PERFORMANCE OF WILD OAT (*AVENA FATUA* L.), WHEAT AND FLAX IN DIRECT-SEEDING SYSTEMS IN RELATION TO MONOAMMONIUM PHOSPHATE AND POTASSIUM CHLORIDE RATE AND PLACEMENT

BY

KRISTEN AILEEN CALLOW

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

MASTER OF SCIENCE

Department of Plant Science
University of Manitoba
Winnipeg, Manitoba

0-612-41685-2

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES
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ABSTRACT

Callow, Kristen Aileen. M.Sc. The University of Manitoba, October 1999. Performance of Wild Oat (*Avena fatua* L.), Wheat and Flax in Direct-Seeding Systems in Relation to Monoammonium Phosphate and Potassium Chloride Rate and Placement. Major Professor; Doug A. Derksen.

To determine the impact of monoammonium phosphate (MAP) and potassium chloride (KCl) fertilizer placement on wild oats in direct-seeded spring wheat and flax, 4 field experiments were conducted on 2 soil types in 1997 and 1998. Growth chamber experiments were conducted to compare the growth response and uptake potential of each species for phosphorus (P) and potassium (K). Growing seasons varied, with 1997 being dry and 1998 wet; however, general yield response was consistent. Yield was decreased by wild oat in 1997 while fertilizer placement influenced yield in 1998. Flax was relatively unresponsive to MAP and KCl addition. Wild oat decreased oil content of flax in 1997. Wheat yield increased with increasing MAP rates, particularly at the clay loam location and in side-banded treatments. Wheat yield was not increased by KCl addition on the loam soil, but yield increased with low levels of side-banded KCl on the clay loam soil. Wild oats affected wheat quality parameters but results were not consistent. In the growth chamber, P and K uptake was greatest in wild oats, followed by wheat and flax, indicating a higher wild oat requirement for these nutrients. The growth of wild oat is affected by temperature, precipitation and soil type, which determined its degree of interference and influence on crop yield. Wild oats are more tolerant to moisture stress

than wheat or flax, which resulted in greater crop yield loss in 1997. This research has shown a need for the re-evaluation of fertilizer recommendations in direct-seeding systems since typical crop responses to MAP and KCl fertilizer addition was not evident. For example; toxicity did not occur with high rates of MAP in the wheat or flax, the 'pop-up' effect from seed-placed MAP fertilizer did not occur and yield advantage from KCl addition occurred only at the clay loam location. These results may be attributed to direct-seeding, changes in available nutrients from long-term fertilization and /or the presence of wild oats.

ACKNOWLEDGMENTS

I am grateful for the opportunity to conduct this research which was funded by the Canadian Fertilizer Institute (CFI) and Agriculture and Agri-Food Canada (AAFC) through MII. Special thanks to the collaborative involvement of the Manitoba Zero-Till Research Association (MZTRA), Ralph Lowes, AAFC Beaverlodge Research Station and Norwest Laboratories.

I am thankful for the advice, guidance, direction and support provided by my supervisory committee; Dr. D.A. Derksen, Dr. C.A. Grant, Dr. R.C. Van Acker and Dr. M. Entz. Without the opportunity presented by Dr. Derksen and the expertise given by all, this project would not have been possible.

Other thanks is required to Ken McGillivary and Paul Watson for technical asssistance, Ray Smith, Shirley Newdorf, Jeff Robsen, Danny Hausermann and the many other summer students for their efforts with field work and sample processing. All staff and graduate students at the Brandon Research Station and the Department of Plant Science at the University of Manitoba should also be mentioned as I am sure each and everyone supported me in some way.

My family and friends need to be greatly accredited for their unconditional support and understanding. Particularly, Mom, Dad, Tanya and Clayton.

FOREWORD

This thesis was written in manuscript style as outlined in the Department of Soil Science "Guide to Thesis Preparation for Graduate Students". All three of the manuscripts are likely to be submitted for publication. The journal(s) to which they will be submitted have yet to be determined.

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1.0 INTRODUCTION

Current weed control strategies involve some combination of herbicide and tillage, however, zero tillage production systems are increasing in popularity on the Canadian prairies (Lafond et al., 1993). Zero tillage has increased 70.4% in Manitoba from 1991 to 1996, and a total of 135.3% across Canada (Statistics Canada, 1997). Conservation-tillage systems reduce soil erosion and degradation, promote water conservation and increase organic matter, but also, place a greater emphasis on pre-seeding herbicide application, thus, tend to increase overall dependence on herbicides (Derksen, 1995). Today, there is a renewed emphasis on using cultural methods for weed control because of environmental and economic concerns.

For decades, wild oats (*Avena fatua* L.) have been recognized as one of the most widespread and troublesome weed species on the Canadian prairies. It has dominated the weed community for the last twenty years (Thomas et al., 1998), and will continue to be one of the most aggressive and difficult to control weed species, as it has developed multiple resistance to herbicide groups 1, 2, 8 and 25[1]. The recurrent use of herbicides with the same mode of action on wild oat populations has selected for biotypes that are resistance to those herbicides (Jana and Naylor, 1982; Heap et al., 1993; Thill et al.,

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[1]Personnel communication. D. Kelner. Westco.123 Avril Lane, Winnipeg, Manitoba. R3R 3CB.

1994). With resistance spreading producers are left with fewer and fewer herbicide options. It is essential, therefore, that herbicides be considered as just one component of an overall integrated system together with cultural control and other management strategies, and that agronomic principles be considered when developing this system (Thill et al., 1994).

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). These IWM production systems should include the enhancement of crop competitiveness. Fertilizer placement affects a crop's ability to compete with weeds. Placing fertilizer where the crop has access to it but the weeds do not, allows the crop to be more competitive (Kelner et al., 1996).

Effective use of fertilizer inputs is one key to profitable grain and oilseed farming. Nutrients are one of the few factors affecting crop production that producers can control or manage. Fertilizers make up between 18 and 30% of oilseed and cereal crop production costs, a range of 5 to 10 dollars ha^{-1} (Anonymous, 1988). Commercial fertilizer application has increased 4% in Manitoba from 1991 to 1996 (Statistics Canada, 1997), therefore, the cost per hectare is probably much higher.

There has been little information obtained concerning fertility interactions between weed and crop plants. Weeds are often more competitive with crops at higher soil nutrient levels, which results in increased dependency on herbicides and tillage to maintain adequate control (Di Thomaso, 1995). Understanding basic biological nutrient requirements of weeds could lead to fertilization strategies which would enhance the competitive ability of crops while reducing competition from weeds. To understand, predict, and manipulate competition between crops and weeds more effectively, more information is needed concerning the underlying resource - related processes (Liebman and Robichaux, 1990).

This study evaluates the impact of side-banded and seed-placed monoammonium phosphate (MAP) and potassium chloride (KCl) fertilizer on wild oats in spring wheat (*Triticum aestivum* L.) and flax (*Linum usitatissium* L.). Phosphorus (P) was chosen since it is a major limiting resource on the Canadian prairies and P fertilizer would be recommended on most fields. Producers are beginning to add potassium (K) in larger and larger quantities, therefore, information on the interaction of K on crop and weed yields is needed. Spring wheat and flax were selected because of their differences in competitive ability against weeds and because of their economic importance to Manitoban agriculture (Statistics Canada, 1997). This study will provide producers with information on P and K fertilizer rates and placements for use in spring wheat and flax in direct seeding-systems that maximize efficient uptake and utilization, while minimizing the impact of wild oats in the Aspen Parkland Ecoregion of Manitoba. The Aspen Parkland Ecoregion is a transitional area between the grasslands in the south and the forest ecosystems in the north and has a transitional grassland ecoclimate. The dominant soil is a Black Chernozem with pockets of Gleysols.

2. LITERATURE REVIEW

2.1 The Black Soil Zone - Aspen Parkland Ecoregion

2.1.1 Soil Phosphorus

Phosphorus is an essential and major crop nutrient. The majority of Canadian prairie soils are deficient in available P needed for maximum production of cereal, oilseed and other field crops. Consequently, prairie farmers use large quantities of P fertilizers every year. Pre-seed banding and placing the fertilizer with the seed are the 2 most common methods of P application. Monoammonium phosphate is the most prevalent P fertilizer source used (Bailey and Grant, 1989). Crop species vary in their response and ability to utilize phosphorus fertilizers (Soper and Kalra, 1969).

Manitoba contains a high proportion of calcareous soils in agricultural areas (Lewis and Racz, 1969). Rapid precipitation of high portions of added P is probably caused by the high levels of calcium (Ca) and magnesium (Mg) coupled with elevated pH in these soil solutions. The rate and extent of P movement in calcareous soils will therefore be more restricted than P in the non-calcareous soils of the western prairies which have lower pH and contain smaller amounts of Ca and Mg in soil solutions (Lewis and Racz, 1969).

Soil type and many other parameters are important in determining soil P uptake potential. Soil P is supplied to plants mainly by diffusion (Itoh and Barber, 1983; Otani and Ae, 1996), therefore, morphological characteristics such as root length, surface area and fineness also influence P uptake (Barley, 1970; Fohse et al., 1991; Otani and Ae, 1996), but crops with longer root systems should not always be considered as the most efficient in P uptake, especially when grown in P limiting conditions (Otani and Ae, 1996). For example; because of dry conditions on the prairies, spring wheat has an extensive root system, but it only has a medium ability to retrieve available P. Crops probably employ additional mechanisms other than increased root length to increase P uptake in such situations (Otani and Ae, 1996).

Phosphorus availability in the seedling stage of all crops is of extreme importance (Vengris et al., 1955). Young plants have substantially higher P content than plants approaching maturity and P exported to the seed is substantially higher in cereals than in pulse or oilseed crops. Selles et al. (1995) found that the amount of P exported to the seed is directly related to P fertilization.

2.1.1.1 Soil Factors Affecting the Behaviour and Bioavailability of Phosphorus.

According to Bray (1954) the value of a soil nutrient to plants depends on its accessibility to roots which in turn, is related to its mobility in soil. Mobile nutrients are absorbed from the total soil volume containing roots, whereas immobile nutrients are absorbed from a thin layer of soil around the root (Strong and Soper, 1974a). Nye (1968) indicated that the zone of nutrient absorption around a single root for P is small relative to that for K or nitrogen (N). Lewis and Quirk (1967) found the zone of depletion for P around a wheat root to extend only 1 mm from the surface. Since this coincided with the length of root hairs, they concluded that root morphology influences plant extraction of P from soil.

Many workers consider the rate limiting step in P absorption to be directly related to the internal metabolic system of the plant. Nye (1968), argued that the specific P requirement of a crop is expressed at its root surface. Various properties of root systems may be involved in plant extraction of soil P, for example; pH at the root surface, rhizosphere organisms and root cation exchange capacity (CEC) (Strong and Soper, 1974a). Uptake of fertilizer P increases with the area of roots in the fertilized soil and with the amount of P applied, and tends to decrease with increasing P concentration in the plant (Duncan and Ohlrogge, 1959).

When water soluble P fertilizers are applied to soil, a wide variety of reaction products may be formed depending on the chemical properties of the soil and the applied P (Lindsay and Taylor, 1960). Soil factors which influence P retention in soils include: oxide content, type and amount of clay, calcium carbonate content, soil pH, soil CEC, soil type and amount of organic matter (Doyle and Cowell, 1993). Generally, aluminum, iron and hydrous oxides play dominant roles in the reaction of P in acid soils, but are not important for P retention in neutral to calcareous soils (Soper and Racz, 1980). Since P is relatively immobile, particularly in calcareous soils, reaction products due to fertilizer addition are usually restricted to a small fraction of the soil volume (Strong and Soper, 1974b).

Numerous studies have suggested that seed-placed P fertilizer is particularly effective when soil temperatures are low or when soils are wet in early spring, or when both conditions exist (Nelson, 1986; Potash and Phosphate Institute, 1986; Power et al., 1964; Simpson, 1960) since low soil temperatures reduce soil P availability and crop uptake (Munson and Murphy, 1986; Wallingford, 1986). Generally, as soil water volume decreases, P availability and uptake decrease, therefore, at a given level of soil P, crop response to fertilizer P often increases as water availability increases (Munson and Murphy, 1986; Nelson, 1986). Consequently, available soil P and soil water will influence response to fertilizer P applications (Wallingford, 1986).

2.1.2 Soil Potassium

Potassium is a major crop nutrient and is required by plants in relatively large amounts. Most western Canadian agricultural soils contain large quantities of K. There is generally more K in the soil than any other nutrient, but plants can only draw on a very small proportion of what is available. Typically, there is enough K in Manitoba soils for maximum crop production (Anonymous, 1988). However, most of the coarse textured soils in Manitoba are low in K (Doyle and Cowell, 1993b). To the east of Winnipeg, there is an area running south from Lake Winnipeg to the USA boundary where the soils do not contain sufficient available K for most crops (Doyle and Cowell, 1993b). Other low K soils are found in areas northwest, west and southwest of Brandon (Beaton, 1980). On average, 5.8% of the fields submitted to the Manitoban soil testing facility were considered K deficient (less than 200 kg K ha^{-1}, in the top 15 cm) (Doyle and Cowell, 1993b). Soil K levels have not changed over the past 25 years in Manitoba (Doyle and Cowell, 1993b).

Generally, barley, wheat, oats, corn and potatoes have a greater response to fertilizer K than oilseeds, such as canola or flax. Among the cereal grains barley responded more consistently and to a greater extent (Doyle and Cowell, 1993b). Crop response to K is greater when K is placed with the seed or banded in the soil near the seed rather than when broadcast (Bailey et al., 1993; Doyle and Cowell, 1993b).

The profitability of K fertilizer is usually high on low-K soils, but, significant yield response to applications of fertilizer K have been recorded in all provinces on soils with high background K levels (Bailey, 1985). The random responses, which occur at sufficiently low frequencies to be graded uneconomic, have been related to disease suppression rather than K nutrition (Doyle and Cowell, 1993b).

2.1.2.1 Soil Factors Affecting the Behaviour and Bioavailability of Potassium. The majority of soil K resides in K-bearing soil minerals which is unavailable to plants (Fanning and Keramidas, 1977). The soil solution and exchangeable K available to plants is low relative to the total K in the soil (Bailey et al., 1993). In most situations K moves to roots via diffusion and mass flow, but at quantities too low to satisfy the requirements of the crop during the growing season (Bailey et al., 1993). Potassium in soil solution is replenished by the release of exchangeable K from clay minerals and organic matter. This is often not large enough to satisfy the requirements of several successive crops, thus, for optimum crop production, the soil solution, clay minerals, and organic matter have to be continually replenished with K through the release of fixed K from soil minerals and through the addition of fertilizer (Bailey et al., 1993). Crop responses to K addition are not as large nor consistent as responses to N or P application. Diffusion is generally thought to be the most important mechanism for K movement to the roots; however, Tisdale et al. (1985) suggested that mass flow could significantly contribute to this process when K concentrations in the soil solution are high.

Cold, compacted or dry soil conditions tend to place more stress on K absorption and may warrant placement of high concentrations of K in the vicinity of developing plant roots (Anonymous, 1987). The presence of high concentrations of Ca and / or Mg in the rooting zone may also interfere with K uptake (Spratt, 1979; Grant et al., 1988). Both of these nutrients compete with soil K for entry into plant roots and may consequently restrict the availability of soil K to plants. Competition among Ca, Mg and K ions has been observed in several studies (Carter et al., 1979; Grant and Racz, 1987). Only a small fraction of the K requirement of plants is present in close proximity to roots (Grimme, 1979). As a result of this competition, consistent economic responses in wheat and barley have been reported in Manitoba from K fertilization on different soils (Beaton, 1980).

2.2 What is a Weed?

In one of his early texts on weed control, A.S. Crafts (1975) begins by saying, "In the beginning there were no weeds." Even though plants have existed for a long time, weeds did not exist before humankind (Radosevich et al., 1997). Typically, the definition of a weed is very broad because it is based on the subjective requirements of the individual making the evaluation (Navas, 1991). It is often said that a weed is a plant growing out of place, a plant growing where it is not wanted. Weeds can be described in either anthropomorphic or biological terms (Radosevich et al., 1997). The Weed Science Society of America (1994) defines a weed as: "any plant that is objectionable or interferes with the activities or welfare of man". However, Zimmerman (1976) believes that the term 'weed' should be used to describe plants that display all of the following characteristics: "they (1) colonize disturbed habitats, (2) are not members of the original plant community, (3) are locally abundant, and (4) are economically of little value (or are costly to control)".

The most important criterion for weediness is interference at some place or time with the values and activities of people - farmers, foresters, and many other segments of society (Radosevich et al., 1997). However, to the producer the abundance of weeds is of much greater importance than their mere presence (Radosevich et al. 1997). Since the advent of chemical herbicides in the 1950's, producers continued on the 'treadmill' of pesticide application. Continued use of herbicides has increased the selection pressure on certain weed species, which has resulted in more problematic weeds as control options become limited.

2.3 Integrated Weed Management

Long-term weed control strategies based on an understanding of biological, ecological and economical processes that drive cropping systems 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 (Schoofs, 1997). 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).

IWM production systems 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). Since this project focuses on only one aspect of an IWM production system, the enhancement of crop competitiveness, only literature in this area will be discussed.

2.3.1 Enhancement of Crop Competitiveness

As a result of the recent trend towards reduced doses of herbicides, greater attention should be given to the optimization of crop competitiveness (Dhaliwal and Froud-Williams, 1993). Crop competitiveness depends on a number of factors including choosing competitive cultivars, timing of crop emergence relative to that of weeds, crop density and spatial arrangement, crop morphological and physiological factors including canopy architecture and photosynthetic efficiency, availability of moisture and nutrients, soil structure and climatic variables (Fisher and Miles, 1973; Cousens, 1985; Wilson, 1986).

Choosing crops that are inherently more competitive is one approach for improving crop competitiveness (Walker and Buchanan, 1982). Pavlychenko and Harrington (1934) ranked wheat a better competitor with weeds than flax. Cropping practices which promote rapid and uniform crop establishment also enhance crop competitive ability against weeds (Swanton and Weise, 1991; Kelner et al., 1996). In an experiment by O'Donovan et al. (1985), the percent yield loss in barley and wheat was greater when wild oats emerged earlier than the crop, as opposed to when wild oats emerged later. Seeding the crop so that it emerges ahead of weeds will enhance its competitive ability.

Crops grown in narrower rows compete better with weeds due to rapid canopy closure and better root distribution (Légère 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 and the time of wild oat germination in spring. The denser the crop canopy, the better these cereal crops competed with emerging weeds.

Fertilizer applications directly affect the nutrient status of the soil, which has implications for crop competition. The modification of nutrient availability has shown variation of response and changes in competitive interactions between plants (Caldwell et al., 1987; Hall, 1974; Glauninger and Holzner, 1982; Hoveland et al., 1976). Crops and weeds compete for soil nutrients. Fertilizer placement to manipulate nutrient supply in favour of the crop, while minimizing nutrient supply to weeds will enhance crop competitiveness (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 received broadcast fertilizer applications 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 120 kg N ha^{-1} was broadcast as compared to 0 kg N ha^{-1}, because wild oats produced more vegetative biomass at 120 kg N ha^{-1}. Conversely, increased crop competitiveness against wild oats was observed from P fertilizer applied with the crop seed (Dhaliwal and Froud-Williams, 1993). These examples indicate the need for selectively banding fertilizers close to the crop row or with the seed to increase accessibility by the crop and decrease accessibility by the weed plants.

To optimize the balance between crops and weeds, information is required on the mechanism(s) of weed-crop interactions and how this balance is affected by availability of limiting resources (Dhaliwal and Froud-Williams, 1993). Evidence available for grassland species suggest that interspecific competition for below ground resources is often greater than competition for above ground light (Snaydon and Harris, 1981; Martin and Field, 1984).

2.3.1.2 Fertilizer Placement. Manipulation of fertilizer sources through placement, can improve resource acquisition by the crop to the weeds' detriment. O'Donovan et al. (1995) found that banding N between barley rows, with herbicide use, reduced green foxtail and stinkweed (*Thlaspi arvensis* L.) infestations compared to herbicide use alone.

Banding fertilizers within the crop row of bean (Otabbong et al., 1991), peanut (Everaarts, 1992), wheat (Cochran et al., 1990), alfalfa and lincoln bromegrass (Brown et al., 1960), little-seed canarygrass (Ahuja and Yaduraju, 1989) and lettuce (Shrefler et al., 1994) not only lowered weed populations compared to broadcast applications, but also increased crop yield (Di Thomaso, 1995).

These studies have shown that nutrient use efficiency can be enhanced through the choice of appropriate cultivars and the employment of cultural practices that maximize nutrient uptake by crops, ie. fertilizer placement technology. With changing management practices more precise fertilizer rates and placements need to be evaluated to demonstrate their effectiveness in current production systems. More efficient fertilization systems may also reduce herbicide rates required to provide adequate weed control (Di Thomaso, 1995).

2.4 Affects of Fertilizer Application and Placement

2.4.1 Phosphorus Fertility and Spring Wheat Yield

Past research has shown that the Chernozemic soils of Manitoba are deficient in P. Consequently, annual application of P is recommended for most crops. Crop response to annual applications of P differ (Bailey et al., 1977). In Manitoba, wheat shows only a medium level response to P fertilizer (Anonymous, 1988).

It is well known that placement of fertilizers in the seed row may damage the germination of some crops. The damage is caused by a direct toxic effect and by increased osmotic pressure in soil solution (Nyborg and Hennig, 1969). The amount of damage varies with the type of fertilizer and crop. Damage also varies with soil texture, soil temperature and especially soil water content. Cereal grains are usually fertilized by seed placement because they are fairly tolerant to damage up to the rate needed to optimize yield.

Dependent on soil P fertility levels, placement of P with the seed of spring wheat could be advantageous. Nakoneshny and Friesen (1961) found that P fertilizer placed with the seed reduced competition from weeds. Seed placed P has hastened plant emergence and plant maturation (haun stage), reduced root disease, and increased dry matter production and grain yields (Lafond et al., 1996). Halvorson and Havlin (1992); however, found that wheat grain yields increased significantly regardless of P placement. The application of P fertilizer may not increase spring wheat yield without an adequate amount of plant available N in the soil (Nuttall et al., 1971).

Applying recommended rates of P fertilizer for the last 20 - 30 years has resulted in increased levels of available soil P on the prairies (Ridley and Hedlin, 1962; Spratt and McCurdy, 1966). Regardless of this, Spratt and McCurdy (1966) found that over time wheat yields increased with increasing rates of fertilizer P application in a long-term study carried out on a thin Black Chernozemic soil at Indian Head Saskatchewan. In contrast, Ridley and Hedlin (1962), in a 38 year study in Winnipeg, Manitoba, found no response by crops to increased soil P resulting from years of continuous P application. In general, crops continue to respond positively to seed-placed P, in spite of the marked increase in available soil P due to fertilization (Zentner et al., 1993).

2.4.2 Phosphorus Fertility and Flax Yield

In field and greenhouse studies, Ukrainetz et al. (1975) and Sadler (1980) found that flax is relatively unresponsive to P fertilizers and generally responded poorly to P placed with the seed, even on soils low in plant available P. Placement of P away from yet near to the seed appears to be very critical not only to minimize seed injury but also to maximize crop response. Racz et al. (1965) found that there was a lack of flax response to 22.4 kg P ha^{-1} as concentrated superphosphate, reasoning that this was due to the fact that flax has a low rate of P uptake and low P requirement compared to rape and wheat. Sadler (1980) and Nyborg (1961) observed reduced germination and a 50 % reduction in flax emergence, respectively, due to placing P with the seed. Bailey and Grant (1989) also reported reduced flax emergence when 15 kg P ha^{-1} or greater was seed placed, therefore, the Flax Council of Canada (1996) recommends a low rate of phosphate - less than 8.74 kg ha^{-1} of P to be seed placed in Manitoba.

Salt toxicity occurs frequently from seed-placed P applications, therefore side banding is a better option in flax crops. Nyborg and Hennig (1969) recorded yield increases of up to 74 % for flax by placing 15 kg P ha^{-1} as MAP 2.5 cm directly below the seed. Similar yield increases in flax have been recorded by Bailey (1974). Another effective band placement at 2.5 cm to the side and 2.5 cm below the seed has been shown (Flax Council of Canada, 1996). Sadler (1980) found uptake of P to increase substantially when P was banded 3 cm to the side and / or 0 - 4.5 cm below the seed, but the further P is placed away from the seed the later the plant will be able to make use of it, resulting in a smaller growth response.

Nyborg and Hennig (1969), Bailey (1974), Sadler (1980) and Grant and Bailey (1993) all agree that restricted root proliferation during the first 3 - 4 weeks after seeding is responsible for the extreme sensitivity of flax to the location of P fertilizer. Flax tends to use native soil P in preference to fertilizer P (Racz et al., 1965). Therefore, producers often increase the level of P application in the preceding cereal crop in order to increase residual P levels for flax (Grant and Bailey, 1993; Bailey et al. 1977; Spratt and Smid, 1978).

2.4.3 Potassium Fertility and Spring Wheat Yield

Potassium is vital to many plant functions, but is not specifically needed for metabolic processes or functioning of plant organs (Andersson, 1997). Potassium affects plant biomass production because it affects plant water relations, enzyme activity and translocation of photosynthates (Hsiao and Läuchli, 1986; Mengel and Kirkby, 1987). Potassium is important when plants are subjected to environmental stresses; such as, drought, heat, low temperatures and attacks by various pests and diseases (Kafkafi, 1990; Lawn and Williams, 1987).

Generally, only a small fraction of the K requirement is present in close proximity to roots (Grimme, 1979), therefore applications of KCl on high K testing soils have frequently increased yields of hard red spring wheat on the prairies. These responses are apparently due to both K and Cl (Anonymous, 1987). Wheat and other cereal crops require as much K as N, and in some instances the need for K may be higher (Kemmler, 1978). Mengel (1982) noted that K uptake by wheat grown under water limiting conditions may be only 50 kg of K ha^{-1}; however, under optimal growth conditions it may reach 200 kg ha^{-1} . The quantities of K taken up per ton of grain and straw of cereals was 5 and 10 - 20 kg, respectively for a wide range of conditions in absence of deficiencies or excesses (Beaton and Sekhon, 1985). Generally, 1 ton of cereal straw will contain about 1 kg of K (Beaton and Sekhon, 1985). Beaton and Sekhon (1985) also showed that K removed by field grown wheat can increase as much as 14 times when high rates of N, P and K are used.

Yield response of wheat to K fertilizer is attributed primarily to increases in single grain weight (1000 kernel weight), but greater numbers of ears unit $area^{-1}$ and number of grains ear^{-1} also contributes to increased yields (Forster and Beringer, 1981; Haeder and Beringer, 1981). Insufficient use of K by small grains can delay anthesis and maturity. This could have serious consequences for areas like Manitoba with short growing seasons and potentially adverse weather conditions that delay harvesting operations. Beaton (1980) found that returns from K fertilizer expenditures in the USA and Canada for wheat were 200 % or higher approximately 60 % of the time.

2.4.3.4 Potassium Fertility and Flax Yield

Flax seed contains a high concentration of K (Lafond et al., 1996), but there has been very little work assessing the effects of K fertilizer on growth, seed yield, oil content or quality of flax. This is partially due to the fact that the crop is generally grown on fine textured soils that have adequate supplies of available K. Flax has a lower potential yield than most other oilseed crops under similar fertility and climatic conditions and therefore, its fertilizer requirements are typically lower. Flax does utilize and require a relatively large amount of K during growth. Bailey (1982) determined that a healthy crop of flax contains approximately 150 kg K ha^{-1} at maximum yield, excluding roots, but Bailey and Soper (1985) stated that of this large quantity of K taken up during growth, only a small portion (1%) is removed with the seed at harvest, therefore like most oilseed crops flax returns the bulk of K to the soil.

Bailey and Soper (1985) suggest flax is likely to respond to applications of K fertilizer when the exchangeable K in the soil is less than 200 kg ha^{-1}. Bailey (1967) reported an increase in seed yield with 9.3 kg K ha^{-1} seed-placed. A synergistic effect of N and K on seed yield was also shown. At flowering, the K concentration of the above ground portion of flax plants on the prairies averages 15 g kg^{-1}, but a level of 20 g kg^{-1} in the aboveground portion of the plants at flowering is required for maximum yield (Bailey and Spratt, 1979). Recommended rates of K for flax production in western Canada are relatively low and range from 29 - 62 kg ha^{-1} because yield response is generally modest. No information of effects of K on germination have been found in the literature; however, K may enhance the osmotic potential of cells, lignification, vigour and the subsequent strength of plants. Banding and placing K with the seed could increase the accessibility of K to the flax plant which could improve establishment and survival of seedlings.

