THE ROLE OF ANNUAL FORAGES IN INTEGRATED WEED MANAGEMENT

A thesis

submitted in partial fulfillment

of the requirements for the degree

of

MASTER OF SCIENCE

by

Allison Schoofs

Department of Plant Science
University of Manitoba
Winnipeg, MB

0-612-23491-6

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

COPYRIGHT PERMISSION

THE ROLE OF ANNUAL FORAGES IN INTEGRATED WEED MANAGEMENT

by

ALLISON SCHOOFS

A Thesis 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

Abstract

The role of annual forages in integrated weed management.

Allison Schoofs, Department of Plant Science, University of Manitoba. Major Professor, Dr. M.H. Entz.

Annual forages may serve as an alternative weed control measure that can be incorporated into an integrated weed management (IWM) system. A first experiment (experiment 1) investigated the effect of cropping systems involving annual forages on the density of weed seeds in the seedbank, density of weed seedlings in a subsequent pea crop, and species composition of weed communities. The 11 treatments for experiment 1 were as follows: wheat (*Triticum aestivum* L. cv. Katepwa) sprayed with grass and broadleaf herbicide, harvested for grain; wheat sprayed with broadleaf herbicide only, harvested for grain; wheat, unsprayed, harvested for grain; winter triticale (*Triticosecale* cv. Pika), simulation grazed; spring triticale (cv. Banjo), cut for silage; winter and spring triticale intercrop, cut for silage then simulation grazed; sorghum sudangrass (*Sorghum bicolor* [L.] Moench X *Sorghum sudanense* [Piper] Stapf., common), cut for hay; non-dormant alfalfa (*Medicago sativa* L. cv. Nitro), cut for hay; weed fallow, cut for silage, sweet clover (*Melilotus officinales* L. cv. Norgold)/triticale doublecrop, cut for hay then simulation grazed; and fall rye, harvested for grain.

Two field trials were conducted in experiment 1 at Carman from 1994 to 1996. Based on the results of the experiment, it can be concluded that annual forages consistently suppressed wild oat in the seedbank, but did not consistently suppress other weed species. Annual forages suppressed weed seedling recruitment in a pea crop better than annual grain crops because there is some regrowth of forage in some of the systems (eg. winter triticale), or an allelopathic effect of residue (eg. sorghum-sudangrass), or a suppressive effect of residue due to shading (eg. fall rye). Despite the variable weed

control afforded by the annual forage systems, in most cases, yield of a pea crop following forages was significantly higher than pea yield following wheat without herbicide, and did not differ from pea yield following the conventional herbicide treatment.

Annual forages had a similar effect on the weed community composition in the seedbank and the weed seedlings recruited in the pea crop in both trials. Annual forages affected the composition of the weed community much like a conventional herbicide treatment when weed pressure was moderate (trial 1), but when weed pressure was high (trial 2) most annual forages did not affect the weed community any differently than a weedy grain crop. In this experiment, annual forages were more strongly associated with broadleaf weed species, and the annual grain crops were more strongly associated with grass weed species.

A second experiment (experiment 2) investigated the effect of selected forage systems on weed density under conventional and zero tillage. The hypothesis was that annual forages will affect weed populations differently under zero tillage than under conventional tillage. In experiment 2, there was a significant interaction between previous crop type and tillage for green foxtail suggesting that annual forages such as sweet clover, fall rye and alfalfa control green foxtail better when zero tillage is used than when conventional tillage is used. Triticale did not control green foxtail better than wheat for either tillage system. There was no significant interaction for previous crop type and tillage for wild oat suggesting the forage suppressor crops controlled wild oat better than wheat in a herbicide-free environment regardless of tillage system used.

The results of these experiments indicate that annual forages may be a viable weed control option when used in the context of an IWM system.

Acknowledgements

I would like to thank Dr. Martin Entz for his vision, wisdom and timely "pep" talks throughout this study. I also thank my committee members, Dr. Anita Brule-Babel, Dr. Karin Wittenberg, and Dr. Rene Van Acker, for the time they took to guide me in this thesis. Thank you also to Keith Bamford for his wisdom and patience for my endless questions.

Thank you to the army of students who spent the summer on their knees counting weeds: Erin Friesen, Jason Watts, Marnie Hamill, Becky Dueck, Orla Nazarko, Brenda Tjaden, and Natasha Slobodian. Thanks also to fellow graduate students Steven Shirtliffe, Pam Ominski and Sangu Angadi for their help and making the experience so much more fun.

Most importantly I would like to acknowledge the "behind the scenes" help that I received from my Lord Jesus Christ, through whom I can do all things (Phillipians 4:13).

Table of Contents

List of Tables

List of Figures

1.0 Introduction

Prior to the advent of synthetic herbicides in the 1950s weed control was achieved predominantly by cultural control methods which included crop rotation, tillage and periods of fallow (Walker and Buchanan, 1982). Since the introduction of chemicals for weed control and synthetic sources of fertilizer nitrogen to replace legumes, dependence on and use of cultural control methods such as crop rotation has decreased (Walker and Buchanan, 1982; Gressel, 1989). Today, the Guide to Chemical Weed Control published by Manitoba Agriculture lists 80 herbicides and makes recommendation on their use for the control of many different agronomic weeds (Manitoba Agriculture, 1995).

Current weed control strategies often involve some combination of herbicide and tillage, however, zero tillage production systems are increasing in popularity. In a conventional tillage system weed control strategies focus on the use of broad spectrum herbicides that kill as many weeds as possible at a wide range of leaf stages (Derksen, 1995). Weed control is carried out via tillage operations in the autumn and spring followed by pre- or post- emergence herbicides for any further "in crop" weed control needed (Derksen, 1995). Conservation tillage, including minimum and zero tillage, has reduced or eliminated the option of tillage for weed control, while maintaining the use of chemical control. In addition, conservation tillage operations place a greater emphasis on pre-seeding herbicide application, thus, increasing the overall dependence on herbicides for weed control when compared to a conventional tillage system (Derksen, 1995).

Today there is renewed emphasis on using cultural methods for weed control because of increasing problems associated with heavy use of synthetic herbicides. Studies have shown that the recurrent use of herbicides with the same mode of action on wild oat populations has selected for resistance to those herbicides (Jana and Naylor, 1982; Heap et al., 1993). The problem has developed at a rapid pace due to the heavy reliance of these groups of herbicides for wild oat control. Modern weed control practices that rely heavily upon herbicides are also linked to non-point source pollution (Hatfield, 1996). Finally, Ghersa et al. (1996) stated that, in Argentina, the most important weed species continue to increase despite the efforts to control them via herbicides because herbicides only affect abundance of weeds at a patch scale for a short period of time.

Long-term weed control strategies based on an understanding of biological, ecological and economical processes that drive the cropping system are needed (Navas, 1991). Integrated weed management (IWM) has been defined as the application of numerous alternative weed control measures, which include cultural, genetic, mechanical, biological, and chemical means of weed control (Edwards and Regnier, 1989; Swanton and Weise, 1991).

An IWM system should include the following characteristics: 1) shift community dominance away from weeds and toward the crop, 2) minimize negative impacts of secondary succession due to disturbance, 3) understand and exploit population biology of crop-weed interactions, and 4) manage selection pressure in a manner that adverse shifts in the weed spectrum are avoided. In doing this, an IWM system will break the life cycle of the weed at some point in time and prevent the increase of the weed seedbank (Kropff et al., 1996).

The IWM production system encompasses the enhancement of crop competitiveness, alternative methods of weed control, the knowledge of the critical period of weed interference for the optimization of herbicide use, tillage system, crop rotation and its effect on seed bank dynamics (Swanton and Weise, 1991; Cussans, 1996).

Annual forages for feed production may serve as an alternative weed control measure that can be incorporated into an IWM system. In Manitoba, annual forages are grown on 68,200 ha and generate $13,090,000 a year (Anon., 1987). Annual forages can be managed in such a way that they have a competitive advantage over weeds, and they can be used with different tillage systems. When used in an IWM system, annual forages may help to shift community dominance away from the weeds, minimize the negative impacts of secondary succession, exploit population biology, and manage selection pressure. Annual forage systems may prevent weed seedlings from developing and producing seed, or they may prevent weed seeds from returning to the seedbank. Coble (1996) suggested that mowing of perennial forage crops is an effective weed control option.

Based on this, the objectives of the present research project were:

1) To determine how annual forage cropping systems without herbicides compare with a conventional weed management treatment (i.e. wheat sprayed with herbicides) in terms of weed management;

2) To determine how annual forage systems affect the density and species community composition of weeds in a subsequent crop;

3) To determine how annual forage systems affect the grain yield of a subsequent pea crop;

4) To determine how conventional tillage affects the weed suppression ability of annual forages when compared with zero tillage.

2.0 Literature Review

2.1 Weed Management

2.1.1 What is a weed?

Traditionally, the definition of a weed is very broad because it is based on the objectives and requirements of the individual that is making the evaluation (Navas, 1991). Definitions often encompass the undesirability of the plant in question (Holzner, 1982). Weeds are often described simply as a plant growing in the wrong place (Bunting, 1960). Because the decision to deem a plant a weed or not is based on subjective criteria, any plant in any ecosystem could potentially be a weed. Baker (1965) and Grime (1977) proposed that the definition of a weed involve plants found predominantly in habitats disturbed by humans. Navas (1991) proposed that a weed is: "a plant that forms populations that are able to enter cultivated habitats, markedly disturbed by man and potentially depress or displace the resident plant populations which are deliberately cultivated or are of ecological and/or aesthetic interest".

2.1.2 History of Weed Control on the Canadian Prairies

Prior to the advent of synthetic herbicides in the 1950s weed control was accomplished predominantly by cultural control methods which included crop rotation, tillage and periods of fallow (Walker and Buchanan, 1982). Crop rotation was the predominant weed control tool available to a producer. Since the introduction of chemicals for weed control and synthetic sources of fertilizer nitrogen to replace legumes, dependence on, and use of, cultural control methods such as crop rotation has decreased (Walker and Buchanan, 1982; Gressel, 1989).

By 1931, less than 30 years after its introduction to the Canadian prairies, wild oat (*Avena fatua* L.) occupied 85% of crop lands in this region (Banting, 1973). In terms of crop losses, wild oat is the most important weed species in cultivated land on the Canadian prairies (Jana and Naylor, 1982). In a continuous grain and fallow rotation, wild oat has been documented as the most "problematic" weed (Siemens, 1963). Long term crop rotation research at the Brandon Experimental Farm between 1911 and 1958, showed that rotations that included a short term (1 to 2 year) forage stand had less wild oat by weight in threshed grain than rotations which did not contain a forage (Siemens, 1963). A fallow-wheat-wheat rotation had 15% wild oat by weight in the threshed wheat (*Triticum aestivum* L.), whereas a hay-oat rotation had 0.5% wild oat by weight in the threshed oat (*Avena sativa* L.) crop, and a hay-hay-wheat rotation had 0.2% wild oat by weight in the threshed wheat crop.

By 1969, there were approximately 120 herbicides available to producers in the United States and Canada (Timmons, 1970). In Alberta, Saskatchewan and Manitoba, use of phenoxy herbicides increased nearly three-fold from 1954 to 1968, and the use of other herbicides increased more than eleven-fold between 1963 and 1968 (Timmons, 1970). The importance of wild oat increased the emphasis on the development of selective herbicides for this weed (Timmons, 1970), and between 1960 and 1963, three new herbicides were introduced to control wild oat in wheat, barley (*Hordeum vulgare* L.) and flax (*Linum usitatissimum* L.) (Banting, 1973). In 1977 and 1982, two more herbicides with improved efficacy on wild oat and action on other economically important weeds were introduced (Heap et al., 1993). The use of these herbicides increased rapidly. In 1977 more than 5.2 million hectares of crop land in Western Canada were treated with herbicides for the control of wild oat (Jana and Naylor, 1982). Today, the Guide to Chemical Weed Control published by Manitoba Agriculture lists 80 herbicides and makes recommendation on their use for the control of many different agronomic weeds (Manitoba Agriculture, 1997).

2.1.3 Current Weed Control Strategies

Producers in western Canada use tillage intensities ranging from conventional tillage to conservation tillage and zero tillage. The type of tillage system chosen will influence the methods of weed control used.

In a conventional tillage system weed control strategies focus on the use of broad spectrum herbicides that kill as many weeds as possible at a wide range of leaf stages (Derksen, 1995). Weed control is carried out via tillage operations in the autumn and spring followed by pre- or post- emergence herbicides for any further "in crop" weed control needed (Derksen, 1995).

Conservation tillage, including minimum and zero tillage, has reduced or eliminated the option of tillage for weed control, while maintaining the use of chemical control. In addition, conservation tillage operations place a greater emphasis on pre-seeding herbicide application, thus, increasing the overall dependence on herbicides for weed control when compared to a conventional tillage system (Derksen, 1995).

2.1.4 Concerns with Herbicides

Today, there is renewed emphasis on using cultural methods for weed control because of increasing problems associated with heavy use of synthetic herbicides. Studies have shown that the recurrent use of herbicides with the same mode of action on wild oat populations has selected for resistance to those herbicides (Jana and Naylor, 1982; Heap et al., 1993). Currently in Western Canada there are over 100 populations of wild oat that have been identified with herbicide resistance to group 1 herbicides (Morrison and Devine, 1994). The problem has developed at a rapid rate due to the heavy reliance on herbicides for wild oat control.

Modern weed control practices that rely heavily upon herbicides are linked to non-point source pollution (Hatfield, 1996). In the United States, at least 28 herbicides are possible contaminants of ground water, 39 herbicides and growth regulators have been proposed for inclusion in a drinking water survey, and 32 of these have been proposed for inclusion in a well survey (Schweizer, 1988). Atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] is a herbicide that is used extensively in the corn growing regions of Canada and the United States. Atrazine is one of the most commonly detected pesticides in groundwater in these regions, and losses of atrazine due to soil erosion can be significant, particularly during the period immediately after application (Pantone et al., 1992). However, due to the sandy nature of soils and heavy pesticide use, the threat for groundwater pollution by pesticides in the Assiniboine Delta Aquifer, Manitoba is relatively high (PFRA, 1992).

Finally, Ghersa et al. (1996) stated that the most important weed species continue to increase in Argentina despite efforts to control them via herbicides, thus, herbicides alone will not eradicate weed problems.

2.2 Weed Ecology

The study of the interaction between plants and the environment that they are in is known as plant ecology. Weed ecology is the study of the interaction between weed plants and the environment that they are in. Weed ecology needs to be considered when developing weed management systems.

A plant community is a collection of plant species that co-exist in a given environment. Plant communities are often characterized by a dominant species (Radosevich and Holt, 1984). Succession is the process of a plant community changing over time (Ghersa et al., 1996). If the microenvironment remains relatively constant over time, the changes in species composition are very slow or non-existent. Secondary succession is the process by which the plant community changes after a radical disturbance so that a new niche is available in the environment for colonization by plants. In agriculture, highly disturbed systems are common, and weeds are those plants that occupy the earliest stages of secondary succession. Annual weeds are r-strategists or ruderals. These are plants adapted to frequently disturbed habitats which have a short-life span and high reproductive capacity (Grime, 1977).

Gause's competitive exclusion principle states that two species cannot coexist permanently in the same niche (Radosevich and Holt, 1984). Thus, in a disturbed crop community, some degree of niche separation must occur in order for weed species to exist in conjunction with crop plants. If a crop plant were to occupy the entire niche, would this mean complete weed suppression? Although some crop plants are superior competitors to weeds, competition alone will not lead to weed extinction.

With these principles of plant ecology in mind, the objective of weed management should be to shift community dominance toward the crop species and away from the weed species (Radosevich and Holt, 1984).

2.2.1 Population Biology

A plant population is a group of individuals, usually within a species, that occupies an environment or habitat small enough to permit interbreeding within the group. Population biology, one branch of the science of ecology, looks at understanding the cause-effect relationships regulating the number of individuals in populations (Numata, 1982).

Weed species do not occur in monospecific stands. In fact, populations are composed of genotypically different, plastic individuals that are heterogenously distributed in space and time (van Groenendal, 1988; Navas, 1991; Jordan and Jannink, 1996). Individual plant populations within a field will have different susceptibilities to the weed control measures imposed upon them. The variability of weed populations will affect their evolutionary responses to selective pressures (i.e. weed control). This must be considered, therefore, when developing a weed management program (Navas, 1991).

There are four phases in the life cycle of a plant population: seedling recruitment in which weed seeds from the seedbank germinate and emerge, the production of dry matter, seed production, and seed rain (Medd and Pandey, 1993; Kropff et al., 1996). Considering these phases, there is one phase in which expansion of the population may occur, the seed rain phase, and four phases where there is potential for loss (Sagar, 1982). Control techniques that break the life cycle of weeds at some point in time will be valuable in developing strategies for weed management (Kropff et al., 1996). Weed control via herbicides focuses on reducing weed populations by increasing weed seedling mortality (Medd and Pandey, 1993).

2.2.2 The Weed Seedbank

The weed seedbank may be a critical feature in determining whether a population increases or declines (Harper, 1977). The flux of seed into and out of a unit of the seedbank determines the potential population of that unit (Norris, 1996). The number of individuals present as dormant propagules vastly exceeds the number of individuals present as growing plants. The weed seedbank may increase in size due to invading species, or via established and stabilized populations maintaining themselves (Harper, 1977). In theory, to reduce or exhaust the seedbank one must simply stop seed production (Forcella et al., 1996; Norris, 1996). However, in reality this is not feasible because no control measure will prevent all seed production. Some scientists suggest that even allowing a single weed to set seed is "detrimental to long-term farm economics" (Forcella et al., 1996).

The focus of weed control strategies should be on weed management as opposed to weed eradication. Forcella et al. (1996) suggested that the timing and manipulation of common soil and crop management practices can regulate the weed seedbank. Weed infestations arise from the weed seedbank and changes in management practices should result in a change in observed weed flora (Ball, 1992). However, because of the buffering effect of the weed seedbank the changes in management must be significant in order to observe a change in weed flora (Roberts, 1963 ; Harper, 1977; Darmency and Aujas, 1987).

2.2.3 Selection Pressure

The genetic structure of plant populations within cultivated fields is a function of the management practices imposed on those populations (Ball, 1992; Darmency and Aujas, 1987; Derksen, 1995). Management practices such as tillage, crop rotation and herbicide application impose a selective pressure on weed populations within a field. This selection pressure will influence the composition and amount of weed seeds in the weed seedbank. Jordan and Jannink (1996) stated that there is abundant evidence that weeds are capable of adapting to all types of weed control measures.

The following examples illustrate how crop production systems apply selection pressure to weed populations. The approach to weed management in a zero-tillage system involves a pre-seeding herbicide application, as well as an early in-crop herbicide application. Under this system, weed control takes place within a four to six week period early in the growing season. This approach to weed management has selected for weeds that emerge after the in-crop herbicide treatment (Derksen, 1995). When inversion tillage is used in a conventional tillage system, weed seeds are buried deeper in the seedbank than when non-inversion tillage is used (Ball, 1992). Seeds buried in the soil have a greater longevity than seeds near the surface and can prolong weed infestations over several growing seasons (Ball, 1992; Roberts, 1963; Roberts and Dawkins, 1967).

Cropping sequence has the most dominant effect on the size and composition of the weed seedbank in the long-term because it affects the timing and type of tillage and the herbicides used (Ball, 1992). Several workers have reported weed species selection due to crop rotation (Johnson and Coble, 1986; Hume et al., 1991). Darmency and Aujas (1986) reported a shift toward vernalization requiring wild oat in populations growing under continuous winter crops in Europe. In another example of crop rotation applying selection pressure, Schoner et al. (1978) found prostrate forms of yellow foxtail (*Setaria glauca* (L.) Beauv.) in alfalfa (*Medicago sativa* L.) fields in California. The prostrate growth habit was selected for by the frequent cutting regimes practiced in the alfalfa production system.

Herbicide use also affects the size and composition of the weed seedbank. Roberts and Neilson (1981) reported that herbicides used in maize (*Zea mays* L.) and carrots (*Daucus carota* L.) had little effect on species composition within the seedbank, but that weed populations in the seedbank where herbicides had been used were smaller than where no herbicides were used. However, where herbicides are used continually, weed selection will be in favour of species that are less susceptible to applied herbicides (Jana and Naylor, 1982; Ball, 1992; Heap et al., 1993).

A preventative approach to weed control would be to design agricultural systems that impede weed adaptation to weed management via increased diversity and varying selection pressures in the system (Jordan and Jannink, 1996; Swanton and Murphy, 1996).

2.3 Integrated Weed Management

Long-term weed control strategies based on an understanding of biological, ecological and economical processes that drive the cropping system are needed (Navas, 1991). Integrated weed management (IWM) has been defined as the application of numerous alternative weed control measures, which include cultural, genetic, mechanical, biological, and chemical means of weed control (Edwards and Regnier, 1989; Swanton and Weise, 1991).

Based on the information in the previous section on weed ecology, an IWM system should include the following characteristics: 1) shift community dominance away from weeds and toward the crop, 2) minimize negative impacts of secondary succession due to disturbance, 3) understand and exploit population biology of crop-weed interactions, and 4) manage selection pressure in a manner that adverse shifts in the weed spectrum are avoided. In doing this, an IWM system will break the life cycle of the weed at some point in time and prevent the increase of the weed seedbank (Kropff et al., 1996).

The IWM production system encompasses the enhancement of crop competitiveness, alternative methods of weed control, knowledge of the critical period of weed interference for the optimization of herbicide use, tillage system, crop rotation and its effect on seed bank dynamics (Swanton and Weise, 1991; Cussans, 1996).

2.3.1 Enhancement of Crop Competitiveness

An IWM system should enhance the competitive ability of the crop to suppress weed growth (Swanton and Weise, 1991). Improved crop competitiveness may have its greatest affect on seedling recruitment and will shift community dominance toward the crop (Kropff et al., 1996).

Choosing crops that are inherently more competitive is one approach for improving crop competitiveness (Walker and Buchanan, 1982). Van Heemst (1985) ranked 25 different crops for their competitiveness with annual weeds. For instance, van Heemst (1985) ranked barley a better competitor than wheat, which was ranked a better competitor than flax. Pavlychenko and Harrington (1934) also ranked wheat a better competitor with weeds than flax.

Cropping practices which promote rapid and uniform crop establishment will also enhance its competitive ability against weeds (Swanton and Weise, 1991). In an experiment by O'Donovan et al. (1985), the percent yield loss in barley and wheat was greater when wild oat emerged earlier than the crop, as opposed to when wild oat emerged later than the crop. Seeding the crop so that it emerges ahead of the weeds will enhance its competitive ability. Alternatively, research has shown that late seeding of crops three years out of six reduced wild oat populations by 86.7% (University of Manitoba, 1968).

Crops grown in narrower rows compete better with weeds due to a more rapid canopy closure and better root distribution (Legere and Schreiber, 1989). Thurston (1962) reported that the effectiveness of winter rye (*Secale cereale* L.) and winter wheat (*Triticum aestivum* L.) in reducing wild oat populations depended on the crop density at the time of wild oat germination in spring. The more dense crop canopy, the better these cereal crops competed with emerging weeds.

Because crops and weeds compete for soil nutrients, fertilizer placement to optimize nutrient supply to the crop, and minimize nutrient supply to weeds will enhance the competitive ability of the crop (Swanton and Weise, 1991). Hume (1982) found an increase in green foxtail (*Setaria viridis* (L.) Beauv.) density and dry weight when grown in plots that had been fertilized as opposed to plots that received no fertilizer. Similarly, Dhaliwal and Froud-Williams (1993) found that barley grain yield was reduced to a greater extent when fertilized with 120 kg N/ha than at 0 kg N/ha and wild oats produced more vegetative biomass at 120 kg N/ha. These examples underscore the need for selectively banding fertilizers close to the crop row to increase accessibility by the crop and decrease accessibility by the weed plants so that crop competitiveness is enhanced.

2.3.2 Alternative Methods of Weed Management

Alternative weed control methods are defined as those involving methods other than herbicides in this document. Cover crops and biological control are two examples of alternative weed control methods to herbicides. Alternative methods of weed management can shift community dominance to the crop, reduce niche availability to the weeds, manage selection pressure and exploit population biology of weeds.

Crops sown into another standing crop, or into stubble after previous crop harvest are known as cover crops or living mulches (Edwards and Regnier, 1989; Swanton and Weise, 1991). Cover crops compete with weeds and prevent seedling recruitment, and if the cover crop is incorporated into the soil it may prevent viable weed seeds from returning to the seedbank. In a zero-tillage production system, where rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth.) cover crop residue biomass exceeded 300 g/m^2 and covered more than 90% of the soil, total weed density was reduced an average of 78% compared to the treatment without cover crop (Teasdale et al., 1991). Teasdale et al. (1991) also suggested that allelopathy may have contributed to the weed suppression effects of the cover crop residue. Putnam et al. (1983) reported up to 95% control of "important agroecosystem weeds" for 30 to 60 days following desiccation of rye, wheat, sorghum (*Sorghum bicolor* (L.) Moench), or barley cover crops. The use of cover crops in dry regions may be limited due to limited availability of moisture. Rice et al. (1993) reported that when alfalfa and Tangier flatpea (*Lathyrus tingitanus* L.) were incorporated into the soil late in the growing season there was 2-3 cm less water in the soil profile than when following summerfallow or early-incorporated lentil (*Lens culinaris* Medikus) and

Tangier flatpea. Reduced weed growth, therefore, may be partly attributed to less soil water.

Biological control of weeds incorporates the use of natural enemies, insects or fungi, to reduce weed populations or suppress their growth (Watson, 1989). Classical biological control, often involving insects, perpetuates itself in the environment for continuous control. The release of the insect *Cactoblastus cactorum* on prickly pear (*Opuntia opuntia*) in Australia is an example of classical biological control (Edwards and Regnier, 1989). Inundative approaches to biological control used predominantly on annual crops. Fungi for biological control can be applied in a similar manner as herbicides, and are often referred to as mycoherbicides. Biomal™ for the control of round-leaved mallow (*Malva pusilla* Sm.) is an example of a mycoherbicide.

2.3.3 Optimization of Herbicide Use

Herbicides are used on seedling weeds to prevent growth as well as seed production and seed rain. The length of time that weed control must be maintained to prevent yield loss, and the length of time that weeds can remain in the crop before they interfere with growth and ultimately reduce yield are components of the critical period of weed interference (Weaver, 1984). Knowledge of the critical period of weed interference with the crop will allow a producer to optimize herbicide use and incorporate alternative methods of weed control into the production system (Swanton and Weise, 1991). The length of these periods will vary depending on the crop type (Burnside and Wicks, 1969). For example, Weaver (1984) found that cabbage (*Brassica oleracea* L.) required a 3 week weed-free period after transplanting. Also, yields were reduced if weeds that emerged with the crop were allowed to remain for 4 to 5 weeks. In the same study, cucumber (*Cucumis sativus* L.) yields were reduced if plots were not kept weed free for up to 4 weeks after seeding, or if plots remained weed infested longer than 3 to 4 weeks

(Weaver, 1984). Chancellor and Peters (1974) found that there were significant reductions in wheat and barley grain yield only when wild oat populations were greater than 150 stems/m^2, and no significant yield reductions were found when stem densities were at 20 to 100/m^2. Chancellor and Peters (1974) also found that where there was a reduction in yield, competition from the wild oat did not begin until the 4 leaf stage which was 4 to 5 weeks after wild oat emergence. Bowden and Friesen (1967), however, suggested that competitive damage by wild oat may precede crop emergence. Further experimentation by Chancellor and Peters (1974) acknowledged that at high weed densities, competition may occur earlier than 4 to 5 weeks.

Information of the critical period of weed interference can potentially reduce the need for continuous control with herbicides, and optimize the dose and timeliness of herbicide application (Swanton and Weise, 1991). Medd and Pandey (1993) reported that conventional herbicide application for weed seedling control resulted in a two to six fold increase in wild oat population, but that when repeated in-crop applications were used to obtain seed kill, the existing wild oat population was contained. O'Donovan (1988) suggested that models may aid in the efforts to reduce herbicide use, but that omission of herbicides in some years will increase dependence on herbicides in subsequent years. In continuous barley, wild oat herbicide application every other year provided the best economic returns, whereas in wheat, wild oat herbicide application was needed every year to provide the best economic returns (O'Donovan, 1988).

2.3.4 Tillage Systems

Tillage system may reduce weed problems by affecting secondary succession, and managing selection pressure. In conservation tillage systems there may be an increased reliance on herbicides for weed control, however, Swanton and Weise (1991) hypothesized that there is potential for a greater reduction in herbicide use under no-till systems if an IWM system is implemented. The potential for a greater reduction in herbicide use under no-till systems can be attributed to changes in the population dynamics of seedbanks under IWM.

Seeds of many weed species can remain viable in the weed seedbank for long periods of time when left undisturbed (Roberts, 1964). Seed buried in the soil can remain viable longer than seed situated near the soil surface (Roberts, 1964; Roberts and Dawkins, 1967). Persistence of weed seeds in the seedbank will influence the potential of a weed to cause infestations and economic loss in the long-term (Ball, 1992).

Blackshaw et al. (1994) reported that under various crop rotations, zero-tillage plots had more weeds and a different species composition than minimum or conventional tillage plots. Dandelion (*Taraxacum officinale* Weber in Wiggers), perennial sow thistle (*Sonchus arvensis* L.), redroot pigweed (*Amaranthus retroflexus* L.) and Russian thistle (*Salsola iberica* Sennen & Pau) increased under minimum and zero-tillage, while flixweed (*Descurainia sophia* (L.) Webb. ex Prantl), field pennycress (*Thlaspi arvense* L.), wild buckwheat (*Polygonum convolvulus* L.) and common lambsquarters (*Chenopodium album* L.) decreased under minimum and zero-tillage (Blackshaw et al., 1994). Hume et al. (1991), on the other hand, found that red root pigweed was at the highest densities under conventional tillage. They reported that in southwestern Saskatchewan foxtail barley (*Hordeum jubatum* L.) can not be effectively controlled in a zero till system due to a lack of effective herbicides.

The tillage system chosen will affect the weed community and the IWM system needed for weed control. Derksen (1995) suggested that reduced herbicide usage in zero-tillage systems can be achieved by selectively using pre-seeding burn-off, in-crop, pre-harvest, and post-harvest herbicide options in conjunction with other components of an IWM system. In doing this, a producer will avoid the selection of weeds with particular emergence habits.

2.3.5 Crop Rotation

The composition and density of weed seeds in the weed seedbank are a reflection of the long-term crop rotation and management systems imposed upon them (Swanton and Weise, 1991). Ball (1992) and Derksen et al. (1996a) stated that cropping sequence is the most dominant factor influencing species composition in the seedbank. Ball attributed this to the influence of cropping sequence on the tillage system and herbicide chosen (Ball, 1992). Derksen et al. (1996a) stated that crop rotation had a greater effect on weed communities than did tillage system. Crop rotation has the potential to affect any one of the four phases in the weed life cycle and hence will have its ultimate effect on the weed seedbank.

Previous research has shown that weeds present a major problem under continuous cropping systems, and that crop rotations can reduce the weed population considerably (Ball, 1992; Blackshaw et al., 1994; Hume et al., 1991; Roberts and Neilson, 1981). Blackshaw et al. (1994) reported fewer weeds in winter wheat-fallow than in continuous winter wheat rotation. Summerfallow for weed control is not a viable option due to negative effects on soil quality. Roberts and Neilson (1981) reported that in the absence of herbicides, continuous cropping of maize or carrots increased the viable weed seedbank. Green foxtail, thyme-leaved spurge (*Euphorbia serpyllifolia* Pers.), vetch (*Vicia* spp.) and Canada thistle (*Cirsium arvense* (L.) Scop.) were found to be more abundant in continuous wheat compared to wheat-fallow (Hume, 1982). Derksen et al. (1996) suggested that weed communities can be "managed" by varying the selection pressure through the use of crop rotation.

Crops with an allelopathic effect may be used in rotation to enhance weed suppression. Living crops or cover crop residues can be used to interfere with the growth of surrounding weeds (Weston, 1996). Some crops that have been shown to have allelopathic effects on weeds are rye, wheat, buckwheat (*Fagopyrum esculentum*

Moench), black mustard (*Brassica nigra* (L.) Koch), and sorghum-sudangrass (*Sorghum bicolor* (L.) Moench x *S. sudanese* (Piper) Stapf) (Weston, 1996).

2.4 Forages

A considerable amount of research has been conducted on the role of forages in weed management.

Thurston (1966) proposed that cutting or grazing a ley frequently during the growing season will prevent seed production by wild oat so that the population would be depleted by their germination or death. In two field experiments, where the survival of wild oat seeds under a 5 year ley was tested, the number of wild oat seeds decreased by 41% and 86% in one year, respectively. There was little subsequent decrease in wild oat seed in either experiment over the next four years suggesting that a one year ley was as effective at reducing the number of wild oat seeds as a five year ley. However, other weed species did not respond to the ley as favourably as wild oat. For example, germination of charlock (*Sinapsis arvensis* L.) under the ley system fluctuated erratically between years (Thurston, 1966). Wilson and Phipps (1985) reported findings similar to Thurston (1966) in an experiment where wild oats were seeded at a rate of 373/m^2. After three years of a grass ley, they found an average of 2 wild oat seedlings /m^2, and an average of 22 seedlings/m^2 in the subsequent wheat crop after six years of grass ley.

