcleod and Doug Love are clay loams. In 1998, Don Friesen a conventional tillage farmer near the town of Altona, MB had a volunteer wheat outlier at the pre-spray sampling period (Figure 5.4). This field had four field operations; two fall cultivations, one anhydrous application and seeding. The soil type on this field was a clay.

Based on the intensity of tillage on the fields, which produced the outliers in the data, it is suspected that all of these outliers are caused by intensive tillage in the fall and the spring that leads to exceptional depths of recruitment. The actual speed and depth of tillage that the farmers are using can vary by as much as 40-60% from what they think.

The depth of tillage may be much greater than reported in cases of extreme tillage as the seedbed becomes softer and equipment is able to pass through the soil easier. This would not only move seed deeper into the soil profile, but the tilled soil would provide less resistance to deeply recruiting seedlings.

Other outliers are not so easily explained. Ed Phillips is a zero tillage farmer near Hartney, MB. An outlier with a low tillage index and a high recruitment depth in the pre-spray wild buckwheat sampling period comes from one of his fields in 1998 (Figure 5.8). In 1998, Ed Phillips used a low disturbance seeder with one inch openers, but in 1997 he was using a higher disturbance seeder with two inch spoons. All other field operations between the two years were the same. Seeding in 1997 may have moved weed seeds deeper into the soil, and in 1998 there might have been deeper recruitment from deeply placed seeds, because of past seeding operations. Although years do not seem to have an affect on mean depth of recruitment (appendix 5.3.1 to 5.3.5), the minimum number of years in zero tillage was three for the fields surveyed. Seedling recruitment may respond to the previous year's management.

**Summary and Conclusions**

The tillage index is based on data that were collected from farmers after the sampling was completed. Fields were initially chosen using very broad definitions of zero tillage and conventional tillage (Chapter 4). The tillage index forms a continuous measurement of soil disturbance, from no disturbance (before seeding in a zero tillage field), to intensive soil disturbance in a conventional tillage field. It was based on

Siemens *et al.* (1993) estimates of percent stubble remaining after a specific implement passes. Soil disturbance and movement might be better measured by integrating speed and depth of each implement pass but these are not reliable measurements unless they are measured in the field.

The tillage index was a way to integrate all factors associated with tillage into a reliable and easy to calculate measurement of soil disturbance. The tillage index used provides a precise measurement of one factor that affects weed seedling recruitment depth. Tillage is the primary factor, but not the only factor affecting weed seedling recruitment. For most weed species, especially for the pre-spray sampling period, the tillage index accounted for close to 50% of the variation associated with recruitment depth. More research is needed measuring weed seedling recruitment depth on different soil types to determine if soil type is important in determining the depth of weed seedling recruitment. Initial analysis of soil type data collected in this study indicated that it was not a consistent factor (appendix 5.3.1 to 5.3.1). Other factors such as soil temperature and moisture are important in determining the depth of weed seedling recruitment but they are difficult to measure on a consistent basis within the weed seedling recruitment zone.

The range of recruitment depths of the weed species sampled in zero and conventional tillage fields were quite narrow. There is only a recruitment depth difference of 5 cm from the lowest tillage index to the highest tillage index. Even if the tillage index was improved to account for more variation due to tillage and other factors that affect recruitment depth, it may still be a challenge for farmers to modify tillage practices enough to affect weed seedling recruitment in such a narrow range.

Other studies have been conducted to determine the depth of weed seedling recruitment from natural weed seedling populations under different tillage practices (de la Cruz, 1974; Chancellor, 1964a; Buhler and Mester, 1991). None of these studies included as extensive a number of locations as did the present study. The large number of fields sampled over the wide geographical area allowed us to create a model of recruitment depth based on the tillage scenarios represented in the data set. With this model farmers may position their system in the tillage continuum based on the simple tillage index calculation. It may be possible for them to then predict, with some reliability, the recruitment depth of a number of common weed species in their own fields. Tillage or application of soil applied herbicides can then be targeted at the depth of weed seedling recruitment to optimize weed control.

The information obtained through this study will be used as a basis in the development of prediction models of the timing of weed seedling recruitment. Combining depth and timing of weed seedling recruitment may allow one to more accurately predict when and where weed control should be applied. Determining the exact timing of weed seedling recruitment in individual fields will allow farmers to optimize current weed control strategies.

# CHAPTER 6

## General Discussion

In this study, the depth of weed seedling recruitment was determined in zero and conventional tillage fields over many locations in Manitoba. The significance of this data comes from the large number of fields sampled over the many locations in a region. Each farmer involved in the survey had a different system and used different machinery. Because, natural seedling populations were measured, as opposed to seeds placed at specific depths in the soil, the results obtained reflect what is happening in farming systems across Manitoba. This represents an improvement over previous studies by Dawson and Bruns (1975), Wiese and Davis (1966) and Stoller and Wax (1973) who placed seeds at specific depths in the soil. The weed seedlings measured were a better measure of weed populations than seed measurements because the seedlings had overcome all of the factors that would have prevented weed seeds from recruiting. Many factors, such as tillage, soil type, soil environment and seed positions may affect the depth of weed seedling recruitment. Soil disturbance caused by tillage and seeding, was the main driving factor influencing depth of weed seedling recruitment for all of the weed species sampled. Across all fields surveyed, the depth of weed seedling recruitment increased as soil disturbance levels due to tillage and seeding increased. Although a large number of fields were sampled in this study, increasing the number of sites might have improved the estimation of the relationship between tillage intensity and depth of recruitment.

The discovery of the morphological marker on wild buckwheat (*Polygonum convolvulus* L.) allowed a broad leaf weed species to be added to the survey in 1998. Although the marker was only found on wild buckwheat, other weeds may also possess an obvious characteristic identifying the point of recruitment. De la Cruz (1974) found a morphological marker on two broad leaf weed species, velvetleaf (*Abutilon theophrasti* Medicus) and smartweed (*Polygonym pensylvanicum* L.). Smartweed and wild buckwheat are in the same family, suggesting that the morphological marker is only present in that family, but since velvetleaf is in a different family, this is not the case. Weeds that were examined for the presence of a morphological marker need to be re-examined and those not considered need to be included in the investigation for the presence of a morphological marker. Knowing the recruitment depth of one weed does not mean that the response will be the same for another. It is important to know the depth of weed seedling recruitment because it is the best measurement of seed movement in the soil. Although wild buckwheat is an economically important broadleaf weed in Manitoba, it is not the only one that can significantly affect yields of crop plants. Broadleaf weeds for which a morphological marker should be identified and depth of recruitment should be determined are: wild mustard (*Sinapsis arvensis* L.), redroot pigweed (*Amaranthus retroflexus* L.) and lamb's quarters (*Chenopodium album* L.). These broadleaf weeds are economically significant in Manitoba (Thomas, 1991; Thomas *et al.*, 1998).

The grassy weeds included in the survey encompass the major species in Manitoba. The numbers of individuals sampled for each species was quite large, except for barnyard grass (*Echinochloa crusgalli* L. Beauv). Because, the information on barnyard grass is limited, solid conclusions about this weed cannot be drawn. Although barnyard grass is very similar to green foxtail in seed size, further investigation needs to be done to confidently determine how tillage affects recruitment depth of barnyard grass. It is important to know the recruitment depth of barnyard grass because it is one of the three major grassy weeds in Manitoba, these being; wild oats (*Avena fatua* L.), green foxtail (*Setaria viridis* L. Beauv) and barnyard grass (Thomas and Donaghy, 1991; Thomas *et al.*, 1998).

The weed species surveyed in this study recruited from quite shallow in the soil profile. Mean recruitment depth for all weed species surveyed was less than 4.5 cm. This does not necessarily indicate that seedlings are unable to recruit from deeper in the soil profile, it only indicates where seeds or microsites are positioned in the soil profile in Manitoba fields. Weed seeds, which are deeper in the soil, may not be able to recruit, because of the lack of suitable microsites. Deeply placed weed seeds may germinate but are beyond maximum emergence depths. As well the percentage of suitable microsites is higher closer to the soil surface. In Manitoba, most tillage is non-inversion or chisel type tillage, which does not create as much soil disturbance as inversion or moldboard ploughing. Although the majority of weed seedlings will still recruit from fairly shallow, even in moldboard ploughing, seed placement has a significant effect on the depth of weed seedling recruitment. This indicates that weed seedlings will tend to recruit from shallower depths in the tillage systems common in Manitoba. The positive relationships between tillage index and recruitment depth support this theory.

The development of the tillage index, based on tillage, harrowing and seeding, allowed fields to be viewed on a continuous scale of soil disturbance rather than as simply zero or conventional tillage. The diversity in management systems today no longer allows such broad terms to be effective in defining any one system. The term zero tillage can refer to tillage intensities that range from one extremely low disturbance field pass to three field passes (seeding, fertilizer application and harrowing) in one field. The latter can be the same amount of disturbance as a minimal tillage system, but because there is no tillage it is still defined as zero tillage. Current definitions of zero tillage are based on the percent of soil disturbance, which is harder to define than soil disturbance based on a tillage index. A tillage index indicates total disturbance because it is a sum of all the field operations that are individually rated with regard to how much soil disturbance each pass caused. It is a simple method that can be completed in a very short period of time. Farmers do not have to go into fields to measure soil disturbance the tillage index can be calculated based on the number of field operations. The tillage index developed in this study is easy to use and highly related to mean recruitment depth for all weed species, but it is still not the best tillage index that can be developed. Soil disturbance is highly dependant on the speed and depth at which any one implement is used, but these two factors need to be measured in the field to ensure accuracy. This was not done but it should be to improve the accuracy of the tillage index. Sampling dates should be coordinated to occur the day the farmer was seeding or tilling. The depth and speed of each operation could be measured at that time. Additional tillage events would have to be measured as well. For now, the tillage index is based on stubble measurements, which is in itself a good measure of soil disturbance even if it is not the best.

During the 1997 and the 1998 sampling seasons, stubble density measurements were taken along with weed seedling measurements. A picture was taken of the soil profile, with a grid overlay. The grid consisted of 640 squares that were 1 $mm^2$. The percentage of squares with more than 60% stubble were tallied to determine mean stubble density on the fields (appendix 5.1). In 1997, three stubble density pictures were taken per field, in 1998 five were taken per field. The stubble density measurements were less strongly related to mean recruitment depth than the tillage index I developed (data not shown). The field measurements were too variable, most likely because not enough replicates were taken in each field. Time limitations, because of the number of fields sampled, prevented more measurements from being taken. The tillage index developed, is a good measure of soil disturbance, but it could be improved by developing a index based on a wider range of farm implements used in Manitoba and incorporating a speed and depth for each pass. An improved tillage index may be able to produce a stronger relationship with recruitment depth, so farmers could have higher level of confidence on the depth of weed seedling recruitment in their fields.

I also conducted soil core experiments during the winters of 1997/98 and 1998/99 (appendix 6.1). The idea was to bring zero and conventional tillage fields to the lab to determine the effect of each system on recruitment depth of weed seedlings. Initially, the purpose was to determine the effect of tillage system on those broadleaf weeds for which a morphological marker could not be found, but it was determined that such a methodology could also be used to investigate the effects of each system under a controlled environment. Weed control in zero tillage is more difficult because tillage, an important means to control weeds, has been removed. The adoption of zero tillage has been slow because of the fear that weeds would be too difficult to control. In some cases there are shifts to increased levels of weed populations because zero tillage favors some types of weeds (Derksen *et al.*, 1993). It was interesting to discover that for the species we investigated there was reduced recruitment in the zero tillage cores. There was something, therefore, in the zero tillage cores that was reducing the percentage of weed seedling recruitment compared to the conventional tillage cores, especially as the depth of planting increased. There may be several reasons for this. The change in environment in zero tillage cores, because of the lack of tillage, may have been detrimental to the weed species tested in this experiment. There may have also been a physical barrier to weed seedling recruitment, the seeds may have germinated but failed to recruit due to physical impediments, which was especially evident as the depth increased. The accuracy of this method can be tested by comparing the response of depth of recruitment in the core to the depth of recruitment in the field, of those weeds that can be measured in the field (grassy weeds and wild buckwheat). If the weed responds similarly in the field and in the indoor experiments, the depth of recruitment of those weeds that cannot be measured in the field may be investigated indoors. Although in this study, this experiment was not expanded beyond the methodology development, it has potential to become a very important research tool in the future. For example, the effect of physical and biological changes in zero versus conventionally tilled fields, on recruitment depth could be investigated. It could also be used to investigate the effects of different moisture levels, temperatures, light and chemicals on recruitment depth at a fine depth scale.

Knowing the depth of weed seedling recruitment under different tillage systems is only the beginning. Results from this project indicate that soil applied herbicides should work in zero tillage systems without incorporation because seedling recruitment is very close to the soil surface. Development of better delivery systems may allow herbicides to be placed in the range of weed seedling recruitment to increase efficacy or reduce rates needed, and the tillage index can be used to inform farmers where recruitment is occurring within their system. The addition of soil applied herbicides is important to the zero tillage farmer because it increases herbicide options for weed control.

The depth of weed seedling recruitment for wild oats, volunteer wheat, green foxtail, wild buckwheat and barnyard grass was determined in zero and conventional tillage fields over a wide geographical area in Manitoba. Mean recruitment depths for all weed species surveyed was deeper in conventional tillage than in zero tillage. Although overall mean recruitment depth was shallow (> 4.5 cm). This indicates that tillage for weed control does not need to be deep. Shallow tillage would not only control weeds but it would also prevent weed seeds from being placed deep in the soil profile.

A model was produced in the form of a tillage index. It can be used to predict the depth of weed seedling recruitment based on tillage levels. Using Table 5.1, each field operation can be rated and the sum of each event can be totaled to give a tillage index for that field. The tillage index can be used to predict the depth of weed seedling recruitment.

The next step is to develop models to predict the timing of weed seedling recruitment. The efficiency of herbicide application can be improved by timing applications to when they provided the best weed control. The number of herbicide applications could be reduced by improving the timing of application to kill weeds before they become competitive and eliminating the need for a second or third application.

## LITERATURE CITED

Anderson, R.L. 1994. Characterizing weed community seedling emergence for a semiarid site in Colorado. Weed Tech. 8: 245-249.

Anderson, R.L. and D.C. Nielson. 1996. Emergence pattern of five weeds in the central great plains. Weed Tech. 10: 744-749.

Ball, D.A. 1992. Weed seedbank response to tillage, herbicides, and crop rotation sequence. Weed Sci. 40: 654-659.

Ball, D.A. and S.D. Miller. 1989. A comparison of techniques for estimation of arable soil seedbanks and their relationship to weed flora. Weed Res. 29: 365-373.

Banting, J.D. 1962. The dormancy behavior of *Avena fatua* L. in cultivated soil. Can. J. Plant Sci. 42: 22-39.

Barrett, S.C. and B.F. Wilson. 1981. Colonizing ability in the *Echinochloa crus-galli* complex (barnyard grass). I. Variation in life history. Can. J. Bot. 59: 1844-1860.

Barrett, S.C. and B.F. Wilson. 1983. Colonizing ability in the *Echinochloa crus-galli* complex (barnyard grass). II. Seed biology. Can. J. Bot. 61. 556-562.

Baskin, J.M. and C.C. Baskin. 1985. The annual dormancy cycle in buried weed seeds: a continuum. BioScience. 35: 492-498.

Benvenuti, S. 1995. Soil light penetration and dormancy of Jimsonweed (*Datura stramonium*) seeds. Weed Sci. 43: 389-393.

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

Blevins, R.L., M.S. Smith, G.W. Thomas and W.W. Frye. 1983. Influence of conservation tillage on soil properties. J. Soil Water Cons. 38: 301-304.

Brandt, S.A. 1992. Zero vs. conventional tillage and their effects on crop yield and soil moisture. Can. J. Plant Sci. 72: 679-688.

Buhler, D.D. 1992. Population dynamics and control of annual weeds in corn (*Zea mays*) as influenced by tillage systems. Weed Sci. 40: 241-248.

Buhler, D.D. 1995. Influence of tillage systems on weed population dynamics and management in corn and soybean in the central USA. Crop. Sci. 35: 1247-1258.

Buhler, D.D. 1997. Effects of tillage and light environment on emergence of 13 annual weeds. Weed Tech. 11: 496-501.

Buhler, D.D., R.G. Hartzler and F. Forcella. 1997. Implications of weed seedbank dynamics to weed management. Weed Sci. 45: 329-336.

Buhler, D.D. and T.C. Mester. 1991. Effect of tillage on the emergence depth of giant (*Setaria faberi*) and green foxtail (*Setaria viridis*). Weed Sci. 39: 200-203.

Campbell, C.A., A.G. Thomas, V.O. Biederbeck, B.G. McConkey, F. Selles, D. Spurr and R.P. Zentner. 1998. Converting from no-tillage to pre-seeding tillage: Influence on weeds, spring wheat grain yields and N, and soil quality. Soil and Tillage Research. 46: 175-185.

Cardina, J., E. Regnier and K. Harrison. 1991. Long-term tillage effects on seed banks in three Ohio soils. Weed Sci. 39: 186-194.

