YIELD PHYSIOLOGY, QUALITY AND SOIL WATER DYNAMICS OF A SEMIDWARF AND A TALL OAT (*Avena sativa* L.) CULTIVAR

By

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

Oat production has increased dramatically in Western Canada. Until recently all oat cultivars have been tall, yet excess straw and lodging are problems facing oat producers. With the development of the new semidwarf oat cultivar, AC Ronald, there is increased interest in how a semidwarf cultivar performs relative to conventional tall oat cultivars. Experiments were conducted in 1999 and 2000 to examine and compare yield physiology and seed quality of AC Ronald and the conventional height oat cultivar Triple Crown under different N fertilizer rates and rotation (grain legume versus oilseed as previous crop). The higher yield potential of AC Ronald was attributed to a greater sink size (i.e. kernel number and panicle density) and higher harvest index. Both cultivars responded similarly to N fertilizer rate and crop rotation, suggesting that different N rates are not required to optimize yield of semidwarf oat cultivars. Highest quality (hectolitre weight) was achieved with AC Ronald; however, seed quality was more influenced by both cultivar choice and sufficient N supply. A second objective was to examine soil water dynamics (evapotranspiration (ET), soil water extraction patterns, and water use efficiency (WUE)) of both oat cultivars under different N fertilizer rates and rotation, and to compare these parameters to semidwarf and conventional height wheat cultivars. Evapotranspiration and soil water extraction patterns of AC Ronald and Triple Crown were similar, indicating the semidwarf trait had little influence on ET and where water was being extracted from the soil profile. Similar results were observed in wheat. Oat had higher seasonal ET than wheat, which was attributed to greater soil water extraction in the 30-90 cm increment of the soil profile. Oat also extracted water from deeper within the soil profile (90-130 cm zone) than wheat, suggesting a possible role for oat in cropping systems where sub-soil moisture or nitrate-N levels exist. The higher ET, along with greater DM production, of oat resulted in greater WUE and productivity (i.e. yield) compared to wheat due to a higher proportion of ET being used as transpiration.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Appendix Tables

1.0 INTRODUCTION

Oat production has increased dramatically in Manitoba and plays an important role in its agricultural industry. In 2000, total production of oat for grain in Manitoba was 1.02 million tonnes with a total farm value of $95.5 million. Many production issues face oat producers in Manitoba such as excess straw production and lodging. Lodging is often the result of excessive N within the cropping system and cultivar choice and can decrease yield and quality and cause difficulties during harvest. Nitrogen supply in cropping systems can come from either a synthetic source, i.e. N fertilizer, or from an organic supply, i.e. legumes. The influence of fertilizer N on oat grain yield and quality has been well documented, though information for newer cultivars grown in Manitoba is still very limited. There is also limited information on the influence of residual legume N from crop rotation on oat production.

Until recently, all oat cultivars available to Manitoba oat producers were tall cultivars. Breeding efforts have resulted in the development of the semidwarf oat cultivar AC Ronald, which is Western Canada's first registered semidwarf oat cultivar. The semidwarf trait in cereals is associated with increased yield potential through a higher harvest index and increased number of productive tillers and seeds per tiller. There is also the possibility of decreased lodging incidence and severity with shorter-statured cultivars under high N supplying environments. The development of AC Ronald necessitates new research to investigate how the semidwarf cultivar performs relative to conventional oat cultivars, and how optimum N supply from fertilizer or rotational crops compares for semidwarf versus tall cultivars. Therefore, the first objective of this study was to compare the yield physiology and seed grain quality of a semidwarf and tall oat cultivar under different N supply conditions. N supply was added both through N fertilizer application and by inclusion of a grain legume in the crop rotation. This study evaluated how the semidwarf trait influenced yield physiology and grain quality, and determined if semidwarf oat cultivars require different N rates than tall oat cultivars to optimize grain yield and seed quality.

Soil water dynamics is an important factor in determining yield potential in cereal crops. As well, environmental issues such as deep drainage are influenced by soil water dynamics. Soil water use and extraction patterns of cereals are influenced by root activity, soil moisture content, cultivar, agronomic practices (e.g. N supply and crop rotation), and environmental conditions. Oats are often grown in wetter areas of Manitoba due to their apparent greater flooding tolerance compared to other cereal crops. However, detailed analysis of soil water parameters (evapotranspiration, soil water extraction patterns, and water use efficiency) for semidwarf and tall oat cultivars has not been conducted. As well, few studies have compared soil water dynamics between oat and wheat, and whether the semidwarf trait in oat affects soil water use differently compared to wheat. Results could suggest possible roles for oat in Manitoba cropping systems.

2.0 LITERATURE REVIEW

2.1 Introduction

Oat (*Avena sativa* L.) ranks sixth in world cereal production, exceeded by wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), rice (*Oryza sativa* L.), barley (*Hordeum vulgare* L.) and sorghum (*Sorghum bicolor* L.) (Murphy and Hoffman, 1992). Oat has historically been a multi-purpose crop. Based on industry source estimates, oat harvested as grain accounts for approximately 60% of total oat crop value (Murphy and Hoffman, 1992). The value of straw, pasture, and forage make up the remaining 40% (Murphy and Hoffman, 1992). Livestock feed accounts for approximately 75% of total consumption of world oat grain, while food and seed use account for the remainder (Murphy and Hoffman, 1992). World production of oat has been trending downward due to emphasis being placed on crops that produce greater amounts of energy or protein (Murphy and Hoffman, 1992) or to increased specialization in agriculture requiring less crop rotation and more pesticide usage (Hoffman, 1995).

In Manitoba, oat production has increased dramatically in recent years. In 2000, 384,500 ha of oats were seeded, of which 338,000 ha were harvested for grain producing 1,016,300 tonnes of oat grain. Average yield of oat in 2000 in Manitoba was 2915 kg ha^{-1} (Manitoba Agriculture and Food, 2000). The province's primary market for oat exports is the United States, with smaller amounts going to Japan, South Korea and 15 other countries.

Manitoba grown oats have been popular for racehorses since the1980s and more recently for milling and cereal products in the United States. The market for human consumption of oat has increased in past years as a result of increased awareness of health benefits associated with the inclusion of oat in diets (Hoffman, 1995).

2.2 Oat Agronomy

Producing high oat yields in Manitoba with high quality involves interactions among numerous biological factors, management strategies, and climatic conditions. Oat grain yield in production fields is the result of the interaction between yield components, such as number of plants per unit area, number of fertile panicles per plant, number of seeds per panicle, and kernel weight, and dry matter production and harvest index (Anderson and McLean, 1989; Marshall et al., 1992). Management factors, which influence these yield components, will determine optimum oat grain yields.

2.2.1 Seeding date

Optimum growing conditions for oats include fertile, well-drained soils in cool and moist climates. To achieve maximum grain yields in Manitoba, oats must be planted early in the growing season (Hamill, 2002). Early seeding ensures efficient use of available moisture, permits escape of midsummer drought and heat which can influence grain filling, and helps to avoid damage by diseases, especially crown (*Puccinia coronata*) and stem rust (*Puccinia graminis*) (Forsberg and Reeves, 1995). Early planting generally results in higher grain yield because of increased seed production per unit area of land through increased tillering and more seeds per panicle (Marshall et al., 1992; Hamill, 2002). Early planting also results in higher grain quality, i.e. higher hectolitre weights that meet the minimum human consumption industry standard of 245 g 0.5 L^{-1} (Hamill, 2002).

2.2.2 Seeding rate and depth

Seeding rate influences the number of plants per unit area, and the effects of higher seeding rates on plant yield components will vary with cultivar, date of seeding, and environmental conditions such as soil fertility, disease, drought and heat stress, and lodging (Marshall et al., 1987). High seeding rates can result in increased interplant competition for available light, moisture and nutrients, cause a decrease in the number of productive panicles per plant, lower kernel production, lower kernel weight, and result in greater lodging incidence (Hamill, 2002). The recommended seeding rate for oat in Manitoba is 57.2 to 114.5 kg ha^{-1} (Manitoba Agriculture and Food, 2001), and Hamill (2002) observed that a range of 200-400 viable seeds per square meter was optimum in Manitoba.

Seeding depth for oats should be 3 to 7.5 cm, depending upon soil moisture content. Seed placed deeper than 5 cm may result in reduced emergence and consequently reduced yield (Manitoba Agriculture and Food, 2001).

2.2.3 Nitrogen management

Optimum N fertilization is important as either too much or too little N can reduce production and therefore profits. Nitrogen fertilizer management practices are influenced by several considerations, including previous crop, soil moisture, inherent soil N supplying capability, crop yield goal, susceptibility to lodging, time of N application, and

N source. Nitrogen directly influences yield by affecting the various yield components, such as panicle density and kernel number, as well as dry matter accumulation and harvest index. The relative contributions of each component in response to increased N level will vary depending on the levels of N used and environmental conditions. Hamill (2002) determined that total N supply (soil nitrate-N to 60 cm in the spring plus fertilizer) of 115 kg ha^{-1} was optimum for maximum yield of oats in Manitoba, though in her study the semidwarf cultivar OT288 had a higher optimum N rate than the tall cultivar AC Assinibioa.

2.2.4 Harvesting

Direct combining of standing grain is the most economical method of harvesting oat if kernel moisture is uniform and at 14.5% or less. Swathing is also possible if the crop is uneven in maturity, if weeds or late secondary tillers are present, or if conditions do not result in rapid drying of the grain and straw (Forsberg and Reeves, 1995). Lodging of oat can often result in harvesting problems with swathing and or direct combining. If the oat crop is severely lodged, yield may decline due to mechanical losses during harvesting (Forsberg and Reeves, 1995).

2.3 Oat Grain Yield Physiology

Compared to wheat, very little research has been conducted on grain yield physiology of oat. While the principles of yield physiology in wheat and other cereals can be applied to oat, numerous important differences exist that make oat unique. One difference is the form of the inflorescence (Peltonen-Sainio, 1999). The green area of the oat panicle is larger and scattered when compared with that of the spikes of wheat. This improves the ability of the oat panicle to intercept solar radiation. The result is a higher contribution of the panicle to photosynthate production during the grain filling period (Jennings and Shibles, 1968).

Oat grain yield is a function of yield components, which include panicle density, kernel number per panicle, and kernel weight. Kernel density per unit area of land is a product of panicle density and kernel number per panicle, and is considered an important measure of yield potential. Other factors determining potential oat grain yield include dry matter accumulation, harvest index (the proportion of grain yield to total above ground biomass), plant height and lodging. All of these factors are strongly affected by environmental conditions, crop genetics, and management practices.

2.3.1 Yield components

2.3.1.1 Panicle number

Panicle production per plant and per unit area of land is important in establishing the post-anthesis sink capacity (i.e., the number of kernels per unit area of land). Final panicle number is dependent upon initiation, survival, and development of the tillers (Shanahan et al., 1984). Tillers are lateral axillary shoots produced from the main stem or lateral stems. Initiation and development of new tillers begins shortly after seedling emergence, is usually maximized at the onset of stem elongation and usually ceases with the reproductive stage (Peltonen-Sainio, 1999). In rare instances, tillers can still grow and develop during later stages of growth (Peltonen-Sainio, 1999). Tillers are a sink for assimilates and nutrients and also serve as a transpiring surface from which water is lost.

Tillers that initiate but fail to produce an inflorescence may in some conditions be considered parasitic to the plant since they utilize water and essential growth materials without adding to the potential grain production (Power and Alessi, 1978).

Genotypic effects on tillering have been reported, and a general trend is for greater tillering among semidwarf lines. A study by Makela et al. (1996) observed higher tiller production and higher head-bearing tiller production in dwarf oat lines compared with conventional height lines. However, the increased number of tillers was unable to compensate for a yield reduction resulting from low yield potential of the main shoot. In wheat, both McNeal et al. (1972) and Lupton et al. (1974) observed greater maximum number of tillers and more spikes for a group of semidwarf than tall cultivars. However, contrary results were reported by Pearman et al. (1978) in winter wheat where no differences in tillering behaviour between the semidwarf cultivars and the conventional height cultivars were observed.

Nitrogen can also influence tiller production. Brown et al. (1980) observed tiller production increased with increased fertilizer application. Power and Alessi (1978) found N fertilizer reduced wheat tiller mortality, providing more spikes per unit area and subsequently greater grain yield. The increased survival probably resulted from increased ability to compete with other tillers for available nutrients, water, light, and other factors required for growth. Under dryland conditions, N can decrease tiller survival due to water shortages induced by too much tiller production (Entz and Fowler, 1989b).

Tiller production is important for determining panicle number per unit area. However, not all tillers that are produced by the crop survive to produce fertile tillers or panicles. Several studies have reported the importance of panicle number in maximizing yield potential. Hamill (2002) observed that grain yield of oat in Manitoba was correlated with panicle numbers per square meter, and Shanahan et al. (1984) and Entz and Fowler (1989a and 1991) observed that wheat grain yield was also highly correlated with panicle number.

The semidwarf character in oat usually results in increased yield potential due to increased production of panicles per unit area. In Australia, Anderson and McLean (1989) reported panicle numbers were the largest, on average, for the semidwarf cultivar Echidna compared to two conventional oat cultivars. In an earlier study by Brinkman and Rho (1984), the shorter-statured oat cultivar Stout had a higher grain yield compared to two conventional cultivars as a result of higher number of panicle per unit area. Hamill (2002) reported similar results in Manitoba where the semidwarf oat cultivar OT288 had the highest panicle numbers per square meter when compared to two conventional cultivars. The increase in panicle number of OT288 resulted in an increase in yield compared to the conventional cultivars.

Nitrogen fertilizer can also strongly influence panicle production. Anderson and McLean (1989) reported an increase in fertilizer N applied resulted in an increase in mean panicle numbers. Similar results were reported earlier by Ahmadi et al. (1988), Brinkman and Rho (1984), and Frey (1959) where an increase in N fertilizer resulted in an increase in yield due to increases in the number of panicles per unit area. No known studies have examined the effect of N supply from crop rotation (i.e. residual and potentially mineralizable nitrate-N) on oat panicle production.

2.3.1.2 Total kernel production

Kernel number per unit area of land is calculated by dividing grain yield per unit area by kernel size (mg kernel^{-1}). For oat, Hamill (2002) observed optimum kernel number was approximately 12,000 to 13,000 kernels per square meter under Manitoba growing conditions. For wheat, optimum kernel number is approximately 14,000 per square meter (Entz, pers. comm.).

Maximum grain yield of a crop depends on the capacity to produce (source strength) and utilize (sink strength) phytosynthate during the grain filling period (Evans et al., 1975). Fischer et al. (1977) suggested that post-anthesis sink limited grain yields are distinguishable by a positive correlation between grain yield and kernel number per unit area, while a lack of association between these two variables indicates source restricted grain yields.

Determining kernel number is a useful method to determine whether seed yield is limited by pre- or post-anthesis events. If grain yield is more closely correlated with kernel number than kernel weight, then seed yield is limited by post-anthesis sink size (which is set prior to anthesis). If seed yield is closely associated with kernel weight, then seed yield is limited by post-anthesis source, i.e., the ability to fill the kernels which mostly occurs after anthesis. As well, kernel number is simple to measure compared to panicle number or kernel number per panicle.

Variation in kernel number per unit area, whether due to environment, genotype, or N supply, is consistently associated with grain yield due to the fact oat yields tend to be limited by sink size (Hamill, 2002). Wheat yields also are limited by post-anthesis sink size (Shanahan et al., 1984; Entz and Fowler, 1989a). Entz and Fowler (1989a) observed that kernel number per square meter was highly correlated with grain yield. In oat, Hamill (2002) also that found kernel number per square meter was the yield component most highly correlated with grain yield (r=0.84).

A relationship also exists between panicle number and kernel number. Kernel number per square meter is a function of panicles per square meter. Hamill (2002) reported that panicle number was highly positively correlated with kernel number. Similar results were reported in oat by Frey (1959) and in wheat by Shanahan et al. (1984) and Entz and Fowler (1989a).

As with panicle number production, cultivar and N can influence kernel production. Anderson and McLean (1989) reported kernel number per unit area was the greatest for the semidwarf cultivar Echidna compared to the two conventional oat cultivars. Hamill (2002) also reported the semidwarf OT288 had significantly higher kernel production than two conventional oat cultivars at three site years. In these same two studies, both Anderson and McLean (1989) and Hamill (2002) reported that fertilizer N increased mean kernel numbers in oat. It is important to note that no previous studies have examined the influence of N supply from crop rotation on oat kernel production.

2.3.1.3 Kernel weight

Kernel weight (mg kernel^{-1}) is calculated by weighing 1000 kernels and then converting 1000 kernel mass to a per kernel weight. The influence of kernel weight on grain yield is variable. Brinkman and Rho (1984) found that kernel weight, along with spikelets per panicle, were responsible for the oat cultivar Stout's grain yield superiority in comparison to the other cultivars in the study. They also indicated that seed yield was limited by post-anthesis source. On the other hand, Hamill (2002) observed that kernel mass was not significantly correlated with grain yield in one site year and was negatively correlated with yield at two other site years. In wheat, studies have shown that final yield is often more strongly influenced by changes in kernel number than by changes in kernel weight (Fischer et al., 1977; French and Schultz, 1984; Shanahan et al., 1984; Entz and Fowler, 1989a; Entz and Fowler, 1991), suggesting seed yield is limited by post-anthesis sink size. However, kernel weight is still relevant in oat production, as kernel weight is an important indicator of quality.

Genetic variation for kernel weight exists. In oats, studies by Anderson and McLean (1989) and Hamill (2002) reported the semidwarf Echidna and OT288, respectively, generally had lower kernel weight than the conventional height oat cultivars. However, a study by Brinkman and Rho (1984) found that kernel weight for the short-statured cultivar Stout was higher compared to two conventional oat cultivars. The increase in kernel weight was due to Stout having greater DM accumulation after heading compared to the two conventional oat cultivars. In wheat, kernel weight of semidwarf cultivars was found to be lower than for tall wheats (McNeal et al., 1972; Pearman et al., 1978).

Nitrogen supply has variable effects on kernel weight. In an experiment by Hamill (2002), she observed that increasing N significantly decreased oat kernel weight, indicating a greater competition for assimilates among individual kernels during grain filling. Similar results were reported in wheat by Shanahan et al. (1984) and Entz and Fowler (1989a) where kernel number was inversely related to kernel weight. Often, yields are not reduced as high kernel number compensates for the lower kernel weight (Campbell et al., 1977).

Marshall et al. (1987) and Brinkman and Rho (1984) reported an increase in N fertilizer resulted in a decrease in kernel weight for both semidwarf and conventional height oat cultivars; however, yield was increased with an increase in N fertilizer indicating kernel weight did not strongly influence yield in this study. Frey (1959) reported contrary results where, with conventional height oat cultivars, N rate decreased kernel weight, which resulted in a decrease in grain yield. Ohm (1976) and Anderson and McLean (1989) reported that an increase in N rate did not affect kernel weight.

Legumes in rotation can also influence kernel weight. Badaruddin and Meyer (1990) observed that kernel weight was significantly higher in wheat following green manured legume crop versus wheat following wheat. Badaruddin and Meyer (1994) also reported similar results where kernel weight was higher following three different grain legume crops compared to wheat. No studies have been done to examine the effect of legumes in rotation on kernel weight of oat.

2.3.1.4 Yield component summary

Panicle number, kernel number, and kernel weight are components that contribute to yield, though a significant amount of compensatory growth occurs between these yield components. While kernel number and weight contribute simultaneously to grain yield (Fischer et al., 1977; Shanahan et al., 1984), there is strong evidence that kernel number is the most important component affecting yield due to the importance of post-anthesis sink size versus sink strength (Fischer et al., 1977; Pearman et al., 1978; Shanahan et al., 1984; Entz and Fowler, 1989a; Entz and Fowler, 1991).

Fertilizer N has a strong influence on yield components and potential yield. The relative contributions of yield components in response to increased N levels may vary depending upon the levels of N used and environmental conditions (Frey, 1959; Brinkman and Rho, 1984; Marshall et al., 1987; Anderson and McLean, 1989; Hamill, 2002). However, the positive effect of N on kernel number tends to result in higher grain yield even when kernel weight is reduced with N fertilizer additions. Observations suggest that the strong effect of N on crop yield is due to factors prior to anthesis.

2.3.2 Dry matter accumulation, partitioning, and harvest index

Solar radiation intercepted by above ground biomass provides the energy for photosynthesis and therefore the starting point for dry matter production following exhaustion of the reserves contained in the seed (Peltonen-Sainio, 1999). The ability of the green area to capture solar radiation and the partitioning of the dry matter between harvestable organs and non-yield structures partly define the major limitations to crop productivity. A strong association between grain yield and vegetative growth rate exists in oats and selection for high vegetative growth rate has resulted in yield increases in oat lines (Takeda and Frey, 1977). Growth rate, dry matter yield, and harvest index are three traits that have been positively associated with grain yield improvements in oats. Salman and Brinkman (1992) observed that as much as 90% of the variation grain yield among genotypes is attributed to those three traits.

2.3.2.1 Pre-anthesis dry matter accumulation

Dry matter accumulation prior to anthesis is an important indicator for crop productivity in wheat (Fischer, 1979), as shown by the positive relationships between dry matter present at anthesis and kernel number (Fischer et al., 1977; Entz and Fowler, 1989a) and between dry matter at anthesis and grain yield (O'Leary et al., 1985; Entz and Fowler, 1989a). In Australia, Anderson and McLean (1989) found maximum oat grain yields of about 4 t ha^{-1} were attained with about 6.5 t ha^{-1} of dry matter production at heading. This is similar to the anthesis dry matter to grain yield ratio reported for wheat in Australia by Fischer (1979) (6300 kg ha^{-1} dry matter at anthesis for 4400 kg ha^{-1} grain yield). For oat, Hamill (2002) observed dry matter accumulation at anthesis in the range of 6000 to 7000 kg ha^{-1} in Manitoba.

The semidwarf character may have an important role in optimizing the relationship between dry matter at anthesis and grain yield. Stem elongation occurring at the time of intensive floret set, together with competition caused by unproductive tillers, may create unnecessary competition for photoassimilates (Peltonen-Sainio, 1999). The introduction of short cultivars may enable the use of photosynthetic products for the set of florets and spikelets. At late pre-anthesis reduced partitioning to stem elongation in short stature cultivars may result in improved ability to reach a high yield potential (i.e., to maintain a high floret number through reduced abortion).

Lupton et al. (1974) found lower anthesis dry matter production for semidwarfs when compared with tall cultivars, and observed that reduced anthesis dry matter for semidwarf wheat did not result in lower yield. Brinkman and Rho (1984) reported similar results where the short statured oat cultivar Stout had lower dry matter production at heading compared to the two conventional oat cultivars.

2.3.2.2 Dry matter accumulation and translocation at maturity

The ability to retain and efficiently remobilize photosynthate and the differences in translocation of photosynthate to the grain post-anthesis may account for differences in grain yield and harvest index (Gent and Kiyomoto, 1989). Hamill (2002) observed dry matter accumulation of oat at maturity to range from 10,000 to 11,000 kg ha^{-1} in Manitoba.