2.4.5 Wild Oat Fertility Interactions

Competitive interactions between plants can change as nutrient availability is modified. Weeds vary in response to differences in soil fertility (Shrefler et al., 1994). Some grow well at low levels of available nutrients, while genotypic plasticity also allows them to take advantage of high fertility (Glauninger and Holzner, 1982). Generally, weeds require the same nutrients at the same time as the crop but are often more successful at obtaining them. Fertilization usually stimulates weed growth to the crops detriment. With low fertility, competition is primarily for nutrients; however, with high fertility competition is primarily for light (Zimdahl, 1993). Competition occurs when two or more organisms seek what they need and the supply falls below the combined demand. Vengris et al. (1995) found that weeds compete strongly for essential nutrients even at high rates of N, P, and K fertilization. Hoveland et al. (1976), found that out of 10 warm season and 7 cool season weed and crop species, the weeds were more sensitive to low soil test P and K, therefore weeds in general are notably better indicators of nutritional deficiencies than the crops in which they are growing.

Research over the past 40 years has led to varied conclusions about the influence of fertilization on wild oat competition with cereal and oilseed crops. Some studies have shown that fertilization increased the yield of wild oats as well as the yield of cereal crops (Henson and Jordan, 1982; Sexsmith and Russell, 1962; and Thurston, 1962). A detailed green house study of the growth responses of wild oat, wheat and barley led Thurston (1959) to conclude that application of N to infested fields would not likely alter the balance between wild oats and crops. Others have reported that N application stimulated wild oat germination in the field (Sexsmith and Pittman, 1963) and that annually applying N increased wild oat infestation in continuous wheat rotation (Watkins, 1971). Carlson and Hill (1985) found that wild oats were better able to utilize the added N and gained a competitive advantage over the crop in gathering other growth resources such as water, other soil nutrients and / or light. This increased competitive ability resulted in decreased crop yields. Conversely, Kirkland (1997) found that side banding N was effective in reducing wild oat density and biomass compared to broadcast applications. A similar study involving flax demonstrated an increase in the proportion of wild oats to flax plants with broadcast N fertilizer (Sexsmith and Russell, 1963). Flax is a poor competitor with wild oats and the addition of fertilizer appeared to benefit the weed alone (Bell and Nalewaja, 1968a and 1968c).

Competition between wild oats and crop plants for P has been given less attention than N over the years. Haynes et al. (1991) found that wild oats produced more root mass and accumulated P more rapidly than tame oats. The wild oat plants also produced significantly more dry matter for a given accumulation of P in this study. McBeath et al. (1975) showed that differential placement of P fertilizer had a pronounced effect on the competitive ability of wild oats in barley. When P was available to barley, the enhanced growth helped to prevent wild oat seed production. Conversely, when P was available to wild oats, the weed offered strong competition to barley and reduced the crop yield. Similarly, Sexsmith and Russell (1963) and Sharma et al. (1977) demonstrated the importance of applying adequate P fertilizer with the seed in a cropping system where wild oats are known to be a problem. Haloin and Sudia (1967) found that wheat and oats appeared to have a competitive advantage over wild oats for P and K, but barley was similar in competitiveness. In contrast, Haynes et al. (1991) found wild oats to have greater uptake and utilization of P compared to cultivated oats.

General fertilization studies determining wild oat competitive effects were also done. Bowden and Friesen (1967) found that once the wild oat density reached 91 plants m^{-2} no marked differences occurred between fertilized and unfertilized treatments of wheat. The weed populations seemed to have negated out any advantage the fertilizer might have provided for the wheat crop. Bell and Nalewaja (1968b) stated that while the addition of fertilizer did not control the wild oats, crop yields could still be increased despite the presence of wild oats. In this study, the fertilized wheat produced larger yields than the corresponding unfertilized plots, but yield loss from wild oats did occur and this prevented the crops from fully utilizing the fertilizer.

The variability of the above results occurred because some experiments were conducted in growth chambers and others in the field. Environmental conditions are controlled in one case and not the other, which indicates that the degree of deficiency of nutrients likely varied. The wild oat populations also came from different sources and therefore, varied in their genetic make-up due to different selection pressures placed on them in the areas they were grown.

2.5 Weed-Crop Interactions

Competition is the most studied form of interference that occurs between weeds and crops. Density is the plant factor that affects interference the most, while species proportion and spatial arrangement among individuals have lesser effects.

Nutrients are a major source of competition among neighbouring plants. Often when weeds are grown in association with crops, the nutrient status of the crop declines when compared to that of the crop growing alone. In some crop and weed combinations, the weeds may even consume nutrients luxuriantly, relative to the crop; however, increased fertility does not substitute for weed density reduction in a cropping system (Radosevich et al., 1997).

Direct resource competition (for nutrients) can be measured by the biomass production of neighbouring plants, since biomass is proportional to total resource use if resource use efficiency is constant (Altieri and Liebman, 1988), but density and spatial arrangement must also be considered. Altieri and Liebman (1988) did not maintain equivalent wild oat densities in each treatment, fertilizer placement in this case can only be look at as indirectly affecting competition between the crops and wild oats. In order to understand the implications of this research the nature of competition between wild oats and spring wheat and flax most be investigated.

2.6 Weed-Crop Competition

2.6.1 Competition Defined

Darwin (1859) identified the central role of competition in selection processes of organisms in general. Since then, competition has been regarded as one of the major forces behind the appearance and life history of plants and the structure and dynamics of plant communities (Grace and Tilman, 1990). In the agricultural sciences, competition studies have focussed on minimizing the effect of weeds by optimization of crop plant densities, and on development of predictive tools for yield loss assessment to develop weed management systems with minimum herbicide inputs (Zimdahl, 1980; Radosevich and Roush, 1990; Altieri and Liebman, 1988).

Grime (1979) defined competition as the 'tendency of neighbouring plants to utilize the same quantum of light, ion or mineral nutrient, molecule of water, or volume of space'. The competitive ability of a species is then determined by the capacity to exploit resources rapidly (Kropff, 1993). Tilman (1987) defined competition as 'the utilization of shared resources in short supply by two or more species'. The competitive ability of a species is then determined by its minimum resource requirement (Kropff, 1993). Grace (1990) concluded that these two theories of competition are not contradictory but complementary: if the habitat is fertilized, the competitive ability of a species is determined by its resource capture capacity; whereas, in low fertility situations the competitive ability is related to the capacity of a species to tolerate low resource availability.

In agricultural systems, crops are grown at moderate to high resource levels. In many of these systems large amounts of resources (nutrients and water) are added to the system to maximize yields. Competition in these systems could be defined as the process of resource capture and utilization of shared resources by the crop and its associated weeds (Kropff, 1993).

2.6.2 Wild Oat Competition on the Canadian Prairies

For decades, wild oats have been recognized as one of the most widespread and troublesome weed species on the Canadian prairies (Bell and Nalewaja, 1968a; Sharma and Vanden Born, 1978). This weed has dominated the weed community for the last twenty years (Thomas et al., 1998), and will continue to be one of the most aggressive and difficult to control weed species, as it has developed multiple resistance. In western Canada, in 1978, it was estimated that the annual crop yield losses and herbicide costs attributable to wild oats was $280 million (Dew, 1978). A weed survey of Manitoba in 1997 indicated that 65.5% of the fields are infested with a wild oat average of 7.1 plants m^{-2} (Thomas et al., 1998). Dew (1972) reported that as few as 5 wild oat plants m^{-2} reduced yields of wheat, barley and flax. Yield losses will vary depending on the tillage system under investigation (Derksen and Hume, 1995) and when the wild oats emerge relative to that of the crop (Hunter, 1983). Considerable yield loss variation may result even with similar densities of wild oats (Bowden and Friesen, 1967; Bell and Nalewaja, 1968b). Wilson and Peters (1982) found similar crop yield losses from five-fold differences in wild oat density.

Wild oat persists in most spring planted small grain and flax fields because the seed ripens earlier than the crop and drops to the ground. Approximately 90 % of wild oat seed drops prior to harvesting operations (Shirtliffe and Entz, 1997). Some of the wild oat seed may remain dormant in the soil for many years, assuring perpetuation of the species (Bell and Nalewaja, 1968a). The wild oat seed is capable of germinating over a wide range of temperatures (2 - 35 °C) (Chancellor, 1976); however, high temperatures near the soil surface prevent germination of wild oat (Sexsmith and Pittman, 1963). Seed dormancy and irregular germination throughout the growing season are the most important features contributing to the persistence of wild oats (Sharma and Vanden Born, 1978). The wild oat seedling is at first weak and very susceptible to competition, but with an enlarging root system and an initially higher net assimilation rate, it gradually catches up to the cereal crop in which it occurs (Chancellor, 1976). The Canadian prairies often experience moisture limitations throughout much of the growing season and under these conditions the competitive effect of wild oats could be expected to occur at earlier growth stages (Kirkland, 1993).

The competitive ability of plant species is affected by their environment (Zimdahl, 1980). The agronomic and environmental conditions under which competition experiments are conducted will clearly modify the competitive effects of weeds on the crop (Carlson and Hill, 1985; Wall et al., 1991). Moisture, temperature, and nutrient levels influence germination, growth and competition. Soil type and characteristics have direct and indirect effects on wild oat incidence and development. Wild oats occur widely on arable soils in temperate climates in the northern hemisphere (Odgaard, 1972). Incidence can be modified by an interaction between soil and climate (Chancellor, 1976). Kühnel (1965) reported that on heavy loam soils a severe winter followed by a dry spring resulted in an increase in wild oat plants, but under the same conditions on sandy loam soils there was a decrease. Climatic factors that indirectly affect wild oats are temperature and moisture. Sexsmith (1969) reported that a higher level of dormancy occurred in seeds from plants grown at low temperatures and moist soil than from those grown at high temperatures in drier soil. This could affect development indirectly through date of germination. Time of weed emergence relative to the crop is important in determining competition (Peterson and Nalewaja, 1992).

Vegetative growth of wild oats varies with competition. In the absence of competition very large plants can be produced with a considerable reproductive capacity, but in competition with a cereal crop the development of the plant is normally very restricted (Chancellor, 1976). Pavlychenko and Harrington (1934) studied competition between various crop and weed species. They ranked the crops in order of competitive ability as follows; barley, spring rye, wheat and oats, and finally flax. Among the weeds, wild oats were one of the most competitive, if not the most.

2.6.2.1 Wild Oat Competition in Wheat. Competition between grassy weeds and cereal crops is a timeless problem in all agricultural production areas of the world. Many experiments have been conducted to determine the nature of this competition. Cudney et al. (1989) suggested that wheat and wild oats are equivalent in competitiveness. Equivalence in competitiveness indicates that wheat could be substituted for wild oats or wild oats for wheat on an equal basis with a similar effect on biomass. Generally, competition between cereals and wild oats occurs below ground (Satorre and Snaydon, 1992). Pavlychenko and Harrington (1934) reported that 5 days after emergence, wild oats had a root system 87 cm in length, and 24 days after emergence the length was 24 m. This root system was more extensive than that of barley, wheat, spring rye or oats; however, in growth chamber experiments, Bingham (1995) and Satorre and Snaydon (1992) found that total root length and overall root agressivity was greater in wheat than wild oats. They attributed this to greater numbers of seminal roots. In a study in which the effects of root and shoot competition were separated, Martin and Field (1987) reported that wild oats were more competitive than spring wheat when the root systems were allowed to mix. The greater competitive ability of wild oat was ascribed (on the basis of Pavlychenko and Harrington's 1934 findings) to its more vigorous adventitious root system. Conversely, in a similar study, Satorre and Snaydon (1992) reported that wheat was more competitive than wild oat. This later study suggests that the adventitious root system of wild oat may not be inherently more vigorous than that of wheat, or that other factors such as the rate of development of the seminal root system, the ability of roots to absorb ions from low concentrations in solution and the efficiency of utilization of nutrients in tissues (Siddiqi et al., 1987) are of overriding importance. Since the pioneering work of Pavlychenko and Harrington (1934) considerable changes have occurred in the morphology and vigour of cereal varieties which may influence their competitive ability (Bingham, 1995). Furthermore, wild oat genotypes vary in morphology and physiological characteristics (Thurston, 1959; Siddiqi et al., 1987).

Pavlychenko and Harrington (1934) found that in the case of wheat, the major part of the root mass is found a considerable distance from the surface. This type of root system is better adapted for drought resistance than for competition with weeds. It allows weeds to become established easily due to the scarcity of wheat roots in upper levels. In drier regions, like the prairies, a longer root system is desirable. Pavlychenko and Harrington (1934) showed that wild oats occupied the soil from the surface to great depths almost completely, the ability of cereals to compete at all with wild oats may be explained first by the slower normal germination of wild oats and secondly by the fact that the wild oat has no more than three primary roots and develops its root system very slowly at early growth stages.

Generally, the longer wild oats remained in plots, the lower the crop yield (Bowden and Friesen, 1967). Similarly, as the density of wild oat seedlings increased this competition reduced the yield of wheat (Bell and Nalewaja, 1968b). This yield reduction was thought to be due to a reduction in the number of fertile tillers of wheat (Bell and Nalewaja, 1968; Kirkland and Hunter, 1991). The exact density of wild oat seedlings which will cause a yield reduction of economic importance is dependent on the environment, herbicide cost, and price of the crop. For example; Bowden and Friesen (1967) found that only 37 wild oat plants m^{-2} were required to reduce wheat yields significantly. Furthermore, Kirkland (1993) showed that an infestation of 118 wild oat plants m^{-2}, maintained up to the 5 leaf (L) stage did not reduce grain yields. But, when the infestation was allowed to remain to the 6 and 7 L stage, grain yield was decreased by 17 and 25 % respectively and 39 % when this density was allowed to compete throughout the whole season.

The above studies provide conflicting results; however, it is known that the agronomic and environmental conditions under which competition experiments are conducted modifies the effects of weed-crop interactions. Using this information, the variability of previous results can be explained. Wheat was only found to be more competitive than wild oats in growth chamber experiments. In these experiments there were no limiting environmental resources (light, water and nutrients) to indirectly affect the competitive outcome and rooting volume was limited. Differences cited from field experiments resulted from a variation in climatic and edaphic factors as well as management practices, such as, method of tillage and fertilization.

2.6.2.2 Wild Oat Competition in Flax. Among cereal and oilseed crops, flax has been shown to be the least competitive with wild oats (Pavlychenko and Harrington, 1934; Sharma and Vanden Born, 1978) and an overall poor competitor with weeds (Friesen and Shebeski, 1960; Dew, 1972). If wild oats emerge before the flax crop, yield loss is greater than if it emerges later. Serious competition starts before the 2 - 3 L stage of wild oats (Sharma and Vanden Born, 1978; Bell and Nalewaja, 1968a).

Bell and Nalewaja (1968a) reported an average flaxseed yield reduction of 70.2 % from only 10 wild oat plants m^{-2} in Manitoba. They also found that flaxseed yield continued to decrease as wild oat densities increased. Components of flaxseed yield, including bolls m^{-2}, seeds $boll^{-1}$, plants m^{-2}, and weight in g 1000 $seeds^{-1}$ were all reduced by wild oat competition (Bell and Nalewaja, 1968a). A density of 37 wild oat plants m^{-2} caused a reduction of 161 bolls m^{-2}, 0.51 seeds $boll^{-1}$, and 8.07 flax plants m^{-2} (Bell and Nalewaja, 1968a). Similarly, Bowden and Friesen (1967) reported average flax yield reductions of 24 and 50 % from 12 and 48 wild oat plants m^{-2}.

Wild oat interference was least detrimental to flax yields after the time of flax boll formation (Bowden and Friesen, 1967; Stevenson and Wright 1996). Bell and Nalewaja (1968c) determined that a maximum yield reduction of 76.3 % occurred when wild oats were allowed to compete until they reached heading and that the critical time of weed removal was as early as possible at high wild oat densities, because early wild oat removal resulted in higher flax yields. The ideal time for control would be at germination or shortly thereafter, but wild oats should be controlled before the 5 L stage, since a rapid increase in competition was observed at this stage (Bell and Nalewaja, 1968c).

2.6.2.3 Wild Oat Competition for Nutrients. Weeds are important competitors with crop plants for all nutrients. Most weeds are capable of absorbing nutrients faster and in relatively larger amounts than crop plants and thus profit more from fertilization (Patterson, 1995). In the presence of a high weed population density, fertilizer application may stimulate weed growth so greatly that the crop plants will be overgrown and suppressed (Alkamper, 1976). Many weeds are able to accumulate mineral nutrients in excess of the critical concentration needed for growth (Radosevich et al., 1997). With low fertility, competition is primarily for nutrients; however, with high fertility, competition is just as vigorous, but primarily for light (Zimdahl, 1993). Most studies investigating competition between species have concluded that 'competition for nutrients' is of greater importance than 'competition for light' (Hall, 1974).

The study of nutrient requirements of various weed species and their relative importance as serious competitors for essential nutrients with crop plants has long been neglected (Vengris et al., 1955). The studies that have been conducted, provide conflicting results, particularly when looking at wild oats. It has been shown that wild oats take up the same amount of N from the soil as winter oats (Thurston, 1959) or up to twice as much (Bowden, 1971). They have taken up as much N as winter wheat (Thurston, 1959) or less than wheat from nutrient solutions (Koch and Köcher, 1968).

Wild oats can take up less N than barley (Koch and Köcher, 1968), as much as barley (Sinyagin, 1966) or more than barley (Thurston, 1959).

Wild oats utilize twice as much P as cultivated oats (Bowden, 1971), but less P than winter wheat and barley (Koch and Köcher, 1968) or little at all (Sinyagin, 1966; Pawlik, 1957). Sexsmith and Russell (1963) and Chancellor (1969) found that P had no effect on growth or seed production of wild oats; however, Haynes et al. (1991) found that each increase in P content resulted in a proportionately greater increase in dry weight for wild oats. Wild oats were as dense and tall and contained the same P content when competing with wheat, barley, oats and other wild oats, whether grown at low or at high nutrient levels (Halloin and Sudia, 1967).

The use of K is even less certain (Chancellor, 1976). Wild oats have been reported to be relatively insensitive to K (Pawlik, 1957), although it has caused a slight weight increase in top growth (Chancellor, 1969). When grown separately in nutrient solution, wild oats took up less K than wheat and barley (Koch and Köcher, 1968). When grown in competition with barley and wheat, wild oat plants were the same height and weight and had the same K content when grown at high or low nutrient levels, but when grown with cultivated oats they contained less K than wild oats growing with other wild oats and this difference was greater with increased nutrient concentration (Halloin and Sudia, 1967).

The lack of consistency in the above results indicates that experimental design and environment influence the outcome of competition trials. Comparing results of nutrient acquisition in the field to the growth chamber is difficult. In the field, genotype by environment (G x E) and G x E x management (G x E x M) interactions have implications that can not be overlooked. The genotypic and phenotypic plasticity of weeds is high, making comparative research with crop plants for nutrient acquisition and uptake problematic.

2.6.2.4 Wild Oat Competitive Affects on Grain Quality. Few studies have considered how individual weed species affect quality aspects of crop production. The studies that have, have found that cereal grain quality appears to be infrequently affected by wild oat competition, but flax seed quality is readily affected (Chancellor and Peters, 1976).

Friesen (1957) found that the protein content of wheat and barley was increased when weeds (mainly wild oats) at densities between 16 and 2665 m^{-2} were removed. Nakoneshny and Friesen (1961) showed that yield increases following fertilizer applications to weedy spring wheat were sometimes association with protein reduction. They concluded that protein reductions could be prevented and protein level subsequently increased by weed removal. Friesen et al. (1960) also found that weeds significantly reduced both protein content and yield of wheat, barley and oats in 22 out of 60 fields. The weed densities ranged from 18 to 1040 m^{-2} and weeds other than wild oats were present. Conversely, Bell and Nalewaja (1968b) found no effect on the 1000 kernel grain weight or protein content of wheat and barley at wild oat densities of up to 300 m^{-2} and Bowden and Friesen (1967) found the protein content of wheat to be unaffected by wild oat populations of up to 228 m^{-2}, regardless of cropping sequence or fertilizer treatment. The fact that other weeds were present in all the instances of protein reduction may indicate that a greater range of nutritional demand than that made by wild oats alone is necessary for reduction. High weed densities and early weed emergence also appear to be prerequisites.

In flax, Bell and Nalewaja (1968a and 1968c) showed that the oil content, the iodine number of the oil and the level of linolenic acid in the seed declined in three separate years as a result of wild oat competition. Conversely, the level of oleic acid increased. These changes occurred with wild oat densities as low as 12 m^{-2}. The effect of duration of competition on flax seed quality was also investigated and, although the number of bolls was reduced by relatively short periods of competition, it was not until the flax had produced bolls and the wild oats were heading that reductions in quality occurred (Bell and Nalewaja, 1968c). Burrows and Olson (1955), Chow and Dorrell (1977) and Frieson (1986) found competition from other weed species did not affect flax seed and oil quality.

2.7 Summary

The literature reviewed indicates that many agronomic factors, encompassing weed ecology and soil fertility, need to be considered before implementation of fertilizer placement as an IWM tool can be fully utilized. An IWM 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 (Schoofs, 1997). Heavy reliance on one method of weed control has selected for certain weed species, making them more abundant and difficult to control in the long term. Use of IWM systems will reduce this selection pressure, while still maintaining adequate weed control for the producer. Fertilizer placement is one tool that the producer can utilize as a component of their IWM system.

Much more information is needed about the basic mechanisms of plant responses to single and interacting resources and how these mechanisms affect and are altered by weed-crop interactions (Radosevich et al., 1997). Such information could be used to develop strategies for fertility management to achieve maximum crop growth and weed control. The few projects that have considered at fertilizer placement as a means to increase crop competitiveness, have provided conflicting results due to variations in their experimental protocols, therefore the objectives of this research project were:

1) To determine the effect of seed-placed and side-banded MAP and wild oats on the performance of direct-seeded spring wheat and flax.

2) To determine the effect of seed-placed and side-banded KCl and wild oats on the

performance of direct-seeded spring wheat and flax.

3) To determine the effect of wild oats on grain quality of spring wheat and oil quality of flax.

3. EFFECT OF MONOAMMONIUM PHOSPHATE FERTILIZER RATE AND PLACEMENT AND WILD OATS ON THE PERFORMANCE OF SPRING WHEAT AND FLAX IN DIRECT SEEDING

3.1 Abstract

Fertilizer placement can directly affect a crop's ability to compete with weeds. To determine the impact of monoammonium phosphate (MAP) fertilizer placement on wild oats in spring wheat and flax, 2 field experiments were conducted on 2 soil types in 1997 and 1998. Growth chamber experiments were conducted to compare phosphorus (P) uptake potential and growth response of each species to P. Environmental conditions from year to year varied, but this did not translate into yearly variations in yield. Crop yields were affected by the presence of wild oats in 1997 and to differences between fertilizer placements in 1998. Flax was relatively unresponsive to MAP addition. Wheat yield increased as MAP rates increased, particularly at the clay loam location and in side-banded treatments. In the growth chamber, P uptake was greatest in wild oats, followed by wheat and flax. The advent of direct-seeding technology may require the re-evaluation of fertilizer recommendations since typical crop responses to MAP fertilizer addition did not occur. For example; there was a lack of toxicity at high MAP rates in both crops and the 'pop-up' effect from low rates of seed-placed MAP did not occur. These results may be attributed to changes in management with direct seeding, subsequent changes in

nutrient availability, cycling of nutrients from residue and to the presence of wild oats.

3.2 Introduction

Phosphorus (P) frequently limits crop yield on the Canadian prairies and P fertilizer would be recommended on most fields (Anonymous, 1998). Monoammonium phosphate (MAP) is the most commonly applied P fertilizer in western Canada (Bailey and Grant, 1985). Crops continue to respond positively to P fertilizer in spite of marked increases in available soil P from annual fertilization (Zentner et al., 1993). Phosphorus recommendations in the Black soil zone need to be reinvestigated due to changing management practices and increased acreages in conservation-tillage.

Wild oats (*Avena fatua* L.) have dominated the weed community on the Canadian prairies for the last 20 years (Thomas et al., 1988), and will continue to be one of the most aggressive and difficult to control weed species, as it has developed multiple resistance to herbicide groups 1, 2, 8 and 25[1]. The development of integrated weed management (IWM) systems is imperative, due to the increasing development of herbicide resistance, especially, in direct-seeding systems where greater emphasis on pre-seeding herbicide applications tend to increase a producers overall dependence on herbicides (Derksen, 1995).

Fertilizers are components of the production system that producers can directly manipulate, therefore, fertilizer placement, as an IWM tool to achieve maximum crop

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growth and weed control, is a means of increasing crop competitive ability against weeds. Weeds are more competitive with crops at higher soil nutrient levels, which can result in increased dependency on herbicides and tillage to maintain adequate control (Di Thomaso, 1995). Structured fertilizer management studies with specific weed species would increase our understanding of the basic biological nutrient requirements of weeds and could lead to strategies that would enhance the competitive ability of crops while reducing yield loss due to interference from weeds.

The objective of this research is to evaluate the impact of seed-placed and side-banded MAP on wild oats in spring wheat (*Triticum aestivum* L.) and flax (*Linum usitatissimum* L.) in the Aspen Parkland Ecoregion - Black Soil Zone of Western Canada. Spring wheat and flax were selected because they represent different extremes of competition and because of their economic importance to Manitoba agriculture (Statistics Canada, 1997). Field experiments were conducted to provide information on how climatic and edaphic factors affect P uptake by each species in direct-seeding systems, and how this affects weed-crop interactions. Growth chamber experiments were conducted to provide insight into P requirements and uptake potential of wild oats.

3.3 Materials and Methods

3.3.1 Growth Chamber Experiments

The effect of MAP biomass accumulation of spring wheat (cv. Teal), flax (cv. Norlin) and wild oats (herbicide susceptible populations, UM5 and Portage la Prairie[2]) was determined. The experiment was arranged in a completely randomized design (CRD), with 3 replicates, and treatments were randomized within replicates. The treatments consisted of 0, 4.37, 8.74, and 17.48 kg P ha^{-1}, for each species, and each date of harvest. Low rates were chosen to determine which species had the greatest P uptake. Five destructive harvests were conducted, beginning at 14 days after emergence (DAE) and continuing at 21, 28, 35 and 42 DAE.

A clay loam soil, low in available P (Table 3.1) was collected from the Manitoba Zero-Till Research Association (MZTRA) farm (SW 27-10-19W). The soil was dried, raked and sifted, and stones and any other debris were removed to obtain uniform consistency. Fertilizer rates and soil field capacity were determined based on a 1 kg soil volume per pot (Cassel and Neilsen, 1986). The pots were made of white plastic, had no drainage and measured 12.7 cm in diameter, with a volume of 950 cm^3. All other nutrients (N, K, and sulphur (S)) were added based on soil test recommendations. Nutrients were weighed and dissolved in distilled water. The soil was then placed in a cement mixer and the nutrients were sprayed onto the soil as a fine mist while it was

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[2]Department of Plant Science. University of Manitoba. Winnipeg, Manitoba. R3T 2N2.

blended. One kg of soil was added to each pot, with a total of 150 pots in the experiment (3 reps, 3 rates, 3 species, 5 harvest dates and 15 controls (3 per harvest, one for each species)). Extra pots at each rate were maintained as replacements if poor germination resulted. Pots were watered to field capacity and allowed to stand for a 72 hour period prior to seeding.

All seeds of each species were placed in petri dishes on moist filter paper (10 mm of distilled water). The petri dishes were raised to a 10° angle in a germination cabinet[3] maintained at a 16 h light / 8 h dark photoperiod and 20 +/- 1°C. The wild oat seeds were placed in the germination cabinet first as they took 3 to 4 days to germinate, whereas, the flax and wheat took 1 to 2 days. After the seeds germinated, they were selected for uniformity and seeded at a rate of 10 per pot. The flax was seeded at a 1cm depth and the spring wheat and wild oats were seeded at 2 cm. Once the seeds emerged they were thinned to 5 plants per pot. All pots were evenly spaced on carts in the growth chamber. The growth chamber was maintained at a 16 h light / 8 h dark photoperiod with temperature maintained at 24°C day / 16°C night. Relative humidity was approximately 60%. The pots were watered to field capacity with distilled water whenever the moisture content fell to 70% of field capacity. Pots were arranged in a CRD and re-randomised after each watering to avoid edge effects and differences in light availability within the growth chamber.

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[3]Model # I18L. Conviron Products Company. A Division of Controlled Environments, Ltd. 1461 St. James St., Winnipeg, Manitoba. R3H 0W9.

Table 3.1 Background soil parameters for phosphorus growth chamber experiments.