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

Cardina, J., D.H. Sparrow, and E.L. McCoy. 1996. Spatial relationships between seedbank and seedling populations of common lambs quarters (*Chenopodium album*) and annual grasses. Weed Sci. 44: 298-308.

Cavers, P.B. 1983. Seed demography. Can. J. Bot. 61: 3578-3590.

Cavers, P.B. 1995. Seed banks: Memory in soil. Can. J. Soil Sci. 75: 11-13.

Chancellor, R.J. 1964a. Emergence of weed seedlings in the field and the effects of different frequencies of cultivation. Proc. 7th British Weed Control Conference. 2: 599-606.

Chancellor, R.J. 1964b. The depth of weed seed germination in the field. Proc. 7th British Weed Control Conference. 2: 607-613.

Chepil, W.S. 1946. Germination of weed seeds I. Longevity, periodicity of germination, and vitality of seeds in cultivated soil. Sci. Ag. 26: 307-346.

Chepil, W.S. 1949. Germination of weed seeds: II. The influence of tillage treatments on germination. Sci. Ag. 26: 347-357.

Clements, D.R., D.L. Benoit, S.D. Murphy and C.J. Swanton. 1996. Tillage effects on weed seed return and seedbank composition. Weed Sci. 44: 314-322.

Conn. J.S. 1990. Seed viability and dormancy of 17 weed species after burial for 4.7 years in Alaska. Weed Sci. 38: 134-138.

Cousens, R. and S.R. Moss. 1990. A model of the effects of cultivation on the vertical distribution of weed seeds in the soil. Weed Res. 30: 61-70.

Coutts, G.R. and Smith, R.K. 1991. Zero tillage: Production manual. Manitoba-North Dakota Zero Tillage Farmers Association-1991. Leech Printing Ltd. Brandon, Manitoba.

Dawson, J.H. and V.F. Bruns. 1962. Emergence of barnyard grass, green foxtail, and yellow foxtail seedlings from various soil depths. Weeds. 10: 136-139.

Dawson, J.H. and V.F. Bruns. 1975. Longevity of barnyard grass, green foxtail and yellow foxtail seeds in soil. Weed Sci. 23: 437-440.

de la Cruz, R. 1974. Weed seedling emergence depth under field conditions. Ph.D. Dissertation. Iowa State Univ., Ames, IA. 115pp.

Derksen, D.A. 1996. Weed community ecology: Tedious sampling or relevant science? A Canadian perspective. Phytoprotection. 77: 29-39.

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

Derksen, D.A., A.G. Thomas, G.P. Lafond, H.A. Loeppky and C.J. Swanton. 1994. Impact of agronomic practices on weed communities: Fallow within tillage systems. Weed Sci. 42: 184-194.

Derksen, D.A., P.R. Watson and H.A. Loeppky. 1998. Weed community composition in seed banks, seedling, and mature plant communities in a multi-year trial in western Canada. Aspects of App. Bio. 51: 43-50.

Domitruk, D., B. Crabtree, G.R. Coutts, and R.K. Smith. Editors. 1997. Zero tillage advancing the art. Manitoba- North Dakota Zero Tillage Farmers Association - 1997. Resby Coutts and Associates. Brandon, Manitoba, Canada. pp. 3-7.

Douglas, B.J., A.G. Thomas, I.N. Morrison and M.G. Maw. 1985. The biology of Canadian weeds. 70. *Setaria viridis* (L.) Beauv. Can. J. Plant Sci. 65: 669-690.

Dyer, W. 1995. Exploiting weed seed dormancy and germination requirements through agronomic practices. Weed Sci. 43: 498-503.

Egley, G.H. and Williams, R.D. 1990. Decline of weed seeds and seedling emergence over five years as affected by soil disturbances. Weed Sci. 38: 504-510.

Feldman, S.R., C. Alzugaray, P.S. Torres and J.P. Lewis. 1998. Gap colonization by weeds in a wheat crop grown under different cultivation regimes. Weed Res. 38: 35-45.

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

Frick, B. and Thomas, A.G. 1992. Weed surveys in different tillage systems in southwestern Ontario field crops. Can. J. Plant. Sci. 72: 1337-1347.

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

Froud-Williams, R.J., R.J. Chancellor. and D.S.H. Drennan. 1984. The effects of seed burial on soil disturbance on emergence and survival of arable weeds in relation to minimal cultivation. J. App. Ecol. 21: 629-641.

Froud-Williams, R.J., D.S.H. Drennan and R.J. Chancellor. 1983. Influence of cultivation regime upon buried weed seeds in arable cropping systems. J. App. Ecol. 20: 199-208.

Harper, J.L. 1959. The ecological significance of dormancy and its importance in weed control. Proc. IV th International Congr. Crop Protection (Hamburg 1957). Pp. 415-420.

Harper, J.L. 1977. Population biology of plants. Academic Press, London.

Hume, L., J. Martinez and K. Best. 1983. The biology of Canadian weeds. 60. *Polygonum convolvulus* L. Can. J. Plant Sci. 63: 959-971.

Hume, L., Tessier, S. and Dyck, F.B. 1991. Tillage and rotation influences on weed community composition in wheat (*Triticum aestivum* L.) in southwestern Saskatchewan. Can. J. Plant. Sci. 71: 783-789.

Johnson, M.D. and B. Lowery. 1985. Effect of three conservation tillage practices on soil temperature and thermal properties. Soil Sci. Soc. Am. J. 49: 1547-1552.

Lewis, J. 1973. Longevity of crop and weed seeds: survival after 20 years in soil. Weed Res. 13: 179-191.

Malone C.R. 1967. A rapid method for enumeration of viable seeds in the soil. Weeds. 15: 381-382.

Manitoba Agriculture Soil Resource Section. Room 346, Ellis Building, University of Manitoba. Reconnaissance Soil Survey Maps. Winnipeg, Manitoba. R3T 2N2. Phone: (204) 474-6112. Fax: (204) 474-76-43.

Miller, S.D. and J.D. Nalewaja. 1990. Influence of burial depth on wild oats (*Avena fatua*) seed longevity. Weed Tech. 4: 514-517.

Mohler, C.L. 1993. A model of the effects of tillage on emergence of weed seedlings. Ecological Applications. 3: 55-73.

Mohler, C.L. and A.E. Galeford. 1997. Weed seedling emergence and seed survival: separating the effects of seed position and soil modification by tillage. Weed Res. 37: 147-155.

Oryokot, J.O.E., S.D. Murphy and C.J. Swanton. 1997. Effect of tillage and corn on pigweed (*Amaranthus* spp.) Seedling emergence and density. Weed Sci. 45: 120-126.

Pareja, M.R. and D.W. Staniforth. 1985. Seed-soil microsite characteristics in relation to weed seed germination. Weed Sci. 33: 190-195.

Pareja, M.R., D.W. Staniforth and G.P. Pareja. 1985. Distribution of weed seed among soil structural units. Weed Sci. 33: 182-189.

Pons, T.L. 1991. Induction of dark dormancy in seeds: its importance for the seed bank in the soil. Functional Ecology. 5: 669-675.

Popay, A.I., T.I. Cox, A. Ingle and R. Kerr. 1994. Effects of soil disturbance on weed seedling emergence and its long-term decline. Weed Res. 34: 403-412.

Rew, L.J. and G.W. Cussans. 1997. Horizontal movement of seeds following tine and plough cultivation: implications for spatial dynamics of weed infestations. Weed Res. 37: 247-256.

Roberts, H.A. 1963. Studies on the weeds of vegetable crops. III. Effect of different primary cultivations on the weed seeds in the soil. J. Ecol. 51: 83-95.

Roberts, H.A. 1984. Crop and weed emergence patterns in relation to time of cultivation and rainfall. Ann. appl. Biol. 105: 263-275.

Roberts, H.A. and P.A. Dawkins. 1967. Effect of cultivation on the numbers of viable weed seeds in soil. Weed Res. 7: 290-301.

Roberts, H.A. and P.M. Feast. 1972. Fate of seeds of some annual weeds in different depths of cultivated and undisturbed soil. Weed Res. 12: 316-324.

Roberts, H.A. and P.M. Feast. 1973a. Emergence and longevity of seeds of annual weeds in cultivated and undisturbed soil. J. App. Eco. 10: 133-143.

Roberts, H.A. and P.M. Feast. 1973b. Changes in the numbers of viable weed seeds in soil under different regimes. Weed Res. 13: 298-303.

Scopel, A.L., C.L. Ballare and S.R. Radosevich. 1994. Photostimulation of seed germination during soil tillage. New Phytol. 126: 145-152.

Siemens, J.C., R.G. Hoeft, A.W. Pauli. 1993. Crop residue management. Pages 84-100. In: Soil Management. Eds. Rockstroh, W.A.

Sharma, M.P. and W.H. Vanden Born. 1978. The biology of Canadian weeds. 27. *Avena fatua* L. Can. J. Plant Sci. 58: 141-157.

Soriano, A., E. Zeiger, E. Servy and A. Suero. 1968. The effect of cultivation on the vertical distribution of seeds in the soil. Journal of Applied Ecology. 5: 253-257.

Staricka, J.A., P.M. Burford, R.R. Allmaras and W.W. Nelson. 1990. Tracing the vertical distribution of simulated battered seeds as related to tillage. Agron. J. 82: 1131-1134.

Stoller, E.W. and L.M. Wax. 1973. Periodicity of germination and emergence of some annual weeds. Weed Sci. 21: 574-580.

Taylorson, R.B. 1970. Changes in dormancy and viability of weed seeds in soils. Weed Sci. 18: 265-269.

Taylorson, R.B. 1987. Environmental and chemical manipulation of weed seed dormancy. Rev. Weed Sci. Am. 3: 135-154.

Teasdale, J.R., C.E. Beste and W.E. Potts. 1991. Response of weeds to tillage and cover crop residue. Weed Sci. 39: 195-199.

Tester, M. and Morris, C. 1987. The penetration of light through soil. Plant, Cell and Enviro. 10: 281-286.

Thomas, A.G. 1986. Longevity of green foxtail seeds in a Canadian prairie soil. Can. J. Plant Sci. 66: 189-192.

Thomas, A.G. 1991. Floristic composition and relative abundance of weeds in annual crops of Manitoba. Can. J. Plant Sci. 71: 831-839.

Thomas, A.G. and D.I. Donaghy. 1991. A survey of the occurrence of seedling weeds in spring annual crops in Manitoba. Can. J. Plant Sci. 71: 811-820.

Thomas, A.G. and B.L Frick. 1993. Influence of tillage systems on weed abundance in southwestern Ontario. Weed Tech. 7: 699-705.

Thomas, A.G., B.Frick, R.C. Van Acker, S.Z. Knezevic and D. Joosse. 1998. Manitoba weed survey of cereal and oilseed fields in 1997. Agriculture and Agri-food Canada Weed Survey Series 98-1. Saskatoon, Saskatchewan, Canada.

Thomas, A.G., D. Kelner, R.F. Wise and B.L. Frick. 1994. Manitoba weed survey: Comparing zero and conventional tillage crop production systems, 1994. Weed Survey series, publication 97-1. Manitoba Agriculture, Soils and Crops Branch, Box 1149, Carman, Manitoba, R0G 0J0. Canada.

Thompson, K., J.P. Grime and G. Mason. 1977. Seed germination in response to diurnal fluctuations of temperature. Nature, London. 67: 147-149.

Thompson, K. and J.P. Grime. 1979. Seasonal variation in the seed banks of herbaceous species in ten contrasting habitats. Journal of Ecology. 67: 893-921.

Thurston, J.M. 1961. The effect of depth of burying and frequency of cultivation on survival and germination of seed of wild oats (*Avena fatua* L. and *Avena ludoviciana* DUR.). Weed Res. 1: 19-31.

Warnes, D.D. and R.N. Anderson. 1984. Decline of wild mustard (*Brassica kaber*) seeds in soil under various cultural and chemical practices. Weed Sci. 32: 214-217.

Wesson, G. and P.F. Wareing. 1969a. The role of light in the germination of naturally occurring populations of buried weed seeds. J. Exp. Bot. 20: 402-413.

Wesson, G. and P.F. Wareing. 1969b. The induction of light sensitivity in weed seeds by burial. J. Exp. Bot. 20: 414- 425.

Wiese, A.F. and R.G. Davis. 1966. Weed emergence from two soils at various moistures, temperatures and depths. Weeds. 15: 118-121.

Wilson, B.J. and G.W. Cussans. 1975. A study of the population dynamics of *Avena fatua* L. as influenced by straw burning, seed shedding and cultivations. Weed Res. 15: 249-258.

Wilson, R.G., E.D. Kerr and L.A. Nelson. 1985. Potential for using weed seed content in the soil to predict future weed problems. Weed Sci. 33: 171-175.

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

Vanden Born, W.H. 1971. Green foxtail: seed dormancy, germination and growth. Can. J. Plant Sci. 51: 53-59.

Yenish, J.P., J.D. Doll and D.D. Buhler. 1992. Effects of tillage on vertical distribution and viability of weed seeds in soil. Weed Sci. 40: 429-433.

Zhang, J., A.S. Hamill, I.O. Gardiner and S.E. Weaver. 1998. Dependence of weed flora on the active soil seedbank. Weed Res. 38: 143-152.

Appendix 4.1.1. Analysis of variance of wild oat recruitment depth as affected by sampling year.

| Source of Variance | Df | SS | Mean Square | F Value |
|---|---|---|---|---|
| Year | 1 | 0.323 | 0.323 | 0.18ns |
| Error | 124 | 218.88 | 1.77 | |
| Total | 125 | 219.21 | | |

ns – not significant

Appendix 4.1.2. Analysis of variance of volunteer wheat recruitment depth as affected by sampling year.

| Source of Variance | Df | SS | Mean Square | F Value |
|---|---|---|---|---|
| Year | 1 | 4.79 | 4.79 | 2.06ns |
| Error | 91 | 211.66 | 2.33 | |
| Total | 92 | 216.45 | | |

ns – not significant

Appendix 4.1.3. Analysis of variance of green foxtail recruitment depth as affected by sampling year.

| Source of Variance | Df | SS | Mean Square | F Value |
|---|---|---|---|---|
| Year | 1 | 7.90 | 7.90 | 7.28** |
| Error | 72 | 78.10 | 1.10 | |
| Total | 73 | 86.00 | | |

** significant at the 1% level

Appendix 4.1.4. Analysis of variance of wild oats recruitment depth as affected by tillage and sampling time.

| Source of Variance | Df | SS | Mean Square | F Value |
|---|---|---|---|---|
| Time | 1 | 15.51 | 15.51 | 16.55** |
| Tillage | 1 | 73.04 | 73.04 | 77.91** |
| Time*Tillage | 1 | 1.28 | 1.28 | 1.37ns |
| Error | 122 | 114.37 | | |
| Total | 125 | 206.14 | | |

** significant at the 1% level
ns – not significant

Appendix 4.1.5. Analysis of variance of volunteer wheat recruitment depth as affected by tillage and sampling time.

| Source of Variance | Df | SS | Mean Square | F Value |
|---|---|---|---|---|
| Time | 1 | 27.11 | 27.11 | 31.71** |
| Tillage | 1 | 68.78 | 68.78 | 80.46** |
| Time*Tillage | 1 | 0.86 | 0.86 | 1.01ns |
| Error | 89 | 205.06 | | |
| Total | 92 | 208.87 | | |

** significant at the 1% level
ns – not significant

Appendix 4.1.6. Analysis of variance of green foxtail recruitment depth as affected by tillage and sampling year

| Source of Variance | Df | SS | Mean Square | F Value |
|---|---|---|---|---|
| Year | 1 | 7.60 | 7.58 | 11.22** |
| Tillage | 1 | 30.54 | 30.54 | 45.22** |
| Year*Tillage | 1 | 0.05 | 0.05 | 0.07ns |
| Error | 70 | 47.30 | | |
| Total | 73 | 86.00 | | |

** significant at the 1% level
ns – not significant

Appendix 4.1.7. Analysis of variance of wild buckwheat recruitment depth as affected by tillage and sampling time.

| Source of Variance | Df | SS | Mean Square | F Value |
|---|---|---|---|---|
| Time | 1 | 10.70 | 10.70 | 22.41** |
| Tillage | 1 | 21.39 | 21.39 | 44.79** |
| Time*Tillage | 1 | 0.84 | 0.84 | 1.75ns |
| Error | 72 | 34.39 | | |
| Total | 75 | 69.24 | | |

** significant at the 1% level
ns – not significant

Appendix 4.1.8. Analysis of variance of barnyard grass recruitment depth as affected by tillage

| Source of Variance | Df | SS | Mean Square | F Value |
|---|---|---|---|---|
| Tillage | 1 | 5.22 | 5.22 | 5.86* |
| Error | 9 | 8.02 | 0.89 | |
| Total | 10 | 13.24 | | |

* significant at the 5% level

Appendix 4.2. Mean temperature and precipitation for May and June 1997, and April, May and June in 1998 at Carman, Manitoba.