In a study by McMullan et al. (1988), oat dry matter accumulation per plant and grain yield per plant were strongly correlated ($r=0.80$). However, no correlation was found between plant dry matter and grain yield on a per hectare basis. In wheat however, a positive correlation between final dry matter and grain yield have been established (Entz and Fowler, 1989a). Tillering by density interactions and/or differences in dry matter (DM) translocation (harvest index) can influence the relationship between DM and grain yield (McMullan et al., 1988).

In a study of wheat by Gent and Kiyomoto (1989), translocation was measured by the radioactivity distribution after photosynthetic assimilation of $^{14}CO_2$. Results showed that almost half of the photosynthate fixed before anthesis was lost from wheat plants by maturity and a similar fraction may be lost by respiration and abscission of plant material during senescence. Wheat that efficiently remobilizes photosynthate to the grain during maturation may retain more photosynthate in the plant and show a higher harvest index (Gent and Kiyomoto, 1989).

Cultivar can also have an effect on dry matter accumulation. Gehl et al. (1990) found a semidwarf wheat cultivar produced the highest total dry matter production in seven of nine trials. They found the higher grain yields and grain yield responses to applied N of the semidwarf cultivars were explained by the greater capacity to convert dry matter into grain yield. However, Brinkman and Rho (1984) reported contrary results where dry matter at maturity by a short-statured oat cultivar was less than two conventional oat cultivars.

Cultivar also has an effect of dry matter translocation. In a 2 year study by Gent and Kiyomoto (1989), partitioning to the spike was more rapid in the semidwarf winter wheat cultivars than in the tall cultivars. During grain filling, the semidwarf winter wheat cultivars were more efficient at distributing radioactivity photosynthate (^{14}C) to the grain. Other researchers have found no differences between semidwarf cultivars and tall cultivars in their ability to distribute photosynthate to the grain at maturity when grown under controlled conditions (Rawson and Evans, 1971), or in the field (Makunga et al., 1978).

2.3.2.3 Harvest index

The semidwarf character is associated with increased yield potential through a higher harvest index (Pearman et al., 1978; Entz and Fowler, 1989a). Under conditions of high yield potential (with irrigation or high rainfall), semidwarf wheat cultivars have shown greater grain yield response due to superior lodging resistance and a higher harvest index (Gehl et al., 1990). Also, there was an increase in harvest index of semidwarf compared to tall cultivars which was related to the tendency of the semidwarf to remobilize a greater proportion of the photosynthate fixed during grain filling to maturity (Gent and Kiyomoto, 1989).

Meyers et al. (1985) reported harvest index of oat had not been altered to an appreciable extent in the dwarfs studied, even though dwarfs were about 30% shorter in stature. However, in a study by Anderson and McLean (1989), they reported the semidwarf oat Echidna had higher harvest index than two conventional oat cultivars. Brinkman and Rho (1984) reported similar results where the shorter-statured cultivar Stout had a greater harvest index than two conventional oat cultivars.

Harvest index is often affected by nitrogen fertilizer application. In oat, Brinkman and Rho (1984) observed decreases in harvest index with increases in N fertilizer application. The decrease in harvest index of the oat cultivars was due to increased dry matter accumulation under higher rates of N fertilizer. Anderson and McLean (1989) observed that harvest index of a semidwarf and conventional oat cultivars was significantly reduced by additions of nitrogen fertilizer at only two of the nine sites. Makela et al. (1996) observed no significant effect of N on harvest index of a semidwarf and conventional oat cultivars.

2.3.3 Nitrogen accumulation

Total plant N is a function of N concentration and total plant dry matter. Plant N content is an indicator of the plant's ability to accumulate N (McMullan et al., 1988).

Grain N content is the result of N translocation and current assimilation prior to anthesis (McMullan et al., 1988). Plants with greater N accumulation in the vegetative tissue prior to anthesis should translocate a larger amount of N to the developing grain.

In the period from anthesis to maturity, vegetative tissue N concentration decreases while grain N content increases. As maturation proceeds, the plant continues to assimilate N, and the amino acids produced may be incorporated directly into grain protein. Also, roots become functionally less active as maturation proceeds and remobilization from senescing lower leaves and stems may become increasingly important to meet the demand of reduced N uptake. Remobilization of N from vegetative plant parts (not including roots) of six oat cultivars between anthesis and maturity accounted for 27 to 47% of the N found in mature panicles (Peterson et al., 1975). In a study by McMullan et al. (1998), they found a positive correlation between oat grain N (protein) content per plant and plant N content (r=0.94) at maturity.

Nitrogen harvest index represents the proportion of total plant N present in the grain at maturity. A larger N harvest index value indicates a higher translocation of vegetative tissue N to the grain (McMullan et al., 1988). In order to maximize grain N content, N supply to the plant should be high during the pre-anthesis period.

Many factors influence the plant's ability to accumulate N. Nitrogen uptake increases with application of fertilizer due to greater N supply, crop yield, and to a lesser extent grain protein (Fowler et al., 1990). N uptake per unit N fertilizer applied is greatest with low levels of applied N and decreases as the amount of N applied increases (Campbell et al., 1977). Also, improved moisture conditions increase N uptake through increased N mobility in the soil and root activity, leading to increased yield potential. For example, under moist conditions, wheat may continue to take up soil N until near maturity. Under dry conditions however, very little N is taken up after anthesis. Field trials conducted with stubbled-in winter wheat have shown that under average

Saskatchewan conditions, 70% of the total dry matter and 89% of the total plant N is accumulated by anthesis (Darroch and Fowler, 1989).

Understanding the effect of crop rotation on crop N uptake is difficult because N is available from a variety of N pools in soils. Crop rotation influences N pools differently, and also influences timing of N availability during the growing season. The N pools available for plant uptake include fertilizer, crop residue, inorganic N, mineralizable N (microbial biomass, soil organic matter, fauna, etc.), fixed N (symbiotic, non-symbiotic), and depositional N (atmospheric, irrigation, run on, etc.). However, N can also be lost or utilized by the plant. Nitrogen outputs include plant uptake, nitrogen lost by erosion, nitrogen lost by leaching and gaseous nitrogen losses. Nitrogen can also be immobilized or chemically fixed (Meisinger, 1984). Badaruddin and Meyer (1994) considered the effects of numerous grain legumes on N uptake and found N uptake for wheat following legumes is greater than that for continuous wheat.

The influence of the semidwarf trait on oat N uptake is not well understood as no known studies have been conducted. In wheat, Fisher (1981) reported a greater N-response for semidwarf wheat than tall types. In contrast, Pearman et al. (1978) found no significant differences in N uptake with plant height while Power and Alessi (1978) reported a higher N requirement for tall genotypes.

2.3.4 Semidwarf trait

In Western Canada, commercial cultivars of spring oats range in height from 80 to 120 cm. Tall plant heights are more susceptible to lodging than shorter-statured plants and this decreases yield and quality (Brown et al., 1980; Hamill, 2002). The development of semidwarf cultivars may be one way of achieving yield advances in oats when grown under management practices that would induce lodging of existing cultivars (Brown et al. 1980).

Brown and coworkers (1980) selected a new vigorous semidwarf oat from a population of line OT184 that was irradiated with fast neutrons. The result was a new semidwarf oat named OT207. Dwarfing of the line OT207 is controlled by a single dominant gene designated *Dw6*, and the gene results in shorter internodes. Meyers et al. (1985) compared four oat selections derived from OT207 to four conventional height cultivars and found them similar in grain yield. The OT207-derived lines produced only 80-90% as much straw, and harvest indexes for the highest yielding dwarfs were similar to the conventional height genotypes, even though the dwarfs were about 30% shorter in stature. However, one limitation of the dwarf oat was that panicles only partially emerged from the flag leaf sheaths.

In Western Australia, new shorter oat cultivars have replaced the formerly widely grown tall cultivars. Echnidna carries the *Dw6* dwarfing gene and was registered in South Australia in 1984 (Anderson and McLean, 1989). In Australia, dwarf oats generally have out-yielded taller types, such as Swan and West.

OT288 is a semidwarf oat developed by the Cereal Research Centre in Winnipeg, Manitoba. This experimental line carries the *Dw6* dwarfing gene. Hamill (2002) compared OT288 to conventional height cultivars grown in Manitoba (AC Assiniboia and AC Medallion) and found that OT288 was the highest yielding cultivar due to the higher kernel and panicle numbers and higher harvest index in four site years. OT288 also had lower levels of lodging than AC Assiniboia and AC Medallion in three of the four site years. However, the increase in yield was achieved at the detriment of milling quality traits. OT288 produced fewer plump kernels and a larger number of smaller sized kernels, having greater hull percentage.

Recently, scientists at Agriculture and Agri-Food Canada's Cereal Research Centre developed a new tall semidwarf oat cultivar called AC Ronald (test name OT296). The pedigree includes Dumont 68, Robert, and OT207. AC Ronald is approximately 8 to 10 cm shorter in height than AC Medallion and CDC Pacer and is rated as having excellent lodging resistance (J. Mitchell-Fetch, A.A.F.C., pers. comm.). Yields of AC Ronald averaged 4070 kg ha^{-1} in 2001 Manitoba cultivar trials (Manitoba Agriculture and Food, 2002), and it has good resistance to most of the prevalent diseases found in the Western Canadian prairies (J. Mitchell-Fetch, pers. comm.). With the introduction of AC Ronald, agronomic information is required to determine if the semidwarf requires different N rates compared to conventional height oat cultivars to optimize grain yield and oat grain quality.

2.3.5 Lodging

Lodging "is the state of permanent displacement of the stems from their upright positions" (Pinthus, 1973). Factors such as cultivar and N supply can result in lodging (Pinthus, 1973; Hamill, 2002). Certain cultivars have weaker culms which make the cultivar more susceptible to lodging (Pinthus, 1973). N supply is also important as excessive N can result in increased vegetative growth, making the crop more susceptible to lodging. Wind, rain, or hail can also induce lodging. However, all factors result in plants being laid flat on the ground and sometimes involving breakage of the stems.

Lodging and the degree to which the culms lean from vertical is often not distributed uniformly throughout the field but scattered over certain sections or areas.

In addition to reducing grain yield, lodging may reduce yield by making mechanical harvesting difficult. However, the most obvious effect of lodging on the plant's physiological processes is its interference with carbohydrate assimilation and translocation. The interference results in the foliage and other photosynthesizing parts being shaded by plants which are leaning or lying on top of them and hindering of carbohydrate translocation during grain filling (Pinthus, 1973).

The effect of lodging on grain yield is dependent upon its severity and on the time of occurrence. Early lodging may have little influence on grain yield because of the plant's ability to recover. Lodging close to maturity cannot affect grain yield directly but may cause losses due to interference with harvest. Lodging at heading and early grain-filling stages has the greatest negative influence on grain yield because both the numbers of kernels per panicle and the individual kernel weight are affected. The inability to fill kernels results in a decrease in the number of kernels per panicle. Lodging that occurs later primarily affects kernel weight. Lodging may also adversely affect grain quality as it may cause shrivelling of the grain and hence reduce its hectolitre weight (Pinthus, 1973).

The promotion of lodging due to abundant N supply is documented in many oat studies (Marshall et al., 1987; Brinkman and Rho, 1984; Hamill, 2002). High N levels can cause lodging in semidwarf as well as tall cultivars of wheat and barley. In wheat, lodging and reduction in grain yield of semidwarf cultivars commenced at higher N levels and seemed to proceed more moderately compared to tall cultivars (Pinthus, 1973).

An improvement in grain yield superiority of new cereal cultivars over older cultivars is partly due to improved lodging resistance (Meyers et al., 1985). Better lodging resistance enables the new cultivars to benefit from high levels of N fertility and thus approach their yield potential. The breeding of short-strawed cultivars has contributed considerably to lodging resistance but has not eliminated the problem of lodging (Meyers et al., 1985; Makela et al., 1996; Hamill, 2002).

2.4 Legumes in Crop Rotation

Throughout the recorded history of agriculture, the use of legumes in cropping systems has been a standard practice by which fixed nitrogen was added to the soil-plant ecosystem (Power, 1990). The most recognized benefit of a legume crop to a succeeding cereal is improvement in yield due to increases in plant available N (Badaruddin and Meyer, 1989; Badaruddin and Meyer, 1990; Wright, 1990, Stevenson and vanKessel, 1996b). However, benefits of legumes can be separated into N and non-N components. The N benefit has been equated to the fertilizer replacement value to the succeeding crop. In the fertilizer replacement value method, the yield of non-legume crop following a legume is compared to the yield of the same non-legume crop with various rates of N fertilizer in cropping systems containing non-legume species. This comparison provides a quantitative estimate of the amount of N that the legume supplies to the non-legume crop (Bullock, 1992). For example, Wright (1990) found a barley-barley rotation required 100 kg ha^{-1} of N fertilizer in order to produce a yield comparable to unfertilized barley following peas. Rotational benefits of legumes not directly associated with N are termed non-N benefits, and include plant disease suppression and effects on soil microflora (Stevenson and VanKessel, 1996a).

The replacement of fertilizer N by symbiotically-fixed N has clear benefits to agricultural systems of developing nations that are seeking to avert resource scarcity and the increasing cost of industrially synthesized fertilizer N (Heichel, 1987). Nitrogen fixed by legumes can be seen as a "free" resource since it occurs as a consequence of energy capture of continuously renewable sunlight in the photoassimilates of green plants. Substituting fixed legume N has lessened dependence upon synthetic N fertilizers. However, maximum benefits from fixed legume N can only occur when the legume is grown and managed with attention to returning fixed legume N to the soil rather than permanently exporting it from the cropping system (Heichel, 1987). The amount of N fixed by a legume and made available to a subsequent nonlegume crop depends upon plant, environmental, and management factors. In legume-nonlegume crop sequences, the amount of fertilizer N that can be replaced by legume N depends upon: (i) the quantity of legume residues returning to the soil, (ii) the content of symbiotically fixed N in the residues, and (iii) the availability of the legume residue N to the succeeding nonlegume crop (Heichel, 1987).

2.4.1 Availability of legume N to subsequent crops

Availability of N from legumes in crop rotation largely relies upon the process of mineralization. Mineralization is the conversion of N from an organic form to an inorganic form by microbial activity (Power, 1990). Mineralization and the subsequent availability of N to the following crop varies widely, depending on a number of factors, including legume characteristics, environmental conditions, and legume management practices (Power, 1990).

Characteristics of the legume that determine the amount of N available to the succeeding crop include legume plant type and its C:N ratio. Perennials, such as alfalfa, are more effective in fixing dinitrogen, with much smaller amounts usually fixed by annual grain legumes (Heichel, 1987). The higher N content (low C:N ratio) of a pea (*Pisium sativum* L.) residue compared with that of wheat residue promotes the mineralization process, thus explaining the greater N availability from pea residue. For example, a succeeding wheat crop derived 2 kg N ha^{-1} from wheat residue versus 11 kg N ha^{-1} from pea residue (Stevenson and VanKessel, 1996b). Wright (1990) reported similar observations.

Environmental factors play a large role in the quantity of nitrogen available for crop uptake. These factors affect the microbial population within the soil profile and will dictate the amount of N converted from organic to inorganic form. Temperature, water supply, soil pH, and soil NO_3-N levels all strongly influence the rate of mineralization that occurs, which can directly affect when N uptake is occurring by the crop (Tisdale, 1993).

The quantity of N added to the soil by legumes is also highly dependent on the manner in which the legume is managed (Heichel, 1987). If the legume crop is harvested for grain, soil N export in the harvested grain may exceed N return to the soil by legume residue. The same would occur with a hay or pasture legume since a portion of the symbiotically-fixed N_2 is removed from the land when the legume is harvested, with the balance remaining in unharvested roots and crowns (Heichel, 1987).

A management option that is receiving renewed attention by agriculturists is the use of annual legumes as green manure crops (Tisdale et al., 1993). In the past, the increased availability and relatively low cost of N fertilizer decreased use of green-manure legumes in cropping systems. However, using legumes as green manures could help control weeds, reduce soil erosion, improve soil fertility, and increase subsequent crop yields (Badaruddin and Meyer, 1990). Green manure is defined as vegetation that is normally incorporated into the soil before it is mature. As a result, green manures do not have the same chemical composition (i.e., lower lignin) as mature plants (Tisdale et al., 1993). The low lignin content (i.e., low C:N ratio) of green manure plants will increase the rate of N mineralization (Tisdale et al., 1993).

Management factors that influence N mineralization from green manure legumes include method of incorporation and drying of the green manure (Tisdale et al., 1993). In terms of decomposition and mineralization rate, incorporation of green manures increases mineralization because the residue is in contact with soil moisture and is in close proximity to the soil's microorganisms. Another option is to not allow the green manure to dry prior to incorporation. Drying green manure decreases the rate of mineralization because drying reduces the easily decomposable organic forms of N (Tisdale et al., 1993).

2.5 Oat Quality

There has been an increase in interest in oat production as medical research has determined that oat fiber has unique physiological properties that can contribute to a reduction in serum cholesterol and also help promote more normal glucose level in persons affected by certain forms of diabetes (Burnette et al., 1992). A change in eating habits has also occurred where consumers are more health conscious and want foods that are quick and easy to prepare. Instant oatmeal, granola bars, cold cereals, and snack foods made with oat are among the products created to meet the demands of today's consumer (Burnette et al., 1992). Therefore, producing high quality oats for human consumption is becoming increasingly important to millers and food processors.

2.5.1 Physical quality traits

Grades and standards have been established for oat that describe the physical characteristic of the commodity and allow oat users to make purchases of the grain without visual inspection. High quality grain is essential for the most economical processing into rolled oats, oatmeal, and other oat products for use as human food. Desired characteristics of an oat sample include minimum foreign material content (1% maximum), moisture (less than 13%), sound count (kernels or pieces of oat that are damaged by weather, disease, insect, mold), minimum hectolitre weight of 245 g per 0.5L, and minimum 11.25% protein (Burnette et al., 1992).

In the milling process, there are many physical traits that millers want in an oat sample to ensure the maximum yield of groats and to maintain or improve the efficiency of the oat milling process. A minimum hectolitre weight of 245 g per 0.5 litre has been universally used as a standard indicator of grain quality due to the ease and speed of measurement in the marketplace. Oat grain with high hectolitre weight receives higher market grades and premium prices in the marketplace.

In oats, hectolitre weight, plump and thin kernel percentage, and groat percentage are important milling physical quality parameters (Humphreys et al., 1994). Physical oat quality parameters are influenced by genetic, agronomic, and environmental conditions, as well they are strongly affected by yield components, such as kernel number and kernel weight.

2.5.1.1 Hectolitre weight

Factors which affect kernel size and shape, such as moisture supply, N supply, and cultivar, influence hectolitre weight. Since hectolitre weight is a volumetric measure, hectolitre weight is more strongly influenced by the shape of the kernel than by the quality of the oat grain (Atkins, 1943). Long kernels (>12 mm) and kernels with 'tippy' hulls (lemmas and paleas with ragged tips) or awns have more air space between them and pack less well than shorter, trim kernels (Humphreys et al., 1994). Well-filled plump kernels generally have acceptable hectolitre weight; while thin kernels resulting from severe disease infection or other stress may have unacceptably low hectolitre weight.

The value of hectolitre weight as a quality measure is not uniformly agreed upon since several researchers have reported that hectolitre weight is not a good indicator of oat grain quality (Zavitz, 1927; Atkins, 1943; Humphreys et al., 1994; Zhou et al., 1998; Hamill, 2002). Long, thin-hulled seeds tended to have a low hectolitre weight but high quality, while short, plump, thick-hulled seeds had high hectolitre weight but are low in terms of other quality traits (e.g. groat percentage).

Nitrogen fertilizer can result in inconsistent effects on hectolitre weight of oats. Ohm (1976) observed a negative response of N on oat hectolitre weight, which was probably caused by incomplete grain filling or dilution effect associated with a higher number of tillers at the higher levels of N fertilizer. In a study by Humphreys et al. (1994), they found N application had no effect on hectolitre weight of four conventional oat cultivars at four site years. These results indicate that other factors such as cultivar and environment had a greater influence on oat grain quality traits than N supply.

Cultivar selection is crucial in achieving milling quality oats. Zhou et al. (1998) found cultivar effects of most quality traits were much larger than those attributed to management practices. Humphreys et al. (1994) examined the milling quality characteristics of four conventional oat cultivars. Results indicated cultivar had a significant effect on hectolitre weight at all four site years. Hamill (2002) found that the semidwarf oat cultivar OT288 had significantly higher hectolitre weights than conventional oat cultivars AC Assiniboia and AC Medallion. The higher hectolitre weight of OT288 was attributed to a large number of smaller kernels with greater hull content, which weighed more than the groat. Both studies concluded that choosing the correct cultivar is crucial for the production of high quality oat grain.

Physiological processes play direct and indirect roles in determining grain quality. Photosynthetic rate, photosynthetic capacity, growth rate, N assimilation, leaf area and duration, mineral uptake, transport, and deposition are examples of processes that influence grain filling and hence the quality of the harvested grain (Forsberg and Reeves, 1992). Severe environmental conditions such as high temperatures, drought, or excessive lodging during grain filling can cause harvested kernels to have low hectolitre weights (Forsberg and Reeves, 1992).

2.5.1.2 Groat percentage

The groat/hull ratio is another reliable and widely used indicator of oat grain quality (Forsberg and Reeves, 1992). Groat is the oat kernel minus the hull. Groat percentage is universally agreed upon as one of the most important quality characters of oat. An oat cultivar with high groat percentage and thin hulls is more desirable than low groat percentage and thick hulls (Atkins, 1943). Oat groat content ranges from 64 to 80% of the grain (Welch et al., 1983). Well-filled kernels with thin, non-overlapping hull components have a higher proportion of groat. The proportion of groat in whole oat grain will vary depending on environment and genetic factors.

Differences in groat quality related to groat position may be due in part to the development pattern of the groats, because spikelets attached at the top of the panicle have florets that bloom and mature earlier than those attached below do. As groats develop in different parts of the panicle, it is probable that nutrition available for the younger groats located near the panicle base may be limited, thereby producing lighter groats (Youngs and Shands, 1974).

Nitrogen fertilizer can influence groat percentage. Humphreys et al. (1994) found in only one of the four site years that an increase in N rate resulted in an increase in groat percentage. These results indicate that other factors such as cultivar and environment had a greater influence on oat grain quality traits than N supply.

Several studies have observed the importance of cultivar selection in obtaining high groat percentage. Humphreys et al. (1994) observed cultivar had a significant effect on groat percentage at all four site years. Hamill (2002) observed significant cultivar effects for groat percentage, where OT288 had significantly lower groat percentage than the conventional oat cultivars. They concluded that choosing the correct cultivar is crucial for the production of high quality oat grain.

Environmental conditions such as high temperatures, drought, or excessive lodging during grain filling can influence groat percentage. Forsberg and Reeves (1992) have reported adverse growing conditions can cause harvested kernels to be thin, have high hull proportions, i.e., low groat percentage (Forsberg and Reeves, 1992).

2.5.1.3 Plump kernel percentage

Kernel size or plump and thin kernel percentage is another physical oat grain quality parameter. Kernel size is primarily determined during the grain filling period, although kernel number may secondarily affect kernel size (Shanahan et al., 1984). In wheat, kernel size is typically negatively associated with kernel number per spike and kernel number (Fischer et al., 1977). In addition, variation in kernel sizes across locations is negatively correlated with spike number. These relationships reflect competition between developing kernels for limited assimilates availability and are indicative of limited source strength during the post-anthesis or grain filling period (Fischer et al., 1977; Shanahan et al., 1984). Therefore, high quality (i.e. increase in plump kernel percentage) is usually obtained at a lower yield potential due to a decrease in post-anthesis source strength.