Wilson and Phipps (1985) considered the effect of barley silage on populations of wild oat. They found that with no new seeding of wild oat, three years of barley cut for silage exhausted the weed seedbank by preventing return of new seeds to the seedbank. They also found that where herbicide or tillage was used in winter wheat and spring barley for wild oat control, the wild oat population shed enough seed to maintain itself. Therefore, annual forage production provided greater wild oat control than either fall-sown crops or tillage. As mentioned earlier, in long term crop rotation research at the

Brandon Experimental Farm between 1911 and 1958, rotations that included a short term (1 to 2 year) forage stand had less wild oat by weight in threshed grain than those without a forage crop (Siemens, 1963). In the same study, a fallow-wheat-wheat rotation had 15% wild oat by weight in the threshed wheat, whereas a hay-oats rotation had 0.5% wild oat by weight in the threshed oats, and a hay-hay-wheat rotation had 0.2% wild oat by weight in the threshed wheat.

In her study, Thurston (1962) also considered the effects of winter wheat, winter rye, and winter barley (*Hordeum vulgare* L.)on the germination and growth of wild oat. She found that wild oat population density was suppressed, and plant size reduced by winter cereals, provided that crop density was adequate (not below 243 plants/m2) when wild oat germinated in spring. However, even the best wild oat suppression by winter wheat and winter rye crops resulted in enough wild oat seed production to maintain the wild oat population (Thurston, 1962). Cousens et al. (1991) studied the effects of competition on wild oat, winter wheat and winter barley when grown in a mixture. They found that prior to anthesis the most abundant species in the mixture were the grain crops, however, at and beyond anthesis the most abundant species in the mixture was wild oat. Although wild oat seedling mass was initially smaller than crop seedling mass, they have a higher net assimilation rate which enables them to grow faster than either winter barley or winter wheat (Thurston, 1962; Cousens et al., 1991). For this reason Thurston (1962) attributed the success of winter cereals at controlling wild oat to their density in spring when wild oat was germinating.

In an experiment in Belarus, Tereshchuk (1996) showed that weed density in barley was greatest after flax, followed by annual grasses for forage, perennial grasses for forage and winter cereals.

2.4.1 Role of Annual Forages in Canadian Prairie Cropping Systems

Annual forages for feed production may serve as an alternative weed control measure that can be incorporated into an IWM system. It is estimated that in Manitoba, annual forages are grown on 68,200 ha and generate $13,090,000 a year (Anon., 1987).

Annual forages offer flexibility to a producer as they only occupy the land for one year and provide a return in the year of establishment. There is reduced risk of establishment failure compared with perennial forages such as alfalfa. Also, there is flexibility in decision making. A producer may decide to graze early growth and allow the crop to recover to harvest grain growth, or the decision whether to harvest for hay or grain may be delayed depending on grain market conditions and feed requirements (Anderson, 1994). Ensiled cereal crops offer a high yielding, reliable source of forage for overwintering cattle in Western Canada (McCartney and Vaage, 1994). Grazing an annual forage can allow a producer to get more use out of a piece of land (Baron et al., 1992). There are many alternatives available. A producer can choose a legume-cereal mixture, a spring planted winter cereal, a spring cereal, or a mixture of both (Berkenkamp and Meeres, 1987; Baron et al., 1992; Jedel and Helm, 1993).

2.4.2 Role of Annual Forages in IWM

Annual forage systems involve two components, the forage crop itself, and forage crop management (egs. seeding, harvest). Two mechanisms that limit weeds in an ecosystem are competition with other plants for nutrients, water, etc., or disturbance that partially or totally destroys plant biomass (Grime, 1977). Annual forages suppress weed populations using both mechanisms. For example, annual forages apply a competitive stress on weeds thereby limiting weed growth. Annual forages, because of the whole plant harvest will partially or totally destroy weed biomass, thereby preventing direct return of weed seeds to the soil. Jones et al. (1996) found cutting annual grass and broadleaf weeds in the vegetative stage at the soil surface was an effective means to control them. Furthermore, they found a reduction in weed biomass of 46 to 82% when weeds were cut 1 cm above the soil surface. Powles and Matthews (1996) found that catching weed seeds at harvest in conjunction with other control measures was an effective means to manage herbicide resistant annual ryegrass (*Lolium rigidum* Gaud.).

Annual forage crops may be an alternative weed control measure to herbicides and may be used in conjunction with other IWM tools. Annual forages can be a part of a producer's crop rotation, they can be managed in such a way that they have a competitive advantage over weeds, and they can be used with different tillage systems. When used in an IWM system, annual forages may help to shift the community dominance away from the weeds, minimize the negative impacts of secondary succession, exploit population biology, and manage selection pressure. Annual forage systems may prevent weed seedlings from developing and producing seed, or they may prevent weed seed return to the seedbank. Coble (1996) suggested that mowing of perennial forage crops could be an effective weed control option.

2.4.2.1 Alfalfa

Non-winter hardy varieties of alfalfa (*Medicago sativa* L.), known as annual varieties of alfalfa, have been developed for the purpose of a one year hay source, and as a fall plough-down green manure crop (Barnes et al., 1988). Annual alfalfa varieties can be seeded alone or with a companion crop. When seeded alone without the use of herbicide, the alfalfa forage yields are less (Moyer, 1985), but total forage yield (alfalfa + weeds) and returns over costs are greater when seeded alone without the use of herbicides (Sheaffer et al., 1989). Alfalfa forage quality is superior when alfalfa is established with the use of herbicides (Temme et al., 1979). Bell (1993) reported that alfalfa yield, where alfalfa was established without the use of herbicides, consisted of 75% weeds at the first harvest, 15% at the second harvest, and 0% at the third harvest. Total forage yield at first harvest was higher for alfalfa established without herbicide than for alfalfa established with herbicide due to the presence of weeds. Alfalfa yields and "weediness" were the same for both treatments at fourth and subsequent harvests.

The most economical harvest system for the annual alfalfa variety "Nitro" consists of frequent harvest during the summer of the seeding year and again in the autumn at approximately the time of the first killing frost (Sheaffer et al., 1989). The roots and crowns are then to be incorporated into the soil.

A single year alfalfa crop may be a valuable tool for weed control because weeds will be removed prior to seed shed thereby preventing weed seed rain. A considerable amount of research has shown that perennial alfalfa stands can effectively control weeds. Hodgson (1958) reported that alfalfa, when mowed twice a year, can effectively eliminate Canada thistle. Alfalfa emerges earlier than Canada thistle in the spring, forming a competitive cover, and recovers faster after mowing than Canada thistle (Hodgson, 1958). Harvey and McNevin (1990) reported that wild-proso millet (*Panicum miliaecum* L.) seedling populations were reduced, and corn yields increased when corn followed 1 to 4 years of alfalfa. They further reported that the effectiveness of herbicides in corn increased after cropping with alfalfa because of reduced numbers of viable millet seed in the soil.

2.4.2.2 Sorghum-Sudangrass

Sorghum-sudangrass (*Sorghum bicolor* (L.) Moench x *S. sudanese* (Pipier) Stapf), a C_4 cereal crop, is used as a source of summer feed and can fit well into livestock forage programs (Forney et al., 1985). Sorghum-sudangrass can supplement cool season forages that decrease in productivity in the hotter parts of summer (George et al., 1971).

Sorghum-sudangrass can be harvested for hay or grazed. However, Clapp and Chamblee (1970) reported that reductions in sorghum-sudangrass regrowth yields were observed when the plants were defoliated to 8 cm as compared with 25 cm. Edwards et al. (1971) reported that dry matter digestibility of sorghum-sudangrass plants decreased from 90% when plants were harvested at 30 cm, to 60% when plants were harvested at 250 cm tall. Cunningham and Ragland (1971) compared a sorghum-sudangrass hybrid with sudangrass and found that although grazing cows had no preference between the two forages, they did prefer sorghum-sudangrass when it was shorter, and trampling damage was more severe in the sorghum-sudangrass due to the brittleness of its thicker stems. They also found that while use of the two forages resulted in similar milk production, cow weight gain was greater for sudangrass resulting in more consistent milk production. It would appear that sorghum-sudangrass is more amenable to being cut for hay as opposed to grazing, and that care in management must be taken to maintain quality.

Dry matter yields of sorghum-sudangrass can reach 12 tonnes/ha or more (George et al., 1971). The requirement of N and P for an intensively managed crop is high, and there is a risk of nitrate and cyanide toxicity problems associated with feeding sorghum-sudangrass (Gillingham et al., 1969; George et al., 1971). Environmental conditions that decrease dry matter production will allow nitrate accumulation (George et al., 1971). McCreery et al. (1966) suggested split applications of N will give optimum yields and prevent nitrate toxicity.

The role of allelopathy for weed control in agriculture has received greater attention in recent years. Forney and Foy (1985) tested sorghum-sudangrass for its phytotoxic activity. They found that in a filter-paper-disk bioassay, seedling root length of alfalfa, johnsongrass (*Sorghum halepense* (L.) Pers.), and common lambsquarters was inhibited 67%, 40%, and 37% respectively by sorghum-sudangrass.

There are a number of instances where researchers have identified weed control benefits of sorghum-sudangrass. In Virginia, sorghum-sudangrass has been used in rotation with corn to reduce johnsongrass infestations (Forney et al., 1985). Burnside and Wicks (1969) reported that when sorghum was grown at a 50 cm row spacing, as compared to a 100 cm row spacing, grain and stover yields were increased and weed dry matter yields were decreased. In their experiment,, the most severe weed competition occurred up to 30 days after planting, and after this any weeds that emerged had little effect on yield (Burnside and Wicks, 1967). Bebawi and Mutwali (1991) observed that small seeded sorghum-sudangrass hybrids could control the parasitic witchweed (*Striga hermonthica* (Del.) Benth) provided that plants were harvested at the boot stage for the first harvest and at maturity for later harvests. When investigating the potential for use of sorghum-sudangrass as a cover crop in tree nurseries, Geneve and Weston (1988) found that growth of Eastern redbud (*Cercis canadensis* L.) seedlings was significantly reduced when co-cultivated with living sorghum-sudangrass or when sorghum-sudangrass leaf material was incorporated into the growing medium. These observations suggest a competitive as well as allelopathic effect of sorghum-sudangrass on weeds.

On the Canadian prairies, sorghum-sudangrass is seeded later than most of the cool-season crops typically grown because it is a warm-season crop. Therefore, prior to later seeding, weed control via herbicide or tillage should take place for good establishment of the crop. Because of this late weed control, the initial flush of many weeds is removed. If the sorghum-sudangrass crop establishes well, its dense canopy will compete with any late emerging weeds and prevent them from producing seeds. Forney et al. (1985) evaluated a sorghum-sudangrass hybrid for its weed suppression effects when grown as annual forage prior to no-till seeding of alfalfa. They found that the sorghum-sudangrass hybrid outyielded existing weeds in the plots and enhanced the subsequent establishment of alfalfa.

2.4.2.3 Triticale

Triticale (*Triticosecale*) is a small grain cereal originally developed for human consumption by crossing wheat (*Triticum* spp.) with rye (*Secale* spp.) (Brown and Almodares, 1976; Goonewardene et al., 1994). The cross was made to obtain the quality and productivity of wheat and the vigour and hardiness of rye. There are both spring and winter types of triticale. Triticale is used extensively for whole plant silage and greenfeed on the Canadian prairies (Baron et al., 1992), and has been fed successfully to cattle as grain (ZoBell et al., 1992). To ensile these plants, they are generally harvested from the late milk to early dough stages. There is also potential to graze spring planted winter types of triticale (Baron et al., 1992).

Spring planted winter cereal crops either grown alone or intercropped with a spring cereal have the potential to greatly extend the grazing season (Baron et al., 1994). Winter triticale will continue to grow in the fall months when other pasture grasses have ceased growing, and may offer four to five harvests in one growing season (Baron et al., 1990). Intercropping of spring and winter types of triticale can be used to take advantage of the differing peak production times of each crop to provide even availability of grazing throughout the season (Agriculture Canada, 1992).

Triticale can be managed in different ways. Berkenkamp and Meeres (1987) found that spring triticale yielded highest when harvested as silage, yielded lowest when harvested as pasture, and yielded in between when harvested as hay. When a spring cereal monocrop, spring planted winter cereal monocrop and a spring and winter cereal intercrop were compared it was found that yield was greatest for the intercrop, followed by the winter monocrop and then the spring monocrop (Baron et al., 1993a). Forage quality was greatest for the winter monocrop, followed by the intercrop and then the spring monocrop (Baron et al., 1992), and seasonal yield distribution was superior for the intercrop when compared to both the winter and spring monocrops (Baron et al., 1993b).

Quality of triticale has been evaluated for growing steers and lactating cows. ZoBell et al. (1992) found that steers fed a mixture of barley grain and triticale silage had similar average daily weight gain, dry matter intake and feed efficiency as steers that were fed a mixture of barley grain and barley silage. They concluded that triticale silage can be used to replace barley silage at moderate levels in growing steer rations that contain barley grain. However, when Fisher (1972) compared triticale silage with corn silage for lactating Holstein cows, silage dry matter intake, milk yield and protein content, and digestibility of dry matter was greater for corn silage. Brown and Almodares (1976) reported that yield and quality of triticale hay is comparable to oats and wheat, and that while rye produced more forage than triticale, it was of lower quality later in the growing season.

Recall that Wilson and Phipps (1985) found that with no new seeding of wild oat, three years of barley cut for silage exhausted the weed seedbank of wild oat by preventing return of new seeds to the seedbank. They also found that where herbicide or tillage were used in winter wheat and spring barley for wild oat control, the wild oat population produced enough seed to maintain itself. Therefore, annual forage production provided greater wild oat control than winter crops or tillage. Triticale forage could potentially reduce weed populations in the same manner as barley forage.

2.4.2.4 Fall Rye

Fall rye (*Secale cereale* L.) is a versatile forage as it can be seeded in spring or fall and used for pasture or harvested as a forage grain or silage (McLelland, 1988). Spring planted fall rye plants will not produce a spike and can be grazed, and will extend the grazing season because they will continue to grow when perennial forages have stopped (Baron et al., 1994). Rye is the most cold hardy of the small cereal grains, and it can provide pasture as early in the season as crested wheatgrass (*Agropyron cristatum* (L.)

Gaertn.). However, unlike crested wheatgrass, rye continues to produce throughout the summer and into the fall (Baron, 1995).

Fall rye can be managed in different ways. Fall seeded fall rye can be used for fall or spring grazing and still produce a grain crop (Agriculture Canada, 1992). Grazing fall rye will reduce subsequent grain yield, however, the benefits of increased pasture may outweigh this grain yield loss (Kilcher, 1982). Spring seeded fall rye can be grazed when it reaches 15 cm, and cattle should be removed at 7.5 cm (Agriculture Canada, 1992). In an experiment by Berkenkamp and Meeres (1987), spring seeded fall rye yielded highest when taken for hay, followed by pasture and then silage. When cut at the proper stages, the quality of fall rye for hay and silage are similar to other cereals (Agriculture Canada, 1992). Fall rye should be cut at the heading to early dough stage for silage, and at the boot to heading stage for hay. When allowed to mature, there is the potential for ergot bodies to form in the rye heads and these can be toxic to cattle.

Fall rye exerts excellent weed competition on spring annual weeds such as wild oat and green foxtail and can reduce herbicide use (Agriculture Canada, 1992). In her study, Thurston (1962) considered the effects of winter wheat, fall rye, and winter barley on the germination and growth of wild oat. She found that wild oat population density was suppressed, and plant size reduced by winter cereals, provided that crop density was adequate (not below 243 plants/m2) when wild oat germinated in spring. Fall rye also provides weed suppression through allelopathic mechanisms. It has been shown that fall rye residues are particularly phytotoxic to annual broadleaf weeds (Weston, 1996).

2.4.2.5 Sweet Clover

Sweet clover (*Melilotus* sp.) is a biennial forage legume crop that can be used as hay, pasture, silage or for soil improvement (Walster, 1924; Christensen and Hopper, 1938). Walster (1924) stated that sweet clover is most useful for soil improvement where it can be used as a summerfallow substitute, cover crop or green manure plough down (Foster and Austenson, 1990). Sweet clover is also useful as a pasture crop for cattle, horses and sheep, but is very limited in its potential for use as a hay crop (Walster, 1924). Alternatively, Foster and Austenson (1990) stated that sweet clover can be used for high quality forage and seed production provided that moisture is not limited. It is interesting to note that sweet clover was legislated against as a noxious weed in the United States prior to its adoption as an agricultural crop (Walster, 1924).

Christenson and Hopper (1938) reported that sweet clover silage (bud to full bloom stage) and hay crops (early bloom) were comparable with alfalfa hay in percentage of digestibility, digestible nutrients, and metabolizable energy. Sweet clover silage, however, had higher digestible crude protein content.

In the Northern Great Plains, a farmer will seed sweet clover in April or May typically with a companion crop (Walster, 1924). Ordinarily, in this region it is not possible to take a hay crop from sweet clover until the second year (Walster, 1924). Graber (1927) stated that sweet clover can be grazed lightly in the year of establishment provided that it is not overgrazed because this can result in high mortality of plants and weakened growth of surviving plants in the next year. Garber et al. (1934) reported that sweet clover cut the same year as it is seeded reduces the yield of hay in the second year, although the total yield from both years is higher than if it were only cut in the second year. Legume crops such as sweet clover can use 10-25% more seasonal water than wheat which may result in depressed yields for subsequent crops in drier growing regions (Foster and Austenson, 1990). Earlier incorporation of sweet clover, when used as a green manure plough down, can lessen drought effects of sweet clover (Foster and Austenson, 1990).

Graber (1927) noted the potential for use of sweet clover pasture to extend the grazing season. Graber (1927) stated that sweet clover, like fall rye, can produce early spring pasture which will make possible the avoidance of heavy grazing of permanent pasture grasses at premature stages of development.

The competition exerted by sweet clover in the establishment year, and its early spring growth in the second year may make sweet clover a valuable weed suppression tool. However, management of the sweet clover stand will affect its ability to suppress weeds. Garber et al. (1934) stated that weeds are most likely to be troublesome in sweet clover if the stand is cut in the same season it is seeded. Major plantain (*Plantago rugelii*), sheep sorrel (*Rumex acetosella* L.), and white top (*Cardaria* spp.) were present in sweet clover plots cut in the year of establishment, but were entirely absent in plots that were not cut the first year (Garber et al., 1934). Foster and Austenson (1990) also suggested that the inclusion of the biennial sweet clover in a wheat rotation will allow more opportunity for cultural weed control either before seeding, during forage harvesting or after harvest.

2.4.2.6 Weed Fallow

A producer may allow weeds to emerge and then remove them via herbicide, tillage, or mowing to prevent weed seeds from returning to the seedbank. This is known as a weed fallow.

There is potential to feed the harvested material from a weed fallow to livestock. Research has been conducted to determine the nutritive quality of several annual weed species, and their effect on the quality of forages. Vengris et al. (1953) considered the chemical composition of 9 different annual weeds including red root pigweed, lambsquarters, smartweed (*Polygonum pensylvanicum* L.) and barnyardgrass (*Echinochloa crusgalli* (L.) Beauv.). They concluded that these weeds harvested at different development stages (ranging from vegetative to bud stage) had a high content of minerals and protein, and as long as they are palatable, should not be overlooked as a potential forage. Marten and Anderson (1975) also studied the forage nutritive value of 12 common annual weeds at early stages of development and their palatability to sheep. They found that redroot pigweed, common lambsquarters, and common ragweed (*Ambrosia artemisiifolia* L.) had nutrient composition and digestibility levels comparable to alfalfa, and that giant foxtail (*Setaria faberi* Herrm.) and smartweed were less digestible than alfalfa. The grass weeds tested had higher acid detergent fibre and lower crude protein levels than alfalfa. Ten of the weed species were more digestible than oats, 9 contained more crude protein than oats, and all of the weed species contained adequate minerals to meet the requirements of ruminants. If broadleaf weeds were fed as the sole ration, potential health problems could arise due to an undesirable Ca/P ratio, however, all species were virtually free of alkaloids and nitrate-N levels were below toxic levels (Marten and Anderson, 1975). Yellow foxtail, barnyardgrass, green foxtail, redroot pigweed, Pennsylvania smartweed, and common lambsquarters were as palatable to sheep as was oats. Giant foxtail, wild mustard (*Sinapsis arvensis* L.), giant ragweed, and common cocklebur (*Xanthium pensylvanicum* Wallr.) were unpalatable to sheep, and common ragweed and velvetleaf (*Abutilon theophrasti* Medic.) were palatable to some sheep, but not to others (Marten and Anderson, 1975).

Seedling forage crops usually contain a mixture of broadleaf and grass weeds (Moyer, 1985). Temme et al. (1979) found that when common lambsquarters, shepherds purse (*Capsella bursa-pastoris* (L.) Medic.), smartweed, redroot pigweed, yellow foxtail, and common ragweed comprised 50% of the forage yield in an alfalfa stand, animal intake and digestion was lower than for weed free alfalfa, but higher than oat hay. Moyer (1985) found that when herbicides were not used in alfalfa and sainfoin (*Onobrychis viciaefolia* Scop.) establishment, weeds comprised 88 and 98% of total yield for the first cut, respectively. This level is well above the suggested acceptable level of 25% weed for livestock feed (Moline and Robinson, 1971). Moyer (1985) suggested that forages with high weed contents may have acceptable nutrient composition but may not be saleable as hay or silage. Moyer and Hironaka (1993) examined the digestible energy and protein content of several annual weeds such as stinkweed (*Thlaspi arvense* L.), flixweed, kochia (*Kochia scoparia* L. Schrader), lambsquarters, redroot pigweed, wild oat and green foxtail, as well as alfalfa, bromegrass (*Bromus spp.*), and tame oat forages. They found that all weeds had similar or greater crude protein and digestible energy than those of bromegrass or tame oat, and that broadleaf weeds had similar crude protein levels to alfalfa. Digestible energy levels for wild oat were significantly higher than alfalfa, and digestible energy levels for redroot pigweed, kochia and stinkweed were significantly lower than for alfalfa. Moyer and Hironaka (1993) suggested that a mixture of weeds and alfalfa or bromegrass would supply high quality feed for ruminants. However, Marten and Anderson (1975) have shown that sheep do not always accept weeds despite high nutritional value.

2.4.3 Considerations When Feeding Weedy Forages

Livestock may ingest weed seeds when grazing pastures and consuming hay, silage or grain (Dore and Raymond, 1942). Weed seeds that retain their viability after passing through the rumen can enhance the spread of weeds, hence there is a risk associated with feeding weeds or weedy forage. In an experiment by Harmon and Keim (1934), an average of 14.2% uninjured weed seeds including field bindweed (*Convolvulus arvensis* L.), white sweet clover (*Melilotus albâ* Desv.), smooth leaf dock (*Rumex acetocella* L.) and smartweed, were recovered from calves, horse, sheep, hogs and chickens. They also found that from each 1,000 seeds fed an average of 6.7% of recovered seeds were still viable. After being buried one month in cow and horse manure, only velvetweed, bindweed, sweet clover and peppergrass (*Lepidium draba* L.) seeds were viable, while all other weed seeds were dead (Harmon and Keim, 1934). Blackshaw and Rode (1991) found that downy brome (*Bromus tectorum* L.), foxtail barley, and barnyardgrass were nonviable after ensiling for 8 weeks or rumen digestion for 24 hours. They also found that 17% of green foxtail and 0-88% of wild oat seeds survived digestion in the rumen, but all were killed by the ensiling process. Furthermore, Blackshaw and Rode (1991) stated, "varying percentages of seeds of kochia, redroot pigweed, lambsquarters, wild buckwheat, round-leaved mallow and field pennycress remained viable after ensiling (3 to 30%), rumen digestion (15 to 98%), and ensiling plus rumen digestion (2 to 19%)."

Annual forage crops may be harvested in numerous ways (Berkenkamp and Meeres, 1987) and the method of harvest can affect weed populations. Recalling that Thurston (1966), and Wilson and Phipps (1985) both observed a reduction in the wild oat population over time due to the prevention of weed seed return to the seedbank via seed rain. This removal of weed seeds from the cropping system may be accomplished via animals, or mechanically via forage harvesting equipment. Thurston (1966) used live animals to implement forage removal, whereas Wilson and Phipps (1985) used mechanical means. Harper (1977) stated that the presence of grazing animals will increase numbers of seeds in the weed seedbank for the following reasons: 1) seeds eaten by animals are forced into dormancy in the faeces, 2) trampling of land creates conditions in which seeds retain greater viability in the soil, and 3) grazing opens up habitats that allow annual weeds with rapid seed production to contribute to the seedbank. In addition, grazing animals may eat only portions of a weed plant still allowing it to set seed, or they may only remove what was already doomed to die from other subsequent "density-dependent" processes (Harper, 1977). However, removal of leaves or roots from weeds in an agroecosystem may damage their position in a competitive hierarchy and reduce their reproductive output (Harper, 1977). Popay and Field (1996) suggested that adjusting grazing timing or intensity could prevent the selection of weed problems when grazing animals.

2.5 Interaction of Tillage and Forages

Much research has been conducted on the effect of tillage on weed populations. Blackshaw et al. (1994) reported that under various crop rotations, zero-tillage plots had a greater abundance of weeds and a different weed species composition compared to minimum or conventional tillage plots. They reported that dandelion, perennial sow thistle, redroot pigweed and Russian thistle increased under minimum and zero-tillage, and flixweed, field pennycress, wild buckwheat and common lambsquarters decreased under minimum and zero-tillage. Alternatively, Hume et al. (1991) found higher densities of red root pigweed under conventional tillage. Buhler (1992) reported that lambsquarters and red root pigweed densities were greater under a zero-tillage system when compared to a conventional tillage system. In a four year experiment, Teasdale et al. (1991) reported that total weed density increased after one year of zero tillage and after two years of conventional tillage, however, lambsquarters density was greatest under conventional tillage in the fourth year of the experiment.

When annual forages are grown under zero tillage they may not have the same affect on weed populations as when they are grown under conventional tillage. Thurston (1966), and Wilson and Phipps (1985) used tillage for seed bed preparation in their experiments. Wilson and Phipps (1985) partially attribute the elimination of wild oats in the seedbank under three years of barley cut for silage to the associated cultivation. Thurston (1966) also noted that longer survival of wild oat seeds was found in undisturbed soil under leys, thus annual systems in which there is greater soil disturbance will select for, and remove, wild oats that are less persistent in the seedbank.

2.6 Conclusion

Because of problems associated with sole dependence on one method of weed control there is a need to research, develop and implement weed control programs that integrate different measures of weed control. An integrated weed management system is one that incorporates a combination of any number of chemical, cultural, mechanical, genetic and biological weed control measures in a single weed control strategy. The management strategies imposed upon any cropping system will influence the existing weed populations that are a part of that system. Heavy reliance on one method of weed control may select for a particular weed species to be more abundant and difficult to control in the long-term. Use of an integrated weed management system can serve to avoid the selection for particularly problematic weed species while still affording the farmer adequate weed control. Annual forage systems may be one tool available to producers wishing to implement an integrated weed management system. Annual forages may serve to reduce weed populations by competing with weeds and preventing weed seeds from returning to the seedbank while providing a direct economic return to the producer.

3.0 Methods and Materials

Field experiments were conducted to investigate the effects of annual forage systems on weed populations. Experiments were conducted at the University of Manitoba field research station at Carman, MB. from 1994 to 1996.

Indigenous summer annual weed populations at Carman were comprised predominantly of green foxtail (*Setaria viridis* [L.] Beauv.), red root pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), wild buckwheat (*Polygonum convolulus* L.), wild mustard (*Sinapsis arvensis* L.) and green smartweed (*Polygonum spp.* L.).

The experimental area at Carman was seeded to wild oat (*Avena fatua* L.), population UM5, a herbicide susceptible population on May 12, 1994. The wild oats were broadcast with a commercial granular fertilizer and herbicide applicator (Valmar Airflo, model 1220) at a rate of 32 kg/ha (200 seeds/m^2). In order to prevent bridging in the Valmar Airflo, the wild oats were blended with granular fertilizer and applied in three separate applications. Fertilizer rates used were according to Manitoba Soil Test Laboratory recommendations. The first application consisted of 10.7 kg/ha wild oat and 151 kg/ha 34-0-0 (51 kg/ha actual N) applied in a north-south direction. The second application consisted of 10.7 kg/ha wild oat and 59 kg/ha 12-51-0 (30 kg/ha actual P_2O_5) applied in an east-west direction. The third application consisted of 10.7 kg/ha wild oat and 147 kg/ha 0-0-50(17) (25 kg/ha actual S) applied in a north-south direction. The wild oats and fertilizer were incorporated into the soil with three passes of a cultivator to a depth of 5 cm on May 16, 1994. The soil bed was then smoothed out with two passes of a harrow. The total area seeded with wild oat was 1.65 ha.

In 1994, two experiments were established at Carman on the experimental area seeded to wild oat. In the first trial of experiment 1 annual forages were established. In the second trial of experiment 1 flax (*Linum usitatissimum* L., cv. Norlin) was established with some plots under seeded to sweet clover (*Meliliotus officinalis* cv. Norgold) and some plots under seeded to fall rye (*Secale cereale* cv. Prima). In experiment 2 flax was established with some plots under seeded to sweet clover, fall rye, and alfalfa (*Medicago sativa* L., cv. OAC Minto). For a summary of field operations for experiments 1 and 2 see appendix Tables A1 and A2.

3.1 Experiment 1

3.1.1 General

Two 2 year field trials were conducted over the course of this study (1994/95 and 1995/96). In the first year, annual forage "weed suppressor" crops were seeded and grown in a herbicide-free environment. In year two, a field pea test crop was grown both with and without herbicides. In this way, the economic weed control of the "suppressor" treatments could be determined. For a summary of treatments conducted in experiment 1 see Table 1 and Figure 1.

3.2 Trial 1

3.2.1 Year 1: Experimental Treatments

The trial was arranged as a randomized complete block design with four replications. The plot sizes were 4 m (twice the width of the seeder) by 8 m. The nine treatments for experiment 1 were: wheat (*Triticum aestivum* L. cv. Katepwa) sprayed with grass and broadleaf herbicide (sprayed wheat), harvested for grain; wheat sprayed with broadleaf herbicide only (partially sprayed wheat), harvested for grain; wheat, unsprayed (unsprayed wheat), harvested for grain; winter triticale (*Triticosecale* cv. Pika), simulation grazed; spring triticale (cv. Banjo), cut for silage; winter and spring triticale intercrop, cut for silage then simulation grazed; sorghum sudangrass (*Sorghum bicolor* [L.] Moench X *Sorghum sudanense* [Piper] Stapf., common), cut for hay; non-dormant alfalfa (*Medicago sativa* L. cv. Nitro), cut for hay; and weed fallow, cut for silage (Table 1).

Table 1. Treatments implemented in trials 1 and 2 of experiment 1 at Carman, MB.

Abbreviation	Crop	Herbicide	Harvest
W+GB	Wheat	Grass and Broadleaf	Grain* (1)
W+B	Wheat	Broadleaf	Grain (1)
W-H	Wheat	None	Grain (1)
WT	Winter Triticale	None	Graze (4 or 5)
IC	Spring and Winter Triticale Intercrop	None	Silage/Graze (3 or 5)
ST	Spring Triticale	None	Silage (2)
SS	Sorghum-Sudangrass	Glyphosate	Hay (1or 2)
ALF	Alfalfa	None	Hay (4 or 5)
WF	No Crop	None	Silage (2)
	Trial 2 only		
DC	Sweet Clover/Winter Triticale Doublecrop	None	Hay/Graze (3)
FR	Fall Rye	None	Grain (1)

*Number in brackets indicates average number of harvests in both years of the study

The experiment was seeded using a small plot double disc drill (Fabro Ltd.). All the treatments in trial 1 of experiment 1 were sown on May 18, 1994, with the exception of the sorghum-sudangrass which was sown on June 14, 1994. Row spacing for all treatments was 15 cm. No additional fertilizer was added with the seed, and no additional cultivation was performed at seeding. Wheat was sown at 130 kg/ha at a depth of 5 cm. Winter triticale was sown in the spring avoiding vernalization and allowing plants to remain vegetative throughout the growing season (Baron et al., 1992). Winter triticale was sown at a rate of 84 kg/ha to a depth of 5 cm. Spring triticale was sown at a rate of 94 kg/ha to a depth of 5 cm. When planted as an intercrop, winter triticale was sown at a rate of 42 kg/ha and spring triticale was sown at a rate of 47 kg/ha. In the intercrop plots, each cultivar of triticale was planted at a row spacing of 30 cm so that there were alternating rows of spring and winter triticale. Alfalfa was sown at a rate of 12.6 kg/ha to a depth of 2.5 cm. Alfalfa was inoculated with *Rhizobium meliloti* prior to seeding. For the weed fallow treatment, no crop was sown, and no herbicide applied so that weeds were allowed to grow. For weed control, plots seeded with sorghum-sudangrass were sprayed with 5 L/ha glyphosate on June 13, 1994, the day before seeding. Sorghum-sudangrass was sown at a rate of 30 kg/ha to a depth of 2.5 cm.