| May 1997 | | June 1997 | | April 1998 | |
|---|---|---|---|---|---|
| Temperature (°C) | Precipitation (mm) | Temperature (°C) | Precipitation (mm) | Temperature (°C) | Precipitation (mm) |
| 4.1 | 0 | 24 | 17.6 | 5.5 | 0 |
| 5.5 | 0 | 21.4 | 0 | 6 | 0 |
| 5.2 | 0 | 22.2 | 0 | 6.6 | 0 |
| 10.6 | 0 | 19.7 | 0 | 7.3 | 0 |
| 8.8 | 0.2 | 17.4 | 0 | 6.3 | 2.4 |
| 7.7 | 0 | 18 | 0 | 3.5 | 13.6 |
| 10.3 | 11 | 18.3 | 0 | 3.5 | 0 |
| 5.2 | 2.8 | 20.1 | 0 | 4.9 | 0 |
| 9.1 | 0 | 22.2 | 0 | 6.5 | 0 |
| 16.2 | 1.8 | 22.3 | 0 | 9.2 | 0 |
| 6.6 | 0.4 | 20.7 | 0 | 8.6 | 0 |
| 3.6 | 0.8 | 19.7 | 0 | 10.6 | 18 |
| 5.2 | 1.8 | 15.5 | 0 | 6.6 | 5.6 |
| 0.8 | 0 | 17 | 2 | 2.3 | 0 |
| 3.3 | 0 | 15.7 | 0.2 | 1.5 | 0 |
| 9.7 | 0 | 16.1 | 0 | 4.4 | 0 |
| 6.6 | 4.2 | 13 | 10.8 | 4.7 | 0 |
| 4.8 | 0 | 13.2 | 0 | 4.2 | 0 |
| 5.3 | 0 | 16 | 11.4 | 5.6 | 0 |
| 4.6 | 0 | 17.5 | 3.6 | 6.3 | 0 |
| 7.7 | 0 | 17.4 | 0 | 8.9 | 0 |
| 12.9 | 0 | 17.7 | 0 | 12.5 | 0 |
| 11.1 | 0 | 21.1 | 9 | 13.8 | 0 |
| 10.6 | 0 | 18.9 | 0.2 | 10.1 | 0 |
| 10.5 | 0 | 15.8 | 4.2 | 13.6 | 0 |
| 11.7 | 0 | 20.1 | 0 | 12.2 | 0 |
| 12.4 | 0 | 22.3 | 0 | 12.3 | 0 |
| 14.7 | 0 | 18.3 | 0 | 15.1 | 0 |
| 15 | 0 | 18.3 | 0 | 17.1 | 0 |
| 19 | 0 | 16.8 | 0 | 17.2 | 0 |
| 20.3 | 1 | | | | |
| Mean Temperature | Total Precipitation | Mean Temperature | Total Precipitation | Mean Temperature | Total Precipitation |
| 9.00 | 24.00 | 18.56 | 59.00 | 8.23 | 39.60 |

Appendix 4.2 (continued)

| May 1998 | | June 1998 | |
|---|---|---|---|
| Temperature (°C) | Precipitation (mm) | Temperature (°C) | Precipitation (mm) |
| 6.7 | 0 | 9 | 1.4 |
| 9 | 0 | 6.1 | 0 |
| 12.1 | 0 | 7.9 | 0 |
| 11.5 | 0 | 8.2 | 0 |
| 10.5 | 0 | 7.2 | 0.4 |
| 4.3 | 2.4 | 9.5 | 0 |
| 8.5 | 0.8 | 11.5 | 0 |
| 12.9 | 0 | 12 | 0 |
| 14.9 | 0 | 14.5 | 0 |
| 16.8 | 6.2 | 15.6 | 18.2 |
| 13.2 | 2.6 | 14.5 | 2.8 |
| 8.6 | 0 | 17.9 | 0 |
| 12.7 | 8.8 | 18.3 | 0.4 |
| 13.8 | 1 | 14.8 | 25.2 |
| 16.7 | 0 | 17 | 0 |
| 13.8 | 1.4 | 15.4 | 0 |
| 14.6 | 5.2 | 17 | 2 |
| 17.3 | 0 | 20.4 | 2.6 |
| 14.2 | 0 | 17.7 | 10.2 |
| 14.5 | 0 | 16.3 | 2.6 |
| 13.7 | 0 | 13.9 | 0.4 |
| 14.1 | 0 | 15 | 0 |
| 14.6 | 0 | 14 | 1.6 |
| 15.9 | 0 | 19.4 | 7.2 |
| 17.3 | 0 | 21.1 | 3 |
| 18 | 0 | 22.2 | 5.6 |
| 18.2 | 6.4 | 19.5 | 8.8 |
| 10.9 | 3.4 | 16.8 | 0.2 |
| 6.5 | 0 | 18.5 | 2 |
| 13.2 | 0 | 19.9 | 0 |
| 11.5 | 0 | | |
| Mean Temperature | Total Precipitation | Mean Temperature | Total Precipitation |
| 12.92 | 38.20 | 15.04 | 94.60 |

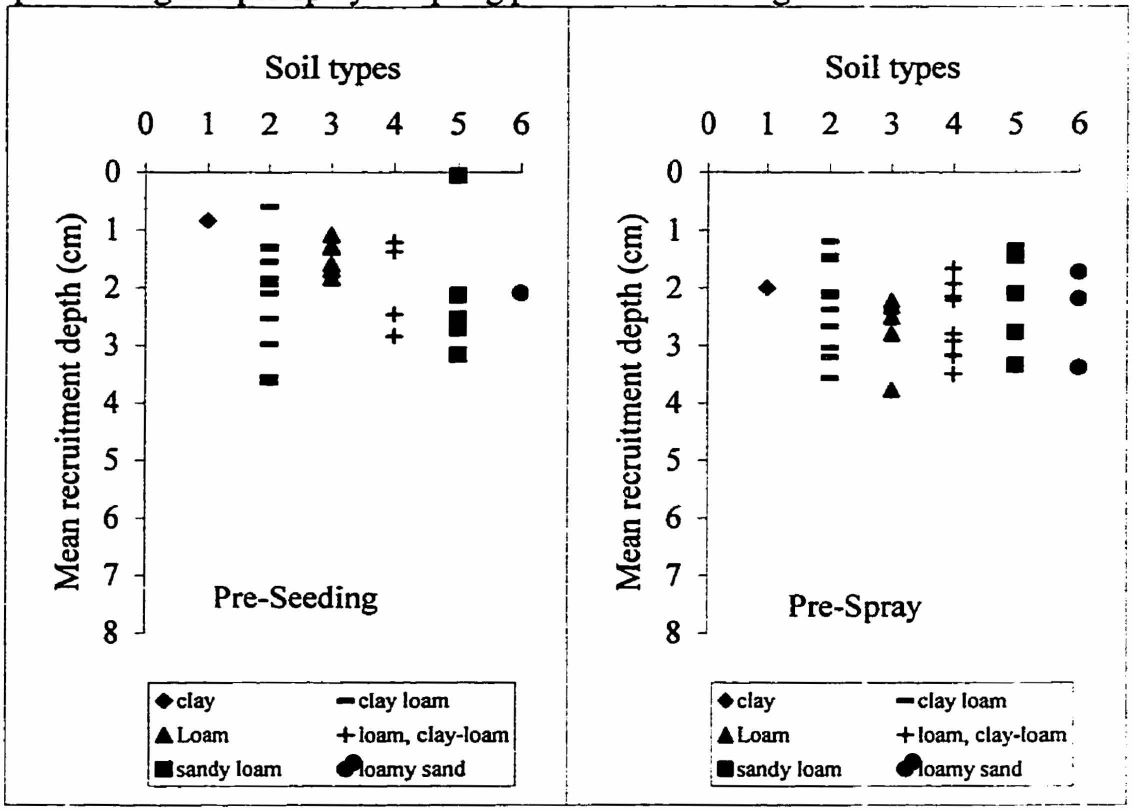
Appendix 5.1. Matrix of field data from 1997 and 1998.