	Soil Parameters	Estimated kg ha^{-1} Available		
	Nitrate-N	26.9		
	Phosphate	26.9		
	Potassium	938.6		
	Sulphate-S	89.6		
	pH	7.1		
	E.C.*	0.4		
Sufficiency Range (P)	Deficient	Marginal	Optimum	Excess
kg ha^{-1}	33.6	56	134.4	>134.4

* E.C.= electrical conductivity of the soil, which is a measure of salinity in dS m^{-1}.
Information provided by Norwest Labs[4] (assessments based on a 0 - 15 cm sampling depth).

3.3.1.1 Data Collected. The above ground portion of each plant species was harvested at 14, 21, 28, 35 and 42 DAE. Main stem Haun staging (Haun, 1973) of wheat and wild oats was determined using a grid system designed by Guy Lafond[5], and height and growth stage of flax (Flax Council of Canada, 1996) was recorded at each harvest. Samples were dried in a 1370 GM gravity oven[6] at 60°C for a minimum of 72 hours and weighed for dry matter determination. Next, they were ground using a cast steel Thomas Wiley mill, to pass through a 1 mm sieve and sent to Norwest Labs for N, P, K, Ca, Mg and sodium (Na) analysis. The N analysis was done by a combustion method using a Leco N-Analyzer. All of the other parameters were analysed starting with an ashing procedure,

[4]#204-545 University Crescent. Winnipeg, Manitoba. R3T 5S6.

[5]Personnel communication. Dr. G. Lafond. AAFC. Box 760, Indian Head, Saskatchewan. S0G 2K0.

[6]VWR Scientific, Canada, Ltd. Box 20060, London, Ontario. N6K 4G0.

followed by an acid dissolving step with analysis by ICP Spectrometry[7]. Phosphorus uptake, expressed in kg ha^{-1}, was then calculated by multiplying dry matter yield by plant P concentration.

3.3.1.2 Statistical Analysis. All data were subjected to ANOVA and orthogonal contrasts using procedures outlined in Statistical Analysis Systems (SAS) software package (SAS Institute, Cary North Carolina, 1990). Regression analysis on fertilizer rate was not consistent, therefore curve fitting was not done. Data was combined from the 2 experiments after passing Bartlett's test and presented as dry matter accumulation, P concentration and P uptake over time.

3.3.2 Field Experiments

These experiments were conducted at 2 locations in 1997 and 1998 in the Aspen Parlkand Ecoregion at Brandon Manitoba. One location was approximately 10 km south of Brandon and 3.2 km west of number 10 highway (NE 32-9-19W) on a loam soil, the second location was approximately 40 km north of Brandon on highway number 10 at the MZTRA (SW 27-10-19W) farm on a clay loam soil. These locations were chosen to represent 2 dominant soil types in western Manitoba; rego chernozem and orthic black chernozem respectively (Table 3.2).

The loam location had been in zero-till for approximately 20 years, and the clay

[7]Personnel communication. Rob Ellis. Norwest Labs. #203-545 University Crescent. Winnipeg, Manitoba. R3T 5S6.

loam location for approximately 8 years. The trials were seeded into wheat stubble at the loam location, and canola stubble at the clay loam location in 1997. In 1998, all trials were seeded directly into canola stubble. The experiments were arranged in a randomized complete block design (RCBD) with 4 replicates. A 4 m by 7 m area constituted the rate and placement of MAP, which was factorially arranged with treatments split (2m by 7m) with and without wild oats. Teal spring wheat[8] was seeded at 100 kg ha^{-1}, at a depth of 3.75 - 5 cm. Norlin flax[9] was seeded at 40 kg ha^{-1}, at a depth of 0.63 - 1.25 cm. An air seeder (Conserva-pak on 20 cm row spacing) was calibrated each year for each product using standard procedures for the "Valmar" boxes with product rates for each gear setting calculated using a spreadsheet[10].

Nitrogen (as 46-0-0) was banded, prior to seeding, across each replication perpendicular to the direction of seeding at a rate of 78.4 kg N ha^{-1} on 20 cm spacing. The MAP fertilizer was applied at seeding. Each plot was planted consecutively (in a serpentine pattern) with gear settings and ratios changed by hand (ie. rate and placement of fertilizer). The seed-placed fertilizer was applied with the seed in the seed row, whereas, the side-banded fertilizer was placed 2.5 cm beside and 2.5 cm below the seed row.

The treatments with and without wild oats were randomized within blocks. The

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[8]Wheat City Seeds. 329 Park Avenue, East. Brandon, Manitoba.

[9]Wheat City Seeds. 329 Park Avenue, East. Brandon, Manitoba.

[10]Personnel communication. Dr. G. Lafond. AAFC. Box 760, Indian Head, Saskatchewan. S0G 2K0.

wild oats came from herbicide susceptible populations. They were broadcast onto the standing stubble 1 week prior to planting in the spring of 1997 and in the fall of 1997, for trials in 1998 using a ground driven cone unit[11] at a speed of 1.42 m s^{-1}. The wild oats were seeded at a rate of 32 kg ha^{-1} (200 seeds m^{-2}) for the wheat trials and 16 kg ha^{-1} (100 seeds m^{-2}) for the flax trials. These rates represented 4 times the desired densities to compensate for the unpredictable germination of wild oat seed. Desired densities were 50 wild oats m^{-2} and 20 - 25 wild oats m^{-2} for the wheat and flax trials respectively. These densities were chosen from the Manitoba Guide to Crop Protection (1997) as densities which would cause crop yield loss from competition for each crop.

Spray applications for unwanted weeds were conducted. A pre-seeding burn-off using glyphosate was applied each year at a rate of 0.44 kg ai ha^{-1}. Indigenous populations of wild oats were controlled where wild oats were not seeded with 0.81 kg ai ha^{-1} diclofop and 0.28 kg ai ha^{-1} bromoxynil at the clay loam locations both years, and at the loam location in 1998. In 1998, severe flax injury resulted due to high humidity and high temperatures directly following application at the loam location. The flax at the clay loam location was sprayed with 0.15 kg ai ha^{-1} sethoxydim. In-crop spray applications occurred in all trials in both years with clopyralid and MCPA ester at 0.004 and 0.56 kg ai ha^{-1} respectively. Subsequent applications of 0.99 kg ai ha^{-1} propanil and 0.28 kg ai ha^{-1} MCPA ester were required at the loam location in both years, due to heavy infestations of green foxtail (*Setaria viridis* Beauv. L.).

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[11]Designed by Dr. D.A. Derksen. AAFC. Box 1000A, Brandon, Manitoba. R7A 5Y3.

Crop diseases were treated to avoid confounding effects with experimental treatments. In 1998, wheat plots were sprayed with 0.83 kg ai ha^{-1} mancozeb and 0.12 kg ai ha^{-1} propiconazole at the loam and clay loam locations, respectively. The incidence of tan spot (*Pyrenophora tritici-repentis*), septoria leaf spot (*Septoria tritici*) and leaf rust (*Puccinia recondita*) was quite high at both locations, while the incidence of fusarium head blight (*Fusarium* spp.) was moderate. In 1997, leaf disease incidence did not appear severe; however, the loam location was affected by septoria leaf spot and fusarium head blight, which contributed to lower yields.

Treatments within a trial at each location were harvested on the same day using a small plot combine (Hege, model 125B) in both years. In 1998, to aid in harvesting (Table 3.3), the flax trials were sprayed with 0.4 kg ai ha^{-1} diquat, as a dessicant.

3.3.2.1 Data Collected. In both years, soil was sampled from each trial at each location prior to seeding. Five 0 to 15 cm cores were taken in each replication, in a W pattern, and bulked per trial. All soil samples were sent to Norwest Labs.

Table 3.2 Background soil parameters for each phosphorus trial at each location in both years (0-15cm).

		1997		1998	
Trial	Parameters[a]	Loam	Clay Loam	Loam	Clay Loam
Wheat / MAP	Nitrate-N	40.3	31.7	26.9	35.8
	Phosphate	42.6	29.1	29.1	31.4
	Potassium	985.6	880.3	694.4	871.4
	Sulphate-S	31.4	85.1	89.6	89.6
	pH	7.4	7.5	7.8	7.7
	EC	0.4	0.8	1.2	0.6
Flax / MAP	Nitrate-N	35.8	40.32	35.8	76.2
	Phosphate	51.5	31.4	38.1	40.3
	Potassium	1064.0	1223.0	1028.2	1164.8
	Sulphate-S	31.4	44.8	89.6	89.6
	pH	7.2	7.2	7.5	7.6
	EC*	0.4	0.6	0.6	0.8
Sufficiency Range (P)		Deficient	Marginal	Optimum	Excess
kg ha^{-1}		33.6	56	134.4	>134.4

[a]nitrate-N, phosphate, potassium, and sulphate-S are estimated available in kg ha^{-1}.
*E.C.= electrical conductivity of the soil, which is a measure of salinity in dS m^{-1}.

Crop and wild oat densities were determined 3 to 4 weeks after seeding. Two crop counts were taken per treatment (based on a 1 m length of row) and averaged. Wild oats were counted (only in plots where they were seeded) in two 0.25 m^2 quadrats and averaged.

Two crop and weed biomass samples (0.25 m^2 quadrats) in each treatment were taken in all trials, in both years, approximately 5 to 6 weeks after planting and at wheat heading, and flax full flower to beginning of boll formation. Quadrats were designed to maintain an equivalent spatial arrangement between the crop and wild oats, with 3 crop rows harvested in all cases. Samples were taken at least 1 m into the plot to avoid edge effects. Each sample was dried at 60°C for a minimum of 72 hours, weighed and ground using a cast steel Thomas Wiley mill, to pass through a 1 mm sieve. Samples were analysed by Norwest Labs for N, P, K, Ca, Mg and Na content. The same procedures of analysis were followed as outlined in the growth chamber experiments. Phosphorus uptake, expressed in kg ha^{-1}, was then calculated by multiplying dry matter yield by plant P concentration. Both biomass sampling times were analysed for nutrient concentrations in 1997; however, it was found that the first biomass tissue nutrient results were difficult to interpret, as sufficiency / deficiency levels at this growth stage were not available in the literature, therefore, the 1998 samples were not analysed in this way.

Grain was harvested and corrected to storage moisture from a 14 m^2 area using a small plot combine. Yield of the crops and wild oats were measured, after being separated using a dockage tester[12]. Dockage of other weed seeds was also determined.

Weather (temperature and precipitation) data, was collected both years at each location (Table 3.5). There were dramatically different weather conditions in 1997 and 1998. In 1997 there was moderately moist planting conditions, followed by a dry growing season (with the exception of July) and dry harvest conditions. In 1998 there was good moisture at planting followed by an extremely wet growing season and a moist but manageable harvest period.

3.3.2.2 Statistical Analysis. All data were subjected to ANOVA and orthogonal contrasts using procedures outlined in Statistical Analysis Systems (SAS) software

[12]Carter Day Industries, Canada, Ltd. 1425 Whyte Avenue, Winnipeg, Manitoba. R3C 2J6.

package (SAS Institute, Cary North Carolina, 1990). Fertilizer rates were not evenly spaced, therefore, the coefficients for the orthogonal contrasts needed to be subjected to polynomial regression in order to sum to zero[13]. Since, there was a lack of consistent fertilizer rate response (ie. linear, quadratic or cubic) across locations and years, curve fitting was not done. Data from field experiments were not combined due to environmental variability across years and because different locations were selected each year.

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[13]Determined using program by Dr. R. Rimmer. Department of Plant Science. University of Manitoba. Winnipeg, Manitoba. R3T 2N2.

3.3 Time line of field operations and data collection for each phosphorus trial at each location in both years.

	Wheat / MAP				Flax / MAP			
Operation/	Loam:		Clay loam:		Loam:		Clay loam:	
Data Collected	1997	1998	1997	1998	1997	1998	1997	1998
Soil sampling	05-01[++]	09-26	05-01	10-01	05-01	09-26	05-01	10-01
Seeder Calibration	05-07	04-24	05-07	04-24	05-07	04-24	05-07	04-24
Weed Spreader Calibration & Seeding	05-08	10-10	05-08	10-10	05-08	10-10	05-08	10-10
Pre-Seed Burn-off	05-12	04-29	05-15	05-08	05-12	04-29	05-15	05-08
N (46-0-0) Application	05-14	04-30	05-16	05-13	05-14	04-30	05-16	05-13
MAP (11-52-0) Application & Seeding	05-14	04-30	05-16	05-13	05-14	04-30	05-16	05-13
Crop Counts	06-04	06-02	06-06	06-09	06-04	06-02	06-06	06-09
Wild Oat Counts	06-13	06-02	06-18	06-09	06-13	06-02	06-18	06-09
In Crop Spray 1:	06-11	05-26	06-16	06-15	06-11	05-26	06-16	06-15
(Tractor) 2:	06-18	06-08	------*	------	06-18	06-08	------	------
In Crop Spray (2 m boom)	------	06-12	06-29	06-22	------	06-12	06-29	06-22
Biomass 1	06-23	06-16	06-25	06-26	06-24	06-16	06-26	06-30
Spray for Disease	------	06-25	------	07-03	------	------	------	------
Biomass 2	07-21	07-13	07-24	07-17	07-29	07-29	08-01	07-27
Crop Dessication	------	------	------	------	------	09-02	------	09-02
Harvest	09-04	08-26	09-09	08-27	09-06	09-10	09-10	09-09

[++]dates are arranged by month, followed by day. Soil sampling, wild oat spreader calibration and seeding all occurred in the fall of 1997, not 1998.

* ------, indicates that the operation did not occur.

3.4 Results

3.4.1 Growth Chamber

Wild oats produced more dry matter than wheat and wheat produced more than flax at each harvest date, except for 14 DAE where wheat produced slightly more than wild oats (Figure 3.1). Wild oat seedlings have been shown to be weak at first, but as root systems enlarge, a higher net assimilation rate occurs compared to other species (Chancellor, 1976). Wild oats had the highest rate of dry matter production compared to wheat and flax which were approximately equivalent (Figure 3.1).

Phosphorus concentration (mg g^{-1}) was highest in wild oats, followed by wheat and then flax at 14 DAE (Figure 3.2). At all other harvest dates flax had the highest P concentration, followed by wild oats and then wheat (Figure 3.2). Typical sufficiency / deficiency values for species P concentration are listed in Table 3.4. At 42 DAE only the flax was within its sufficiency range. Wheat and wild oats began showing P deficiency symptoms at 21 DAE. Early symptoms on wheat were leaf tip yellowing and a reddish discolouration on tillers, eventually the deficiency led to entire tiller leaf necrosis and stunted plants. Deficiency symptomology on the wild oats was expressed as red / purple discolouration on tillers, turning eventually to tiller necrosis. The wild oats appeared healthier than the wheat plants throughout the experiments; however, the wheat reached heading earlier than the wild oats (Figure 3.4) indicating that, all reserves were allocated to the seed to ensure reproduction.

Wheat and wild oats were equivalent in P uptake at 14 DAE, but after

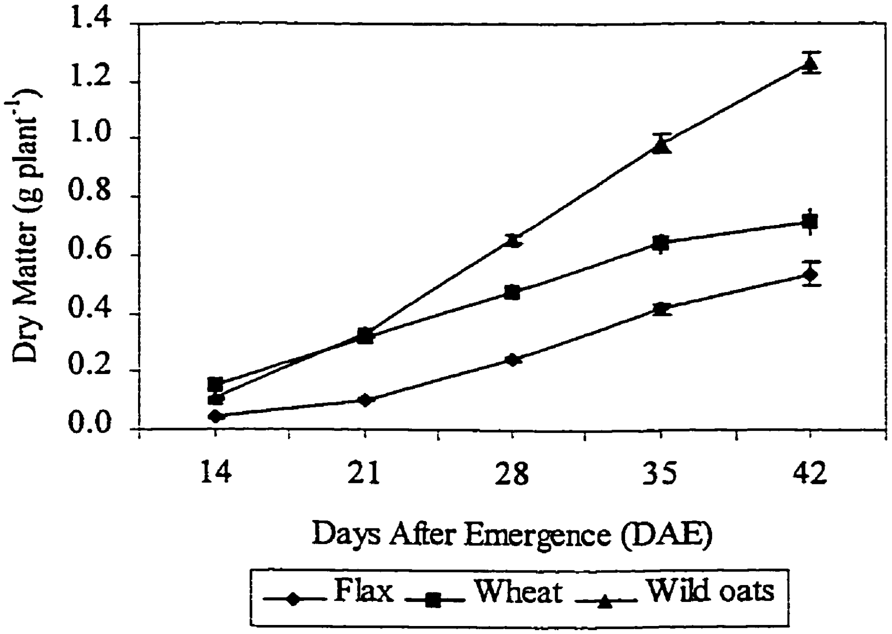

Figure 3.1 Species comparison of dry matter accumulation (g plant^{-1}) over time as influenced by MAP fertilization. Combined analysis of two experiments.

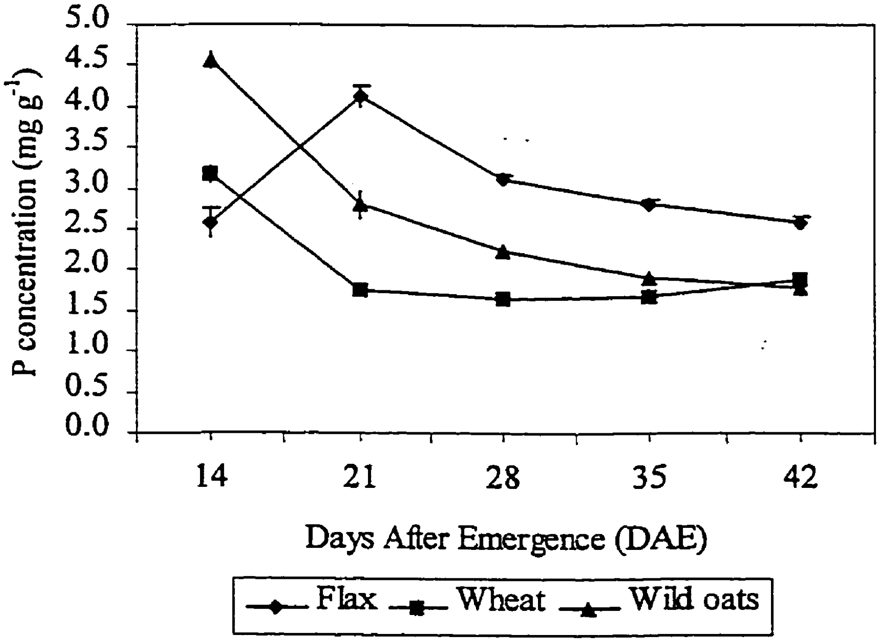

Figure 3.2 Species comparison of P concentration (mg g^{-1}) in tissue over time. Combined analysis of two experiments.

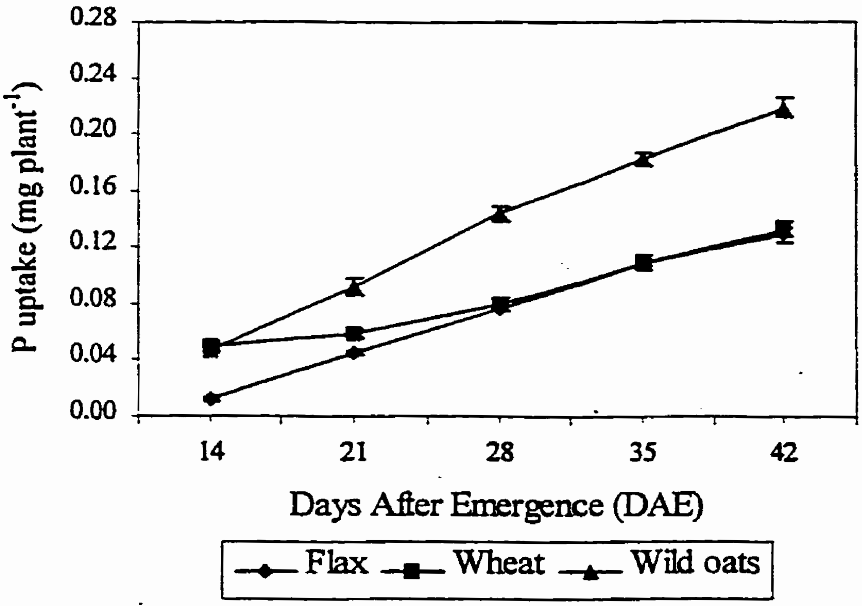

Figure 3.3 Species comparison of P uptake (mg plant^{-1}) over time. Combined analysis of two experiments.

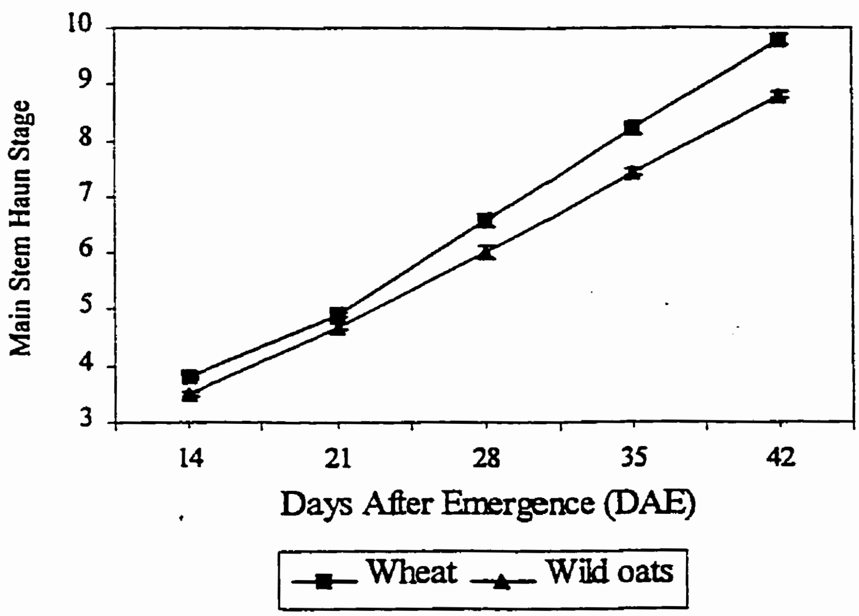

Figure 3.4 Main stem haun stage comparison of wheat and wild oats over time as influenced by MAP fertilization. Combined analysis of two experiments.

establishment the wild oats had the highest rate of P uptake at all other harvest dates (Figure 3.3). Early in the experiments wheat had a greater P uptake than flax; however, their P uptake became similar by 28 DAE (Figure 3.3).

Table 3.4 Sufficiency range of P (mg g^{-1}) in whole plant flax, wheat and tame oats (at flowering of flax and heading of wheat and tame oats) as recommended by the Manitoba Provincial Soil Testing Laboratory.

Crop	Low	Marginal	Sufficient	High	Excess
Flax	2.0	2.0 - 2.5	2.5 - 5.0	5.0 - 8.0	8.0
Wheat	1.5	1.5 - 2.5	2.6 - 5.0	5.0 - 8.0	8.0
Tame oats	1.5	1.5 - 2.5	2.6 - 5.0	5.0 - 8.0	8.0

* there is no sufficiency range determination for wild oats.

3.4.2 Field

3.4.2.1 Flax. Overall yield trends were similar in both years; however, treatments without wild oats had higher yields only in 1997, whereas, differences between fertilizer placements occurred only in 1998 (Tables 3.6 and 3.7). The greater plant density in treatments containing flax and wild oats resulted in more P uptake, which minimized the difference between fertilizer placements in 1997. These results may be related to the differences in temperature and precipitation recorded in 1997 versus 1998 (Table 3.5).

The highest flax yields occurred at the loam location, in both years, at the 3.5 kg P ha^{-1} rate (Table 3.6). Yield did not increase with MAP application at the clay loam location (Table 3.7).

Dry weights from flax full flower to the beginning of boll formation growth stage followed the same pattern as the seed yield data (Tables A.5 and A.6). Differences in concentration and P uptake occurred in treatments without wild oats in 1997; however, differences between fertilizer placements occurred in the overall experiment as well as in plots with wild oats at the clay loam location in 1998 (Tables A.7, A.8, A.9 and A.10). These results differ from yield and dry weights at flax full flower to beginning of boll formation. Yields and dry weights were higher in plots without wild oats in 1997 and differences between fertilizer placements resulted in yield differences in plots without wild oats in 1998. Concentration of P in flax tissue was well within the sufficiency range at the loam location but at the lower end at the clay loam location (Tables A.7 and A.8), due to differences in background soil P levels (Table 3.2). Wild oats were deficient in P concentration at both locations in both years, indicating a higher species P requirement (Tables A.7 and A.8) .

3.4.2.2 Wheat. Wild oats reduced wheat yield at both locations in 1997 (Tables 3.8 and 3.9). In 1998, at the clay loam location, all side-banded treatments produced higher yields than seed-placed treatments, except for the 17.48 kg P ha^{-1} rate (Table 3.9). The wheat responded similarly to flax, possibly due to differences in the recorded temperature and precipitation data from 1997 to 1998. At both the loam (Table 3.8) and clay loam (Table 3.9) locations, fertilization increased gram yield, but, yields at the loam location levelled off as fertilizer rates increased, whereas those at the clay loam location continually increased, indicating a rate response to high applications of MAP. Fertilizer placement did not affect yield at the loam location, even in 1998.

3.5 Monthly mean air temperature and precipitation at both locations in 1997 and 1998, and the 30 year average (1966-96)**.

	Temperature (°C)						Precipitation (mm)				
	Location 1: Loam		Location 2: Clay Loam				Location 1: Loam		Location 2: Clay Loam		
	1997	1998	1997*	1998	30-yr. Avg.		1997	1998	1997*	1998	30-yr. Avg.
May	9.9	14.7	10.7	12.8	11.5		0	29	14	51	46
June	18.8	14.7	19.7	15.0	16.6		50	193	53	174	73
July	19.2	18.9	18.1	19.4	18.9		127	107	98	37	74
August	18.1	19.6	18.7	19.8	17.9		32	144	45	137	69
September	14.0	16.6	14.8	13.8	12.0		11	6	4	24	50
Average	16.0	16.9	16.4	16.2	15.4	Total	220	479	214	423	312

* 1997 Location 2 data came from the Brandon Research Station (March, 1997).

** 30 year data from Brandon, Research Station.

Table 3.6 Yield (kg ha^{-1}) of flax and wild oats as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil

Actual P Rate (kg ha^{-1})	1997 Flax SP +	1997 Flax SP -	1997 Flax SB +	1997 Flax SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Flax SP +	1998 Flax SP -	1998 Flax SB +	1998 Flax SB -	1998 Wild Oats SP	1998 Wild Oats SB
0.00	1783.72	2013.81	1783.72	2013.81	53.94	53.94	796.41	808.92	796.41	808.92	53.96	53.96
3.50	1891.91	2033.56	1818.09	1948.34	54.69	54.75	937.78	1199.59	802.38	1165.25	50.53	57.31
4.37	1577.75	1950.13	1596.63	2182.78	73.59	79.81	505.63	651.75	584.47	1077.38	52.84	44.56
6.56	1618.47	1849.66	1631.84	1902.16	66.66	59.44	809.84	1133.91	452.09	563.88	63.41	49.50
8.74	1625.91	1986.69	1643.13	2017.09	92.78	93.72	485.53	790.56	305.97	553.53	66.63	59.06
17.48	1554.88	2063.22	1598.66	1851.19	82.59	82.19	304.63	747.63	616.09	858.91	53.34	43.88

Orthogonal Contrasts: Main Effects	1997 Flax SP +	1997 Flax SP -	1997 Flax SB +	1997 Flax SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Flax SP +	1998 Flax SP -	1998 Flax SB +	1998 Flax SB -	1998 Wild Oats SP	1998 Wild Oats SB
Rate Linear	*0.0866	ns	ns	ns	ns	ns	0.0769	ns	ns	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.0778	ns	ns
Rate Cubic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.0929

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	0.0001	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	0.0033	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 3.7 Yield (kg ha^{-1}) of flax and wild oats as influenced by MAP fertilization, MAP placement and the presence of wild oats on clay loam soil over two years.