On June 10, 1994, chemical weed control was implemented on the wheat in experiment 1. In one treatment, wheat was sprayed with 0.99 kg/ha tralkoxydim and 1.0 L/ha bromoxynil and MCPA ester for control of grass and broadleaf weeds. In a second treatment, wheat was sprayed with 1.0 L/ha of bromoxynil and MCPA ester only for control of broadleaf weeds, and in a third treatment wheat was left unsprayed.

Each treatment was harvested at different dates throughout the growing season. Wheat was harvested on Aug. 26, 1994 with a small plot combine (Hege, model 125B) and grain yield was determined. Wheat was harvested at a cutting height of 25 cm. Each forage treatment was harvested using a small plot forage harvester (Haldrup, model 1500). Winter triticale was harvested when the triticale plants reached an average height of 40 cm resulting in five harvests (June 20, July 8, Aug. 2, Sept. 23, Oct. 23). Spring triticale was cut once for silage on July 26 at soft dough stage, and subsequent growth of weeds was mowed on Sept. 7. The spring and winter triticale intercrop was first cut for silage on July 20 at the soft dough stage, and subsequent regrowth of the winter triticale was grazed on Sept. 23 when it reached an average height of 40 cm. Sorghum-sudangrass was cut for hay on Aug. 31 when the panicles were half emerged from the boot. A second cut was taken on Sept. 23 when the sorghum-sudangrass regrowth had reached 55 cm in height. Alfalfa was cut for hay at 10% bloom resulting in four harvests (June 20, July 25, Sept. 23, and Oct. 23). The weed fallow treatment was cut for silage on July 20, and subsequent growth of weeds was mowed on Sept. 7. Each forage was harvested at a cutting height of 5 cm.

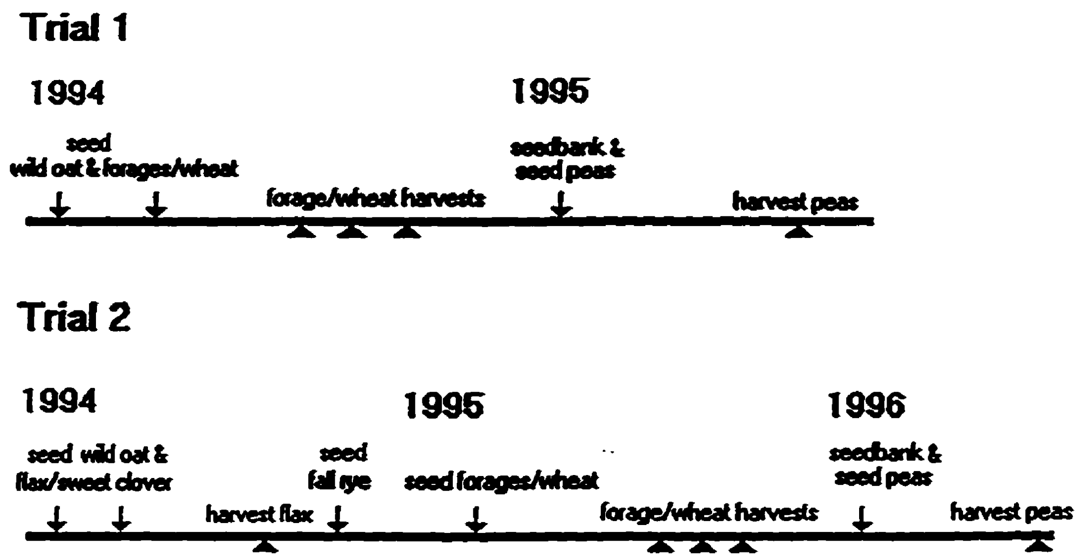


Figure 1. Timeline of field operations for trials 1 and 2 of experiment 1.

3.2.2 Measurements

An initial weed count was performed on May 31, 1994, prior to herbicide application in wheat. All weed species were counted on this date. Wild oat seedling populations in the field were counted within four 25- by 25-cm quadrats for each plot at each harvest date. Weed seedlings were identified, counted and their height was measured.

At each harvest date, forage, wheat and weed samples were removed from each 25- by 25-cm quadrat at a height of 5 cm, separated, dried at 55 C for 72 hours and weighed to determine dry matter yield for crop and for weeds. There were two categories once separated, "crop" and "weeds". Four quadrats per plot were sampled.

3.2.3 Year 2: Seedbank Enumeration and Production of Pea Test Crop

The weed seedbank was assessed in year two of the study. Soil samples were extracted from the field using a stratified random sampling method in experiment 1 on April 25, 1995 prior to the seeding of a pea test crop (Krebs, 1989). In this method each plot was subdivided into four strata from which soil cores were randomly extracted. Fifteen soil cores were taken from each plot, four in each of the north-east, south-east and north-west strata, and three in the south-west stratum. Each soil core was 6.5 cm in diameter, and 8 cm in depth. Each soil core was spread into a 12- by 10-cm cell of a tray lined with paper towel.

The tray method was used for enumerating the seedbank (Cardina and Sparrow, 1996). Forcella (1991) suggested that this method provides a better assessment of field weed seedling densities than seed extraction. Cardina and Sparrow (1996), however, state that the tray method is a better indicator of total, nondormant, viable seeds than a reflection of field emergence. The trays containing soil samples were placed in a greenhouse maintained at day/night temperature of approximately 30/22 C. Daily surface irrigation maintained even soil moisture content for all samples. Weed seedlings were identified, counted and removed. After approximately one month germination ceased, the soil was allowed to dry, and the trays were placed in a dark freezer (-8 C) for one month. Gross (1990) found that more weed species were detected when cold-stratification was used than when only direct germination was used. When the trays were removed from the freezer the soil was thoroughly mixed and replaced in the trays, and the trays were placed back in the greenhouse to permit further germination. This process was repeated three times from April to October, at which time no more seedlings emerged.

The cumulative seedling emergence data collected from seedbank enumeration were recorded on a m^2 soil surface area basis.

A crop of semi-leafless peas (*Pisum sativum* cv. Danto) was seeded in all plots in the year after the forage suppressor treatments (i.e. 1995) to determine pea seed yield. Because of the presence of alfalfa in the previous year, peas were chosen to avoid the confounding effects of adding nitrogen fertilizer due to N-fixation by the previous crop of alfalfa. Peas inoculated with *Rhizobium* bacteria were sown on May 9, 1995 at a rate of 170 kg/ha at a depth of 5 cm. Twenty kg/ha P_2O_5 was placed with the seed. Glyphosate at a rate of 5 L/ha was sprayed on this experimental area on May 10, 1995, however, half of the plots (2- by 8-m) containing winter triticale were left unsprayed in order to obtain a grain yield from the triticale which had successfully survived over winter.

Weed seedlings were identified and counted in the field on June 5 within two 25- by 25-cm quadrats per plot for each of the previous year's treatments.

Half of the peas were sprayed with herbicide for grass and broadleaf weed control to determine the economic benefit of using annual forages. The other half was left unsprayed to assay the effect that annual forages had on weed populations. On June 8, 1995 half of each pea plot was sprayed with imazethapyr at a rate of 0.21 L/ha. Due to spray misses sethoxydim was sprayed on the peas at a rate of 2.5 L/ha on June 23, 1995. Further hand weeding was necessary to keep plots weed free. The triticale plots that had not been sprayed off with glyphosate were not sprayed with any herbicide in 1995.

On Aug. 2, 1995 the winter triticale planted in the previous spring that had survived the winter was harvested and grain yield was measured. On Aug. 17, 1995 the peas were harvested and grain yield for sprayed and unsprayed peas was obtained by harvesting a 1 m^2 area in each subplot.

3.3 Trial 2

3.3.1 Establishment Year

Trial 2 of experiment 1 was arranged as a randomized complete block design with four replications. The plot sizes were 4 m by 8 m. In trial 2, flax (*Linum usitatissimum* cv. Norlin) was established on May 18, 1994 on the experimental area that had been sown to wild oat (Figure 1). Flax was sown at a rate of 45 kg/ha to a depth of 3 cm. No additional fertilizer was added, and no additional cultivation was performed. On May 25, 1994 the sweet clover treatment was sown at a rate of 10 kg/ha to a depth of 2.5 cm using a disc drill. Broadleaf weeds were removed from trial 2 using 1.0 L/ha bromoxynil and MCPA ester on June 10, 1994. Broadleaf weeds were removed from the sweet clover plots by hand at the same time the other plots were sprayed. The grass weeds, predominantly wild oat, were allowed to establish and shed seed throughout the growing season. The flax was swathed on Aug. 30, 1994 and the plant material was baled off the plot area. On Aug. 31, 1994, trial 2 was cultivated with the exception of the sweet clover plots. On Sept. 1, 1994, the fall rye treatment was sown with 30 kg/ha P_2O_5 at a rate of 95 kg/ha at a depth of 5 cm. All plots with the exception of sweet clover and fall rye plots were cultivated to a depth of 5 cm in the fall of 1994.

3.3.2 Year 1: Experimental Treatments

The treatments for trial 2 were the same as for trial 1 with the addition of sweet clover and fall rye. Sweet clover was cut for hay and then seeded to winter triticale which was grazed, while the fall rye was harvested for grain.

The wheat and forage suppressor crops were direct seeded into trial 2 on May 10, 1995 using a small plot double disc drill (Fabro Ltd.). The same seeding rates were used as in trial 1. Nitrogen fertilizer at a rate of 70 kg/ha ammonium nitrate was banded into all plots except the sweet clover plots on May 10, 1995 using the small plot double disc drill. Fertilizer N was placed at a depth of 5 cm, while 45 kg/ha P_2O_5 was placed with the seed. Twenty kg/ha P_2O_5 was broadcast by hand in the sweet clover and the weed fallow plots. The sorghum-sudangrass was seeded on June 16, 1995, and the weeds in these plots were sprayed with 5 L/ha glyphosate on June 19, 1995. On June 21, 1995, after the harvest of sweet clover, winter triticale (cv. Pika) was direct seeded into the sweet clover at a rate of 105 kg/ha at a depth of 5 cm. No additional P_2O_5 was added to these plots at the time of seeding.

Wheat plots designated for herbicide treatment were sprayed on June 8, 1995. The herbicides used and rates were the same as in trial 1. Spray misses occurred in the wheat sprayed with grass and broadleaf herbicide due to the spray boom being too low, therefore this treatment was sprayed again on June 21, 1995 with 5 L/ha of flamprop-methyl for grass weed control.

Each treatment in trial 2 was harvested at different dates throughout the growing season. Wheat was harvested on Aug. 15, 1995 using similar methods as in trial 1. Forage treatments were again harvested using a small plot forage harvester. A grazing treatment was simulated on the winter triticale 4 times during the growing season (June 26, July 19, Aug. 16, Oct. 3) with the forage harvester when the triticale plants reached an average height of 40 cm. Spring triticale was cut once for silage on July 6, 1995 at soft dough stage, and again on Aug. 9, 1995. The spring and winter triticale intercrop was first cut for silage on July 6, 1995 at the soft dough stage, and subsequent regrowth of the winter triticale was "grazed" on Aug. 16 and Oct. 3, 1995. Sorghum-sudangrass was cut for hay on Aug. 16, 1995 when the panicles were half emerged from the boot. Only one cut of sorghum-sudangrass was taken in this trial. Alfalfa was cut for hay at 10% bloom on June 26, July 19, Aug. 16, and Oct. 3, 1995. The weed fallow treatment was cut for silage on July 6, 1995, and again on Aug. 9, 1995. All forage treatments were cut at a height of 5 cm.

3.3.3 Measurements

Due to the fact that there were significantly more weeds in trial 2 than there had been in trial 1 the number of samples, and sample size was decreased for enumeration of field seedling populations. Weed seedling populations in the field were counted within two 12.5- by 12.5-cm quadrats per plot. Weed species, height, and development stage were assessed for each treatment at each harvest. An initial weed count was done on May 30, 1995, prior to herbicide application in wheat. Development stage of the crop was also assessed at each harvest using the Zadoks scale (Zadoks et al., 1974).

At each harvest, forage, wheat and weed samples were removed from two 25- by 25-cm quadrats at a height of 5 cm, separated, dried at 55 C for 72 hours and weighed to determine dry matter yield for crop and for weeds. Weeds were separated from the crop, so that there was a total of two categories: "crop", and "weeds".

3.3.4 Year 2: Seedbank Enumeration and Production of Pea Test Crop

Soil samples were taken from trial 2 on May 1, 1996 prior to the seeding of a pea test crop. The soil samples were extracted from the field and enumerated using the same methods outlined in trial 1.

A pea test crop was once again seeded in plots in year two of the study. Once again, all plots were sprayed prior to seeding with 5 L/ha glyphosate except for the half of the plots that contained winter triticale. The peas were seeded on May 13, 1996 at a rate of 200 kg/ha.

Weed seedling populations in the field were counted on June 3, 1996 within four 12.5- by 12.5-cm quadrats per plot for each of the treatments.

On June 7, 1996, half of each pea plot was sprayed with imazethapyr (0.21 L/ha) and sethoxydim (1.3 L/ha). Due to poor wild oat control, peas were sprayed with sethoxydim again on June 24, 1996 at a rate of 2.7 L/ha. On Aug. 2, 1996, the winter triticale planted in the previous spring that had survived the winter was harvested and grain yield was measured. Peas were harvested on Aug. 17, 1996 in both sprayed and unsprayed subplots.

3.4 Statistical Analysis

Most data sets for experiment 1 from Carman were analyzed as randomized complete block design (RCBD) experiments, using analysis of variance (ANOVA) procedures on the Statistical Analysis Systems (SAS) software package (SAS Institute, 1986). Pea grain yield data was analyzed as a split plot design with herbicide treatment as mainplot and suppressor crop as subplot using ANOVA procedures. Means were compared using Fisher's Least Significant Difference (LSD) test at the $p < 0.05$ level. Principal component analysis (PCA) and canonical discriminant analysis (CDA) were performed on the seedbank data to determine if there were any differences in weed community between the treatments (Manley, 1994). CDA was performed using the object scores obtained from the PCA. The association of weed species with forage system could be determined for each trial by comparing species vector length and direction. Homogeneity of variances was tested using Bartlett's test and log transformation of data was performed in accordance with the results of the Bartlett's test. Data is presented as actual values in the Results and Discussion section. It has been indicated where log transformation of data was performed. Log transformed data including least significant difference (LSD) and Coefficient of Variation (C.V.) values is presented in the Appendix.

3.5 Experiment 2

3.5.1 Establishment Year

This experiment was designed to study the effect of selected forage systems on weeds under two tillage systems. The experiment was arranged as a 4 replicate split plot design with tillage as the mainplot factor (zero tillage, conventional tillage), and crop type as the subplot factor (sweet clover, fall rye, spring triticale, spring wheat, alfalfa). The plot sizes were 4 m by 6 m. For a summary of the timeline used in this study see Figure 2.

Flax (*Linum usitatissimum* L., cv. Norlin) was established on May 18, 1994 on the experimental area that had been sown to wild oat and fertilized in spring of 1994. Flax was sown at a rate of 45 kg/ha to a depth of 3 cm. No additional fertilizer was added, and no additional cultivation was performed (see section 3.01). On May 25, 1994 plots were under-seeded to sweet clover cv. Norgold at a rate of 10 kg/ha and alfalfa cv. OAC Minto at a rate of 12.6 kg/ha. Both sweet clover and alfalfa were sown at a depth of 2.5 cm. The weeds, predominantly wild oat, were allowed to establish and shed seed throughout the first growing season. On Aug. 30, 1994 the flax was swathed and baled. On Sept. 1, 1994 fall rye was sown with 30 kg/ha P_2O_5 at a rate of 95 kg/ha to a depth of 5 cm into selected plots. The fall rye plots under the conventional tillage treatment were cultivated before seeding, and fall rye was sown directly into the zero tillage plots with no herbicide applied before seeding. On Sept. 7, 1994 the plots where no sweet clover or alfalfa had been seeded also were cultivated in the conventional tillage treatments. Nothing was done to the remaining zero-tillage plots at this point.

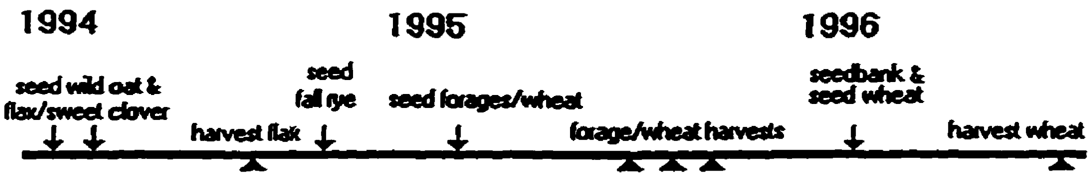


Figure 2. Timeline of field operations for experiment 2.

3.5.2 Year 1: Experimental Treatments

Conventional tillage plots were cultivated and packed, and zero tillage plots were sprayed with 5 L/ha glyphosate on May 10, 1995. Spring wheat (cv. Katepwa) and spring triticale (cv. Banjo) were sown on May 11, 1995 at a rate of 135 kg/ha and 115 kg/ha, respectively, to a depth of 2.5 cm. Fertilizer N (ammonium nitrate) was banded at a rate of 60 kg N/ha into fall rye, wheat and triticale plots just prior to seeding of wheat and triticale. Phosphate was placed with the seed at a rate of 30 kg/ha P_2O_5, and 30 kg/ha P_2O_5 was broadcast by hand on the forages. On June 6, 1995 broadleaf weeds were sprayed in all plots with 1 L/ha bromoxynil and MCPA ester. Because of poor control, broadleaf weeds were sprayed again on June 23, 1995 using Refine Extra (thifensulfuron methyl plus tribenuron methyl) at a rate of 19.8 g/ha.

Each treatment was harvested at different dates throughout the growing season. Wheat was harvested on Aug. 16, 1995 with a small plot combine and grain yield was determined. Wheat was harvested at a height of 25 cm. Each forage treatment was harvested using a small plot forage harvester. Sweet clover was harvested on June 19, 1995 and subsequent regrowth was mowed on July 11 and Aug. 4, 1995. Alfalfa was harvested on June 19, July 18, and Aug. 10, 1995 at 10% bloom. Triticale was harvested on July 12, 1995 at the soft dough stage, and subsequent regrowth was cut on July 19 and Aug. 8, 1995. Fall rye was harvested for grain on July 31, 1995.

On Aug. 12, 1995 alfalfa, triticale and sweet clover plots were cultivated in the conventional tillage plots, and sprayed with 5 L/ha glyphosate, and 1 L/ha 2-4, D in the zero tillage plots.

3.5.3 Measurements

Only wild oat and green foxtail populations were assessed in this experiment. Weed seedlings were identified and enumerated within four 25- by 25-cm quadrats for each plot at each harvest date. An initial weed count was done on May 30, 1995. At each harvest, forage and weed samples were removed from the same four 25- by 25-cm quadrats at a height of 5 cm, separated, dried at 55 C for 72 hours and weighed to determine dry matter yield for crop and for weeds at each harvest. There was a total of two categories once separated, "crop" and weeds".

3.5.4 Year 2: Production of Wheat Test Crop

The entire test was seeded to a spring wheat test crop in the spring of 1996. Wheat was sown on May 15, 1996 at a rate of 135 kg/ha and to a depth of 5 cm. Once again, no grass herbicides were applied to the plot area. Broadleaf weeds were controlled with Refine Extra (thifensulfuron methyl plus tribenuron methyl) at a rate of 19.8 g/ha.

An initial weed count was done on June 5 and 6, 1996 in the seedling wheat crop. Weed seedlings were identified and enumerated within two round quadrats 0.1 m in diametre for each plot.

3.6 Statistical Analysis

This experiment was analyzed as a split plot design, using analysis of variance procedures and Fisher's LSD test of means after ANOVA indicated significant ($p < 0.05$) differences. Homogeneity of variances was tested using Bartlett's test and log transformation of data was performed in accordance with the results of the Bartlett's test. Data is presented as actual values in the Results and Discussion section. It has been indicated where log transformation of data was performed. Log transformed data including least significant difference (LSD) and Coefficient of Variation (C.V.) values are presented in the Appendix.

4.0 Results and Discussion

4.0.1 Environmental Parameters

In 1994-1996, mean air temperature was close to the long-term average (Table 2). Precipitation in 1994 was below the long-term average, and precipitation in 1995 and 1996 was close to the long-term average. Mean air temperature from May to September was similar in all three years. Total precipitation, however, was highest in 1996 followed by 1995 and 1994.

4.1 Experiment 1

4.1.1 Forage Year

4.1.1.1 Weed Population Density

Weed population density was measured in the year of forage to better understand the process by which forages interfered with weeds and to aid in interpretation of results found in the test crop year. Initial early in-crop grass weed population density in trial 2 was higher than in trial 1 because grass weeds were allowed to shed seed prior to the trial 2 forage year (Tables 3 and 4). In trial 1, the early in-crop wild oat population density was significantly higher for sorghum-sudangrass and weed fallow than for all other treatments (Table 3). This observation was attributed to the fact that no crop was growing in the sorghum-sudangrass and weed fallow plots when weeds were counted on May 31, 1994. While, all other treatments had been sown two weeks prior to counting, and the seedling crops were competing with the wild oat seedlings. No significant treatment differences were observed for early in-crop green foxtail, red root pigweed,

Table 2. Monthly mean air temperature and precipitation at Carman, Manitoba in 1994, 1995, and 1996, and the 30- year average (1961-1990)*.

	Temperature (C)					Precipitation (mm)			
	1994	1995	1996	30-yr. Avg.		1994	1995	1996	30-yr. Avg.
May	13.2	11.1	9.6	11.6		41	62	68	54
June	18.1	20.4	18.3	17.1		27	41	69	75
July	18.7	19.8	18.5	19.8		66	84	111	77
August	17.4	19.6	18.9	18.4		70	100	41	66
September	14.7	12.7	12.6	12.5		63	40	49	49
Avg.	16.4	16.7	15.6	15.9	Total	267	327	338	334

* Environment Canada Atmospheric Environment Service, Winnipeg, Manitoba. R3C 3V4.

Table 3. Initial early season in-crop weed density (seedlings/metre squared) for trial 1 at Carman, 1994. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment	Wild Oat	Green Foxtail	Red Root Pigweed	Lambs-quarter	Wild Buckwheat	Wild Mustard	Green Smartweed
Wheat+Grass and Broadleaf Herbicide	80 *b*	233 *a*	87 *a*	85 *a*	5 *a*	3 *a*	16 *a*
Wheat+Broadleaf Herbicide	84 *b*	139 *a*	112 *a*	81 *a*	8 *a*	10 *a*	8 *a*
Wheat-Herbicide	80 *b*	174 *a*	97 *a*	132 *a*	5 *a*	10 *a*	13 *a*
Winter Triticale	84 *b*	292 *a*	117 *a*	74 *a*	1 *a*	9 *a*	5 *a*
Winter and Spring Triticale	74 *b*	310 *a*	122 *a*	109 *a*	5 *a*	7 *a*	7 *a*
Spring Triticale	66 *b*	316 *a*	99 *a*	87 *a*	5 *a*	8 *a*	13 *a*
Sorghum-Sudangrass	157 *a*	193 *a*	139 *a*	83 *a*	9 *a*	9 *a*	10 *a*
Alfalfa	92 *b*	187 *a*	136 *a*	72 *a*	4 *a*	14 *a*	9 *a*
Weed Fallow	147 *a*	203 *a*	108 *a*	94 *a*	4 *a*	6 *a*	10 *a*
L.S.D.	37	188	63	56	6	10	12
C.V.	27	57	38	42	85	86	81

Table 4. Initial early season in-crop weed population density (seedlings per metre squared) for trial 2 at Carman, 1995. Means with the same letters are not significantly different LSD ($p<0.05$).

Treatment	Wild Oat	Green Foxtail	Lambs-quarter	Red Root Pigweed	Wild Buckwheat	Green Smartweed
Wheat+Grass and Broadleaf Herbicide	2188 ab	3876 ab	10 a	131 bcd	3 b	4 a
Wheat+Broadleaf Herbicide	1744 ab	2960 ab	16 a	200 ab	5 ab	4 a
Wheat-Herbicide	2096 ab	3588 ab	14 a	60 de	2 b	4 a
Winter Triticale	2284 a	2900 ab	20 a	261 a	3 ab	3 a
Winter and Spring Triticale Intercrop	1844 ab	4076 a	14 a	127 bcd	5 ab	3 a
Spring Triticale	2084 ab	3248 ab	18 a	178 abc	7 ab	3 a
Sorghum-Sudangrass	1908 ab	2732 b	14 a	237 ab	6 ab	3 a
Alfalfa	1852 ab	2892 ab	14 a	132 bcd	3 ab	2 a
Sweet Clover/Triticale Doublecrop	424 c	1124 c	12 a	4 e	14 a	2 a
Fall Rye	552 c	184 c	6 a	1 e	9 ab	6 a
Weed Fallow	1592 b	3624 ab	8 a	70 cde	10 ab	0 a
L.S.D.	620	1310	14	114	11	8
C.V.	25	32	73	62	131	172

lambsquarter, and wild buckwheat densities in trial 1.

In trial 2, early in-crop wild oat, green foxtail and red root pigweed densities were significantly lower for sweet clover/triticale doublecrop and fall rye than for most other treatments (Table 4). Wild oat, green foxtail, and red root pigweed densities were variable for the remaining treatments. In trial 2, fall rye and sweet clover were seeded in 1994 (i.e. the previous year). These crops initiated growth earlier in 1995 than the spring-seeded forages, thereby providing superior weed competition. Thurston (1962) found that wild oat was controlled by autumn-sown cereals regardless of crop type, provided spring crop plant population density was sufficient. No significant treatment differences were observed for early in-crop lambsquarter density in the present study. Population density of these weeds was low relative to the other weed species in this experiment.

In trial 1, only wild oat plants were counted at each harvest (Table 5, and Appendix Table A3). No significant changes in wild oat density from the early in-crop weed count to last harvest count were observed for the wheat sprayed with broadleaf herbicide only, wheat with no herbicide, spring triticale, and the weed fallow treatments. Thus, these treatments were not effective in reducing the wild oat population. For the winter triticale and alfalfa treatments, wild oat density was greatest at the first harvest (June 20), and these two treatments had higher early wild oat populations than the other treatments. This may be due to the fact that these forage crops had a more prostrate growth habit than the other forages and did not provide the same degree of competition with weeds for light. Wild oat densities in the winter triticale, alfalfa, triticale intercrop and sorghum-sudangrass treatments were significantly less at last harvest than at the early in-crop weed count. Thus, these treatments were effective in reducing the wild oat population.

In trial 2, grass and broadleaf weeds were counted at each harvest (Table 6, and Appendix Table A4). Weed density for each weed type was significantly lower for the

Table 5. Wild oat density (plants per metre squared) in treatments for trial 1 at Carman, 1994. Statistical analysis was performed within crop type on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Date	Treatment
	Wheat + Grass and Broadleaf Herbicide
May 31	80 *a*
August 26	0 *b*
	Wheat + Broadleaf Herbicide
May 31	84 *a*
August 26	112 *a*
	Wheat - Herbicide
May 31	80 *a*
August 26	109 *a*
	Winter Triticale
May 31	84 *b*
June 20	328 *a*
July 8	36 *c*
August 2	36 *c*
September 23	7 *d*
	Triticale Intercrop
May 31	74 *b*
July 20	127 *a*
September 23	2 *c*
	Spring Triticale
May 31	66 *a*
July 26	55 *a*
	Sorghum-Sudangrass
May 31	157 *a*
August 31	2 *b*
September 23	0 *b*
	Alfalfa
May 31	92 *b*
June 20	278 *a*
July 25	269 *a*
September 23	4 *c*
	Weed Fallow
May 31	147 *a*
July 20	228 *a*

final weed count of the season vs. the early in-crop weed count for each treatment. This is in contrast to results in trial 1, where weed density did not decrease significantly over the season in the partially sprayed and unsprayed wheat treatments. The reason for a weed population decline over time in trial 2 was because weed pressure was so intense that the weeds themselves competed with each other. Also, broadleaf weeds in trial 2 were eliminated in all treatments because they could not compete with the dense infestation of grass weeds. Only in the sweet clover/triticale doublecrop did weed densities increase over time. After the sweet clover component of the doublecrop was harvested, green foxtail and lambsquarter density increased and was significantly higher than at the early in-crop count. Temporary lack of crop competition, soil disturbance that occurred when the winter triticale was seeded, or release of nitrogen from sweet clover residue may have stimulated these weeds to germinate. By the end of the season, these weeds were at low densities.

Table 6. Weed density (plants per metre squared) in treatments for trial 2 at Carman, 1995. Statistical analysis was performed within crop type on log transformed data. Means with the same letter are not significantly different ($p<0.05$).

Date	Wild Oat	Green Foxtail	Red Root Pigweed	Lambs-quarters	Wild Buckwheat
			Wheat + Grass and Broadleaf Herbicide		
May 31	2188 *a*	3876 *a*	131 *a*	10 *a*	3 *a*
August 16	844 *b*	566 *b*	0 *b*	0 *b*	0 *a*
October 3	179 *c*	0 *c*	0 *b*	0 *b*	0 *a*
			Wheat + Broadleaf Herbicide		
May 31	1744 *a*	2960 *a*	200 *a*	16 *a*	5 *a*
August 16	668 *b*	466 *b*	0 *b*	0 *b*	0 *b*
October 3	246 *c*	0 *c*	0 *b*	0 *b*	0 *b*
			Wheat - Herbicide		
May 31	2096 *a*	3588 *a*	60 *a*	14 *a*	2 *a*
August 16	818 *b*	280 *b*	2 *b*	0 *b*	1 *a*
October 3	376 *c*	0 *c*	0 *b*	0 *b*	0 *a*

Table 6 (continued). Weed density (plants per metre squared) in treatments for trial 2 at Carman, 1995. Statistical analysis was performed within crop type on log transformed data. Means with the same letter are not significantly different (p<0.05).

Date	Wild Oat	Green Foxtail	Red Root Pigweed	Lambs-quarters	Wild Buckwheat
			Winter Triticale		
May 31	2284 *a*	2900 *a*	261 *a*	20 *a*	3 *ab*
June 26	434 *a*	1794 *a*	6 *b*	2 *b*	5 *a*
July 20	181 *b*	842 *b*	8 *b*	10 *b*	4 *ab*
August 16	104 *c*	342 *c*	3 *b*	1 *c*	1 *ab*
October 3	19 *d*	0 *d*	0 *c*	0 *c*	0 *b*
			Triticale Intercrop		
May 31	1844 *a*	4076 *a*	127 *a*	14 *a*	5 *a*
July 6	1476 *a*	626 *b*	3 *c*	8 *a*	8 *a*
August 16	181 *b*	554 *b*	9 *b*	3 *b*	4 *a*
October 3	16 *c*	0 *c*	0 *d*	0 *b*	0 *b*
			Spring Triticale		
May 31	2084 *a*	3248 *a*	178 *a*	18 *a*	7 *a*
July 6	1182 *b*	502 *c*	4 *b*	13 *a*	8 *a*
August 9	429 *c*	675 *b*	8 *b*	10 *a*	4 *ab*
October 3	58 *d*	0 *d*	0 *c*	0 *b*	0 *b*
			Sorghum-Sudangrass		
May 31	1908 *a*	2732 *a*	237 *a*	14 *a*	6 *a*
August 16	37 *b*	368 *b*	22 *a*	1 *a*	0 *b*
October 3	45 *b*	0 *c*	0 *b*	0 *a*	0 *b*
			Alfalfa		
May 31	1852 *a*	2892 *a*	132 *a*	14 *a*	3 *ab*
June 26	1464 *a*	1610 *b*	16 *b*	11 *a*	2 *bc*
July 20	404 *b*	1032 *b*	22 *a*	12 *a*	5 *a*
August 16	293 *b*	1202 *b*	2 *bc*	2 *b*	2 *bc*
October 3	47 *c*	0 *c*	0 *c*	0 *b*	0 *c*
			Weed Fallow		
May 31	1592 *a*	3624 *a*	70 *a*	8 *ab*	10 *a*
July 6	1808 *a*	982 *b*	4 *b*	14 *a*	9 *a*
August 9	553 *b*	717 *c*	7 *b*	6 *b*	4 *b*
October 3	50 *c*	0 *d*	0 *b*	0 *c*	0 *b*
			Sweet Clover/Triticale		
May 31	424 *a*	1124 *b*	1 *bc*	12 *ab*	14 *a*
June 20	309 *a*	290 *c*	0 *c*	10 *ab*	8 *ab*
July 20	56 *b*	1744 *a*	5 *a*	43 *a*	6 *ab*
August 28	54 *b*	1200 *ab*	4 *ab*	3 *bc*	0 *b*
October 3	55 *b*	0 *d*	0 *c*	0 *c*	0 *b*
			Fall Rye		
May 31	552 *a*	184 *a*	1 *a*	6 *a*	9 *a*
July 26	225 *b*	352 *a*	1 *a*	1 *a*	2 *ab*
October 3	120 *c*	0 *b*	0 *a*	0 *a*	0 *b*

When wild oat density was compared at the last harvest of each treatment in trial 1, the treatments that did not differ significantly from sprayed wheat were winter triticale, alfalfa, the triticale intercrop, and sorghum-sudangrass (Table 7). Therefore, in the absence of herbicide, these treatments were as effective as the typical in-crop herbicide approach for controlling wild oat. Spring triticale had significantly more wild oat than these treatments; however, it still had significantly fewer wild oat than the partially sprayed and unsprayed wheat, and weed fallow treatments. Thus, all annual forage systems reduced the wild oat population when compared to the weedy check treatments in trial 1.