| Fields | Weed Recruitment Pre-Seeding | | | | Pre-Spray | | | | | Stubble Densities | | Seeding | | | | | | Tillage | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | WO | VW | GF | WB | WO | VW | GF | WB | BYG | Pre-see | Prespra | Type | Openers | width inches | spacing inches | Depth inches | Spee (m/h) | Pull Number | Type |
| AC1-W | | 2.39 | | | | 4.54 | 4.3 | | | 12.89 | 8.95 | john deer hoe drill | hoe opener | 2.5 | 7 | 2 | 4.5 | 1 | tandem disk @ 9" spacing |
| AC2-C | | | | | | | 2.98 | | | 2.81 | 1.85 | double disk press drill | double disk | | | | 5.5 | 2 | deep tiller w/ 10" sweep @ 13"spacing |
| AC3-W | | 2.68 | | | 4.5 | 4.5 | 2.38 | | | 13.83 | 14.82 | double disk press drill | double disk | | | | 5.5 | 2 | deep tiller w/ 10" sweep @ 13"spacing |
| AZ1-W | | 0.48 | | | 2.21 | 2.24 | 3.24 | | | 36.08 | 32.86 | john deer hoe drill | adam jet | 3/4 | 7 | 0.75 | 4 to 8 | | |
| AZ2-C | | | | | | | | | | 37.59 | 48.15 | air seeder | adam jet | 3/4 | low dist. | | 5 | | |
| AZ3-W | | 0 | | | 2.19 | | 2.41 | | | 28.84 | 45.17 | air seeder | adam jet | 3/4 | low dist. | | 5 | | |
| BC1-W | 3.23 | 4.18 | | | | | 2.95 | | | 8 | 3.84 | bourgou air drill | Gem of alberta | 2 | 6 | 1.5 | 5 | 1 | international viber till @ 10" spacing w/ |
| BC2-C | | | | | | | 3.4 | | | 16.71 | 5.02 | air seeder | shovels | 9 | 8 | 2 | 5 | 2 | heavy cult w/10"shovels @12"spacing |
| BZ1-W | | 0 | | | | | 1.59 | | | 31.34 | 17.19 | hoe press | hoe opener | 3/4 | 7 | 1 | 5 | | |
| BZ2-C | | 0.56 | | | | | 1.63 | | | 18.23 | 8.14 | seed hawk | knife | 3/4 | 10.5 | 0.75 | 4.5 | | |
| CC2-W | 2.93 | | | | | | 4.91 | | | 14.06 | 4.64 | melrow 202 | double disk | 3/4 | 6 | 1 | 4.5 | 1 | deep tiller w/ 4" shovel @ 12"spacing |
| CC3-W | | | | | | | 5.18 | | | | 2.84 | International press drill | double disk | 2.5 | 6 | 0.5-0.7 | 4.5 | 2 | heavy duty cultivator w/ 4"points @ 12" |
| CZ2-W | 1.56 | 0.17 | | | 2.38 | | 2.08 | | | 36.33 | 37.74 | hoe press drill | adam jet | 3/4 | 7 | 0.5 | 4.5 | | |
| CZ3-W | 1.37 | 1.4 | | | 2.8 | 2.45 | 2.88 | | | 25.43 | 38.73 | Edwards hoe drill | hoe | 2 | 8 | 1 | 5.5-6 | | |
| DC1-W | 4.85 | | | | 7.15 | | 6.62 | | | 2.55 | 1.28 | hoe press drill | eagle beaks | 1.5 | 7 | 1.75 | 6 | 2 | 5000 viber chisel 4"shovel; 10" shovel |
| DC2-C | 3.95 | | | | 3.7 | | 3.78 | | | 1.75 | 7.2 | seed right 80-11 | shovels w/rod weeder | | | | 5 | 1 | chisel plough @ 12" spacings |
| DC3-W | | | | | 1.77 | 3.25 | 3.11 | | | 16.43 | 16.1 | hoe press drill | hoe | 1.5 | 7 | 1 | 5 | 1 | deep tiller w/10"shovels @1' spacing |
| DC4-C | | | | | 3.45 | | 3.29 | | | 5.3 | 11.41 | air seeder | shovel | 12 | | | 5 | 1 | chisel W/ 2" width |
| DC4-W | | | | | 3.33 | 3.33 | | | | 12.12 | 13.64 | air seeder | shovel | 12 | | | 5 | 1 | chisel W/ 2" width |
| DC5-W | | | | | 3.8 | | 3.25 | | | 5.54 | 1.23 | mellrow disk drill | disk | 1/2 | 6 | 1 | 6 | 1 | deep tiller w/10"shovels |
| DZ1-C | 3.63 | | | | 3.2 | | 3.3 | | | 19.28 | 30.26 | flexicoil air drill | spoons | 2 | 9 | 0.75-1 | 5 | | |
| DZ2-C | | | | | 3.57 | | 1.51 | | | 26.94 | 22.59 | zero-till air drill | eagle beaks on hoe | 1.5 | 9 | 1.5 | 5 | | |
| DZ3-W | 1.33 | 0.63 | | | 2.15 | | 2.24 | | | 34.33 | 25.57 | hoe press drill | hoe | 3/4 | 12 | 0.5 | 4 to 5 | | |
| DZ4-C | 2.1 | | | | 2.13 | | | | | 19.6 | 22.68 | Edwards zero till drill | adam jet | 3/4 | 12 | 1.25 | 4.5 | | |
| DZ4-W | 1.55 | 0 | | | 2.08 | | | | | 40.84 | 47.21 | Edwards zero till drill | adam jet | 3/4 | 12 | 1.25 | 4.5 | | |
| DZ5-W | | 0.06 | | | 3.39 | | 2.74 | | | 33.71 | 16.62 | Flexicoil 5000 | dutch knife eagle beak | 3/4 | 7.25 | 1 | 6 | | |
| EC1-W | 1.83 | 1.2 | | | 3.63 | 2.15 | 3.25 | | | 8.1 | 12.88 | zerotill drill | knives | 3/4 | 8 | 0.5 | 4.5 | 0 | |
| EC1-C | 2.87 | | | | 3.52 | | 2.42 | | | | 5.29 | | | | | | | | |
| EC2-W | | | | | 4.3 | 4.18 | | | | | 12.03 | bourgou air seeder | adam jet | 1 | 8 | 1 | 5 | 1 | herbicide encorp. 14" sweeps @12" spa |
| EZ1-W | 0.06 | | | | 2.77 | | 2.65 | | | 36.88 | 18.75 | Morris hoe drill | narrow point | 1 | 7.5 | 1 | 5 | | |
| EZ2-W | 1.21 | 1.17 | | | 2.93 | | 3.83 | | | 37.78 | 18.37 | amazon hoe drill | hoe opener | 1 | 7 | 1.5 | 4 | | |
| EZ3-W | 2.13 | 0.22 | | | 1.45 | | 3 | | | 35.72 | 23.72 | hay buster 1000 | double disk | 1.5 | 7 | 1 | 5 | | |
| FC2-C | 1.9 | | | | 4.58 | | 3.65 | | | 6.58 | 3.62 | flexicoil 5000 | sweeps | 11 | 9 | 1.5 | 6.5 | 2 | heavy duty cultivator w/4" sweeps @ 12 |
| FC2-W | 2.36 | 1.48 | | | 4.48 | 2.67 | 3.95 | | | 14.31 | 4.59 | flexicoil 5000 | sweeps | 11 | 9 | 1.5 | 6.5 | 2 | heavy duty cultivator w/4" sweeps @ 12 |
| FC3-W | 5.25 | 2.72 | | | 2.75 | 3.83 | 5.25 | | | 9.14 | 8.85 | flexicoil 5000 | knife | 1 | 5 | 2 | 5.5 | 1 | flexicoil cultivator, w/8" shovels @9"sp |
| FZ1-C | 1.28 | 0.4 | | | | | 1.43 | | | 38.95 | 51.09 | flexicoil | single barton disk | | 10 | 2 | 5 | | |
| FZ2-W | 1.59 | 1.5 | | | 2.23 | | 2.28 | | | 48.89 | 41.15 | flexicoil | single barton disk | | 10 | 2 | 5 | | |
| FZ3-W | 1.83 | 0 | | | 2.5 | | 2 | | | 30.59 | 13.07 | Bourgou air drill | spoons | 2 | 10 | 0.5 | 5.5 | | |
| GC1-C | | 2.48 | | | | | 3.42 | 4.32 | | 10.06 | 3.78 | air | cult w/boot | 4 | 4 | 2 | 6 | 2 | deep tiller w/ 12"sweeps @ 10"spacing |
| GC1-W1 | 1.7 | 1.64 | | | | | 4.04 | | | 9.32 | 4.86 | 8row planter | disk - | 3/4-1/ | 30 | 1.5 | 5 1/2 | 2 | deep tiller w/ 12"sweeps @ 10"spacing |
| GC1-W2 | | 2.04 | | | | | 3.89 | | | 17.76 | 3.81 | 8row planter | disk | 3/4-1/ | 30 | 1.5 | 5 1/2 | 2 | deep tiller w/ 12"sweeps @ 10"spacing |
| GC1-W3 | | 2.68 | | | 4.6 | 6.78 | 2.56 | | | 13.04 | 7.93 | air | cult w/boot | 4 | 4 | 2 | 6 | 2 | deep tiller w/ 12"sweeps @ 10"spacing |
| GZ1-C | | 0.5 | | | 1.67 | 2.12 | 1.8 | | | 63.66 | 35.34 | | | | | | | | |
| GZ1-W | | 0.32 | | | | 1.09 | 1.34 | 1.62 | 0.97 | 53.78 | 41.48 | 750zotilldrill | singledisk | 1/8 | 7 1/2 | 0.75 | 5 | | |
| GZ1-WW1 | | 0.73 | | | | | | | | 52.1 | | zerotill7200maxmerge | doubledisk | 1/8 | 30 | 1 | 4 1/2 | | |
| GZ1-WW2 | | 0.59 | | | 2.15 | 2.02 | | 1.6 | | 40.28 | 76.34 | zerotill7200maxmerge | doubledisk | 1/8 | 30 | 1 | 4 1/2 | | |
| HC1-C | 6.13 | 5.2 | 2.63 | 3.27 | 6.94 | | 3.43 | 3.16 | | 3.41 | 6.39 | john deer | hoe | 2 | 7 | 1.5 | 4.5 | 1 | deep tiller w/12" shovels @12" spacing |
| HC1-W | 4.2 | 2.87 | 2.02 | 3.22 | 3.68 | 4.16 | 3.12 | 4.21 | | 34.52 | 22.93 | john deer | hoe | 2 | 7 | 1.5 | 4.5 | 1 | deep tiller w/12" shovels @12" spacing |
| HZ1-C | 2.84 | 2.74 | | 3.73 | 3.19 | | | 2.94 | | 45.6 | 23.62 | hoe drill | knife | 3/4 | 7 | 0.75 | 4.8 | | |
| HZ1-W | 2.46 | 0.8 | | 1.66 | 1.93 | 1.12 | | 1.67 | | 79.72 | 67.84 | hoe drill | knife | 3/4 | 7 | 0.5 | 4.8 | | |
| IC1-C | 2.14 | | 1.85 | 2.54 | 4.71 | | 3.49 | 4.06 | 3.98 | 12.07 | 3.66 | hoe press | knife | 1 | 7 | 1 | 5 | 2 | deep tillw/8"shovels@12"spacing; cultiv |
| IC1-W | 2.17 | 1.98 | | 2.12 | 4.13 | 4.97 | 2.33 | 2.68 | 2.3 | 16.36 | 13.01 | hoe press | knife | 1 | 7 | 1.5 | 5 | 2 | deep tillw/8"shovels@12"spacing; cultiv |
| IC2-W | | 1.91 | | 2.19 | 4.45 | 4.79 | 3.67 | 3.76 | 3.55 | 11.51 | 15.31 | corn planter | doubledisk | 1/2 | 36 | 1.75-2 | 5 | 2 | tandom disk 8"spacing; heavy duty cultiv |
| IZ1-C | 0.6 | 1.06 | | 1.21 | | | 2.27 | 2.31 | | 42.64 | 43.81 | Hoe press | hoe | 3/4 | 7 | 1.5 | 5 | | |
| IZ1-W | 0.84 | 0 | 0.61 | 0.92 | 2 | 2.3 | 1.63 | 2.15 | 1 | 47.56 | 41.22 | Hoe press | hoe | 3/4 | 7 | 2 | 5 | | |
| IZ2-W | | 1.03 | | 1.09 | | 2.07 | 1.95 | 2.41 | | 64.29 | 27.64 | seed hawk | knife | 3/4 | 10.5 | 0.75 | 4.5 | | |
| JC1-W | 3.43 | 1.54 | | 2.28 | 3.21 | | 2.37 | 3.02 | 2.88 | 14.38 | 5.82 | international 7200 | adam jet | 3/4 | 7 | 1.5-1.7 | 4.5 | 1 | deep tiller w/4"shovel @12"spacing |
| JC2-C1 | 2.98 | | | 2.06 | 3.63 | | 3.8 | 4.27 | | 5.34 | 3.98 | press drill | disk | 2.5 | 6 | 1-1.25 | 4.5 | 2 | heavy duty cultivator w/ 4"points @ 12" |
| JC2-C2 | 3.14 | 5.2 | | 2.68 | 3.44 | | 2.41 | 2.94 | 3.75 | 11.56 | 5.97 | press drill | disk | 2.5 | 6 | 1-1.25 | 4.5 | 2 | heavy duty cultivator w/ 4"points @ 12" |
| JZ1-C | 1.29 | 0.48 | | 0.67 | 1.2 | | 0.92 | 1.54 | 2.8 | 67.76 | 52.33 | international 7200 | adam jet | 3/4 | 7 | 1-0.75 | 4.5 | | |
| JZ2-C | | | | | 3.5 | | 1.88 | 2.16 | 0.93 | 47.61 | 22.98 | Edwards hoe drill | flat bottom hoe | 2 | 8 | 1 | 5.5-6 | | |
| JZ2-W | | 0.74 | | | 3.16 | 2.7 | 2.32 | 2.87 | 2.25 | 62.05 | 21.53 | Edwards hoe drill | flat bottom hoe | 2 | 8 | 0.5-0.7 | 5.5-6 | | |
| KC1-C | 5.75 | 4.4 | | 3.79 | 6.8 | | 5.04 | 4.67 | | 13.35 | 3.41 | hoe press | hoe-eagle beaks | 1.5 | 7 | 1.75 | 6 | 2 | 5000 viber chisel 4"shovel; 10" shovel |
| KC2-W | 4.29 | | | | 3.79 | 4.8 | 2.87 | 3.88 | | 19.69 | 17.36 | marsh hoe drill | shovels | 5 | 8 | 2 | 5 | 1 | chisel plough,10"shovels @12"spacing |
| KC3-W | 3.93 | | | | 3.19 | 3.97 | 2.98 | 3.93 | | 1.56 | 26.93 | hoe press drill | hoe | 1.5 | 7 | 1 | 5 | 1 | deep tiller w/10"shovels @1' spacing |
| KC4-W1 | 3.45 | 3.97 | | | 3.87 | 3.93 | | 2.56 | | 22.24 | 21.22 | Flexi-coil air drill | narrow hoe | 3/4 | 9 | 1 | 5.5 | 1 | chisel w/3/4 twisted shovels,3.5 "wide |
| KC4-W2 | 3.49 | 3.66 | | 2.48 | 3.16 | 3.43 | | 2.76 | | 11.48 | 18.41 | Flexi-coil air drill | narrow hoe | 3/4 | 9 | 1 | 5.5 | 1 | chisel w/3/4 twisted shovels,3.5 "wide |
| KC5-W | 2.82 | 2.78 | | 2 | 3.49 | | | 3.67 | | 10.37 | 3.47 | international press | double disk | 1/2 | 6 | 0.5 | 6 | 2 | both viber chisel @9"spacing w/10"shov |
| KZ1-C | 2.98 | | | 2.38 | 3.04 | | 2.34 | 2.78 | | 61.53 | 31.76 | Flexi-coil air drill | spoons | 2 | 9 | 0.75-1 | 5 | | |
| KZ2-W | 1.95 | 0.83 | | | 2.66 | 2.78 | 1.91 | 2.83 | | 55.85 | 53.35 | zero-till air drill | eagle beaks on hoe | 2 | 9 | 1.5 | 5 | | |
| KZ3-W | 1.84 | 0.63 | | 1.45 | 1.45 | | 1.72 | 1.96 | | 68.64 | 34.52 | hoe press drill | hoe | 3/4 | 12 | 0.5 | 4 to 5 | | |
| KZ4-C1 | 3.55 | 1.81 | | 2.13 | 2.67 | | 1.63 | 2.18 | | 55.43 | 41.36 | Edwards hoe drill | adam jet | 0.75 | 12 | 1.25 | 4.5 | | |
| KZ4-C2 | 2.54 | | | 2.02 | 1.51 | | | 1.85 | | 64.2 | 51.05 | Edwards hoe drill | adam jet | 0.75 | 12 | 1.25 | 4.5 | | |
| KZ5-W | 2.09 | 2 | | 1.94 | 1.73 | 1.76 | 1.86 | 1.56 | | 16.16 | 23.92 | Flexi-coil air drill | dutch knife eagle beak | 1-3/4 | 7.25 | 0.75 | 6 | | |
| LC1-W | | 1.74 | | 2.09 | | 1.42 | 1.52 | 2.1 | | 30.4 | 47.22 | zerotill drill | knives | 3/4 | 8 | 0.5 | 4.5 | 0 | |
| LC2-W | 2.88 | 2.61 | | | 3.31 | 2.65 | 2.8 | | | 14.63 | 13.55 | Flexi-coil air drill | stelth opener,knife | 3/4 | 7.2 | 1 | 6.5 | 2 | deep tiller 12" sweeps |
| LC3-W | 2.38 | 2.77 | | 1.84 | 4.33 | 2.41 | 1.87 | 2.44 | | 15.91 | 2.9 | Flexi-coil air drill | stelth opener,knife | 3/4 | 7.2 | 1 | 6.5 | 2 | deep tiller 12" sweeps |
| LZ1-C | 2.54 | 2.21 | | 1.35 | 1.36 | | 1.77 | 2.08 | | 40.97 | 58.81 | Morris hoe drill | narrow point | 1 | 8 | 1.5 | 5 | | |
| LZ2-W | 3.16 | 0.74 | | 1.66 | 2.1 | | 0.78 | 1.86 | | 47.93 | 29.97 | amazon hoe drill | hoe | 1 | 7 | 1.5 | 4 | | |
| LZ3-W | 2.71 | 0.5 | | 1.73 | 3.33 | | 1.87 | 1.66 | | 63.15 | 39.85 | hay buster 1000 | double disk | 1.5 | 7 | 1 | 5 | | |
| MC1-C | 1 | | | 4.43 | 5.09 | | 3.49 | 3.26 | | 4.91 | 9.57 | 5000 flexi-coil air drill | shovels | 10 | 9 | 1.5 | 6-6.5 | 1 | deeptiller w/ 4" shovels @12 inch spacin |
| MC1-W | 2.88 | | | | 3.79 | 2.99 | 2.47 | 3.28 | | 11.22 | 14.86 | 5000 flexi-coil air drill | shovels | 10 | 9 | 1.5 | 6-6.5 | 1 | deeptiller w/ 4" shovels @12 inch spacin |
| MC2-C | | 2.35 | | 2.09 | | | 3.09 | 3.86 | 1.38 | 14.52 | 1.56 | Flexi-coil 5000 air drill | knife | 1 | 9 | 2 | 5.5 | 1 | flexicoil cultivator, w/8" shovels @9"sp |
| MC2-W | 2.96 | 2.34 | | 1.7 | 4.48 | | 3.67 | 4.11 | | 11.53 | 13.81 | Flexi-coil 5000 air drill | knife | 1 | 9 | 2 | 5.5 | 1 | flexicoil cultivator, w/8" shovels @9"sp |
| MZ1-C | | 1.47 | | 1.32 | 1.46 | 2.35 | 1.49 | 1.78 | | 67.36 | 56.68 | Bourgou air drill | bending knife | 5/8 | 8 | 0.75-1 | 5.5 | | |
| MZ1-W | 1.68 | 0.31 | | 1.32 | 2.32 | 2.43 | 1.69 | 1.9 | | 67.87 | 44.97 | flexi-coil disk drill | single disk | 7 | 10 | 2 | 5.5 | | |
| MZ2-C | 1.3 | | | 1.22 | 3.77 | | 2.59 | 2.47 | | 34.49 | 54.55 | Bourgou air drill | knife | 1 | 10 | 1.5-2 | 5.5 | | |
| MZ2-W | 1.08 | 0.31 | | | 2.79 | | 3.41 | 4.06 | | 58.78 | 48.13 | Bourgou air drill | knife | 1 | 10 | 1.5-2 | 5.5 | | |