	Location 2: Clay Loam Soil											
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	1434.88	1804.00	1434.88	1804.00	221.44	221.44	1637.50	1905.38	1637.50	1905.38	63.58	63.58
3.50	1306.06	2111.63	1282.44	2108.91	363.63	340.22	1488.84	1886.34	1662.53	1940.97	106.84	86.72
4.37	1239.53	2133.09	1087.03	2102.47	367.44	357.50	1664.16	1849.41	1737.66	1931.75	92.25	65.88
6.56	1194.78	1992.16	1159.97	2121.41	362.69	358.12	1823.59	1905.59	1601.88	1883.56	58.78	69.16
8.74	1351.47	2058.63	1615.09	1976.53	329.25	240.44	1493.31	1762.19	1581.22	1835.72	64.69	62.50
17.48	1650.00	2080.88	1003.13	2046.78	253.88	310.69	1689.00	1906.19	1645.09	1865.25	66.84	78.97
Orthogonal Contrasts												
Main Effects												
Rate Linear	*0.0866	ns	ns	ns	0.0384	ns	ns	ns	ns	ns	0.0353	ns
Rate Quadratic	ns	ns	0.0797	ns	ns	0.0648	ns	ns	ns	ns	0.0119	0.0269
Rate Cubic	ns	ns	0.0680	ns	ns	0.0276	0.0045	ns	ns	ns	ns	ns
Simple Effects			Flax		Wild Oats				Flax		Wild Oats	
Overall Placement (SP vs SB)			ns		ns				ns		ns	
Overall +/- Wild Oats			0.0001		-				ns		-	
SP and SB + Wild Oats			ns		-				ns		-	
SP and SB - Wild Oats			ns		-				0.0001		-	

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Wild oats decreased dry matter yield at heading in wheat in 1997 at both locations (Tables 3.10 and 3.11). Dry matter yield at heading was affected by fertilizer placement with or without wild oats, but, the effect was not consistent better than the other at the loam location in 1998 (Table 3.10).

Phosphorus concentration and uptake results were similar to the dry weight results at heading of wheat (Tables 3.12, 3.13, 3.14 and 3.15 respectively). The P concentration in the wheat tissue was in the marginal to low sufficiency range at the loam location, and within the marginal range at the clay loam location (Tables 3.12 and 3.13). Conversely, the wild oat concentrations were well within the sufficiency range at both locations and in some cases relatively high (Tables 3.12 and 3.13); however, the wild oats in the flax trials were deficient in their P concentration, which may be explained by the lower rates of P applied in the flax trials and by the fact that flax prefers soil P to fertilizer P.

3.5 Discussion

Climatic and edaphic factors play extremely important roles when dealing with immobile nutrients, like P (Nelson, 1986; Potash and Phosphate Institute, 1986; Fohse et al., 1991; Otani and Ae, 1996). This was evident in 1998 where treatment yields, dry weights and concentrations varied due to differences between fertilizer placements possibly due to excess moisture. Soil and crop type affected this outcome. At a given level of soil P, crop response to fertilizer P often increases as water availability increases (Munson and Murphy, 1986; Nelson, 1986). Conversely, the dry conditions in 1997 resulted in a lack of P availability and subsequent crop uptake.

Table 3.8 Yield (kg ha^{-1}) of wheat and wild oats as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil

Actual P Rate (kg ha^{-1})	1997 Wheat SP +	1997 Wheat SP -	1997 Wheat SB +	1997 Wheat SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Wheat SP +	1998 Wheat SP -	1998 Wheat SB +	1998 Wheat SB -	1998 Wild Oats SP	1998 Wild Oats SB
0.00	1431.19	1856.09	1431.19	1856.09	149.38	149.38	2572.50	2455.75	2572.50	2455.75	22.96	22.96
4.37	1494.34	1952.91	1549.66	1839.38	134.97	141.72	2908.81	2992.88	2650.28	2499.19	20.78	15.94
8.74	1651.13	1898.88	1591.13	1958.19	119.50	129.44	2864.84	2815.38	3130.75	2981.53	15.31	20.47
17.48	1681.78	1951.69	1376.19	1931.19	133.91	117.78	2683.22	3160.56	3087.94	2998.06	17.84	16.13
34.96	1593.53	1880.00	1627.13	1977.13	147.19	149.19	2757.63	3051.53	2973.41	2997.63	10.38	10.56
52.44	1622.88	1923.44	1731.72	2009.16	165.03	121.72	2841.09	2977.44	2886.25	2942.88	10.23	7.06
Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	ns	*0.0983	ns	ns	ns	ns	ns	0.0058	0.0043
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	0.0939	ns	ns	ns
Rate Cubic	ns	ns	ns	ns	ns	ns	ns	ns	0.0894	ns	ns	ns

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	0.0001	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 3.9 Yield (kg ha^{-1}) of wheat and wild oats as influenced by MAP fertilization, MAP placement and the presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil												
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	2187.03	2729.94	2187.03	2729.94	84.66	84.66	2833.96	2965.25	2833.96	2965.25	65.58	65.58
4.37	2418.25	2916.28	2379.47	2906.63	79.50	70.09	2801.88	3101.75	3086.03	3155.59	104.63	62.59
8.74	2695.13	2884.06	2915.13	3028.06	54.94	48.59	2685.09	3021.88	2864.63	3215.28	56.13	31.69
17.48	2910.06	3126.31	2729.56	3205.13	42.16	40.25	2913.44	3130.16	2760.63	3008.75	39.88	48.03
34.96	2875.16	3288.81	3007.59	3322.72	41.09	39.97	3035.78	3148.31	3352.97	3407.09	37.13	28.88
52.44	2605.78	3271.47	3018.44	3641.16	41.13	41.25	2911.47	3157.94	3209.97	3600.63	78.56	22.97
Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	0.0002	0.0133	0.0001	0.0001	0.0826	ns	ns	0.0732	0.0017	ns	0.0183
Rate Quadratic	*0.0466	0.0447	ns	ns	0.0001	ns	ns	ns	ns	ns	0.0601	ns
Rate Cubic	ns	ns	ns	ns	0.0022	ns	ns	ns	0.0269	ns	ns	ns
Simple Effects			Wheat		Wild Oats				Wheat		Wild Oats	
Overall Placement (SP vs SB)			0.0514		ns				0.0185		0.0543	
Overall +/- Wild Oats			0.0001		-				ns		-	
SP and SB + Wild Oats			ns		-				0.0756		-	
SP and SB - Wild Oats			ns		-				0.0022		-	

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 3.10 Dry weight (g m^{-2}) of wheat and wild oats at heading of wheat as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam soil over two years.

	Location 1: Loam Soil											
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	430.40	480.00	430.40	480.00	148.20	148.20	598.53	604.40	598.53	604.40	83.47	83.47
4.37	397.10	568.50	449.50	445.40	211.50	187.00	690.70	665.00	557.80	496.40	82.70	30.20
8.74	456.40	463.30	394.70	486.20	139.30	148.00	707.70	592.30	651.40	710.70	74.90	49.90
17.48	469.20	504.10	464.60	519.10	153.50	145.20	642.00	749.30	760.20	747.30	40.20	50.30
34.96	409.20	407.90	519.90	565.70	224.60	101.90	764.60	731.10	697.00	722.40	23.80	16.50
52.44	412.50	471.10	484.50	551.40	220.30	128.60	757.50	791.60	682.20	657.60	28.00	22.10
Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	*0.0381	0.0797	0.0911	ns	ns	ns	0.0021	ns	ns	ns	0.0264
Rate Quadratic	ns	0.0392	ns	ns	ns	ns	ns	ns	0.0178	0.0037	ns	ns
Rate Cubic	ns	ns	ns	ns	0.0860	ns	ns	ns	0.0446	0.0282	ns	0.0125
Simple Effects			Wheat		Wild Oats				Wheat		Wild Oats	
Overall Placement (SP vs SB)			0.0823		0.0290				0.0367		ns	
Overall +/- Wild Oats			0.0038		-				ns		-	
SP and SB + Wild Oats			ns		-				ns		-	
SP and SB - Wild Oats			ns		-				ns		-	

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 3.11 Dry weight (g m^{-2}) of wheat and wild oats at heading of wheat as influenced by MAP fertilization, MAP placement and the presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil													
	1997						1998						
Actual	Wheat				Wild Oats		Wheat				Wild Oats		
P Rate	SP		SB		SP	SB	SP		SB		SP	SB	
(kg ha^{-1})	+	-	+	-			+	-	+	-			
0.00	531.90	518.20	531.90	518.20	104.10	104.10	401.33	538.26	401.33	538.26	51.07	51.07	
4.37	453.10	565.90	555.90	636.00	133.30	137.00	559.30	575.30	566.20	536.40	42.10	65.30	
8.74	506.90	498.90	559.80	588.80	173.70	134.00	496.30	581.90	589.10	634.40	60.50	45.50	
17.48	606.00	659.10	538.00	645.00	110.50	123.30	669.50	664.10	529.10	581.60	34.80	83.60	
34.96	523.40	664.40	570.00	651.90	161.00	87.30	669.10	653.80	716.00	722.60	41.00	24.80	
52.44	599.00	676.50	617.30	718.20	92.10	112.00	657.30	714.20	637.30	633.50	86.10	24.90	
Orthogonal Contrasts													
Main Effects													
Rate Linear	*0.0499	0.0331	ns	0.0842	ns	ns	ns	0.0743	0.0993	0.0446	ns	ns	
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.0599	ns	ns	
Rate Cubic	0.0335	ns	ns	ns	ns	ns	ns	ns	0.0988	ns	ns	ns	

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	0.0986	ns	ns	ns
Overall +/- Wild Oats	0.0004	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 3.12 Phosphorus (mg g^{-1}) concentration of wheat and wild oat tissue at heading of wheat as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil												
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	2.13	2.17	2.13	2.17	2.80	2.80	2.03	2.03	2.03	2.03	3.43	3.43
4.37	2.40	2.45	2.40	2.30	3.03	2.88	1.95	2.10	2.05	2.23	3.40	3.83
8.74	2.25	2.39	2.33	2.18	2.95	3.18	1.93	2.08	2.48	2.08	3.28	3.63
17.48	2.45	2.33	2.18	2.35	3.00	2.98	2.25	2.10	2.53	2.03	3.98	2.98
34.96	2.63	2.75	2.40	2.53	3.38	3.28	2.20	2.15	2.45	2.23	3.45	3.28
52.44	2.63	2.65	2.60	2.50	3.33	3.38	2.28	2.38	2.23	2.20	3.83	3.28

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	*0.0065	ns	ns	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	0.0335	-
SP and SB - Wild Oats	0.0183	-	ns	-

* = p value; ns = non significant; SP = seed-placed; SB = side-banded; +/- = plots with and without wild oats respectively.

Table 3.13 Phosphorus (mg g^{-1}) concentration of wheat and wild oat tissue at heading of wheat as influenced by MAP fertilization, MAP placement and presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil

Actual P Rate (kg ha^{-1})	1997						1998					
	Wheat				Wild Oats		Wheat				Wild Oats	
	SP		SB		SP	SB	SP		SB		SP	SB
	+	-	+	-			+	-	+	-		
0.00	2.20	2.27	2.20	2.27	2.97	2.97	1.98	1.98	1.98	1.98	3.33	3.33
4.37	1.95	2.23	2.03	2.20	2.70	2.73	1.95	2.08	2.00	1.90	3.18	2.95
8.74	2.05	2.20	2.13	2.28	2.78	2.90	2.10	1.98	2.15	1.93	3.20	3.28
17.48	2.00	2.18	2.15	2.18	2.73	2.73	2.25	2.08	2.05	2.13	3.65	3.55
34.96	2.23	2.20	2.08	2.18	2.95	2.98	2.25	2.28	2.25	2.10	3.48	3.40
52.44	2.25	2.23	2.05	2.28	3.05	2.88	2.25	2.38	2.45	2.68	3.50	3.53

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	*0.0078	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed; SB = side-banded; +/- = plots with and without wild oats respectively.

Table 3.14 Phosphorus (kg ha^{-1}) uptake of wheat and wild oat tissue at heading of wheat as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam soil over two years.

	Location 1: Loam Soil											
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	889.60	1062.51	889.60	1062.51	434.92	434.92	1221.90	1245.45	1221.90	1245.45	229.38	229.38
4.37	964.77	1392.00	1062.43	1025.22	634.04	536.48	1348.96	1399.36	1153.42	1094.76	257.50	114.32
8.74	1032.85	1101.39	915.08	1063.05	411.84	461.24	1363.67	1233.61	1599.60	1471.00	225.93	177.88
17.48	1153.34	1178.74	1008.85	1218.66	465.41	424.60	1450.77	1572.34	1901.28	1514.98	158.72	157.13
34.96	1070.82	1122.09	1242.89	1445.73	741.64	323.26	1684.10	1564.17	1703.72	1608.81	77.60	55.46
52.44	1080.30	1247.54	1255.40	1373.38	726.75	439.18	1718.19	1886.27	1518.64	1452.42	100.63	72.82

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	ns	0.0204	ns	ns
Overall +/- Wild Oats	*0.0029	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 3.15 Phosphorus (kg ha^{-1}) uptake of wheat and wild oat tissue at heading of wheat as influenced by MAP fertilization, MAP placement and the presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil												
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	1185.68	1268.11	1185.68	1268.11	329.92	329.92	813.59	962.85	813.59	962.85	168.49	168.49
4.37	891.53	1258.81	1127.51	1395.66	362.74	365.96	1091.88	1175.39	1133.18	1021.85	125.55	197.29
8.74	1021.91	1097.58	1184.42	1331.57	459.53	398.63	1027.66	1142.90	1271.31	1221.42	176.34	147.50
17.48	1217.93	1444.42	1160.53	1395.64	301.76	337.62	1465.39	1368.40	1081.65	1230.76	115.38	240.91
34.96	1178.90	1456.53	1186.16	1417.60	466.15	259.94	1498.01	1466.42	1608.88	1518.57	145.24	82.34
52.44	1338.80	1477.95	1262.15	1634.04	283.18	322.24	1499.97	1696.52	1549.80	1702.99	284.65	85.32

Simple Effects	Wheat (1997)	Wild Oats (1997)	Wheat (1998)	Wild Oats (1998)
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	*0.0001	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Flax yield was not increased by applied MAP. Numerous field and growth chamber studies have shown that flax grown in prairie soils is relatively unresponsive to P fertilizer, even P placed with the seed at recommended rates in soils low in available phosphorus (Ukrainetz, 1963; Soper and Racz, 1963; Racz, 1969; Ridley and Tayakepisuthe, 1974). The expected dramatic yield reduction to the high rates of seed-placed P found by many others did not occur (Nyborg, 1961; Sadler, 1980; Bailey and Grant, 1989). Molberg (1961) found salt toxicity to seed-placed fertilizers greater in dry years, this was not evident here; however, side-banding generally provided higher yields indicating that some salt toxicity may have occurred in seed-placed MAP treatments.

Fertilizer placement affected grain yield, dry matter yield and P concentration of wheat experiments but only at the clay loam location. This may be due to the higher moisture retention and subsequent P availability on clay loam soils. Other edaphic factors may explain the differences between these soil types; however, this was not explored. In wet years, yield and P uptake have been found to be greater than in dry years (Bailey et al., 1977). Yield was higher in 1998 at the loam location than in 1997, due to adequate moisture and lower disease incidence in 1998. In comparison yields were high in both years at the clay loam location. This may be explained by the higher water holding capacity of clay loam soil. The side-banded fertilizer treatments produced higher yields probably due to less crop injury from the seed-placed MAP, even though this was not observed in the field.

Wild oats reduced grain yield, dry matter yield and P concentrations in 1997 but not in 1998. Wild oat growth may be directly and indirectly affected by soil type

(Chancellor, 1976), and climatic conditions such as temperature and moisture (Kühnel, 1965; Thurston, 1962; Sexsmith, 1969; Sharma et al. 1977). Thurston's work (1962) suggests that wild oats may be more tolerant to soil moisture stress than crop plants, and Sharma et al. (1977) showed that flax, rapeseed, wheat and barley were affected more by moisture stress than wild oats.

Phosphorus tissue concentration (mg g^{-1}) of all species varied from the growth chamber to the field. Wild oats showed the greatest variation with P concentration. They were severely deficient in the growth chamber and flax field experiments, but sufficient and high in the wheat field experiments. The growth chamber and flax field MAP rates only increased to 17.48 kg P ha^{-1}, which is insufficient for cereal or oilseed growth on soils of low to marginal initial P status, whereas the MAP rates increased to 52.44 kg P ha^{-1} in the wheat experiments. The differences in P concentration in wild oat tissue and subsequent uptake indicates that the more applied the more they will accumulate. In the growth chamber the wild oats had the highest P uptake, even though flax had greater P concentration, due to their higher biomass production. Under the limited environmental stress and equal advantage given to each species in the growth chamber experiments wild oats had a greater ability for P uptake than wheat or flax.

3.6 Conclusions

Environment, both climatic and edaphic, play important roles when dealing with nutrients. In the dry year (1997) treatments without wild oats had higher yields, dry weights and concentrations; however, in the wet year (1998) differences between fertilizer placements caused differences in yield, dry weights and concentrations. General yield trends in relation to fertilizer rate were not affected by year to year variation in temperature and precipitation.

Fertilizer rates should be re-evaluated in direct seeding regarding the lack of toxicity found at the high fertilizer rates and because the 'pop-up' effect to low rates of seed-placed MAP was not observed. Fertilizer recommendations may no longer be accurate because soils have changed due to increased acreages in direct-seeding systems. Direct seeding has resulted in increased organic matter levels, which results in a higher proportion of nutrients in the mineralized fraction, which is more difficult to measure by current soil testing methods.

Producers tend to apply more herbicides in wet years; however, wild oats have a greater impact in dry years. This increased competition from wild oats in dry years and their high P uptake potential will directly affect current production systems. Further competition work is needed to understand wild oat - crop interactions for nutrients, as well as the mechanisms of nutrient uptake. The probability of P - mycorrhizal interactions with weed - crop interference should also be investigated.

4. EFFECT OF POTASSIUM CHLORIDE FERTILIZER RATE AND PLACEMENT AND WILD OATS ON THE PERFORMANCE OF SPRING WHEAT AND FLAX IN DIRECT SEEDING

4.1 Abstract

Weeds require the same nutrients as crop plants and are often better at obtaining them. Placing fertilizer where the crop has access to it but the weeds do not will increase the crop's competitiveness. To determine the impact of potassium chloride (KCl) fertilizer placement on wild oats in direct-seeded spring wheat and flax, 2 field experiments were conducted on 2 soil types in 1997 and 1998. Growth chamber experiments were conducted to compare potassium (K) uptake potential and growth response of each species to K. Data were subjected to ANOVA and orthogonal contrasts. Regression analysis did not provide consistent rate responses, therefore, curve fitting was not done. Amount of seasonal precipitation plays an important role in plants uptake ability of immobile nutrients, like K. Climate varied; however, general yield response was consistent between years. Differences in yield occurred; however, due to the presence of wild oats in 1997 and due to differences between fertilizer placements in 1998. Flax was relatively unresponsive to KCl addition. There was no wheat yield response to KCl addition at the loam location, but slight yield increases occurred at low KCl rates at the clay loam location. In the growth chamber, K uptake was greatest in wild

oats, followed by wheat and flax. Wild oats appear to have a high species requirement for K and continually increase their uptake as more K becomes available. Since a consistent yield response to KCl addition was not evident in the wheat experiments, fertilizer recommendations in direct-seeding systems may need to be re-evaluated, and experiments conducted to determine these recommendations need to include weeds.

4.2 Introduction

Potassium (K) is a major crop nutrient and is required by plants in relatively large amounts. In western Canadian agricultural soils there is generally more K than any other nutrient, but plants can only draw on a very small proportion of what is present. Typically, there is enough K in Manitoban soils for maximum crop production (Anonymous, 1988); however, producers on the prairies are beginning to add K in larger and larger quantities since yield responses to KCl fertilizer have been recorded in all provinces. This yield increase may be due to K in some cases and Cl in others. Potassium recommendations in the Black soil zone need to be reinvestigated due to changing management practices, such as direct-seeding and continuous cropping.

Wild oats (*Avena fatua* L.) have been a timeless problem on the prairies and will continue to be an economic concern to producers due to their multiple resistance to several herbicide groups (Thomas et al., 1988). Development and implementation of integrated weed management (IWM) systems is becoming more and more essential as producers find their control options for wild oats diminishing. Determining wild oat nutrient requirements and incorporating this information with fertilizer placement technology will increase crop competitiveness and keep wild oats off balance. IWM strategies will reduce management selection pressures on the prairies and will increase the longevity of our cropping systems.

The objective of this research was to evaluate the impact of seed-placed and side-banded KCl fertilizer on wild oats in direct-seeded spring wheat and flax. Field experiments were conducted to provide information on how climatic and edaphic factors affect KCl uptake by each species in direct-seeding systems, and how this affects weed-crop interactions. Growth chamber experiments were conducted to provide insight into K requirements and uptake potential of wild oats.

4.3 Materials and Methods

4.3.1 Growth Chamber Experiments

The effect of KCl on biomass accumulation of spring wheat (cv. CDC Teal), flax (cv. Norlin) and wild oats (herbicide susceptible populations, UM5 and Portage la Prairie[1]) was determined. The experiment was arranged in a completely randomized design (CRD), with 3 replicates, and treatments were randomized within replicates. The treatments consisted of 0, 8.3, 16.6, and 33.2 kg K ha^{-1}, for each species, and each date of harvest. Low rates were chosen to determine which species had the greatest K uptake. Five destructive harvests were conducted, beginning at 14 days after emergence (DAE) and continuing at 21, 28, 35 and 42 DAE.

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[1]Department of Plant Science. University of Manitoba. Winnipeg, Manitoba. R3T 2N2.

A loam soil, low in exchangeable K (Table 4.1) was collected from a site 5 minutes north of the Brandon Research Centre (SW 3-11-19W1) on the Trans Canada Highway. The soil was dried, raked and sifted, and stones and any other debris were removed to obtain uniform consistency. Fertilizer rates and soil field capacity were determined based on a 1 kg soil volume per pot (Cassel and Neilsen, 1986). The pots were made of white plastic, had no drainage and measured 12.7 cm in diameter, with a volume of 950 cm^2. All other nutrients (N, P and S) were added based on soil test recommendations. Nutrients were weighed and dissolved in distilled water. The soil was then placed in a cement mixer and the nutrients were sprayed onto the soil as a fine mist while it was blended. One kg of soil was added to each pot, with a total of 150 pots in the experiment (3 reps, 3 rates, 3 species, 5 harvest dates and 15 controls (3 per harvest, one for each species)). Extra pots at each rate were maintained as replacements if poor germination resulted. Pots were watered to field capacity and allowed to stand for a 72 hour period prior to seeding.

All seeds of each species were placed in petri dishes on moist filter paper (10 mm of distilled water). The petri dishes were raised to a 10° angle in a germination cabinet[2] maintained at a 16 h light / 8 h dark photoperiod and 20 +/- 1°C. The wild oat seeds were placed in the germination cabinet first as they took 3 to 4 days to germinate, whereas, the flax and wheat took 1 to 2 days. After the seeds germinated, they were selected for uniformity and seeded at a rate of 10 per pot. The flax was seeded at a 1cm depth and the

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[2]Model # I18L. Conviron Products Company. A Division of Controlled Environments, Ltd. 1461 St. James St., Winnipeg, Manitoba. R3H 0W9.

spring wheat and wild oats were seeded at 2 cm. Once the seeds emerged they were thinned to 5 plants per pot. All pots were evenly spaced on carts in the growth chamber. The growth chamber was maintained at a 16 h light / 8 h dark photoperiod with temperature maintained at 24°C day / 16°C night. Relative humidity was approximately 60%. The pots were watered to field capacity with distilled water whenever the moisture content fell to 70 % of field capacity. Pots were arranged in a CRD and re-randomised after each watering to avoid edge effects and differences in light availability within the growth chamber.

Table 4.1 Background soil parameters for potassium chloride growth chamber experiments.

	Soil Parameters	Estimated kg ha^{-1} Available		
	Nitrate-N	62.7		
	Phosphate	65.0		
	Potassium	401.0		
	Sulphate-S	22.4		
	pH	6.6		
	E.C.*	0.2		
Sufficiency Range (K)	Deficient	Marginal	Optimum	Excess
kg ha^{-1}	168	336	1120	>1120

* E.C.= electrical conductivity of the soil, which is a measure of salinity in dS m^{-1}. Information provided by Norwest Labs[3] (assessments based on a 0 - 15 cm sampling depth).

4.3.1.1 Data Collected. The above ground portion of each plant species was harvested at 14, 21, 28, 35 and 42 DAE. Main stem Haun staging (Haun, 1973) of wheat and wild

[3]#204-545 University Crescent. Winnipeg, Manitoba. R3T 5S6.

oats was determined using a grid system designed by Guy Lafond[4], and height and growth stage of flax (Flax Council of Canada, 1996) was recorded at each harvest. Samples were dried in a 1370 GM gravity oven[5] at 60°C for a minimum of 72 hours and weighed for dry matter determination. Next, they were ground using a cast steel Thomas Wiley mill, to pass through a 1 mm sieve and sent to Norwest Labs for N, P, K, Ca, Mg and Na analysis. The N analysis was done by a combustion method using a Leco N-Analyzer. All of the other parameters were analysed starting with an ashing procedure, followed by an acid dissolving step with analysis by ICP Spectrometry[6]. Potassium uptake, expressed in kg ha^{-1}, was then calculated by multiplying dry matter yield by plant K concentration.

4.3.1.2 Statistical Analysis. All data were subjected to ANOVA and orthogonal contrasts using procedures outlined in Statistical Analysis Systems (SAS) software package (SAS Institute, Cary North Carolina, 1990). Regression analysis on fertilizer rate was not consistent, therefore curve fitting was not done. Data was combined from the 2 experiments after passing Bartlett's test and presented as dry matter accumulation, K concentration and K uptake over time.

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[4]Personnel communication. Dr. G. Lafond. AAFC. Box 760, Indian Head, Saskatchewan. S0G 2K0.

[5]VWR Scientific, Canada, Ltd. Box 20060, London, Ontario. N6K 4G0.

[6]Personnel communication. Rob Ellis. Norwest Labs. #203-545 University Crescent. Winnipeg, Manitoba. R3T 5S6.

4.3.2 Field Experiments

These experiments were conducted at 2 locations in 1997 and 1998 in the Aspen Parlkand Ecoregion at Brandon Manitoba. One location was approximately 10 km south of Brandon and 3.2 km west of number 10 highway (NE 32-9-19W) on a loam soil, the second location was approximately 40 km north of Brandon on highway number 10 at the MZTRA (SW 27-10-19W) farm on a clay loam soil. These locations were chosen to represent 2 dominant soil types in western Manitoba; Rego Chernozem and Orthic Black Chernozem respectively (Table 3.2).

The loam location had been in zero-till for approximately 20 years, and the clay loam location for approximately 8 years. The trials were seeded into wheat stubble at the loam location, and canola stubble at the clay loam location in 1997. In 1998, all trials were seeded directly into canola stubble. The experiments were arranged in a randomized complete block design (RCBD) with 4 replicates. A 4 m by 7 m area constituted the rate and placement of KCl fertilizer, which was factorially arranged with treatments split (2m by 7m) with and without wild oats. CDC Teal spring wheat[7] was seeded at 100 kg ha^{-1}, at a depth of 3.75 - 5 cm. Norlin flax[8] was seeded at 40 kg ha^{-1}, at a depth of 0.63 - 1.25 cm. An air seeder (Conserva-pak on 20 cm row spacing) was calibrated each year for each product using standard procedures for the "Valmar" boxes with product rates for each gear

[7]Wheat City Seeds. 329 Park Avenue, East. Brandon, Manitoba.

[8]Wheat City Seeds. 329 Park Avenue, East. Brandon, Manitoba.

setting calculated using a spreadsheet[9].

Nitrogen (as 46-0-0) was banded, prior to seeding, across each replication perpendicular to the direction of seeding at a rate of 78.4 kg N ha^{-1} on 20 cm spacing. The KCl fertilizer was applied at seeding. Each plot was planted consecutively (in a serpentine pattern) with gear settings and ratios changed by hand (ie. rate and placement of fertilizer). The seed-placed fertilizer was applied with the seed in the seed row, whereas, the side-banded fertilizer was placed 2.5 cm beside and 2.5 cm below the seed row.

The treatments with and without wild oats were randomized within blocks. The wild oats came from herbicide susceptible populations. They were broadcast onto the standing stubble 1 week prior to planting in the spring of 1997 and in the fall of 1997, for trials in 1998 using a ground driven cone unit[10] at a speed of 1.42 m s^{-1}. The wild oats were seeded at a rate of 32 kg ha^{-1} (200 seeds m^{-2}) for the wheat trials and 16 kg ha^{-1} (100 seeds m^{-2}) for the flax trials. These rates represented 4 times the desired densities to compensate for the unpredictable germination of wild oat seed. Desired densities were 50 wild oats m^{-2} and 20 - 25 wild oats m^{-2} for the wheat and flax trials respectively. These densities were chosen from the Manitoba Guide to Crop Protection (1997) as densities which would cause crop yield loss.