Table 7. Wild oat density at last harvest of each treatment for trial 1 (1994) at Carman, MB. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment and Harvest Date	plants per metre squared
Wheat + Grass and Broadleaf Herbicide (August 26)	0 *d*
Wheat + Broadleaf Herbicide (August 26)	112 *b*
Wheat - Herbicide (August 26)	109 *b*
Winter Triticale (September 23)	7 *cd*
Triticale Intercrop (September 23)	2 *d*
Spring Triticale (July 26)	55 *c*
Sorghum-Sudangrass (August 31)	0 *d*
Alfalfa (September 23)	4 *d*
Weed Fallow (July 20)	228 *a*
LSD ($p < 0.05$)	46.87
C.V.	53.13

In trial 2, the annual forage treatments had significantly fewer wild oat at the last harvest than all of the wheat treatments and the weed fallow (Table 8, and Appendix Table A5). Therefore in this trial, annual forages were more effective than herbicide in reducing the wild oat population. Only wild oat density in spring triticale did not differ significantly from that in partially sprayed wheat; a similar observation was made in trial 1, suggesting that this treatment is less effective in reducing wild oat populations than the other forages. Winter triticale and the triticale intercrop were the most effective treatments in reducing wild oat density.

Green foxtail density at the last harvest was significantly less for winter triticale, the triticale intercrop and alfalfa than for all other treatments (Table 8). These treatments were harvested last on October 3, 1995. At this point only wild oat plants were living because temperatures were too cold for green foxtail, thus this measurement may not be a good indication of the effectiveness of the these treatments in controlling green foxtail. Green foxtail density in these treatments was relatively high at the second last harvest (Table 6). It is interesting to note that there was significantly more green foxtail in sprayed wheat than in unsprayed wheat (Table 8). Wild oat density in these treatments was similar, therefore, this cannot account for the difference in green foxtail. Green foxtail density in the remaining annual forage treatments did not differ significantly from that in sprayed wheat, and in some cases was greater than in unsprayed wheat. Thus, annual forages in trial 2 did not suppress green foxtail.

Although the density of broadleaf weeds was relatively low in trial 2, some treatments may allow for broadleaf weeds to become a problem. For instance, the spring triticale and weed fallow treatments consistently had significantly higher levels of broadleaf weeds than unsprayed wheat. In another example, the sorghum-sudangrass and sweet clover triticale doublecrop treatments had significantly more red root pigweed at the last harvest of each treatment.

Table 8. Weed population density at last harvest (plants per metre squared) for trial 2 at Carman, 1995. Statistical analysis was performed on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment	Wild Oat	Green Foxtail	Lambs-quarter	Red Root Pigweed	Wild Buckwheat
Wheat+Grass and Broadleaf Herbicide (Aug. 15)	844 a	566 bc	0 c	0 d	0 c
Wheat+Broadleaf Herbicide (Aug. 15)	668 ab	466 bc	0 c	0 d	0 c
Wheat-Herbicide (Aug. 15)	820 a	280 d	0 c	8 cd	0 c
Winter Triticale (Oct. 3)	19 ef	0 e	0 c	0 d	0 c
Winter and Spring Triticale Intercrop (Oct. 3)	16 f	0 e	0 c	0 d	0 c
Spring Triticale (Aug. 9)	429 bc	675 ab	10 a	30 ab	4 ab
Sorghum-Sudangrass (Aug. 16)	37 de	368 cd	1 c	90 a	0 c
Alfalfa (Oct. 3)	47 de	0 e	0 c	0 d	0 c
Sweet Clover/Triticale Doublecrop (Aug. 28)	54 d	1200 a	3 bc	14 bc	8 a
Fall Rye (July 26)	225 c	352 cd	1 cd	3 cd	2 bc
Weed Fallow (Aug. 9)	553 ab	717 ab	6 ab	28 ab	4 b

4.1.1.2 Development Stage

Weed development stage is an indication of the seed production potential of that weed at the time of measurement. Seed production potential of the weeds was variable between treatments because each treatment was harvested a different number of times. Development stage for crops and weeds (wild oat and green foxtail only) were measured at each harvest in trial 2 only.

In general, weeds were less developed at time of harvest in treatments with a frequent harvest schedule and more competitive crop plants. In the three wheat treatments, wild oat and green foxtail plants were mature (Zadoks 90) at time of grain harvest (Table 9). Fall rye was also harvested for grain, however, it was harvested on July 26, 1995, when wild oat and green foxtail plants were at Zadoks 21 and had not yet produced seed. Because fall rye had been seeded the previous fall, and had initiated growth earlier in spring than wheat, it provided more competition with the grass weeds. Even though the spring triticale and weed fallow treatments were harvested earlier, and more frequently than fall rye, wild oat and green foxtail plants in these treatments were more developed and likely shed more seed than under fall rye. Less competition in these treatments emphasizes the importance of the fall growth habit of fall rye. In the sweet clover/triticale doublecrop weed plants were still in the vegetative stage at the first two harvests (one sweet clover; and one triticale); however, at the final harvest, some weed plants had produced seed. Winter triticale, and the triticale intercrop were harvested on August 16, 1995, but wild oat and green foxtail had not yet produced mature seed because they had been harvested on previous occasions (Table 9). Sorghum-sudangrass was also harvested on August 16, 1995, but because it was late seeded the wild oat and green foxtail plants in this treatment had not produced mature seed.

Based on observations of wild oat and green foxtail development stage at the various harvests, the effectiveness of the treatments to reduce weed development ranked fall rye > winter triticale > the triticale intercrop = sorghum-sudangrass = alfalfa > spring triticale = weed fallow = sweet clover/triticale doublecrop > wheat (all 3 herbicide regimes).

Table 9. Development stage range for crop and grass weeds at each harvest in trial 2 (Carman, 1995).

		Development Stage (Zadoks)		
Treatment	Date	Crop	Wild Oat	Green Foxtail
Wheat+Grass and Broadleaf Herbicide	Aug. 15	90	90	90
Wheat+Broadleaf Herbicide Only	Aug. 15	90	90	90
Wheat-Herbicide	Aug. 15	90	90	90
Winter Triticale	June 26	14-21	14-49	11-15
	July 20	14-24	13-69	12-59
	Aug. 16	15-24	52-69	12-59
	Oct. 3	29	12-45	0
Spring and Winter Triticale	July 6	14-59*	45-69	11-16
	Aug. 16	29**	56-85	0-59
	Oct. 3	29**	0-47	0
SpringTriticale	July 6	49-69	45-69	13-22
	Aug. 9	59-60	47-73	90
Sorghum-Sudangrass	Aug. 16	16-22	54-85	12-59
Alfalfa	June 26	2-9***	45-49	12-16
	July 20	5-11***	12-69	12-59
	Aug. 16	4-8***	69-85	59
	Oct. 3	spindly	13-26	0
Weed Fallow	July 6	--	45-69	12-21
	Aug. 9	--	45-73	90
Sweet Clover/Winter Triticale	June 20	50%bloom	13-45	11-13
	July 20	13-15	47-69	13-47
	Aug. 28	14-22	47-90	59
Fall Rye	July 26	90	10-21	11-21

* Spring and Winter Triticale, ** Winter Triticale Only, *** Number of Trifoliate Leaves

4.1.1.3 Dry Matter Production

Dry matter production is a measure of growth. Forage and weed dry matter production was measured to determine 1) forage growth potential in herbicide-free production systems, and 2) the extent to which annual forage systems influenced weed dry matter production. Total dry matter production of forage and weed for each treatment as well as the crop:weed biomass ratio was lower in trial 2 than in trial 1 (Tables 10 and 11, and Appendix Tables A6 and A7). Grass weed pressure was more intense in trial 2 because grass weed seeds were allowed to shed freely in the year previous to the trial 2 forage year.

Table 10. Total seasonal forage and weed dry matter production (kg/ha) for trial 1 (Carman, 1994). Statistical analysis was performed on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment	Forage		Weed		Total		Weed/Total x 100 (%)
Winter Triticale	3971	*b*	1871	*c*	5879	*b*	32
Spring and Winter Triticale Intercrop	4070	*b*	3303	*b*	7377	*a*	45
Spring Triticale	4462	*b*	3082	*b*	7544	*a*	41
Sorghum-Sudangrass	7838	*a*	1322	*d*	9159	*a*	14
Alfalfa	1840	*c*	5971	*a*	7768	*a*	76
Weed Fallow	0	*d*	8270	*a*	8270	*a*	100

Table 11. Total seasonal forage and weed dry matter production (kg/ha) for trial 2 (Carman, 1995). Statistical analysis was performed on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment	Forage		Weed		Total		Weed/Total x 100 (%)
Winter Triticale	1212	*c*	3708	*abc*	4920	*b*	75
Spring and Winter Triticale Intercrop	1360	*c*	4126	*ab*	5487	*b*	75
Spring Triticale	482	*de*	4858	*a*	5341	*b*	91
Sorghum-Sudangrass	360	*e*	3138	*bc*	3497	*c*	90
Alfalfa	692	*d*	4465	*a*	5166	*b*	87
Sweet Clover/Triticale Doublecrop	3136	*b*	2817	*c*	5953	*ab*	47
Fall Rye	7492	*a*	62	*d*	7554	*a*	1
Weed Fallow	0	*f*	5181	*a*	5245	*b*	100

Total seasonal dry matter production for the forage treatments in trial 1 is shown in Table 10. Based on production of weed dry matter, the sorghum-sudangrass treatment was most successful in suppressing weed dry matter production > winter triticale > the triticale intercrop and spring triticale treatments > alfalfa and weed fallow (Table 10). In trial 2, the fall rye treatment was most successful in suppressing weed dry matter production > sweet clover/triticale doublecrop and sorghum-sudangrass > winter triticale, the triticale intercrop, alfalfa, spring triticale and weed fallow (Table 11).

Table 12. Forage and weed dry matter production (kg/ha) at each harvest date for trial 1 at Carman, 1994.

Date	Forage	Weed	Total	Weed/Total x 100 (%)
		Winter Triticale		
June 20	1070	1281	2350	54
July 8	910	325	1235	26
September 23	1295	250	1545	16
October 23	735	15	749	2
		Triticale Intercrop		
July 20	3165	2915	6079	48
September 23	905	393	1298	30
		Spring Triticale		
July 26	4462	3082	7544	41
		Sorghum-Sudangrass		
August 31	7545	1321	8866	15
September 23	293	0	293	0
		Alfalfa		
June 20	267	1779	2046	87
July 25	217	3850	4067	95
September 23	1327	329	1655	20
		Weed Fallow		
July 20	--	8270	8270	100

In most cases, weed yield was lowest on the last harvest date of the treatment (Table 12). In trial 1, yield of winter triticale did not seem to be affected by the weed yield; the crop yield was similar for all four harvests, but weed yield decreases from first to last harvest. This suggests that the factor that was reducing the weed population was the repeated harvests. Alternatively, alfalfa yield was highest at the last harvest when weed yield was the lowest. Weed yield for alfalfa was highest at the second harvest.

Even though crop yield at the second harvest for the triticale intercrop and sorghum-sudangrass was lower than at the first, weed yield at the second harvest was also lower than at the first, suggesting that the first harvest sufficiently suppressed weeds.

In trial 2, weed yield was also lowest at the last harvest. Yield of winter triticale, and alfalfa was greater than weeds at the last harvest. As in trial 1, weed yield for alfalfa was high at the second harvest suggesting that seedling alfalfa remains a very poor competitor with weeds for a long period of time (Table 13). It has been suggested that when alfalfa is established with a companion crop, the companion crop should be harvested at an early development stage (eg. boot stage in small grain crop) to reduce competition-related reductions in seedling growth (Sheaffer et al., 1989). Spring triticale yield was lower than weeds at both harvests suggesting that in a year with very high weed infestations this crop does not effectively reduce weed biomass. It is interesting to note that yield of sweet clover in the sweet clover/triticale doublecrop treatment was higher than weeds at the first harvest, but yield of the winter triticale component at the next two harvests was lower than weed yield. Because the sweet clover component had been established in the previous year it provided strong competition with weeds. Plant stand for the winter triticale component was good, but the winter triticale remained small and did not tiller as much as the stand that was established on its own in spring (visual observation). Fall rye also had a higher dry matter yield when harvested because it competed well with weeds.

Dry matter production values recorded in the present study are similar to values found in the literature. Previous research has shown that winter triticale cut four times for pasture yielded 1844 kg/ha (Berkenkamp and Meere, 1987); spring triticale cut once for silage yielded 8069 kg/ha (Berkenkamp and Meere, 1987); sorghum-sudangrass cut for greenfeed yielded 3706 kg/ha (Manitoba Agriculture, 1992); alfalfa seeded alone without herbicide yielded 5050 kg/ha (9000 kg/ha including weeds) (Sheaffer et al., 1989); and sweet clover yielded 4119 kg/ha (Manitoba Agriculture, 1992).

Table 13. Forage and weed dry matter production (kg/ha) at each harvest date for trial 2 at Carman, 1995.

Date	Forage	Weed	Total	Weed/Total x 100 (%)
	Winter Triticale			
June 26	593	20	614	3
July 20	19	1801	1820	99
August 16	217	1523	1740	88
October 3	384	353	736	48
	Triticale Intercrop			
July 6	745	27	771	3
August 16	200	3312	3512	94
October 3	415	788	1204	65
	Spring Triticale			
July 6	330	3810	4140	92
August 9	153	1049	1201	87
	Sorghum-Sudangrass			
August 16	359	3138	3497	90
	Alfalfa			
June 26	55	1936	1991	97
July 20	15	1819	1834	99
August 16	24	656	680	96
October 3	599	62	661	9
	Sweet Clover/Triticale Doublecrop			
June 20	2946*	172	3118	6
July 20	151**	1859	2010	92
August 28	39**	787	825	95
	Fall Rye			
July 26	7492	62	7554	1
	Weed Fallow			
July 6	--	3893	3893	100
August 9	--	1352	1352	100

* sweet clover, ** winter triticale

The suggested acceptable level of weeds in forage for livestock feed is 25% (Moline and Robinson, 1971). Moyer (1985), on the other hand, suggested that forages with weed levels of 80% or more may have acceptable nutrient compositions. In the present study, only sorghum-sudangrass (in trial 1, Table 10) and fall rye (in trial 2, Table 11) were found to have weed yield percentage of less than 25%. In trial 1, the triticale treatments had a weed yield less than 50% of total yield, and alfalfa had a weed yield less than 80% of total yield (Table 10). In trial 2, the sweet clover/triticale and fall rye treatments had a weed yield less than 50% of total (Table 11). Winter triticale and the triticale intercrop had weed yields less than 80% of the total yield, but all other treatments had a weed yield greater than 80% of total yield.

Most of the weed plants in this experiment were no longer vegetative when harvested, however, they were usually harvested before the seeds were ripe (Table 9). Marten and Anderson (1975) stated that some common annual weeds do not decrease the nutritive value of forages if used at "relatively early stages of maturity". They tested weeds that had a range of development stages from vegetative to green seed. Moyer and Hironaka (1993) concluded that when annual grass and broadleaf weeds were harvested at the soft to hard dough stage, protein digestibility of these weeds was similar to, or better than, that for tame oats. Also, they concluded that digestible energy content for five of the eight weed species was similar to, or greater than, that of alfalfa or meadow bromegrass (Moyer and Hironaka, 1993). Based on the results of this experiment, and the observations made in other experiments, it appears that the annual forage treatments in the present study may be an acceptable source of livestock feed.

4.1.1.4 Grain Yield

Grain yield for wheat was higher in trial 1 than in trial 2 because competition from weeds was much more intense in trial 2.

In trial 1, grain yield for wheat was significantly different for all treatments (Table 14). In trial 2, grain yield for wheat sprayed with grass and broadleaf herbicide was significantly higher than for the other two wheat treatments (Table 14). The mean yield of Katepwa wheat for Manitoba over 74 site-years is 3230 kg/ha (Seed Manitoba, 1996). Results of the present study indicate that trial 1 was conducted under "typical" weed population levels, while trial 2 was conducted under extremely intense weed competition.

Fall rye was grown in trial 2 only. Grain yield for fall rye was 2991 kg/ha when no herbicide was used. Typical grain yield for Prima fall rye using optimum management practices in the Black soil zone region of the Canadian prairies is approximately 4105 kg/ha thus, it is likely that yield loss was suffered in this experiment due to the absence of herbicides (Agriculture Canada, 1992).

Table 14. Grain yield (kg/ha) for Katepwa wheat in trials 1 (1994) and 2 (1995) at Carman. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment	Trial 1	Trial 2
Wheat + Grass and Broadleaf Herbicide	3215 *a*	313 *a*
Wheat + Broadleaf Herbicide	2122 *b*	39 *b*
Wheat - Herbicide	1203 *c*	65 *b*
L.S.D	427	111
C.V.	11	46

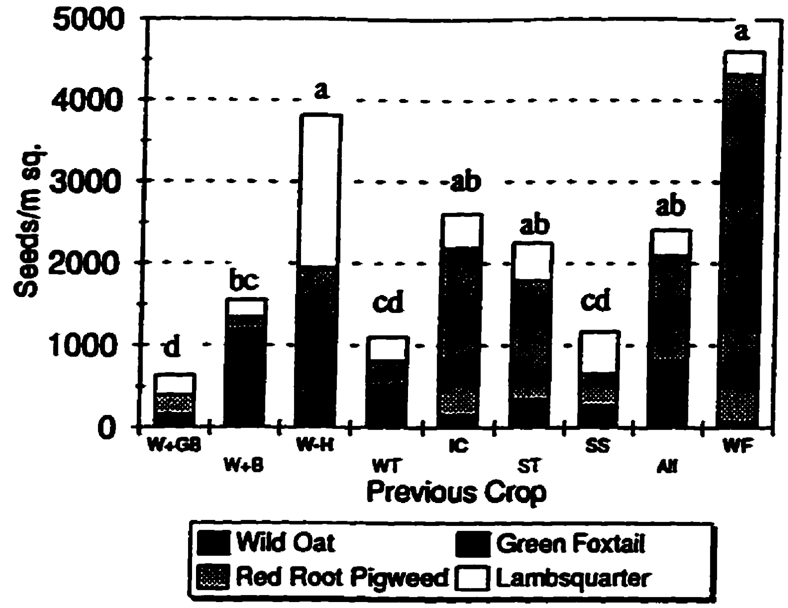
4.1.2 Test Crop Year

In the year after the annual forage suppressor treatments, the weed seedbank was assessed to determine the effect of annual forage systems on weed seed density and community composition in the seedbank. Soil cores were removed from all plots, transferred to the greenhouse, and weeds were forced to germinate and enumerated. Also, a crop of semi-leafless peas was seeded in all plots to determine pea seed yield potential following the various annual forage systems. Weeds emerging in the seedling pea crop were counted prior to herbicide application. After weed seedlings were counted, grass and broadleaf herbicide was applied to half of each pea plot. Pea grain yield was measured at the end of the season in sprayed and unsprayed subplots.

4.1.2.1 Weed Population Dynamics in the Seedbank

To determine the impact of annual forage systems on weed populations the density of weed seeds in the seedbank was determined in the year after forages. For all treatments the density of weed seeds in the seedbank was greater in trial 2 than in trial 1. This was because grass weeds were allowed to produce and shed seed the year before forage establishment in trial 2. The seedbank in trial 2 was dominated by green foxtail for all treatments while, no one weed species dominated over the treatments in trial 1.

In trial 1, total weed seed density for winter triticale and sorghum-sudangrass did not differ significantly from sprayed wheat (Figure 3a, and Appendix Table A8). These treatments had significantly fewer weed seeds than all other treatments. Therefore, these treatments provided effective weed suppression while reducing or eliminating the use of herbicide for one year. Total weed density for the triticale intercrop, spring triticale, weed fallow and alfalfa treatments, on the other hand, did not differ significantly from unsprayed wheat. Therefore, these treatments were not effective in weed suppression a)



b)

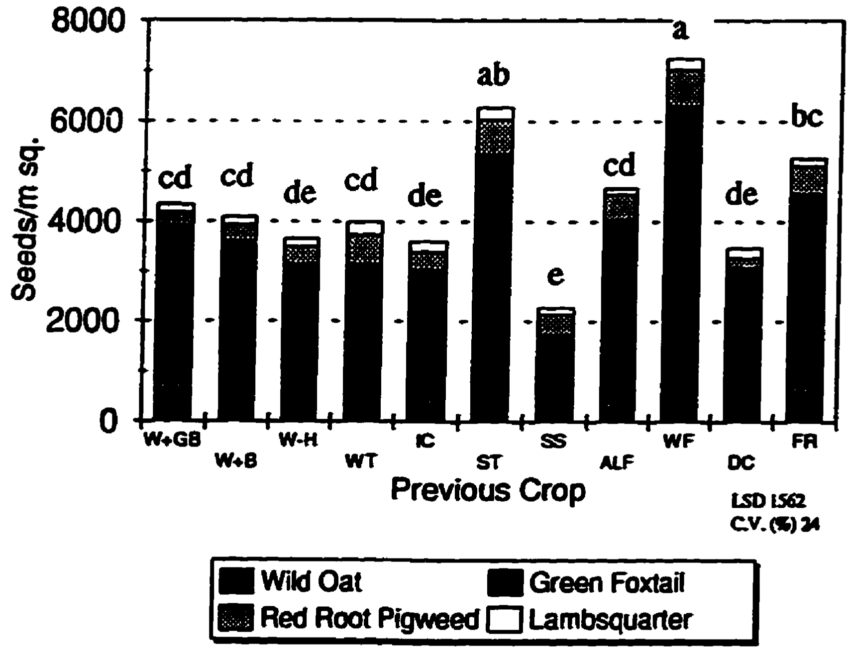


Figure 3. Density of weed seeds of four dominant weed species in the seedbank after treatments for a) trial 1 (1995) and b) trial 2 (1996). Statistical analysis was performed on log transformed total weed seed density for trial 1, and actual total weed seed density for trial 2. Means with the same letter are not significantly different LSD ($p<0.05$).

alone, and may need to be combined with herbicide to provide effective weed suppression.

In trial 2, weed density of sprayed wheat did not differ significantly from unsprayed wheat in terms of total density of weeds in the seedbank (Figure 3b). Thus, in a year where weed pressure is extreme, even herbicides are not able to affect weed seed production. Ghersa et al. (1996) state that herbicides alone will not eradicate weed problems because they only affect abundance of weeds at a patch scale for a short period of time. The spring triticale, weed fallow and fall rye treatments allowed significantly more weed seeds to return to the seedbank than the annual grain crop that had no herbicide. All other forage treatments did not differ significantly from unsprayed wheat. Sorghum-sudangrass had significantly fewer weeds than sprayed wheat, but this treatment did not differ significantly from unsprayed wheat.

The flux of weed seed into and out of a unit of the seedbank determines the potential population of that unit (Norris, 1996). In theory, to reduce or exhaust the seedbank one must stop seed production (Forcella et al., 1996; Norris, 1996). Annual forages have the potential to prevent established and stabilized weed populations from maintaining themselves. Based on these results, in a year when weed pressure was moderate, winter triticale and sorghum-sudangrass were effective in reducing the amount of weed seed returning to the seedbank to the same extent as a conventional herbicide treatment. However, under extreme weed pressure, neither the herbicidal or cultural weed control strategies were effective in reducing the amount of weed seeds returning to the seedbank.

Annual forages in the present study provided good control of wild oat. All forage systems tested in this experiment consistently controlled wild oat as well or better than sprayed wheat, and better than unsprayed wheat. In trial 1, wild oat density for all forage treatments did not differ significantly from sprayed wheat, and was significantly lower than in the partially sprayed and unsprayed wheat treatments (Table 15, and Appendix Table A9).

In trial 2, the alfalfa, weed fallow and sweet clover/triticale doublecrop treatments provided better wild oat control than sprayed wheat (Table 16). All other forage treatments provided similar wild oat control to sprayed wheat. All forage treatments provided better wild oat control than the partially sprayed and unsprayed wheat treatments. A dramatic reduction in the wild oat population can be achieved if input of new seeds into the soil is limited. The results of this experiment show that annual forage systems can reduce input of new wild oat seeds to the soil as well as or better than herbicides. Wild oat seed persists in the seedbank and small quantities are capable of reinfesting the field. This underscores the need for continued good control in subsequent years (Banting, 1973).

Seedbank densities for green foxtail were greater in trial 2 than in trial 1 for all treatments. In trial 1, the triticale intercrop, spring triticale, sorghum-sudangrass, and weed fallow treatments provided similar control of green foxtail as sprayed wheat, while winter triticale and alfalfa had significantly more green foxtail than sprayed wheat (Table 15). Winter triticale and alfalfa had the most frequent harvest schedule. The green foxtail plants in these treatments had a more prostrate growth habit. Schoner et al. (1978) observed this phenomenon with yellow foxtail in alfalfa subjected to a frequent cutting schedule. This enabled the green foxtail under these treatments to shed more seed than in the other forage treatments because the plants were maturing below cutting height at subsequent harvests.

In trial 2, no forage treatment had significantly fewer green foxtail seeds than unsprayed wheat (Table 16). The treatments that had significantly more green foxtail density than unsprayed wheat were spring triticale, alfalfa, fall rye and weed fallow. When spring triticale and the weed fallow were harvested for the second time on August

Table 15. Density of weed seeds (seeds per metre squared) in the seedbank for trial 1 (Carman, 1995). Statistical analysis was performed on log transformed data. Means with the same letters are not significantly different LSD ($p<0.05$).

Treatment	Wild Oat	Green Foxtail	Red Root Pigweed	Lambs-quarter	Wild Buckwheat	Green Smartweed	Wild Mustard
Wheat + Grass and Broadleaf Herbicide	35 *b*	126 *cd*	236 *cd*	244 *de*	33 *a*	3 *a*	15 *a*
Wheat + Broadleaf Herbicide	448 *a*	742 *ab*	156 *d*	204 *e*	40 *a*	10 *a*	73 *a*
Wheat - Herbicide	407 *a*	968 *a*	568 *c*	1874 *a*	23 *a*	5 *a*	50 *a*
Winter Triticale	13 *b*	511 *ab*	289 *cd*	294 *cde*	23 *a*	5 *a*	20 *a*
Spring and Winter Triticale Intercrop	30 *b*	128 *cd*	2025 *ab*	428 *bcd*	20 *a*	8 *a*	28 *a*
Spring Triticale	28 *b*	322 *abc*	1441 *b*	465 *bc*	25 *a*	13 *a*	40 *a*
Sorghum-Sudangrass	20 *b*	249 *bcd*	395 *c*	508 *b*	23 *a*	8 *a*	28 *a*
Alfalfa	43 *b*	780 a	1283 *b*	309 *bcde*	33 *a*	8 *a*	18 *a*
Weed Fallow	18 *b*	60 *d*	4245 *a*	282 *cde*	30 *a*	8 *a*	13 *a*

Table 16. Density of weed seeds (seeds per metre squared) in the seedbank for trial 2 (Carman, 1996). Means with the same letters are not significantly different LSD ($p<0.05$).

Treatment	Wild Oat	Green Foxtail	Red Root Pigweed	Lambs-quarter	Wild Buckwheat	Green Smartweed	Wild Mustard
Wheat + Grass and Broadleaf Herbicide	664 *bc*	3252 *cde*	254 *cd*	181 *ab*	28 *bc*	3 *c*	30 *ab*
Wheat + Broadleaf Herbicide	1335 *a*	2271 *def*	319 *cd*	151 *b*	20 bc	13 *abc*	20 *ab*
Wheat - Herbicide	991 *b*	2158 *ef*	342 *cd*	156 *b*	5 *c*	5 *bc*	33 *a*
Winter Triticale	367 *cde*	2774 *cdef*	583 *abc*	259 *a*	40 *abc*	5 *bc*	23 *ab*
Spring and Winter Triticale Intercrop	350 *cde*	2684 *cdef*	357 *bcd*	204 *ab*	23 *bc*	18 *ab*	3 *b*
Spring Triticale	538 *cde*	4801 *ab*	684 *ab*	254 *a*	65 *ab*	25 *a*	30 *ab*
Sorghum-Sudangrass	425 *cde*	1305 *f*	405 *abcd*	131 *b*	43 *abc*	5 *bc*	15 *ab*
Alfalfa	309 *de*	3712 *bcd*	513 *abcd*	118 *b*	30 *bc*	0 *c*	15 *ab*
Sweet Clover/Triticale Doublecrop	307 *de*	2764 *cdef*	186 *d*	206 *ab*	86 *a*	5 *bc*	13 ab
Fall Rye	598 cd	3959 bc	551 abc	143 b	80 a	13 abc	5 ab
Weed Fallow	254 *e*	6044 *a*	732 *a*	204 *ab*	28 *bc*	5 *bc*	13 ab
LSD	335	1524	342	94	46	14	30
C.V. (%)	42	33	53	36	77	110	114

9, 1995, green foxtail had already produced viable seed (Table 9). The weed fallow treatment in trial 2 had the highest green foxtail population, thus emphasizing the value of crop competition under extreme weed pressure (Table 16). Green foxtail density for all other forage treatments in trial 2 did not differ significantly from unsprayed wheat (Table 16). Results of the present study indicate that when green foxtail density was extremely high (trial 2), neither annual forages or in-crop herbicides effectively controlled this weed. When green foxtail populations were lower (trial 1), the triticale intercrop, sorghum-sudangrass and weed fallow gave effective control; control which was comparable to an in-crop herbicide treatment.

Red root pigweed seed density was greater in trial 1 than in trial 2. This was attributed to the extreme competition from grass weeds in the forage year of trial 2, which reduced seed production in some weeds. In trial 1, winter triticale and sorghum-sudangrass reduced red root pigweed seedbank density as well as sprayed wheat. Treatments which had a significantly higher red root pigweed seed density than sprayed wheat were the triticale intercrop, spring triticale, alfalfa, and weed fallow (Table 15). Weaver and McWilliams (1980) stated that red root pigweed is seldom found in "closed or shaded communities". In trial 1, the wheat, winter triticale and sorghum-sudangrass treatments competed better with red root pigweed than the remaining forage treatments possibly because they shaded the weeds more than the other treatments. Also, if the terminal inflorescence is damaged, red root pigweed can initiate elongated inflorescences from the lateral leaf axils and almost assume a prostrate growth habit (Weaver and McWilliams, 1980). This habit may account for the greater red root pigweed densities in the annual forages as opposed to the wheat which was not disturbed to the same extent during the growing season.

In trial 2, no significant differences were observed for red root pigweed density between the wheat treatments, indicating that herbicide regime had a minor influence on the population density of this weed (Table 16). This was most likely due to the fact that red root pigweed density in trial 2 was low because the grass weed population was very high. The only treatment to have less red root pigweed than sprayed wheat in trial 2 was the sweet clover/triticale doublecrop. All other treatments had more red root pigweed than unsprayed wheat, although the differences were not significant for the winter triticale, triticale intercrop, sorghum-sudangrass, alfalfa and fall rye treatments. Only spring triticale and the weed fallow had significantly more red root pigweed than sprayed wheat. In trial 1, winter triticale and sorghum-sudangrass controlled red root pigweed as well as herbicide, and in trial 2, only the sweet clover/triticale doublecrop treatment controlled red root pigweed better than herbicide.

Lambsquarter density in the seedbank was greater in trial 1 than in trial 2. Again, this was attributed to the greater competition from grass weeds in the forage year of trial 2 than trial 1. In trial 1, all forage treatments provided control of lambsquarter similar to sprayed wheat except spring triticale and sorghum-sudangrass (Table 15). Spring triticale and sorghum-sudangrass did, however, provide superior lambsquarter control to unsprayed wheat.

In trial 2, all annual forage treatments provided similar lambsquarter control to sprayed wheat (Table 16). The winter triticale and spring triticale treatments had significantly more lambsquarter seed in the seedbank than unsprayed wheat. Lambsquarter density in the seedbank of partially sprayed and unsprayed wheat may be low because of the high number of wild oat seed in the seedbank for these treatments. Based on the observations made in both trials, annual forage systems gave good control of lambsquarter. Bassett and Crompton (1978) state in their paper on the biology of lambsquarter that this weed is unable to withstand clipping and that seed production is greatly reduced when plants are in competition with other plants. Thus, annual forage systems most likely suppress lambsquarter populations by reducing seed production through competition and prevention of flowering.