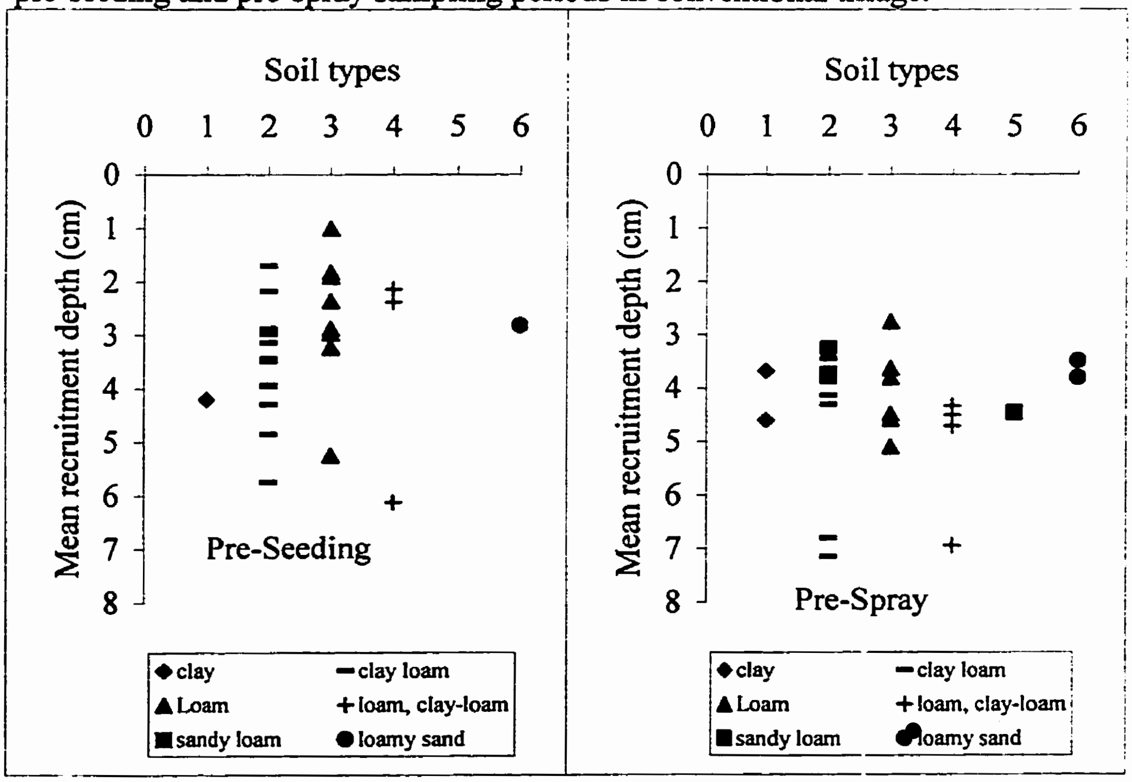
| | | | | | Tillage | | | | | | Fertilizer | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | width inches | spacing inches | Depth inches | Spee (m/h | Fall Numbe | Type | Depth | Speed | Spring number | Type | Dept | Speed | What | When | How |
| | 2.5 | 7 | 2 | 4.5 | 1 | tandem disk @ 9" spacing | 3 to 4 | 5 | 2 (1 fert) | spring tooth cultivator 9" shovels @7" spacing | 2 | 5 | anhydrous | spring | viber shank, a |
| | | | | 5.5 | 2 | deep tiller w/ 10" sweep @ 13"spacing; tandem disk @ 10" spacing | 4 | 5.5 | 1 | cultivator w/ 8"sweeps @ 6" spacing | 2.5 | 5.5 | anhydrous | fall | rake style appl |
| | | | | 5.5 | 2 | deep tiller w/ 10" sweep @ 13"spacing; tandem disk @ 10" spacing | 4 | 5.5 | 1 | cultivator w/ 8"sweeps @ 6" spacing | 2.5 | 5.5 | anhydrous | fall | rake style appl |
| | ¾ | 7 | 0.75 | 4 to 8 | | | | | | | | | anhydrous | fall | blue jet, very |
| | ¾ | low dist. | | 5 | | | | | | | | | liquid | spring | dribble with s |
| | ¾ | low dist. | | 5 | | | | | | | | | liquid | spring | dribble with s |
| | 2 | 6 | 1.5 | 5 | 1 | international viber till @ 10" spacing w/ 10" sweeps | 3 | 6 | 1 | international viber till @ 10" spacing w/ 10" sweeps | 3 | 6 | anhydrous | spring | w/seed 1½" d |
| | 9 | 8 | 2 | 5 | 2 | heavy cult w/10"shovels @12"spacing | 3 | 5.5 | 0 | | | | anhydrous | fall | w/cultivator |
| | ¾ | 7 | 1 | 5 | | | | | | | | | urea;dry | with seed | b/w seed rows |
| | ¾ | 10.5 | 0.75 | 4.5 | | | | | | | | | liquid | spring | below & to si |
| | ¾ | 6 | 1 | 4.5 | 1 | deep tiller w/ 4" shovel @ 12"spacing | 4 to 5 | 5 | 2 | deep till w/4"shovel@12"spacing;cult w/9"shovels @6"spacing | 4;2 | 5;5 | liquid; dry | spring | deep band liq |
| | 2.5 | 6 | 0.5-0.7 | 4.5 | 2 | heavy duty cultivator w/ 4"points @ 12"spacing | 6 | 5.5 | 1 | light duty field cultivated w/ 9" shovels @ 6" spacing | 2.5-3 | 5.5 | anhydrous | fall | deep tiller |
| | ¾ | 7 | 0.5 | 4.5 | | | | | | | | | dry | spring | w/seed |
| | 2 | 8 | 1 | 5.5-6 | | | | | | | | | anhydrous,dry | fall;spring | deep tiller w/ |
| | 1.5 | 7 | 1.75 | 6 | 2 | 5000 viber chisel 4"shovel; 10" shovel | 2.5;2.5 | 5.5 | 2 | viber chisel w/12"sweeps | 2.5 | 5.5 | liquid | spring | with cultivato |
| rr | | | | 5 | 1 | chisel plough @ 12" spacings | 2.5-3 | 5.5 | 2 | chisel plough, 12"spacing | 2.5-3 | 5.5 | liquid | spring | with cultivato |
| | 1.5 | 7 | 1 | 5 | 1 | deep tiller w/10"shovels @1' spacing | 3 | 6 | no | | | | anhydrous | spring | deep tiller |
| | 12 | | | 5 | 1 | chisel W/ 2" width | 4 | 5.5 | anhydrous | | | | anhydrous | spring | chisel w/2" w |
| | 12 | | | 5 | 1 | chisel W/ 2" width | 4 | 5.5 | anhydrous | | | | anhydrous | spring | chisel w/ 2" w |
| | ½ | 6 | 1 | 6 | 1 | deep tiller w/10"shovels | 2 | 5.5 | 1 | viber chisel w/ 10" shovels @ 9" spacing | 2 | 5.5 | anhydrous | spring | before seeding |
| | 2 | 9 | 0.75-1 | 5 | | | | | | | | | anhydrous | fall | dutch knives w |
| | 1.5 | 9 | 1.5 | 5 | | | | | | | | | liquid | spring | deep band w/ |
| | ¾ | 12 | 0.5 | 4 to 5 | | | | | | | | | liquid | spring | on side of hoe |
| | ¾ | 12 | 1.25 | 4.5 | | | | | | | | | liquid and dry | spring | beside seed; l |
| | ¾ | 12 | 1.25 | 4.5 | | | | | | | | | liquid and dry | spring | beside seed; l |
| ik | ¾ | 7.25 | 1 | 6 | | | | | | | | | dry | spring | with seed |
| | ¾ | 8 | 0.5 | 4.5 | 0 | | | | | | | | anhydrous | fall | knived in w/1 |
| | 1 | 8 | 1 | 5 | 1 | herbicide encorp. 14" sweeps @12" spacing | 3 to 4 | 6 | 1 | anhydrous, 16"sweep @ 12" spacing | 2 | 6 | anhydrous | spring | in spring cult |
| | 1 | 7.5 | 1 | 5 | | | | | | | | | dry | spring | side banded w |
| | 1 | 7 | 1.5 | 4 | | | | | | | | | liquid | fall | spoke wheel |
| | 1.5 | 7 | 1 | 5 | | | | | | | | | dry | spring | with seed |
| | 11 | 9 | 1.5 | 6.5 | 2 | heavy duty cultivator w/4" sweeps @ 12"spacing | 4 to 5 | 7 | no | | | | anhydrous | fall | heavy duty cu |
| | 11 | 9 | 1.5 | 6.5 | 2 | heavy duty cultivator w/4" sweeps @ 12"spacing | 4 to 5 | 7 | no | | | | anhydrous | fall | heavy duty cu |
| | 1 | 5 | 2 | 5.5 | 1 | flexicoil cultivator, w/8" shovels @9"spacing | 3 | 5 | 1 | flexicoil cultivator, w/8" shovels @9"spacing | 3 | 5 | | fall | anhydrous wi |
| | | 10 | 2 | 5 | | | | | | | | | dry | spring | in row with s |
| | | 10 | 2 | 5 | | | | | | | | | dry | spring | in row with s |
| | 2 | 10 | 0.5 | 5.5 | | | | | | | | | dry | spring | with the seed |
| | 4 | 4 | 2 | 6 | 2 | deep tiller w/ 12"sweeps @ 10"spacing | 5 | 5 | 1 | spring cultivation w/12"sweeps @4" spacing | 2 | 6 | dry | spring | w/ seeder |
| | 3/4-1/ | 30 | 1.5 | 5 1/2 | 2 | deep tiller w/ 12"sweeps @ 10"spacing | 5 | 5 1/2 | 1 | spring cultivation w/12"sweeps @4" spacing | 2 | 6 | dry | spring | w/ seeder |
| | 3/4-1/ | 30 | 1.5 | 5 1/2 | 2 | deep tiller w/ 12"sweeps @ 10"spacing | 5 | 5 1/2 | 1 | spring cultivation w/12"sweeps @4" spacing | 2 | 6 | dry | spring | w/ seeder |
| | 4 | 4 | 2 | 6 | 2 | deep tiller w/ 12"sweeps @ 10"spacing | 5 | 5 1/2 | | | | | anhydrous | fall | cultivator, ap |
| | | | | | | | | | | | | | | with seed | side banded |
| | ⅛ | 7 1/2 | 0.75 | 5 | | | | | | | | | | with seed | |
| | ⅛ | 30 | 1 | 4 1/2 | | | | | | | | | | with seed | side banded |
| | ⅛ | 30 | 1 | 4 1/2 | | | | | | | | | | with seed | |
| | 2 | 7 | 1.5 | 4.5 | 1 | deep tiller w/12" shovels @12" spacing; tandom disk @ 9"spacing | 4 | 4.5-5 | no | | | | anhydrous | fall | chisel w/7"d |
| | 2 | 7 | 1.5 | 4.5 | 1 | deep tiller w/12" shovels @12" spacing; tandom disk @ 9"spacing | 4 | 5.5 | 1 | light duty field cultivated w/9" shovels @7"spacing | 2 | 5.5 | broadcast | spring | |
| | ¾ | 7 | 0.75 | 4.8 | | | | | | | | | anhydrous | fall; spring | narrow blade |
| | ¾ | 7 | 0.5 | 4.8 | | | | | | | | | dry | spring | broadcast |
| | 1 | 7 | 1 | 5 | 2 | deep tillw/8"shovels@12"spacing; cultivator w/12"shovels@9.75"spacing | 4 ; 4 | 5;5 | 1 | light duty field cultivated w/ 12"shovels @ 9.75"spacing | 2 | 5 | dry | spring | w/ seeder |
| | 1 | 7 | 1.5 | 5 | 2 | deep tillw/8"shovels@12"spacing; cultivator w/12"shovels@9.75"spacing | 4 ; 4 | 5;5 | 1 | light duty field cultivated w/ 12"shovels @ 9.75"spacing | 2 | 5 | dry;liquid | spring | broadcast |
| | ½ | 36 | 1.75-2 | 5 | 2 | tandom disk 8"spacing; heavy duty cultivator 12"sweeps | 3-4; 3- | 6;6 | 1 | viber shank light duty 7" | 3-4" | 6 | dry | fall | w/heavy cult |
| | ¾ | 7 | 1.5 | 5 | | | | | | | | | urea; dry | with seed | b/w seed ro |
| | ¾ | 7 | 2 | 5 | | | | | | | | | dry | with seed | |
| | ¾ | 10.5 | 0.75 | 4.5 | | | | | | | | | liquid | seeding | below & be |
| | ¾ | 7 | 1.5-1.7 | 4.5 | 1 | deep tiller w/4"shovel @12"spacing | 4-4.5 | 5 | 2 | deep tillw/4"shovel@12"spacing; cult w/9"sweeps@6"spacing | 3;2.5 | 5;5 | liquid rhizobia | | |
| | 2.5 | 6 | 1-1.25 | 4.5 | 2 | heavy duty cultivator w/ 4"points @ 12"spacing | 6 to 7 | 5.5-6 | 1 | field cult w/ 9"shovels @ 6"spacing w/mulchers | 4 | 5.5 | anhydrous;dry | fall;spring | cultivator;w |
| | 2.5 | 6 | 1-1.25 | 4.5 | 2 | heavy duty cultivator w/ 4"points @ 12"spacing | 6 to 7 | 5.5-6 | 1 | field cult w/ 9"shovels @ 6"spacing w/mulchers | 4 | 5.5 | anhydrous;dry | fall;spring | cultivator;w |
| | ¾ | 7 | 1-0.75 | 4.5 | | | | | | | | | dry;liquid | spring | seeder;broa |
| | 2 | 8 | 1 | 5.5-6 | | | | | | | | | dry;anhydrous | spring | seeder; cult |
| | 2 | 8 | 0.5-0.7 | 5.5-6 | | | | | | | | | dry;anhydrous | spring | seeder; cult |
| | 1.5 | 7 | 1.75 | 6 | 2 | 5000 viber chisel 4"shovel; 10" shovel | 3;3.25 | 5;6 | 2 | 12"sweeps; 12" sweeps | 3;3 | 6;6 | anhydrous/dry | fall;spring | knives @3" |
| | 5 | 8 | 2 | 5 | 1 | chisel plough,10"shovels @12"spacing | 3-3.5 | 5.5 | 1 | chisel plough,10"shovels @12"spacing | 3-3.5 | 5.5 | anhydrous,dry | spring | w/tillage; w |
| | 1.5 | 7 | 1 | 5 | 1 | deep tiller w/10"shovels @1' spacing | 3 | 6 | no | | | | anhydrous | spring | deep tiller |
| | ¾ | 9 | 1 | 5.5 | 1 | chisel w/¾ twisted shovels,3.5 "wide | 3 | 6 | no | | | | anhydrous;dry | spring | 2"chisel on |
| | ¾ | 9 | 1 | 5.5 | 1 | chisel w/¾ twisted shovels,3.5 "wide | 3 | 6 | no | | | | anhydrous;dry | spring | 2"chisel on |
| | ½ | 6 | 0.5 | 6 | 2 | both viber chisel @9"spacing w/10"shovels | 2.5-3 | 5 | 1 | viber chisel @9"spacing w/10"shovels | 2 | 5 | dry | spring | with cultiva |
| | 2 | 9 | 0.75-1 | 5 | | | | | | | | | anhydrous;dry | fall; spring | knives @18 |
| | 2 | 9 | 1.5 | 5 | | | | | | | | | dry | spring | dutch knife |
| | ¾ | 12 | 0.5 | 4 to 5 | | | | | | | | | liquid | spring | beside seed |
| | 0.75 | 12 | 1.25 | 4.5 | | | | | | | | | liquid;dry | spring | dribble ban |
| | 0.75 | 12 | 1.25 | 4.5 | | | | | | | | | liquid;dry | spring | dribble ban |
| ak | 1-¾ | 7.25 | 0.75 | 6 | | | | | | | | | anhydrous; dry | fall | banded 3-4" |
| | ¾ | 8 | 0.5 | 4.5 | 0 | | | | | | | | anhydrous | fall | knived in w |
| | ¾ | 7.2 | 1 | 6.5 | 2 | deep tiller 12" sweeps | 3 | 5 | | | | | anhydrous | fall (2nd till) | 12"sweeps, |
| | ¾ | 7.2 | 1 | 6.5 | 2 | deep tiller 12" sweeps | 3 | 5 | | | | | anhydrous | fall (2nd till) | 12"sweeps, |
| | 1 | 8 | 1.5 | 5 | | | | | | | | | dry | spring | w/seed and |
| | 1 | 7 | 1.5 | 4 | | | | | | | | | liquid; dry | fall;spring | spoke whee |
| | 1.5 | 7 | 1 | 5 | | | | | | | | | dry | spring | with seed |
| | 10 | 9 | 1.5 | 6-6.5 | 1 | deeptiller w/ 4" shovels @12 inch spacing | 4 to 5 | 6.5 | no | | | | with cultivation | fall | |
| | 10 | 9 | 1.5 | 6-6.5 | 1 | deeptiller w/ 4" shovels @12 inch spacing | 4 to 5 | 6.5 | no | | | | with cultivation | fall | 2" point on |
| | 1 | 9 | 2 | 5.5 | 1 | flexicoil cultivator, w/8" shovels @9"spacing | 4 | 5 | no | | | | anhydrous w/till | fall | |
| | 1 | 9 | 2 | 5.5 | 1 | flexicoil cultivator, w/8" shovels @9"spacing | 4 | 5 | no | | | | anhydrous w/till | fall | |
| | ⅝ | 8 | 0.75-1 | 5.5 | | | | | | | | | dry | spring | w/seed and |
| | 7 | 10 | 2 | 5.5 | | | | | | | | | dry | spring | w/seed |
| | 1 | 10 | 1.5-2 | 5.5 | | | | | | | | | dry | spring | w/seed |
| | 1 | 10 | 1.5-2 | 5.5 | | | | | | | | | dry | spring | w/seed |