Spray applications for unwanted weeds were conducted. A pre-seeding burn-off

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[9]Personnel communication. Dr. G. Lafond. AAFC. Box 760, Indian Head, Saskatchewan. S0G 2K0.

[10]Designed by Dr. D.A. Derksen. AAFC. Box 1000A, Brandon, Manitoba. R7A 5Y3.

using glyphosate was applied each year at a rate of 0.44 kg ai ha^{-1}. Indigenous populations of wild oats were controlled where wild oats were not seeded with 0.81 kg ai ha^{-1} diclofop and 0.28 kg ai ha^{-1} bromoxynil at the clay loam locations both years, and at the loam location in 1998. In 1998, severe flax injury resulted due to high humidity and high temperatures directly following application at the loam location. The flax at the clay loam location was sprayed with 0.15 kg ai ha^{-1} sethoxydim. In crop spray applications occurred in all trials in both years with clopyralid and MCPA ester at 0.004 and 0.56 kg ai ha^{-1} respectively. Subsequent applications of 0.99 kg ai ha^{-1} propanil and 0.28 kg ai ha^{-1} MCPA ester were required at the loam locations in both years, due to heavy infestations of green foxtail (*Setaria viridis* Beauv. L.).

Crop diseases were treated to avoid confounding effects with experimental treatments. In 1998, wheat plots were sprayed with 0.83 kg ai ha^{-1} mancozeb and 0.12 kg ai ha^{-1} propiconazole at the loam and clay loam locations respectively. The incidence of tan spot (*Pyrenophora tritici-repentis*), septoria leaf spot (*Septoria tritici*) and leaf rust (*Puccinia recondita*) was quite high at both locations, while the incidence of fusarium head blight (*Fusarium* spp.) low. In 1997, leaf disease incidence did not appear severe; however, the loam location was affected by septoria leaf spot and fusarium head blight, which contributed to lower yields.

Treatments within a trial at each location were harvested on the same day using a small plot combine (Hege, model 125B) in both years. In 1998, to aid in harvesting (Table 4.3), the flax trials were sprayed with 0.4 kg ai ha^{-1} diquat, as a dessicant.

4.3.2.1 Data Collected. In both years, soil was sampled from each trial at each location prior to seeding. Five 0 to 15 cm cores were taken in each replication, in a W pattern, and bulked per trial. All soil samples were sent to Norwest Labs.

Table 4.2 Background soil parameters for each potassium chloride trial at each location in both years (0-15cm).

		1997		1998	
Trial	Parameters[a]	Loam	Clay Loam	Loam	Clay Loam
Wheat / KCl	Nitrate-N	49.3	40.3	35.8	80.6
	Phosphate	62.7	38. 1	33.6	100.8
	Potassium	1344.0	795.2	864.6	1344.0
	Sulphate-S	40.3	44.8	89.6	89.6
	pH	7.1	7.7	7.7	7.3
	EC*	0.4	0.6	0.4	0.6
Flax / KCl	Nitrate-N	35.8	35.8	40.3	53.8
	Phosphate	56.0	33.6	49.3	35.8
	Potassium	1355.0	866.9	1117.8	949.8
	Sulphate-S	35.8	49.3	76.2	89.6
	pH	7.3	7.5	7.4	7.3
	EC*	0.4	0.8	0.6	1.7
Sufficiency Range (K)		Deficient	Marginal	Optimum	Excess
kg ha^{-1}		168	336	1120	>1120

[a]nitrate-N, phosphate, potassium, and sulphate-S are estimated available in kg ha^{-1}.
*EC= electrical conductivity of the soil, which is a measure of salinity in dS m^{-1}.

Crop and wild oat densities were determined 3 to 4 weeks after seeding. Two crop counts were taken per treatment (based on a 1 m length of row) and averaged. Wild oats were counted (only in plots where they were seeded) in two 0.25 m^2 quadrats and averaged.

Two crop and weed biomass samples (0.25 m^2 quadrats) in each treatment were taken in all trials, in both years, approximately 5 to 6 weeks after planting and at wheat heading, and flax full flower to beginning of boll formation. Quadrats were designed to maintain an equivalent spatial arrangement between the crop and wild oats, with 3 crop rows harvested in all cases. Samples were taken at least 1 m into the plot to avoid edge effects. Each sample was dried at 60 °C for a minimum of 72 hours, weighed and ground using a cast steel Thomas Wiley mill, to pass through a 1 mm sieve. Samples were analysed by Norwest Labs for N, P, K, Ca, Mg and Na content. The same procedures of analysis were followed as outlined in the growth chamber experiments. Potassium uptake, expressed in kg ha^{-1}, was then calculated by multiplying dry matter yield by plant K concentration. Both biomass sampling times were analysed for nutrient concentrations in 1997; however, it was found that the first biomass tissue nutrient results were difficult to interpret, as sufficiency / deficiency levels at this growth stage were not available in the literature, therefore, the 1998 samples were not analysed in this way.

Grain was harvested from a 14 m^2 area using a small plot combine and corrected to storage moisture. Yield of the crops and wild oats were measured, after being separated using a dockage tester[11]. Dockage of other weed seeds was also determined.

Weather (temperature and precipitation) data, was collected both years at each location (Table 3.5). Weather conditions differed between 1997 and 1998. The 1997 season had moderately moist planting conditions, followed by a dry growing season (with the exception of July) and dry harvest conditions, while 1998 provided good moisture at planting followed by an extremely wet growing season and a moist but

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[11]Carter Day Industries, Canada, Ltd. 1425 Whyte Avenue, Winnipeg, Manitoba. R3C 2J6.

manageable harvest period.

4.3.2.2 Statistical Analysis. All data were subjected to ANOVA and orthogonal contrasts using procedures outlined in Statistical Analysis Systems (SAS) software package (SAS Institute, Cary North Carolina, 1990). Fertilizer rates were not evenly spaced, therefore, coefficients for the orthogonal contrasts were subjected to polynomial regression until the contrast coefficients summed to zero[12]. Since, there was a lack of consistent fertilizer rate response (ie. linear, quadratic or cubic) across locations and years, curve fitting was not done. Data from field experiments were not combined due to environmental variability across years and because different locations were selected each year.

[12]Determined using program by Dr. R. Rimmer. Department of Plant Science. University of Manitoba. Winnipeg, Manitoba. R3T 2N2.

4.3 Time line of field operations and data collection for each potassium chloride trial at each location in both years.

	Wheat / KCl				Flax / KCl			
Operation/	Loam:		Clay loam:		Loam:		Clay loam:	
Data Collected	1997	1998	1997	1998	1997	1998	1997	1998
Soil sampling	05-01	++09-26	05-01	10-01	05-01	09-26	05-01	10-01
Seeder Calibration	05-07	04-24	05-07	04-24	05-07	04-24	05-07	04-24
Weed Spreader Calibration & Seeding	05-08	10-10	05-08	10-10	05-08	10-10	05-08	10-10
Pre-Seed Burn-off	05-12	04-29	05-15	05-08	05-12	04-29	05-15	05-08
N (46-0-0) Application	05-14	04-30	05-16	05-13	05-14	04-30	05-16	05-13
KCl (0-0-60) Application & Seeding	05-14	04-30	05-16	05-13	05-14	04-30	05-16	05-13
Crop Counts	06-04	06-02	06-06	06-09	06-04	06-02	06-06	06-09
Wild Oat Counts	06-13	06-02	06-18	06-09	06-13	06-02	06-18	06-09
In Crop Spray 1:	06-11	05-26	06-16	06-15	06-11	05-26	06-16	06-15
(Tractor) 2:	06-18	06-08	------	------	06-18	06-08	------	------
In Crop Spray (2 m boom)	------*	06-12	06-29	06-22	------	06-12	06-29	06-22
Biomass 1	06-23	06-16	06-25	06-29	06-24	06-16	06-26	06-29
Spray for Disease	------	06-25	------	07-03	------	------	------	------
Biomass 2	07-21	07-13	07-25	07-22	07-30	07-29	08-01	08-03
Crop Dessication	------	------	------	------	------	09-02	------	09-02
Harvest	09-04	08-26	09-09	08-27	09-07	09-10	09-10	09-09

++dates are arranged by month, followed by day. Soil sampling, wild oat spreader calibration and seeding all occurred in the fall of 1997, not 1998.

* ------, indicates that the operation did not occur.

4.4 Results

4.4.1 Growth Chamber

Wild oats produced more dry matter than wheat and wheat produced more dry matter than flax at each harvest date, except for 14 DAE where wheat produced slightly more dry matter than wild oats (Figure 4.1). Wild oat seedlings have been shown to be weak at first, but as root systems enlarge, a higher net assimilation rate occurs compared to other species (Chancellor, 1976). Wild oats had the highest rate of dry matter production compared to wheat and flax which were approximately equivalent (Figure 4.1).

Potassium concentration (mg g^{-1}) was highest in wild oats, followed by wheat and then flax at 14 DAE (Figure 4.2). At all other harvest dates wild oats had the highest K concentration, followed by flax and then wheat (Figure 4.2). Typical sufficiency / deficiency values for species K concentration are listed in Table 4.4. All species were within their sufficiency range throughout the entire experiment. Wheat and wild oats; however, began showing K deficiency symptoms at 21 DAE. Early symptoms on the wheat and wild oats were leaf tip yellowing / scorching of the primary tillers, leading to entire tiller leaf necrosis by experiment end. The wild oats appeared to be a much lighter green colour throughout the entire experiment than the wheat, indicating, perhaps a greater K deficiency. Observed deficiencies were greater than the P experiments due to differences in background soil K levels. Tissue analysis indicated adequate K levels. Deficiency symptomology could have resulted, therefore, from root binding in the small pots and / or because of an imbalance of other nutrients. Wheat reached heading earlier than the wild oats (Figure 4.4), ensuring all reserves were allocated to the seed to maximize reproduction. The wheat may have also reached maturity earlier than the wild oats due to its lack of genetic variability as compared to the wild oats.

Wheat had a slightly higher K uptake at 14 DAE than wild oats, but after establishment the wild oats had the highest rate of K uptake at all other harvest dates (Figure 4.3). Early in the experiments wheat had a greater K uptake than flax; however, their K uptake became similar as the experiment progressed (Figure 4.3).

Table 4.4 Sufficiency range of K (mg g^{-1}) in whole plant flax, wheat and tame oats (at flowering of flax and heading of wheat and tame oats) as recommended by the Manitoba Provincial Soil Testing Laboratory.

Crop	Low	Marginal	Sufficient	High	Excess
Flax	10.0	10.0 - 15.0	15.0 - 30.0	30.0 - 50.0	50.0
Wheat	10.0	10.0 - 15.0	15.0 - 30.0	30.0 - 50.0	50.0
Tame oats*	10.0	10.0 - 15.0	15.0 - 30.0	30.0 - 50.0	50.0

* there is no sufficiency range determination for wild oats.

4.4.2 Field

4.4.2.1 Flax. Overall yield trends were the same in both years; however, treatments without wild oats had higher yields only in 1997, whereas, differences between fertilizer placements without wild oats occurred only at the clay location in 1998 (Tables 4.5 and 4.6). These results may be related to the differences in temperature and precipitation in 1997 versus 1998 (Table 3.5).

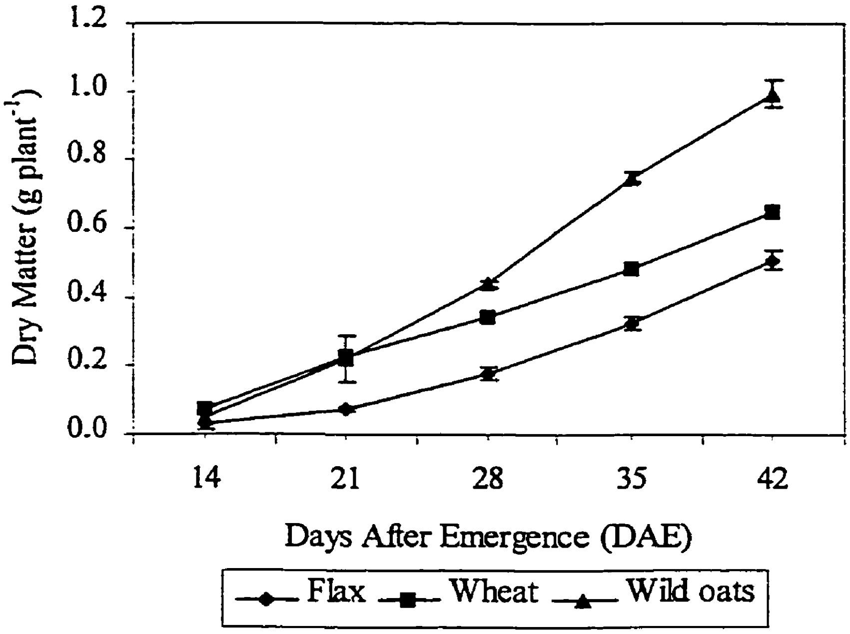

Figure 4.1 Species comparison of dry matter accumulation (g $plant^{-1}$) over time as influenced by KCl fertilization. Combined analysis of two experiments.

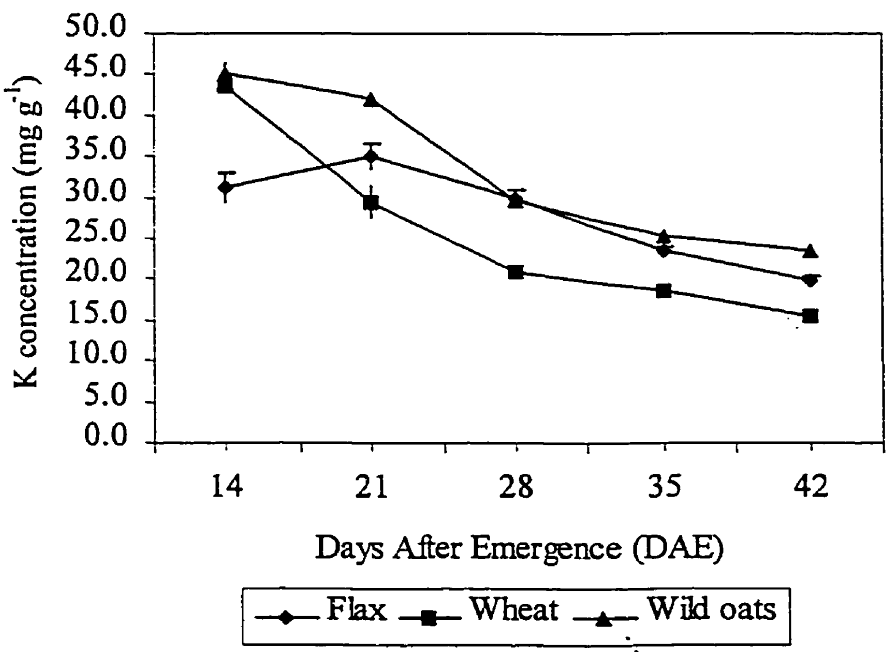

Figure 4.2 Species comparison of K concentration (mg g^{-1}) in tissue over time. Combined analysis of two experiments.

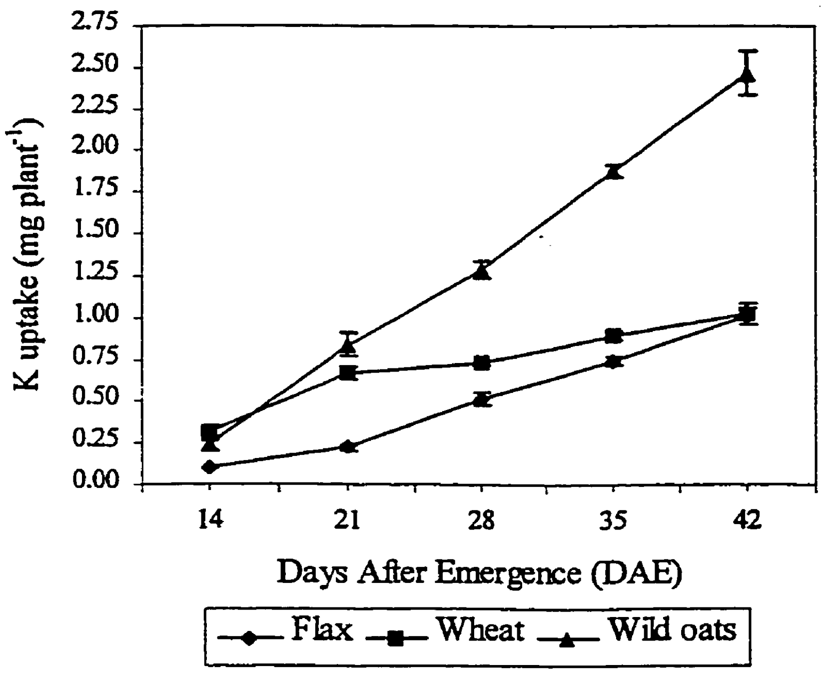

Figure 4.3 Species comparison of K uptake (mg plant^{-1}) over time. Combined analysis of two experiments.

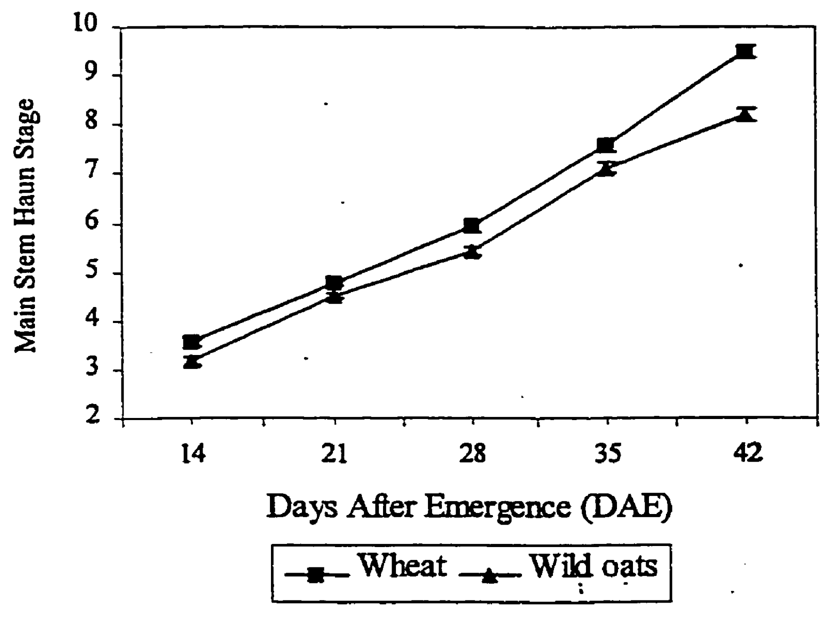

Figure 4.4 Main stem haun stage comparison of wheat and wild oats over time as influenced by KCl fertilization. Combined analysis of two experiments

The highest flax yields occurred at the loam location in 1997 at the 12.45 kg K ha^{-1} seed-placed rate without wild oats (Table 4.5). Yields were highest at the clay loam location at the highest seed-placed KCl rates without wild oats in 1997 and 1998 (Table 4.6). The greatest yield of flax occurred at the 16.6 kg K ha^{-1} side-banded rate in 1997, however; all side-banded KCl rates provided equivalent yields in 1998, maybe due to excess moisture (Table 4.6). This indicates, perhaps, that K addition is of greater importance on fine-textured soils with high clay contents when moisture is limiting, but the clay loam locations used for the flax trials also had lower background K levels than the coarse-textured loam soils. The lattice of clay minerals in the Newdale soil at the MZTRA farm readily fix K, K content on the coarse textured soil appears adequate. The Cl could also be playing a role as both soils were very high in exchangeable K.

Dry weights from flax full flower to the beginning of boll formation growth stage showed the same patter as the seed yield data, with higher yields in treatments without wild oats in 1997, and to differences between fertilizer placements in treatments without wild oats in 1998 (Tables A.19 and A.20). Seed placement produced higher wild oat dry weights at the clay loam location in 1997, presumably due to toxicity to the flax crop (Table A.20). Flax dry matter yield was higher with seed-placed than side-banded KCl at the clay loam location in 1998 (Table A.20). As differences occurred from fertilizer placement at flax full flower to beginning of boll formation that did not carry through to yield the effects of weed-crop interactions for immobile nutrients may be more adequately measured prior to yield determination. Higher amounts of K uptake occurred only in treatments without wild oats in 1997 (Tables A.23 and A.24). Potassium uptake differed between fertilizer placements only with the wild oats in 1997 at the clay loam location (Table A.24). These results differ from yield and dry weights at flax full flower to beginning of boll formation. Concentration of K in flax tissue was within the sufficiency range at the loam location but deficient at the clay loam location, indicating that K concentration in flax tissue was not increased by KCl addition, but tended to decrease (Tables A.21 and A.22). This may be due to the clay lattices fixing K and making it unavailable at the clay loam location, or to the restricted rooting of flax, or to the differences in soil temperatures affecting mobility, or due to differences in background soil K levels (Table 4.2). Wild oats were sufficient in K concentration at both locations in both years, indicating a better species uptake ability and higher K requirement (Tables A.21 and A.22).

4.4.2.2 Wheat. Wild oats decreased seed yield at both locations in 1997 (Tables 4.7 and 4.8). In 1998, at the clay loam location, all side-banded treatments provided higher yields than seed-placed treatments, except for the 33.2 kg K ha^{-1} rate with wild oats, where they were approximately equivalent (Table 4.8). Differences between fertilizer placements were only evident in 1998, with higher yields due to side-banded fertilizer at the loam location in all treatments regardless of the presence of wild oats (Table 4.8). At the clay loam location, higher yields occurred only in side-banded fertilizer treatments without wild oats (Table 4.8). Yield was higher on the loam (Table 4.7) than the clay loam (Table 4.8) location. Yields did not increase above the control at the loam location in either year. Yields at the clay loam location; however, increased slightly above the control at all seed-

Table 4.5 Yield (kg ha^{-1}) of flax and wild oats as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

	Location 1: Loam Soil											
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	1866.84	2055.63	1866.84	2055.63	47.81	47.81	545.38	653.44	545.38	653.44	80.31	80.31
8.30	1806.41	2064.75	1753.81	2039.50	39.53	43.81	665.84	950.22	380.59	535.28	56.03	83.38
12.45	1982.81	2175.16	1840.88	2091.25	35.28	39.75	343.38	476.79	487.00	648.47	68.25	67.22
16.60	1739.19	1848.88	1747.97	2065.94	53.41	54.31	707.22	755.81	662.92	1026.33	52.19	51.83
24.90	1847.72	2149.22	1756.19	1996.38	49.59	46.22	868.22	626.16	659.16	944.72	55.63	63.72
33.20	1609.88	1957.47	1937.19	1978.44	55.44	53.81	599.81	877.31	727.31	868.03	67.75	55.19

Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*0.0621
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rate Cubic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Simple Effects	Flax	Wild Oats	Flax	Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	0.0001	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 4.6 Yield (kg ha^{-1}) of flax and wild oats as influenced by KCl fertilization, KCl placement and the presence of wild oats on clay loam soil over two years.

	Location 2: Clay Loam Soil											
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	1250.88	1644.38	1250.88	1644.38	191.63	191.63	1372.88	1551.33	1372.88	1551.33	75.58	75.58
8.30	1253.25	1710.00	1476.84	1957.63	212.81	242.34	1196.66	1348.44	1328.88	1594.56	91.53	94.34
12.45	1108.44	1748.09	1109.75	1668.50	325.69	315.53	1357.56	1434.31	1202.75	1450.47	78.09	107.91
16.60	1166.84	1810.84	1167.13	2041.53	315.19	297.03	1125.81	1308.97	1339.41	1529.16	73.91	84.75
24.90	1356.03	1627.59	1389.69	1939.88	278.97	241.28	1232.84	1660.28	1345.56	1412.34	118.13	73.75
33.20	907.59	1836.84	1321.44	1641.56	327.13	216.25	1248.13	1563.88	1439.94	1519.75	115.66	87.19
Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	ns	ns	ns	ns	0.0616	ns	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rate Cubic	ns	ns	ns	ns	*0.0353	ns	ns	ns	ns	ns	ns	ns
Simple Effects			Flax		Wild Oats				Flax		Wild Oats	
Overall Placement (SP vs SB)			ns		ns				ns		ns	
Overall +/- Wild Oats			0.0001		-				ns		-	
SP and SB + Wild Oats			ns		-				ns		-	
SP and SB - Wild Oats			ns		-				0.0001		-	

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

placed and side-banded rates without wild oats, but only up to the 16.60 kg K ha^{-1} rate with wild oats at both placements in 1997. In 1998 higher yields occurred only in side-banded treatments without wild oats.

Like the yield data, wild oats decreased dry matter yield at heading of wheat in 1997 at both locations (Tables 4.9 and 4.10). Differences between fertilizer placements on dry weights were also the same as the yield results in both years; however, one fertilizer placement method was not consistently better than the other (Tables 4.9 and 4.10).

As found in the yield and dry weight data, wild oat competition reduced K uptake of wheat at both locations in 1997 (Tables 4.13 and 4.14). Potassium concentration in the wheat tissue was in the sufficiency range at both locations in both years (Tables 4.11 and 4.12). The greatest concentrations occurred at the clay loam location in 1998. This may be explained by the increased moisture in 1998 allowing the K to remain in solution longer before becoming unavailable due to fixation by the clay lattice structures, thereby increasing concentration by lengthening the time of uptake. Conversely, the wild oat concentrations were in the high range at both locations in both years, with the exception of the clay loam location in 1997 where concentrations were only sufficient (Tables 4.11 and 4.12). Generally, the wild oats had much higher concentrations than the wheat, again, indicating a greater species ability for luxury consumption. It is evident when comparing wild oat K concentrations from both wheat and flax trials, that the more K applied the greater the wild oat uptake (Tables 4.11, 4.12, A.21 and A.22, respectively). This may indicate that wild oats are luxury consumers of K, since they were sufficient in the flax

Table 4.7 Yield (kg ha^{-1}) of wheat and wild oats as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil

Actual K Rate (kg ha^{-1})	1997 Wheat SP +	1997 Wheat SP -	1997 Wheat SB +	1997 Wheat SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Wheat SP +	1998 Wheat SP -	1998 Wheat SB +	1998 Wheat SB -	1998 Wild Oats SP	1998 Wild Oats SB
0.00	1937.88	2231.19	1937.88	2231.19	113.13	113.13	2747.71	2762.00	2747.71	2762.00	25.04	25.04
8.30	1671.22	2082.03	1531.94	1959.38	145.38	139.81	2743.31	2646.38	2830.66	2946.53	24.50	20.94
16.60	1613.34	2083.44	1822.97	2265.88	152.28	109.97	2489.91	2616.00	2715.69	2829.03	36.78	25.40
33.20	1405.44	1912.97	1640.09	2058.22	170.78	137.69	2509.00	2528.22	2747.66	2725.03	21.22	19.78
66.40	1340.28	1940.41	1524.50	2020.91	201.75	154.25	2670.28	2659.50	2546.50	2614.25	37.13	38.27
99.60	1207.75	1669.22	1557.94	1985.09	238.94	150.63	2481.63	2607.00	2635.22	2778.34	34.34	29.91

Orthogonal Contrasts

Main Effects	1997 Wheat SP +	1997 Wheat SP -	1997 Wheat SB +	1997 Wheat SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Wheat SP +	1998 Wheat SP -	1998 Wheat SB +	1998 Wheat SB -	1998 Wild Oats SP	1998 Wild Oats SB
Rate Linear	*0.0033	0.0169	ns	ns	0.0001	ns	ns	ns	ns	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.0889	ns	ns
Rate Cubic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (*SP vs SB*)	0.0009	0.0001	0.0192	0.0590
Overall +/- Wild Oats	0.0001	-	0.0480	ns
SP and SB + Wild Oats	0.0054	-	ns	ns
SP and SB - Wild Oats	0.0430	-	ns	ns

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 4.8 Yield (kg ha^{-1}) of wheat and wild oats as influenced by KCl fertilization, KCl placement and the presence of wild oats on clay loam soil over two years.