Wild buckwheat density in the seedbank was similar in trial 1 and trial 2. In trial 1, all forage treatments provided similar wild buckwheat control to sprayed wheat (Table 15). In trial 2, the treatments that provided similar wild buckwheat control to sprayed wheat were winter triticale, the triticale intercrop, sorghum-sudangrass, alfalfa, and the weed fallow (Table 16). The spring triticale, sweet clover/triticale doublecrop, and fall rye treatments had significantly more wild buckwheat than unsprayed wheat. Pressure from grass weeds in the forage year of unsprayed wheat was high (Table 6), therefore, wild buckwheat density was low in this treatment. Therefore, even though wild buckwheat seed density in the spring triticale, sweet clover/triticale doublecrop, and fall rye treatments was greater than in unsprayed wheat (Table 16), this observation does not imply that these forages give poor control of wild buckwheat.

Based on the observations made in both trials, annual forage treatments reduce wild buckwheat seed density as well as herbicide treated wheat. It has been suggested that delayed crop seeding will allow early flushes of wild buckwheat to be killed by cultivation (Hume et al., 1983). In trial 2, each treatment was cultivated prior to seeding in 1995 with the exception of sweet clover and fall rye which were seeded in 1994. This may attribute to the higher wild buckwheat density in the seedbank for these treatments. Sweet clover had significantly more wild buckwheat at the early in-crop weed count in 1995 than sprayed wheat (Table 4).

Wild mustard density in the seedbank was similar in trial 1 and trial 2. In trial 1, no significant differences in wild mustard density were observed between treatments (Table 15). However, wild mustard density in the seedbank was highest in the partially sprayed and unsprayed wheat treatments. Therefore, in trial 1, the annual forage treatments provided wild mustard control which was similar to sprayed wheat.

In trial 2, all forage treatments provided wild mustard control which was similar to sprayed wheat (Table 16). In fact, most of the forage treatments had less wild mustard than sprayed wheat. All forage treatments had less wild mustard than unsprayed wheat, and this difference was significant for the triticale intercrop. Based on these observations, annual forage systems consistently controlled wild mustard as well as sprayed wheat. In fact, in most cases less wild mustard seed had returned to the seedbank under the annual forages than under the unsprayed wheat. Mulligan and Bailey (1975) stated that mature wild mustard seed pods don't shatter before the cereal crop is harvested. The annual forages in this experiment were harvested in most cases before wild mustard produced mature seed pods, thus preventing the return of new seed to the seedbank.

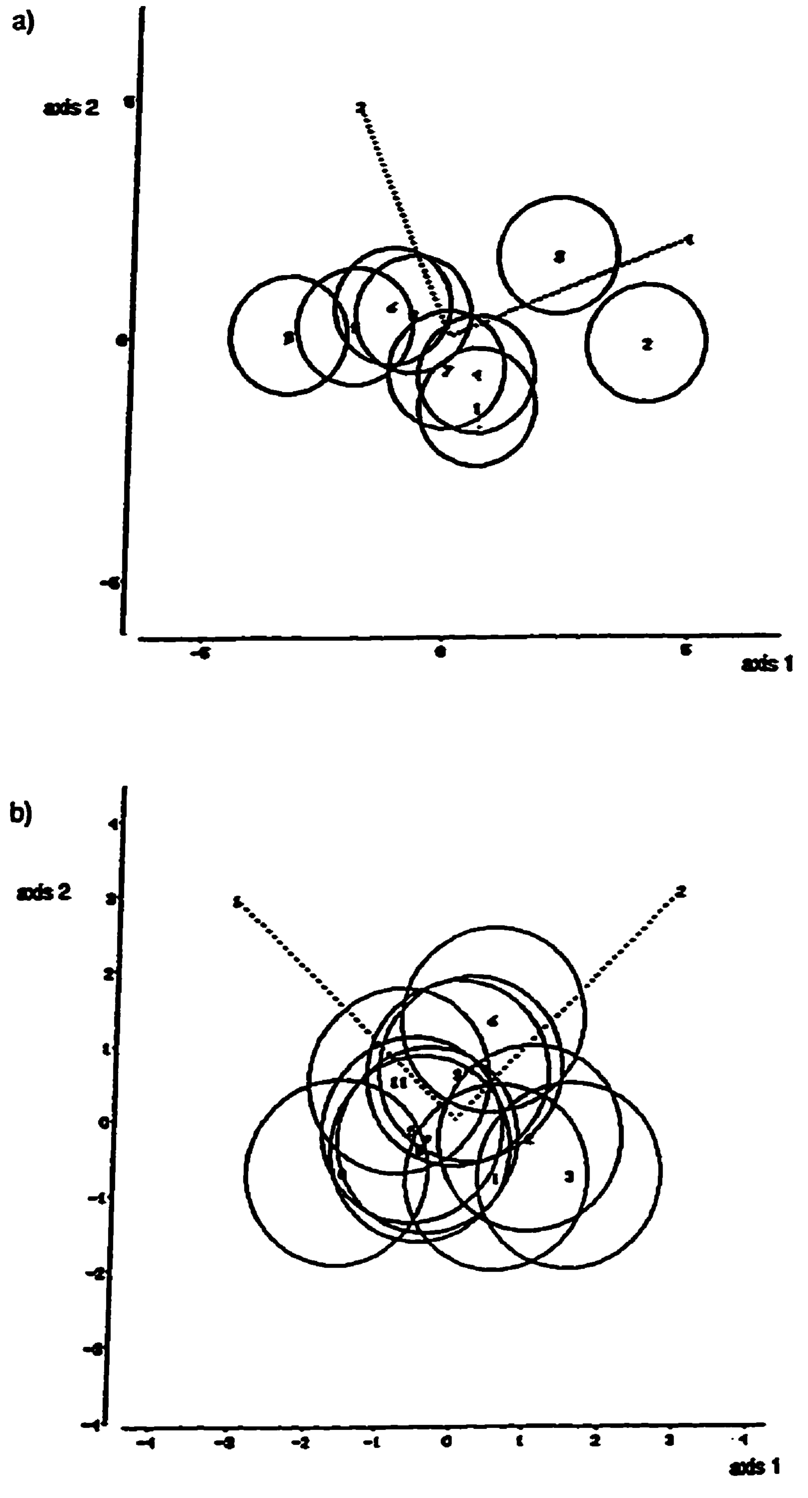
Green smartweed density in the seedbank was similar in trial 1 and trial 2. In trial 1, green smartweed density was greatest in the spring triticale treatment, however, the differences observed between treatments were not significant (Table 15). Therefore, in trial 1, the annual forage treatments provided green smartweed control which was similar to sprayed wheat.

In trial 2, the treatments that provided green smartweed control which was similar to sprayed wheat were winter triticale, sorghum-sudangrass, alfalfa, weed fallow, sweet clover/triticale, and fall rye (Table 16). The triticale intercrop and spring triticale treatments allowed more green smartweed seed to return to the seedbank than unsprayed wheat. Based on the observations made in both trials, annual forages give good control of green smartweed with the possible exceptions of the triticale intercrop and spring triticale treatments.

4.1.2.2 Seedbank Weed Community Composition

The effect of annual forages on composition of the weed seed community was determined using multivariate analyses. Canonical discriminant analysis (CDA) was performed on the seedbank data to determine if there were significant treatment differences for community composition (Manly, 1994). Circles that overlap represent treatments that are not significantly different from one another ($p<0.05$) (Figures 4a and 4b). Principal component analysis (PCA) was performed on the seedbank data to determine the association of the annual forage treatments with weed species (Manly, 1994). The association of weed species with forage system could be determined for each trial by comparing vector direction and length (Figures 5a and 5b). Direction of the vector indicates the association, and proximity of treatment number to vector indicates the strength of association. Longer vectors indicate that there is more variation for that weed species. Treatments that are located further up the vector are more strongly associated with that weed species.

Distinct community differences between treatments were observed for trial 1 but not for trial 2 (Figures 4a and 4b). In trial 1, the forage treatments that affected the weed community in the seedbank most like the conventional herbicide treatment were sorghum-sudangrass, winter triticale, and alfalfa. These treatments did not differ significantly from sprayed wheat in terms of species composition. Sorghum-sudangrass and winter triticale also did not differ significantly from herbicide treated wheat in terms of total weed density in the seedbank (Figure 3a). The treatments that had a significantly different weed community than sprayed wheat were the triticale intercrop, spring triticale, and weed fallow treatments (Figure 4a). Despite the fact that seedbank weed community for these forages was different than for sprayed wheat, the weed community for all forage treatments was significantly different from unsprayed and partially sprayed wheat. Even the weed fallow treatment had a significantly different community



1=sprayed wheat, 2=partially sprayed wheat, 3=unsprayed wheat, 4=winter triticale
5=triticale intercrop, 6=spring triticale, 7=sorghum-sudangrass, 8=alfalfa,
9=weed fallow, 10=sweet clover/triticale, 11=fall rye.

Figure 4. Multivariate analysis of the weed community in the weed seedbank after annual forage systems. a) canonical discriminant analysis (CDA) for trial 1 (1995), b) CDA for trial 2 (1996). Non-overlapping circles are significantly different ($p<0.05$).

composition than unsprayed wheat suggesting that the harvest imposed on this treatment affected the composition of the weed community.

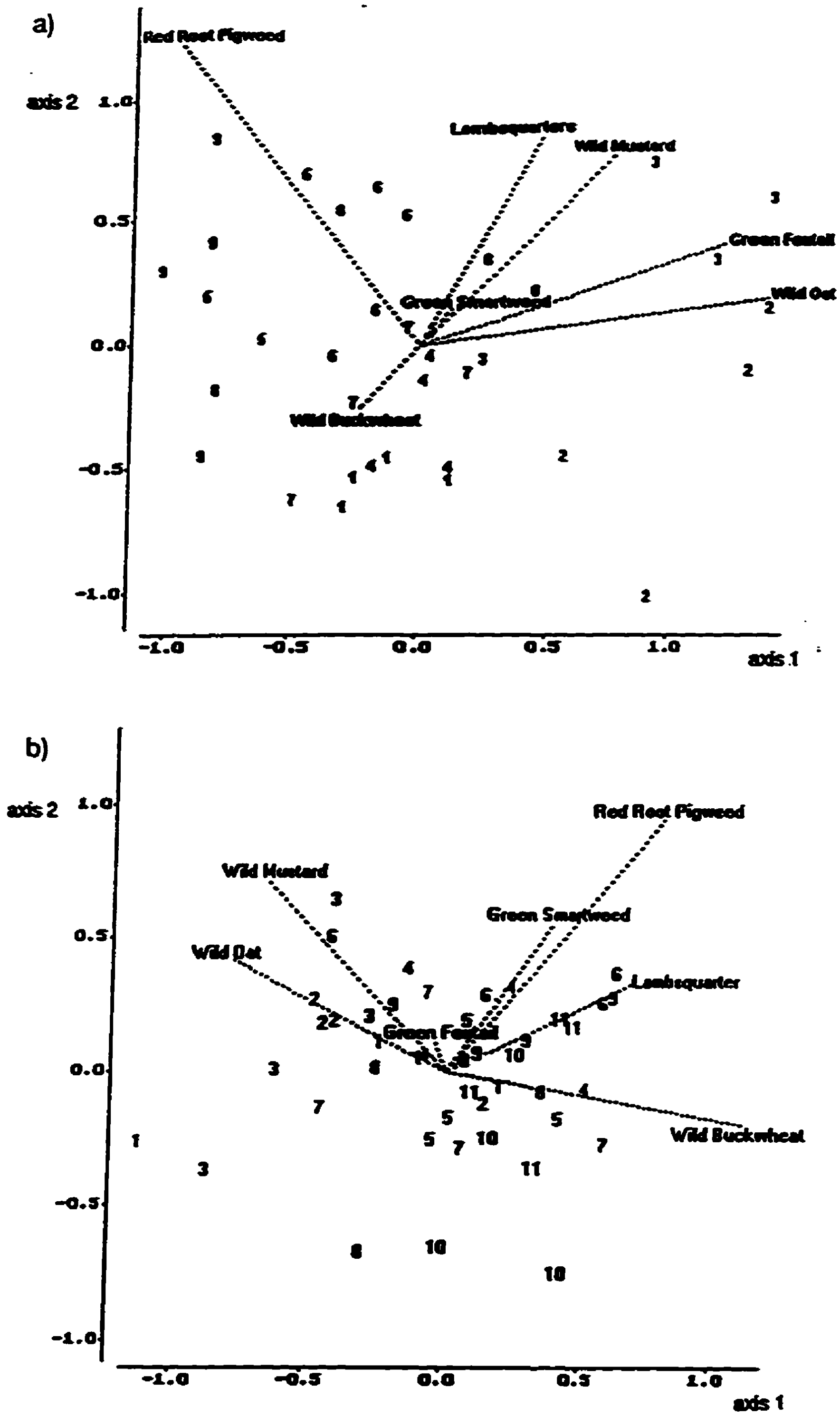
In trial 2, no forage treatment had a significantly different weed community than sprayed wheat (Figure 4b). However, the unsprayed and partially sprayed wheat treatments also did not have a significantly different weed community than sprayed wheat. The only treatments to have a significantly different weed community than unsprayed wheat were fall rye, and the sweet clover/triticale doublecrop. These treatments are unique because they had been sown in the year previous to the other forages, and this may account for the observed difference in community composition when compared with unsprayed wheat.

When competitive pressure from weeds was moderate, as in trial 1, annual forages affected the seedbank weed community in a similar manner to herbicide treated wheat. The forage and sprayed wheat treatments all shifted the seedbank weed community away from that found under unsprayed wheat. However, when competitive pressure from weeds was extreme, as in trial 2, most annual forages and herbicide treated wheat did not affect the seedbank weed community any differently than wheat that had not received herbicide. Derksen et al. (1996a) found that crop rotation had a larger effect on weed community than did tillage. In this experiment, obvious community differences were not observed for trial 2 because in the year previous to forages, grass weeds were allowed to shed seed. Therefore, it would appear that environmental factors (i.e. greater initial weed density in the community) had a greater effect on weed community composition in trial 2, and cropping system had a greater effect on weed community composition in trial 1.

Clear associations of the treatments with weed species were observed for trial 1, but not for trial 2 (Figures 5a and 5b). In trial 1, the treatments that were not associated with any one weed species were sprayed wheat, winter triticale, sorghum-sudangrass and alfalfa. The winter triticale and sorghum-sudangrass treatments behaved much like the conventional herbicide treatment by reducing the number of weed seeds returning to the seedbank (Figure 3a) while not selecting for any one weed species. The partially sprayed and unsprayed wheat treatments had a strong association with the two grass weed species. The unsprayed wheat was also strongly associated with wild mustard. Wild oat and wild mustard are known to be associated with wheat (Mulligan and Bailey, 1975; Sharma and Vanden Born, 1978). The remaining annual forage treatments were associated with the broadleaf weed species to various degrees. For example, both the weed fallow and spring triticale treatments were associated with red root pigweed, but the association was stronger for the weed fallow treatment.

In trial 2, the treatments that were not associated with any one weed species were sorghum-sudangrass, and the sweet clover/triticale doublecrop. The remaining treatments were associated with the various weed species, but none of these associations were strong. The partially sprayed and unsprayed wheat treatments were associated with wild oat, and unsprayed wheat was associated with wild mustard. This was observed in trial 1 as well. No one treatment was more strongly associated with green foxtail than any other (as indicated by the short vector in Figure 5b). This was attributed to the fact that green foxtail density was high in all treatments (Table 16). As in trial 1, the remaining annual forage treatments were associated with the broadleaf weed species to various degrees.

Weed communities are composed of genotypically different, plastic individuals that are heterogenously distributed in space and time (Van Groenendal, 1988; Navas, 1991; Jordan and Jannink, 1996). The variability of weed communities will affect their evolutionary responses to selective pressures such as weed control. The results from



1=sprayed wheat, 2=partially sprayed wheat, 3=unsprayed wheat, 4=winter triticale
5=triticale intercrop, 6=spring triticale, 7=sorghum-sudangrass, 8=alfalfa,
9=weed fallow, 10=sweet clover/triticale, 11=fall rye.

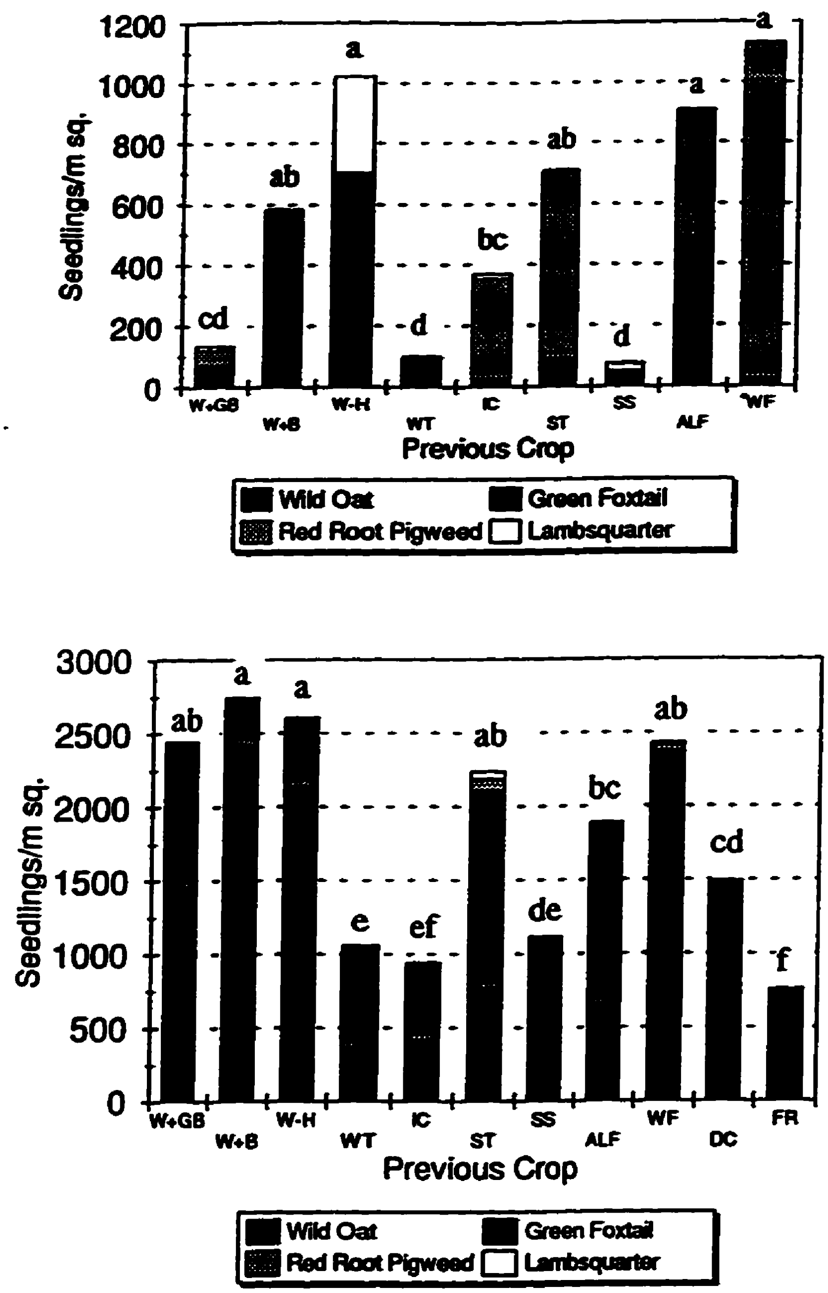
Figure 5. Multivariate analysis of the weed community in the weed seedbank after annual forage systems. a) principal component analysis (PCA) for trial 1 (1995), b) PCA for trial 2 (1996). Proximity of treatment number to vector indicates strength of association.

both trials indicate that annual grain crops may select for grass weeds to become a problem. In both trials partially sprayed and unsprayed wheat were associated with wild oat and green foxtail. Also, in trial 2, wheat sprayed with grass and broadleaf herbicide was moderately associated with wild oat. Wild oat and green foxtail are known to be associated with cereal crops (Sharma and Vanden Born, 1978; Douglas et al., 1985). Broadleaf weeds were more dominant in the seedbank community after annual forages, with the exception of winter triticale (trial 1 only), sorghum-sudangrass, and sweet clover/triticale doublecrop which were not associated more with one weed type over another. Wild buckwheat, red root pigweed, and lambsquarter have been cited as being common in disturbed and open habitats which may explain why these weeds were associated more with the forage treatments than the grass weeds (Bassett and Crompton, 1978; Weaver and McWilliams, 1980; and Hume et al., 1983). Annual forage systems could potentially select for broadleaf weed species to become a problem. Results of this study suggest that a diversity of crops in an IWM system will vary the selective pressure imposed on weed communities (Jordan and Jannink, 1996; Swanton and Murphy, 1996). In doing so, it may be possible to avoid adverse shifts in the weed spectrum.

4.1.2.3 Weed Population Dynamics in a Pea Test Crop

Peas were sown in the year following forages to determine the effect of the forages on weed populations in a subsequent crop. Peas were chosen so that nitrogen fertilizer would not have to be added. The addition of nitrogen may have confounded the experiment because some of the forages were nitrogen fixers and some were not. In addition, placement of nitrogen fertilizer can influence weed growth. Weed seedling density was measured in a herbicide-free seedling pea test crop in trials 1 and 2.

In trial 1, the treatments that controlled the total number of weeds emerging in the pea test crop as well or better than herbicide treated wheat were winter triticale, a)



b)

Figure 6. Density of four dominant weed species present in peas (prior to herbicide) following forages for a) trial 1 (1995) and b) trial 2 (1996). Statistical analysis was performed on log transformed total weed density. Means with the same letter are not significantly different LSD ($p<0.05$).

triticale intercrop and sorghum-sudangrass (Figures 6a, and Appendix Table A8). The treatments that did not control weeds any better than unsprayed wheat were spring triticale, alfalfa and the weed fallow. In trial 2, all forage treatments had less total weed seedlings emerge in peas than the sprayed wheat (Figure 6b, and Appendix Table A8). The treatments that had significantly fewer weeds emerge than sprayed wheat were winter triticale, triticale intercrop, sorghum-sudangrass, sweet clover/triticale and fall rye. Alfalfa provided similar weed control to sprayed wheat. The spring triticale and weed fallow treatments did not control weeds any better than unsprayed wheat.

Based on the observations made in trials 1 and 2, winter triticale, the triticale intercrop, sorghum-sudangrass, sweet clover/triticale doublecrop, and fall rye consistently suppressed the total number of weed seedlings being recruited in a subsequent crop as well as or better than herbicides. Spring triticale, alfalfa and the weed fallow did not suppress the number of weed seedlings being recruited in a subsequent crop as well as herbicides.

When each major weed was considered separately, wild oat density was found to follow a similar trend in both trial 1 and trial 2. In trial 1, the treatments that had significantly fewer wild oat seedlings than sprayed wheat were winter triticale, the triticale intercrop, and sorghum-sudangrass (Table 17, and Appendix Table A10). The treatments that did not differ significantly from sprayed wheat for wild oat were spring triticale, alfalfa, and weed fallow. Wild oat density in partially sprayed and unsprayed wheat was significantly higher than in all other treatments. In trial 2, wild oat densities were significantly lower in all forage treatments when compared with sprayed wheat (Table 18, and Appendix Table A11). The only exception was the sweet clover/triticale treatment, which did not differ significantly from sprayed wheat. Also, wild oat density in the partially sprayed and unsprayed wheat treatments was significantly higher than in all other treatments.

Table 17. Density of weeds emerged (seedlings per metre squared) in a pea test crop for trial 1 (Carman, 1995). Statistical analysis was performed on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment	Wild Oat	Green Foxtail	Red Root Pigweed	Lambs-quarter	Wild Buckwheat
Wheat + Grass and Broadleaf Herbicide	29 *b*	42 *cde*	50 *c*	12 *bc*	11 *a*
Wheat + Broadleaf Herbicide	283 *a*	290 *ab*	3 *d*	8 *bc*	10 *ab*
Wheat - Herbicide	283 *a*	333 *abc*	88 *c*	318 *a*	9 *a*
Winter Triticale	4 *e*	91 *bcd*	4 *d*	2 *c*	2 *c*
Spring and Winter Triticale Intercrop	10 *de*	18 *de*	327 *b*	15 *b*	5 *abc*
Spring Triticale	31 *b*	60 *bcd*	611 *ab*	9 *bc*	9 *ab*
Sorghum-Sudangrass	12 *cd*	30 *cde*	8 *d*	25 *b*	2 *bc*
Alfalfa	30 *b*	460 *a*	406 *b*	11 *bc*	2 *c*
Weed Fallow	20 *bc*	8 *e*	1096 *a*	7 *bc*	5 *abc*

Table 18. Density of weeds emerged (seedlings per metre squared) in a pea test crop for trial 2 (Carman, 1996). Statistical analysis was performed on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment	Wild Oat	Green Foxtail	Red Root Pigweed	Lambs-quarter	Wild Buckwheat
Wheat + Grass and Broadleaf Herbicide	1461 *b*	962 *abc*	20 *ab*	1 *bc*	1 *c*
Wheat + Broadleaf Herbicide	2426 *a*	316 *d*	2 *bcd*	0 *c*	1 *c*
Wheat - Herbicide	2144 *a*	461 *cd*	1 *cd*	3 *bc*	1 *c*
Winter Triticale	369 *f*	669 *bcd*	13 *abc*	6 *bc*	1 *c*
Spring and Winter Triticale Intercrop	421 *f*	490 *cd*	24 *abcd*	7 *bc*	16 *abc*
Spring Triticale	773 *de*	1338 *ab*	79 *a*	51 *a*	4 *bc*
Sorghum-Sudangrass	1001 *cd*	103 *e*	12 *abcd*	4 *abc*	41 *ab*
Alfalfa	662 *e*	1205 *ab*	19 *a*	7 *abc*	5 *abc*
Sweet Clover/Triticale Doublecrop	1077 *bc*	404 *d*	2 *bcd*	9 *abc*	17 *abc*
Fall Rye	744 de	16 f	0 d	0 c	51 *a*
Weed Fallow	667 *e*	1712 *a*	35 *a*	16 *ab*	18 abc

Based on these results, it can be concluded that annual forages suppressed the density of wild oat emerging in a subsequent crop as well or better than a conventional herbicide treatment. Annual forages also suppressed the density of wild oat seed returning to the seedbank as well as or better than the herbicide treated grain crop (Tables 15 and 16). The results from this experiment are similar to those found by other researchers. For instance, Thurston (1966) found that a one year ley was as effective at reducing the number of wild oat seeds returning to the seedbank as a five year ley. Similarly, Wilson and Phipps (1985) found that three years of barley cut for silage exhausted the wild oat seedbank by preventing return of new seeds.

It is interesting to note that density of wild oat emerged in the seedling pea crop was greater than that found in the seedbank for trial 2 (Tables 16 and 18). This may be due to a number of factors. For instance, it is possible that wild oat emerged in the seedling pea crop from a depth below what was sampled (i.e. 8 cm) for the seedbank study. It is also possible that the sample number for the seedbank study was not large enough to give an accurate description of the density of seeds in the seedbank. It is also possible that not all the wild oat seed was forced to germinate in the greenhouse. Despite this discrepancy in the data between seedbank and test crop wild oat density, the relative density of wild oat for each treatment is the same and conclusions on the effeicacy of each treatment can be made.

Transformation of the data was performed where necessary to correct for non-heterogeneity of variance in this experiment. It was found that square root transformation did not correct the problem, thus, log transformation was chosen. In most cases log transformation was found to have an effect on mean separation and, therefore, on final conclusions drawn from the data. However, in some cases the relative ranking of two means was reversed when the data was transformed (see Table 17, green foxtail and wild buckwheat; and Table 18, red root pigweed, lambsquarter and wild buckwheat). This problem has been noted to happen when using arcsine and square root transformations

(Ahrens et al., 1990). Thus, the limitations of log transformation have been acknowledged when making conclusions from the data where this reversal has occurred.

In trial 1, all forage treatments with the exception of alfalfa provided green foxtail control which was similar to wheat sprayed with grass and broadleaf herbicide (Table 17). In trial 2, the sorghum-sudangrass, fall rye and sweet clover/triticale doublecrop treatments had fewer green foxtail seedlings than the sprayed wheat while the remaining treatments had green foxtail populations similar to the sprayed wheat (Table 18).

One interesting observation was that while the fall rye treatment had significantly more green foxtail seeds in the seedbank in spring than the sprayed wheat (Table 16), the fall rye treatment had significantly fewer green foxtail seedlings in the pea crop (Table 18). Therefore, the fall rye appears to have reduced seedling recruitment of green foxtail to a greater extent than the other treatments. This may have been attributed to allelopathic effects of fall rye or the physical fall rye residue present in spring (Weston, 1996). In trial 2, those treatments which left some residue on the soil after harvest, or had some regrowth in spring, (all except spring triticale, alfalfa, and weed fallow), provided better green foxtail suppression.

In trial 1, winter triticale and sorghum-sudangrass provided red root pigweed control which was similar to wheat sprayed with grass and broadleaf herbicide (Table 17). All other treatments had significantly more red root pigweed than unsprayed wheat. In trial 2, red root pigweed density in peas for partially sprayed and unsprayed wheat was less than for sprayed wheat (Table 18). This was most likely due to the competition from high densities of wild oat in these treatments. Fall rye was the only annual forage treatment to provide better red root pigweed control in peas than sprayed wheat. All other treatments provided control which was similar to sprayed wheat.

In trial 1, density of red root pigweed in the seedbank (Table 15) for the triticale intercrop did not differ significantly from that in the weed fallow treatment, but in peas red root pigweed density was significantly less (Table 17). Also, density of red root pigweed seed in the seedbank for the spring triticale treatment was significantly less than for the weed fallow treatment, but in peas these treatments did not differ. These differences observed between the seedbank and seedling recruitment in peas can be attributed to the fact that the winter triticale portion of the intercrop regrew in spring prior to seeding with peas and suppressed recruitment of red root pigweed. The same weed suppression was not observed for spring triticale because there was no regrowth of this crop in spring. In trial 2, fall rye had significantly less red root pigweed emerged in peas than spring triticale, but these treatments did not differ significantly for red root pigweed density in the seedbank (Table 16). This suggests that the high levels of residue in the fall rye treatment, or the allelopathic effect of fall rye residue suppressed red root pigweed emergence (Weston, 1996).

Based on these results, sorghum-sudangrass and winter triticale provided good red root pigweed control in both trials. Red root pigweed, a warm-season weed, is not typically found in closed or shaded habitats which may account for the successful red root pigweed suppression by these treatments (Weaver and McWilliams, 1980). The weed fallow and spring triticale treatments, which left little residue on the soil surface, had the highest density of red root pigweed of any treatments in both years. When density of red root pigweed was lower (trial 2), annual forages were effective in reducing the population in the subsequent crop. When density of red root pigweed was higher, however, (trial 1) only winter triticale and sorghum-sudangrass were effective in reducing the population in the subsequent crop.

In trial 1, all forage treatments provided lambsquarter control which was similar to wheat sprayed with grass and broadleaf herbicide (Table 17). This same trend was observed in the seedbank for this weed (Table 15). In trial 2, all forage treatments, except spring triticale, provided lambsquarter control which was similar to sprayed wheat (Table 18). Lambsquarter density was significantly higher in the spring triticale treatment than in unsprayed wheat. In the seedbank, all forage treatments provided lambsquarter control which was similar to sprayed wheat (Table 16).

In trial 2, density of lambsquarter in the spring triticale seedbank did not differ significantly from that in the winter triticale seedbank (Table 16), but in the seedling pea crop, spring triticale had significantly more lambsquarter than winter triticale (Table 18). This was attributed to the fact that winter triticale initiated regrowth in the spring prior to pea seeding, therefore, it suppressed lambsquarter emergence whereas spring triticale did not. The weed fallow treatment in trial 2 also had less lambsquarter in peas than the spring triticale treatment. This was attributed to the intense competition of green foxtail with lambsquarter for this treatment. The good control of lambsquarter in the seedbank provided by annual forages was attributed to the fact that lambsquarter plants do not withstand clipping, and seed production is reduced by interspecific competition (Bassett and Crompton, 1978). It would appear from the results of lambsquarter seedling recruitment in peas that competition is a major factor in determining the density of lambsquarter emerging in the crop.

In trial 1, all forage treatments provided wild buckwheat control which was similar to, or better than, wheat sprayed with grass and broadleaf herbicide (Table 17). The treatments that had significantly less wild buckwheat than unsprayed wheat were winter triticale, sorghum-sudangrass, and alfalfa. In trial 2, the treatments that provided wild buckwheat control which was similar to sprayed wheat were winter triticale, the triticale intercrop, sorghum-sudangrass, alfalfa, and fall rye (Table 18). All other forage treatments had significantly more wild buckwheat than unsprayed wheat.