| Type | Dept. | Speed | Fertilizer What | When | How | Soil type | LLD | Harrowing | Years in ZT |
|---|---|---|---|---|---|---|---|---|---|
| spring tooth cultivator 9" shovels @7" spacing | 2 | 5 | anhydrous | spring | viber shank, narrow openers | loam,clay loam, clay | SW 24-13-7 | No | |
| cultivator w/ 8"sweeps @ 6" spacing | 2.5 | 5.5 | anhydrous | fall | rake style applicator | loam,clay loam, clay | NW 16-13-6 | No | |
| cultivator w/ 8"sweeps @ 6" spacing | 2.5 | 5.5 | anhydrous | fall | rake style applicator | loam,clay loam, clay | NW 16-13-6 | No | |
| | | | anhydrous | fall | blue jet, very narrow knives | loam, clay loam | NE 23-13-7 | No | 6 |
| | | | liquid | spring | dribble with seed | clay silty clay | NW 20-13-6 | No | 8 |
| | | | liquid | spring | dribble with seed | sandy loam, loam, clay loam | NW 29-13-6 | No | 9 |
| international viber till @ 10" spacing w/ 10" sweeps | 3 | 6 | anhydrous | spring | w/seed 1\2" deeper than seed | loam | NW 26-6-4 | No | |
| | | | anhydrous | fall | w/cultivator | sandy loam, loam | NE 19-5-4 | No | |
| | | | urea;dry | with seed | b/w seed rows; with seed | silty clay loam | SE 36-6-4W | spring w/spring tine harrow | 22 |
| | | | liquid | spring | below & to side of seed | loam | NW 29-5-4 | No | 3 |
| deep till w/4"shovel@12"spacing;cult w/9"shovels @6"spacing | 4;2 | 5;5 | liquid; dry | spring | deep band liquid; dry with seed | clay loam, loam-clay loam | NE 7-3-13 | No | |
| light duty field cultivated w/ 9" shovels @ 6" spacing | 2.5-3 | 5.5 | anhydrous | fall | deep tiller | clay loam, loam-clay loam | NW 22-1-12 | Once | |
| | | | dry | spring | w/seed | clay loam | NE 7-3-13 | No | 4 |
| | | | anhydrous,dry | fall;spring | deep tiller w/1"opener @12"spacing | clay loam, loam | NE 21-1-12 | No | 4 |
| viber chisel w/12"sweeps | 2.5 | 5.5 | liquid | spring | with cultivator | clay loam | NW 25-12-16 | No | |
| chisel plough, 12"spacing | 2.5-3 | 5.5 | liquid | spring | with cultivator | clay loam | NE 33-15-18 | Twice | |
| | | | anhydrous | spring | deep tiller | clay loam | NW 14-15-18 | No | |
| | | | anhydrous | spring | chisel w/2" width 4" deep | clay loam | SE 13-16-20 | Heavy harrow | |
| | | | anhydrous | spring | chisel w/ 2" width 4" deep | clay loam | SE 13-16-20 | Heavy harrow | |
| viber chisel w/ 10" shovels @ 9" spacing | 2 | 5.5 | anhydrous | spring | before seeding w/one tillage events | loamy fine sand | SW 13-15-13 | No | |
| | | | anhydrous | fall | dutch knives w/ 3\4 width @ 18"spacing | clay loam | SE 1-13-16 | No | 9 |
| | | | liquid | spring | deep band w/ dutch knives @ 1' spacing | clay loam | SW 31-15-18 | No | 8 |
| | | | liquid | spring | on side of hoe with seed | clay loam | NE 15-15-18 | No | 19 |
| | | | liquid and dry | spring | beside seed; between rows | clay loam | E 7-16-19 | No | 7 |
| | | | liquid and dry | spring | beside seed; between rows | clay loam | E 7-16-19 | No | 7 |
| | | | dry | spring | with seed | sandy loam-clay loam | NE 9-15-13 | No | 5 |
| | | | anhydrous | fall | knived in w/3\4" openers, 3"deep @5.5mph | loam, silty loam | NW 2-11-18 | Spring 1\2" @ 6.5mph | |
| anhydrous. 16"sweep @ 12" spacing | 2 | 6 | anhydrous | spring | in spring cult | clay, clay loam | SW 23-11-18 | No | |
| | | | dry | spring | side banded with seed | silty loam | SW 3-11-18 | No | 18 |
| | | | liquid | fall | spoke wheel w/ spikes 6" apart | clayloam, loamysand | NE 10-11-18 | in fall 1" deep | 17 |
| | | | dry | spring | with seed | silty loam | SE 2-11-18 | No | 19 |
| | | | anhydrous | fall | heavy duty cult (same as tillage) | loam | S 24-6-22 | No | |
| | | | anhydrous | fall | heavy duty cult (same as tillage) | loam | S 24-6-22 | No | |
| flexicoil cultivator, w/8" shovels @9"spacing | 3 | 5 | | fall | anhydrous with fall tillage | loam | SE 4-6-23 | No | |
| | | | dry | spring | in row with seeds | loam | W 28-6-22 | No | 8 |
| | | | dry | spring | in row with seeds | loam | E 29-6-22 | No | 8 |
| | | | dry | spring | with the seed | loam | E 36-5-24 | No | 7 |
| spring cultivation w/12"sweeps @4" spacing | 2 | 6 | dry | spring | w/ seeder | clay | NE&SE 27-2-2 | No | |
| spring cultivation w/12"sweeps @4" spacing | 2 | 6 | dry | spring | w/ seeder | clay loam-clay, loam | NW 26-2-2W | No | |
| spring cultivation w/12"sweeps @4" spacing | 2 | 6 | dry | spring | w/ seeder | loam, clay loam-loam | SW 35-2-2 | No | |
| | | | anhydrous | fall | cultivator, spike,1" | clay | NE&SE 27-2-2 | No | |
| | | | | with seed | side banded | clay loam, loam | NW 2-2-2W | Once | 4 |
| | | | | with seed | | clay, loam | NW 32-2-2W | No | 4 |
| | | | | with seed | side banded beside and below | clay loam, clay | NW 20-2-1W | No | 4 |
| | | | | with seed | | clay loam,loam | NW 14-2-2W | No | 4 |
| | | | anhydrous | fall | chisel w/7"shovels @6.75"spacing, 4.5",5 mph | loam, clay loam,loam | NE 34-13-7 | Fall&spring, tine harrows,1" | |
| light duty field cultivated w/9"shovels @7"spacing | 2 | 5.5 | broadcast | spring | | clay-sandy loam-silty clay | SW 2-14-7 | No | |
| | | | anhydrous | fall; spring | narrow blade 3\8"deep, 3"space; with seed | loam, clay loam | NE 23-13-7 | Fall, sping tooth 1\2 deep | 8 |
| | | | dry | spring | broadcast | loam, clay loam | NE 23-13-7 | Fall, sping tooth 1\2 deep | 8 |
| light duty field cultivated w/ 12"shovels @ 9.75"spacing | 2 | 5 | dry | spring | w/ seeder | loam, silty clay loam | 36-6-4 | No | |
| light duty field cultivated w/ 12"shovels @ 9.75"spacing | 2 | 5 | dry;liquid | spring | broadcast | clay loam, loam | 35-6-4 | No | |
| viber shank light duty 7" | 3-4" | 6 | dry | fall | w/heavy cult | very fine sandy loam,loam | NW 19-5-4 | No | |
| | | | urea; dry | with seed | b/w seed rows; with seed | silty clay loam | SE 36-6-4W | spring w/spring tine harrow | 23 |
| | | | dry | with seed | | clay | SE 36-6-4W | spring w/spring tine harrow | 23 |
| | | | liquid | seeding | below & beside seed | loam | NW 29-5-4 | No | 4 |
| deep tillw/4"shovel@12"spacing; cult w/9"sweeps@6"spacing | 3;2.5 | 5;5 | liquid rhizobia | | | clay loam | NE 7-3-13 | No | |
| field cult w/ 9"shovels @ 6"spacing w/mulchers | 4 | 5.5 | anhydrous;dry | fall;spring | cultivator;with seed | clay loam, loam-clay loam | SE 22-1-12 | No | |
| field cult w/ 9"shovels @ 6"spacing w/mulchers | 4 | 5.5 | anhydrous;dry | fall;spring | cultivator;with seed | clay loam | SE 28-1-12 | No | |
| | | | dry;liquid | spring | seeder;broadcast | clay loam | NE 7-3-13 | Dimond harrows | 5 |
| | | | dry;anhydrous | spring | seeder; cult w/1"opener on 12"spacing | loam, clay loam | SE 31-1-12 | 1 spring tooth harrow | 9 |
| | | | dry;anhydrous | spring | seeder; cult w/1"opener on 12"spacing | clay loam, loam | NE 21-1-12 | fall, spring tooth harrow bar | 5 |
| 12"sweeps; 12" sweeps | 3;3 | 6;6 | anhydrous'dry | fall;spring | knives @3" spacing, 1.5"wide;w/spring cult | clay loam | SE 26-12-16 | No | |
| chisel plough,10"shovels @12"spacing | 3-3.5 | 5.5 | anhydrous,dry | spring | w/tillage; w/seed | clay loam | SW 25-15-19 | No | |
| | | | anhydrous | spring | deep tiller | clay loam | NW 27-15-18 | No | |
| | | | anhydrous;dry | spring | 2"chisel on cult @3" spacing, 6mph;w/seed | clay loam | S3-16-20 | No | |
| | | | anhydrous;dry | spring | 2"chisel on cult @3" spacing, 6mph;w/seed | clay loam | W 1-16-20 | No | |
| viber chisel @9"spacing w/10"shovels | 2 | 5 | dry | spring | with cultivator | loamy fine sand | NE 36-15-14 | No | |
| | | | anhydrous;dry | fall; spring | knives @18"spacing, 3"deep; w/seed | clay loam | NW35-12-16 | No | 8 |
| | | | dry | spring | dutch knife deep tiller @ 1' spacing 1" deep | clay loam | SW 20-15-18 | Spring-1\2" aggressive | 4 |
| | | | liquid | spring | beside seed | clay loam | N&SE11-15-18 | No | 14 |
| | | | liquid;dry | spring | dribble banded;w/seed | clay loam | W 23-16-20 | No | 7 |
| | | | liquid;dry | spring | dribble banded;w/seed | clay loam | E 7-16-19 | No | 7 |
| | | | anhydrous; dry | fall | banded 3-4" w/bourgou knife @1foot spacing | loamy fine sand | NE 1-15-13 | No | 5 |
| | | | anhydrous | fall | knived in w/3\4" openers, 3"deep @5.5mph | loam, silty loam | NW 2-11-18 | Spring 1\2" @ 6.5mph | |
| | | | anhydrous | fall (2nd till) | 12"sweeps,4"deep | clay loam, clay loam-silty loam | 5-11-18 | No | |
| | | | anhydrous | fall (2nd till) | 12"sweeps,4"deep | silty loam-clay loam, clay loam | 7-11-18 | No | |
| | | | dry | spring | w/seed and broadcast | silty loam | SW 3-11-18 | Last fall 0.25" deep | 18 |
| | | | liquid; dry | fall;spring | spoke wheel, spikes every 6"; with seed | silty loam | NE 2-11-18 | Fall 1.0" deep | 18 |
| | | | dry | spring | with seed | silty loam, loam-silty clay loam | NW 1-11-18 | Fall 0.25" deep | 20 |
| | | | with cultivation | fall | | carrol clay loam | S W-36-21 | No | |
| | | | with cultivation | fall | 2" point on deep tiller | loam | SE 24-6-22 | land was rolled | |
| | | | anhydrous w/till | fall | | loam | E 8-6-23 | Field harrows, scratch soil | |
| | | | anhydrous w/till | fall | | loam | W 7-6-23 | Field harrows, scratch soil | |
| | | | dry | spring | w/seed and broadcast | clay loam-fine loam | SE 4-7-22 | No | 10 |
| | | | dry | spring | w/seed | loam | N 32-6-22 | No (land was rolled) | 10 |
| | | | dry | spring | w/seed | loam | E 26-5-24 | No | 8 |
| | | | dry | spring | w/seed | loam | W 36-5-24 | No | 8 |

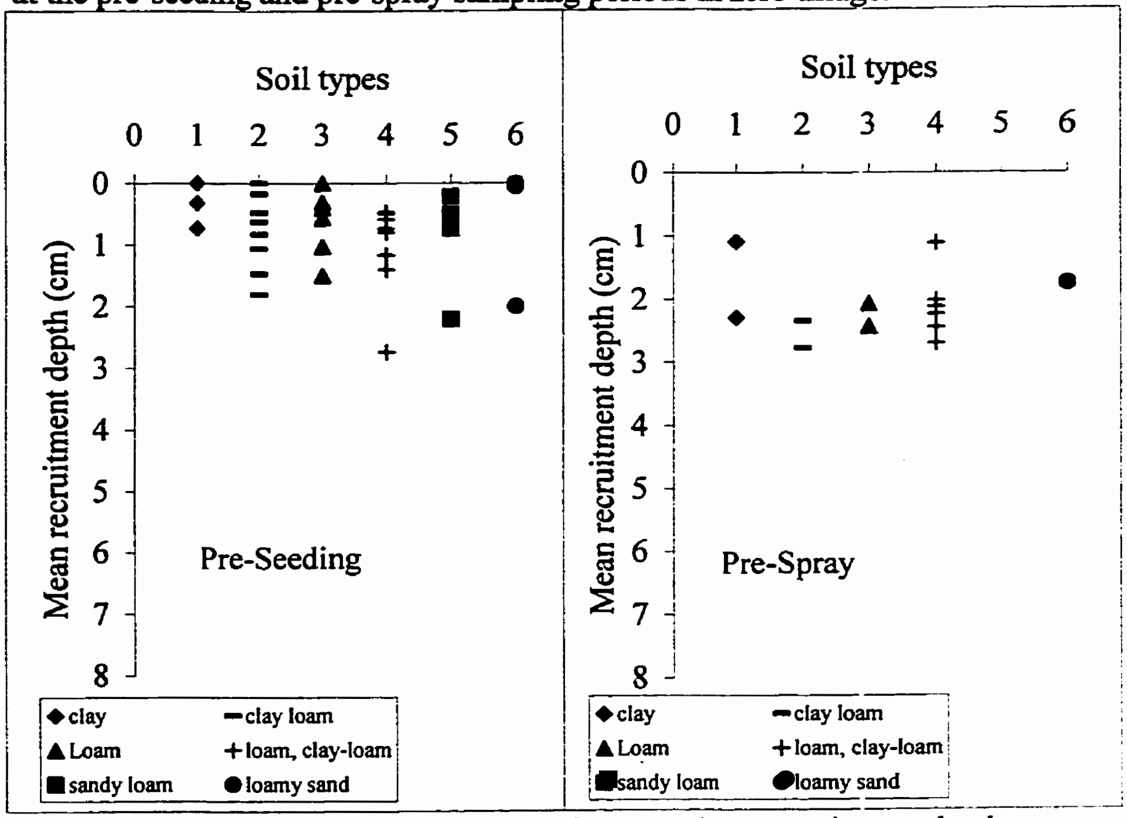
Appendix 5.2.1. Effect of soil type on wild oat recruitment depth at the pre-seeding and pre-spray sampling periods in zero tillage.



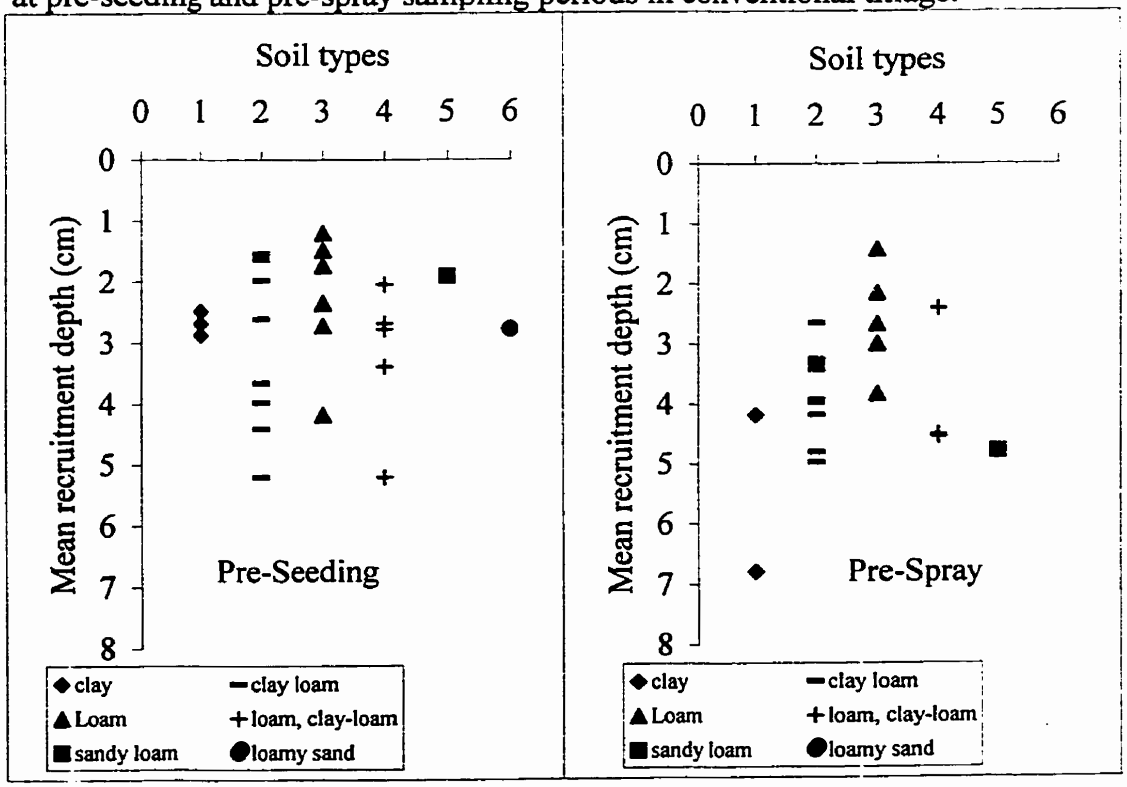

Appendix 5.2.2. Effect of soil type on wild oat recruitment depth at the pre-seeding and pre-spray sampling periods in conventional tillage.



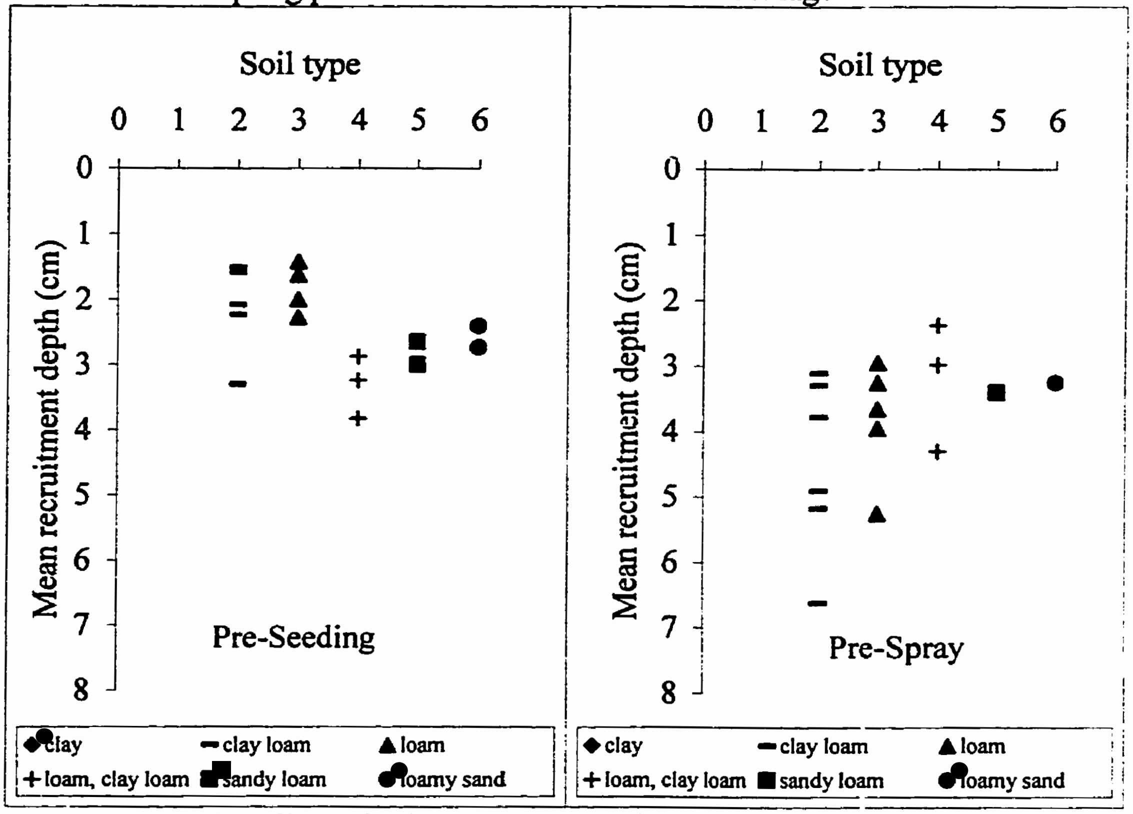
Appendix 5.2.3. Effect of soil type on volunteer wheat recruitment depth at the pre-seeding and pre-spray sampling periods in zero tillage.