Actual K Rate (kg ha^{-1})	Location 2: Clay Loam Soil											
	1997						1998					
	Wheat				Wild Oats		Wheat				Wild Oats	
	SP		SB		SP	SB	SP		SB		SP	SB
	+	-	+	-			+	-	+	-		
0.00	1996.00	2444.91	1996.00	2444.91	100.56	100.56	3268.29	3372.21	3268.29	3372.21	54.92	54.92
8.30	2317.44	2791.94	2177.59	2857.38	45.13	62.91	3235.94	3369.53	3254.84	3480.34	64.38	29.13
16.60	2089.03	2935.63	2226.44	2571.81	75.09	71.63	3115.72	3327.25	3300.19	3395.94	55.72	46.41
33.20	1930.66	2827.19	1873.97	2926.56	117.59	87.53	3196.59	3285.56	3175.81	3368.81	58.03	54.31
66.40	2028.06	2587.75	1968.50	2659.59	109.63	103.72	2966.84	3202.13	3222.22	3432.75	104.66	93.47
99.60	2102.97	2775.50	1941.19	2646.59	70.06	72.63	2781.78	3066.06	2931.84	3230.25	120.63	97.82
Orthogonal Contrasts												
Main Effects												
Rate Linear	*ns	ns	ns	ns	ns	ns	0.0541	ns	ns	ns	0.0256	ns
Rate Quadratic	ns	ns	ns	ns	0.0422	0.0837	ns	ns	ns	ns	ns	ns
Rate Cubic	ns	ns	ns	ns	ns	ns	0.0028	ns	ns	ns	ns	ns
Simple Effects			Wheat		Wild Oats				Wheat		Wild Oats	
Overall Placement (SP vs SB)			ns		ns				ns		0.0680	
Overall +/- Wild Oats			0.0001		-				ns		-	
SP and SB + Wild Oats			ns		-				ns		-	
SP and SB - Wild Oats			ns		-				0.0001		-	

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 4.9 Dry weight (g m^{-2}) of wheat and wild oats at heading of wheat as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

Actual K Rate ($kg\ ha^{-1}$)	Location 1: Loam Soil 1997 Wheat SP +	1997 Wheat SP -	1997 Wheat SB +	1997 Wheat SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Wheat SP +	1998 Wheat SP -	1998 Wheat SB +	1998 Wheat SB -	1998 Wild Oats SP	1998 Wild Oats SB
0.00	476.50	571.20	476.50	571.20	132.80	132.80	530.93	655.60	530.93	655.60	100.53	100.53
8.30	385.40	491.90	404.40	488.00	140.80	173.50	577.80	614.70	550.30	604.20	29.10	38.90
16.60	466.50	555.10	503.20	551.50	117.00	82.90	613.40	566.80	617.60	609.30	65.40	37.50
33.20	408.40	464.90	420.10	550.70	131.60	139.60	574.80	562.80	565.80	624.50	24.40	88.50
66.40	363.10	534.50	373.70	465.50	147.50	149.00	576.10	547.40	634.30	612.20	75.60	59.10
99.60	324.80	474.00	396.20	168.40	109.60	168.40	497.40	543.00	657.10	584.20	61.50	58.20
Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	ns	ns	ns	*0.0870	ns	ns	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rate Cubic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Simple Effects			Wheat		Wild Oats				Wheat		Wild Oats	
Overall Placement (SP vs SB)			ns		ns				0.0373		ns	
Overall +/- Wild Oats			0.0001		-				ns		-	
SP and SB + Wild Oats			ns		-				ns		-	
SP and SB - Wild Oats			ns		-				ns		-	

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 4.10 Dry weight (g m^{-2}) of wheat and wild oats at heading of wheat as influenced by KCl fertilization, KCl placement and the presence of wild oats on clay loam soil over two years.

Actual K Rate (kg ha^{-1})	1997 Wheat SP +	1997 Wheat SP -	1997 Wheat SB +	1997 Wheat SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Wheat SP +	1998 Wheat SP -	1998 Wheat SB +	1998 Wheat SB -	1998 Wild Oats SP	1998 Wild Oats SB
	Location 2: Clay Loam Soil											
0.00	315.80	434.20	315.80	434.20	318.10	318.10	466.93	718.13	466.93	718.13	43.33	43.33
8.30	413.90	561.50	500.90	557.40	178.40	144.70	688.20	584.80	741.00	757.60	39.70	66.80
16.60	496.60	576.40	428.00	472.20	299.90	178.60	586.00	740.10	654.10	653.40	23.90	158.10
33.20	387.00	504.50	404.70	519.70	287.70	199.30	565.20	623.60	549.00	661.70	81.70	36.10
66.40	438.10	505.80	404.20	493.70	249.20	197.40	655.60	755.50	578.80	640.10	126.80	70.70
99.60	326.70	535.50	351.00	504.30	218.20	302.50	537.00	600.50	490.20	627.80	122.30	55.80
Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	ns	ns	0.0650	0.0541	ns	ns	ns	0.0256	ns
Rate Quadratic	ns	*0.0895	ns	ns	ns	ns	ns	ns	ns	ns	0.0990^{T}	ns
Rate Cubic	ns	ns	ns	ns	ns	ns	0.0028	ns	ns	ns	ns	ns

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	0.0001	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	0.0086	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 4.11 Potassium (mg g^{-1}) concentration of wheat and wild oat tissue at heading of wheat as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil												
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	26.33	22.67	26.33	22.67	31.00	31.00	20.75	20.50	20.75	20.50	33.00	33.00
8.30	25.00	23.25	21.75	23.75	33.00	31.00	19.50	19.00	19.25	20.00	32.50	33.50
16.60	26.25	23.75	21.75	22.50	36.00	29.50	19.50	20.25	19.00	19.00	31.50	33.25
33.20	24.75	23.75	24.50	23.00	32.75	31.50	19.25	19.75	18.50	20.00	33.00	31.75
66.40	22.50	23.75	25.50	24.25	34.75	36.00	20.75	21.00	18.50	18.50	31.00	30.50
99.60	24.50	26.00	24.00	23.75	33.75	31.50	21.50	20.00	22.00	21.25	37.75	36.75

Simple Effects	Wheat (1997)	Wild Oats (1997)	Wheat (1998)	Wild Oats (1998)
Overall Placement (SP vs SB)	•ns	ns	ns	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

• = p value; ns = non significant; SP = seed-placed; SB = side-banded; +/- = plots with and without wild oats respectively.

Table 4.12 Potassium (mg g^{-1}) concentration of wheat and wild oat tissue at heading of wheat as influenced by KCl fertilization, KCl placement and the presence of wild oats on clay loam soil over two years.

	Location 2: Clay Loam Soil											
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	20.33	16.00	20.33	16.00	17.33	17.33	28.50	29.50	28.50	29.50	38.00	38.00
8.30	21.75	21.25	21.25	16.75	13.00	21.00	29.50	27.50	28.50	30.25	40.00	37.25
16.60	18.25	22.25	18.25	18.00	21.50	27.75	27.50	28.00	27.75	27.50	37.00	33.50
33.20	18.50	19.75	17.75	18.25	28.50	28.75	24.25	27.50	27.25	26.50	34.75	35.00
66.40	20.75	19.25	19.00	18.75	21.50	25.75	29.75	27.50	24.75	26.00	39.00	32.75
99.60	18.00	19.50	20.75	21.25	20.75	20.25	25.25	24.50	25.75	26.50	35.00	38.50

Simple Effects	Wheat (1997)	Wild Oats (1997)	Wheat (1998)	Wild Oats (1998)
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	*0.0757	-	ns	-

* = p value; ns = non significant; SP = seed-placed; SB = side-banded; +/- = plots with and without wild oats respectively.

Table 4.13 Potassium (kg ha^{-1}) uptake of wheat and wild oat tissue at heading of wheat as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil												
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	13070.13	13662.27	13070.13	13662.27	2716.40	2716.40	12288.20	13535.60	12288.20	13535.60	2738.40	2738.40
8.30	9412.60	11587.50	8446.30	11330.30	4683.80	5403.60	11293.30	11618.40	10504.20	12123.00	1016.10	1290.20
16.60	12339.00	13159.50	11025.00	12409.30	4153.30	2548.60	11978.40	11483.70	11619.30	11598.90	2128.70	1272.90
33.20	10027.70	11039.50	10324.10	12713.40	4463.30	4241.80	11080.80	11207.80	10545.30	12507.30	757.10	2684.90
66.40	8226.10	12767.90	9789.70	11581.20	5146.80	5498.20	11943.10	11464.00	11745.20	11315.90	2356.90	1829.40
99.60	7869.80	12570.80	9477.00	11472.30	3737.70	5520.60	10734.60	10917.70	14630.90	12350.60	2252.20	2131.50

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	*0.0002	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 4.14 Potassium (kg ha^{-1}) uptake of wheat and wild oat tissue at heading of wheat as influenced by KCl fertilization, KCl placement and the presence of wild oats on clay loam soil over two years.

	Location 2: Clay Loam Soil											
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	6523.87	6212.80	6523.87	6212.80	3728.00	3728.00	14564.80	21042.20	14564.80	21042.20	1623.70	1623.70
8.30	8897.70	11915.20	11010.60	9381.30	2680.80	3971.00	20383.10	16028.20	21113.40	22859.50	1508.70	2529.00
16.60	9083.60	12895.70	7632.40	8575.80	6005.40	5067.00	15933.30	20868.60	18465.50	17643.30	893.60	5189.20
33.20	7101.30	9990.40	7070.60	9576.60	8121.00	5808.40	13688.00	17292.10	14890.80	17358.90	2910.70	1313.80
66.40	9166.20	9823.90	7755.00	9200.40	5855.40	5077.10	19336.90	20796.20	14545.90	16614.60	4584.60	2270.50
99.60	5872.60	10394.70	7437.50	10737.70	5570.30	7093.30	13585.50	14819.50	12767.30	16652.80	4366.10	1814.80

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	*0.0007	-	0.0373	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	0.0577	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

trials where KCl applications only reached 33.2 kg K ha^{-1}, but in the high range in the wheat trials where KCl was applied up to 99.6 kg K ha^{-1}.

4.5 Discussion

The K requirement of all crops is as much or more than the requirement for N. Potassium does not become part of the plants chemical structure but is involved in many vital roles, particularly osmoregulation. Adequate K is essential when crops are subjected to climatic stresses; such as, drought, heat, and low temperatures (Kafkafi, 1990; Lawn and Williams, 1987). Depending on edaphic factors, particularly texture, K application may be required irrespective of high soil test values (Anonymous, 1987). Moisture increases the mobility of K and its time in solution, which is important because K may be readily fixed in soils with high clay levels (Potash and Phosphate Institute, 1998). This was evident in 1998 where treatment yields, dry weights and uptake varied between fertilizer placements due to excess moisture levels. Soil and crop type affected this outcome. Dry conditions in 1997 resulted in a lack of K availability and subsequent crop uptake because moisture is needed for root growth to new supplies of K. Moisture is also needed for mass-flow movement of K to the plant root and for the diffusion of K to the roots to resupply K taken up by the roots (Potash and Phosphate Institute, 1998).

Flax showed no yield response to applied KCl in either the field or growth chamber experiments. This result is not surprising as Bailey and Soper (1985) suggested that flax would only respond to applications of KCl fertilizer when the exchangeable K in the soil was less than 200 kg ha^{-1}. The soil used in the growth chamber experiments had the lowest exchangeable K at 401 kg ha^{-1} (Table 4.1). The tap root of flax also decreases its ability to obtain K from the soil compared to grass species (Potash and Phosphate Institute, 1998).

Differences in yield and dry weights between fertilizer placements occurred in the wheat experiments at both locations in 1998. Side-banded treatments at the loam location provided higher yields and dry weights than seed-placed treatments whether wild oats were present or not due to salt toxicity. At the clay loam location side-banded treatments without wild oats provided the highest yields and dry weights, because of toxicity from seed-placement as well as competition from the wild oats for K. Yields and dry weights above those of the control only occurred at the clay loam location in both years.

Addition of KCl on high K testing soils may occasionally increase yields of hard red spring wheat on the prairies, particularly on fine texture soils (Anonymous, 1987). The higher moisture retention on clay loam soils, especially in direct-seeding systems increases K availability. Yield was higher in 1998 at the loam location than in 1997, due to greater moisture and less disease incidence in 1998. Yields were highest in both years at the clay loam location and in all side-banded treatments; however, this yield difference between soils likely had nothing to do with K addition. Side banding may have provided higher yields in all treatments because of the salt toxicity from seed placement, which in turn increased wild oat densities and competition.

Wild oats decreased seed yields, dry weights and K uptakes in 1997 but not in 1998. This indicates that wild oats have a greater impact on crop growth, development and subsequent yield in dry years. Wild oat growth can be directly and indirectly affected by soil type (Chancellor, 1976), and climatic conditions such as temperature and moisture (Kühnel, 1965; Thurston, 1962; Sexsmith, 1969; Sharma et al. 1977). Thurston's work (1962) suggests that wild oats may be more tolerant to soil moisture stress than crop plants, and Sharma et al. (1977) found that flax, rapeseed, wheat and barley are more adversely affected by moisture stress than wild oats, thereby collaborating our results.

Potassium tissue concentration (mg g^{-1}) of wild oats varied from sufficient in the flax experiments and wheat experiment at the loam location in 1997 to high in all other wheat experiments at both locations in 1997 and 1998. Tissue concentration of the wild oats in the growth chamber experiments ranged from high to sufficient as time progressed. These results indicate that the amount of K uptake by wild oats is proportional to the amount of K available, indicating that wild oats are sink driven rather than source driven. In the growth chamber the wild oats had the highest K uptake, K concentration and dry matter production. The limited environmental stress and equal advantage given to each species in the growth chamber experiments indicates that wild oats have a greater ability for K uptake than wheat or flax. This may be due to their intense luxury consumption ability, or due to their genotypic plasticity.

Wild oats have been an ongoing economic problem for producers in the prairie provinces, and many believe that they continue to dominate the weed spectrum because of current management practices selecting for them. This research provides evidence of their high K requirement and luxury consumption ability, therefore it is possible that they may be a particular problem in western Canada because of the high background soil K levels.

4.6 Conclusions

Climatic and edaphic factors greatly affect the dynamics and availability of nutrients. In the dry year (1997) treatments without wild oats had higher yields, dry weights and K uptake. In the wet year (1998) differences between fertilizer placements caused differences in yield, dry weights and K uptake. Yield response to fertilizer rate was not affected by environment.

Potassium chloride fertilizer applications should be re-evaluated in direct-seeding systems with regard to the lack of yield increase to KCl additions on the loam soil compared to increases in yield at low KCl rates on the clay loam soil in the wheat experiments. These results could be explained by higher background soil K levels in the coarse-textured soil and, generally, more K availability than the clay loam soil, which, in turn, caused toxicity. It may; however, be due simply to wild oat competition. Wild oats require K in large amounts, therefore KCl application increased their competitiveness. Fertilizer recommendations may no longer be accurate in direct-seeding systems due to increased organic matter levels. An increase in organic matter changes the amount of nutrients in the mineralized soil fraction. Also, producers should realize that fertilizer recommendations are based on experiments where weeds were controlled. Future fertilizer work should include a weedy check to provide more accurate recommendations.

Producers tend to apply more herbicides in wet years; however, in this study, wild oats had a greater impact in dry years. This increased competition from wild oats in dry years, combined with their high K uptake potential may explain wild oat dominance on the prairies for the last two decades. Potassium may be the missing link explaining wild oat abundance. Incorporating current soil maps with recent weed survey information may provide this answer. Further competition work is needed to understand wild oat - crop interactions for K, as well as wild oat mechanisms of K uptake.

5. EFFECT OF WILD OATS ON GRAIN QUALITY OF SPRING WHEAT AND OIL QUALITY OF FLAX

5.1 Abstract

Individual weed species effects on grain and oil seed quality have not been extensively investigated. To determine, therefore, the impact of wild oats on grain quality of spring wheat and oil quality of flax, 4 field experiments were conducted on 2 soil types in 1997 and 1998. Data were subjected to ANOVA and orthogonal contrasts. Regression analysis did not provide consistent rate responses, therefore, curve fitting was not done. Temperature and precipitation varied, with 1997 being hot and dry and 1998 wet. This climatic variattion determined the extent of the impact of wild oats. Wild oats decreased the percent oil content of flax in 1997. Wild oats did not affect wheat quality in either the MAP or KCl experiments. The effects of wild oats on crop quality parameters should be considered in conjunction with yield loss predictions when producers evaluate their criteria for spray determination.

5.2 Introduction

Yield and crop quality determine the overall management requirements of a production system. Wild oat directly affects yield of spring wheat and flax, therefore, it is likely that it also affects crop quality parameters. Few studies have considered how individual weed species affect crop quality. The studies that have, have found that cereal grain quality appears to be infrequently affected, but flax seed quality is readily affected by wild oat competition (Chancellor and Peters, 1976). Current direct-seeding systems and continuous cropping patterns on the prairies may influence these results.

The most important factor in nutrient management for enhanced protein concentration is the availability of adequate N. Phosphorus and K have minimal effects on grain protein concentration under field conditions, apart from dilution effects that may occur when grain yield is increased (Grant and Flaten, 1998). Yield response of wheat to KCl fertilizer is attributed primarily to increases in single grain weight (1000 kernel weight). Potassium is important in N relations within the plant and therefore may indirectly affect protein; however, in field studies, Campbell et al. (1996) showed no effect of K fertilization on grain protein.

Producers may improve economic returns from wheat by obtaining premiums with high protein precentages. Previous weed studies evaluating affects on cereal protein considered densities of weeds and were not species or cropping system specific. Friesen (1957) found that the protein content of wheat and barley increased when weeds (mainly wild oats), at densities between 16 and 2665 m^{-2}, were removed. Nakoneshny and Friesen

(1961) showed that yield increases following fertilizer applications to weedy spring wheat were sometimes association with decreased protein. They concluded that protein reductions could be prevented and protein content increased by weed removal. Friesen et al. (1960) also found that weeds significantly reduced both protein content and yield of wheat, barley and oats in 22 out 60 fields. The weed densities ranged from18 to 1040 m^{-2} and weeds other than wild oats were present. Conversely, Bell and Nalewaja (1968b) and Bowden and Friesen (1967) found no effect on the 1000 kernel grain weight or protein content of wheat and barley at wild oat densities of up to 300 m^{-2}, regardless of cropping sequence or fertilizer treatment. The fact that other weeds were present in all of these studies may indicate that a greater range of nutritional demand than that made by wild oats alone is necessary for reduction in crop grain protein. High weed densities and early weed emergence also appear to be prerequisites for protein reduction.

In flax, Bell and Nalewaja (1968a and 1968c) showed that oil content, iodine number and level of linolenic acid in the seed, declined in three separate years as a result of wild oat competition. Conversely, the level of oleic acid increased. These changes occurred with wild oat densities as low as 12 m^{-2}. Moreover, Burrows and Olson (1955), Chow and Dorrell (1977) and Friesen (1986) found that competition from other weed species did not affect seed and oil quality.

The literature cited indicates that wild oats do affect crop quality parameters; however, the affect and extent in direct-seeding systems is not known. The objective of this research is, therefore, to evaluate the impact of wild oats on grain quality of spring wheat (*Triticum aestivum* L.) and oil quality of flax (*Linum usitatissimum* L.) in the

Aspen Parkland Ecoregion - Black Soil Zone of western Canada.

5.3 Materials and Methods

Four experiments were conducted at 2 locations in 1997 and 1998 in the Aspen Parlkand Ecoregion at Brandon Manitoba. They were designated as flax / monoammonium phosphate (MAP), flax / potassium chloride (KCl), wheat / MAP and wheat / KCl. These experiments were conducted at 2 locations in 1997 and 1998 in the Aspen Parlkand Ecoregion at Brandon Manitoba. One location was approximately 10 km south of Brandon and 3.2 km west of number 10 highway (NE 32-9-19W) on a loam soil, the second location was approximately 40 km north of Brandon on highway number 10 at the MZTRA (SW 27-10-19W) farm on a clay loam soil. These locations were chosen to represent 2 dominant soil types in western Manitoba; Rego Chernozem and Orthic Black Chernozem respectively (Table 3.1 and 4.1). For further agronomic information relating to these experiments see sections 3.3.2 and 4.3.2.

5.3.1 Data Collected. Grain was harvested from a 14 m^2 area using a small plot combine and corrected to storage moisture. Yield and 1000 kernel weights of the crops and wild oats were measured, after being separated using a dockage tester[1]. The grain from the wheat and wild oats was ground using a Black and Decker coffee grinder. These samples were analysed by Norwest Labs for N, P, K, Ca, Mg, and Na concentration. The N

[1]Carter Day Industries, Canada, Ltd. 1425 Whyte Avenue, Winnipeg, Manitoba. R3C 2J6.

analysis was done by a combustion method using a Leco N-Analyzer. All of the other parameters were analysed starting with an ashing procedure, followed by an acid dissolving step with analysis by ICP Spectrometry[2]. Flax oil content was determined by Nuclear Magnetic Resonance (NMR)[3]. The protein content of the wheat and wild oats was determined by multiplying the % N content by a factor of 5.7 (Bushuk, 1977) for the wheat / KCl and flax / KCl trials (wild oats only). The percent P in the seed was used as a measure of quality for the wheat and wild oats in the wheat / MAP trials, and for the wild oats in the flax / MAP trials.

Weather (temperature and precipitation) data, was collected both years at each location (Table 3.5). There were dramatically different weather conditions in 1997 and 1998. The 1997 growing season had moderately moist planting conditions, followed by a dry growing season (with the exception of July) and dry harvest conditions. The 1998 growing season provided good moisture at planting followed by an extremely wet growing season and a moist but manageable harvest. For other data collected in these trials see sections 3.3.2.1 and 4.3.2.1.

5.3.2 Statistical Analysis. All data were subjected to ANOVA and orthogonal contrasts using procedures outlined in Statistical Analysis Systems (SAS) software package (SAS Institute, Cary North Carolina, 1990). Fertilizer rates were not evenly spaced, therefore,

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[2]Personnel communication. Rob Ellis. Norwest Labs. #203-545 University Crescent. Winnipeg, Manitoba. R3T 5S6.

[3]Analysis by M. Luman. AAFC. Beaverlodge, Alberta. T0H 0C0.

the coefficients for the orthogonal contrasts were subjected to polynomial regression until the contrast coefficients summed to zero[4]. Since, there was a lack of consistent fertilizer rate response (ie. linear, quadratic or cubic) across locations and years, curve fitting was not done. Data from field experiments were not combined due to environmental variability across years and because different locations were selected each year.

5.4 Results

5.4.1 Flax

The oil content of flax was decreased by wild oats in all trials in 1997, and on the clay loam in 1998 (Tables 5.1, 5.2 , 5.3 and 5.4). Placement of fertilizer affected oil content in 1998, but the effects were not consistent (Tables 5.1, 5.2 , 5.3 and 5.4). The variation in results from year to year may be explained by the differences in temperature and precipitation from 1997 to 1998 (Table 3.5) causing a greater impact from wild oats in the dry year since flax was relatively unresponsive to MAP or KCl fertilization.

Phosphorus concentration and protein in the wild oat seed increased above that of the control at the loam location but not the clay loam (Tables 5.1, 5.2, 5.3 and 5.4). This may be due to differences in background soil P and K levels (Table 3.1 and 4.1, respectively) or because of a soil type affect on wild oats as reported by Chancellor (1976).

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[4]Determined using program by Dr. R. Rimmer. Department of Plant Science. University of Manitoba. Winnipeg, Manitoba. R3T 2N2.

Table 5.1 Oil content (%) of flax and P concentration (mg g^{-1}) in wild oat grain as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam soil over two years.

Site 1: Loam Soil												
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	39.63	39.80	39.63	39.80	2.70	2.70	39.80	39.68	39.80	39.68	2.75	2.75
3.50	38.85	39.55	39.00	39.10	2.88	2.93	40.65	39.83	40.18	39.95	2.83	2.68
4.37	38.65	39.38	37.68	38.00	2.98	2.93	40.23	39.80	39.35	39.78	3.08	2.90
6.56	38.23	39.23	38.20	39.25	2.83	2.93	39.13	39.95	40.03	39.38	2.90	2.93
8.74	38.10	39.33	38.23	39.25	2.95	2.85	39.73	39.43	39.40	39.50	2.98	3.20
17.48	38.28	39.70	37.75	39.13	2.95	3.15	39.20	39.65	38.70	39.30	3.35	3.13

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	0.0869*	ns	ns	ns
Overall +/- Wild Oats	0.0002	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	0.0033	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 5.2 Oil content (%) of flax and P concentration (mg g^{-1}) in wild oat grain as influenced by MAP fertilization, MAP placement and the presence of wild oats on clay loam soil over two years.

Actual P Rate (kg ha^{-1})	Site 2: Clay Loam Soil 1997 Flax SP +	SP -	SB +	SB -	Wild Oats SP	SB	1998 Flax SP +	SP -	SB +	SB -	Wild Oats SP	SB
0.00	40.97	43.00	40.97	43.00	2.47	2.47	40.08	40.35	40.08	40.35	2.83	2.83
3.50	40.88	43.00	41.30	43.00	2.58	2.45	40.28	41.10	39.93	40.33	2.85	2.73
4.37	40.85	42.68	40.58	43.60	2.30	2.43	39.93	40.53	40.63	40.98	2.65	2.73
6.56	40.68	42.03	40.55	43.25	2.45	2.60	40.38	40.83	40.28	40.45	2.68	2.75
8.74	41.13	43.28	40.23	43.20	2.45	2.53	39.98	40.33	40.38	40.48	2.73	2.70
17.48	41.05	42.68	39.08	42.03	2.65	2.68	40.05	40.65	40.00	40.23	2.80	2.68

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	0.0001*	-	0.0050	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 5.3 Oil content (%) of flax and protein (%) of wild oats as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil

Actual K Rate (kg ha^{-1})	1997 Flax SP +	1997 Flax SP -	1997 Flax SB +	1997 Flax SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Flax SP +	1998 Flax SP -	1998 Flax SB +	1998 Flax SB -	1998 Wild Oats SP	1998 Wild Oats SB
0.00	33.40	38.53	33.40	38.53	12.54	12.54	39.63	39.97	39.63	39.97	8.42	8.42
8.30	38.25	38.48	37.80	38.63	12.75	12.77	40.55	40.30	40.28	40.60	8.78	8.50
12.45	38.88	39.30	38.60	38.88	12.97	12.90	40.45	40.17	40.00	40.45	8.40	8.50
16.60	38.03	38.50	38.13	39.10	12.95	12.43	40.45	39.68	40.70	40.40	9.14	8.76
24.90	38.40	39.40	38.03	38.90	12.53	13.00	40.50	39.98	40.70	40.65	8.71	8.87
33.20	38.00	38.83	38.95	39.22	12.90	12.63	40.35	40.50	41.10	40.63	8.64	8.18

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	0.0006*	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 5.4 Oil content (%) of flax and protein (%) of wild oats as influenced by KCl fertilization, KCl placement and the presence of wild oats on clay loam soil over two years.

	Location 2: Clay Loam Soil											
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	41.70	41.87	41.70	41.87	5.68	5.68	41.75	42.20	41.75	42.20	9.69	9.69
8.30	42.15	42.23	41.93	43.23	4.35	9.49	42.38	42.33	41.30	42.08	10.28	10.22
12.45	41.18	43.00	42.10	42.53	9.31	6.54	41.98	42.33	41.78	42.15	10.00	9.33
16.60	42.80	42.75	41.55	43.45	6.58	8.89	41.93	42.73	41.53	41.75	9.81	9.92
24.90	41.50	43.10	42.40	42.85	8.95	7.28	41.70	42.43	41.48	42.05	9.85	9.82
33.20	40.98	42.98	42.18	42.15	9.09	5.13	41.73	41.95	41.68	42.08	9.62	9.79

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	0.0010	ns
Overall +/- Wild Oats	0.0002*	-	0.0001	-
SP and SB + Wild Oats	ns	-	0.0105	-
SP and SB - Wild Oats	ns	-	0.0292	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

5.4.2 Wheat

Wild oats affected the wheat quality parameters measured; however, the results were not consistent. Wild oats decreased wheat P concentrations in the MAP experiments in 1997 and 1998 at the clay loam location (Table 5.6). In the KCl experiments wild oats increased protein content at the loam location in 1997 (Table 5.7), but decreased protein content at the clay loam location in 1997 and 1998 (Table 5.8). Wild oat also decreased 1000 kernel weights in the KCl experiments at the clay loam location in 1997 (Table 5.10). Differences in 1000 kernel weights due to wild oats also occurred at the loam location in 1998; however, treatments with higher weights were not consistent (Table 5.9).

Phosphorus concentrations and 1000 kernel weights of wild oats generally increased as MAP and KCl rates increased (Tables 5.5, 5.6, 5.9 and 5.10, respectively) irrespective of fertilizer placement method, but wild oat protein was not affected (Tables 5.7 and 5.8). The inconsistency of results may be due to the genetic variability of wild oats and the lack of uniform maturity of the seed that was harvested. Unlike crop plants, wild oats have not been bred to germinate, grow and mature in a given number of days. The wild oats were harvested with the crop, but most of the mature seed had already dropped to the ground.