Nitrogen fertilizer application can affect plump kernel percentage. Humphreys et al. (1994) found in only one of the four site years that an increase in N rate resulted in an increase in plump kernels. These results indicated that other factors such as cultivar and environment had a greater influence on oat grain quality traits than N supply.

Legumes in rotation with oat can also influence physical quality parameters. Badaruddin and Meyer (1994) found the level of available soil N and N accumulation affected grain protein percentage and plumpness of grain. They discovered wheat and barley grain protein percentage following legumes was greater than that of continuous wheat or barley. These results support the observations of Wright and Coxworth (1987) in which legume residue affected barley quality by increasing kernel weight and percent plump kernels by 5% and protein percentage by 0.6 percentage point.

Cultivar selection is important for achieving high plump kernel percentage. Humphreys et al. (1994) observed cultivar had a significant effect on plump kernels at all four site years. Hamill (2002) observed significant cultivar effect on percent plump kernels, where OT288 had significantly lower plump kernel percentage than the conventional height cultivars. Both studies concluded that choosing the correct cultivar is crucial for the production of high quality oat grain.

2.6 Soil Water Dynamics

No previous studies have been conducted to intensively examine oat soil water use or extraction patterns during the growing season. Sorrells and Simmons (1992) hypothesized that patterns are not likely to differ for oat in principle from patterns observed for other determinate crops, such as wheat or barley.

2.6.1 Evapotranspiration

Water use or evapotranspiration (ET) is defined as the sum of water use by the crop plus precipitation during the growing season. Evapotranspiration of wheat has been well documented. Ash et al. (1992) estimated crop demand for short seasoned crops such as wheat to be 275 to 325 mm in southern Manitoba. In Saskatchewan, growing season ET for Norstar winter wheat ranged from 286 to 297 mm, depending upon N treatment (Entz and Fowler, 1989a). In one of the few studies comparing wheat, barley and oat ET, Hobbs and Krogman (1974) observed oat and wheat to have similar ET (481 mm and 492 mm, respectively) under irrigation in Alberta, and oat did have significantly greater ET than barley in the same study (481 mm versus 428 mm).

Timing of crop soil water use is also an important soil water dynamic measure. Both high and low yielding wheat crops used more than 70% of their total water by anthesis, with 40% or more being used in the interval from the end of tillering to anthesis in a Mediterranean-type environment (French and Schultz, 1984). Regardless of crop species however, ET will depend upon root activity, soil moisture content, cultivar, N supply, and crop rotation.

Root development is an important adaptation for coping with conditions of insufficient or excessive soil moisture and will affect soil water use. Barbour and Murphy (1984) conducted an experiment to investigate a short and long oat root system under water stressed conditions. Contrary to the hypothesis that long root systems should be advantageous under limited precipitation conditions, there were no differences in agronomic performance between the long and short root systems when grown in water-stressed environment (Barbour and Murphy, 1984). However, the effect of water stressed conditions on soil water use was not directly examined in their study.

Cannell et al. (1985) investigated effects of waterlogging on root systems of winter oats and determined that under those conditions, continued root development depended on the availability of oxygen in the soil profile. Root extension ceased when flux density of oxygen was zero (Cannell et al., 1985). The effect of high soil water conditions on soil water use was not measured directly. Under Manitoba conditions, oat tends to withstand excess soil water better than other cereals (Entz, pers. comm.). However, no previous studies in oat have been conducted in Manitoba to determine how high soil moisture conditions affect ET.

Nitrogen can increase crop water use by either increasing transpiring surfaces and/or causing deeper root development resulting in more water extraction from deeper depths. Nitrogen can come either from synthetic N fertilizer or by including legumes in crop rotation. Fertilizer N has been shown to enhance top growth and increase total soil water use in wheat due to increased transpiration and consequently increased soil water use (Campbell et al., 1977). Singh and Kumar (1981) reported N fertilization increased water use by wheat and barley 9 and 8%, respectively. Forster (1999) observed alfalfa in rotation resulted in higher ET by the subsequent wheat crop. No studies have examined the effect of N supply from fertilizer or crop rotation on oat ET.

The semidwarf character can also influence soil water use. Richards (1992) and Entz et al. (1992) observed no differences in water use between tall and dwarf spring wheat. However, Ehdaie and Waines (1996) observed tall standard height Maringa wheat lines used an average of 7% more water than short statured Maringa wheat lines. No studies have been conducted to intensively examine the effect of the semidwarf trait on oat soil water use.

2.6.2 Net soil water extraction

Net soil water extraction is calculated by subtracting soil water content at maturity from the soil water content in the spring and describes the percentage of ET derived from water present in the soil at spring seeding. In wheat, Entz et al. (1992) observed net soil water extraction in the soil profile (0-130 cm) averaged 27 mm for Norstar, 20 mm for Norwin, 43 mm for Katepwa, and 48 mm for HY320 wheat. Entz et al. (1992) observed net soil water extraction across all winter and spring wheat cultivars amounted to approximately 20% (range 5-35%) of the total ET. Similar observations were made in a previous study for winter wheat, cv. Norstar, by Entz and Fowler (1989a).

The semidwarf trait can influence net water extraction. Angadi and Entz (2002) observed greater water depletion by standard height sunflower hybrids compared to dwarf hybrids and dwarf open pollinated cultivars. The greater water depletion was a result of the standard height cultivars having deeper rooting depths and more efficient water extraction. No studies have been conducted to examine the effect of the semidwarf trait on net water extraction in oat.

2.6.3 Soil water extraction patterns

Water extraction patterns of wheat have been well documented. In wheat, Entz et al. (1992) observed that wheat extracted most of the water from the upper 70 cm of soil. Soil water extraction patterns for barley are also documented. Singh and Kumar (1981) observed 89 to 92% of the water was extracted from the upper 90cm of soil profile. As well, Singh and Kumar found barley extracted more water (35.3%) from deeper layers in the soil profile (31-60 cm increment) than wheat (33.3%). However, no studies have examined soil water extraction patterns in oat.

A plant's rooting pattern within the soil profile will affect the amount and timing of water utilization. Roots may have a direct effect by changing the total supply of water available to the crop, or an indirect effect by changing the rate at which that supply becomes available (Ludlow and Muchow, 1990). In a study by Singh and Kumar (1981), they found barley extracted more water from deeper in the soil profile than wheat. They concluded the difference in water depletion at this depth was due to the more extensive root system of barley. As well, a well-distributed root system, or an especially deep root system, if capable of delaying or avoiding the water stress at a critical stage, could increase crop productivity.

The effect of N fertilizer on root distribution within the soil profile has been found to be variable. N fertilization can alter plant morphology by increasing shoot elongation and decreasing root growth. No studies have examined the influence of N fertilizer on soil water use or extraction patterns of oat. In wheat, Comfort et al. (1988) found that there were no differences in water use for the wheat cultivars, but differences in depths from which soil water was extracted were observed in response to N fertilization. Comfort et al. (1988) found 67 kg N ha^{-1} stimulated root growth and therefore increased water use within the top 30 cm of the soil profile, while a 135 kg N ha^{-1} rate caused either no change or a decline in root length. Russell (1973) observed contrary results where increased N resulted in a deeper root system. Campbell et al. (1977) found that the rate of N fertilization had no effect on the root distribution of spring wheat (cv. Manitou). However, Campbell et al. (1977) concluded that if the soil were low in N, fertilizer would result in better-developed root systems that will have the potential to grow to greater soil depths. However, the effects of N on soil water extraction patterns in the studies by Russell (1973) and Campbell et al. (1977) were not directly measured.

Root growth and development effects on soil water extraction is also strongly influenced by water supply. When water supply is high in the upper soil profile, rooting depth remains shallow. Campbell et al. (1977) reported that the proportion of the wheat root system present in the top 15 cm of soil was not influenced by N but was affected by moisture and plant development stage. They found a greater percentage of the root system was present in the top 15 cm of the soil under wet (54.5%) than under dry conditions (50%). However, Entz et al. (1992) found drier conditions promoted root elongation and increased the degree of branching in wheat cultivars.

In one of the few studies of in oat of the effect of cultivar on root systems, MacKey (1988) observed that root length of a shorter-statured oat cultivar was up to 30% shorter when compared to an conventional height cultivar. Furthermore, the bulk of the root mass (53%) in the conventional cultivar occurred below 60 cm, whereas in the short-statured cultivar, only 6% of the root mass penetrated to such a depth and 42% was formed in the top 20 cm of the soil. Soil water extraction patterns by the oat cultivars and the influence of the semidwarf character was not determined in this study. In wheat, Cholick et al. (1977) and Entz et al. (1992) found no significant relationships between cultivar height and water extraction patterns.

Crop rotation may also influence soil water extraction patterns. Forster (1999) observed alfalfa in rotation resulted in more soil deeper rooting and therefore greater water extraction by the subsequent wheat crop. “Biological tillage” by alfalfa was credited with increasing total net water extraction in the 0 to 150 cm soil depth. Alfalfa in rotation generally resulted in increased soil water extraction deeper in the soil profile, particularly in growing seasons with a soil water deficit.

2.6.4 Water use efficiency

Water use efficiency (WUE), defined as yield per unit of ET, is an important factor for determining crop productivity (French and Schultz, 1984; Entz and Fowler, 1991). In a study by French and Schultz (1984) in a Mediterranean-type environment, they observed WUE for grain production ranged from 12.7 kg ha^{-1} mm^{-1} ET for a high yielding crop to 4.8 kg ha^{-1} mm^{-1} ET for a low yielding crop. In Saskatchewan, WUE of grain yield averaged 12 and 7 kg ha^{-1} mm^{-1} ET for Norstar and Katepwa wheat cultivars, respectively (Entz and Fowler, 1991). In the same study by Entz and Fowler (1991), WUE of DM production averaged 28 and 22 kg ha^{-1} mm^{-1} ET for Norstar and Katepwa, respectively.

In order for any management or genetic factor to increase WUE, it must increase the transpiration/ET ratio. In a study by Entz and Fowler (1989a), N additions significantly increased WUE for grain yield and dry matter at anthesis and maturity. Singh and Kumar (1981) also observed increases in WUE of wheat and barley after applications of N fertilizer. The increase in WUE of wheat and barley was due to considerable increase in grain yield with marginal increase in water use as well as a reduction in evapotranspiration losses, i.e. more rapid crop ground cover.

Higher WUE can also result from increased residual N supply from including legumes into cropping rotations. Forster (1999) observed including alfalfa in rotation generally increased WUE for wheat grain yield and biomass production.

Genetic variation for plant WUE exists both among and within species. Modern short wheat cultivars, on average, have higher WUE than old tall cultivars in well-watered (1.22 vs. 0.98 g kg^{-1}) and droughted pot conditions (1.20 vs. 0.86 g kg^{-1}), due mainly to higher harvest index (Ehdaie, 1995). In a study by Entz and Fowler (1989a), the average grain WUE was greater for the semidwarf wheat cultivar 'Norwin' versus the tall cultivar 'Norstar', indicating the semidwarf cultivar was more responsive to added water. Contrary results were reported by Richards (1992) where WUE declined with plant height in both glasshouse and field experiments, and by Ehdaie and Waines (1996) where dwarfing genes decreased WUE by 15% in the Maringa lines.

No studies have been conducted to investigate the WUE of oat grain yield or dry matter production for oat cultivars as influenced by the semidwarf character, N rate, or legumes in crop rotation.

2.6.5 Approaches for measuring soil water dynamics

2.6.5.1 Soil water content

Water in the soil profile can be measured either directly or indirectly. Direct measurement of soil water content can be made on samples of known weight or volume dried at 105°C in an oven. Samples are usually obtained with an auger or sampling tube. The direct measurement method requires many samples obtained at various depths, resulting in considerable disturbance of the soil and increased labour costs (Kramer and Boyer, 1995).

Indirect methods involve determining soil water content by some kind of calibration procedure. Examples include neutron scattering, gamma ray attenuation, electrical capacitance, electrical conductance, and heat conductance (Kramer and Boyer, 1995).

The neutron probe is used extensively to make repeated measurements of water content at several depths with minimum disturbance. It is based on the fact that hydrogen atoms have a high capacity to slow down and scatter fast neutrons and water is the chief source of hydrogen atoms in most soils. A neutron probe consists of a source of fast neutrons and a detector for slow neutrons connected to an amplifier and counter. The probe is lowered in an access tube inserted in the soil and measurements are made at various depths. The probe readings are converted to volumetric water content via a regression equation derived through a field calibration. The results can be affected by other sources of hydrogen atoms, such as a high organic matter content, or by the presence of a high concentration of Cl, Fe, or B (Kramer and Boyer, 1995). Results can also be affected if runoff or deep drainage occurs. In many agronomic trials, these are considered to be negligible.

2.6.5.2 Root activity

Soil water extraction is defined as the change in soil water content between sampling dates. Total soil water use, or ET, is the net water extracted plus the precipitation in a given time frame.

Two techniques for measuring rooting activity in crops is the soil water extraction method (indirect) and the profile wall technique (direct measurement) (Bohm, 1979). With the soil water extraction method, effective rooting depth is defined as the lowest increment in which a significant decrease in soil water between sampling dates is detected (Forster, 1999). Differences between cultivars are detected more easily with the soil water extraction method than with the profile wall technique (Entz et al., 1992; Angadi and Entz, 2002). This may be due to greater replication, easier use, and the fact that the technique is less labour intensive.

Therefore, for estimates of root activity (i.e., soil-water extraction) and maximum rooting depth, soil water extraction patterns measured with a neutron probe would be the method of choice. The profile wall method is advantageous if an actual measure of root distribution in the soil is required (Entz et al., 1992).

3.0 MATERIALS AND METHODS

3.1 Background

Field experiments were conducted at the University of Manitoba Research Station at Carman, MB in 1999 and at Carman and at the Department of Plant Science Field Research Station at Winnipeg, MB in 2000. The soil type at the Carman site was an Almasippi, fine sandy loam soil in 1999, and an Almasippi loam soil in 2000. The Winnipeg experiment was conducted on a Riverdale, silty clay soil.

The experimental design for each experiment was a split-split plot with previous crop as the main plot, cultivar as the subplot, and N fertilizer rate as the sub-subplot. Four replicates were used at all sites. The previous crop included pea (*Pisium sativa* L. cv. Grande), and flax (*Linum usitatissimum* L. cv. NorLin). Prior to pea and flax seeding, nitrogen fertilizer (34-0-0) was broadcasted and incorporated. Nitrogen rates were based on soil test results. Pea was seeded at a rate of 106 kg ha^{-1} and flax was seeded at a rate of 45 kg ha^{-1}. Cell-Tech C inoculant was applied to the pea seed prior to seeding at a rate of 75 mL per 27 kg of seed. In-crop weed control in the pea and flax treatments was done using Basagran (480 g L^{-1} bentazon) at a rate of 2.25 L acre^{-1}. The flax crop was taken to seed yield where in 1998, the yield averaged 1406 kg ha^{-1}, and in 1999, yield averaged 1768 kg ha^{-1} in Carman and 1611 kg ha^{-1} in Winnipeg. The pea crop was soil incorporated at flowering by discing 2 to 3 times. In 1998, pea dry matter yield taken immediately prior to incorporation was 6095 kg ha^{-1}. In 1999, samples were misplaced and dry matter yield could not be determined.

Two wheat and two oat cultivars were established in all experiments. Wheat cultivars included AC Barrie, a tall cultivar, and AC Taber, a semidwarf cultivar. Oat cultivars included Triple Crown, a tall oat cultivar, and AC Ronald, a tall semidwarf cultivar. Triple Crown was chosen due to its high lodging resistance. The wheat cultivars were included in the study to compare soil water use, ET, and rooting depth with the oat cultivars. Fertilizer N treatments consisted of three N rates (0, 40, and 80 kg N ha^{-1}) in 1999 due to plot space limitations, and four N rates (0, 40, 80, and 120 kg N ha^{-1}) in 2000. Fertilizer was applied as ammonium nitrate (34-0-0) topdressed immediately after crop emergence (Table 3.1).

Table 3.1. Summary of seeding dates, fertilizer application rates, lodging score dates, and grain harvest dates for trials located at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

Year	Site	Seeding Date	N Fertilizer Applied	Lodging Assessed	Harvest Date
1999	Carman	17-May-99	31-May-99	20-Aug-99	15-Sep-99
2000	Carman	04-May-00	24-May-00	20-Jul-00 15-Aug-00	24-Aug-00
2000	Winnipeg	01-May-00	25-May-00	21-Jul-00 18-Aug-00	24-Aug-00

Four soil samples were taken from each replicate in the spring two to three weeks prior to oat and wheat seeding at depths of 0-15 cm, 15-60 cm, and 60-120 cm. Samples were sent to Norwest Labs (Winnipeg, MB) to determine nitrate-N supply, and phosphorus, potassium, and sulphur levels. Soil test results are presented in Tables 3.2 and 3.3.

Table 3.2. Soil nitrate-N levels for trials located at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

Year	Site	Previous Crop	Soil Depth (cm) 0-15	15-60	60-120	0-120
			NO_3-N kg ha^{-1}			
1999	Carman	Pea	36.5	97.7	58.4	192.6
		Flax	14.0	38.7	74.1	126.8
2000	Carman	Pea	53.9	82.5	37.2	173.6
		Flax	16.8	45.5	20.2	82.5
2000	Winnipeg	Pea	51.6	79.1	35.9	166.7
		Flax	24.1	28.6	30.5	83.3

Table 3.3. Summary of phosphorus, potassium, and sulphur nutrients concentrations for trials located at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

			Nutrient Concentration (ppm)		
Year	**Site**	**Previous Crop**	**Phosphate 0-15 cm**	**Potassium 0-15 cm**	**Sulphur 0-60 cm**
1999	Carman	Pea	18	205	9
		Flax	19	216	8
2000	Carman	Pea	29	260	10
		Flax	29	265	10
2000	Winnipeg	Pea	>60	448	14
		Flax	>60	443	12

Prior to seeding, sites were cultivated and harrowed to ensure an even seedbed. Trials were seeded with a Fabro no-till offset disc press drill (Swift Machinery Co., Swift Current, SK) with a cone seed distributor at a seeding depth of 3.7 to 5 cm. Seeding dates are presented in Table 3.1. A seeding rate of 300 viable seeds m^{-2} (approximately 96 kg ha^{-1}) was used for both oat and wheat. Each sub plot contained 12 rows with 15 cm spacing between rows, and a plot length of 8 m at the Carman sites and 6 m at the Winnipeg site. Phosphate fertilizer was banded with the seed at a rate of 13 kg P ha^{-1}. In-crop weed control was performed using a tank mix of Stampede EDF (80% propanil) at a rate of 24.3 kg ha^{-1}, with Refine Extra (50% thifensulfuron and 25% tribenuron methyl) at a rate of 0.4 g ha^{-1}. In Carman 1999, Folicur (43% tebuconazole) was applied at a rate of 292 mL ha^{-1} to control leaf diseases and fusarium head blight in both the oat and wheat treatments.

Measurements conducted on AC Ronald and Triple Crown included grain yield, yield components, dry matter accumulation, N accumulation, milling parameters, and water use efficiency of grain and biomass yield. AC Barrie and AC Taber were assessed for grain yield and dry matter accumulation, as well. Both oat and wheat cultivars were measured for effective rooting depth and soil water use.

3.2 Yield and Yield Component Determination

Oat yield and yield components were measured or calculated for each treatment. Plant population density was determined by counting the number of plants in two-one meter sections of row at the 2-3 leaf stage. These sections were flagged and used later in the growing season for tiller and panicle counts. The data was converted to a m^2 basis.

The sub-sub plot area harvested for grain yield ranged from 1.9 to 5.2 m^{-2}, depending upon location and year. A Hege combine was used to harvest the middle eight rows in each plot at the Winnipeg 2000 and Carman 1999 sites, and a Wintersteiger was used to harvest the middle ten rows in each plot at the Carman 2000 site on dates summarized in Table 3.1. Kernel weight (KWT) (mg $kernel^{-1}$) was calculated by measuring the number of kernels in a 10 g sample. Bosom (double kernels) and dehulled kernels were removed prior to determining thousand kernel weight. Kernel number (kernels m^{-2}, (KNO)) was calculated by dividing grain yield m^{-2} by KWT. The number of seeds per panicle was calculated by dividing KNO by panicle number. Harvest index was calculated by dividing grain yield (m^{-2}) by dry matter accumulation (m^{-2}) at harvest.

Plant height, from soil surface to the tip of the panicle, was measured one week to one day prior to grain harvest. Lodging scores were also taken prior to harvest on dates summarized on Table 3.1 using a scale of 1 to 9. A rating of 1 indicated no lodging and a rating of 9 indicated 100% of the plot was lodged. Values between 1 and 9 were visually determined on the basis of degree and percentage of the plot area affected (Marshall et al., 1987).

Wheat grain yield was also determined for each treatment.

3.3 Dry Matter Accumulation and N Accumulation Measurements

Total aerial dry matter accumulation of the oat and wheat cultivars was determined at stem elongation, anthesis, and maturity by harvesting two-one meter sections of row within each sub-sub plot. Samples were dried at 65°C for at least 72 hours before dry weights were determined and converted to a m^2 basis. The dry matter samples were then ground using a Wiley Mill with a two mm mesh screen. Nitrogen concentration of ground plant material was measured using a dry combustion method with a Leco nitrogen analyzer (model FP-428; Leco Corp., Mississauga, ON). Total N accumulation (kg N ha^{-1}) was calculated by multiplying % N by total above ground dry matter (kg ha^{-1}).

3.4 Soil Water Content Determination

One aluminum neutron access tube was placed in the center of each oat and wheat sub-sub-plot receiving 0 and 80 kg N ha^{-1} immediately after seeding. Soil water to 1.30 m in 20 cm increments was measured at the seedling, stem elongation, anthesis, and harvest stages using a field calibrated neutron probe (Model 3330; Troxler Laboratories; Triangle Park, NC). Surface soil water content (0-10 cm) was determined using the neutron probe in combination with a surface shield, which is comprised of a thick plastic sheet covered by a lead sheet. Regression equations, developed separately for 10-130 cm and surface 10 cm soil zones (Bullied, 1997) were used to convert neutron probe readings into volumetric soil moisture content. Dates for soil water measurements are summarized in Table 3.4.

Table 3.4. Sampling dates for soil volumetric water content measurements for trials located at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

		Date			
Year	Site	Seedling	Stem Elong.	Anthesis	Maturity
1999	Carman	31-May-99	30-Jun-99	19-20-Jul-99	30-31-Aug-99
2000	Carman	24-May-00	22-Jun-00	20-Jul-00	14-Aug-00
2000	Winnipeg	23-May-00	26-Jun-00	21-Jul-00	14-Aug-00

3.4.1 Soil water extraction patterns

Soil water content measurements were used to determine pre-anthesis, post-anthesis, and growing season soil extraction and evapotranspiration (ET). Soil water extraction for both wheat and oat cultivars to the 130 cm depth was calculated by subtracting soil water content at anthesis and maturity from initial soil water content (which was at the first sampling date). ET was calculated as the sum of water use from the whole profile (0-130 cm) between sampling dates plus the precipitation received during that interval. Daily precipitation during the growing season at each site was obtained from the Department of Plant Science's Point and Carman Research Station weather stations (Appendix Tables A.3.0 to A.3.3). When calculating soil water use or extraction, deep percolation, upward soil moisture flux, run-on, and runoff were assumed to be negligible.