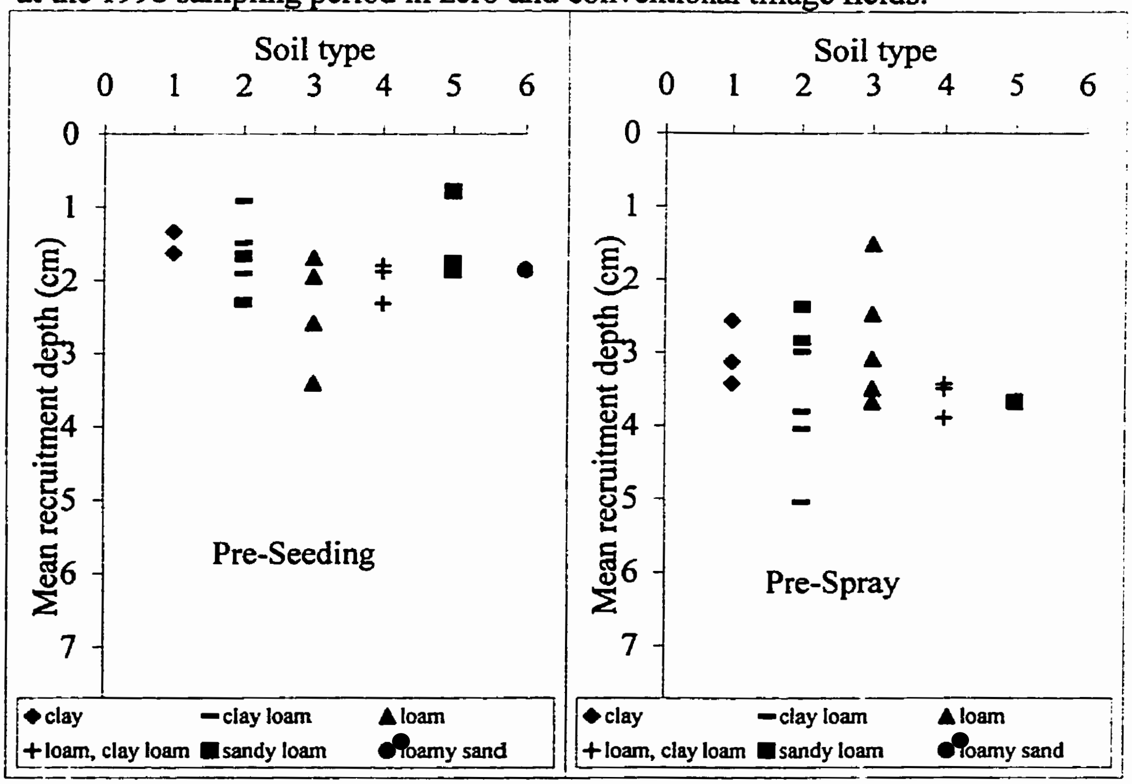

Appendix 5.2.4. Effect of soil type on volunteer wheat recruitment depth at pre-seeding and pre-spray sampling periods in conventional tillage.



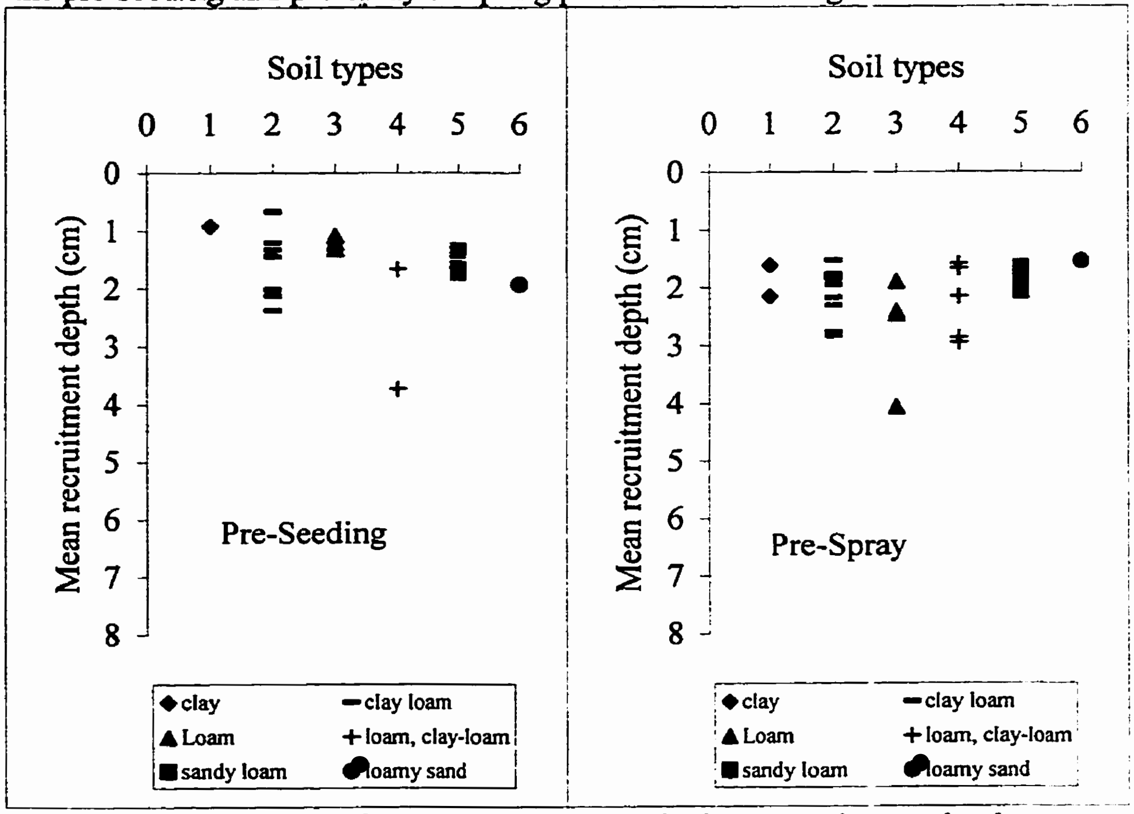
Appendix 5.2.5. Effect of soil type on green foxtail recruitment depth at the 1997 sampling period in zero and conventional tillage.



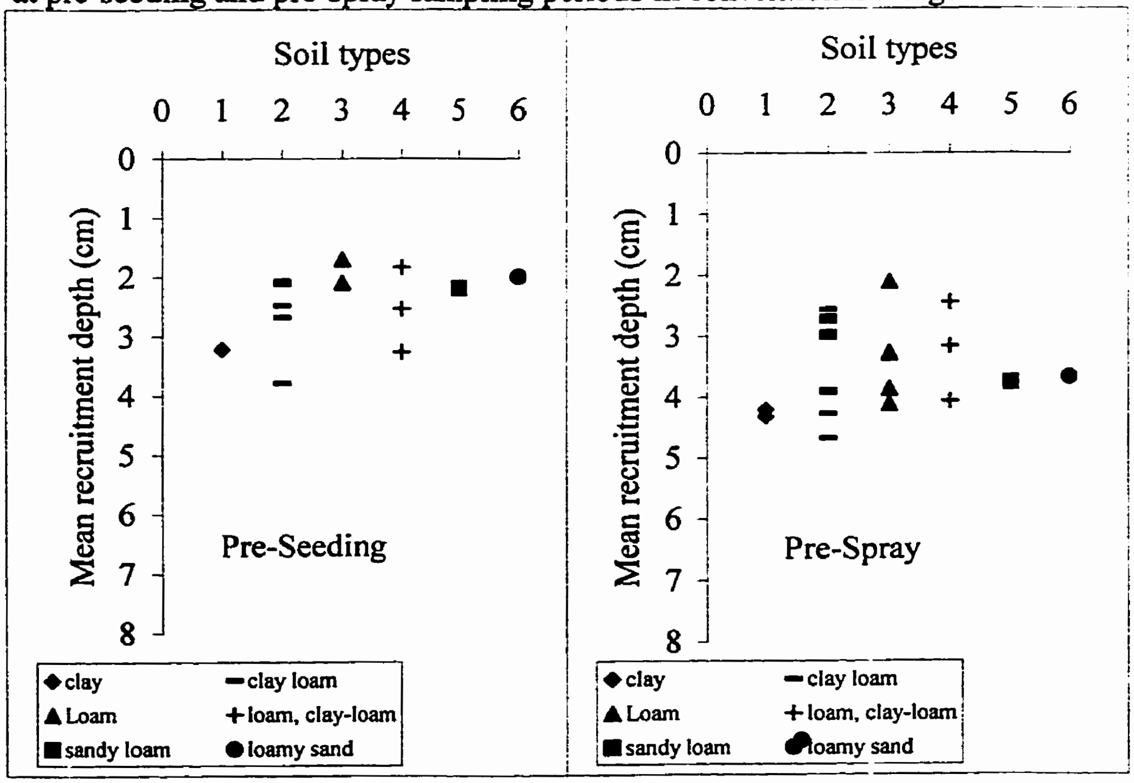

Appendix 5.2.6. Effect of soil type on green foxtail recruitment depth at the 1998 sampling period in zero and conventional tillage fields.



Appendix 5.2.7. Effect of soil type on wild buckwheat recruitment depth the pre-seeding and pre-spray sampling periods in zero tillage.

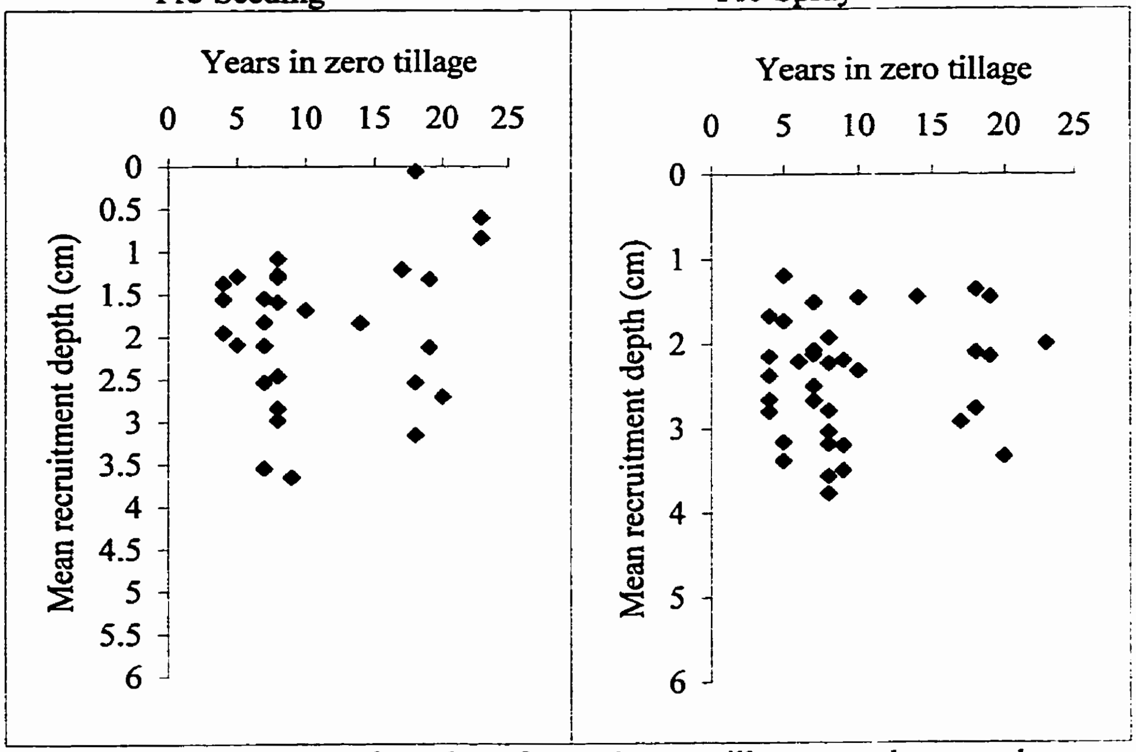



Appendix 5.2.8. Effect of soil type on wild buckwheat recruitment depth at pre-seeding and pre-spray sampling periods in conventional tillage.



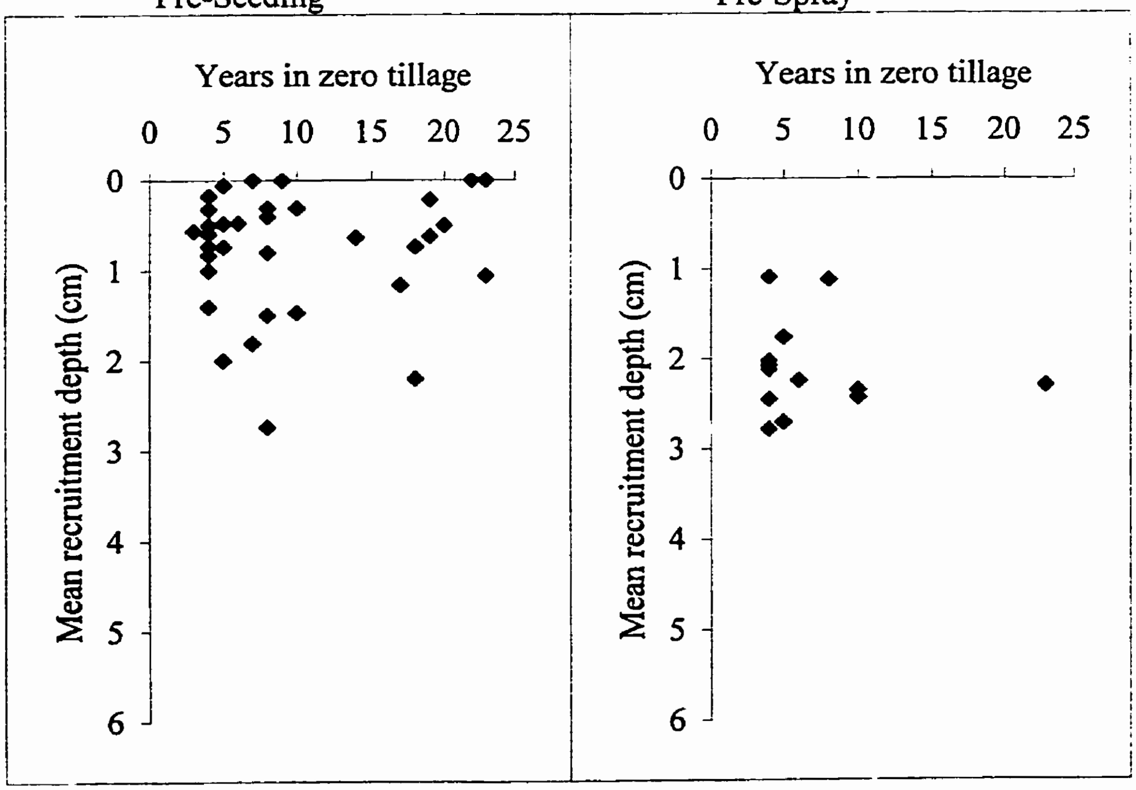
Appendix 5.3.1. Effect of number of years in zero tillage on wild oat seedling mean recruitment depth.

Pre-Seeding Pre-Spray

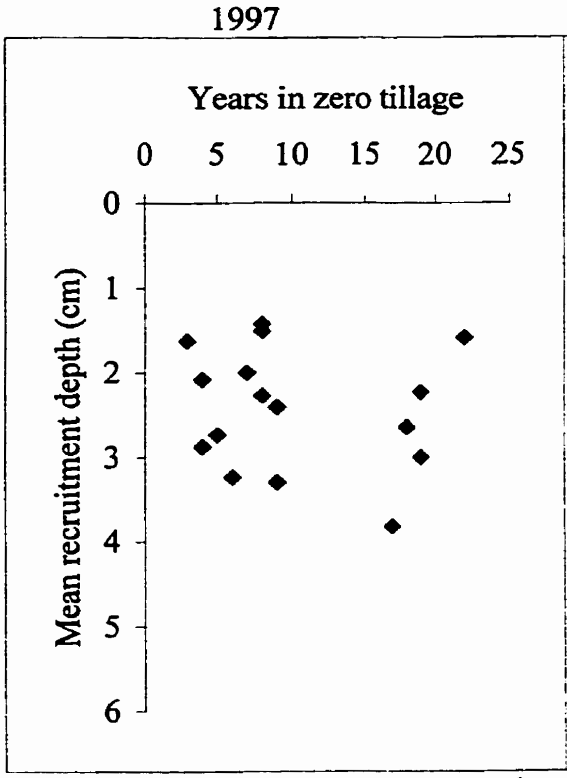


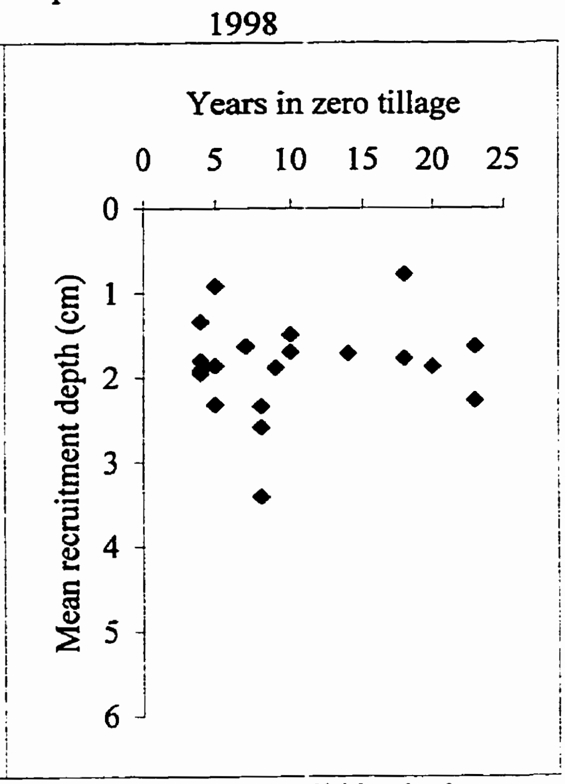

Appendix 5.3.2. Effect of number of years in zero tillage on volunteer wheat mean seedling recruitment depth.