Table 5.5 Phosphorus concentration (mg g^{-1}) in wheat and wild oat grain as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil												
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	4.37	4.47	4.37	4.47	3.37	3.37	4.18	4.20	4.18	4.20	3.20	3.20
4.37	4.55	4.58	4.43	4.60	3.25	3.50	4.18	4.05	4.25	4.25	3.23	3.20
8.74	4.60	4.45	4.45	4.45	3.38	3.40	4.23	4.10	4.10	4.23	3.33	3.33
17.48	4.55	4.53	4.58	4.55	3.45	3.43	4.20	4.30	4.30	4.18	3.43	3.40
34.96	4.73	4.65	4.68	4.70	3.40	3.60	4.30	4.18	4.23	4.30	3.38	3.48
52.44	4.75	4.73	4.75	4.65	3.45	3.60	4.25	4.35	4.15	4.28	3.50	3.45

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	ns	0.0186*	ns	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 5.6 Phosphorus concentration (mg g^{-1}) in wheat and wild oat grain as influenced by MAP fertilization, MAP placement and the presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil

Actual P Rate (kg ha^{-1})	1997						1998					
	Wheat				Wild Oats		Wheat				Wild Oats	
	SP		SB		SP	SB	SP		SB		SP	SB
	+	-	+	-			+	-	+	-		
0.00	4.33	4.50	4.33	4.50	3.27	3.27	4.15	4.18	4.15	4.18	3.03	3.03
4.37	4.30	4.55	4.30	4.60	3.25	3.20	4.23	4.33	4.30	4.50	3.33	3.25
8.74	4.38	4.50	4.43	4.63	3.25	3.50	4.18	4.48	4.28	4.35	3.25	3.28
17.48	4.28	4.48	4.43	4.55	3.45	3.45	4.25	4.30	4.30	4.48	3.30	3.40
34.96	4.33	4.43	4.30	4.35	3.48	3.43	4.23	4.38	4.18	4.20	3.33	3.28
52.44	4.40	4.48	4.28	4.35	3.53	3.53	4.18	4.38	4.23	4.28	3.55	3.45

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	0.0001*	-	0.0041	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 5.7 Protein (%) of wheat and wild oats as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

Actual K Rate (kg ha⁻¹)	1997 Wheat SP +	1997 Wheat SP -	1997 Wheat SB +	1997 Wheat SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Wheat SP +	1998 Wheat SP -	1998 Wheat SB +	1998 Wheat SB -	1998 Wild Oats SP	1998 Wild Oats SB
0.00	16.76	16.55	16.76	16.55	12.01	12.01	16.09	16.50	16.09	16.50	10.02	10.02
8.30	17.07	16.66	17.13	16.56	11.50	11.93	15.93	15.94	15.86	16.05	9.54	10.06
16.60	17.14	16.60	16.91	16.50	11.96	12.10	15.90	15.90	16.14	16.13	9.74	9.99
33.20	15.87	16.77	17.01	16.44	11.64	12.04	15.66	15.78	15.83	15.89	10.25	10.36
66.40	17.40	16.64	17.01	16.62	11.53	12.23	16.26	16.27	15.99	16.03	9.74	10.12
99.60	17.40	16.44	17.04	16.43	11.80	12.24	15.91	16.12	16.09	15.91	9.69	10.26

Location 1: Loam Soil

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	0.0163
Overall +/- Wild Oats	0.0131*	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 5.8 Protein (%) of wheat and wild oats as influenced by KCl fertilization, KCl placement and the presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil												
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	16.87	16.72	16.87	16.72	9.84	9.84	18.43	18.30	18.43	18.30	10.29	10.29
8.30	16.94	17.24	16.50	16.80	10.60	9.78	18.26	18.35	18.15	18.39	9.69	11.17
16.60	16.97	17.40	16.36	16.62	10.29	9.69	18.31	18.48	17.91	18.18	10.02	10.65
33.20	16.86	17.41	16.87	16.69	9.52	9.75	16.16	18.46	18.29	18.21	12.20	10.59
66.40	16.54	16.84	16.62	16.83	9.85	9.90	16.26	18.53	18.03	18.08	12.42	9.85
99.60	16.72	16.97	16.86	16.72	10.50	10.22	15.35	18.57	18.09	18.47	9.78	9.78

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	0.0054*	ns	ns	ns
Overall +/- Wild Oats	0.0632	-	0.0344	-
SP and SB + Wild Oats	ns	-	0.0283	-
SP and SB - Wild Oats	0.0042	-	ns	-

*= p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 5.9 One thousand kernel weights (g) of wheat and wild oats as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil												
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	28.00	28.33	28.00	28.33	17.67	17.67	30.75	30.50	30.75	30.50	16.00	16.00
8.30	27.25	27.25	25.50	27.00	18.00	18.00	29.50	29.25	30.25	30.00	15.75	16.00
16.60	27.00	27.75	28.50	28.25	17.25	19.00	29.00	27.50	29.25	29.75	16.25	16.00
33.20	27.00	26.50	27.50	27.50	19.00	18.50	29.50	29.25	29.75	28.75	16.00	16.25
66.40	27.25	27.00	26.50	26.50	18.25	18.50	31.00	29.25	29.75	28.75	15.50	16.50
99.60	26.25	29.00	26.75	27.75	18.25	18.50	29.25	30.25	29.50	28.75	16.25	17.00

Simple Effects	Wheat	Wild Oats	Wheat	Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	ns	-	0.0431	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table 5.10 One thousand kernel weights (g) of wheat and wild oats as influenced by KCl fertilization, KCl placement and the presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil

Actual K Rate ($kg\ ha^{-1}$)	1997 Wheat SP +	1997 Wheat SP -	1997 Wheat SB +	1997 Wheat SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Wheat SP +	1998 Wheat SP -	1998 Wheat SB +	1998 Wheat SB -	1998 Wild Oats SP	1998 Wild Oats SB
0.00	31.00	32.00	31.00	32.00	15.33	15.33	35.25	36.00	35.25	36.00	18.00	18.00
8.30	30.75	32.25	31.50	31.00	15.50	15.75	35.50	35.50	35.75	35.00	18.50	19.00
16.60	29.50	31.00	31.00	30.75	16.00	16.75	35.75	35.50	36.25	36.00	19.25	18.50
33.20	29.75	31.25	29.75	31.75	16.50	16.00	36.50	35.00	36.00	36.00	19.25	19.50
66.40	31.25	31.75	29.75	29.75	16.50	16.75	36.00	36.00	36.25	35.50	18.00	18.50
99.60	30.25	30.75	30.00	30.50	16.75	16.75	36.50	36.25	36.00	36.75	20.00	18.50

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	0.0073*	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

5.5 Discussion

Determination of factors that affect crop quality parameters of cereals and oilseeds in direct-seeding systems is essential because protein percentage determines wheat profits and investigation into oil quality for use in nutraceuticals is occurring on the prairies. Individual weed species effects on these parameters have not been investigated, therefore, wild oats were chosen because of their abundance on the prairie provinces (Thomas et al., 1998).

Percent oil content in flaxseed was higher in all plots without wild oats in 1997. This result agrees with Bell and Nalewaja's findings (1968a and 1968c). The varying results in 1998 indicate that temperature and precipitation may also have an affect on crop quality. Moisture was higher in 1998, which could have increased the movement of the MAP and KCl applied providing a greater effect from these relatively immobile nutrients. In contrast, 1997 was dry, which could have limited the amount of time these nutrients remained in solution and were available to the crop plant. Also, wild oats have been shown to be directly and indirectly affected by climatic conditions such as temperature and moisture (Kühnel, 1965; Thurston, 1962; Sexsmith, 1969; Sharma et al., 1977). Thurston's (1962) work suggests that wild oats are more tolerant to soil moisture stress and therefore, have a greater impact in dry years. This is consistent with what we have found.

The varied results in the wheat experiments indicate that wild oats can affect wheat quality parameters, but the effects of temperature, precipitation and edaphic factors are difficult to separate. Of all the crop nutrients, N has by far the greatest influence on grain protein concentration. Effects of other crop nutrients are primarily through changes in crop yield, which influences dilution of protein in the grain (Grant and Flaten, 1998; Campbell et al., 1996). In order to determine the exact effect of wild oats on spring wheat quality parameters studies should be completed in association with N fertilizer.

5.6 Conclusions

It is evident that wild oats can seriously reduce crop yields and cause extensive crop losses; however, their effect on crop quality parameters is less clear. Oil content of flax was affected by wild oats in the dry year. This demonstrates the importance of understanding an individual weed species biology when determining its impact. The wheat results were varied, showing that wild oats do affect quality parameters, but their impact cannot be separated from the influence of climatic and edaphic variables. The flax results were consistent, which could have resulted from their lack of yield response to MAP and KCl fertilizers as compared to wheat. Further research into weed species affects on crop quality will be important as crops grown for nutraceutical markets expand, but these studies should include N fertilizer management as a component.

6. GENERAL DISCUSSION

Climatic and edaphic factors play extremely important roles when dealing with relatively immobile nutrients, like P (Nelson, 1986; Potash and Phosphate Institute, 1986; Fohse et al., 1991; Otani and Ae, 1996) and K (Potash and Phosphate Institute, 1998). This was evident in 1998 where treatment yields and dry weights of all MAP and KCl field experiments varied due to moisture with differences between fertilizer placements evident. Theses responses in 1998 varied with MAP affecting percent P concentration in wheat and flax tissue and KCl affecting overall wheat and flax uptake. Uptake is a measure of dry matter production and percent nutrient concentration in the crop tissue. Adequate K promotes efficient N use, which, in turn promotes greater vegetative production and yields, therefore, uptake would be increased by KCl addition due to increases in dry matter.

Soil and crop type also influence nutrient uptake, depending on background P and K levels in the soil and the crop requirement for these nutrients. Conversely, the dry conditions in 1997 resulted in a lack of P and K availability and reduced subsequent crop uptake because crop response to fertilizer P often increases as water availability increases (Munson and Murphy, 1986; Nelson, 1986) and moisture is needed for root growth to new supplies of K. Moisture is also needed for mass-flow movement of K to the plant root and for the diffusion of K to the roots to resupply K taken up by the roots (Potash and

Phosphate Institute, 1998).

Flax did not show a yield response to applications of MAP or KCl in either the field or growth chamber experiments. These results are new with respect to direct-seeding systems; however, numerous conventional-tillage field experiments and growth chamber studies have shown that flax grown on prairie soils is relatively unresponsive to MAP fertilizer, even MAP placed with the seed at recommended rates in soils low in available P (Ukrainetz, 1963; Soper and Racz, 1963; Racz, 1969; Ridley and Tayakepisuthe, 1974). Bailey and Soper (1985) suggested that flax would only respond to applications of KCl fertilizer when the exchangeable K in the soil was less than 200 kg ha^{-1}. The soil used in the growth chamber experiments had the lowest exchangeable K at 401 kg ha^{-1} (Table 4.1), therefore a response was not likely. The tap root of flax also decreases its ability to obtain K from the soil compared to grass species (Potash and Phosphate Institute, 1998).

The expected dramatic flax yield reduction to the high rates of seed-placed P found by many others, did not occur (Nyborg, 1961; Sadler, 1980; Bailey and Grant, 1989). Molberg (1961) found salt toxicity to seed-placed fertilizers was greater in dry years. This was not evident in our experiments and, therefore, this lack of toxicity could be linked to the maintenance of moisture and increased organic matter in direct-seeding systems, which, in turn, increases the amount of nutrients in the mineralized soil fraction. Side-banding, generally, provided higher flax yields than seed-placed fertilizer treatments. This indicates that toxicity did occur, but it was not visually evident. The higher yields in the side-banded fertilizer treatments were not significantly greater than yields obtained from the non-fertilized controls.

The results in all flax experiments in 1997 (dry year) were different from those in 1998 (wet year). In 1997, treatments without wild oats had higher yields, dry weights, concentrations (MAP experiments), uptake (KCl experiments) and percent oil than those with wild oats. Whereas, differences between fertilizer placements were evident in 1998 due to the excess moisture. The affect of wild oats on flax oil quality agrees with Bell and Nalewaja's findings (1968a and 1968c); however, they did not consider climatic variation.

Differences in yield, dry weights and concentration due to differences between fertilizer placement treatments occurred in the wheat MAP field experiments at the clay loam location in both years. These differences were found at both locations in the wheat KCl experiments in 1998 only. These results may be explained by the higher moisture retention and subsequent P availability on clay loam soils and in wet years, yield and P uptake are greater than in dry years (Bailey et al., 1977). Differences between fertilizer placements occurred in the wheat KCl experiments only in 1998, possibly because the excess moisture allowed the K to remain in solution longer allowing a greater chance for crop uptake. Potassium availability may have also increased for these reasons.

Side-banded fertilizer treatments provided higher yields for both the MAP and KCl wheat experiments. The higher yields from side-banding were likely due to salt toxicity from the seed placement this; however, was not visually evident in the MAP trials, as it was in the KCl trials. The lower yields in the seed-placed treatments may have also occurred due to increased wild oat densities and subsequent competition. In the KCl field experiments, yields and dry weights above those of the non-fertilized control occurred only at the clay loam location in both years. This may be due to the lower background K levels in some cases and to the higher K fixing ability of these fine textured high clay content soils, resulting in less toxicity in others. At the loam location yields were higher in both wheat experiments in 1998 than in 1997. This was attributed to more available moisture and less disease incidence in 1998. All wheat yields were higher at the clay loam location in both years. This may be explained by the higher water holding capacity of clay loam soils allowing these relatively immobile nutrients to remain in solution for longer periods of time, allowing crop uptake to occur over a longer period of time. The higher moisture retention may have also supported a higher yield, regardless of P or K effects.

In 1997, wild oat decreased wheat yields, dry weights, P concentrations (MAP experiments) and K uptake levels (KCl experiments). This indicated a greater impact of wild oats in the dry year. The wild oats also affected wheat quality parameters, as measured by percent P content in the seed in the wheat MAP experiments and by protein content and 1000 kernel weights in the wheat KCl experiments. Studies by Friesen (1957), Nakoneshny and Friesen (1961) and Friesen et al. (1960) found wild oats (with other weeds present) reduced protein. In our experiments, affects on protein were found at both locations in 1997 and the clay loam location in 1998. One thousand kernel weights, were only affected at the loam location in 1998 and the clay loam location in 1997. Unlike in the flax experiments, wild oats did not affect grain quality of the wheat in either year. This indicates that further weed impacts on wheat quality parameters should involve N management since P and K do not directly affect protein content. Soil type, levels of background nutrients, year to year climatic variation and the fact that the wheat responded to the addition of both nutrients may have also contributed to this inconsistency.

Wild oat growth and development was affected by temperature and precipitation in the field experiments. They had a greater impact on crop yield in the dry year due to their greater tolerance to moisture stress than crop plants (Sexsmith, 1969). Climatic affects on wild oats have been shown by various authors (Kühnel, 1965; Thurston, 1962; Sexsmith, 1969; Sharma et al. 1977). Soil type may also affect their impact (Chancellor, 1976).

The field and growth chamber data indicated that wild oats had a much greater ability to accumulate P and K than either the spring wheat or flax. Accumulation of these nutrients did increase with the amount applied. The P tissue concentration of wild oats varied from severely deficient in the growth chamber and flax field experiments to sufficient and high in the wheat field experiments. Whereas, the K tissue concentration of wild oats varied from sufficient in the flax experiments and wheat experiment at the loam location in 1997 to high in all other wheat experiments at both locations in 1997 and 1998.

The flax field experiments and the growth chamber experiments had the lowest rates of P and K applied, which may explain the higher P and K concentrations found in the wild oat / wheat experiments. This indicates that wild oats can accumulate P better than wheat, but not flax. Flax is better able to access soil P than fertilizer P, therefore flax can uptake P better than wild oats on soils with marginal background P levels than on soils with deficient P levels, when fertilizer P is applied. In the growth chamber, the wild oats may not have taken up as much P as possible due to its root densities becoming to high in the small soil volume conferred by the pots, and intra-specific root competition may have occurred for the nutrient (Newman and Andrews, 1973).

In 1997, the wild oats at the clay loam location had greater K uptake than those at the loam location. This was likely due to the greater water holding capacity of the clay loam soil. The excess moisture in 1998 provided greater uptake at the loam location than in 1997. This indicates the importance of soil type in wild oat nutrient uptake as reported by Chancellor (1976). These results indicate that the amount of P and K available is proportional to the amount of P and K uptake by wild oat, ie. the greater the amount available the greater the uptake.

The results from the field and growth chamber experiments indicate that wild oats have greater K uptake accumulation compared to P. Regardless of background soil K levels, the more K applied, the greater their accumulation, particularly in the wheat experiments. This K luxury consumption by wild oats may be due to their phenotypic plasticity (Siddiqi et al., 1987). Unlike crop plants, wild oats will grow and mature sporadically throughout the season, and therefore, have learned to adapt to differences in nutrient availability. In Canada, wild oat is prevalent on the prairies where a high percentage of the soils are high in available K. Incorporating recent weed survey information with soil survey data could provide valuable ecophysiological information on wild oat species dispersion patterns. Is K the key dimension in the wild oat niche?

Fertilizer recommendations in direct-seeding systems need to be re-evaluated because typical responses to the addition of MAP and KCl fertilizer did not necessarily occur. The lack of toxicity to high rates of MAP in the wheat and flax experiments could be due to a management affect of direct seeding or to the presence of wild oats in these experiments. The disparity of yield increases to KCl addition occurred because none of the locations in either year were K deficient. It would therefore be advantageous to do detailed fertility experiments in direct-seeding systems, to determine how management has affected nutrient partitioning and cycling, especially in the presence of weeds. Direct-seeding increases the amount of organic matter in the soil over time, which contributes to increased mineralization of nutrients which current soil testing methods do not measure. Direct-seeding also has a high proportion of beneficial mycorrhizal fungi, since the mycelium is left relatively undisturbed and regeneration time is therefore limited (Pérez-Moreno and Ferrera-Cerrato, 1997). The presence of mycorrhizae can aid in nutrient capture, this could be particularly important with P uptake in calcareous soils with high pH, where Ca and Mg bind P.

7. SUMMARY AND CONCLUSIONS

Fertilizer placement affects a crop's ability to compete with weeds. The 'pop-up' effect from MAP and KCl addition at low to moderate rates was not observed, therefore a crop competitive advantage against wild oats from seed-placement of these nutrients did not occur, which could be due to already favourable nutrient and moisture conditions in direct-seeding systems. High rates of KCl addition resulted in toxicity; however, there was a difference in yield advantage to KCl addition based on soil texture and background soil K levels. Side-banding provided higher crop yields and lower wild oat growth compared to seed-placed fertilizer applications indicating that some toxicity did occur in the MAP experiments. Even though 1997 and 1998 were two very different growing seasons, fertilizer rate responses were the same both years. In the dry year of 1997 losses due to the presence of wild oats occurred, while in 1998, a wet year, the differences in crop yield between side-banded and seed-placed fertilizer was particularly evident.

Flax was relatively unresponsive to MAP and KCl addition. Wheat showed significant increases in yield to high rates of MAP, yield increases to low rates of KCl on soils with average background K levels, and a yield decline at all KCl rates on soils with high background K levels. The yield decline corresponded with an increase to wild oats, therefore, the effect may have been due to increased wild oat competition when KCl is added to soils already high in K.

In the growth chamber, P and K uptake was greatest in wild oats, followed by wheat and flax. This shows wild oats to be luxury consumers of these nutrients. It was speculated that this was due to an inherent need, genetic variability, plasticity or an adaptation by wild oats to management selection pressure on the prairies. Temperature, precipitation and soil type directly affect the biology of wild oats. Wild oat has a greater impact on crop yield in dry years. Further research into the effect of MAP and KCl on weed-crop competition in direct-seeding systems would lead to improved fertilizer recommendations.

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9. APPENDIX

Table A.1 Dry weight (g m^{-2}) of flax and wild oats approximately five to six weeks after emergence as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam soil over two years.

	Location 1: Loam Soil												
	1997						1998**						
Actual	Flax				Wild Oats		Flax				Wild Oats		
P Rate	SP		SB		SP	SB	SP		SB		SP	SB	
(kg ha^{-1})	+	-	+	-			+	-	+	-			
0.00	51.00	53.20	51.00	53.20	4.80	4.80	11.07	14.93	11.07	14.93	7.20	7.20	
3.50	54.10	51.80	43.50	45.50	3.20	3.90	18.80	18.10	23.00	15.00	17.90	13.10	
4.37	45.80	53.30	48.30	53.30	5.60	4.10	19.20	19.90	14.20	19.20	12.00	7.90	
6.56	53.50	52.40	50.60	45.40	5.20	5.80	16.40	18.70	19.90	23.90	4.80	24.00	
8.74	53.00	43.40	46.40	54.00	7.30	5.40	27.70	24.10	24.20	27.60	9.20	37.90	
17.48	42.10	48.20	49.80	48.20	6.60	4.50	21.20	21.60	26.40	26.30	20.80	15.00	

Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	ns	ns	ns	ns	ns	0.0993	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.0984	ns	0.0576
Rate Cubic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	0.0026	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

** 1998 flax dry weights were multiplied by a correction factor of .4 (40%) due to spray error.

Table A.2 Dry weight (g m^{-2}) of flax and wild oats approximately five to six weeks after emergence as influenced by MAP fertilization, MAP placement and the presence of wild oats on clay loam soil over two years.

	Location 2: Clay Loam Soil											
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	22.20	24.00	22.20	24.00	5.10	5.10	66.80	42.80	66.80	42.80	7.20	7.20
3.50	26.20	25.90	22.10	25.60	13.40	7.20	61.30	53.80	43.20	55.40	12.40	9.30
4.37	27.60	23.50	25.50	28.00	9.80	14.10	52.90	57.10	58.60	50.60	12.20	8.00
6.56	31.60	30.70	25.30	30.50	8.60	11.70	62.40	51.30	58.10	71.50	6.10	12.90
8.74	26.50	23.20	23.00	18.00	7.50	3.50	50.80	54.70	54.50	69.20	9.50	5.00
17.48	27.80	28.10	24.50	30.50	7.00	13.00	42.60	62.60	67.40	53.70	2.60	10.40
Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	ns	ns	ns	ns	ns	0.0616	ns	0.0106	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rate Cubic	ns	ns	ns	*0.0818	ns	0.0623	ns	ns	ns	ns	ns	ns
Simple Effects			Flax		Wild Oats				Flax		Wild Oats	
Overall Placement (SP vs SB)			ns		ns				ns		ns	
Overall +/- Wild Oats			ns		-				ns		-	
SP and SB + Wild Oats			ns		-				ns		-	
SP and SB - Wild Oats			ns		-				ns		-	

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.3 Phosphorus (mg g^{-1}) concentration of flax and wild oat tissue approximately five to six weeks after emergence as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam and clay loam soil in 1997.

Actual	Loam						Clay Loam					
P Rate	Flax				Wild Oats		Flax				Wild Oats	
($kg\ ha^{-1}$)	SP		SB		SP	SB	SP		SB		SP	SB
	+	-	+	-			+	-	+	-		
0.00	4.07	3.80	4.07	3.80	3.57	3.57	3.50	3.13	3.50	3.13	3.30	3.30
3.50	4.10	4.08	3.95	4.08	3.43	3.40	3.68	3.65	3.50	3.50	3.53	3.20
4.37	4.28	4.33	4.28	4.30	3.68	3.60	3.28	3.60	3.28	3.55	3.33	3.55
6.56	4.28	4.15	4.28	4.58	3.43	3.63	3.68	3.75	3.65	3.48	3.30	3.35
8.74	4.38	4.13	4.03	4.23	3.88	3.63	3.85	4.00	4.00	4.18	3.45	3.65
17.48	4.68	4.30	4.53	4.53	3.70	3.80	4.33	4.10	4.35	4.00	3.83	3.75

Simple Effects	Loam Flax	Loam Wild Oats	Clay Loam Flax	Clay Loam Wild Oats
Overall Placement (SP vs SB)	*ns	ns	ns	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.4 Phosphorus (kg ha^{-1}) uptake of flax and wild oat tissue approximately five to six weeks after emergence as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam and clay loam soil in 1997.

Actual	Loam						Clay Loam					
P Rate	Flax				Wild Oats		Flax				Wild Oats	
(kg ha^{-1})	SP		SB		SP	SB	SP		SB		SP	SB
	+	-	+	-			+	-	+	-		
0.00	207.48	198.09	207.48	198.09	13.67	13.67	86.27	71.81	86.27	71.81	36.29	36.29
3.50	215.03	207.37	171.27	185.86	11.20	13.57	98.24	94.79	81.09	92.28	47.37	25.03
4.37	194.34	228.12	206.25	231.81	20.65	14.47	89.97	86.73	82.08	99.37	33.22	50.24
6.56	229.47	217.81	218.90	207.00	17.79	21.89	117.75	112.85	92.81	107.66	29.54	39.87
8.74	232.82	179.88	186.07	225.35	28.71	19.58	101.04	93.36	67.07	101.04	26.06	41.63
17.48	196.73	206.84	224.25	217.54	24.77	17.22	104.09	130.17	103.92	121.64	33.74	49.15

Simple Effects	Loam Flax	Loam Wild Oats	Clay Loam Flax	Clay Loam Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.5 Dry weight (g m^{-2}) of flax and wild oats at full boll formation of flax as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil												
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	597.30	625.70	597.30	625.70	98.70	98.70	318.40	247.07	318.40	247.07	273.33	273.33
3.50	556.90	710.00	578.10	585.10	91.40	95.90	280.00	343.00	297.30	357.00	165.60	272.10
4.37	498.80	572.30	557.40	680.40	116.30	136.60	201.30	270.30	279.60	347.40	370.10	305.90
6.56	462.40	623.50	577.30	693.80	145.40	138.00	307.50	455.20	198.30	245.00	243.40	417.40
8.74	540.40	591.80	529.60	623.20	114.10	152.50	202.20	331.90	100.90	308.40	294.80	382.30
17.48	440.60	614.20	554.20	598.80	191.00	110.60	115.50	308.10	289.80	379.00	233.70	393.60
Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	ns	0.0952	ns	ns	ns	ns	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	0.0446	ns	ns	ns
Rate Cubic	ns	ns	ns	*0.0761	ns	ns	ns	ns	ns	ns	ns	ns

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	0.0933	ns	ns	0.0176
Overall +/- Wild Oats	0.0001	-	ns	-
SP and SB + Wild Oats	0.0552	-	ns	-
SP and SB - Wild Oats	ns	-	0.0037	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.6 Dry weight (g m^{-2}) of flax and wild oats at full boll formation of flax as influenced by MAP fertilization, MAP placement and the presence of wild oats on clay loam soil over two years.