In trial 1, there were no significant differences in wild buckwheat density in the seedbank between treatments (Table 15), but in the seedling pea crop the wheat treatments had more wild buckwheat than most of the forages (Table 17). This was attributed to the competition that the forage treatments exerted prior to the seeding of the pea test crop. In the wild buckwheat seedbank for trial 2, the sweet clover/triticale doublecrop and fall rye treatments had significantly more wild buckwheat than unsprayed wheat (Table 16). This was attributed to the lack of spring cultivation for these treatments. Wild buckwheat density in the seedling pea crop for the doublecrop treatment was significantly higher than for unsprayed wheat, but density of wild buckwheat for the fall rye treatment did not differ significantly from that of sprayed wheat (Table 18). Fall rye suppressed wild buckwheat from emerging in the subsequent pea crop whereas the doublecrop did not. In trial 1, wild buckwheat density in annual forages was less than in the wheat treatments, but in trial 2, buckwheat density in annual forages was greater than in the wheat treatments. Thus, in a year where wild buckwheat density is higher, as in trial 2, wild buckwheat is not a problem for annual grain crops, but may become one in annual forages.

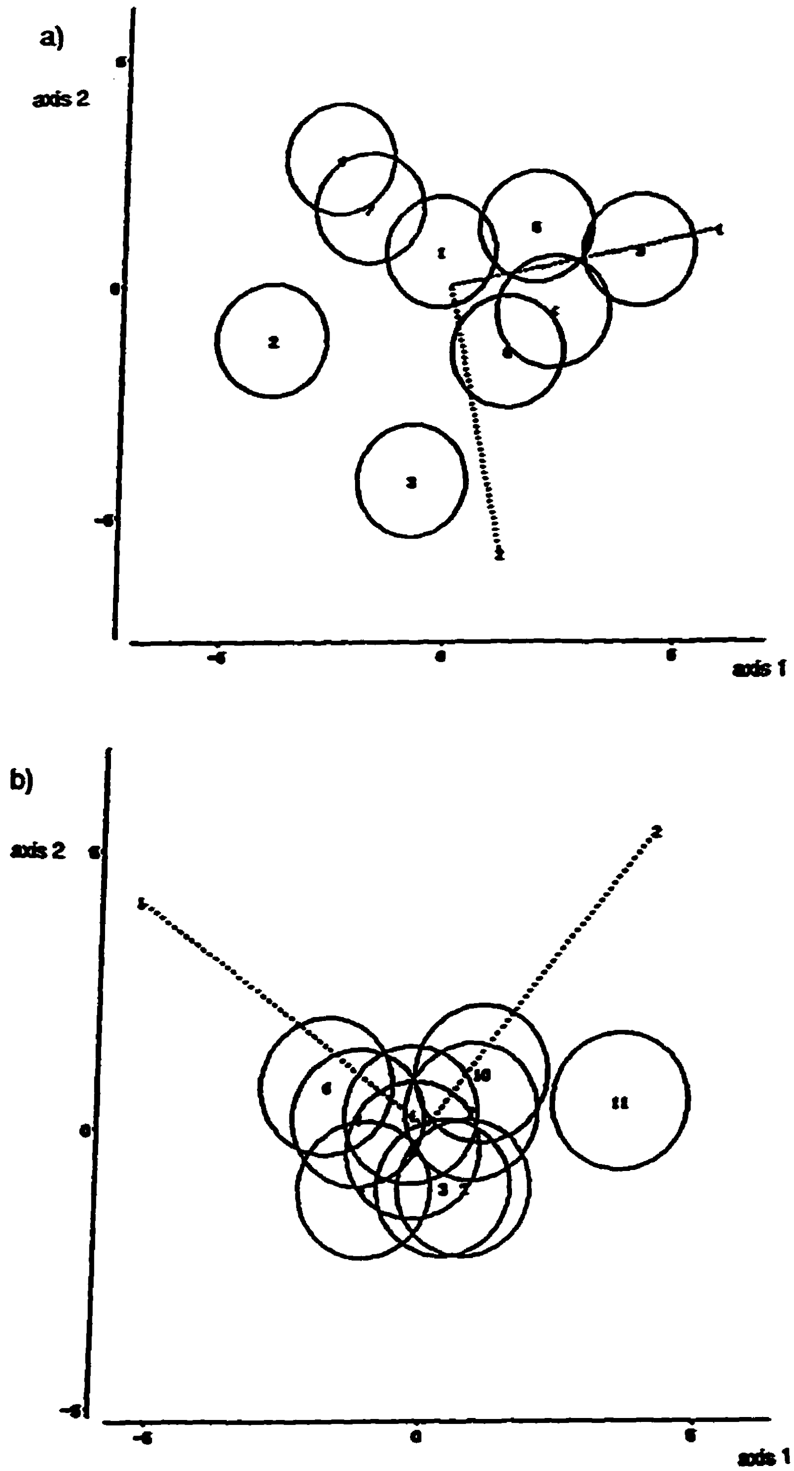
There are four phases in the life cycle of a plant population: seedling recruitment in which weed seeds germinate and emerge, the production of dry matter, seed production, and seed rain (Medd and Pandey, 1993; Kropff et al., 1996). Considering these phases, there is one phase in which expansion of the population may occur, the seed rain phase, and four phases where there is potential for loss (Sagar, 1982). Thus, control techniques that break the life cycle of weeds at some point in time will be valuable in developing strategies for weed management (Kropff et al., 1996). Annual forages have the potential to break the life cycle of weeds at any one of these phases. The forages themselves can reduce seedling recruitment (in forage and post-forage year) or reduce the production of weed dry matter and seed by competing with weeds, and the harvest of forage dry matter can prevent seed rain. Weed control via herbicides focuses only on reducing weed populations by increasing weed seedling mortality (Medd and Pandey, 1996)

The weeds that emerge in the field in spring do not necessarily reflect the proportion of weeds in the seedbank (Vleeshouwers and Kropff, 1996). Thus, some treatments that did not appear to control weeds in the seedbank actually suppressed weed seedling recruitment in the subsequent crop. For example, in trial 1, total weed seed density for the triticale intercrop treatment did not differ significantly from total weed seed density in unsprayed wheat. However, in the pea test crop significantly fewer weeds were recruited in the triticale intercrop treatment than for unsprayed wheat because of the competition exerted by the regrowth of winter triticale in this treatment. In trial 2, many of the forage treatments had a similar or greater density of weed seeds in the seedbank than the wheat treatments, but in the pea test crop fewer total weeds were recruited in most of the forage treatments than in the wheat treatments. Thus, reduced seedling recruitment in the subsequent pea crop via crop residue, allelopathy, or forage regrowth was also a valuable part of the annual forage treatments.

4.1.2.4 Weed Community Composition in Peas

The effect of annual forages on composition of the weed community in a subsequent pea crop was determined using multivariate analyses. Canonical discriminant analysis (CDA) was performed on the seedbank data to determine if there were significant treatment differences for community composition (Manly, 1994). Circles that overlap represent treatments that are not significantly different from one another (Figures 7a and 7b). Principal component analysis (PCA) was performed on the seedbank data to determine the association of the annual forage treatments with weed species (Manly, 1994). The association of weed species with forage system could be determined for each trial by comparing vector direction and length (Figures 8a and 8b). Direction of the vector indicates the association, and length indicates the strength of association. Longer vectors indicate that there is more variation for that weed species. Treatments that are located further up the vector are more strongly associated with that weed species.

In both trials of the present experiment, the forage treatments significantly altered the species composition of the weed community in the pea test crop. Differences were more distinct in trial 1 than in trial 2 (Figures 7a and 7b). This was similar to the trend seen for the seedbank. In trial 1, the forage treatments that affected the weed community in the seedling pea crop in a manner most like the conventional herbicide treatment were the triticale intercrop and sorghum-sudangrass (Figure 7a). The forage treatments that had a significantly different species composition compared to sprayed wheat were winter triticale, spring triticale, alfalfa and the weed fallow. Despite the fact that the weed community in peas for these forages was significantly different than for sprayed wheat, the weed community for all forage treatments was significantly different from partially sprayed and unsprayed wheat. Even the weed fallow treatment had a significantly different community composition than unsprayed wheat suggesting that the harvest



1=sprayed wheat, 2=partially sprayed wheat, 3=unsprayed wheat, 4=winter triticale
5=triticale intercrop, 6=spring triticale, 7=sorghum-sudangrass, 8=alfalfa,
9=weed fallow, 10=sweet clover/triticale, 11=fall rye.

Figure 7. Multivariate analysis of the weed community in the seedling pea test crop after annual forage systems. a) canonical discriminant analysis (CDA) for trial 1 (1995), b) CDA for trial 2 (1996). Non-overlapping circles are significantly different ($p<0.05$).

imposed on this treatment affected the composition of the weed community. These results were similar to those observed for the seedbank analysis (Figure 5a).

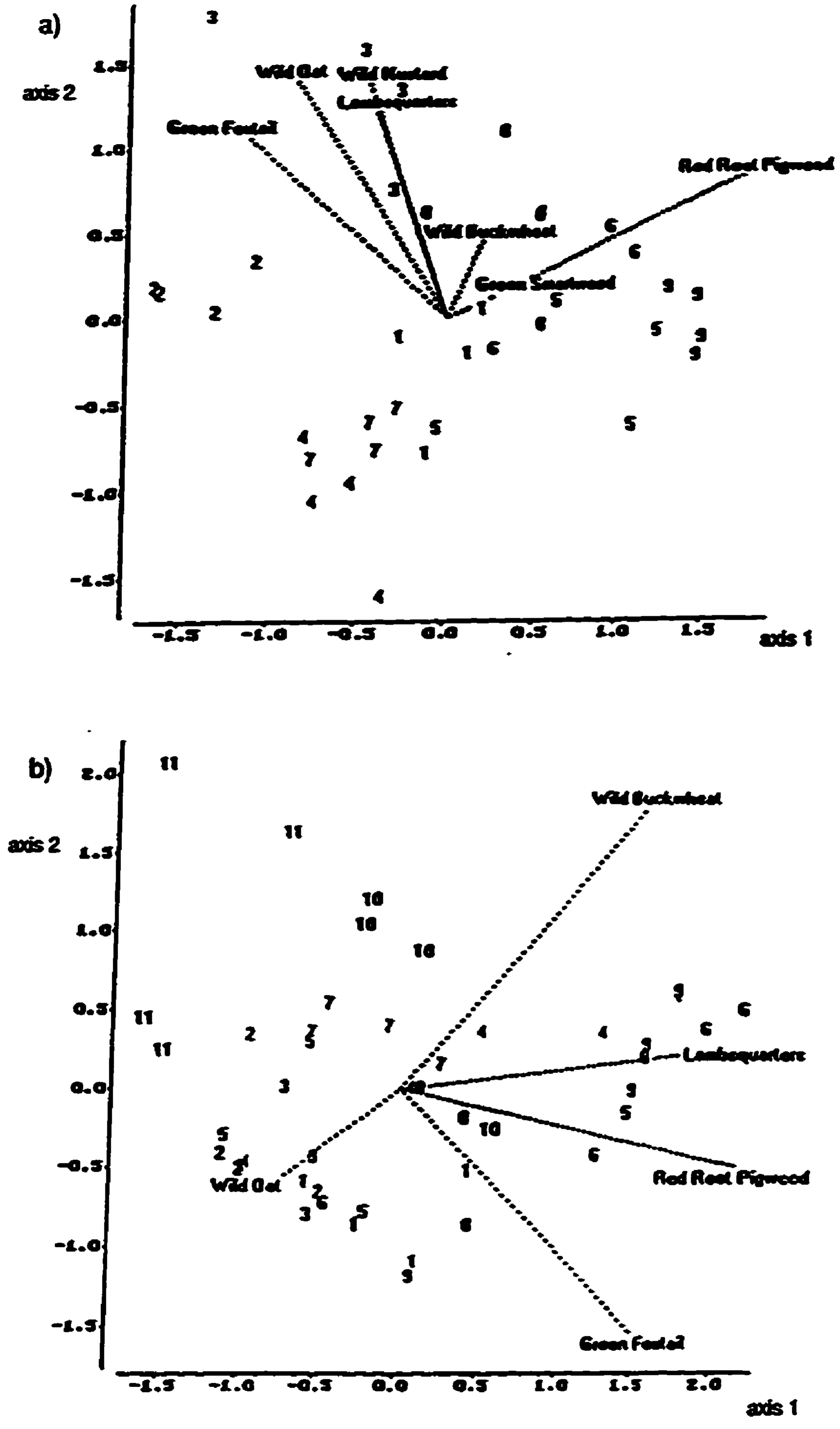
In trial 2, the only treatments to differ significantly from sprayed wheat for weed community composition in peas were sweet clover/triticale doublecrop and fall rye (Figure 7b). The weed community in fall rye was also significantly different from that in unsprayed wheat. All other forage treatments and herbicide sprayed wheat were not significantly different from unsprayed wheat for weed community composition. The fall rye treatment was unique because it had been sown in the year previous to the other forages, and this may account for the observed difference in community composition when compared with unsprayed wheat. It is interesting to note that although the sweet clover/triticale treatment had a different weed community than unsprayed wheat in the seedbank, it did not in the pea test crop. This treatment did not have a great deal of residue, and the winter triticale plants in this treatment were small (as evidenced by the lower grain yield for this treatment than for the other triticale treatments, section 4.1.2.6), so the doublecrop treatment most likely did not compete with weeds to the same extent as fall rye (Figure 6b).

The effect of annual forages on the composition of the weed community in a pea test crop was very similar to the effect on the seedbank weed community. When competitive pressure from weeds was moderate, as in trial 1, all annual forages affected the test-crop weed community in a similar manner to herbicide treated wheat. However, when competitive pressure from weeds was extreme, as in trial 2, most annual forages and herbicide treated wheat did not affect the test-crop weed community any differently than wheat that had not received herbicide. Some treatments that did not appear to control weeds in the seedbank actually suppressed weed seedling recruitment in the subsequent crop. Reduced seedling recruitment in the subsequent pea crop via crop residue, allelopathy, or forage regrowth was also a valuable part of the annual forage treatments. Reduction of seedling recruitment in the test crop by annual forages did not seem to alter the effect of annual forages on weed community composition in peas as the same trends were noticed in the seedbank.

Clear associations of the treatments with weed species were observed for most treatments in both trials (Figures 8a and 8b). In trial 1, the treatments that were not associated with any one weed species were sprayed wheat, winter triticale and sorghum-sudangrass (Figure 8a). The winter triticale and sorghum-sudangrass treatments behaved much like the conventional herbicide treatment by reducing the total number of weed seedlings recruited in the pea crop (Figure 6a) and by not selecting for any one weed species. Partially sprayed wheat was associated with green foxtail, and unsprayed wheat was associated with wild oat, wild mustard and lambsquarter (Figure 8a). The remaining annual forage treatments were associated with the broadleaf weed species to various degrees. For example, spring triticale and the weed fallow were both strongly associated with red root pigweed, whereas alfalfa was moderately associated with broadleaf weeds in general. Thus, spring triticale and the weed fallow treatments may be more apt to select for red root pigweed to become a problem. The trends seen for weed community composition in peas in trial 1 were similar to those found in the seedbank for trial 1.

In trial 2, the treatments that were not associated with any one weed species were sorghum-sudangrass, sweet clover/triticale and fall rye (Figure 8b). All three wheat treatments were strongly associated with wild oat. The density of wild oat in the field was greatest for these treatments as well (Table 18). As in trial 1, the remaining forage treatments were mainly associated with the various broadleaf weed species to different degrees. For example, spring triticale was moderately associated with red root pigweed and lambsquarter, and the weed fallow was strongly associated with lambsquarter.

The association of the various annual forage systems with weed species was similar in the pea test crop and weed seedbank. The results from both trials indicate that annual grain crops may select for grass weeds. Broadleaf weeds were more dominant in



1=sprayed wheat, 2=partially sprayed wheat, 3=unsprayed wheat, 4=winter triticale
5=triticale intercrop, 6=spring triticale, 7=sorghum-sudangrass, 8=alfalfa,
9=weed fallow, 10=sweet clover/triticale, 11=fall rye.

Figure 8. Multivariate analysis of the weed community in the seedling pea test crop after annual forage systems. a) principal component analysis (PCA) for trial 1 (1995), b) PCA for trial 2 (1996). Proximity of treatment number to vector indicates strength of association.

the seedbank community after annual forages, with the exception of winter triticale (trial 1 only), sorghum-sudangrass, sweet clover/triticale and fall rye which were not associated with any one weed species over another.

4.1.2.5 Pea Grain Yield

After measuring weed density in the pea test crop, half of each plot was sprayed with grass and broadleaf herbicide while half was left unsprayed. The average pea grain yield over both trial years was 2857 kg/ha for sprayed peas and 218 kg/ha for unsprayed peas, therefore, herbicide use was warranted in all cases. Pea grain yield was significantly affected by forage treatment in both sprayed and unsprayed treatments. The average yield for Danto peas in Manitoba taken over 42 site-years is 3009 kg/ha (Seed Manitoba, 1996).

In trial 1, a significant forage treatment x herbicide regime interaction was observed for pea grain yield (Table 19, and Appendix Table A12). The basis for the interaction was attributed to the fact that there was a greater increase in pea grain yield when herbicide was used on peas following partially sprayed and unsprayed wheat, and the weed fallow treatment than when herbicide was used on peas following sprayed wheat and the remaining annual forage treatments. In trial 1, peas following annual forages yielded as well as peas following sprayed wheat with the exception of alfalfa for sprayed and unsprayed subplots. Peas following alfalfa, however, yielded significantly greater than peas following partially sprayed or unsprayed wheat. It appears that the treatments (partially sprayed and unsprayed wheat, weed fallow) that had significantly more green foxtail emerging in spring (Table 17) had lower pea yields and benefited the most when herbicide was applied (Table 19).

In trial 2, a significant forage treatment x herbicide regime interaction was found (Table 19). The interaction in trial 2 was not as distinct as that found in trial 1. The basis for the interaction was attributed to the fact that increase in pea grain yield was much greater when herbicide was used on peas following partially sprayed wheat than when herbicide was used on the other treatments. The partially sprayed wheat treatment most likely exhibited a greater improvement in pea yield when compared to the other treatments because of the large density of wild oat seed present in the seedbank for this treatment (Table 16).

Table 19. Yield (kg/ha) of herbicide-treated and herbicide-free peas following the annual forage systems for trials 1 (1995) and 2 (1996) at Carman, MB. Data was analyzed as a split plot design with herbicide treatment as mainplot and suppressor crop as subplot. Statistical analysis was performed on transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment	Trial 1		Trial 2	
	Treated	Free	Treated	Free
Wheat + Grass and Broadleaf Herbicide	3662	440 *a*	2473	63 *def*
Wheat + Broadleaf Herbicide	2226	40 *c*	2013	11 *f*
Wheat - Herbicide	754	17 *d*	1436	68 *ef*
Winter Triticale	4098	463 *a*	3132	291 *ab*
Spring and Winter Triticale Intercrop	3872	395 *a*	4288	246 *a*
Spring Triticale	3209	383 *a*	3909	90 *def*
Sorghum-Sudangrass	3252	425 *a*	2359	132 *abc*
Alfalfa	1449	148 *a*	3158	96 *bcd*
Weed Fallow	2910	234 *ab*	2897	219 *ab*
Sweet Clover/Triticale Doublecrop	--	--	2016	111 *cde*
Fall Rye	--	--	4076	354 *a*

In trial 2, peas that followed the annual forage systems yielded as well as or better than peas that followed herbicide treated wheat for both sprayed and unsprayed subplots (Table 19). The fall rye and triticale intercrop treatments had the lowest density of weeds recruited in the field (Figure 6b) and the highest pea grain yield (Table 19). The trend in pea grain yield does not always reflect the trend in weed seedling recruitment seen in the seedling pea crop. For instance, sorghum-sudangrass and the sweet clover/triticale doublecrop had less weeds emerged in the field than spring triticale (Figure 6b), but pea yield following these treatments was either less than pea yield following spring triticale (sprayed subplots), or not different than pea yield following spring triticale (unsprayed subplots) (Table 19). The reason for the lower yields after the sorghum-sudangrass and sweet clover/triticale treatments cannot be explained by the density of weeds emerged in the seedling pea crop because other forage treatments had more weeds emerged in the spring. More weeds may have germinated later under these treatments, however, this does not seem likely because weed density in the seedbank is relatively low for these treatments (Figure 3b). Other possible reasons for the low yields may be that sorghum-sudangrass residue may have an allelopathic effect on the pea plants (Forney and Foy, 1985), and the sweet clover/triticale doublecrop may have used more water than the other treatments (Foster and Austenson, 1990).

Based on the observations in both trials of this experiment it can be concluded that peas following annual forages yielded as well as or better than peas following sprayed wheat. Furthermore, peas following annual forages yielded better than peas following partially sprayed or unsprayed wheat. In trial 1, peas that followed all annual forage treatments yielded as well as peas that followed sprayed wheat. In trial 2, peas that followed sorghum-sudangrass, winter triticale, weed fallow, triticale intercrop and fall rye yielded better than peas that followed sprayed wheat. Wilson and Phipps (1985) found wheat grain yield to be higher when it followed three years of barley silage or perennial grass than when it followed a cereal crop treated with herbicide and cultivation for weed control. Similarly, Forney et al. (1985) found that the percentage of total dry matter yield comprised by alfalfa was greater, in most cases, when plots were previously cropped with a forage suppressor crop (sorghum-sudangrass or foxtail millet) than when no suppressor crop was used.

It is clear that annual forages do not provide adequate weed suppression to allow for the elimination of herbicide in the subsequent crop. O'Donovan (1988) suggested that in order to obtain the best economic returns, wild oat control strategies must be implemented every year. The annual forage systems tested in this experiment allowed the elimination or reduction of herbicide use in one year while still providing effective weed control. Where herbicides are used continually, weed selection will be in favour of species that are less susceptible to applied herbicides (Jana and Naylor, 1982; Ball, 1992; Heap et al., 1993). Thus, the reduction/elimination of herbicide use for one year when growing annual forages is advantageous from a herbicide resistance management viewpoint.

4.1.2.6 Triticale Grain

Spring seeded winter triticale does not produce seed, however, if it survives the winter it will produce seed the next year. Winter triticale seeded in the plots at Carman survived the winter in both years of the study. Half of each of these plots was allowed to go to seed. Grain yield and weed density at time of harvest were measured. No herbicide was used in these plots.

Triticale grain yield was variable between the two trial years. In trial 1, triticale grain yield was 2299 kg/ha for winter triticale, and 5785 kg/ha for triticale intercrop. Density of green foxtail was much higher in the winter triticale treatment than in the triticale intercrop treatment which would account for the lower grain yield (Table 20).

In trial 2, triticale grain yield was 4082 kg/ha for winter triticale, 3832 kg/ha for triticale intercrop, and 3603 kg/ha for sweet clover/triticale doublecrop. Wild oat and green foxtail density in the triticale intercrop treatment was higher than in the winter triticale treatment which may account for the lower grain yield (Table 20). However, wild oat and green foxtail density in the sweet clover/triticale doublecrop was less than in the triticale intercrop treatment, but grain yield was also less. When winter triticale was established in the doublecrop treatment in 1995, June precipitation was 34 mm below the 30 year average. It was observed that plants were spindly and did not tiller by the end of the growing season to the extent that winter triticale plants did in the other treatments which may account for the lower grain yield observed for this treatment in the subsequent year.

Average grain yield for triticale cv. Banjo in Manitoba over 12 site-years is 4000 kg/ha (Seed Manitoba, 1996). The grain yields obtained in this experiment were similar to the Manitoba average. The highest grain yield was observed for the triticale intercrop treatment in trial 1. This treatment also had the lowest total weed density of all the treatments in both trials. It is significant to note that triticale grain yield for all treatments was obtained without the use of herbicide in either year of the triticale stand. The annual forage treatments involving winter triticale may allow a producer two years without herbicide. This could be a viable option when managing herbicide resistance (Jana and Naylor, 1982; Ball, 1992; Heap et al., 1993).

The triticale intercrop treatment was grown under zero-tillage on a field scale at Brandon, MB. It was observed that a sufficient number of plants did not survive the winter there, so the stand was terminated. Thus, this may not be an option for farmers in parts of Manitoba where snow coverage is not adequate. Spring seeded winter wheat is more subject to winter damage, and seed production is reduced when it is sown before the optimum date of late-August (Fowler, 1992). Thus, the triticale seeded in the doublecrop system would have the best chance for winter survival because it was seeded later in the year nearer to the optimum seed date.

Table 20. Weed density (plants per metre squared) in triticale grain crop for trials 1 (1995) and 2 (1996) at Carman, MB.

	Trial 1		Trial 2	
Treatment	Wild Oat	Green Foxtail	Wild Oat	Green Foxtail
Winter Triticale	3	489	32	325
Spring and Winter Triticale Intercrop	3	150	77	426
Sweet Clover/Triticale Doublecrop	--	--	67	213

4.2 Experiment 2

4.2.1 Suppressor Crop Year

4.2.1.1 Weed Population Density in Forages

This experiment was designed to test the effect of competitive crops under two tillage systems. The hypothesis was that annual forage suppressor crops would provide superior grass weed control when tillage was used to establish the crops than when zero tillage was used. A number of crops, including forages, were grown for one year under conventional and zero tillage in the absence of grass weed herbicide. Wilson and Phipps (1985) suggested that an arable silage was more effective than a perennial ley in reducing wild oat populations because the associated cultivations encouraged the germination of weeds and their subsequent death. Thurston (1951) attributes similar findings to the fact that wild oat seed survives longer in undisturbed soil.

An initial weed count was done in the seedling forage and wheat crops in 1995. There was a significant crop x tillage interaction for wild oat, but not for green foxtail (Tables 21 and 22, and Appendix Tables A13 and A14). The interaction for wild oat was attributed to the fact that, under zero tillage, the wild oat population density for wheat and triticale was similar to the other treatments, but under conventional tillage it was much higher (Table 21). Because sweet clover, fall rye and alfalfa had been seeded in the previous year, they did not receive tillage in the year that the weeds were counted. Conversely, the wheat and triticale treatments did receive tillage, and hence more wild oat was encouraged to germinate in these treatments. The interaction obtained in this experiment was the result of a combination of two factors. First, sweet clover, fall rye and alfalfa exerted a greater competitive pressure on wild oat seedlings than triticale or wheat in spring because they were seeded in the previous year, and second, these treatments avoided tillage in the spring. Initial wild oat density was significantly lower for sweet clover, fall rye and alfalfa than for triticale and wheat over both tillage systems.

Table 21. Initial wild oat density (seedlings per metre squared) as affected by crop type and tillage system (Carman, 1995). Statistical analysis was performed as a split plot with tillage system as mainplot and suppressor crop as subplot on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Crop Type	Conventional Tillage	Zero Tillage	Cropping System Average
Sweet Clover	107	59	83 *b*
Fall Rye	103	7	55 *c*
Spring Triticale	675	46	360 *a*
Wheat	648	105	376 *a*
Alfalfa	45	23	34 *c*
Tillage System Average	315 *a*	48 *b*	Crop x Tillage *

* significant at 0.05 probability level

Table 22. Initial green foxtail density (seedlings per metre squared) as affected by crop type and tillage system (Carman, 1995). Statistical analysis was performed as a split plot with tillage system as mainplot and suppressor crop as subplot on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Crop Type	Conventional Tillage	Zero Tillage	Cropping System Average
Sweet Clover	79	225	152 *b*
Fall Rye	30	90	60 *b*
Spring Triticale	400	572	486 *a*
Wheat	232	469	350 *a*
Alfalfa	6	26	16 *c*
Tillage System Average	149 *a*	276 *a*	Crop x Tillage NS

NS = nonsignificant at 0.05 probability level

Initial green foxtail density over both tillage treatments was significantly greater in triticale and wheat than in the other forage treatments, suggesting that the competitive pressure exerted by the crops that had been seeded in the previous year was an effective means of suppressing green foxtail emergence (Table 22). Alfalfa had significantly less green foxtail than all other treatments. The lack of both a significant crop x tillage interaction or a tillage effect for green foxtail, however, suggests that crop type was more important in reducing green foxtail density than tillage system.

A post-harvest weed count (wild oat only) was conducted on October 12, 1995, after all crops were harvested. Results indicated a significant crop x tillage interaction for wild oat (Table 23, and Appendix Table A15). This interaction was attributed to the fact that under zero tillage, wild oat density in wheat was similar to the other crop treatments, however under conventional tillage wild oat density in wheat was much greater than in the other crop treatments. One explanation for this observation is that wild oat seedlings present after harvest were from seed that had shed in that season, and not from existing seed in the seedbank (Banting, 1973). This suggestion is supported by the following observations: Less wild oat seed had shed during the season for wheat under zero till than under conventional till because less wild oat had germinated for wheat under zero tillage than conventional tillage (Table 21). Post-harvest wild oat density for triticale under conventional tillage was similar to the other treatments, thus the crop x tillage interaction observed earlier in the season for this treatment did not carry through to the end of the growing season (Table 23). Even though, initially, there was significantly more wild oat in triticale under conventional tillage than for the forage treatments under conventional tillage, the triticale silage harvest prevented wild oat seed from returning to the seedbank.

Table 23. Post-harvest wild oat density (seedlings per metre squared) as affected by crop type and tillage system (Carman, 1995). Statistical analysis was performed as a split plot with tillage system as mainplot and suppressor crop as subplot on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Crop Type	Conventional Tillage	Zero Tillage	Cropping System Average
Sweet Clover	71	45	58 *b*
Fall Rye	33	29	31 *c*
Spring Triticale	43	31	37 *c*
Wheat	114	53	83 *a*
Alfalfa	27	35	31 *c*
Tillage System Average	57 *a*	39 *b*	Crop x Tillage *

* significant at 0.05 probability level

4.2.2 Test Crop Year

4.2.2.1 Weed Population Density in Wheat Following Forages

The effect of crop type and tillage system on wild oat and green foxtail populations was further investigated by measuring the density of these weeds in a spring wheat test crop which was established the year after the suppression treatments. A significant tillage x previous crop interaction for green foxtail was attributed to a differential response of spring-seeded annual grain crops, and the various forage crops, to tillage system (Table 24). For example, under zero tillage, green foxtail density after fall rye was among the lowest of all crops, while under conventional tillage, green foxtail population after fall rye was higher than after the other crops. In the suppressor crop year, less green foxtail had emerged in the fall rye treatment in the spring than in the other treatments except for alfalfa, for both tillage systems (Table 22). Also in the suppressor crop year, there was no significant interaction between crop and tillage, and there was no significant difference between tillage systems in terms of green foxtail density. Fall rye suppressed green foxtail well in the year of suppressor crop, however, when the soil was disturbed by tillage after fall rye harvest, green foxtail that had been dormant in the seedbank was encouraged to germinate. Thurston (1962) cites this as the reason for similar findings with wild oat. Another possible reason for the interaction is that there may be an allelopathic effect of the fall rye stubble which was greater in the zero tillage plots than in the tilled plots (Teasedale et al., 1991).

Despite the fact that initial green foxtail density in the suppressor crop year was higher when zero tillage was employed than when conventional tillage was employed, forages, such as sweet clover, fall rye and alfalfa, suppressed green foxtail better in a subsequent wheat crop when zero tillage was used than when conventional tillage was used (Table 24). Green foxtail density in wheat following the spring triticale and wheat suppressor crops was higher than the other suppressor crop treatments when zero tillage was used. In the suppressor crop year, there was no significant tillage effect for green foxtail, however, all crop treatments had more green foxtail under zero tillage than under conventional tillage (Table 22). Buhler (1992) reported that green foxtail was more abundant in zero tillage corn than conventional tillage corn. Thus, it would appear that when spring planted cereals were grown using zero tillage, green foxtail density was high. However, the negative effects of zero tillage on green foxtail density were not observed for the sweet clover/triticale, fall rye and alfalfa treatments.

Table 24. Green foxtail density (seedlings per metre squared) in a seedling wheat crop as affected by previous crop type and tillage system (Carman, 1996). Data analyzed as a split plot design with tillage system as mainplot and suppressor crop as subplot. Means with the same letter are not significantly different LSD (p<0.05).

Crop Type	Conventional Tillage	Zero Tillage	Cropping System Average
Sweet Clover	101	37	69 *b*
Fall Rye	231	9	120 *ab*
Spring Triticale	159	247	203 *a*
Wheat	101	131	116 *ab*
Alfalfa	39	6	23 *b*
Tillage System Average	126 *a*	86 *b*	Crop x Tillage *
C.V. (%)			37.7

L.S.D. of tillage system = 44.68; L.S.D. of crop type = 112.20

* significant at 0.05 probability level

While a significant crop x tillage interaction for initial and post-harvest wild oat density in the suppressor crop year (Tables 21 and 23) had been recorded, there was no significant interaction between tillage and previous crop for wild oat density in the test crop (Table 25). This lack of a significant interaction in the test crop most likely occurred because all crops in the tillage treatments received tillage after the suppressor crop year; in the previous year, the forages in the conventional tillage sub-plots were not tilled whereas the annual grain crop treatments were. Therefore, in the test crop year, it was observed that crop type was a more important factor in wild oat suppression than tillage.