3.4.2 Estimation of rooting depth

Soil water depletion patterns of both oat cultivars, along with both wheat cultivars, were used as indirect measures of effective crop rooting depth. Effective rooting depth is defined as the deepest 20 cm increment showing a significant ($p<0.05$) difference between the soil water content in the spring sampling date and the midseason or harvest sampling date. This technique is termed the 'water use method' for estimating effective rooting depth (Entz et al., 1992). The deepest effective rooting depth represents the maximum depth for each cultivar (Forster, 1999; Angadi and Entz, 2002).

3.4.3 Water use efficiency of grain and biomass yield

Water use efficiency for above ground dry matter production and grain yield was determined for AC Ronald, Triple Crown, AC Taber, and AC Barrie. Grain WUE was calculated by dividing grain yield (kg ha^{-1}) by growing season ET (mm). WUE for dry matter was calculated by dividing dry matter yield (kg ha^{-1}) by ET (mm).

3.5 Oat Quality Parameters

Oat quality attributes were tested in all trials from a randomly drawn sample of 500 g of grain from each sub-subplot. Hectolitre weight was calculated using a Cox funnel, which measures the weight in grams of grain fitting into a 0.5 L volume. Percent plump and thin kernels were determined by placing 20 g of grain onto two sets of screens (bosom and dehulled kernels were removed prior to determination). The top screen had openings of 2.4 by 19 mm, and the bottom screen had openings of 0.8 by 19 mm. With the slots of the screens facing towards the sampler, the seed was placed on the screen. The screens were rocked from side to side ten times so that the seeds moved across the direction of the slots. Percent plump kernels were determined as the percentage by weight of the 20 g of grain that did not pass through the 2.4 mm by 19 mm screen. The percent thin kernels was the percentage by weight of the 20 g of grain that passed through the 0.8 by 19 mm screen.

The theoretical milling yield (groat percentage) was measured by passing a 70 g sample through a Codema Laboratory hulling machine (LH 5095 Codema Inc., Vancouver, BC.), measuring the weight of hulls and groats separately, then calculating the percentage by weight of groats.

3.6 Statistical Analysis

Grain yield, yield components, plant height, lodging scores, dry matter accumulation, N uptake, quality parameters, and water use efficiency for grain and biomass yield were analyzed using analysis of variance (ANOVA) (SAS Institute Inc., 1990). The parameters were analyzed in a split-split plot design with previous crop as the main plot effect, oat cultivars alone as the subplot effect, and N fertilizer rate as the sub-subplot effect. The ANOVA model used is presented in Appendix Table A.2.0.

Soil water use and effective rooting depth were also analyzed in a split-split plot design, with previous crop as main plot effect, cultivar (Triple Crown, AC Ronald, AC Barrie, and AC Taber) as the subplot effect, and N fertilizer rate (0 and 80 kg ha^{-1}) as the sub-subplot effect. The ANOVA model used is presented in Appendix Table A.2.0.

Where significant differences were observed, Fisher's protected Least Significant Difference test (LSD) was used to separate means (Gomez and Gomez, 1984).

4.0 RESULTS AND DISCUSSION

4.1 Environmental and Soil Conditions at Experimental Sites

The average and long-term monthly precipitation and temperature at the University of Manitoba Carman Research Station in Carman, MB. and the Department of Plant Science Field Research Station in Winnipeg, MB. during the growing season are presented in Table 4.10. Daily precipitation amounts from May to August are presented in Appendix Tables A.3.0 to A.3.3.

At the Carman 1999 site, there was a high amount of rainfall during May compared to long term averages (Table 4.10). During the months of June and July, an average amount of precipitation occurred. However, in August, a low amount of precipitation was received compared to the long term precipitation average. At the Carman 2000 site, only 68% of average precipitation was received during the month of July. However, in August, precipitation was greater than the long term average.

At the Winnipeg 2000 site, excessive precipitation occurred during the entire growing season (Table 4.10). During the months of June, July, and August, precipitation was approximately 263, 142, and 181% more than the long term average data. In general, growing conditions were considered stressful to plant growth at the Winnipeg site.

The pea and flax stubble had varying levels of residual N supply at the Carman and Winnipeg sites (Table 3.2). Nitrate-N levels following flax ranged from 83 kg ha^{-1} to 127 kg ha^{-1}, and from 167 kg ha^{-1} to 193 kg ha^{-1} following pea. Therefore, the average boost in soil nitrate N with the pea green manure over the flax treatment was approximately 80 kg ha^{-1}. In the present study, nitrate-N levels following pea and flax

Table 4.10. Monthly actual and long-term average precipitation and average temperature at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

		Carman				Winnipeg			
		Precipitation (mm)[y]	Temperature (°C)[x]			Precipitation (mm)	Temperature (°C)		
			Max	Min	Mean		Max	Min	Mean
May	Actual	143.8	17.0	6.8	11.8				
1999	Normal[z]	52.7			11.6				
June	Actual	74.0	21.4	10.0	16.0				
1999	Normal	72.8			17.1				
July	Actual	83.2	24.7	13.0	18.8				
1999	Normal	69.1			19.8				
August	Actual	38.8	23.1	10.4	16.8				
1999	Normal	65.5			18.4				
May	Actual	54.8	18.7	4.3	11.5	69.2	19.5	5.9	12.9
2000	Normal	52.7			11.6	56.8			11.9
June	Actual	93.6	20.0	9.2	14.6	249.8	21.0	10.6	15.8
2000	Normal	72.8			17.1	94.9			16.6
July	Actual	46.8	25.3	12.6	18.9	100.5	27.2	15.0	21.0
2000	Normal	69.1			19.8	70.6			19.4
August	Actual	86.0	25.5	11.8	18.7	109.7	26.6	14.2	19.9
2000	Normal	65.5			18.4	60.5			18.1

[z] Source Environment Canada long term average 1960-1990.

[y] Precipitation measured in millimetres

[x] Temperature measured in degrees Celsius

treatments were higher in comparison to previous studies. For example, Stevenson and van Kessel (1996b) reported soil N by a pea grain was 54 kg ha^{-1} greater than wheat across three sites, while Badaruddin and Meyer (1990) reported soil N after various green manured annual legumes was 53 kg ha^{-1} greater than following wheat across four site years. With the application of inorganic N fertilizer at rates up to 120 kg ha^{-1}, total available N was over 200 kg ha^{-1} for some treatments in the present study, which exceeded the 115 kg N ha^{-1} recommendation for oats in Manitoba (Hamill, 2002).

There were also differences in soil nitrate-N availability between sites. At both Carman sites (with the Carman 1999 site having the highest residual soil nitrate-N levels), there were higher amounts of nitrate-N available, probably as a result of alfalfa several years earlier in the rotation. At the Winnipeg site, excessive amounts of precipitation occurred at this site, which may have led to denitrification decreasing the amount of available nitrate-N to the plant in comparison to the Carman sites (Tisdale et al., 1993). Furthermore, total N accumulation by the oat cultivars was the greatest at the Carman 1999 and lowest at the Winnipeg 2000 site, confirming that soil N supply was higher at the Carman 1999 site and lower at Winnipeg.

4.2 Yield Physiology and N Accumulation of a Semidwarf and a Tall Oat Cultivar

4.2.1 Grain yield

In cereals, the semidwarf character is often associated with increased yield potential. Yield of AC Ronald, a semidwarf oat cultivar, and Triple Crown, a conventional height oat cultivar, was measured to determine if there is a yield advantage due to the semidwarf character under Manitoba growing conditions, and whether both cultivars require similar N rates to maximize yield.

Cultivar had a significant effect on yield at the Carman 1999 ($p<0.01$) and 2000 ($p=0.086$) site years, with the semidwarf AC Ronald yielding more than Triple Crown (Tables 4.20, 4.21). There was no significant difference between cultivars at the Winnipeg site (Table 4.22). Previous research indicates the semidwarf oat trait has an inconsistent effect on grain yield. For example, Hamill (2002) found OT288, a semidwarf oat cultivar, yielded significantly greater than the conventional height oat cultivars AC Assiniboia and AC Medallion, while Brown et al. (1980) and Meyers et al. (1985) reported similar yields for semidwarf and conventional height oat genotypes.

Nitrogen rate significantly increased grain yield at the Winnipeg 2000 site year (Table 4.22); however, no significant effect of N on grain yield was observed at the other two sites (Tables 4.20, 4.21). At the Winnipeg 2000 site, grain yield was still increasing up to an estimated N supply of 245 kg N ha^{-1} (120 kg ha^{-1} applied N fertilizer and approximately 125 kg ha^{-1} nitrate-N available in the soil profile), which was much greater than the recommended rate of 115 kg ha^{-1} (Hamill, 2002). One explanation for this observation is that because soil conditions were extremely wet at Winnipeg, denitrification may have occurred decreasing the amount nitrate-N available to the plant (Tisdale et al., 1993). As a result, a more sustained, but less efficient N fertilizer response was observed at this site.

The increased N rates applied in this study did not result in an increase in yield at two of the three sites (Carman 1999 and 2000), which is contrary to many studies (Brinkman and Rho, 1984; Marshall et al., 1987; Anderson and McLean, 1989; Hamill,

Table 4.20. Oat grain yield, panicle number, kernel number, kernel number per panicle, kernel weight, and harvest index response to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999).

Main Effect	**Yield** kg ha^{-1}	**Panicle No.** m^{2}	**Kernel No.** m^{2}	**Kernel No.** panicle^{-1}	**Kernel Weight** mg	**Harvest Index** %
Previous Crop						
Pea	4946	236	15025	64.3	33.0	40.0
Flax	4898	235	14912	64.5	32.9	43.7
LSD (0.05)	263	28	278	6.2	2.0	6.1
Cultivar						
AC Ronald	5309*a*^{z}	268*a*	16484*a*	62.4	32.3*b*	45.2*a*
Triple Crown	4534*b*	204*b*	13453*b*	66.5	33.7*a*	37.5*b*
LSD (0.05)	354	23	847	8.7	1.4	3.4
N Rate (kg ha^{-1})						
0	5008	232	15220	65.9*a*	33.0	43.3
40	4879	228	14870	66.2*a*	32.9	41.3
80	4878	247	14815	61.1*b*	33.0	39.5
LSD (0.05)	318	15	902	3.5	0.8	3.9
Source of Variation	ANOVA (P>F)					
Previous Crop (PC)	0.5700	0.8377	0.1244	0.6490	0.9858	0.2689
Cultivar (Cvr)	0.0022	0.0007	0.0002	0.3290	0.0447	0.0024
PC x Cvr	0.8895	0.6884	0.7763	0.6363	0.6186	0.9301
N Rate	0.6150	0.0859	0.5320	0.0267	0.9250	0.1589
PC x N Rate	0.5659	0.1170	0.2352	0.0153	0.5637	0.7647
Cvr x N Rate	0.7466	0.0585	0.4882	0.0027	0.5944	0.9648
PC x Cvr x N Rate	0.7533	0.9417	0.4734	0.3997	0.1135	0.0605

[z] Means followed by the same letters are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Table 4.21. Oat grain yield, panicle number, kernel number, kernel number per panicle, kernel weight, and harvest index response to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (2000).

Main Effect	**Yield** $kg\ ha^{-1}$	**Panicle No.** m^2	**Kernel No.** m^2	**Kernel No.** $panicle^{-1}$	**Kernel Weight** mg	**Harvest Index** %
Previous Crop						
Pea	4540*b*[z]	389*a*	14959	39.1*b*	30.4*b*	37.2*b*
Flax	5039*a*	346*b*	14959	44.2*a*	34.2*a*	44.9*a*
LSD (0.05)	212	35	307	3.3	2.4	5.3
Cultivar						
AC Ronald	5022	414*a*	16515*a*	40.4	30.5*b*	43.7*a*
Triple Crown	4541	319*b*	13351*b*	42.9	34.0*a*	38.1*b*
LSD (0.05)	475	33	1088	4.7	1.4	2.8
N Rate ($kg\ ha^{-1}$)						
0	4737	323*c*	14260*b*	45.3*a*	33.6*a*	43.6
40	4731	387*ab*	14814*ab*	38.5*b*	32.4*b*	39.3
80	4762	356*b*	15039*ab*	42.7*ab*	31.6*ab*	41.5
120	4905	403a	15776a	39.9*b*	31.2*c*	39.3
LSD (0.05)	321	31	1040	4.3	0.8	3.7
Source of Variation	ANOVA (P>F)					
Previous Crop (PC)	0.0043	0.0284	0.8634	0.0145	0.0146	0.0196
Cultivar (Cvr)	0.0862	0.0005	0.0006	0.1932	0.0006	0.0046
PC x Cvr	0.5672	0.7785	0.9423	0.7057	0.0526	0.3475
N Rate	0.7428	<.0001	0.0365	0.0152	<.0001	0.0754
PC x N Rate	0.0074	0.3125	0.0012	0.4132	0.0297	0.8552
Cvr x N Rate	0.4513	0.9574	0.2806	0.3040	0.7574	0.6475
PC x Cvr x N Rate	0.8872	0.0106	0.4830	0.1878	0.4096	0.7561

[z] Means followed by the same letters are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Table 4.22. Oat grain yield, panicle number, kernel number, kernel number per panicle, kernel weight, and harvest index response to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Winnipeg, MB (2000).

Main Effect	Yield kg ha^{-1}	Panicle No. m^2	Kernel No. m^2	Kernel No. panicle^{-1}	Kernel Weight mg	Harvest Index %
Previous Crop						
Pea	4510	279	13521	49.0	33.5*b*	37.6
Flax	4180	271	12201	45.4	34.3*a*	39.7
LSD (0.05)	377	9	1398	4.4	0.7	5.5
Cultivar						
AC Ronald	4408	297*a*	13563*a*	46.0	32.6*b*	41.3*a*
Triple Crown	4281	254*b*	12159*b*	48.4	35.2*a*	36.0*b*
LSD (0.05)	298	18	1165	3.7	1.0	4.0
N Rate (kg ha^{-1})						
0	3795*c*^{z}	236*b*	11138*c*	47.4	34.1	39.3
40	4284*b*	279*a*	12716*b*	45.9	33.9	38.6
80	4600*ab*	285a	13606*ab*	48.1	33.9	39.0
120	4700*a*	301*a*	13984a	47.4	33.7	37.8
LSD (0.05)	413	25	1194	4.7	0.7	4.8
Source of Variation	ANOVA (P>F)					
Previous Crop (PC)	0.0688	0.0664	0.0575	0.8000	0.0317	0.3305
Cultivar (Cvr)	0.3386	0.0012	0.0256	0.1781	0.0010	0.0176
PC x Cvr	0.5983	0.7296	0.3568	0.7649	0.1934	0.2917
N Rate	0.0003	<.0001	0.0001	0.8149	0.7179	0.9220
PC x N Rate	0.2671	0.0962	0.4296	0.9670	0.3435	0.8141
Cvr x N Rate	0.6998	0.9609	0.7920	0.6965	0.0183	0.5664
PC x Cvr x N Rate	0.7145	0.0126	0.8107	0.0117	0.1604	0.8258

^{z}Means followed by the same letters are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

2002). The lack of significant N responses in the present study was attributed to the high levels of indigenous soil N at the study sites (Table 3.2) due to the history of alfalfa in rotation at Carman. It is noteworthy that oat yield was not depressed with N application, even though total N (soil N plus fertilizer N) was over 200 kg ha^{-1} in some cases. Given that the maximum N supply for oat production in Manitoba has been estimated to be 115 kg ha^{-1} (Hamill, 2002), the additional mineralization of soil N during the growing season would have rendered additional fertilizer N unimportant for yield at these sites.

There were no consistent effects of previous crop on oat yield at the three site years. At the Carman 2000 site, yields were significantly greater on flax stubble than on pea stubble. A possible explanation could be that excessive N supply in the pea system led to a decrease in oat grain yield compared to the flax system. Frey (1959) observed similar results where increased N rates led to a decrease in yield due to a decrease in kernel weight.

At the Winnipeg 2000 site, oat grain yield was greater (p=0.06) on pea stubble versus flax. Wright (1990) and Badaruddin and Meyer (1990) also observed higher cereal grain yields due to the inclusion of legumes in rotation. The increase in yield in the pea system may be due to the high soil water levels leading to denitrification of nitrate-N at the Winnipeg 2000 site. Losses of nitrate-N in the soil at this site compared with the Carman sites may have increased the relative value of N supplied from the pea stubble, resulting in an increase in yield in this system compared to the flax system.

One of the main objectives of this study was to determine whether the semidwarf cultivar would respond differently than a tall cultivar to increases in N supply (either by N fertilizer or green manure supply). Cultivar interactions with N rate or previous crop on oat grain yield were found to be non-significant in this study. The lack of interaction indicates both AC Ronald and Triple Crown responded similarly to N fertilizer additions under both high (Carman) and moderate (Winnipeg) N fertility environments. A study by Brinkman and Rho (1984) also found no significant cultivar by N interaction, supporting the present study results.

4.2.2 Yield components

Panicle number, kernel number, kernel number per panicle, and kernel weight are components that simultaneously contribute to yield. Yield components were measured in the present study in an attempt to better understand how yield was "constructed" for the semidwarf and tall cultivar, and to determine the nature of cultivar response to N fertilizer and previous crop.

4.2.2.1 Panicle number

Cultivar had a significant effect on panicle number at all three site years. AC Ronald had significantly ($p<0.05$) higher panicle numbers per square meter than Triple Crown (Tables 4.20, 4.21, 4.22). Similar results were reported by Brinkman and Rho (1984), Anderson and McLean (1989), and Hamill (2002) where panicle density was higher for the semidwarf cultivars Stout, Echidna, and OT 288, respectively. On the other hand, Meyers et al. (1985) observed similar panicle densities between tall and semidwarf oat cultivars.

Nitrogen rate had a significant effect on panicle density at two of the three site years. At the Carman and Winnipeg 2000 sites, there was a significant ($p<0.05$) increase in panicle number per square meter with increasing N rates; an increase at $p<0.10$ was observed at the Carman 1999 site. Results from the present study are consistent with results obtained by Frey (1959), Ohm (1976), Brinkman and Rho (1984), and Hamill (2002) where increases in N rate increased panicle number per unit area.

There was a previous crop effect at the Carman 2000 site only, where panicle density was higher following pea than flax. This observation suggests that the greater N supply in the pea system (Table 3.2) resulted in greater productivity potential in the following oat crop.

No interactions between cultivar and previous crop or between cultivar and N rate for panicle density were observed at any of the three sites, indicating AC Ronald and Triple Crown responded similarly to both low and high N supplying environments in terms of inflorence number. However, a significant interaction between previous crop by cultivar by N rate existed at two of the three sites (Figures 4.20, 4.21).

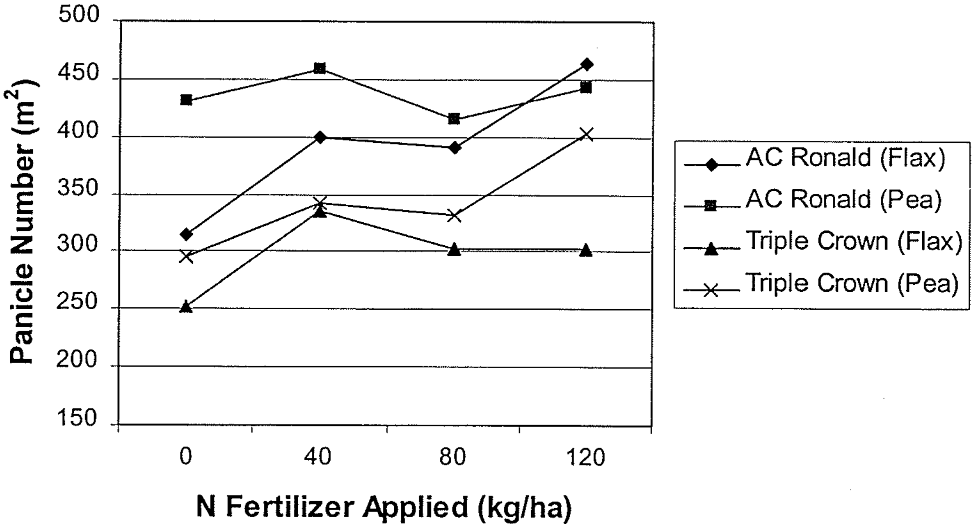

Figure 4.20. Illustration of the cultivar by previous crop by nitrogen fertilizer rate interaction (p=0.0106) on oat panicle number per square meter at Carman, MB (2000).

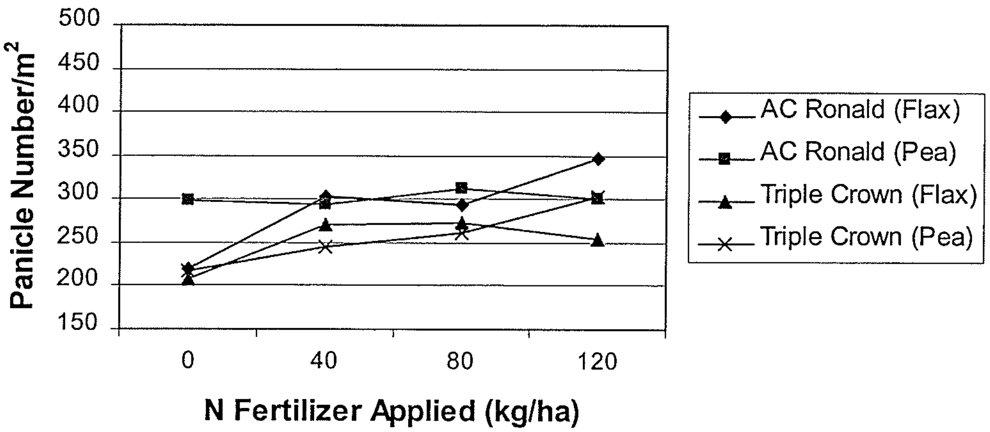

Figure 4.21. Illustration of the cultivar by previous crop by nitrogen fertilizer rate interaction (p=0.0126) on oat panicle number per square meter at Winnipeg, MB (2000).

At the Carman and Winnipeg 2000 sites, panicle density for Triple Crown increased with increasing N rate under pea stubble while under flax stubble, panicle density increased up to 40 kg ha^{-1}, then decreased. Also at both sites, panicle density for AC Ronald did not increase consistently with N rates on pea stubble. However, on flax stubble panicle numbers per square meter of AC Ronald increased steadily with increasing N rate indicating the semidwarf was essentially more responsive to N than the tall conventional under lower N supply situations (flax versus pea systems).