Actual P Rate (kg ha^{-1})	Location 2: Clay Loam Soil											
	1997						1998					
	Flax				Wild Oats		Flax				Wild Oats	
	SP		SB		SP	SB	SP		SB		SP	SB
	+	-	+	-			+	-	+	-		
0.00	360.40	373.60	360.40	373.60	322.27	322.27	409.87	458.80	409.87	458.80	144.80	144.80
3.50	334.20	407.00	314.20	524.10	352.27	331.73	412.20	475.20	420.10	459.50	76.70	141.90
4.37	306.80	489.60	282.10	471.20	301.20	395.80	408.40	509.30	400.10	450.20	105.00	105.70
6.56	314.60	508.90	319.20	512.30	288.40	419.33	400.40	508.40	428.80	417.00	116.10	145.70
8.74	324.10	505.60	352.40	500.10	277.47	293.40	362.20	457.80	460.10	597.20	185.70	79.90
17.48	355.50	583.70	323.10	480.20	242.80	355.00	331.70	500.00	404.70	486.70	85.80	202.00

Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	*0.011	ns	ns	ns	ns	0.0863	ns	ns	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.0677	ns
Rate Cubic	ns	ns	ns	ns	ns	0.0958	ns	ns	ns	0.0962	ns	ns

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	ns	0.0851	ns	ns
Overall +/- Wild Oats	0.0001	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	0.0001	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.7 Phosphorus (mg g^{-1}) concentration of flax and wild oat tissue at full boll formation of flax as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil												
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	3.37	3.00	3.37	3.00	1.97	1.97	3.10	3.10	3.10	3.10	1.95	1.95
3.50	3.43	3.23	3.20	3.15	1.93	2.13	3.20	3.10	2.63	3.23	2.53	2.63
4.37	3.25	3.20	3.38	3.25	2.13	2.10	3.18	3.30	2.78	3.05	2.48	2.33
6.56	3.33	3.43	3.45	3.48	1.98	1.95	2.95	3.03	3.13	3.13	2.35	2.53
8.74	3.48	3.35	3.48	3.33	2.15	2.25	3.08	3.00	3.15	3.33	3.10	3.15
17.48	3.45	3.35	3.50	3.30	2.23	2.15	3.48	3.18	3.03	2.80	3.23	2.75

Simple Effects	Flax	Wild Oats	Flax	Wild Oats
Overall Placement(SP vs SB)	ns	ns	0.0980	ns
Overall +/- Wild Oats	*0.0305	-	ns	-
SP and SB + Wild Oats	ns	-	0.0291	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed; SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.8 Phosphorus (mg g^{-1}) concentration of flax and wild oat tissue at full boll formation of flax as influenced by MAP fertilization, MAP placement and the presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil

Actual P Rate ($kg\ ha^{-1}$)	1997 Flax SP +	1997 Flax SP -	1997 Flax SB +	1997 Flax SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Flax SP +	1998 Flax SP -	1998 Flax SB +	1998 Flax SB -	1998 Wild Oats SP	1998 Wild Oats SB
0.00	2.27	2.43	2.27	2.43	1.07	1.07	2.60	2.63	2.60	2.63	1.83	1.83
3.50	2.70	2.35	2.75	2.55	1.58	1.50	2.78	2.75	2.58	2.65	1.85	1.90
4.37	2.63	2.18	2.75	2.38	1.45	1.65	2.60	2.55	2.65	2.70	1.93	1.88
6.56	2.58	2.33	2.83	2.43	1.75	1.63	2.65	2.38	2.53	2.45	1.68	2.05
8.74	2.88	2.33	2.53	2.23	1.68	0.88	2.65	2.75	2.80	2.63	1.83	1.83
17.48	2.55	2.55	2.85	2.45	1.33	1.65	2.73	2.48	2.80	2.85	2.03	1.88

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	*0.0004	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed; SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.9 Phosphorus (kg ha^{-1}) uptake of flax and wild oat tissue at full boll formation of flax as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil												
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	1806.17	1839.47	1806.17	1839.47	228.36	228.36	1109.0	903.7	1109.0	903.7	523.1	523.1
3.50	1904.83	2288.13	1851.42	1822.66	173.10	202.58	838.9	1038.9	756.4	1112.2	444.2	572.6
4.37	1603.83	1832.38	1880.79	2207.72	239.84	290.14	568.6	900.4	743.6	1034.5	948.1	754.6
6.56	1538.27	2133.87	1982.11	2409.69	285.83	258.84	880.5	1398.5	629.9	737.2	575.4	1057.4
8.74	1872.56	1977.33	1851.20	2071.01	252.26	332.92	612.5	1020.9	315.1	1046.2	883.5	1152.7
17.48	1533.02	2069.12	1937.48	1991.48	430.84	238.16	406.1	984.4	859.7	1088.3	698.5	957.5

Simple Effects	Flax (1997)	Wild Oats (1997)	Flax (1998)	Wild Oats (1998)
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	*0.0007	-	0.0007	-
SP and SB + Wild Oats	0.0550	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.10 Phosphorus (kg ha^{-1}) uptake of flax and wild oat tissue at full boll formation of flax as influenced by MAP fertilization, MAP placement and the presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil													
	1997						1998						
Actual	Flax				Wild Oats		Flax				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	752.49	776.39	752.49	776.39	624.32	624.32	1139.62	1344.95	1139.62	1344.95	219.67	219.67
3.50	893.38	953.18	842.00	1345.23	592.35	489.80	1156.85	1303.68	1098.22	1232.71	133.29	258.60
4.37	813.83	1065.08	763.20	1121.74	412.07	652.98	1076.23	1291.83	1043.82	1196.20	210.19	189.09
6.56	802.74	1181.11	912.45	1242.83	509.86	679.48	1057.57	1197.66	1082.88	1023.05	187.83	309.89
8.74	940.87	1177.69	822.21	1091.29	486.95	369.57	971.40	1232.59	1275.63	1538.93	334.46	142.03
17.48	884.18	1490.30	922.72	1177.94	429.11	601.70	897.01	1255.21	1181.35	1385.15	156.43	385.85

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	*0.0001	-	0.0029	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.11 Dry weight (g m^{-2}) of wheat and wild oats approximately five to six weeks after emergence as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil												
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	49.70	63.60	49.70	63.30	5.10	5.10	64.00	73.73	64.00	73.73	0.53	0.53
4.37	55.40	56.10	64.30	62.30	5.20	8.60	124.40	117.30	77.80	64.10	2.20	0.90
8.74	69.10	68.10	73.30	80.60	9.00	5.00	106.80	102.50	113.80	96.50	3.70	6.29
17.48	66.20	71.80	65.10	74.90	6.30	4.90	105.40	115.10	130.80	102.10	1.70	3.20
34.96	66.70	67.00	70.60	86.30	7.20	9.10	154.80	123.70	142.40	136.60	0.40	5.80
52.44	68.50	69.60	73.90	90.90	10.90	6.20	156.50	156.00	149.80	115.60	0.40	0.40
Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	*0.0358	ns	ns	0.0263	0.0054	0.0037	0.0157	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.0459	ns	ns
Rate Cubic	ns	ns	ns	ns	ns	0.0227	ns	ns	ns	ns	ns	ns

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	0.0124	ns	0.0303	ns
Overall +/- Wild Oats	0.0491	-	0.0220	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	0.0085	-	0.0582	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.12 Dry weight (g m^{-2}) of wheat and wild oats approximately five to six weeks after emergence as influenced by MAP fertilization, MAP placement and the presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil												
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	58.40	71.60	58.40	71.60	6.50	6.50	107.87	94.93	107.87	94.93	5.60	5.60
4.37	59.80	52.50	72.20	72.80	4.30	9.20	122.60	118.70	119.50	102.00	10.70	5.00
8.74	74.60	58.20	84.40	82.60	6.70	3.70	130.20	113.30	141.60	122.80	7.50	4.70
17.48	73.20	86.10	89.90	91.30	7.40	7.00	177.10	136.60	122.90	125.20	7.70	14.00
34.96	85.50	98.20	112.10	106.90	5.10	6.00	148.80	140.70	174.90	151.90	9.70	6.90
52.44	89.90	91.60	108.50	107.80	9.50	9.20	159.80	166.70	197.60	181.00	9.60	6.30
Orthogonal Contrasts												
Main Effects												
Rate Linear	*0.0038	0.0002	0.0337	0.0038	ns	ns	ns	0.0044	0.0004	0.0003	ns	ns
Rate Quadratic	ns	0.0043	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rate Cubic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	0.0004	ns	ns	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	0.0066	-	ns	-
SP and SB - Wild Oats	0.0151	-	0.0250	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.13 Phosphorus (mg g^{-1}) concentration of wheat and wild oat tissue approximately five to six weeks after emergence as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam and clay loam soil in 1997.

Actual P Rate (kg ha^{-1})	Loam						Clay Loam					
	Wheat				Wild Oats		Wheat				Wild Oats	
	SP		SB		SP	SB	SP		SB		SP	SB
	+	-	+	-			+	-	+	-		
0.00	3.63	3.53	3.63	3.53	3.13	3.13	3.30	3.30	3.30	3.30	4.20	4.20
4.37	3.88	3.78	3.83	3.70	3.85	3.88	3.23	3.15	3.30	3.10	4.00	4.30
8.74	4.05	3.85	3.90	3.90	4.00	3.83	3.48	3.28	3.60	3.45	4.48	4.43
17.48	4.25	4.03	3.98	3.83	4.33	3.80	3.63	3.58	3.80	3.65	4.28	4.05
34.96	4.08	4.15	4.45	4.23	4.30	4.40	3.93	3.93	4.05	3.83	4.75	3.80
52.44	4.38	4.40	4.55	4.08	4.25	4.40	4.20	4.20	3.98	4.05	4.20	4.65

Simple Effects	Loam Wheat	Loam Wild Oats	Clay Loam Wheat	Clay Loam Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	*0.0096	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.14 Phosphorus (kg ha^{-1}) uptake of wheat and wild oat tissue approximately five to six weeks after emergence as influenced by MAP fertilization, MAP placement and the presence of wild oats on loam and clay loam soil in 1997.

Actual	Loam						Clay Loam					
	Wheat				Wild Oats		Wheat				Wild Oats	
P Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	191.24	226.35	191.24	226.35	15.83	15.83	188.45	269.45	188.45	269.45	24.05	24.05
4.37	215.17	213.34	248.04	230.16	19.80	33.31	191.07	165.84	236.66	223.46	16.96	39.28
8.74	280.41	261.72	285.32	312.67	35.88	18.76	259.25	189.65	307.52	286.20	29.43	16.75
17.48	285.91	287.90	258.43	291.98	27.10	19.17	265.66	304.93	341.28	332.78	30.93	30.56
34.96	272.41	278.12	313.08	364.57	30.24	40.57	338.03	390.20	461.28	401.09	23.16	31.24
52.44	299.34	305.91	337.36	370.17	47.82	35.79	374.93	385.88	450.03	434.71	45.26	45.13

Simple Effects	Loam Wheat	Loam Wild Oats	Clay Loam Wheat	Clay Loam Wild Oats
Overall Placement (SP vs SB)	*0.0399	ns	0.0018	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	0.0070	-
SP and SB - Wild Oats	0.0380	-	0.0717	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.15 Dry weight (g m^{-2}) of flax and wild oats approximately five to six weeks after emergence as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil

Actual K Rate (kg ha^{-1})	1997 Flax SP +	1997 Flax SP -	1997 Flax SB +	1997 Flax SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998** Flax SP +	1998** Flax SP -	1998** Flax SB +	1998** Flax SB -	1998** Wild Oats SP	1998** Wild Oats SB
0.00	41.40	45.10	41.40	45.10	3.50	3.50	28.00	19.33	28.00	19.33	16.93	16.93
8.30	42.80	44.80	46.00	40.40	4.40	2.30	21.80	39.00	17.50	23.10	29.40	38.50
12.45	42.70	43.80	30.30	37.80	2.30	2.40	24.90	26.00	29.10	24.50	26.70	27.00
16.60	40.00	35.90	22.50	37.30	2.00	2.80	21.00	22.00	18.30	24.90	17.00	17.30
24.90	32.50	37.50	34.40	45.60	1.80	1.50	23.60	18.00	29.90	24.80	17.10	21.00
33.20	34.00	36.00	35.70	39.60	2.40	3.20	16.70	23.00	21.80	25.80	19.20	8.30
Orthogonal Contrasts												
Main Effects												
Rate Linear	*0.0319	ns	ns	ns	ns	ns	0.0888	0.0984	ns	ns	ns	0.0351
Rate Quadratic	ns	ns	0.0038	ns	0.0388	ns	ns	0.0852	ns	ns	ns	ns
Rate Cubic	ns	ns	0.0114	ns	ns	ns	ns	ns	ns	ns	ns	ns

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	0.0660	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	0.0006	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

** 1998 flax dry weights were multiplied by a correction factor of .4 (40%) due to spray error.

Table A.16 Dry weight (g m^{-2}) of flax and wild oats approximately five to six weeks after emergence as influenced by KCl fertilization, KCl placement and the presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil												
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	17.60	23.00	17.60	23.00	6.60	6.60	47.73	34.40	47.73	34.40	6.40	6.40
8.30	21.40	22.10	26.60	29.90	3.00	8.20	42.00	46.90	35.40	35.40	14.70	8.10
12.45	31.30	22.10	22.80	20.40	11.00	2.60	33.10	33.90	38.20	47.00	3.00	5.30
16.60	21.40	20.80	24.20	21.90	6.10	8.50	39.60	34.90	26.90	30.80	15.10	4.40
24.90	28.50	22.00	19.90	27.80	5.70	7.40	35.00	48.50	38.90	32.90	10.60	7.40
33.20	19.50	27.00	25.60	28.00	26.20	6.90	35.70	41.70	38.30	23.30	11.80	3.80
Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	ns	ns	ns	ns	ns	ns	*0.0715	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rate Cubic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Simple Effects			Flax		Wild Oats				Flax		Wild Oats	
Overall Placement (SP vs SB)			ns		ns				0.0818		0.0521	
Overall +/- Wild Oats			ns		-				0.0715		-	
SP and SB + Wild Oats			ns		-				ns		-	
SP and SB - Wild Oats			ns		-				ns		-	

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.17 Potassium (mg g^{-1}) concentration of flax and wild oat tissue approximately five to six weeks after emergence as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam and clay loam soil in 1997.

Actual K Rate ($kg\ ha^{-1}$)	Loam						Clay Loam					
	Flax				Wild Oats		Flax				Wild Oats	
	SP		SB		SP	SB	SP		SB		SP	SB
	+	-	+	-			+	-	+	-		
0.00	29.33	28.67	29.33	28.67	37.00	37.00	23.67	23.67	23.67	23.67	42.00	42.00
8.30	31.75	39.50	30.00	30.75	43.50	41.25	25.00	26.25	26.75	24.50	42.25	44.00
12.45	22.50	28.25	30.75	29.75	37.25	42.00	24.50	26.00	26.00	25.00	40.25	41.25
16.60	29.50	32.25	30.50	29.00	43.25	43.00	24.00	23.75	23.00	24.00	42.00	40.05
24.90	31.00	30.50	31.50	30.50	42.50	44.67	24.50	25.50	26.00	25.25	42.00	43.50
33.20	31.75	33.25	32.50	31.50	42.25	43.25	25.00	25.00	26.50	23.50	30.75	42.00

Simple Effects	Flax	Wild Oats	Flax	Wild Oats
Overall Placement (SP vs SB)	*ns	ns	ns	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.18 Potassium (kg ha^{-1}) uptake of flax and wild oat tissue approximately five to six weeks after emergence as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam and clay loam soil in 1997.

Actual K Rate (kg ha^{-1})	Loam						Clay Loam					
	Flax				Wild Oats		Flax				Wild Oats	
	SP		SB		SP	SB	SP		SB		SP	SB
	+	-	+	-			+	-	+	-		
0.00	1019.07	1358.80	1019.07	1358.80	122.00	122.00	488.67	592.40	488.67	592.40	445.07	445.07
8.30	1345.20	1635.80	1386.60	1264.10	192.90	97.40	494.60	632.60	742.70	746.30	1036.00	361.90
12.45	935.30	1235.40	928.80	1127.20	94.90	101.30	776.50	586.10	556.40	531.40	439.90	352.80
16.60	1183.30	1152.50	673.20	1079.50	86.50	124.00	476.30	527.10	533.60	522.60	387.30	344.30
24.90	1002.00	1119.50	1080.40	1377.30	77.50	85.47	699.60	558.40	515.20	697.80	249.90	522.30
33.20	1084.70	1196.50	1167.00	1244.60	104.60	137.50	486.20	672.10	713.50	634.30	1033.50	639.80

Simple Effects	Loam Flax	Loam Wild Oats	Clay Loam Flax	Clay Loam Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	*0.011	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.19 Dry weight (g m^{-2}) of flax and wild oats at flax full flower to beginning of boll formation as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

	Location 1: Loam Soil											
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	527.30	652.90	527.30	652.90	129.60	129.60	229.00	211.00	229.00	211.00	323.60	323.60
8.30	537.50	606.70	590.50	642.10	147.80	96.10	291.60	395.40	187.00	266.70	257.50	353.50
12.45	532.70	643.00	537.10	644.30	75.00	165.70	231.20	226.53	228.50	279.30	360.93	340.60
16.60	558.10	601.50	554.00	538.60	163.70	95.80	359.00	293.30	290.53	307.33	294.40	256.93
24.90	514.80	624.50	526.20	596.70	91.00	137.90	325.80	392.30	363.30	379.40	348.30	239.30
33.20	560.70	605.50	499.50	582.70	132.30	168.70	183.50	243.90	284.90	316.90	352.20	307.40

Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rate Cubic	ns	ns	ns	ns	ns	ns	ns	*0.0271	ns	ns	ns	ns

Simple Effects	Flax (1997)	Wild Oats (1997)	Flax (1998)	Wild Oats (1998)
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	0.0001	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.20 Dry weight (g m^{-2}) of flax and wild oats at flax full flower to beginning of boll formation as influenced by KCl fertilization, KCl placement and the presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil

Actual K Rate ($kg\ ha^{-1}$)	1997 Flax SP +	1997 Flax SP -	1997 Flax SB +	1997 Flax SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Flax SP +	1998 Flax SP -	1998 Flax SB +	1998 Flax SB -	1998 Wild Oats SP	1998 Wild Oats SB
0.00	387.40	440.10	387.40	440.10	220.40	220.40	230.13	289.07	230.13	289.07	29.33	29.33
8.30	328.90	444.80	426.20	449.70	360.90	266.50	288.00	337.60	242.00	279.00	80.40	66.20
12.45	290.30	390.10	346.40	362.40	588.50	262.40	261.70	280.80	246.20	314.60	54.80	74.00
16.60	318.70	428.90	254.00	493.80	322.10	395.30	315.40	260.00	263.20	282.80	64.60	68.80
24.90	375.50	473.30	415.70	482.50	226.80	172.40	317.20	378.40	303.30	277.40	150.00	73.20
33.20	253.20	464.70	342.50	433.20	459.50	326.10	274.60	323.30	294.00	277.70	109.30	75.60
Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rate Cubic	ns	ns	ns	ns	*0.063	0.0921	ns	0.0019	ns	ns	ns	ns

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	ns	0.0479	0.0847	ns
Overall +/- Wild Oats	0.0001	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	0.0765	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.21 Potassium (mg g^{-1}) concentration of flax and wild oat tissue at flax full flower to beginning of boll formation as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

	Location 1: Loam Soil												
	1997						1998						
Actual	Flax				Wild Oats		Flax				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	17.50	17.00	17.50	17.00	21.50	21.50	21.33	17.00	21.33	17.00	28.33	28.33
8.30	18.75	19.75	19.25	19.00	22.75	24.75	19.25	17.00	20.75	18.00	26.75	27.25
12.45	18.50	18.50	19.50	19.25	25.25	23.75	20.33	19.00	20.25	17.75	31.33	20.00
16.60	18.75	18.50	17.75	17.50	25.75	24.00	16.75	17.00	17.33	17.00	31.50	28.67
24.90	18.25	18.50	19.75	18.75	25.25	24.25	18.00	17.00	20.25	19.00	31.25	25.25
33.20	18.50	18.25	18.00	17.75	23.50	25.25	18.50	17.50	16.25	17.25	27.00	27.50

Simple Effects	Flax	Wild Oats	Flax	Wild Oats
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	ns	-	*0.0915	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed; SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.22 Potassium (mg g^{-1}) concentration of flax and wild oat tissue at flax full flower to beginning of boll formation as influenced by KCl fertilization, KCl placement and the presence of wild oats on clay loam soil over two years.

Location 2: Clay Loam Soil												
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	17.25	17.00	17.25	17.00	10.50	10.50	14.00	13.00	14.00	13.00	28.75	28.75
8.30	15.00	18.25	14.25	13.75	10.25	21.25	13.75	12.50	13.25	13.25	28.50	26.75
12.45	15.50	13.50	14.00	16.50	21.75	16.50	13.00	13.75	13.25	13.50	29.50	26.75
16.60	16.75	12.00	13.75	12.25	17.50	22.75	13.50	13.25	13.25	13.00	27.50	27.50
24.90	13.25	13.50	14.75	13.00	22.25	17.75	13.75	13.00	13.50	13.25	24.50	27.50
33.20	15.50	13.00	18.50	13.00	25.00	12.50	14.00	13.50	13.50	14.25	25.25	28.00

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	*ns	ns	ns	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed; SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.23 Potassium (kg ha^{-1}) uptake of flax and wild oat tissue at flax full flower to beginning of boll formation as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

	Location 1: Loam Soil											
	1997						1998					
Actual	Flax				Wild Oats		Flax				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	9230.70	11161.30	9230.70	11161.30	2688.70	2688.70	5132.80	3801.07	5132.80	3801.07	11013.60	11013.60
8.30	9996.90	11952.30	11394.80	12215.70	3311.00	2387.10	4961.30	6588.10	3545.50	4920.70	6927.60	9845.70
12.45	9957.20	11898.70	10439.30	12368.00	1733.60	3790.40	4427.60	4229.20	4004.50	4869.60	11232.80	5145.20
16.60	10177.40	11120.10	9840.30	9430.40	4250.40	2270.10	5963.30	4940.20	5061.87	5174.93	9406.00	7287.20
24.90	9314.70	11516.70	10386.70	11062.70	2326.10	3453.80	5913.90	6698.00	6061.30	6740.40	11050.70	6248.50
33.20	10282.40	11060.20	9052.60	10463.30	3135.30	4569.60	3137.10	3846.30	4580.60	5534.50	9677.70	7711.90

Simple Effects	Flax (1997)	Wild Oats (1997)	Flax (1998)	Wild Oats (1998)
Overall Placement (SP vs SB)	ns	ns	ns	ns
Overall +/- Wild Oats	*0.0007	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.24 Potassium (kg ha^{-1}) uptake of flax and wild oat tissue at flax full flower to beginning of boll formation as influenced by KCl fertilization, KCl placement and the presence of wild oats clay loam soil over two years.

Location 2: Clay Loam Soil

Actual K Rate (kg ha^{-1})	1997 Flax SP +	1997 Flax SP -	1997 Flax SB +	1997 Flax SB -	1997 Wild Oats SP	1997 Wild Oats SB	1998 Flax SP +	1998 Flax SP -	1998 Flax SB +	1998 Flax SB -	1998 Wild Oats SP	1998 Wild Oats SB
0.00	6761.30	7791.70	6761.30	7791.70	3483.90	3483.90	2960.90	3671.00	2960.90	3671.00	2209.80	2209.80
8.30	4830.20	8998.80	6060.70	6262.20	2692.20	5817.60	3974.20	4212.10	3199.60	3745.30	2240.70	1808.80
12.45	4478.00	5379.40	4880.30	5339.20	13201.00	4392.80	3437.60	3843.60	3308.90	4292.20	1502.40	1936.70
16.60	5401.10	5163.30	3469.40	6089.80	5070.20	8892.60	4248.20	3454.00	3459.70	3710.30	1754.40	1814.90
24.90	4948.30	6383.80	6304.60	6172.30	5085.20	3686.80	4381.00	4919.20	4101.70	3750.70	3285.60	1974.30
33.20	3932.80	6071.50	6094.20	5631.20	11363.30	2697.60	3822.00	4398.70	4035.90	3888.40	2638.80	2186.60

Simple Effects	1997 Flax	1997 Wild Oats	1998 Flax	1998 Wild Oats
Overall Placement (SP vs SB)	ns	0.0789	ns	ns
Overall +/- Wild Oats	*0.0387	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.25 Dry weight (g m^{-2}) of wheat and wild oats approximately five to six weeks after emergence as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam soil over two years.

Location 1: Loam Soil												
	1997						1998					
Actual	Wheat				Wild Oats		Wheat				Wild Oats	
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	81.90	78.60	81.90	78.60	7.40	7.40	89.33	90.00	89.33	90.00	1.73	1.73
8.30	84.70	73.50	80.00	84.50	7.10	5.80	74.40	81.60	85.90	73.60	0.60	0.40
16.60	85.40	83.90	78.50	71.20	8.80	5.40	77.30	76.00	98.30	98.90	2.00	3.20
33.20	73.20	69.20	60.40	81.20	9.10	5.40	91.80	82.20	112.10	85.50	4.20	0.40
66.40	68.10	72.00	78.70	61.00	10.30	5.10	77.20	69.80	93.40	72.10	2.10	0.40
99.60	51.10	41.50	63.40	61.90	5.50	11.40	69.80	71.50	85.00	93.40	1.30	1.20
Orthogonal Contrasts												
Main Effects												
Rate Linear	*0.0149	0.0105	ns	0.0017	ns	0.0776	ns	ns	ns	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	0.0421	ns	ns	ns	ns	ns	ns	ns
Rate Cubic	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.0905	ns	ns

Simple Effects	1997 Wheat	1997 Wild Oats	1998 Wheat	1998 Wild Oats
Overall Placement (SP vs SB)	ns	ns	0.0248	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	0.0343	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.26 Dry weight (g m^{-2}) of wheat and wild oats approximately five to six weeks after emergence as influenced by KCl fertilization, KCl placement and the presence of wild oats on clay loam soil over two years.

	Location 2: Clay Loam Soil												
	1997						1998						
Actual	Wheat				Wild Oats		Wheat				Wild Oats		
K Rate	SP		SB		SP	SB	SP		SB		SP	SB
(kg ha^{-1})	+	-	+	-			+	-	+	-		
0.00	56.90	42.20	56.90	42.20	15.40	15.40	195.87	190.13	195.87	190.13	7.87	7.87
8.30	65.50	84.70	61.00	58.90	3.70	17.10	152.60	138.90	213.30	185.60	9.90	5.70
16.60	62.00	62.50	68.20	64.60	9.70	12.90	182.70	146.00	155.80	204.10	8.40	5.80
33.20	39.80	66.80	68.00	69.40	13.90	17.70	183.70	129.60	198.90	193.70	3.70	8.40
66.40	61.10	63.40	56.50	59.60	10.70	8.00	189.90	146.10	157.10	149.10	6.60	2.80
99.60	58.40	66.80	65.00	53.50	8.20	11.80	115.80	151.00	163.50	167.10	5.80	9.00
Orthogonal Contrasts												
Main Effects												
Rate Linear	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rate Quadratic	ns	ns	ns	ns	0.0522	ns	0.0289	ns	ns	ns	ns	ns
Rate Cubic	*0.0524	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.0463
Simple Effects			Wheat		Wild Oats				Wheat		Wild Oats	
Overall Placement (SP vs SB)			ns		ns				0.0071		ns	
Overall +/- Wild Oats			ns		-				0.0046		-	
SP and SB + Wild Oats			ns		-				ns		-	
SP and SB - Wild Oats			ns		-				ns		-	

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.27 Potassium (mg g^{-1}) concentration of wheat and wild oat tissue approximately five to six weeks after emergence as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam and clay loam soil in 1997.

Actual	Loam						Clay Loam					
K Rate	Wheat				Wild Oats		Wheat				Wild Oats	
(kg ha^{-1})	[a]SP		SB		SP	SB	SP		SB		SP	SB
	+	-	+	-			+	-	+	-		
0.00	46.00	45.00	46.00	45.00	46.33	46.33	35.33	36.67	35.33	36.67	43.67	43.67
8.30	44.00	44.75	42.75	44.50	46.25	45.50	37.50	36.25	35.75	34.50	42.25	40.25
16.60	44.25	44.75	45.00	43.75	47.25	44.75	36.75	36.00	37.00	36.50	42.50	42.75
33.20	43.75	44.25	44.25	42.75	47.50	45.00	35.00	36.25	39.00	37.75	41.50	44.25
66.40	39.25	42.75	43.00	42.75	45.75	43.25	38.00	38.50	37.75	36.50	41.25	42.75
99.60	42.75	40.75	41.00	43.25	48.33	42.75	35.75	36.50	37.00	36.75	40.00	44.75

Simple Effects	Loam Wheat	Loam Wild Oats	Clay Loam Wheat	Clay Loam Wild Oats
Overall Placement (SP vs SB)	*ns	ns	ns	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.

Table A.28 Potassium (kg ha^{-1}) uptake of wheat and wild oat tissue approximately five to six weeks after emergence as influenced by KCl fertilization, KCl placement and the presence of wild oats on loam and clay loam soil in 1997.

Actual K Rate (kg ha^{-1})	Loam						Clay Loam					
	Wheat				Wild Oats		Wheat				Wild Oats	
	SP		SB		SP	SB	SP		SB		SP	SB
	+	-	+	-			+	-	+	-		
0.00	3941.07	3721.07	3941.07	3721.07	357.47	357.47	1947.87	1862.40	1947.87	1862.40	1117.33	1117.33
8.30	3767.70	3326.70	3421.20	3713.90	349.60	264.90	2382.20	3126.30	1919.70	2257.20	443.70	788.40
16.60	3758.60	3760.10	3565.60	3152.50	422.70	252.20	2091.50	2426.50	2524.10	2379.40	515.60	529.80
33.20	3263.50	3069.90	2738.70	3492.80	435.50	241.00	1398.30	2416.30	2634.20	2574.90	571.20	768.70
66.40	2684.40	3135.20	3546.10	2636.30	475.30	215.80	2492.70	2238.00	2145.20	2167.80	448.30	342.80
99.60	2217.60	1725.30	2618.30	2687.70	319.87	505.90	1974.50	2594.60	2253.70	2108.10	423.00	558.10

Simple Effects	Loam Wheat	Loam Wild Oats	Clay Loam Wheat	Clay Loam Wild Oats
Overall Placement (SP vs SB)	*ns	ns	ns	ns
Overall +/- Wild Oats	ns	-	ns	-
SP and SB + Wild Oats	ns	-	ns	-
SP and SB - Wild Oats	ns	-	ns	-

* = p value; ns = non significant; SP = seed-placed and SB = side-banded; +/- = plots with and without wild oats respectively.