Over both tillage systems, there was significantly more wild oat in wheat following wheat than in wheat following all other crops (Table 25). Initial wild oat density in wheat in the suppressor crop year was significantly greater than for all other treatments as well (Table 21). Wild oat is known the be associated with annual cereal crops (Sharma and Vanden Born, 1978). Initial wild oat density in triticale was also significantly greater than for the other forage treatments in the suppressor crop year, however, wild oat density in wheat following triticale was significantly less than wild oat density in wheat following wheat (Table 25). This is most likely due to the fact that the triticale silage crop was better able to prevent weed seeds from returning to the seedbank than the wheat grain crop even though the two treatments had a similar amount of wild oat initially in the suppressor crop year. Wilson and Phipps (1985) suggested that barley silage prevented more wild oat seed from returning to the seedbank than winter grain crops or tillage. Wild oat density in wheat following alfalfa was significantly less than in any other treatment. Alfalfa has been cited in other research as an effective means of reducing weed populations (Hodgson, 1958; Harvey and McNevin, 1990). The forages tested in this experiment suppressed wild oat better than wheat in a herbicide-free environment regardless of tillage system used.

Table 25. Wild oat density (seedlings per metre squared) in a seedling wheat crop as affected by previous crop type and tillage system (Carman, 1996). Data analyzed as a split plot design with tillage system as mainplot and suppressor crop as subplot. Means with the same letter are not significantly different LSD ($p<0.05$).

Crop Type	Conventional Tillage	Zero Tillage	Cropping System Average
Sweet Clover	217	218	218 *bc*
Fall Rye	349	206	278 *b*
Spring Triticale	175	133	154 *cd*
Wheat	909	607	758 *a*
Alfalfa	57	68	63 *d*
Tillage System Average	341 *a*	246 *a*	Crop x Tillage * NS
C.V. (%)			100.8

L.S.D. of tillage system = 129.56; L.S.D. of crop type = 116.88

NS = nonsignificant at 0.05 probability level

Results from this experiment were variable. Better green foxtail control was provided by sweet clover, fall rye, and alfalfa when zero tillage was used. Conversely, better green foxtail control was provided by wheat and triticale when conventional tillage was used. Tillage had no effect on the efficacy of the suppressor crops for wild oat control in wheat following forages. The findings for wild oat were contrary to those found by Thurston (1966) and Wilson and Phipps (1985) who had suggested that the success of annual forages in controlling wild oat could be partially attributed to the associated cultivation. In this experiment, annual forages provided superior wild oat control to wheat in the absence of herbicide, with alfalfa and spring triticale providing the best control.

5.0 Summary and General Discussion

This study evaluated the role of annual forages in an integrated weed management system. In addition, it was determined how conventional tillage affects the weed suppression ability of annual forages when compared with zero tillage. Based on the results of this study, it can be concluded that annual forages consistently give good control of wild oat, but inconsistent control of other weeds (Table 26). Thurston (1966) found that a one to five year ley was effective in controlling wild oat, but that germination of charlock fluctuated erratically between years. Despite the variable weed control afforded by the annual forage systems, in most cases, yield of a pea crop following forages was significantly higher than pea yield following wheat without herbicide, and did not differ from pea yield following wheat given the conventional herbicide treatment.

In trial 1, where competitive pressure from weeds was moderate, the relative density of weed seedlings recruited in the pea test crop reflected the relative density of weed seeds in the seedbank. The treatments that suppressed the total weed population density in the seedbank and in the pea test crop as well as herbicide treated wheat were winter triticale, and sorghum-sudangrass. The triticale intercrop also suppressed weed seedling recruitment in peas as well as sprayed wheat.

In trial 2, where competitive pressure from weeds was high, the relative density of weed seedlings recruited in the pea test crop did not reflect the relative density of weed seeds in the seedbank. No forage treatment suppressed the total density of weed seeds returning to the seedbank better than unsprayed wheat. In fact, the spring triticale, weed fallow and fall rye treatments allowed significantly more weed seeds to shed than unsprayed wheat. However, most annual forages reduced weed seedling recruitment in the subsequent pea crop better than herbicide treated wheat. Reduced weed seedling recruitment in the subsequent crop was attributed to regrowth of forage in some of the

Table 26. Summary of weed suppression ability of annual forage systems. Suppression ability determined by comparing annual forage performance with performance of wheat check treatments. Weed species named indicate that treatment was successful in suppressing that species.

	Moderate Weed Infestation (Trial 1)		Extreme Grass Weed Infestation (Trial 2)	
Annual Forage	Seedbank	Seedling Peas	Seedbank	Seedling Peas
Winter Triticale	• wild oat, wild buckwheat, wild mustard, green smartweed, red root pigweed, lambsquarter	•wild oat, green foxtail, wild buckwheat, red root pigweed, lambsquarter	•wild oat, wild buckwheat, wild mustard, green smartweed	• wild oat, green foxtail, wild buckwheat, red root pigweed, lambsquarter
Triticale Intercrop	•wild oat, wild mustard, lambsquarter, green foxtail, wild buckwheat, green smartweed	• wild oat, lambsquarter, green foxtail green foxtail, wild buckwheat	•wild oat, wild mustard, lambsquarter, red root pigweed, wild buckwheat	•wild oat, lambsquarter, red root pigweed, wild buckwheat
Spring Triticale	•wild oat, wild mustard, green smartweed, lambsquarter, wild buckwheat	•wild oat, green foxtail, lambsquarter	•wild oat, wild mustard	•wild oat
Sorghum-Sudangrass	•wild oat, green foxtail, red root pigweed, lambsquarter, wild buckwheat, wild mustard, green smartweed	•wild oat, green foxtail, red root pigweed, lambsquarter, wild buckwheat	•wild oat, green foxtail, red root pigweed, lambsquarter, wild buckwheat, wild mustard, green smartweed	•wild oat, green foxtail, red root pigweed, lambsquarter, wild buckwheat
Alfalfa	•wild oat, lambsquarter, wild buckwheat, wild mustard, green smartweed	•wild oat, lambsquarter, wild buckwheat,	•wild oat, lambsquarter, wild buckwheat, wild mustard, green smartweed	•wild oat, lambsquarter, wild buckwheat,
Sweet Clover/ Triticale	***	***	•wild oat, red root pigweed, lambsquarter wild mustard, green smartweed	•wild oat, green foxtail, red root pigweed, lambsquarter
Fall Rye	***	***	•wild oat, red root pigweed, lambsquarter wild mustard, green smartweed	•wild oat, lambsquarter, green foxtail, red root pigweed, wild buckwheat
Weed Fallow	•wild oat, lambsquarter, wild mustard, green smartweed, green foxtail, wild buckwheat	•wild oat, lambsquarter, green foxtail, wild buckwheat	•wild oat, lambsquarter, wild mustard, green smartweed, wild buckwheat	•wild oat, lambsquarter, wild mustard,

systems (eg. winter triticale), an allelopathic effect of residue (eg. sorghum-sudangrass), or a suppressive effect of residue due to shading (eg. fall rye).

Annual forages had a similar effect on the weed community composition in the seedbank and the weed seedlings recruited in the pea crop in both trials. In trial 1, where competitive pressure from weeds was moderate, weed community in the seedbank and pea test crop for the annual forage treatments was similar to sprayed wheat and significantly different than unsprayed wheat. The treatments that did not have a significantly different weed community than sprayed wheat were winter triticale and sorghum-sudangrass.

In trial 2, where competitive pressure from weeds was high, weed community in the seedbank and pea test crop for most annual forage treatments was not significantly different from unsprayed wheat. Only, the sweet clover /triticale and fall rye seedbanks were significantly different from unsprayed wheat, and the weed community recruited in peas after fall rye was significantly different from unsprayed wheat. Thus, annual forages affect the weed community much like a conventional herbicide treatment when weed pressure is moderate, but when weed pressure is high, most annual forages do not affect the weed community any differently than a weedy grain crop.

The association of the various annual forage systems with weed species was similar in the weed seedbank and pea test crop. The results from this experiment suggest that annual grain crops may select for grass weeds, while annual forages may select for broadleaf weeds. The treatments that did not exhibit selection for any one weed species when weed pressure was moderate (trial 1), were sprayed wheat, winter triticale and sorghum-sudangrass (seedbank and pea test crop); and when weed pressure was high (trial 2), sorghum-sudangrass and sweet clover/triticale (seedbank and pea test crop); and fall rye (pea test crop).

Spring planted winter triticale will continue to grow in the fall months when other pasture grasses have ceased growing, and may offer four to five harvests in one growing season (Baron et al., 1990). In this experiment, winter triticale was effective in controlling most weed species (Table 26). The success of this treatment was most likely dependent upon its frequent harvest schedule and its prostrate growth habit which formed a dense ground cover that shaded weeds (Grime, 1977).

Intercropping of spring and winter triticale can be used to take advantage of the different peak production times of each crop to provide continuous forage availability throughout the season (Agriculture Canada, 1992). In this experiment, the first harvest of the triticale intercrop was taken when the spring triticale component reached the early dough stage. The remaining harvests consisted mostly of the winter triticale regrowth. This treatment controlled weeds well, particularly in a year where weed pressure was high (Table 26). The density of weed seeds in the seedbank was high for trial 1, however, the density of weed seedlings recruited in the subsequent pea crop was suppressed by triticale regrowth. When red root pigweed density was high (trial 1) the triticale intercrop did not suppress this weed well. In fact, red root pigweed was moderately associated with this treatment in trial 1.

Spring triticale is used extensively for whole plant silage on the Canadian prairies (Baron et al., 1992). In this experiment, spring triticale silage suppressed wild oat well (as was found by Wilson and Phipps (1985)), but control of other weed species was variable (Table 26). For example, in both trial years, red root pigweed and green foxtail were not controlled by this treatment. The spring triticale silage treatment was also associated with red root pigweed. Although popular as a cereal silage among prairie farmers, the harvest of triticale as silage was not found to be an effective means of suppressing weeds other than wild oat.

Sorghum-sudangrass can supplement cool season forages which have decreased in productivity in the hotter periods of summer (George et al., 1971). In this experiment, sorghum-sudangrass was effective in controlling all weed species (Table 26). Sorghum-sudangrass has been widely investigated for its weed suppression capabilities (Burnside and Wicks, 1967; Forney and Foy, 1985; Forney et al., 1985; Geneve and Weston, 1988; Bebawi and Mutwali, 1991). The success of this treatment in this experiment was most likely due to the fact that this crop was late seeded and the initial flush of weeds was removed by herbicide. In addition, the canopy is dense and competes well with weeds, and there is a known allelopathic effect of sorghum-sudangrass residue on weeds.

Non-winter hardy varieties of alfalfa, also known as annual varieties of alfalfa, have been developed for the purpose of a one year hay source, and as a fall plough-down green manure crop (Barnes et al., 1988). Alfalfa provided variable weed control (Table 26). Where weed pressure was moderate, alfalfa did not control weeds any better than unsprayed wheat. Where weed pressure was high, alfalfa controlled weeds as well as sprayed wheat, however, neither of these treatments controlled weeds any better than unsprayed wheat. Of the four major weeds studied in this experiment, alfalfa controlled wild oat and lambsquarter well, but not green foxtail or red root pigweed. Alfalfa is frequently established without the use of herbicides (Bell, 1993). Yield at the first harvest is often comprised of 75% weeds, while yield at last harvest is comprised of no weeds. In this experiment, however, harvest of alfalfa was not sufficient to destroy weed biomass and prevent weed seeds from returning to the seedbank. Thus, this treatment may not be an effective option for a producer wishing to control weeds.

Sweet clover is a biennial forage legume crop that can be used as hay, pasture, silage or for soil improvement (Walster, 1924; Christensen and Hopper, 1938). In this experiment, sweet clover was seeded in 1994 and harvested in 1995. After sweet clover harvest, plots were seeded to winter triticale. The sweet clover/triticale doublecrop treatment was effective at controlling all weeds except for wild buckwheat (Table 26). It is possible that the lack of spring tillage in 1995 for this treatment allowed wild buckwheat to proliferate (Hume et al., 1983). Despite the fact that wild buckwheat density was higher in this treatment than in other treatments, the doublecrop treatment did not select for this weed or any other weed. In fact, in a year of high weed pressure, the doublecrop treatment was one of two forage treatments that had a different weed community than unsprayed wheat in the seedbank.

Fall rye is a versatile forage as it can be seeded in spring or fall and used for pasture or harvested as a forage grain or silage (McLelland, 1988). The success of fall rye in suppressing weeds varied between the seedbank and seedling pea crop. The total density of weeds in the seedbank was significantly greater for the fall rye treatment than for the unsprayed wheat treatment, however, in the seedling pea crop it was significantly less. This suggests that the competition, and allelopathic effect of fall rye residue is an important means by which this treatment can suppress weeds (Agriculture Canada, 1992; Weston, 1996). The fall rye treatment had relatively high levels of green foxtail and red root pigweed in the seedbank. It is likely, that after the fall rye harvest in July, 1995, these warm-season weed species germinated and emerged because climatic conditions were favourable (Table 2) and much of the crop competition was removed.

A weed fallow treatment was included in this experiment, where weeds were allowed to grow and were removed by a forage harvester. There is potential to feed the harvested material from a weed fallow to livestock (Vengris et al., 1953; Marten and Anderson, 1975; Moyer and Hironaka, 1993). The total density of weeds in the seedbank or seedling pea crop after the weed fallow treatment was highest or among the highest of all treatments in this experiment. In trial 1, red root pigweed was the main weed found in this treatment, and in trial 2, green foxtail was the main weed found. Wild oat and the minor broadleaf weeds were controlled well by this treatment.

An IWM system should include the following characteristics: 1) shift community dominance away from the weeds and toward the crop, 2) minimize negative impacts of secondary succession due to disturbance, 3) understand and exploit population biology of crop-weed interactions, and 4) manage selection pressure in a manner that adverse shifts in the weed spectrum are avoided.

In a disturbed crop community, some degree of niche separation must occur in order for weed species to exist in conjunction with crop plants (Radosevich and Holt, 1984). If community dominance can be shifted toward the crop plant as opposed to the weed plant, successful weed management should be achieved. Crop competition may have its greatest affect on seedling recruitment and will shift community dominance toward the crop (Kropff et al., 1996). Annual forages such as fall rye and sorghum-sudangrass were more competitive than alfalfa, for instance, and these treatments suppressed weed populations better than alfalfa. The destruction of weed biomass by forage harvest allowed for community dominance to be shifted toward the forage crop, particularly for those systems which included spring planted winter triticale which was characterized by rapid regrowth. Coble (1996) suggested that mowing perennial forage crops is an effective weed control option.

Agricultural systems are typically highly disturbed systems, and weeds are those plants that occupy the earliest stages of secondary succession (Grime, 1977; Ghersa et al., 1996). Forages with a regrowth habit, such as winter triticale and alfalfa, or double cropping systems will occupy the niche opened up by plant removal and minimize the impact of secondary succession. Also, forages that leave a dense layer of residue on the soil surface, such as fall rye, or whose residues exert an allelopathic effect, such as sorghum-sudangrass, will minimize the impact of secondary succession. It was interesting to note that the spring triticale and weed fallow treatments, which did not regrow or leave much residue on the soil surface, had the highest total weed densities in the seedbank and seedling pea crop in both trial years.

There are four phases in the life cycle of a weed plant population where weed control techniques can have an affect (Kropff et al., 1996). Understanding and exploiting the population biology of crop-weed interactions will be valuable in developing IWM systems. For instance, it is known that wild buckwheat can be controlled with spring tillage (Hume et al., 1983). The sweet clover/triticale and fall rye treatments, however, did not receive spring tillage in 1995, therefore, these treatments had a higher density of wild buckwheat than the other forage treatments. In another example, red root pigweed density was greater in the annual forage treatments than in the wheat treatments regardless of herbicide used. If the terminal inflorescence is damaged, red root pigweed can initiate elongated inflorescences from the lateral leaf axils and almost assume a prostrate growth habit. This may account for the higher density of this species in the more disturbed forage treatments of this experiment (Weaver and McWilliams, 1980). An understanding of how certain weed species will react to the weed management system will help determine which system should be utilized to control them.

The genetic structure of plant populations within cultivated fields is a function of the management practices imposed on those populations (Ball, 1992; Darmency and Aujas, 1987; Derksen, 1995). Jordan and Jannink (1996) stated that there is abundant evidence that weeds are capable of adapting to all types of weed control measures. Winter triticale and alfalfa both selected for green foxtail types with a more prostrate growth habit because of their frequent cutting schedules. Thus, green foxtail was below cutting height at subsequent harvests of these treatments, and was allowed to shed seed. The spring triticale and weed fallow treatments selected for red root pigweed. Once these treatments were cut, the pigweed continued to develop and shed seed, and there was little regrowth from the spring triticale or other weeds to suppress pigweed growth. When designing an IWM program, varying selection pressure in the system is important to impede weed adaptation to weed management (Jordan and Jannink, 1996; Swanton and Murphy, 1996). Even though annual forages tended to select for broadleaf weeds in general, if these systems are included in a weed management system involving varied weed control approaches, selection for certain weeds should not be a problem.

Medd and Pandey (1996) suggested that preventing weed seeds from returning to the seedbank can dramatically reverse population growth. The results of this experiment show that annual forages do not successfully prevent all weed seeds from returning to the seedbank. The only annual forage that was successful in suppressing all weed species was sorghum-sudangrass. The remaining forage treatments did not suppress all weed species, particularly the four species of greatest abundance (wild oat, green foxtail, lambsquarter, and red root pigweed). O'Donovan (1988) suggested that omitting weed control during some years may increase weed populations to unmanageable levels in future years. Thus, annual forages may only be useful when the main weed to be controlled is wild oat, when certain "problem" weeds are not part of the weed spectrum (eg. green foxtail when spring triticale is grown), or when weed infestation is low to moderate. However, in this experiment, herbicide was not successful in suppressing weeds in all cases either.

Growing annual forages under zero tillage may not have the same effect on all weed populations as when grown under conventional tillage. There was a significant interaction between previous crop type and tillage for green foxtail suggesting that annual forages such as sweet clover, fall rye and alfalfa control green foxtail better when zero tillage is used than when conventional tillage is used. Results obtained from the literature varied. Buhler (1992) stated that green foxtail densities in continuous corn were greater when zero-tillage was used as opposed to conventional tillage. Alternatively, Hume et al. (1991) stated that green foxtail densities in continuous wheat were greater under conventional tillage. Furthermore, Derksen et al. (1993) found in their study that green foxtail was not associated with one tillage system over another. In this study, triticale did not control green foxtail better than wheat for either tillage system.

There was no significant interaction between previous crop type and tillage for wild oat control suggesting that the forage suppresser crops controlled wild oat better than wheat in a herbicide-free environment regardless of tillage system used. These findings do not concur with the results found by other researchers. Wilson and Phipps (1985) partially attribute the depletion of wild oats in the seedbank under three years of barley cut for silage to the associated cultivation. Thurston (1966) also notes that longer survival of wild oat seeds will be found in undisturbed soil under leys, thus annual systems in which there is greater soil disturbance will select for, and remove wild oats that are less persistent in the seedbank.

The results obtained from experiment 2 were in some cases contrary to what is in the literature. This suggests that more research is needed. It would appear, from this experiment, that the success of annual forages in suppressing green foxtail is dependent on the tillage system chosen, but that tillage is not a factor in determining the success of annual forages in suppressing wild oat.

Based on the results of these experiments it is recommended that in a year where weed infestation is moderate, winter triticale and sorghum-sudangrass can be used to suppress the density of weed seeds that return to the seedbank as well as herbicide. In a year where grass weed infestation is extreme, only sorghum-sudangrass may suppress weed seed return to the seedbank better than a herbicide. However, annual forages may suppress the density of weeds emerging in a subsequent crop due to early spring regrowth or residue cover even when many weed seeds have previously been returned to the seedbank. In this regard, annual forages may be effective in reducing weed populations in the short-term. In the long-term, however, they may prove to be detrimental to a producer's weed control efforts due to high densities of dormant weed seeds in the seedbank. Annual forages such as alfalfa may be effective in suppressing moderate weed infestations if certain weeds are omitted from the spectrum of weeds to be controlled. For example, green foxtail was the main weed found in the alfalfa treatment because of this treatment's frequent cutting schedule. If this weed were not a problem in a producer's field, alfalfa may be effective in reducing populations of other weeds in the field. This illustrates the need for better understanding of the biology of weeds and their potential response to weed control efforts.

The results of these experiments indicate that annual forages may be a viable weed control option when used in the context of an IWM system. The benefits of including annual forages in rotation are: weed suppression comparable to herbicide, the reduction or elimination of herbicide use in the year of forage, and improved efficacy of herbicide in a subsequent crop.

6.0 References

Agriculture Canada. 1992. Fall rye reference manual. Agdex 117/20: 46pp.

Ahrens, W.H., D.J. Coc, and G. Budhwar. 1990. Use of the arcsine and square root transformations for subjectively determined percentage data. *Weed Sci.* 38: 452-458.

Anderson, W. 1994. Benefits emerge from dual purpose crops. *Farming Ahead* 29: 28.

Anonymous. 1987. Manitoba forage profile. Manitoba Agriculture, Soils and Crops, Carman, MB, R0G 0M0.

Baker, H.G. 1965. Effects of certain environmental factors on net assimilation in cotton. *Crop Sci.* 5: 53-56.

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

Banting, J.D. 1973. How wild oats grow. *In* Let's Clean Up on Wild Oats. Agriculture Canada, pp. 16-19.

Barnes, D.K., C.C. Sheaffer, G.H. Heichel, D.M. Smith, and R.N. Peaden. 1988. Registration of 'Nitro' alfalfa. *Crop Sci.* 28: 718.

Baron, V.S., A.C. Dick, and E.A. de St. Remy. 1994. Response of forage yield and yield components to planting date and silage/pasture management in spring seeded winter cereal/spring oat cropping systems. *Can. J. Plant Sci.* 74: 7-13.

Baron, V.S., H.G. Najda, D.F. Salmon, and A.C. Dick. 1992. Post-flowering forage potential of spring and winter cereal mixtures. *Can. J. Plant Sci.* 72: 137-145.

Baron, V.S., H.G. Najda, D.F. Salmon, and A.C. Dick. 1993b. Cropping systems for spring and winter cereals under simulated pasture: yield and yield distribution. *Can. J. Plant Sci.* 73: 703-712.

Baron, V.S., H.G. Najda, D.F. Salmon, J.R. Pearen, and A.C. Dick. 1993a. Cropping systems for spring and winter cereals under simulated pasture: sward structure. *Can. J. Plant Sci.* 73: 947-959.

Baron, V.S., D.F. Salmon, H.G. Najda, ang E.A. de St. Remy. 1990. Feasibility of double cropping and intercropping of winter cereals for fall pasture. Farming for the Future Report #87-0064. 99 pp.

Bassett, I.J., and C.W. Crompton. 1978. The biology of Canadian weeds. 32 *Chenopodium album* L. *Can. J. Plant Sci.* 58: 1061-1072.

Bebawi, F.F., and E.M. Mutwali. 1991. Witchweed management by sorghum-sudangrass seed size and stage of harvest. *Agron. J.* 83: 781-786.

Bell, C. 1993. Weed management in seedling alfalfa (*Medicago sativa* L.); long term effects. *In* 8th EWRS Symposium, Braunschweig, pp. 761-768.

Berkenkamp, B., and J. Meeres. 1987. Mixtures of annual crops for forage in central Alberta. *Can. J. Plant Sci.* 67: 175-183.

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.

Blackshaw, R.E., and L.M. Rode. 1991. Effect of ensiling and rumen digestion by cattle on weed seed viability. *Weed Sci.* 39: 104-108.

Bowden, B.A., and G. Friesen. 1967. Competition of wild oats (*Avena fatua* L.) in wheat and flax. *Weed Res.* 7: 349-359.

Brown, A.R., and A. Almodares. 1976. Quantity and quality of triticale forage compared to other small grain. *Agron. J.* 68: 264-266.

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

Bunting, A.H. 1960. Some reflections on the ecology of weeds. *In* The Biology of Weeds (J.L. Harper ed.) *Symp. Br. ecol. Soc.* 1: 11-26. Blackwell, Oxford.

Burnside, O.C., and G.A. Wicks. 1967. The effect of weed removal treatments on sorghum growth. *Weeds* 15: 204-207.

Burnside, O.C., and G.A. Wicks. 1969. Influence of weed competition on sorghum growth. *Weed Sci.* 17: 332-334.

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

Chancellor, R.J., and N.C.B. Peters. 1974. The time of onset of competition between wild oats (*Avena fatua* L.) and spring cereals. *Weed Res.* 14: 197-202.

Christensen, F.W., and T.H. Hopper. 1938. Digestible nutrients and metabolizable energy in certain silages, hays, and mixed rations. *J. Agric. Res.* 57: 477-512.

Clapp, J.G., and D.S. Chamblee. 1970. Influence of different defoliation systems on the regrowth of pearl millet, hybrid suangrass, and two sorghum-sudangrass hybrids from terminal, axillary, and basal buds. *Crop Sci.* 10: 345-349.

Coble, H.D. 1996. Weed management tools and their impact on the agro-ecosystem. *Proc. 2nd Intl. Weed Control Congress*, Copenhagen. pp 1143-1146.

Cousens, R.D., S.E. Weaver, T.D. Martin, A.M. Blair, and J.Wilson. 1991. Dynamics of competition between wild oats (*Avena fatua* L.) and winter cereals. *Weed Res.* 31: 203-210.

Cunningham, M.D., and W.W. Ragland. 1971. Plant composition and feeding value of sudangrass and sorghum-sudangrass in a controlled grazing system. *J. Dairy Sci.* 54: 1461-1464.

Cussans, G.W. 1996. Which weed management strategies are appropriate? *Second International Weed Control Congress*, Copenhagen. pp. 1159-1166.

Darmency, H., and C.Aujas. 1987. Character inheritance and polymorphism in a wild oat (*Avena fatua*) population. *Can. J. Bot.* 65: 2352-2356.

Derksen, D.A. 1995. Towards a new understanding of weed management in zero-tillage systems. *From* Agronomy Workshop, pp. 192-199.

Derksen, D.A., G.P. Lafond, A.G. Thomas, H.A. Loeppky, and C.J. Swanton. 1996a. Impact of agronomic practices on weed communities: tillage systems. *Weed Sci.* 41: 409-417.

Derksen, D.A., A.G. Thomas, G.P. Lafond, and H.A. Loeppky. 1996b. Understanding weed community dynamics. *Second International Weed Control Congress*, Copenhagen. pp. 49-54.

Dhaliwal, B.K., and R.J. Froud-Williams. 1993. Physiological basis of competition between spring barley and wild oat (*Avena fatua* L.). *In* 8th EWRS Symposium, Braunschweig, pp. 151-157.

Dore, W.G., and L.C. Raymond. 1942. Viable seeds in pasture soil and manure. *Sci. Agric.* 23: 69-79.

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

Edwards, N.C., H.A. Fribourg, and M.J. Montgomery. 1971. Cutting management effects on growth rate and dry matter digestibility of the sorghum-sudangrass cultivar Sudax SX-11. *Agron. J.* 63: 267-271.

Edwards, C.A., and E.E. Regnier. 1989. Designing integrated low-input farming systems to achieve effective weed control. *Brighton Crop Protection Conference* pp. 585-590.

Fisher, L.J. 1972. Evaluation of triticale silage for lactating cows. *Can. J. Anim. Sci.* 52: 373-376.

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

Forcella, F., B.R. Durgan, and D.D. Buhler. 1996. Management of weed seedbanks. *Second International Weed Control Congress*, Copenhagen. pp. 21-28.

Forney, D.R., and C.L. Foy. 1985. Phytotoxicity of products from rhizospheres of a sorghum-sudangrass hybrid (*Sorghum bicolor x Sorghum sudanese*). *Weed Sci.* 33: 597-604.

Forney, D.R., C.L. Foy, and D.D. Wolf. 1985. Weed suppression in no-till alfalfa (*Medicago sativa*) by prior cropping of summer-annual forage grasses. *Weed Sci.* 33: 490-497.

Foster, R.K., and H.M. Austenson. 1990. Management of sweet clover and alfalfa in cereal rotations. *In* Transition to Organic Agriculture Conference. pp. 32-47.

Fowler, D.B. 1992. Crop residue/trash management. In Winter wheat production manual. pp. 501-511.

Garber, R.J., M.M. Hoover, and L.S. Bennett. 1934. The effect upon yield of cutting sweet clover (*Melilotus alba*) at different times and at different heights. *J. Am. Soc. Agron.* 26: 974-977.

Geneve, R.L., and L.A. Weston. 1988. Growth reduction of eastern redbud (*Cercis canadensis* L.) seedlings caused by interaction with a sorghum-sudangrass hybrid (Sudex). *J. Environ. Hort.* 6(1): 24-26.

George, J.R., C.L. Rhykerd, and C.H. Noller. 1971. Effect of light, temperature, nitrogen, and stage of growth on nitrate accumulation and dry matter production of a sorghum-sudangrass hybrid. *Agron. J.* 63: 413-415.

Ghersa, C.M., M.A. Martinez-Ghersa, and S.Suarez. 1996. Spatial and temporal patterns of weed invasions: implications for weed management and crop yield. *Second International Weed Control Congress*, Copenhagen. pp. 41-46.

Gillingham, J.T., M.M. Shirer, J.J. Starnes, N.R. Page, and E.F. McClain. 1969. Relative occurrence of toxic concentrations of cyanide and nitrate in varieties of sudangrass and sorghum-sudangrass hybrids. *Agron. J.* 61: 727-730.

Goonewardene, L.A., D.R. ZoBell, and J.A. Basarab. 1994. Comparison of growth and feed efficiency of steers fed barley and triticale diets. *Can. J. Anim. Sci.* 74: 159-161.

Graber, L.F. 1927. Improvement of permanent bluegrass pastures with sweet clover. *J. Am. Soc. Agron.* 19: 994-1005.

Gressel, J. 1989. Why get resistance? It can be prevented or delayed. *In* Herbicide Resistance in Weeds and Crops. *11th Long Ashton International Symposium*, Bristol. (In press).

Grime, J.P. 1977. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *Am. Nat.* 111: 1169-1194.

Gross, K.L. 1990. A comparison of methods for estimating seed numbers in the soil. *J. Ecol.* 78: 1079-1093.

Harmon, G.H., and F.D. Keim. 1934. The percentage and viability of weed seeds recovered in the feces of farm animals and their longevity when buried in manure. *J. Am. Soc. Agron.* 26: 762-767.

Harper, J.L. 1977. Population Biology of Plants. Academic Press, London. pp. 892.

Harvey, R.G., and G.R. McNevin. 1990. Combining cultural practices and herbicides to control wild-proso millet (*Panicum miliaceum*). *Weed Tech.* 4: 433-439.

Hatfield, J.L. 1996. Environmental sustainability in modern farming practices. *Second International Weed Control Congress*, Copenhagen. pp. 1339-1348.

Heap, I.M., B.G. Murray, H.A. Loeppky, and I.N. Morrison. 1993. Resistance to aryloxyphenoxyproprionate and cyclohexanedione herbicides in wild oat (*Avena fatua*). *Weed Sci.* 41: 232-238.

Hodgson, J.M. 1958. Canada thistle (*Cirsium arvense* Scop.) control with cultivation, cropping and chemical sprays. *Weeds* 6(1): 1-10.

Holzner, W. 1982. Concepts, categories and characteristics of weeds. *In* Biology and ecology of weeds. Eds. W. Holzner, and M. Numata. Dr. W. Junk Publishers, The Netherlands. pp. 3-20.

Hume, L. 1982. The long-term effects of fertilizer application and three rotations on weed communities in wheat (after 21-22 years at Indian Head, Saskatchewan). *Can. J. Plant Sci.* 62: 741-750.

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

Jana, S., and J.M. Naylor. 1982. Adaptation for herbicide tolerance in populations of *Avena fatua*. *Can. J. Bot.* 60: 1611-1617.

Jedel, P.E., and J.H. Helm. 1993. Forage potential of pulse-cereal mixtures in central Alberta. *Can. J. Plant Sci.* 73: 437-444.

Jones, P.A., A.M. Blair, and J.H. Orson. 1996. Mechanical damage to kill weeds. *Second International Weed Control Congress*, Copenhagen. pp. 949-954

Jordan, N.R., and J.L. Jannink. 1996. Evolution in weed populations: when should it concern weed managers? *Second International Weed Control Congress*, Copenhagen. pp. 27-34.

Kilcher, M.R. 1982. Effect of cattle grazing on subsequent grain yield of fall rye (*Secale cereale* L.) in southwestern Saskatchewan. *Can. J. Plant Sci.* 62: 795-796.

Krebs, C.J. 1989. Stratified random sampling. *In* Ecological Methodology. Harper & Row, New York. pp. 211-213.

Kropff, M.J., J. Wallinga, and L.A.P. Lotz. 1996. Weed population dynamics. *Proc. 2nd Intl. Weed Control Congress*, Copenhagen. pp 3-14.

Legere, A., and M.M. Schreiber. 1989. Competition and canopy architecture as affected by soybean (*Glycine max*) row width and density of red root pigweed (*Amaranthus retroflexus*). *Weed Sci.* 37: 84-92.

Manitoba Agriculture. 1995. Guide to crop protection.

Manly, B.F.J. 1994. Multivariate statistical methods: a primer. Chapman & Hall, London. 215 pp.

Marten, G.C., and R.N. Andersen. 1975. Forage and nutritive value and palatibility of 12 common annual weeds. *Crop Sci.* 15: 821-827.

McCartney, D.H., and A.S. Vaage. 1994. Comparative yield and feeding value of barley, oat and triticale silages. *J. Anim. Sci.* 74: 91-96.