4.2.2.2 Kernel number

Kernel number (KNO) per unit area of land represents the post-anthesis sink size (Shanahan et al., 1984), which, in cereals, is strongly associated with grain yield (Shanahan et al., 1984; Entz and Fowler, 1989a). In wheat, optimum KNO is approximately 12,000 kernels per square meter (Entz, pers. comm.), and the optimum number increases as growing conditions improve. For oat, Hamill (2002) observed optimum KNO was approximately 12,000 to 13,000 kernels per square meter under Manitoba growing conditions.

Cultivar had a significant effect on KNO at all three site years, with AC Ronald demonstrating a significantly ($p<0.05$) higher KNO than Triple Crown (Tables 4.20, 4.21, 4.22). Previous studies in oats have also shown semidwarf oat cultivars have higher KNO than conventional cultivars (Anderson and McLean, 1989; Hamill, 2002). Observations from the present study indicate that AC Ronald has a higher sink capacity than Triple Crown, and therefore higher yield potential (Shanahan et al., 1984).

In a previous study, Hamill (2002) observed optimum KNO was approximately 12,000 to 13,000 kernels per square meter under Manitoba growing conditions. In the present study, KNO ranged from 13,500 to 16,500 for AC Ronald and from 12,200 to 13,400 for Triple Crown. However, a decrease in AC Ronald's KWT was observed, indicating higher KNO was at the expense of KWT due to competition for assimilates between kernels. Therefore, the present study may suggest that KNO around 13,000 to 14,000 kernels per square meter may be the maximum for oat in Western Canada because higher kernel production results in a decrease in KWT.

It is interesting to note that at both Carman sites (Tables 4.20 and 4.21), higher KNO due to cultivar coincided with higher grain yields, while at Winnipeg this trend was not observed (Table 4.22). A possible explanation could be that the optimum KNO for maximizing grain yield was not reached at Winnipeg. Kernel number for AC Ronald and Triple Crown at the Carman sites ranged from 13,300 to 16,500 kernels per square meter compared to a range from 12,100 to 13,500 at Winnipeg.

Nitrogen rate had a significant effect on KNO at two of the three site years. At the Carman and Winnipeg 2000 sites, increasing N rate significantly ($p<0.05$) increased KNO. This indicates that while N does not always significantly increase yield (e.g. Carman 2000 site), N additions did increase sink size and hence yield potential.

There was a significant ($p=0.057$) effect of previous crop on KNO at the Winnipeg 2000 site (Table 4.22), while there was no effect of previous crop on KNO at the other two sites years (Tables 4.20 and 4.21). Kernel number for the cultivars was greater in the pea system versus the flax system at Winnipeg due to the higher N supply in the pea system. The higher KNO led to a significant increase in oat grain yield in the pea system at this site (Table 4.22). A possible explanation for a significant response of previous crop at the Winnipeg 2000 site compared to the Carman sites may be due losses of nitrate-N in the soil at this site compared with the Carman sites due to high soil water levels leading to denitrification. Also, the lower nitrate-N at the Winnipeg site plus the absence of previous alfalfa crops in rotation led to the previous crop treatment significantly influencing KNO and yield.

There were no interactions between cultivar and previous crop or N rate at all three site years, indicating both cultivars responded similarly under both N supplying environments and rotation strategies. In summary, both cultivar and N rate positively affected sink capacity in the present study

4.2.2.3 Kernel number per panicle

Cultivar did not significantly affect kernel number per panicle at any site year (Tables 4.20, 4.21, 4.22). Previous studies, such as Hamill (2002), have also reported no cultivar effects on kernel number per panicle. However, as mentioned earlier, KNO per unit area in the present study was highly dependent on cultivar. Therefore, since cultivar did not affect kernel number per panicle, this strongly suggests that higher KNO per unit area in the semidwarf was due to higher panicle density.

Nitrogen rate had a significant effect on kernel number per panicle at two of the three site years. At the two high N site years (Carman 1999 and 2000), increasing N rate significantly ($p<0.05$) decreased kernel numbers per panicle. Panicle density increased with increased N application, while kernel number remained fairly constant, leading to a decrease in the number of kernels produced per panicle. Frey (1959), Ohm (1976), Brinkman and Rho (1984), and Hamill (2002) observed similar results where kernels per panicle decreased due to the increase in panicle density and KNO per unit area remaining constant across N rates.

Previous crop had a significant ($p<0.05$) effect on kernel number per panicle at only one of the three site years. At the Carman 2000 site, number of kernels per panicle were lower following pea compared to flax. The decrease in kernel number per panicle may be due to the significant increase in panicle number and no significant effect on KNO following pea versus flax (Table 4.21).

There were no interactions between cultivar and previous crop, indicating Triple Crown and AC Ronald responded similarly to previous crop in terms of kernels per panicle. No interaction between cultivar and N rate at the Carman and Winnipeg 2000 sites was observed (Tables 4.21, 4.22). A cultivar by N rate interaction at the Carman 1999 site indicated that kernel number per panicle for AC Ronald decreased under increasing N rates while kernel number per panicle for Triple Crown increased up to 40 kg ha^{-1} rate, then decreased (Figure 4.22).

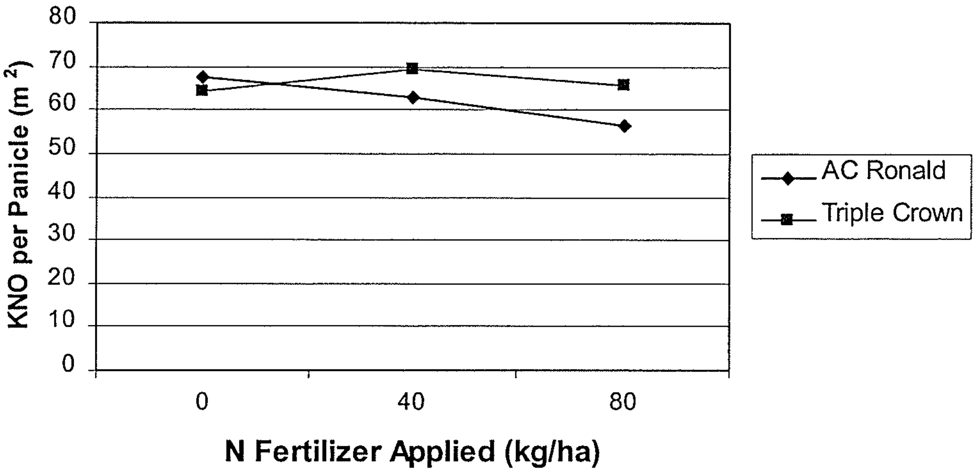

Figure 4.22. Illustration of the cultivar by nitrogen fertilizer rate interaction (p=0.0027) on oat kernel number (KNO) per panicle at Carman, MB (1999).

4.2.2.4 Kernel weight

Cultivar had a significant effect on kernel weight (KWT) at all three site years. Triple Crown consistently had higher KWT than AC Ronald (Tables 4.20, 4.21, 4.22). Previous studies in wheat (McNeal et al., 1972; Pearman et al., 1978) and oat (Hamill, 2002) also showed the KWT of semidwarf cultivars to be lower than that of tall cultivars. The lower KWT of AC Ronald at all three sites did not translate into decreased yield. In fact, at the Carman 1999 and Carman 2000 sites AC Ronald had significantly (p=0.002 and p=0.069, respectively) higher yields than Triple Crown. The present study suggests, therefore, that yield potential of the semidwarf was more affected by the pre-anthesis sink size, i.e. KNO per unit area and panicle density, than post-anthesis source size, i.e. KWT.

Nitrogen rate had inconsistent effects on KWT. At the Carman 2000 site, increasing N rate significantly ($p<0.05$) decreased KWT (Table 4.21), while at the other two sites, N did not significantly affect KWT (Tables 4.20, 4.22). Previous studies in wheat (Entz and Fowler, 1989a) and oat (Brinkman and Rho, 1984; Marshall et al., 1987) have shown decreased KWT with increased N rates, illustrating a greater competition for assimilates among individual kernels during grain filling under high N supply.

Previous crop had a significant effect on KWT at two of the three site years. At the Carman and Winnipeg 2000 sites, KWT was higher ($p<0.05$) after flax compared with pea. The increased N supplying power of the pea system may have contributed to a lower KWT of oats grown in this environment. Lower KWT of oat grain following pea indicates the increased N supply may have led to greater competition for assimilates between the increased number of kernels, which were produced under the high N supply conditions.

There was an interaction ($p<0.05$) between cultivar and N rate at one of the three site years. At the Winnipeg 2000 site, KWT for Triple Crown increased steadily under increasing N rates, while AC Ronald's KWT decreased up to 80 kg ha^{-1}, then remained unchanged (Figure 4.23).

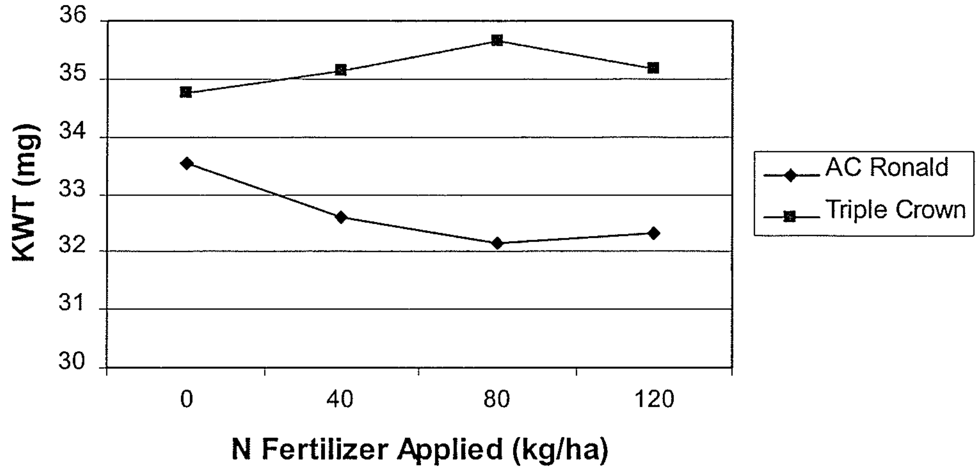

Figure 4.23. Illustration of the cultivar by nitrogen fertilizer rate interaction ($p=0.0183$) on oat kernel weight (KWT) at Winnipeg, MB (2000).

The decrease in AC Ronald's KWT may be due to the increased KNO of AC Ronald, leading to greater competition for assimilates between kernels. There were no interactions between cultivar and previous crop at any site years indicating AC Ronald and Triple Crown responded similarly to high and low N supplying environments.

4.2.2.5 Yield components summary

Panicle number, KNO, kernel number per panicle, and KWT all contribute to oat grain yield. In the present study, the semidwarf oat AC Ronald generally had higher yield, along with greater panicle density and KNO, compared to the conventional oat cultivar Triple Crown. It is also interesting to note that the oat yields obtained in the present study are high (4281 to 5309 kg ha^{-1}) in comparison to the average yield of oat production in 2000 in Manitoba (2915 kg ha^{-1}) (Manitoba Agriculture and Food, 2000), suggesting oat yields in the present study are reaching the maximum yield potential for oat in Manitoba.

There is strong evidence that variation in kernel number, whether produced by environment, genotype, or N fertilization, is the main contributor to grain yield in small grain cereals (Fischer et al., 1977; Shanahan et al., 1984). In the present study, KNO was largely determined by cultivar and N supply, therefore cultivar and N supply were the main contributors to yield potential and they acted independently due to no interaction between cultivar and N rate or previous crop.

In an earlier study with wheat, Fischer (1979) showed that the development of adequate spike number, along with kernel number, are critical to wheat grain yield. In the present study, the semidwarf AC Ronald had significantly higher panicle numbers per square meter than Triple Crown at all three sites. The higher panicle density, leading to higher KNO, led to a larger sink size, again illustrating the importance of sink strength in determining oat grain yield.

Kernel weight can be a limiting factor to increasing grain yields due to competition between developing kernels for limited assimilate availability, indicating a source restriction (Shanahan et al., 1984). The lower KWT of AC Ronald did not result in a decrease in yield because the greater kernel production (KNO per unit area) compensated for the lower weight. The greater KNO illustrates the importance of sink size in determining yield potential. Studies by Shanahan et al. (1984) and Hamill (2002) observed similar results where decreases in KWT did not translate into decreased yield. However, decreases in KWT may lead to a decrease in quality of oat grain.

4.2.3 Dry matter accumulation and harvest index

Final grain yield is a function of total dry matter accumulation and the percentage of dry matter partitioned to the seed, i.e., harvest index. The plant's ability to efficiently remobilize photosynthate to the grain during maturation results in a higher harvest index and therefore improves yield potential. Dry matter accumulation by AC Ronald and Triple Crown at stem elongation, anthesis, and maturity, as well as harvest index were measured to determine the differences in productivity between semidwarf and conventional height oat cultivars under different rotation and N fertilizer conditions.

4.2.3.1 Dry matter accumulation

Oat dry matter accumulation in the present study was higher than levels reported by Brinkman and Rho (1984) (approximately 9700 kg ha^{-1}) and Salman and Brinkman

(1992) (6385 kg ha^{-1}), but similar to levels reported by Hamill (2002) (10,000 to 11,000 kg ha^{-1}). Therefore, the productivity of oat in the present study can be considered to be very high.

At stem elongation, there was no consistent cultivar effect on dry matter (DM) accumulation at the three site years. At the Carman 1999 site, Triple Crown had a significantly higher DM accumulation than AC Ronald (Table 4.23), while at the remaining two site years, no significant difference was observed between cultivars.

At anthesis, significant cultivar effects on DM accumulation were observed at two of the three site years (Table 4.23). At Carman in 1999 and 2000, Triple Crown had significantly higher DM accumulation at anthesis than AC Ronald. Lupton et al. (1974) reported greater anthesis DM production for tall winter wheat cultivars compared to semidwarf winter wheat cultivars.

At maturity, a significant ($p<0.05$) cultivar effect on DM accumulation was observed at one of the three site years (Table 4.23). At Winnipeg in 2000, Triple Crown had significantly higher DM accumulation than AC Ronald. At Carman in 1999 and 2000, there was no significant difference between cultivars. Hamill (2002) showed the semidwarf OT288 produced similar dry matter amounts at maturity to that of tall cultivars AC Assiniboia and AC Medallion.

Generally, AC Ronald and Triple Crown had similar DM accumulation levels at stem elongation and maturity. In the one case where DM accumulation at anthesis was greater for Triple Crown (Table 4.23), no difference between Triple Crown and AC Ronald DM accumulation was observed at maturity indicating AC Ronald had greater DM accumulation after anthesis. Brinkman and Rho (1984) found similar results where

Table 4.23. Oat dry matter accumulation response to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

	Carman 1999			Carman 2000			Winnipeg 2000		
	Dry Matter Accumulation			Dry Matter Accumulation			Dry Matter Accumulation		
	Stem	Anthesis	Maturity	Stem	Anthesis	Maturity	Stem	Anthesis	Maturity
Main Effect		kg ha^{-1}			kg ha^{-1}			kg ha^{-1}	
Previous Crop									
Pea	1969	6616	12455	3610*a*	10419*a*	12367	3871*a*	10149	12223*a*
Flax	1664	5936	11612	2330*b*	9226*b*	11316	3384*b*	9674	10692*b*
LSD (0.05)	445	698	1373	728	610	1610	408	1103	805
Cultivar									
AC Ronald	1674*b*[z]	5955*b*	11884	2883	9584*b*	11651	3516	9668	10833*b*
Triple Crown	1960*a*	6597*a*	12173	3058	10061*a*	12033	3739	10156	12083*a*
LSD (0.05)	259	366	566	212	365	601	387	683	1012
N Rate (kg ha^{-1})									
0	1601*b*	5878*b*	11716	2835*a*	9449*b*	11000*c*	3343*b*	8832*b*	9934*c*
40	1853*ab*	6276*ab*	11941	2863*a*	9810*ab*	12260*ab*	3464*b*	10203*a*	11334*b*
80	1996*a*	6675*a*	12428	2462*b*	10250*a*	11604*bc*	3831*a*	10293*a*	11928*ab*
120	n/a	n/a	n/a	2720*a*	9781*ab*	12503*a*	3872*a*	10321*a*	12634*a*
LSD (0.05)	297	429	869	530	501	853	311	740	866
Source of Variation	ANOVA (P>F)								
Previous Crop (PC)	0.1047	0.0565	0.1474	0.0113	0.0084	0.1293	0.0320	0.2543	0.0091
Cultivar (Cvr)	0.0421	0.0087	0.3585	0.0903	0.0187	0.1709	0.2078	0.1235	0.0234
PC x Cvr	0.9388	0.3309	0.5007	0.0656	0.3521	0.3940	0.4675	0.2233	0.3309
N Rate	0.0375	0.0033	0.2386	0.0323	0.0239	0.0044	0.0022	0.0003	<.0001
PC x N Rate	0.9276	0.9092	0.8708	0.0383	0.0010	0.0825	0.2174	0.4327	0.2735
Cvr x N rate	0.3109	0.5009	0.4091	0.6721	0.3308	0.8150	0.2323	0.7932	0.8873
PC x Cvr x N rate	0.5807	0.8230	0.0806	0.1793	0.4872	0.3752	0.6624	0.7099	0.3197

[z] Means followed by the same letters are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

the semidwarf cultivar Stout had greater DM production after anthesis than two tall oat cultivars. The greater DM production after anthesis led to a higher KWT for Stout versus the two tall oat cultivars. In the present study, higher DM accumulation after anthesis did not translate into higher KWT for AC Ronald (Tables 4.20 to 4.22).

Nitrogen fertilizer application significantly ($p<0.05$) increased DM accumulation of both AC Ronald and Triple Crown at stem elongation and anthesis at all three site years, and increased DM accumulation at maturity at two of the three site years (Tables 4.21 and 4.22). Welch and Leggett (1997) reported similar results in oat where total plant dry matter yields showed significant increases with increasing nitrogen fertility level.

Previous crop type had a significant effect on DM accumulation at stem elongation at two of the three site years (Table 4.23). The oat crop after pea had significantly greater DM accumulation at stem elongation than the oat crop grown after flax. Previous crop had a significant effect on DM accumulation at maturity at only one of the three site years. At the lower residual N site (Winnipeg 2000), the oat crop grown after pea had significantly higher DM accumulation at maturity than the oat crop grown after flax. At the higher residual N sites (Carman in 1999 and 2000), there was no significant previous crop effect on oat DM accumulation at maturity.

Previous crop had an inconsistent effect on DM accumulation at all three crop stages at each site year. Where significant effects did occur, the oat after pea had significantly higher DM accumulation than the oat after flax, and greater DM accumulation after pea was attributed to a higher soil N supply.

There was no cultivar by previous crop and N rate interactions for DM accumulation at stem elongation, anthesis, and maturity at any of the three site years, indicating AC Ronald and Triple Crown responded similarly to N supply in terms of DM assimilation. In fact, DM production at maturity for each cultivar was remarkably similar at all three sites (Table 4.23). Results are similar to those reported by Brinkman and Rho (1984) where no interactions were seen between cultivar and N rate for DM production.

4.2.3.2 Harvest index

The harvest index (HI) for Triple Crown and AC Ronald in the present study were similar to HI levels reported for other conventional and short statured oat cultivars in previous studies (Brinkman and Rho, 1984; Meyers et al., 1985; McMullan et al., 1988; Anderson and McLean, 1989; Salman and Brinkman, 1992).

Cultivar had a significant effect on HI at all three site years, with AC Ronald having a significantly ($p<0.05$) higher HI than Triple Crown (Tables 4.20, 4.21, 4.22). Higher HI for the semidwarf cultivar indicates it is more efficient at partitioning DM into grain yield. The importance of cultivar effect on HI in this study confirms previous studies by Brinkman and Rho (1984), Anderson and McLean (1989), and Hamill (2002) who also observed higher HI among short-statured oat cultivars. However, Meyers et al. (1985) found no difference in HI between four dwarfs and four conventional height oat cultivars.

Harvest index has been positively correlated with grain yield improvements in oat (Salman and Brinkman, 1992). The present study supports this observation, as higher HI for AC Ronald coincided with higher grain yield for AC Ronald compared with Triple Crown at the Carman 1999 and 2000 sites (Tables 4.20 and 4.21).

Nitrogen fertilizer rate had no significant effect on HI at all three site years although N supply was extremely high under all three environments. This is important since it is often reported that excessive N reduces a crops' ability to partition DM into grain yield (Entz and Fowler, 1989a). For example, Brinkman and Rho (1984) reported lower HI with increasing N. Previous crop also had no significant effect on HI at two of the three site years.

There were no significant interactions between cultivar and previous crop or N rates at all site years. The lack of interaction indicates genotype is a major determining factor for harvest index and that cultivars will respond similarly to both low and high N supplying environments.

4.2.3.3 Dry matter accumulation and harvest index summary

Dry matter accumulation and HI directly influence oat grain yield potential. Generally, Triple Crown had greater DM accumulation at anthesis and maturity than AC Ronald (Table 4.23). This greater DM production did not result in greater yield, however, as Triple Crown did not have significantly higher grain yields than AC Ronald (Tables 4.20, 4.21, 4.22). Similar results were reported by McMullan et al. (1988) who also found no correlation between oat plant DM at maturity and grain yield of different cultivars, and Lupton et al. (1974) who found that lower anthesis DM production for semidwarf winter wheat did not reduce grain yield compared with tall cultivars. However, these results are inconsistent with several studies where higher DM accumulation was associated and resulted in higher grain yields in wheat (Fischer et al., 1977) and oat (Brinkman and Rho, 1984; Salmon and Brinkman, 1992). A possible explanation could be maximum DM yields were obtained by the oat cultivars in the present study so no more DM was required.

Although AC Ronald had lower DM accumulation than Triple Crown, AC Ronald did have a significantly higher HI (Tables 4.20, 4.21, 4.22), suggesting the semidwarf cultivar was more efficient in partitioning dry matter into grain yield. The partitioning of DM into yield is the reason why AC Ronald yielded higher than Triple Crown in the absence of higher DM accumulation. The agronomic benefits of lower DM production may include less straw to manage post-harvest. However, if producers utilize straw for bedding purposes, a decrease in straw quantity may not be desirable.

4.2.4 Plant height and lodging

Short-statured oat cultivars are thought to have greater yield potential relative to tall cultivars through improved lodging resistance. Plant height and lodging resistance of AC Ronald and Triple Crown were measured to determine the differences between semidwarf and conventional height oat cultivars, and whether N management influenced lodging incidence.

AC Ronald was significantly ($p<0.05$) shorter than Triple Crown at all three site years (Table 4.24). Nitrogen rate had a significant effect on plant height at three of the three site years where an increase in N rate led to an increase in plant height. As well, at two of the three sites, there was a previous crop effect where oat following pea was significantly taller than oat following flax (Table 4.24). The positive effects of N on oat plant height, either from organic or inorganic sources, are well documented (Ohm, 1976; Brinkman and Rho, 1984; Marshall et al., 1987; Ahmadi et al., 1988; Hamill, 2002).