Pre-Seeding Pre-Spray

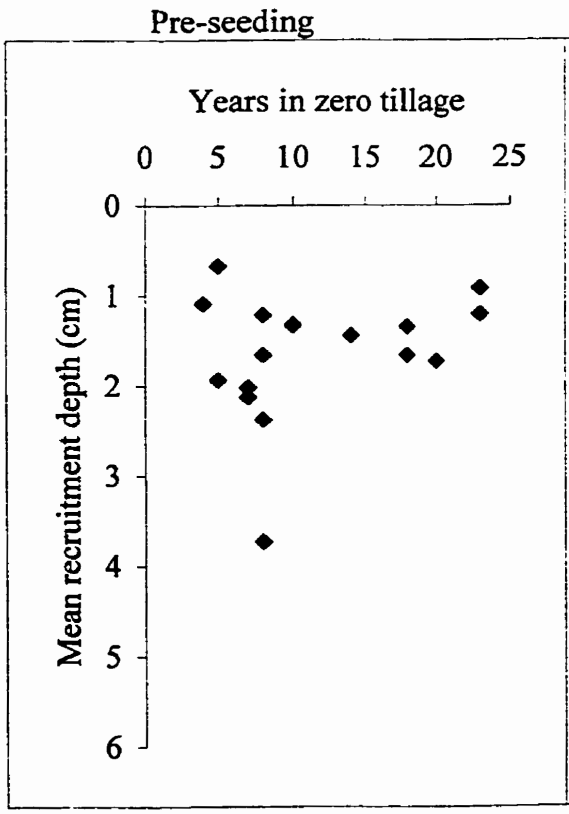


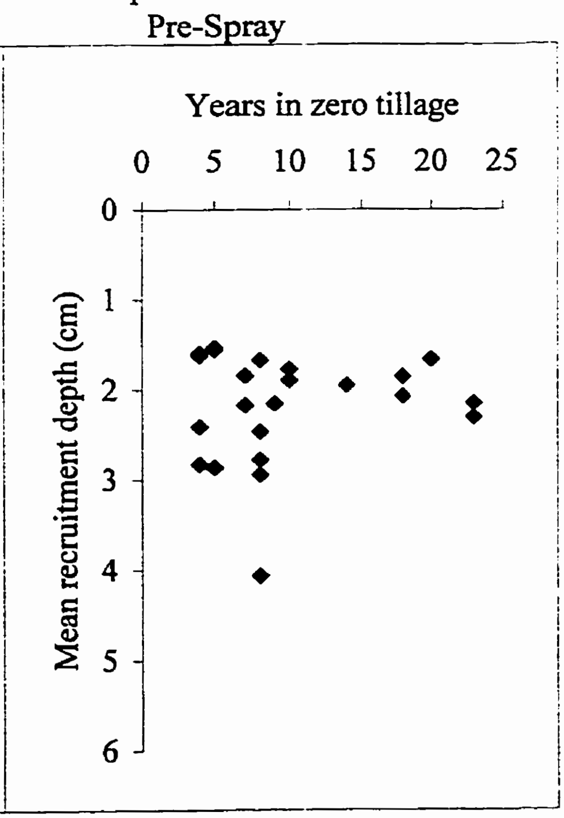
Appendix 5.3.3. Effect of number of years in zero tillage on green foxtail mean seedling recruitment depth.



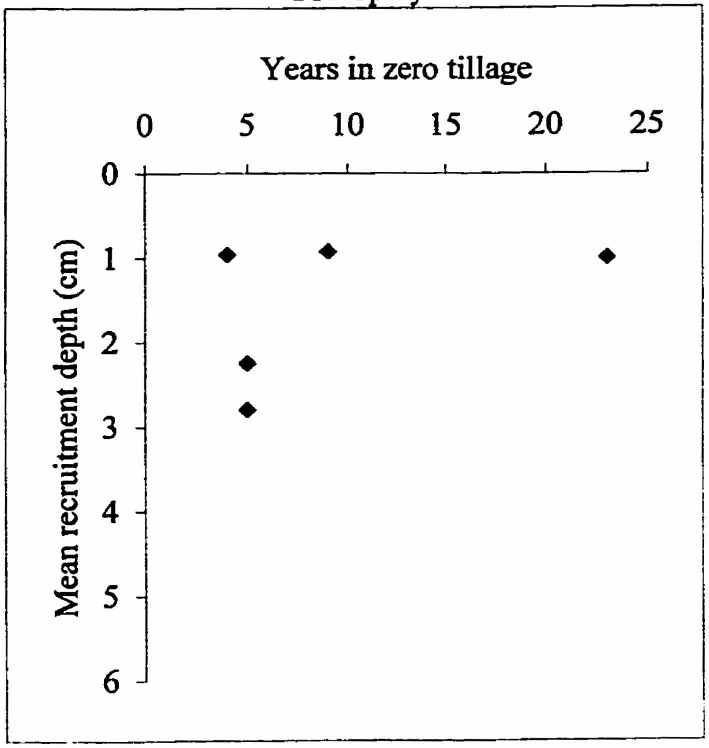

Appendix 5.3.4. Effect of number of years in zero tillage on wild buckwheat mean seedling recruitment depth.



Appendix 5.3.5. Effect of number of years in zero tillage on barnyard grass mean recruitment depth

Pre-Spray



# APPENDIX 6.1

## Development of a methodology to determine the effect of tillage on weed seedling recruitment depth for species with no morphological marker.

### Introduction.

Seeds in the seed bank are affected by many different factors, including light, moisture, gaseous environment, temperature and tillage, the later of which can also influence all of the previous factors mentioned (Buhler *et al.*, 1997; Taylorson, 1987; Pons, 1991; Wesson and Wareing, 1968a). Tillage affects the density of the weed seedbank, species composition and the location and distribution of seeds in the seed bank (Buhler *et al*, 1997). Tillage also affects the presence of microsites within the soil profile. Seeds inside soil aggregates are exposed to high moisture concentrations and low oxygen tensions that inhibits germination and promotes dormancy (Paraja *et al.*, 1985; Pareja and Staniforth, 1985). Pareja and Staniforth (1985) also indicated that a fine seed bed created by tillage provides better weed seed-soil contact and, therefore, a better chance for seed germination, when compared to seedbeds that are left coarse. Soil structure creates a heterogeneity of soil environments that, in turn, creates a variety of micorsites for weed seeds (Pareja and Staniforth, 1985).

Increased organic matter in zero tillage fields can also influence the weed seedbank via increased activity of soil borne organisms. Increased activity of soil borne organisms can either break or promote dormancy (Cavers, 1994). Derksen *et al.* (1998) found that differences in weed densities did not exist in the weed seedbank or in the residual weed community, but densities did differ in the seedling communities under different tillage systems. This result may indicate that seedling recruitment is delayed in zero tillage. The environments present in zero and conventional tillage fields may differ enough to affect the depth and amount of weed seedling recruitment.

Determining from where in the soil profile weeds are successfully recruited could improve management by optimizing different types of weed control methods. Many different environmental and physical factors affect the depth of seedling recruitment. Specific environmental factors that are unique to each tillage system are hard to duplicate in plot and lab experiments. Measuring the weed seedbank is very labour intensive and does not provide the best measure of future weed seedling populations (Baskin and Baskin, 1985; Cardina *et al.*, 1996; Taylorson, 1987). Measuring the depth of recruitment of most broadleaf weed seedlings is not possible because an indicator of the point of germination is not present. A methodology was developed to determine the effect of tillage system on the depth of recruitment of those weeds that do not poses a morphological marker.

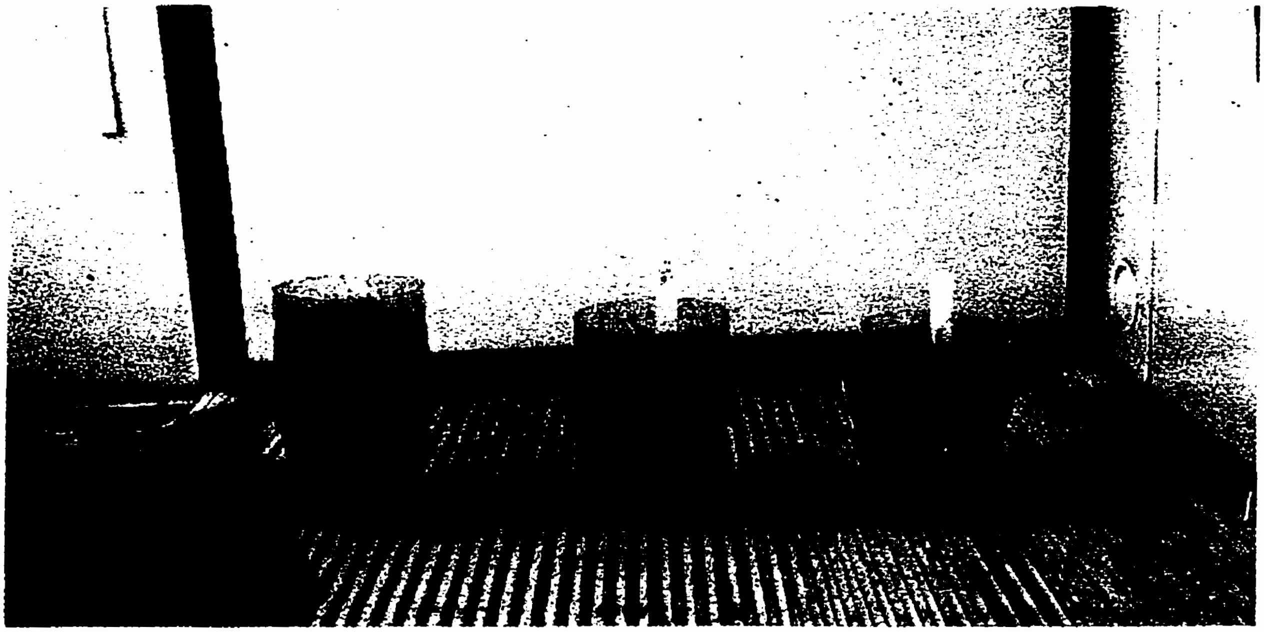
The objectives of this study were:

1) To determine a methodology that could determine the effects of tillage on the depth of those broadleaf weed seedlings that do not have a morphological marker or an indicator of the point of germination.
2) To develop a controlled system that mimicked field conditions in which we could more intensively investigate the effect of tillage on depth of recruitment of all weed species.

**Materials and Methods**

**Soil core sampling.** In the fall of 1998, after harvest and before the first snowfall, soil cores were taken from zero and conventional tillage fields. The fields were located in the Homewood, MB area (N49'30.264" W097'49.171"). Both the zero and the conventional tillage fields were on a clay loam soil. Since the zero tillage field had been under zero tillage for 23 years changes due to zero tillage had taken place. The conventional tillage field had been tilled once in the spring with a light duty field cultivator with 12" shovels and had been tilled once in the fall before sampling with a deep tiller with 8" shovels. Soil cores were taken with 4" acetate liners to three depths; 2, 3.8 and 7.6 cm. Each core was pushed into the soil manually to reduce the amount of compaction of soil in the core. The soil around the core was removed and a flat piece of metal was pushed under the core to help maintain the integrity of the soil core (Figure 6.1.1). The bottom of the core was capped with plastic lids so that the cores could be transported. Soil cores were disturbed as little as possible to maintain the soil structure within the cores as close as possible to field situations. The same procedure for core collection was followed in both the conventional and zero tillage except for the 2 cm depth cores. In the conventional tillage field the soil was shoveled into the core because the soil was so dry and loose that it had no structure. A total of 288 soil cores were taken, 114 in each field.

Appendix 6.1.1. Removal of a soil core from a field using a flat piece of metal to maintain soil integrity.



Appendix 6.1.2. Soil cores placed on top of pots that contained weed seeds and a base layer of soil/sand mixture.

**Soil core preparation.** The soil cores were saturated with water and placed in the freezer for a minimum of three weeks before planting. After the soil cores had been frozen, half (144 cores) were removed from the freezer and placed in a growth cabinet for two to three weeks. During this time any seedlings that emerged from the cores were removed, this was done to reduce the natural weed seed population in the soil cores. The day before planting the 2 and 3.8 cm soil cores were frozen to help maintain core integrity during planting.

**Experimental set-up.** The experiment was run at two temperatures, low ( 12°C day/7°C night) and a warm (20°C day/ 12°night). For each weed species there were six conventional tillage and six zero tillage cores used for each depth. A blank run was planted to account for any viable natural weed seeds present in the soil core.

**Planting.** The recruitment ability of three weed species, green foxtail (*Setaria viridis* L. Beauv.), wild buckwheat (*Polygonum convolvulus* L.) and redroot pigweed (*Amaranthus retroflexus* L.) was tested at different soil depths in zero and conventional soil cores under two temperatures. A base soil mixture of two parts soil and one part sand was heat steam sterilized to remove any weed seeds present. The base soil was put in a 5" diameter pot over a thin layer of peat and saturated with water (Figure 6.1.2). A layer of 40 seeds from each weed species was placed on top of the soil/sand mixture. The soil core was pushed firmly on top of the soil/sand mixture with the seeds to ensure good seed-soil contact. The core set-up was then placed in poly lined trays in the growth chamber. The soil cores were watered from the bottom by filling the trays with water. This ensured a constant supply of water to the seeds.

**Weed counts.** Cores were counted every three to four days. Newly recruited seedlings were counted and removed. Green foxtail seedlings were considered successfully recruited at the three leaf stage and wild buckwheat and redroot pigweed seedlings were considered successfully recruited at the one true leaf stage.

## Results and Discussion

Mean weed seedling recruitment was higher at the warmer temperature in both tillage systems (Table 7.1 and 7.2). This indicates that weed seedling recruitment is affected by temperature. This was expected for green foxtail and redroot pigweed since they are both $C_4$ species, which do better as the temperature increases.

Table 7.1. Mean weed seedling recruitment depth at low temperature (12°C day/7°C night).

| | Zero Tillage | | | Conventional Tillage | | |
|---|---|---|---|---|---|---|
| Soil core depth (cm) | 2 | 3.8 | 7.6 | 2 | 3.8 | 7.6 |
| Redroot pigweed | 3.8 | 0 | 0 | 8.2 | 0.7 | 0 |
| Wild buckwheat | 0 | 0 | 0.2 | 0.2 | 0 | 0 |
| Green foxtail | 12.8 | 13 | 7.7 | 13 | 14.7 | 8.7 |

Table 7.2. Mean weed seedling recruitment depth at warm temperature (20°C day/12°C night).

| | Zero Tillage | | | Conventional Tillage | | |
|---|---|---|---|---|---|---|
| Soil core depth (cm) | 2 | 3.8 | 7.6 | 2 | 3.8 | 7.6 |
| Redroot pigweed | 8.8 | 3.2 | 0 | 16.5 | 6.7 | 0 |
| Wild buckwheat | 0.7 | 0.8 | 0.2 | 2.5 | 1.8 | 0 |
| Green foxtail | 15.7 | 19 | 8.7 | 18.7 | 16.5 | 5.5 |

The response to temperature was reflected in the field survey results, where the majority of green foxtail seedlings were found at the pre-spray sampling period, when the temperatures were warmer. As well, the greatest percentages of recruitment occurred at shallow rather than deep depths for green foxtail seedlings in the field. These results were confirmed in this study (Table 7.1 and 7.2). Wild buckwheat should have recruited more successfully in the cooler temperatures than it did, but the seed was dormant. Total recruitment for all weed species decreased as seedling depth increased. Most weeds have higher germination percentages closer to the soil surface (Dawson and Bruns, 1962; de la Cruz, 1974 and Vanden Born, 1971). Less recruitment was observed in zero tillage soil cores (Table 1 and 2). The reasons for this were unclear, but it does suggest that either a soil impedance factor or environmental conditions associated with zero tillage inhibited weed seedling recruitment. More testing is needed to determine what factors are affecting weed seedling recruitment under zero tillage systems. The methodology used in the study was successful in pointing out differences between the two tillage systems in total recruitment amounts at each level tested. It did not explain why those differences were occurring and, therefore, more study is needed. Results from this study can be used to study the differences between zero and conventional tillage fields under a controlled system.

**Conclusions.**

The results from this study suggests seedling recruitment for green foxtail, redroot pigweed and wild buckwheat is affected by tillage system. The results for green foxtail and wild buckwheat resembled the results from the field; therefore, the methodology may be an effective means of examining the effects of conventional and zero tillage environments on weed seedling recruitment. The core experiments may be a useful precursor and compliment to field experiments. More experimentation is needed to determine the exact effects of each tillage system on weed seedling recruitment and what specific factors reduced recruitment in the zero tillage soil cores. When it is known what factors are affecting weed seedling recruitment in each tillage system, improved weed control could be developed by manipulating or enhancing the environments that reduced weed seedling recruitment in both zero and conventional tillage fields.