McCreery, R.A., S.M. Hajjati, and E.R. Beaty. 1966. Nitrates in annual forages as influenced by frequency and height of clipping. *Agron. J.* 58: 381-382.

McLelland, M.B. 1988. Fall rye production. Publication, Alberta Agriculture (Agdex 117/20-1): 12 pp.

Medd, R.W., and S. Pandey. 1993. Compelling grounds for controlling seed production in *Avena* species (wild oats). *In* 8th EWRS Symposium, Braunschweig, pp. 769-776.

Moline, W.J., and L.R. Robinson. 1971. Effects of herbicides and seeding rates on the production of alfalfa. *Agron. J.* 63: 614-616.

Morrison, I.A., and M.D. Devine. 1994. Herbicide resistance in the Canadian prairie provinces: five years after the fact. *In* Herbicide Resistance Workshop, Edmonton.

Moyer, J.R. 1985. Effect of weed control and companion crop on alfalfa and sainfoin establishment, yields and nutrient composition. *Can. J. Plant Sci.* 65: 107-116.

Moyer, J.R., and R. Hironaka. 1993. Digestible energy and protein content of some annual weeds, alfalfa, bromegrass, and tame oats. *Can. J. Plant Sci.* 73: 1305-1308.

Mulligan, G.A., and L.G. Bailey. 1975. The biology of Canadian weeds. 8. *Sinapsis arvensis* L. *Can. J. Plant Sci.* 55: 171-183.

Navas, M.L. 1991. Using plant population biology in weed research: a strategy to improve weed management. *Weed Res.* 31: 171-179.

Norris, R.F. 1996. Weed population dynamics: seed production. *Proc. 2nd Intl. Weed Control Congress*, Copenhagen. pp 15-20.

Numata, M. 1982. A methodology for the study of weed vegetation. *In* Biology and ecology of weeds. Eds. W. Holzner, and M. Numata. Dr. W. Junk Publishers, The Netherlands. pp. 21-34.

O'Donovan, J.T. 1988. Wild oat (*Avena fatua*) infestations and economic returns as influenced by frequency of control. *Weed Tech.* 2: 495-498.

O'Donovan, J.T., E.A. de St. Remy, P.A. O'Sullivan, D.A. Dew, and A.K. Sharma. 1985. Influence of the relative time of emergence of wild oat (*Avena fatua*) on yield loss of barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*). *Weed Sci.* 33:498-503.

Pantone, D.J., R.A. Young, D.D. Buhler, C.V. Eberlein, W.C. Koskinen, and F.Forcella. 1992. Water quality impacts associated with pre- and postemergence applications of atrazine in maize. *J. Environ. Qual.* 21: 567-573.

Pavlychenko, T.K., and J.B. Harrington. 1934. Competitive efficiency of weeds and cereal crops. *Cdn. J. Res.* 10: 77-94.

Popay, I., and R. Field. 1996. Grazing animals as weed control agents. *Weed Tech.* 10: 217-231.

Powles, S.B., and J.M. Matthews. 1996. Integrated weed management for the control of herbicide resistant annual ryegrass (*Lolium rigidum*). *Second International Weed Control Congress*, Copenhagen. pp. 407-414.

Prairie Farm Rehabilitation Association, 1992. Groundwater quality assessment of the assiniboine delta aquifer. 12 pp.

Putnam, A.R., J. DeFrank, and J.P. Barnes. 1983. Exploitation of alleopathy for weed control in annual and perennial cropping systems. *J. Chem. Ecol.* 9(8): 1001-1010.

Radosevich, S.R., and J.S. Holt. 1984. Weed ecology : Implications for Vegetation Management. Wiley, New York.

Rice, W.A., P.E. Olsen, L.D. Bailey, V.O. Biederbeck, and A.E. Slinkard. 1993. The use of annual legume green-manure crops as a substitute for summerfallow in the Peace River region. *Can. J. Soil Sci.* 73: 243-252.

Roberts, H.A. 1963. Emergence and longevity in cultivated soil of seeds of some annual weeds. *Weed Res.* 4: 296-307.

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 J.E. Neilson. 1981. Changes in th soil seed bank of four long-term crop/herbicide experiments. *J. Appl. Ecol.* 18: 661-668.

Sagar, G.R. 1982. An introduction to the population dynamics of weeds. *In* Biology and ecology of weeds. Eds. W. Holzner, and M. Numata. Dr. W. Junk Publishers, The Netherlands. pp. 161-168.

Schoner, C.A., R.F. Norris, and W. Chilcote. 1978. Yellow foxtail (*Setaria lutescens*) biotype studies: growth and morphological characteristics. *Weed Sci.* 26: 632-636.

Schweizer, E.E. 1988. New technological developments to reduce groundwater contamination by herbicides. *Weed Tech.* 2: 223-227.

Seed Manitoba, 1996.

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.

Sheaffer, C.C., D.K. Barnes, and G.H. Heichel. 1989. "Annual" alfalfa in crop rotations. Stn.-Bull.-MN-Ag.-Exp.-Stn., University of Minnesota.

Siemens, L.B. 1963. Weed control through crop rotations. *In* Cropping Systems: An Evaluative Review of Literature. pp. 35-37.

Swanton, C.J., and S.D. Murphy. 1996. Integrated weed management (IWM) promotes increased energy efficiency and biodiversity. *Second International Weed Control Congress*, Copenhagen. pp. 1369-1374.

Swanton, C.J., and S.F. Weise. 1991. Integrated weed management: the rationale and approach. *Weed Tech.* 5: 657-663.

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

Temme, D.G., R.G. Harvey, R.S. Fawcett, and A.W. Young. 1979. Effects of annual weed control on alfalfa forage quality. *Agron. J.* 71: 51-54.

Tereshchuk, V.S. 1996. Occurrence of weeds in barley depending on the preceding crop. *Proc. 2nd Intl. Weed Control Congress*, Copenhagen. pp 259-264.

Thurston, J.M. 1962. The effect of competition from cereal crops on the germination and growth of *Avena fatua* L. in a naturally infested field. *Weed Res.* 2: 192-207.

Thurston, J.M. 1966. Survival of seeds of wild oat (*Avena fatua* L. and *Avena ludoviciana* DUR.) and charlock (*Sinapsis arvensis* L.) in soil under leys. *Weed Res.* 6: 67-80.

Timmons, F.L. 1970. A history of weed control in the United States and Canada. *Weed Sci.* 18: 294-307.

Unknown. 1968. Principles and practices of agriculture, University of Manitoba. p. 202.

Van Groenendael, J.M. 1988. Patchy distribution of weeds and some implications for modelling population dynamics: a short literature review. *Weed Res.* 28: 437-441.

Van Heemst, H.D.J. 1985. The influence of weed competition on crop yield. *Agric. Systems* 18: 81-93.

Vengris, J., M. Drake, W.G. Colby, and J. Bart. 1953. Chemical composition of weeds and accompanying crop plants. *Agron. J.* 45: 213-218.

Vleeshouwers, L.M., and M.J. Kropff. 1996. Prediction of weed emergence in the field. *Second International Weed Control Congress*, Copenhagen. pp. 209-214.

Walker, R.H., and G.A. Buchanan. 1982. Crop manipulation in integrated weed management systems. *Weed Sci.* 30: 17-24.

Walster, H.L. 1924. Sweet clover as a hay crop. *J. Am. Soc. Agron.* 16: 182-186.

Watson, A.K. 1989. Current advances in bioherbicide research. *Proc. Br. Crop Prot. Conf.-Weeds* 3: 987-996.

Weaver, S.E. 1984. Critical period of weed competition in three vegetable crops in relation to management practices. *Weed Res.* 24: 317-325.

Weaver, S.E., and E.L. McWilliams. 1980. The biology of Canadian weeds. 44. *Amaranthus retroflexus* L., *A. Powellii* S. Wats. and *A. hybridus* L. *Can. J. Plant Sci.* 60: 1215-1234.

Weston, L.A. 1996. Utilization of allelopathy for weed management in agroecosystems. *Agron. J.* 88: 860-866.

Wilson, B.J., and P.A. Phipps. 1985. A long-term experiment on tillage, rotation and herbicide use for the control of *Avena fatua* in cereals. *Proc. British Crop Prot. Conf.* 693-700.

Zadoks, J.C., T.T Chang, and C.F. Konzak. 1974. A decimal code for the growth stages of cereals. *Weed Res.* 14: 415-421.

ZoBell, D.R., L.A. Goonewardene, and D.F. Engstrom. 1992. Use of triticale silage in diets for growing steers. *Can. J. Anim. Sci.* 72: 181-184.

7.0 Appendix

Table A1. Field operations performed on trial 1 at Carman (1994, 1995).

Date	Operation
1994	
May 12	wild oat broadcast with fertilizer
May 16	wild oat incorporated
May 18	all treatments seeded except sorghum-sudangrass
May 31	initial early season in-crop weed count
June 10	wheat sprayed with herbicide
June 13	sorghum-sudangrass plots sprayed with glyphosate
June 14	sorghum-sudangrass seeded
June 20	winter triticale and alfalfa harvested
July 8	winter triticale harvested
July 20	triticale intercrop and weed fallow harvested
July 25	alfalfa harvested
July 26	spring triticale harvested
August 2	winter triticale harvested
August 26	all wheat treatments harvested
August 31	sorghum-sudangrass harvested
September 7	weed fallow and spring triticale mowed
September 23	winter triticale, intercrop, sorghum-sudangrass and alfalfa harvested
October 23	winter triticale and alfalfa harvested
1995	
April 25	seedbank sampled
May 9	peas seeded
May 10	plots sprayed with glyphosate
June 5	initial early season in-crop weed count
June 8	half of peas sprayed with grass and broadleaf herbicide
June 23	peas sprayed again due to inadequate weed control
August 2	triticale grain harvested
August 17	peas harvested

Table A2. Field operations performed on trial 2 at Carman (1994-1996).

Date	Operation
1994	
May 12	wild oat broadcast with fertilizer
May 16	wild oat incorporated
May 18	flax seeded
May 25	sweet clover seeded
June 10	broadleaf weeds removed
August 30	flax swathed
August 31	plots cultivated
September 1	fall rye seeded
1995	
May 10	all treatments seeded except sorghum-sudangrass
May 30	early season in-crop weed count
June 8	wheat sprayed with herbicide
June 16	sorghum-sudangrass seeded
June 19	sorghum-sudangrass plots sprayed with glyphosate
June 21	sweet clover harvested and winter triticale seeded
June 26	winter triticale and alfalfa harvested
July 6	spring triticale, triticale intercrop and weed fallow harvested
July 19	winter triticale and alfalfa harvested
July 20	sweet clover/triticale doublecrop harvested
July 26	fall rye harvested
August 9	spring triticale and weed fallow harvested
August 15	all wheat treatments harvested
August 16	winter triticale, intercrop, sorghum-sudangrass and alfalfa harvested
August 28	sweet clover/triticale doublecrop harvested
October 3	winter triticale, intercrop and alfalfa harvested
1996	
May 1	seedbank sampled
May 13	peas seeded, plots sprayed with glyphosate
June 3	early season in-crop weed count
June 7	half of peas sprayed with grass and broadleaf herbicide
June 24	peas sprayed again due to inadequate weed control
August 2	triticale grain harvested
August 17	peas harvested

Table A3. Wild oat density (plants per metre squared) in treatments for trial 1 at Carman, 1994. Statistical analysis was performed within crop type on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Date	Treatment
	Wheat + Grass and Broadleaf Herbicide
May 31	1.3 *a*
August 26	0.0 *b*
LSD	0.2
C.V. (%)	16.4
	Wheat + Broadleaf Herbicide
May 31	1.3 *a*
August 26	1.4 *a*
LSD	0.2
C.V. (%)	7.9
	Wheat - Herbicide
May 31	1.3 *a*
August 26	1.4 *a*
LSD	0.4
C.V. (%)	12.1
	Winter Triticale
May 31	1.3 *b*
June 20	1.9 *a*
July 8	0.9 *c*
August 2	0.9 *c*
September 23	0.2 *d*
LSD	0.3
C.V. (%)	19.7
	Triticale Intercrop
May 31	1.3 *b*
July 20	1.5 *a*
September 23	0.2 *c*
LSD	0.2
C.V. (%)	11.1
	Spring Triticale
May 31	1.2 *a*
July 26	1.1 *a*
LSD	0.1
C.V. (%)	3.8
	Sorghum-Sudangrass
May 31	1.6 *a*
August 31	0.2 *b*
September 23	0.0 *b*
LSD	0.2
C.V. (%)	24.9
	Alfalfa
May 31	1.4 *b*
June 20	1.8 *a*
July 25	1.8 *a*
September 23	0.2 *c*
LSD	0.2
C.V. (%)	11.2
	Weed Fallow
May 31	1.6 *a*
July 20	1.7 *a*
LSD	0.3
C.V. (%)	8.4

Table A4. Weed density (plants per metre squared) in treatments for trial 2 at Carman, 1995. Statistical analysis was performed within crop type on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Date	Wild Oat	Green Foxtail	Red Root Pigweed	Lambs-quarters	Wild Buckwheat
			Wheat + Grass and Broadleaf Herbicide		
May 31	2.7 *a*	3.0 *a*	1.3 *a*	0.5 *a*	0.1 *a*
August 16	2.3 *b*	2.1 *b*	0.0 *b*	0.0 *b*	0.0 *a*
October 3	1.7 *c*	0.0 *c*	0.0 *b*	0.0 *b*	0.0 *a*
LSD	0.1	0.3	0.6	0.2	0.3
C.V. (%)	3.6	10.7	86.6	71.4	346.4
			Wheat + Broadleaf Herbicide		
May 31	2.6 *a*	2.9 *a*	1.7 *a*	0.6 *a*	0.3 *a*
August 16	2.2 *b*	2.1 *b*	0.0 *b*	0.0 *b*	0.0 *b*
October 3	1.8 *c*	0.0 *c*	0.0 *b*	0.0 *b*	0.0 *b*
LSD	0.1	0.1	0.2	0.4	0.1
C.V. (%)	2.5	4.4	21.4	130.2	66.0
			Wheat - Herbicide		
May 31	2.7 *a*	2.9 *a*	1.0 *a*	0.6 *a*	0.2 *a*
August 16	2.3 *b*	1.7 *b*	0.2 *b*	0.0 *b*	0.0 *a*
October 3	2.0 *c*	0.0 *c*	0.0 *b*	0.0 *b*	0.0 *a*
LSD	0.2	0.4	0.5	0.2	0.2
C.V. (%)	4.3	16.2	66.5	69.2	151.5
			Winter Triticale		
May 31	2.7 *a*	2.8 *a*	1.8 *a*	0.8 *a*	0.2 *ab*
June 26	2.5 *a*	2.6 *a*	0.8 *b*	0.5 *b*	0.3 *a*
July 20	2.0 *b*	2.3 *b*	0.9 *b*	0.5 *b*	0.2 *ab*
August 16	1.4 *c*	1.9 *c*	0.5 *b*	0.1 *c*	0.0 *ab*
October 3	0.7 *d*	0.0 *d*	0.0 *c*	0.0 *c*	0.0 *b*
LSD	0.3	0.2	0.4	0.1	0.3
C.V. (%)	9.6	8.3	30.2	25.9	106.7
			Triticale Intercrop		
May 31	2.6 *a*	3.0 *a*	1.5 *a*	0.6 *a*	0.3 *a*
July 6	2.6 *a*	2.1 *b*	0.5 *c*	0.5 *a*	0.5 *a*
August 16	1.6 *b*	2.1 *b*	1.0 *b*	0.2 *b*	0.3 *a*
October 3	0.6 *c*	0.0 *c*	0.0 *d*	0.0 *b*	0.0 *b*
LSD	0.4	0.3	0.2	0.2	0.3
C.V. (%)	13.1	9.8	20.6	45.9	67.4
			Spring Triticale		
May 31	2.7 *a*	2.9 *a*	1.6 *a*	0.7 *a*	0.4 *a*
July 6	2.5 *b*	2.1 *c*	0.7 *b*	0.4 *a*	0.4 *a*
August 9	2.0 *c*	2.2 *b*	0.9 *b*	0.5 *a*	0.2 *ab*
October 3	1.2 *d*	0.0 *d*	0.0 *c*	0.0 *b*	0.0 *b*
LSD	0.2	0.1	0.2	0.4	0.3
C.V. (%)	4.8	4.4	19.5	55.5	63.9

Table A4 (continued). **Weed density (plants per metre squared) in treatments for trial 2 at Carman, 1995 Statistical analysis was performed within crop type on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).**

Date	Wild Oat	Green Foxtail	Red Root Pigweed	Lambs-quarters	Wild Buckwheat
			Sorghum-Sudangrass		
May 31	2.7 *a*	2.8 *a*	1.7 *a*	0.5 *a*	0.3 *a*
August 16	1.0 *b*	1.9 *b*	1.2 *a*	0.1 *a*	0.0 *b*
October 3	1.1 *b*	0.0 *c*	0.0 *b*	0.0 *a*	0.0 *b*
LSD	0.2	0.2	0.6	0.5	0.3
C.V. (%)	6.6	8.5	38.4	160.7	148.5
			Alfalfa		
May 31	2.7 *a*	2.8 *a*	1.4 *a*	0.6 *a*	0.2 *ab*
June 26	2.6 *a*	2.5 *b*	0.8 *b*	0.5 *a*	0.1 *bc*
July 20	2.0 *b*	2.4 *b*	1.3 *a*	0.6 *a*	0.3 *a*
August 16	1.8 *b*	2.5 *b*	0.4 *bc*	0.2 *b*	0.1 *bc*
October 3	1.0 *c*	0.0 *c*	0.0 *c*	0.0 *b*	0.0 *c*
LSD	0.3	0.2	0.5	0.3	0.2
C.V. (%)	9.1	7.2	37.1	44.1	75.7
			Weed Fallow		
May 31	2.6 *a*	3.0 *a*	1.2 *a*	0.5 *ab*	0.4 *a*
July 6	2.7 *a*	2.4 *b*	0.6 *b*	0.6 *a*	0.4 *a*
August 9	2.1 *b*	2.2 *c*	0.8 *b*	0.3 *b*	0.2 *ab*
October 3	1.1 *c*	0.0 *d*	0.0 *c*	0.0 *c*	0.0 *b*
LSD	0.2	0.1	0.3	0.3	0.4
C.V. (%)	6.0	4.5	26.3	49.9	89.7
			Sweet Clover/Triticale		
May 31	2.0 *a*	2.4 *b*	0.3 *bc*	0.6 *ab*	0.5 *a*
June 20	1.9 *a*	1.8 *c*	0.0 *c*	0.5 *ab*	0.3 *ab*
July 20	0.9 *b*	2.6 *a*	0.7 *a*	0.9 *a*	0.4 *ab*
August 28	1.1 *b*	2.5 *ab*	0.5 *ab*	0.2 *bc*	0.0 *b*
October 3	1.1 *b*	0.0 *d*	0.0 *c*	0.0 *c*	0.0 *b*
LSD	0.3	0.2	0.4	0.4	0.4
C.V. (%)	13.5	6.9	94.3	64.9	80.0
			Fall Rye		
May 31	2.1 *a*	1.4 *a*	0.1 *a*	0.2 *a*	0.4 *a*
July 26	1.7 *b*	1.9 *a*	0.2 *a*	0.1 *a*	0.1 *ab*
October 3	1.5 *c*	0.0 *b*	0.0 *a*	0.0 *a*	0.0 *b*
LSD	0.3	0.8	0.3	0.4	0.4
C.V. (%)	8.3	44.4	207.7	184.3	125.3

Table A5. Weed population density at last harvest (plants per metre squared) for trial 2 at Carman, 1995. Statistical analysis performed on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment	Wild Oat	Green Foxtail	Lambs-quarter	Red Root Pigweed	Wild Buckwheat
Wheat+Grass and Broadleaf Herbicide (Aug. 15)	2.3 a	2.1 bc	0.0 c	0.0 d	0.0 c
Wheat+Broadleaf Herbicide (Aug. 15)	2.2 ab	2.1 bc	0.0 c	0.0 d	0.0 c
Wheat-Herbicide (Aug. 15)	2.3 a	1.7 d	0.0 c	0.2 cd	0.0 c
Winter Triticale (Oct. 3)	0.7 ef	0.0 e	0.0 c	0.0 d	0.0 c
Winter and Spring Triticale Intercrop (Oct. 3)	0.6 f	0.0 e	0.0 c	0.0 d	0.0 c
Spring Triticale (Aug. 9)	2.0 bc	2.2 ab	0.5 a	0.9 ab	0.2 ab
Sorghum-Sudangrass (Aug. 16)	1.0 de	1.9 cd	0.1 c	1.2 a	0.0 c
Alfalfa (Oct. 3)	1.0 de	0.0 e	0.0 c	0.0 d	0.0 c
Sweet Clover/Triticale Doublecrop (Aug. 28)	1.1 d	2.5 a	0.2 bc	0.5 bc	0.4 a
Fall Rye (July 26)	1.7 c	1.9 cd	0.1 cd	0.2 cd	0.1 bc
Weed Fallow (Aug. 9)	2.1 ab	2.2 ab	0.3 ab	0.8 ab	0.2 b
LSD	0.3	0.3	0.2	0.4	0.2
C.V. (%)	13.2	13.4	128.2	80.1	139.2

Table A6. Total seasonal forage and weed dry matter production (kg/ha) for trial 1 (Carman, 1994). Statistical analysis was performed on log transformed data. Means with the same letter are not letter are not significantly different LSD (p<0.05).

Treatment	Forage	Weed	Total
Winter Triticale	2.0 *b*	1.7 *c*	2.2 *b*
Spring and Winter Triticale Intercrop	2.0 *b*	1.9 *b*	2.3 *a*
Spring Triticale	2.0 *b*	1.9 *b*	2.3 *a*
Sorghum-Sudangrass	2.3 *a*	1.5 *d*	2.4 *a*
Alfalfa	1.7 *c*	2.2 *a*	2.3 *a*
Weed Fallow	0.0 *d*	2.3 *a*	2.3 *a*
LSD	0.1	0.2	0.1
C.V. (%)	5.4	6.1	2.9

Table A7. Total seasonal forage and weed dry matter production (kg/ha) for trial 2 (Carman, 1995). Statistical analysis was performed on log transformed data. Means with the same letter are not letter are not significantly different LSD (p<0.05).

Treatment	Forage	Weed	Total
Winter Triticale	1.5 *c*	2.0 *abc*	2.1 *b*
Spring and Winter Triticale Intercrop	1.5 *c*	2.0 *ab*	2.1 *b*
Spring Triticale	1.1 *de*	2.1 *a*	2.1 *b*
Sorghum-Sudangrass	1.0 *e*	1.9 *bc*	1.9 *c*
Alfalfa	1.2 *d*	2.1 *a*	2.1 *b*
Sweet Clover/Triticale Doublecrop	1.9 *b*	1.9 *c*	2.2 *ab*
Fall Rye	2.3 *a*	0.4 *d*	2.3 *a*
Weed Fallow	0.0 *f*	2.1 *a*	2.1 *b*
LSD	0.2	0.1	0.1
C.V. (%)	10.4	5.0	3.0

Table A8. Total density of weed seeds (seeds per metre squared) in the seedbank, and weed seedlings (seedlings per metre squared) in a seedling pea crop for trials 1 (1995) and 2 (1996) at Carman, MB.

Treatment	Seedbank	Pea Test Crop	
	Trial 1	Trial 1	Trial 2
Wheat + Grass and Broadleaf Herbicide	1.8 *d*	1.5 *cd*	3.4 *ab*
Wheat + Broadleaf Herbicide	2.2 *bc*	2.2 *ab*	3.4 *a*
Wheat - Herbicide	2.6 *a*	2.4 *a*	3.4 *a*
Winter Triticale	2.1 *cd*	1.3 *d*	3.0 *e*
Spring and Winter Triticale Intercrop	2.4 *ab*	1.8 *bc*	3.0 *ef*
Spring Triticale	2.3 *ab*	2.2 *ab*	3.4 *ab*
Sorghum-Sudangrass	2.1 *cd*	1.3 *d*	3.0 *de*
Alfalfa	2.4 *ab*	2.3 *a*	3.3 *bc*
Weed Fallow	2.6 *a*	2.5 *a*	3.4 *ab*
Sweet Clover/Triticale Doublecrop	–	–	3.2 *cd*
Fall Rye	–	–	2.9 *f*
LSD	0.2	0.4	0.1
C.V. (%)	7.5	15.2	2.9

Table A9. Density of weed seeds (seeds per metre squared) in the seedbank for trial 1 (Carman, 1995). Statistical analysis was performed on log transformed data. Means with the same letters are not significantly different LSD ($p<0.05$).

Treatment	Wild Oat	Green Foxtail	Red Root Pigweed	Lambs-quarter	Wild Buckwheat	Green Smartweed	Wild Mustard
Wheat + Grass and Broadleaf Herbicide	0.6 *b*	1.1 *cd*	1.4 *cd*	1.4 *de*	0.6 *a*	0.1 *a*	0.4 *a*
Wheat + Broadleaf Herbicide	1.6 *a*	1.7 *ab*	1.2 *d*	1.3 *e*	0.5 *a*	0.3 *a*	0.6 *a*
Wheat - Herbicide	1.6 *a*	1.8 *a*	1.7 *c*	2.2 *a*	0.5 *a*	0.1 *a*	0.6 *a*
Winter Triticale	0.3 *b*	1.7 *ab*	1.5 *cd*	1.4 *cde*	0.5 *a*	0.1 *a*	0.6 *a*
Spring and Winter Triticale Intercrop	0.5 *b*	1.1 *cd*	2.2 *ab*	1.6 *bcd*	0.5 *a*	0.2 *a*	0.5 *a*
Spring Triticale	0.5 *b*	1.5 *abc*	2.1 *b*	1.7 *bc*	0.5 *a*	0.3 *a*	0.5 *a*
Sorghum-Sudangrass	0.5 *b*	1.3 *bcd*	1.6 *c*	1.7 *b*	0.4 *a*	0.2 *a*	0.6 *a*
Alfalfa	0.5 *b*	1.8 *a*	2.1 *b*	1.5 *bcde*	0.6 *a*	0.2 *a*	0.4 *a*
Weed Fallow	0.4 *b*	0.8 *d*	2.5 *a*	1.4 *cde*	0.6 *a*	0.2 *a*	0.3 *a*
LSD	0.4	0.5	0.3	0.2	0.4	0.3	0.6
C.V. (%)	32.5	24.2	13.0	9.6	47.5	105.1	88.0

Table A10. Density of weeds emerged (seedlings per metre squared) in a pea test crop for trial 1 (Carman, 1995). Statistical analysis was performed on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment	Wild Oat	Green Foxtail	Red Root Pigweed	Lambs-quarter	Wild Buckwheat
Wheat + Grass and Broadleaf Herbicide	0.9 *b*	0.9 *cde*	1.1 *c*	0.5 *bc*	0.5 *a*
Wheat + Broadleaf Herbicide	1.8 *a*	1.8 *ab*	0.2 *d*	0.4 *bc*	0.4 *ab*
Wheat - Herbicide	1.8 *a*	1.5 *abc*	1.3 *c*	1.9 *a*	0.5 *a*
Winter Triticale	0.3 *e*	1.2 *bcd*	0.3 *d*	0.1 *c*	0.1 *c*
Spring and Winter Triticale Intercrop	0.5 *de*	0.7 *de*	1.7 *b*	0.5 *b*	0.3 *abc*
Spring Triticale	0.9 *b*	1.2 *bcd*	2.1 *ab*	0.5 *bc*	0.4 *ab*
Sorghum-Sudangrass	0.6 *cd*	0.9 *cde*	0.5 *d*	0.7 *b*	0.2 *bc*
Alfalfa	0.9 *b*	1.9 *a*	1.9 *b*	0.5 *bc*	0.2 *c*
Weed Fallow	0.8 *bc*	0.4 *e*	2.4 *a*	0.3 *bc*	0.3 *abc*
LSD	0.3	0.7	0.4	0.4	0.3
C.V. (%)	18.4	41.6	22.1	46.7	54.3

Table A11. Density of weeds emerged (seedlings per metre squared) in a pea test crop for trial 2 (Carman, 1996). Statistical analysis was performed on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment	Wild Oat	Green Foxtail	Red Root Pigweed	Lambs-quarter	Wild Buckwheat
Wheat + Grass and Broadleaf Herbicide	3.2 *b*	3.0 *abc*	1.0 *ab*	0.2 *bc*	0.2 *c*
Wheat + Broadleaf Herbicide	3.4 *a*	2.5 *d*	0.2 *bcd*	0.0 *c*	0.2 *c*
Wheat - Herbicide	3.3 *a*	2.7 *cd*	0.2 *cd*	0.3 *bc*	0.2 *c*
Winter Triticale	2.6 *f*	2.8 *bcd*	0.9 *abc*	0.4 *bc*	1.0 *abc*
Spring and Winter Triticale Intercrop	2.6 *f*	2.7 *cd*	0.8 *abcd*	0.4 *bc*	0.5 *bc*
Spring Triticale	2.9 *de*	3.1 *ab*	1.5 *a*	1.3 *a*	1.2 *ab*
Sorghum-Sudangrass	3.0 *cd*	2.0 *e*	0.8 *abcd*	0.5 *abc*	0.8 *abc*
Alfalfa	2.8 *e*	3.1 *ab*	1.2 *a*	0.6 *abc*	1.0 *abc*
Sweet Clover/Triticale Doublecrop	3.0 *bc*	2.5 *d*	0.2 *bcd*	0.6 *abc*	1.5 *a*
Fall Rye	2.9 de	1.0 f	0.0 d	0.0 c	0.7 abc
Weed Fallow	2.8 *e*	3.2 *a*	1.5 *a*	1.0 *ab*	1.3 *ab*
LSD	0.1	0.4	0.9	0.8	0.9
C.V. (%)	3.4	10.5	78.5	126.8	83.1

Table A12. Average yield (kg/ha) of herbicide-treated and herbicide-free peas following the annual forage systems for trials 1 (1995) and 2 (1996) at Carman, MB. Data was analyzed as a split plot design with herbicide treatment as mainplot and suppressor crop as subplot. Statistical analysis was performed on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Treatment	Trial 1	Trial 2
Wheat + Grass and Broadleaf Herbicide	2.2 *a*	1.5 *def*
Wheat + Broadleaf Herbicide	1.5 *c*	1.3 *f*
Wheat - Herbicide	1.2 *d*	1.4 *ef*
Winter Triticale	2.2 *a*	1.9 *ab*
Spring and Winter Triticale Intercrop	2.2 *a*	2.1 *a*
Spring Triticale	2.1 *a*	1.5 *def*
Sorghum-Sudangrass	2.2 *a*	1.8 *abc*
Alfalfa	1.8 *a*	1.7 *bcd*
Weed Fallow	2.0 *ab*	1.9 *ab*
Sweet Clover/Triticale Doublecrop	--	1.6 *cde*
Fall Rye	--	2.1 *a*
LSD	0.3	0.3
C.V. (%)	13.9	14.9

Table A13. Initial wild oat density (seedlings per metre squared) as affected by crop type and tillage system (Carman, 1995). Statistical analysis was performed as a split plot with tillage system as mainplot and suppressor crop as subplot on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Crop Type	Conventional Tillage	Zero Tillage	Cropping System Average
Sweet Clover	107	59	1.2 *b*
Fall Rye	103	7	0.9 *c*
Spring Triticale	675	46	1.6 *a*
Wheat	648	105	1.8 *a*
Alfalfa	45	23	0.9 *c*
Tillage System Average	315 *a*	48 *b*	Crop x Tillage * *
LSD			0.3
C.V (%)			20.2

* significant at 0.05 probability level

Table A14. Initial green foxtail density (seedlings per metre squared) as affected by crop type and tillage system (Carman, 1995). Statistical analysis was performed as a split plot with tillage system as mainplot and suppressor crop as subplot on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Crop Type	Conventional Tillage	Zero Tillage	Cropping System Average
Sweet Clover	79	225	1.8 *b*
Fall Rye	30	90	1.4 *b*
Spring Triticale	400	572	2.5 *a*
Wheat	232	469	2.3 *a*
Alfalfa	6	26	0.6 *c*
Tillage System Average	149 *a*	276 *a*	Crop x Tillage * NS
LSD			0.5
C.V. (%)			26.3

NS = nonsignificant at 0.05 probability level

Table A15. Post-harvest wild oat density (seedlings per metre squared) as affected by crop type and tillage system (Carman, 1995). Statistical analysis was performed as a split plot with tillage system as mainplot and suppressor crop as subplot on log transformed data. Means with the same letter are not significantly different LSD ($p<0.05$).

Crop Type	Conventional Tillage	Zero Tillage	Cropping System Average
Sweet Clover	71	45	1.2 *b*
Fall Rye	33	29	0.9 *c*
Spring Triticale	43	31	1.0 *c*
Wheat	114	53	1.3 *a*
Alfalfa	27	35	0.9 *c*
Tillage System Average	57 *a*	39 *b*	Crop x Tillage * *
LSD			0.1
C.V. (%)			11.6

* significant at 0.05 probability level