Table 4.24. Oat plant height and lodging response to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

	Carman 1999		Carman 2000		Winnipeg 2000	
Main Effect	**Plant Height (cm)**	**Lodging Scores (out of 9)**	**Plant Height (cm)**	**Lodging Scores (out of 9)**	**Plant Height (cm)**	**Lodging Scores (out of 9)**
Previous Crop						
Pea	106.8	4.7	123.8*a*	8.8*a*	115.8*a*	3.8*a*
Flax	101.9	4.8	115.4*b*	6.3*b*	109.5*b*	1.1*b*
LSD (0.05)	6.6	2.8	4.6	0.8	3.7	1.3
Cultivar						
AC Ronald	96.1*b*[z]	3.0*b*	109.4*b*	7.4	100.7*b*	2.2
Triple Crown	112.6*a*	6.4*a*	129.7*a*	7.7	124.6*a*	2.7
LSD (0.05)	2.3	1.1	3.7	0.3	4.4	1.0
N Rate (kg ha^{-1})						
0	103.5*b*	4.5*b*	115.3*b*	5.2*c*	105.3*c*	0.6*c*
40	103.6*b*	4.6*ab*	119.9*a*	7.8*b*	114.2*b*	1.3*c*
80	106.0*a*	5.1*a*	121.7*a*	8.5*a*	113.0*b*	2.9*b*
120	n/a	n/a	121.4*a*	8.6*a*	118.3*a*	4.9*a*
LSD (0.05)	1.6	0.5	2.8	0.5	3.0	0.8
Source of Variation	ANOVA (P>F)					
Previous Crop (PC)	0.0943	0.9687	0.0101	0.0021	0.0124	0.0069
Cultivar (Cvr)	<.0001	0.0003	<.0001	0.0924	<.0001	0.2437
PC x Cvr	0.2420	0.2936	0.8256	0.3559	0.7363	0.7169
N Rate	0.0032	0.0465	0.0001	0.0001	<.0001	0.0001
PC x N Rate	0.0442	0.5885	0.1294	0.0001	0.0601	0.0038
Cvr x N Rate	0.6024	0.0211	0.8537	0.9696	0.5167	0.1041
PC x Cvr x N Rate	0.3773	0.3140	0.5615	0.3776	0.2660	0.3962

[z] Means followed by the same letters are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

There were no interaction effects between cultivar and previous crop or N rate, indicating similar height responses between cultivars. This result is to be expected as the shorter plant height of the semidwarf is due to shorter internodes (Brown et al., 1980).

Lodging was measured on one date at the Carman 1999 site and two dates at the Carman and Winnipeg 2000 sites (Table 3.1). However, the first date at both 2000 site years was not used to calculate lodging scores presented in Table 4.24 as the lodging scores for both cultivars under all treatments at this stage were rated at a one.

Cultivar had no consistent significant effect on lodging scores. Only at the Carman 1999 site did Triple Crown have significantly ($p<0.05$) higher lodging scores than AC Ronald (Table 4.24). Nitrogen rate, on the other hand, consistently increased ($p<0.05$) lodging scores. Brinkman and Rho (1984) and Hamill (2002) reported similar results. At Carman and Winnipeg in 2000, there was an increase in lodging score in oat following pea versus flax. The higher N supplying power of the pea stubble may have led to the increase of lodging incidence of both crops.

At one of the three site years, there was an interaction between cultivar and N rate for lodging scores. At Carman in 1999, lodging for AC Ronald increased with increases in N supply while lodging in Triple Crown remained unchanged (Figure 4.24).

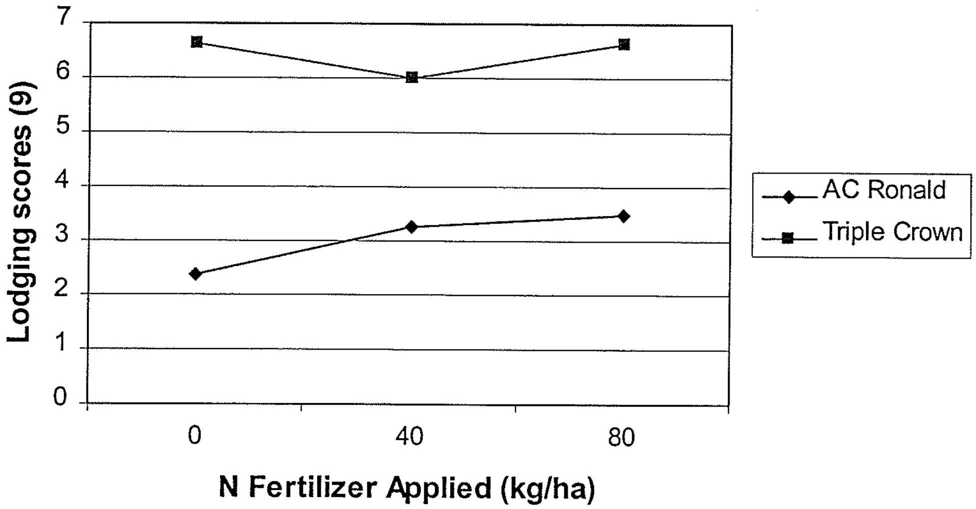

Figure 4.24. Illustration of the cultivar by nitrogen fertilizer rate interaction (p=0.0211) on oat lodging at Carman, MB (1999).

Lodging was already severe for Triple Crown under zero N fertilizer applied at that site and no further lodging increases with increased N due to high indigenous soil N supply at this site. However, lodging for AC Ronald was low and increases slightly with increased N rate.

There were no interactions between cultivar and previous crop at all three sites, illustrating both cultivars responded similarly in regards to lodging following a high and low N supplying crop.

4.2.4.1 Plant height and lodging summary

McNeal et al. (1972), Brown et al. (1980), and Marshall et al. (1985) suggested semidwarfs have a yield advantage due to increased lodging resistance. Results from the present study do not support their conclusions, as there was little effect of cultivar on lodging. Another suggestion is that lodging is related to plant height (Brown et al., 1980; Marshall et al, 1985). In the present study, while the greatest degree of lodging occurred at Carman 2000, the site with the tallest plants, plants at Winnipeg 2000 were almost as tall as those at Carman 2000, but lodging was much lower. Therefore, while plant height can play a role in the lodging incidence of oat, lodging was more influenced by environment, i.e., site year, than by crop height in the present study likely because lodging is a result of a combination of factors including plant height, wind, and precipitation.

In the present study, lodging was more influenced by N supply than by plant height. Hamill (2002) obtained similar results, where lodging incidence of OT288, a semidwarf, was more influenced by N supply and environmental conditions than by height.

Lodging is thought to influence grain yield by decreasing kernel weight due to a decreased flow of assimilates to the kernel (Pinthus, 1973). Under the three environments examined in this study, the lodging that occurred did not negatively impact yield. For example, while AC Ronald generally out-yielded Triple Crown at all three sites, the semidwarf cultivar did not have significantly lower lodging scores. In fact, in the present study, KWT was higher for Triple Crown, which generally had a greater degree of lodging, indicating lodging occurred either too late in the season to affect assimilate flow, or the oat crop partially recovered from early season lodging. It is important to note that in the present study, lodging was not evaluated continuously over the season (Table 3.1), and without this information only limited conclusions can be drawn from the lodging data.

Lodging is also thought to influence yield indirectly by making mechanical harvesting difficult (Pinthus, 1973). There were no major problems in harvesting the severely lodging treatments in the present study.

The yield advantage of the semidwarf AC Ronald can be attributed to increased kernel number per unit area and panicle number, as well as improved HI, rather than improved lodging resistance. Hamill (2002) made a similar conclusion.

4.2.5 Total N accumulation

Nitrogen uptake and accumulation is strongly influenced by environmental conditions throughout the growing season, N fertilization, and cultivar. Total N uptake at stem elongation, anthesis, and maturity of AC Ronald and Triple Crown were measured to determine the influence of genetic and management factors on the ability of oats to accumulate N into above around plant biomass.

Cultivar had a significant ($p<0.05$) effect on N uptake at stem elongation at two of the three site years. In Carman 1999 and 2000, Triple Crown had significantly higher N uptake than AC Ronald (Table 4.25) due to higher DM production of Triple Crown (Table 4.23). Cultivar had no effect on N uptake at anthesis and maturity at all three site years, where N uptake was similar for AC Ronald and Triple Crown (Table 4.25).

AC Ronald and Triple Crown had similar N uptake patterns where both cultivars had the greatest N uptake prior to anthesis. Pearman et al. (1978) also observed wheat to accumulate the highest proportion of N prior to anthesis.

Nitrogen rate had a significant ($p<0.05$) effect on N uptake at stem elongation, anthesis, and maturity at three of the three site years. As N rate increased, N uptake by

Table 4.25. Oat total nitrogen (N) accumulation response to cultivar, nitrogen fertilizer rate, and previous crop treatment effects at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

	Carman 1999			Carman 2000			Winnipeg 2000		
	N Uptake			N Uptake			N Uptake		
	Stem	Anthesis	Maturity	Stem	Anthesis	Maturity	Stem	Anthesis	Maturity
Main Effect		kg ha^{-1}			kg ha^{-1}			kg ha^{-1}	
Previous Crop									
Pea	82.6	183.9	250.0	180.2*a*	239.2*a*	231.6*a*	107.5	150.7	149.2
Flax	67.7	152.4	217.9	100.9*b*	154.2*b*	157.6*b*	89.9	126.2	129.9
LSD (0.05)	27.6	34.7	58.6	35.1	17.9	35.7	27.7	29.1	32.7
Cultivar									
AC Ronald	68.1*b*^{z}	163.7	226.0	134.6*b*	197.1	196.3	93.8	135.2	132.2
Triple Crown	82.2*a*	172.5	241.9	146.5*a*	196.2	193.0	103.7	141.4	146.9
LSD (0.05)	10.2	13.1	16.4	10.1	12.4	16.7	10.5	16.4	28.9
N Rate (kg ha^{-1})									
0	65.4*b*	151.84*b*	219.5*b*	122.0*b*	163.0*c*	162.3*c*	67.0*c*	96.6*d*	107.8*d*
40	75.8*ab*	164.1*b*	232.4*a*	132.1*b*	184.0*b*	193.6*b*	88.2*b*	135.8*c*	129.5*c*
80	84.4*a*	188.4*a*	245.0*a*	170.4*a*	216.5*a*	197.9*b*	115.3*a*	152.4*b*	152.0*b*
120	n/a	n/a	n/a	137.6*b*	223.1*a*	224.7*a*	124.4*a*	168.9a	168.9a
LSD (0.05)	12.5	15.4	16.9	26.3	13.8	19.3	11.3	12.2	12.7
Source of Variation	ANOVA (P>F)								
Previous Crop (PC)	0.1698	0.0633	0.1846	0.0056	0.0006	0.0071	0.1351	0.0754	0.1571
Cultivar (Cvr)	0.0210	0.2671	0.1102	0.0290	0.8698	0.6459	0.0601	0.3696	0.2570
PC x Cvr	0.5716	0.1817	0.8529	0.1321	0.1295	0.5141	0.9565	0.3195	0.6217
N Rate	0.0162	0.0002	0.0041	0.0043	<.0001	<.0001	<.0001	<.0001	<.0001
PC x N Rate	0.8954	0.5679	0.6358	0.0052	0.0300	0.3189	0.2859	0.5707	0.3315
Cvr x N Rate	0.2051	0.8499	0.4339	0.6812	0.4287	0.6667	0.1389	0.7436	0.7849
PC x Cvr x N Rate	0.8520	0.8429	0.1402	0.2750	0.3387	0.3524	0.5406	0.7671	0.2651

[z] Means followed by the same letters are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

the oat crop also increased. Welch and Leggett (1997) reported similar results where total plant N yield showed significant increases with increasing N fertility level.

Previous crop had no consistent effect on N uptake at stem elongation, anthesis, and maturity. At the Carman 2000 site, the N uptake by the oat crop following pea was significantly greater than the N uptake by the oat crop following flax. The pea system had approximately 90 kg ha^{-1} greater N than the flax stubble (Table 3.2), and the oat cultivars took up 75 to 85 kg N ha^{-1} more in the pea system than the flax stubble. At the other two site years (Table 4.25), there was no significant difference in N uptake by the oat crop following either pea or flax, although there was a difference in N supply between the pea and flax treatments (Table 3.2).

There were no interactions between cultivar and N rate or previous crop at stem elongation, anthesis, and maturity at all three site years, indicating that in terms of total plant N uptake, AC Ronald and Triple Crown responded similarly to high and low supplying N environments. Therefore, the results suggest that both cultivars accumulate similar amounts of N regardless of cultivar and N supply.

4.2.6 Yield physiology and N accumulation summary

Earlier, researchers hypothesised newer semidwarf oat cultivars may respond differently to N fertilizer than older, taller types (Brinkman and Rho, 1984; Meyers et al., 1984; Marshall et al., 1987). This hypothesis was the basis of the present study comparing AC Ronald, Canada's first registered semidwarf oat cultivar, with a conventional oat cultivar. Results of this study indicated that yield and yield components of AC Ronald and Triple Crown responded similarly to rotation and N fertilizer rate.

One reason for the similar response by each cultivar may be due the high soil N at each site. The present study was conducted on soils with a high N supplying power. In fact, only the Winnipeg 2000 site had N uptake levels in the control treatments below the critical level of 115 kg ha^{-1} (Hamill, 2002). Therefore, conditions in the present study were not optimum for testing the relative response of oat cultivars to N fertilizer application, since most soil systems were able to supply the 115 kg ha^{-1} N required to optimize oat grain yield. The high soil N supplying power also limited the usefulness of the "high soil N supplying treatment" (i.e. pea green manure). However, in the present study since both cultivars had similar N uptake and requirements, the higher yields of the semidwarf AC Ronald compared with Triple Crown were due to factors other than differences in response to N.

Cultivar differences were very evident in the present study. AC Ronald had significantly higher KNO and panicle number per unit area than Triple Crown, but had significantly lower KWT. Clearly, the post-anthesis sink size was higher for AC Ronald than Triple Crown. Previous research with wheat (Shanahan et al., 1984; Entz and Fowler, 1989a), and oat (Hamill, 2002) indicate that sink strength is more important than source strength in determining yield potential. However, KWT in the present study decreased due to the increase in KNO. Decreases in KWT did not appear to limit yield in the present study, though decreases in quality of oat grain are possible. An optimum sink size (KNO) for oat in Manitoba suggested by the present study would be in the range of 13,000 to 14,000 kernels per square meter.

Dry matter accumulation is an important benchmark of crop productivity. A large proportion of grain carbohydrate is derived from $C0_2$ fixed during the grain filling period.

Therefore, maximum grain yield of the crop depends on the capacity to produce and utilize photosynthate during this period. As well, there has been extensive evidence showing a positive relationship between DM accumulation by anthesis and grain yield. In the present study, the greater DM accumulation of Triple Crown did not translate into greater grain yield. In fact, higher HI for AC Ronald compared with Triple Crown indicated that the semidwarf was more efficient at partitioning dry matter between vegetative and reproductive tissues.

Lodging is a serious issue for oat producers in Manitoba, and may reduce grain yield potential. Conventional height oat cultivars in Manitoba tend to be susceptible to lodging, although the tall cultivar included in the present study is among the most lodging resistance oat cultivar presently available (Manitoba Agriculture and Food, 2002). The breeding of semidwarf cultivars may lead to improved grain yields through decreased lodging incidence. However, the results from this study show inconsistent effects of cultivar on lodging, and that N supply, not cultivar choice, had the strongest effect on lodging. Results of the present study show that the yield advantage of the semidwarf arises from an improvement in numerous yield components, specifically increased KNO per unit area, panicle number, and an increase in HI, but not decreased lodging resistance.

Previous researchers have suggested intensive management practices may be needed to achieve yield advances with semidwarf oat cultivars. Under the three environments in the present study, both AC Ronald and Triple Crown responded similarly to both low and high N supplying environments. Instead, higher yields of the semidwarf was a result of greater physiological efficiency (increased KNO per unit area and panicle number per unit area, and improved HI). According to the results obtained in this study, semidwarfs do not require different N rates than conventional height cultivars to maximize grain yield.

In the future, it may be important to test the N response of these two cultivars under lower soil N levels. As well, with advancements in oat breeding, research evaluating newly developed dwarf cultivars versus conventional height cultivars will be warranted.

4.3 Physical Quality Parameters of a Semidwarf and a Tall Oat Cultivar

Quality of oat grain can be determined by measuring the following parameters: hectolitre weight, plump and thin kernels, and groat percentage. Crop management factors such as N supply influence these parameters (Humphreys et al., 1994; Zhou et al., 1998). Grain quality is also cultivar dependent (Humphreys et al., 1994; Hamill, 2002). Examining the effects of crop management, specifically N supply, on semidwarf and conventional cultivars could lead to an improvement in milling quality along with production.

4.3.1 Hectolitre weight

Hectolitre weight is the standard quality measure for the Canadian oat industry, where a minimum level of 245 g 0.5 L^{-1} is required. Hectolitre weight is a volumetric measure significantly influenced by the shape and size of individual grains. Hectolitre weight depends upon other quality parameters, such as kernel plumpness, groat percentage, hull content, KWT, and by yield components such as panicle and kernel number.

Cultivar had a significant effect on hectolitre weight at two of the three site years, with AC Ronald having a significantly ($p<0.05$) higher hectolitre weight than Triple Crown at the Carman 1999 and 2000 sites (Tables 4.30 and 4.31). At the Carman 1999 site, the significant decrease in hectolitre weight of Triple Crown may have been due to the increased lodging of Triple Crown compared to AC Ronald (Table 4.24). The higher lodging of Triple Crown may have resulted in a decrease of carbohydrate translocation to the grain, thereby decreasing kernel plumpness and KWT (Pinthus, 1973). Hamill (2002) also observed significant cultivar effects for hectolitre weight in four site years of trials.

Table 4.30. Oat quality parameter reponse to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999).

Main Effect	**Plumps** **%**	**Thins** **%**	**Groat** **%**	**Hectolitre Wt** **g 0.5L^{-1}**
Previous Crop				
Pea	67.3	1.7	72.0	249.7
Flax	62.3	1.9	71.2	251.4
LSD (0.05)	12.4	0.9	1.5	2.8
Cultivar				
AC Ronald	71.8*a*^{z}	2.1	74.0*a*	256.2*a*
Triple Crown	57.8*b*	1.5	69.2*b*	244.9*b*
LSD (0.05)	5.3	0.7	1.2	6.0
N Rate (kg ha^{-1})				
0	63.9	1.9	71.3	251.6
40	64.8	1.7	71.2	250.8
80	65.7	1.9	71.8	249.1
LSD (0.05)	4.0	0.5	0.8	3.1
Source of Variation	ANOVA (P>F)			
Previous Crop (PC)	0.2850	0.8264	0.1671	0.1760
Cultivar (Cvr)	0.0008	0.0503	<.0001	0.0046
PC x Cvr	0.4561	0.4591	0.6128	0.8958
N Rate	0.6206	0.6789	0.3822	0.2677
PC x N Rate	0.1984	0.3243	0.7439	0.5160
Cvr x N Rate	0.9962	0.6844	0.5814	0.2945
PC x Cvr x N Rate	0.6996	0.1157	0.2332	0.9101

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Table 4.31. Oat quality parameter reponse to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (2000).

Main Effect	Plumps %	Thins %	Groat %	Hectolitre Wt g 0.5L^{-1}
Previous Crop				
Pea	55.6	3.5	66.3	213.9*b*
Flax	62.6	2.1	66.9	226.1*a*
LSD (0.05)	8.4	1.5	1.7	5.9
Cultivar				
AC Ronald	60.6	3.5*a*	68.7*a*	225.2*a*
Triple Crown	57.3	2.1*b*	64.3*b*	214.0*b*
LSD (0.05)	4.7	0.7	0.8	6.3
N Rate (kg ha^{-1})				
0	61.1*a*[z]	2.4*b*	66.6	225.6*a*
40	60.6*a*	2.8*ab*	66.7	220.9*b*
80	58.2*ab*	2.8*ab*	67.1	218.3*bc*
120	56.2*b*	3.3*a*	66.0	215.0*cd*
LSD (0.05)	3.3	0.6	0.9	3.4
Source of Variation	ANOVA (P>F)			
Previous Crop (PC)	0.0752	0.0558	0.3459	0.0071
Cultivar (Cvr)	0.1787	0.0034	<.0001	0.0071
PC x Cvr	0.1345	0.1360	0.0073	0.4737
N Rate	0.0088	0.0259	0.2177	<.0001
PC x N Rate	0.0009	0.4469	0.5394	0.0442
Cvr x N Rate	0.0310	0.9607	0.0766	0.5058
PC x Cvr x N Rate	0.6117	0.2260	0.4848	0.1021

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

In her trials, OT288, a semidwarf oat cultivar, had higher hectolitre weights than conventional height cultivars AC Assiniboia and AC Medallion. Humphreys et al. (1994) also showed a significant effect of cultivar on hectolitre weight between four conventional height oat cultivars.

Nitrogen rate had a significant ($p<0.05$) effect on hectolitre weight at two of the three site years. At the Carman and Winnipeg 2000 sites, hectolitre weight decreased with increased N supply (Tables 4.31 and 4.32). The higher N levels at the Carman and Winnipeg 2000 sites led to increased KNO and decreased KWT (Tables 4.21 and 4.22), which likely contributed to a decreased hectolitre weight. At the remaining site (Carman 1999), increased N rate did not increase KNO or decrease KWT and, coincidentally, no significant effect on hectolitre weight was observed (Table 4.20).

Previous crop had a significant ($p<0.05$) effect on hectolitre weight at the Carman 2000 (Table 4.31), where oat following flax had a greater hectolitre weight than oat following pea. However, previous crop had no effect on hectolitre weight at the remaining two sites (Tables 4.30 and 4.32).

Some interactions between cultivar and previous crop or N rate on hectolitre were observed. Significant cultivar by previous crop (Figure 4.30) and cultivar by N rate (Figure 4.31) interactions were observed at the Winnipeg 2000 site.

Table 4.32. Oat quality parameter reponse to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Winnipeg, MB (2000).

Main Effect	**Plumps %**	**Thins %**	**Groat %**	**Hectolitre Wt g 0.5L^{-1}**
Previous Crop				
Pea	71.0	1.4	69.6*a*	244.9
Flax	70.6	1.2	68.1*b*	245.4
LSD (0.05)	6.0	0.6	1.1	2.6
Cultivar				
AC Ronald	66.6*b*^{z}	2.1*a*	69.9*a*	243.9
Triple Crown	75.0*a*	0.5*b*	67.8*b*	246.3
LSD (0.05)	4.9	0.2	1.3	2.7
N Rate (kg ha^{-1})				
0	69.4*b*	1.4	67.4*d*	247.6*a*
40	69.7*b*	1.3	68.4*c*	246.0*ab*
80	70.2*b*	1.3	69.2*b*	245.1*b*
120	73.9*a*	1.3	70.3*a*	241.8*c*
LSD (0.05)	2.9	0.3	0.7	2.6
Source of Variation	ANOVA (P>F)			
Previous Crop (PC)	0.8337	0.3942	0.0253	0.6171
Cultivar (Cvr)	0.0058	<.0001	0.0081	0.0717
PC x Cvr	0.3268	0.0324	0.5216	0.0157
N Rate	0.0118	0.9880	<.0001	0.0006
PC x N Rate	0.9705	0.3926	0.1090	0.8748
Cvr x N Rate	0.5958	0.2916	0.1514	0.0117
PC x Cvr x N Rate	0.1718	0.3844	0.1298	0.0499

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

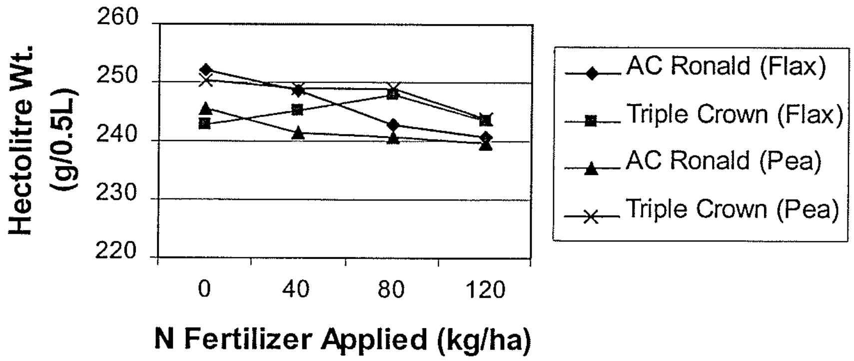

Figure 4.30. Illustration of the cultivar by previous crop interaction (p=0.0157) on oat hectolitre weight at Winnipeg, MB (2000).

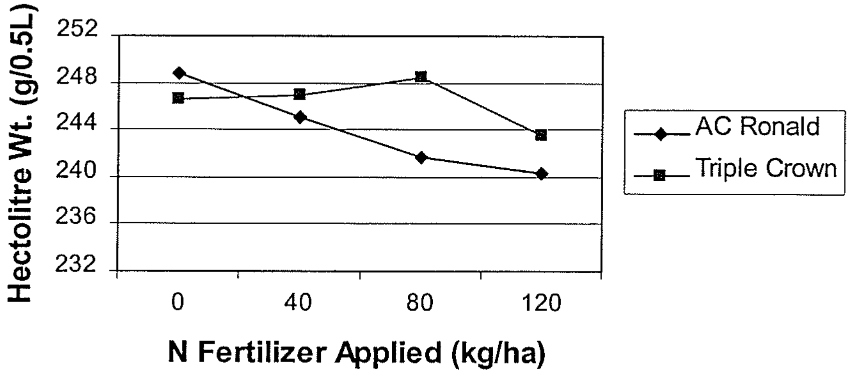

Figure 4.31. Illustration of the cultivar by nitrogen fertilizer rate interaction (p=0.0017) on oat hectolitre weight at Winnipeg, MB (2000).

Both interactions showed that hectolitre weight of Triple Crown increased with rate of applied N up to 80 kg N ha^{-1} and then decreased when more N was applied, while the hectolitre weight of AC Ronald decreased steadily as N rate increased. However, the lack of consistent interactions between cultivar and previous crop and N rate indicated that hectolitre weight in both AC Ronald and Triple Crown responded similarly to different N supplying environments.

It was interesting to note that the minimum standard hectolitre weight of 245 g 0.5 L^{-1} was only achieved at the Carman 1999 and Winnipeg 2000 sites (Tables 4.30 and 4.32). A possible explanation for the lower hectolitre weight at the Carman 2000 site could be that low proportion of plump kernels with a high groat percentage (Table 4.31), which is known to result in lower hectolitre weights (Humphreys et al., 1994). Another possible explanation is that there were higher lodging scores at the Carman 2000 site compared to the other two sites (Table 4.24), suggesting lodging affected grain filling by interfering with carbohydrate translocation (Pinthus, 1973).

4.3.2 Plump and thin kernels

Cultivar had a significant effect on percent plump kernels at two of the three site years (Tables 4.30, 4.31, 4.32). At the Carman 1999 site, AC Ronald had a greater percentage of plump kernels than Triple Crown. A possible explanation could be that Triple Crown had significantly higher lodging scores than AC Ronald, which decreased DM translocation and grain filling in Triple Crown (Table 4.24). The opposite trend was observed at the Winnipeg 2000 site. Hamill (2002) observed that OT288, a semidwarf oat cultivar, had significantly fewer plump kernels than the conventional oat cultivars AC

Assiniboia or AC Medallion. Plump kernels may be more affected by environmental influences, such as temperature and water supply, or by disease pressure, which influence DM translocation and grain filling, than by cultivar. However, detailed measurements of environmental factors were not taken in the present study to adequately answer that question.

Nitrogen rate also had a significant ($p<0.05$) effect on percent plump kernels at two of the three site years (Tables 4.31 and 4.32). At the Carman 2000 site, increasing N rate significantly decreased kernel plumpness, while at the Winnipeg 2000 site, increasing N rate significantly increased kernel plumpness. The decrease in plump kernels at the Carman 2000 site may be attributed to a significant decrease in KWT with N (Table 4.21). The increased competition for assimilates between kernels due to the significant increase in panicle and KNO led to a decrease in KWT, and also a possible decrease in the percentage of plump kernels at this site. An increase in percent plump kernels with N at the Winnipeg 2000 site coincided with no significant effect of N on KWT (Table 4.22). Although the increase in fertilizer rate did significantly increase panicle and KNO, the nitrogen supply increased post-anthesis source, which produced plump kernels with high kernel weights.

Previous crop and the interactions between cultivar and previous crop and N rate had varying effects on plump kernels depending upon site year. There was no effect of previous crop on percent plump kernels at any of the three sites. At two out of the three locations there was no interaction between cultivar and previous crop or N rate indicating both cultivars responded similarly to N supply. Humphreys et al. (1994) also observed no significant interaction between N rate and cultivar for percent plump kernels in four site years of trials. However, at the Carman 2000 site, there was a cultivar by N rate interaction (Figure 4.32), where plump kernel percentage for AC Ronald increased up to 80 kg ha^{-1} applied N and then decreased, and plump kernel percentage for Triple Crown decreased steadily with increasing N rate. This may indicate AC Ronald is more responsive to N under higher supplies of N than Triple Crown.

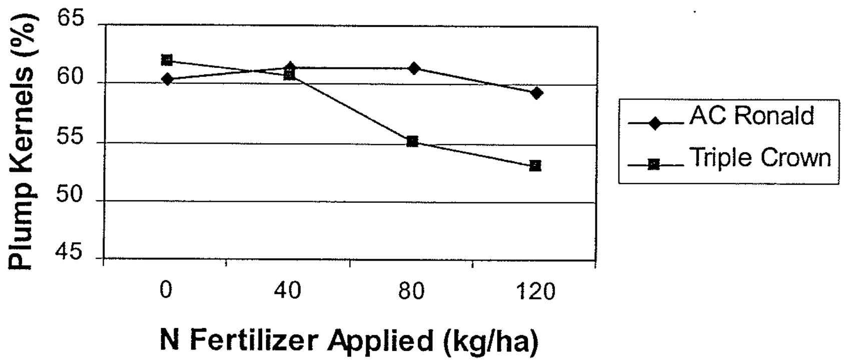

Figure 4.32. Illustration of the cultivar by nitrogen fertilizer rate interaction (p=0.0310) on oat plump kernel percentage at Carman, MB (2000).

Cultivar had a significant ($p<0.05$) effect on percent thin kernels at all three site years, where AC Ronald had a significantly higher percentage of thin kernels than Triple Crown. There was no significant effect of N rate or previous crop on thin kernel percentage, except at the Carman 2000 site where increasing N rate increased percent thin kernels. This observation follows the negative effect of N fertilizer additions on percentage of plump kernels at this site (Table 4.31). There were no interactions between cultivar and previous crop or N rate, except at the Winnipeg 2000 site (Figure 4.33).

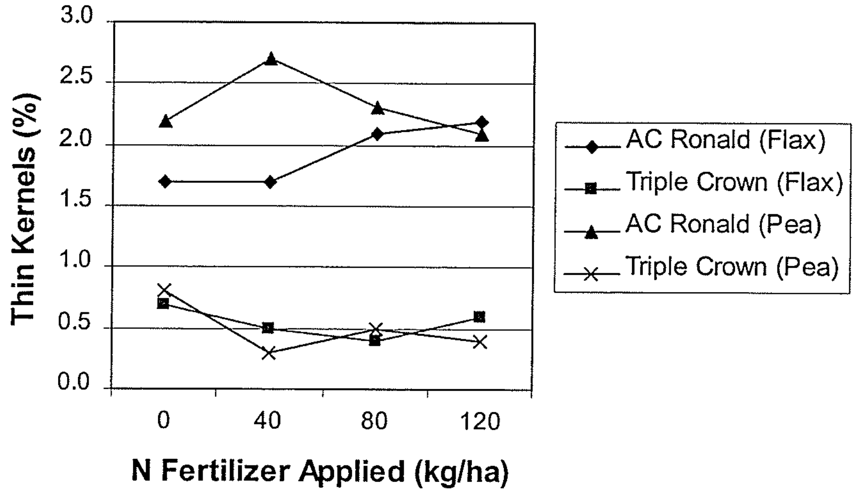

Figure 4.33. Illustration of the cultivar by previous crop interaction (p=0.0324) on oat thin kernel percentage at Carman, MB (2000).

4.3.3 Groat percentage

Groat percentage is an important indicator of oat grain quality. Oat groat content can range from 64 to 80% of the grain depending upon environment and genetic factors (Welch et al., 1983). Environmental stresses during grain filling period, such as moisture deficiency or intense heat, usually result in a decrease in DM accumulation and reduced groat percentage (Forsberg and Reeves, 1992).

Cultivar had a significant ($p<0.05$) effect on groat percentage at all three site years. AC Ronald had a significantly higher groat percentage than Triple Crown (Tables 4.30, 4.31, 4.32). This result may indicate AC Ronald was more efficient at partitioning DM into the oat grain than Triple Crown. The opposite trend was observed by Hamill (2002) who found that a semidwarf oat cultivar had a significantly lower groat percentage than two conventional height cultivars, indicating not all semidwarf oat cultivars are similar. Although the semidwarf cultivar AC Ronald in the present study had a significantly higher groat percentage, results from previous work indicate groat percentage is significantly affected by differences between cultivars not related to the semidwarf character (Humphreys et al., 1994; Zhou et al., 1998).

Nitrogen rate and previous crop had a significant ($p<0.05$) effect on groat percentage at the Winnipeg 2000 site only, where increased N supply from inorganic or indigenous sources resulted in a higher groat percentage. Response of groat percentage to N fertilizer at this site may be due to high soil water content during the growing season resulting in denitrification and therefore a decrease in available nitrate-N to the crop. Humphreys et al. (1994) and Zhou et al. (1998) observed a positive relationship between N rate and groat percentage.

There was no consistent interaction between cultivar and previous crop or N rates, except at the Carman 2000 site (Figure 4.34), indicating that groat percentage of AC Ronald and Triple Crown responded similarly to N supply. Humphreys et al. (1994) also observed similar response at groat percentage to N for four conventional oat cultivars.

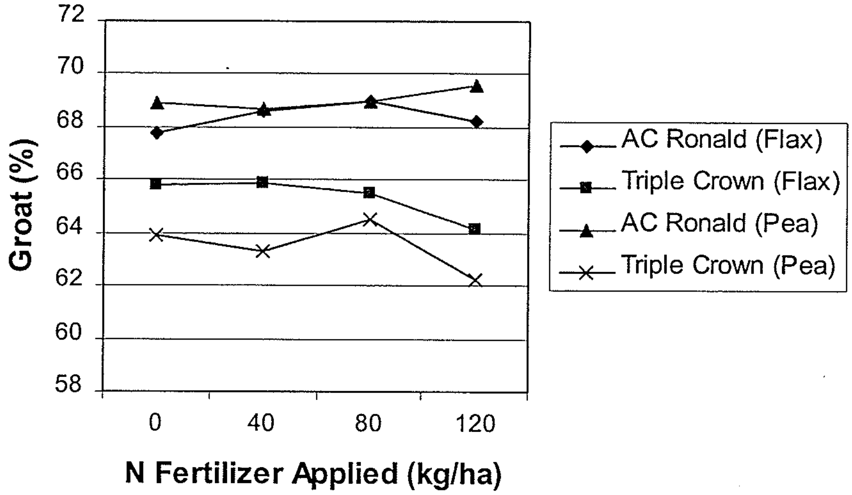

Figure 4.34. Illustration of the cultivar by previous crop interaction ($p=0.0073$) on oat groat percentage at Carman, MB (2000).

4.3.4 Interaction among quality parameters and grain yield

Plump and thin kernels and groat percentage quality parameters influence hectolitre weight (Humphreys et al., 1994; Zhou et al., 1998). A high proportion of plump kernels, with a high groat percentage, is known to result in high hectolitre weights (Humphreys et al., 1994). This trend was seen in the present study. At two of the three sites, higher hectolitre weight coincided with a higher percentage plump kernels and groat percentage for AC Ronald versus Triple Crown (Tables 4.30, 4.31). At the Winnipeg 2000 site, higher percentage plump kernels for Triple Crown coincided with higher hectolitre weight for Triple Crown compared with AC Ronald (Table 4.32). Results from the present study indicate hectolitre weight is a reasonable integrative measure of quality for the oat industry.

Hectolitre weight can also be influenced by the presence of a large number of smaller kernels due to the improved packing ability of smaller kernels. AC Ronald had a smaller average kernel mass than Triple Crown, as the KWT for AC Ronald was significantly lower than Triple Crown at all three site years (Tables 4.20, 4.21, 4.22). The smaller kernels, along with high groat percentage of AC Ronald translated into higher hectolitre weight compared to Triple Crown.

Oat quality may decrease due to increased kernel production. The increased kernel production leads to higher yield potential. However, higher kernel number can result in a decrease in KWT and percentage plump kernels due to increased competition between kernels for assimilates.

4.3.5 Quality parameter summary

Hectolitre weight is the most relevant measure of quality in the oat industry today. AC Ronald generally had a higher hectolitre weight than Triple Crown. However, it is not clear from the present study whether differences in quality between cultivars were related to the semidwarf character *per se*. Hectolitre weight was strongly influenced by N supply. As N supply increased, hectolitre weight decreased due to the increased competition between kernels for assimilates.

It is important to note that hectolitre weight may not continue to be the indicator of optimum milling quality. Plump and thin kernels, and groat percentage are gaining popularity as more stable indicators of oat quality (Hamill, 2002). Cultivar had a significant effect on all three quality parameters; however, there were no consistent trends seen in plump kernel percentage. AC Ronald did have significantly higher thin kernel percentage and groat percentage than Triple Crown. However, it is unclear from the present study whether differences in quality between cultivars were related to the semidwarf character *per se*. N supply had inconsistent effects on plump and thin kernels, and groat percentage. The inconsistent results could be due to factors other than cultivar or N supply. These would include weather, which affect grain filling and therefore grain size. However, the present study did not adequately measure temperature and moisture during the growing season to determine if weather influenced grain filling and therefore oat grain quality.

According to the results obtained in the present study, cultivar and N supply can have a significant effect on oat quality parameters. The best strategy to optimize oat grain quality under Manitoba conditions appears to be to choose an appropriate cultivar and adequate (115 kg ha^{-1} as recommended by Hamill, 2002)), but not excessive amounts of N.

4.4 Soil Water Dynamics of a Semidwarf and a Tall Oat Cultivar

Soil water availability is a major factor limiting cereal grain production in Western Canada (deJong and Steppuhn, 1983). Soil water availability is influenced by factors such as crop choice, environmental conditions, and agronomic management strategies. Examining crop evapotranspiration (ET) and soil water extraction patterns is important for determining how much water is used by the crop, and when and where water use is occurring in the soil profile. WUE (yield per unit of ET) is an important measure describing efficiency of water use (French and Schultz, 1974; Entz and Fowler, 1991).

4.4.1 Evapotranspiration

4.4.1.1 ET at stem elongation

Between crop establishment and stem elongation, ET for the oat cultivars ranged from 45 to 188 mm (Table 4.40). No significant ($p<0.05$) difference in ET between oat cultivars was observed at any of the three site years, indicating AC Ronald and Triple Crown had similar ET early in the growing season. For wheat, ET ranged from 35 to 185 mm (Table 4.40). No significant ($p<0.05$) difference in ET between wheat cultivars was observed at any of the three sites. Entz and Fowler (1989a) also reported no effect of the semidwarf character on ET in wheat prior to anthesis.

At the Carman 1999, Carman 2000, and Winnipeg 2000 sites, the oat cultivars had an average ET of 89, 50, and 187 mm at each site, respectively, while the wheat cultivars had an average ET of 81, 39, and 184 mm at each site, respectively. The only significant ($p<0.05$) difference in ET between oat and wheat cultivars was observed at the

Table 4.40. Evapotranspiration response of oat and wheat to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

	Carman 1999			Carman 2000			Winnipeg 2000		
	Evapotranspiration			Evapotranspiration			Evapotranspiration		
	Stem	Anthesis	Maturity	Stem	Anthesis	Maturity	Stem	Anthesis	Maturity
Main Effect		mm			mm			mm	
Previous Crop									
Pea	87	187	299	44	161	253	188	319	415
Flax	84	179	292	46	159	249	184	314	403
LSD (0.05)	10	20	10	30	18	26	16	19	30
Cultivar									
AC Ronald	87	180	308*a*[z]	55*a*	175*a*	270*a*	187	316	414*b*
Triple Crown	91	200	314*a*	45*ab*	161*ab*	263*ab*	188	321	433*a*
AC Taber	78	177	285*b*	35*b*	147*b*	228*c*	183	315	401*c*
AC Barrie	85	176	275*b*	44*ab*	157*ab*	245*bc*	185	314	388*c*
LSD (0.05)	10	21	19	14	20	25	7	6	13
N Rate (kg ha^{-1})									
0	85	182	300*a*	44	156	251	186	315*b*	400*b*
80	85	185	291*b*	46	164	251	185	318*a*	418*a*
LSD (0.05)	6	14	8	10	10	13	5	3	4
Source of Variation	ANOVA (P>F)								
Previous Crop (PC)	0.4731	0.3207	0.0933	0.8525	0.6485	0.6888	0.4932	0.5261	0.2727
Cultivar (Cvr)	0.0812	0.0934	0.0009	0.0450	0.0482	0.0104	0.4321	0.0852	<.0001
PC x Cvr	0.6144	0.4814	0.9047	0.3743	0.5758	0.5691	0.2452	0.3360	0.6890
N Rate	0.9895	0.7045	0.0484	0.6386	0.1494	0.9350	0.8555	0.0324	<.0001
PC x N Rate	0.4779	0.1921	0.5468	0.1068	0.0236	0.0428	0.9107	0.6967	0.2887
Cvr x N Rate	0.5779	0.4764	0.8073	0.6331	0.8819	0.2759	0.8287	0.1682	0.2963
PC x Cvr x N Rate	0.6498	0.5094	0.2764	0.4154	0.6769	0.5790	0.9353	0.1346	0.3302

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Carman 2000 site where AC Ronald had greater ET than AC Taber (Table 4.40).

No significant ($p<0.05$) effect of N fertilizer rate or previous crop on ET was observed at any of the three site years; nor were there any significant interactions between cultivar and N rate or previous crop observed at any of the three sites (Table 4.40). This indicates that with respect to ET all cultivars responded similarly to high and low N supplying environments.

4.4.1.2 Pre-anthesis ET

Between crop establishment and anthesis, ET for the oat cultivars ranged from 161 to 321 mm (Table 4.40). For wheat, ET ranged from 147 to 315 mm (Table 4.40). A large range of ET was observed due to different amounts of precipitation at each site (Table 4.10). No significant ($p<0.05$) effect of cultivar on pre-anthesis ET was observed for either oat or wheat at any of the three site years. Entz and Fowler (1989a) reported similar results in wheat where the semidwarf trait had no effect on pre-anthesis ET. Therefore, results of the present study suggest that the semidwarf character does not influence pre-anthesis ET and that ET may be more influenced by daily weather and water availability than by genetic factors.

Oat cultivars generally had higher pre-anthesis ET than the wheat cultivars. For example, at the Carman 1999, Carman 2000, and Winnipeg 2000 sites, oat cultivars used an average of 190, 168 and 319 mm of water, respectively, while wheat cultivars used an average of 177, 152 and 314 mm of water, respectively. Significant ($p<0.05$) effects of cultivar on ET were observed at the Carman 2000 site where AC Ronald had significantly greater ET than AC Taber (Table 4.40).

A significant ($p<0.05$) effect of N rate on pre-anthesis ET was observed at the Winnipeg 2000 site where N significantly increased ET (Table 4.40). No significant effect of previous crop on ET was observed at any of the three site years (Table 4.40), which indicates the high N supply of the pea green manure treatment did not affect ET in comparison to the low N supply of the flax system. There was also no significant interaction between cultivar and N rate or previous crop, indicating both cultivars responded similarly to high and low N supplying environments.

For both oat cultivars, approximately 61 to 75% of the total ET occurred by anthesis, while for the wheat cultivars, approximately 63 to 79% of seasonal ET occurred by anthesis. Higher values were seen at Winnipeg due to greater amounts of pre-anthesis precipitation that occurred at this site (Table 4.10). These values are similar to the 72% of total soil water extraction of wheat that occurred by anthesis in a study by French and Schultz (1984).

4.4.1.3 Growing season ET

Between crop establishment and maturity, ET for the oat cultivars ranged from 263 to 433 mm (Table 4.40). The range in ET values is due to varying amounts of precipitation at each site (Table 4.10). A significant ($p<0.05$) effect of cultivar on oat ET was observed only at the Winnipeg 2000 site, where Triple Crown had a greater ET than AC Ronald. Higher ET for Triple Crown at the Winnipeg 2000 site coincided with greater DM accumulation for Triple Crown than AC Ronald. No difference in either DM accumulation or ET was observed between Triple Crown and AC Ronald at the other two sites (Table 4.23), supporting the argument that higher ET for Triple Crown was due to higher biomass. A similar observation was made by Campbell et al. (1977) and Entz and Fowler (1989a) where an increase in total soil water use in wheat was due to increased biomass resulting in increased transpiration.

For wheat, ET between crop establishment and maturity ranged from 228 to 401 mm (Table 4.40). No significant ($p<0.05$) effect of cultivar on wheat ET was observed at any of the three site years. Entz and Fowler (1989a) also reported similar results in wheat where there was no effect of the semidwarf character on ET after anthesis. The general lack of differences in ET between tall and semidwarf crops in this study suggests that the semidwarf trait in oat or wheat does not appear to strongly influence growing season ET.

At maturity, the oat cultivars generally had higher seasonal ET than the wheat cultivars. For example, the average oat cultivar ET was 311, 266 and 424 mm at the Carman 1999, Carman 2000, and Winnipeg 2000 sites, respectively, compared with 280, 236 and 375 mm, respectively, for wheat. Significant differences between oat and wheat cultivars were observed at the Carman 1999 and Winnipeg 2000 site where AC Ronald and Triple Crown had significantly ($p<0.05$) higher ET than AC Taber and AC Barrie, and at the Carman 2000 site where both oat cultivars had higher ET than AC Taber (Table 4.43). In one of the few previous studies comparing oat and wheat, Hobbs and Krogman (1974) observed no significant ($p<0.05$) difference in seasonal ET for the two crop species (492 mm for wheat and 481 mm for oat) where the crops received an average of 472 mm of moisture (from precipitation and irrigation). However, results from the present study demonstrate greater seasonal ET for oat compared to wheat.

At the Carman 1999 and Winnipeg 2000 sites, N rate significantly increased seasonal ET (Table 4.40). Campbell et al. (1977) and Singh and Kumar (1981) reported similar results in wheat where N applications increased water use. Entz and Fowler (1989a) reported contrary results, however, where N additions did not significantly increase ET in winter wheat cultivars.

No significant ($p<0.05$) effect of previous crop on seasonal ET was observed at any of the three site years (Table 4.40). There was also no interaction between cultivar and N rate or previous crop, indicating all cultivars responded similarly to high and low N supply.

4.4.1.4 ET summary

Evapotranspiration varied substantially between sites due to different amounts of precipitation. In oat and wheat, the semidwarf character had little influence on ET at all three growth stages at all three site years. The only exception occurred at the Winnipeg 2000 site where Triple Crown had a higher seasonal ET than AC Ronald. However, Triple Crown also had significantly greater DM accumulation at maturity than AC Ronald. The increased biomass production of Triple Crown led to greater ET for Triple Crown due to greater transpirational leaf area. However, the relationship between increased DM accumulation translating into increased ET was not observed at all sites for all treatments. ET may have been more influenced by environmental factors, such as daily weather and water availability than genetics. However, we did not examine these phenomena in detail.

At all three site years, oat had greater seasonal ET than wheat seasonal ET for oat was 30-49 mm higher for oat than wheat. The higher ET for the oat cultivars led to higher productivity of the oat versus the wheat (i.e. grain yield) (Appendix Table A.4.0).

Therefore, oat may have a beneficial role in situations where soil dewatering is important, such as in years with excessive early season precipitation. Greater early resource capture by oat (i.e. greater water use) may also explain the greater competitiveness with weeds of oat versus wheat.

4.4.2 Net water extraction

Net water extraction is "the proportion of ET derived from soil water present at seeding" (Entz, pers. comm.). Net water extraction is an important soil water measure since it indicates how efficient the crop is at extracting water from the soil profile.

Net water extraction as a fraction of total growing season ET were similar for both oat cultivars (Tables 4.40 to 4.43). Similar results were observed for the wheat cultivars.

Net soil water extraction as a fraction of total growing season ET was greater for the oat cultivars than the wheat cultivars. At the Carman 1999 site, net soil water extracted from the soil profile up to 130 cm compared to total soil water use by oat and wheat was approximately 37 and 30% of total ET, respectively. At the Carman 2000 site, oat and wheat derived 25 and 15% of total ET from soil water present at spring seeding, respectively, from the profile compared to total soil water use. At the Winnipeg 2000 site, oat and wheat extracted 7 and 2% of total ET from soil water present at spring seeding, respectively, from the soil profile compared to total soil water use. The high values observed at the Carman 1999 site were due to lower amounts of precipitation during the growing season resulting in greater water extraction from the soil profile

Table 4.41. Soil water extraction response of oat and wheat at three soil depth increments to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999).

	Soil Water Use (mm)											
	Stem Elongation				Anthesis				Maturity			
	Depth (cm)				Depth (cm)				Depth (cm)			
Main Effect	**0-30**	**30-90**	**90-130**	**0-130**	**0-30**	**30-90**	**90-130**	**0-130**	**0-30**	**30-90**	**90-130**	**0-130**
Previous Crop												
Pea	4.1	9.4	-0.8	12.7	8.5	14.5	2.6	25.5	30.3	49.8	22.9	103
Flax	1.4	9.7	-1.1	10.1	4.2	15.0	3.3	22.4	28.3	49.1	18.4	95.8
LSD (0.05)	5	8	3	10	5	12	7	13	4	18	10	9
Cultivar												
AC Ronald	4.0	9.2	0.2	13.4	6.7	12.3*b*^{z}	3.5	22.5	31.4	53.6*ab*	27.3*ab*	112.4*a*
Triple Crown	4.2	13.6	-0.8	17.1	8.5	21.7*a*	3.6	33.7	29.6	59.2*a*	29.2*a*	118.0*a*
AC Taber	-0.6	6.2	-1.6	4.0	4.4	11.8*b*	4.2	20.4	29.0	47.9*b*	11.7*c*	88.6*b*
AC Barrie	3.4	9.3	-1.6	11.1	5.8	13.1*b*	0.4	19.4	27.1	37.1c	14.4*bc*	78.7*b*
LSD (0.05)	5	5	3	10	4	7	8	13	4	9	13	19
N Rate (kg ha^{-1})												
0	2.3	9.7	-0.5	11.4	5.9	14.6	4.5	25.0	29.3	51.0	23.3*a*	103.6*a*
80	3.2	9.5	-1.3	11.4	6.8	14.9	1.3	23.0	29.2	48.0	18.1*b*	95.2*b*
LSD (0.05)	3	3	2	6	2	3	5	7	2	4	5	8
Source of Variation	ANOVA (P>F)											
Previous Crop (PC)	0.1736	0.9180	0.8000	0.4731	0.0600	0.9069	0.7855	0.5152	0.2055	0.9168	0.2495	0.0933
Cultivar (Cvr)	0.2061	0.0558	0.5912	0.0812	0.2207	0.0205	0.7596	0.1227	0.1178	0.0004	0.0251	0.0009
PC x Cvr	0.7734	0.4475	0.9201	0.6144	0.5189	0.3148	0.3267	0.3463	0.2412	0.4662	0.6480	0.9047
N Rate	0.4850	0.8671	0.3945	0.9895	0.2679	0.8634	0.2161	0.5847	0.9005	0.0925	0.0331	0.0484
PC x N Rate	0.6269	0.3136	0.9084	0.4779	0.6726	0.2223	0.2840	0.2279	0.5990	0.5428	0.1018	0.5468
Cvr x N Rate	0.7106	0.6522	0.4565	0.5779	0.9062	0.3750	0.5473	0.4555	0.5070	0.3625	0.0950	0.8073
PC x Cvr x N Rate	0.3230	0.8909	0.6639	0.6498	0.2904	0.4658	0.4148	0.6309	0.8710	0.5145	0.1622	0.2764

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Table 4.42. Soil water extraction response of oat and wheat at three soil depth increments to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (2000).

	Soil Water Use (mm)											
	Stem Elongation				Anthesis				Maturity			
	Depth (cm)				Depth (cm)				Depth (cm)			
Main Effect	0-30	30-90	90-130	0-130	0-30	30-90	90-130	0-130	0-30	30-90	90-130	0-130
Previous Crop												
Pea	-10.8	-14.3	-5.0	-30.0	14.9	18.4	-0.5	32.8	3.0	37.5	11.8	52.3
Flax	-12.9	-13.4	-1.8	-28.1	13.7	15.2	1.2	30.0	2.8	35.3	10.7	48.7
LSD (0.05)	6.1	16.1	9.6	30.3	2.8	13.9	3.9	17.5	2.9	20.3	5.9	25.8
Cultivar												
AC Ronald	-9.5*a*[z]	-9.8*a*	0.9	-18.4*a*	17.1	23.3	6.3	46.6*a*	4.4	43.8*a*	20.8*a*	69.0*a*
Triple Crown	-11.1*ab*	-12.7*a*	-5.0	-28.9*ab*	15.1	18.2	-0.9	32.4*ab*	3.4	45.5*a*	13.2*a*	62.1*ab*
AC Taber	-13.0*b*	-19.4*b*	-6.8	-39.1*b*	13.3	9.2	-4.4	18.0*b*	3.7	23.0*b*	0.4*b*	27.1*c*
AC Barrie	-13.8*b*	-13.3*ab*	-2.6	-29.8*ab*	11.6	16.6	0.5	28.7*ab*	0.2	33.2*ab*	10.6*ab*	44.0*bc*
LSD (0.05)	2.7	6.4	8.6	13.9	4.7	9.8	9.7	19.6	4.3	12.8	12.7	24.9
N Rate (kg ha^{-1})												
0	-11.3	-14.6	-4.0	-30.2	13.8	15.0	-1.2	27.7	2.6	36.5	11.7	50.8
80	-12.2	-13.1	-2.7	-27.9	14.7	18.6	1.9	35.2	3.2	36.2	10.8	50.3
LSD (0.05)	1.5	4.4	6.0	9.7	2.1	5.1	5.9	10.4	1.9	6.5	7.7	13.1
Source of Variation	ANOVA (P>F)											
Previous Crop (PC)	0.3593	0.8745	0.3738	0.8525	0.5242	0.5089	0.2585	0.6485	0.7994	0.7496	0.5961	0.6888
Cultivar (Cvr)	0.0136	0.0382	0.3089	0.0450	0.0871	0.0517	0.1719	0.0482	0.2111	0.0056	0.0261	0.0104
PC x Cvr	0.7748	0.7752	0.2729	0.3743	0.3495	0.7074	0.5808	0.5758	0.6893	0.6077	0.4553	0.5691
N Rate	0.4514	0.4853	0.6544	0.6386	0.3973	0.1690	0.2833	0.1494	0.5214	0.9283	0.8270	0.9350
PC x N Rate	0.2355	0.0853	0.2795	0.4068	0.1308	0.0073	0.2509	0.0236	0.5497	0.0067	0.2138	0.0428
Cvr x N Rate	0.5187	0.9425	0.4263	0.6331	0.4030	0.6537	0.5431	0.8819	0.6966	0.3299	0.1866	0.2759
PC x Cvr x N Rate	0.6800	0.8046	0.3185	0.4154	0.6124	0.7219	0.2995	0.6769	0.1272	0.4388	0.9320	0.5790

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Table 4.43. Soil water extraction response of oat and wheat at three soil depth increments to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Winnipeg, MB (2000).

	Soil Water Use (mm)											
	Stem Elongation				Anthesis				Maturity			
	Depth (cm)				Depth (cm)				Depth (cm)			
Main Effect	**0-30**	**30-90**	**90-130**	**0-130**	**0-30**	**30-90**	**90-130**	**0-130**	**0-30**	**30-90**	**90-130**	**0-130**
Previous Crop												
Pea	-14.0	-18.9	-5.5	-38.3	-1.2	-14.4	-7.5	-23.1	12.2	14.1	-3.1	23.2
Flax	-16.0	-20.2	-6.1	-42.3	-1.2	-17.4	-8.8	-27.4	10.2	5.5	-5.2	10.6
LSD (0.05)	10.4	4.1	2.2	16.1	7.7	7.7	4.6	19.2	7.4	18.2	6.0	30.1
Cultivar												
AC Ronald	-14.2	-19.8	-5.3	-39.3	-1.4*ab*[z]	-16.6	-7.8	-25.7	12.8*b*	13.1*b*	-4.2	21.7*b*
Triple Crown	-14.0	-18.9	-5.2	-38.1	2.1*a*	-14.5	-8.0	-20.4	20.7*a*	23.7*a*	-3.4	41.0*a*
AC Taber	-16.6	-20.3	-6.3	-43.1	-2.4*b*	-16.6	-8.8	-26.9	8.0*bc*	4.8*c*	-4.1	8.6*c*
AC Barrie	-15.1	-19.4	-6.3	-40.8	-3.1*b*	-16.0	-7.9	-28.0	3.5*c*	-2.5*c*	-4.7	-3.8*c*
LSD (0.05)	3.9	3.9	2.2	6.6	3.6	3.8	1.5	6.2	5.8	8.1	2.2	12.8
N Rate (kg ha^{-1})												
0	-15.6	-18.9	-5.6	-40.1	-3.6*b*	-15.7	-7.9	-27.1*b*	6.7*b*	5.3*b*	-3.9	8.2*b*
80	-14.3	-20.2	-6.0	-40.5	1.2*a*	-16.1	-8.4	-23.3*a*	15.7*a*	14.2*a*	-4.3	25.6*a*
LSD (0.05)	2.9	2.3	1.7	4.7	2.2	2.0	1.3	3.5	2.7	2.3	1.3	4.3
Source of Variation	ANOVA (P>F)											
Previous Crop (PC)	0.5819	0.3651	0.4681	0.4932	0.9985	0.2996	0.4392	0.5261	0.4500	0.2310	0.3475	0.2727
Cultivar (Cvr)	0.5012	0.8917	0.5720	0.4321	0.0330	0.6383	0.4339	0.0852	<.0001	<.0001	0.6474	<.0001
PC x Cvr	0.6757	0.4324	0.2937	0.2452	0.4633	0.7542	0.6013	0.3360	0.6413	0.5450	0.5861	0.689
N Rate	0.3720	0.2624	0.6237	0.8555	0.0002	0.6687	0.4344	0.0324	<.0001	<.0001	0.4781	<.0001
PC x N Rate	0.5713	0.6430	0.9773	0.9107	0.7826	0.9860	0.5561	0.6967	0.2932	0.4355	0.9909	0.2887
Cvr x N Rate	0.8483	0.8783	0.9985	0.8287	0.1892	0.6479	0.8762	0.1682	0.8715	0.2360	0.5554	0.2962
PC x Cvr x N Rate	0.8295	0.8287	0.3316	0.9353	0.1409	0.7562	0.0468	0.1346	0.7834	0.5217	0.1491	0.3302

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

compared to total ET. At the Winnipeg 2000 site, there was a high amount of precipitation, leading to low net water being extracted. Similar net water extraction values (approximately 20% with a range of 5-35%) were observed in wheat by Entz et al. (1992) and in winter wheat by Entz and Fowler (1989b). Higher net soil water extraction as a fraction of seasonal ET of oat versus wheat indicates that oat is more efficient at extracting water from the soil profile present at spring seeding. This may be important in wetter areas to help remove excess water. However, it is also interesting to note that the low net water extraction at the wet Winnipeg site suggests that even high water use by annual crops such as oat cannot "drain" the soil profile, which can lead to environmental issues such as leaching of nitrate-N.

4.4.3 Soil water extraction patterns

Soil water extraction patterns are useful because they illustrate when and where in the soil profile water use occurs. Soil water extraction depends on both environmental and genetic factors. Maximum soil water extraction depths reported for wheat range from 70 to 200 cm (Hurd, 1968; Lupton et al., 1974). Previous studies have shown no significant correlation between plant height and soil water extraction patterns or rooting depth for different winter wheat cultivars (Lupton et al., 1974; Cholick et al., 1977; Entz et al., 1992) or spring wheat (Entz et al., 1992). No studies on soil water extraction patterns in oats appear in the literature. Therefore, little is known about the influence of the semidwarf character on soil water extraction patterns of oat. In the present study, soil water extraction patterns by oat cultivars AC Ronald and Triple Crown and wheat cultivars AC Taber and AC Barrie were measured at stem elongation, anthesis, and maturity at three different soil depths (0-30 cm, 30-90 cm, and 90-130 cm) to determine if differences exist for oat and wheat cultivars and if the semidwarf character influenced water extraction in the profile. The influences of N fertilizer and crop rotation on water extraction patterns were also examined.

4.4.3.1 Soil water extractions patterns at stem elongation

No significant ($p<0.05$) effect of cultivar within oat or wheat was observed for soil water extracted in the 0-30, 30-90, and 90-130 cm soil depths at stem elongation for any of the three site years (Tables 4.41 to 4.43). However, it is interesting to note that the majority of water was extracted by oat and wheat in the top 90 cm of the soil profile. Singh and Kumar (1981) and Entz et al. (1992) reported similar results for wheat.

Significant ($p<0.05$) differences between oat and wheat soil water extraction patterns within the soil profile at stem elongation were observed at the Carman 2000 site where both oat cultivars extracted more water in the 30-90 cm soil depth than AC Taber (Table 4.42). Greater soil water extraction by AC Ronald than AC Taber at the 30-90 cm depth led to an increase in net water extraction by AC Ronald. However, at the other two sites, no significant ($p<0.05$) difference between oat and wheat soil water extraction patterns were observed (Tables 4.41 and 4.43). These results indicate that even though oat and wheat tended to extract the majority of water from the top 90 cm of the soil profile at stem elongation, both oat and wheat cultivars were extracting similar amounts of water from the soil profile.

No significant ($p<0.05$) effect of N rate or previous crop was observed on soil water extraction patterns at stem elongation for any of the three site years (Tables 4.41 to

4.43). As well, there were no interactions between cultivar and N rate or previous crop, indicating all cultivars responded similarly to high and low N supply. Therefore, the present study suggests differences in water use were genetic, not environmental or management related.

4.4.3.2 Pre-anthesis soil water extraction patterns

Among oat cultivars, a significant ($p<0.05$) effect of cultivar on pre-anthesis soil water extraction was observed at the Carman 1999 site where Triple Crown extracted significantly more water in the 30-90 cm soil depth than AC Ronald (22 versus 12 mm) (Table 4.41). The increase in water extraction was due to Triple Crown extracting more water from lower within the 30-90 cm increment (i.e. 70-90 cm zone) (Appendix Tables A.4.14, A.4.17, A.4.20). No significant ($p<0.05$) effect of cultivar on pre-anthesis soil water extraction by oat in the 0-30, 30-90, and 90-130 cm soil depths was observed at the two remaining site years (Tables 4.42 to 4.43).

At the Carman 1999 site, pre-anthesis soil water extraction by AC Ronald in the 0-30, 30-90, and 90-130 cm increments was 6.7, 12, and 3.5 mm, respectively, which represents 30, 55, and 16% of net soil water extraction in the profile, respectively (Table 4.41). Soil water extraction by Triple Crown for the three soil increments was 8.5, 21.7, 3.6 mm, respectively, which represents 25, 64, and 11%, respectively, of net water extraction in the profile. It is interesting to note that prior to anthesis, Triple Crown extracted a greater percentage of water from the 30-90 cm increment than AC Ronald. This supports the previous observation where Triple Crown extracted significantly more water in the 30-90 cm depth than AC Ronald at stem elongation. At Carman 2000 and

Winnipeg 2000, a recharge of water between the initial water measurement and anthesis led to negative values of soil water extraction (Tables 4.42 and 4.43), so the percentage of water extracted from each increment compared to total net water extraction could not be determined. General trends indicate that both AC Ronald and Triple Crown extracted the majority of water pre-anthesis in the top 90 cm of the soil profile. Water extraction at this depth indicates there is root activity up to 90 cm. Within the top 90 cm of the soil profile, the majority of water was extracted in the 30-90 cm increment. However, rain may have masked water use from the 0-30 cm zone. At the Carman 2000 site, there was more water extracted in the 0-30 increment by both oat cultivars versus the Carman 1999 and Winnipeg 2000 sites. A possible explanation could be due to lower amounts of precipitation prior to moisture content determination at anthesis compared to the other two sites (Appendix Tables A.3.0 to A.3.3).

Among wheat cultivars, no significant ($p<0.05$) effect of cultivar on pre-anthesis soil water extraction in the 0-30, 30-90, and 90-130 cm soil depths was observed at any of the three site years (Tables 4.41 to 4.43). This result indicates the semidwarf character in wheat did not influence soil water patterns in the soil profile. As seen previously with oat in the present study, the majority of water extracted by wheat occurred in the top 90 cm of the soil profile. Within the top 90 cm, more water was being extracted in the 30-90 cm soil depth. However, once again, rain may have masked water use from the 0-30 cm zone.

Significant ($p<0.05$) differences between wheat and oat cultivars were observed in soil water extraction in the 0-30 and 30-90 cm soil depths at anthesis at two of the three sites. At the Carman 1999 site (Table 4.41), Triple Crown extracted more water than AC

Taber and AC Barrie in the 30-90 cm soil depth. At the Winnipeg 2000 site (Table 4.43), the only significant ($p<0.05$) effect of cultivar on soil water extraction pattern occurred in the 0-30 cm soil depth where Triple Crown extracted more water than both wheat cultivars. The lack of significant difference between oat and wheat soil water extraction patterns indicates all cultivars extracted water from similar depths in the soil profile.

No significant ($p<0.05$) effect of nitrogen rate on soil water extraction patterns at the three soil depths were observed at anthesis for the two Carman sites (Tables 4.41 and 4.42). At the Winnipeg 2000 site (Table 4.43), an increase in N rate led to an increase in water extracted at the 0-30 cm depth and, overall, for 0-130 cm. Although N fertilizer rate did not influence soil water extraction patterns at each soil depth, it is interesting to note that in the fertilized and unfertilized treatments, the majority of water extraction occurred in the top 90 cm of the soil profile. Comfort et al. (1988) observed contrary results where depth of soil water use was greater at a rate of 67 kg N ha^{-1} versus 134 kg N ha^{-1}.

No significant ($p<0.05$) effect of previous crop on soil water extraction patterns at all three soil depths were observed at any of the three site years (Tables 4.41 to 4.43). There was also no interaction between cultivar and N rate or previous crop, indicating all cultivars responds similarly to high or low N supply.

4.4.3.3 Soil water extraction patterns at maturity

No significant ($p<0.05$) effect of cultivar on oat soil water extraction patterns in the 0-30, 30-90, and 90-130 cm soil depths were observed at the Carman 1999 and 2000 sites (Tables 4.41 and 4.42). However, at the Winnipeg 2000 site (Table 4.43), Triple

Crown extracted significantly more water than AC Ronald up to 90 cm. The increase in soil water extracted by Triple Crown was due to greater water extraction lower within the 30-90 cm increment (70-90 cm zone) than AC Ronald (Appendix Tables A.4.15, A.4.18, and A.4.21).

At the Carman 1999 site, soil water extraction in each depth increment for AC Ronald over the growing season was 31.4, 53.6, 27.3 mm, respectively, which represents 28, 48, and 24% of total net water extracted. Triple Crown extracted 29.6, 59.2, and 29.2 mm of water in the 0-30, 30-90, and 90-130 cm zones, respectively, which represents 25, 50, and 25% of total net soil water extraction in the profile (Table 4.41). Therefore, the seasonal soil water use patterns was similar for the two oat cultivars at this site.

At the Carman 2000 site, soil water extraction by AC Ronald at maturity in the 0-30, 30-90, and 90-130 cm was 4.4, 43.8, and 20.8 mm, respectively, which equals 6, 64, and 30%, respectively, of total net soil water extracted. Triple Crown extracted 3.4, 45.5, and 13.2 mm of water from each three depth increments, which represents 6, 73, and 21%, respectively, of the net soil water extracted (Table 4.42). It is interesting to note the range in proportion of water use by oat in the 30-90 cm zone at both Carman sites (48 to 73%). Higher proportion of water extraction in 30-90 cm zone at the Carman 2000 site than the Carman 1999 site may have been due to less precipitation near maturity at the 2000 site compared to the 1999 site (Table 4.10), possibly indicating that drier conditions increased rooting depth and water use at greater depths.

At the Winnipeg 2000 site at maturity, a recharge of water between the initial soil water measurement and maturity led to negative values in soil water extraction. Therefore, the percentage of water from each increment extracted compared to net water extraction could not be determined.

At maturity, the majority of water extracted by the oat cultivars occurred in the top 90 cm of the soil profile. The greatest extraction occurred in the 30-90 cm depth. However, 0-30 cm zone was difficult to examine because of soil water recharge occurring at this depth. Entz et al. (1992) reported similar results in wheat, where most soil water extraction occurred in the upper 70 cm of the soil profile. Singh and Kumar (1981) also reported similar results in wheat and barley where those crop species extracted most of the water (89-92%) from the upper 90 cm of soil.

At the Carman 1999 and 2000 sites, both oat cultivars extracted water in the 90-130 cm increment, indicating root activity at this depth (Table 4.40 and 4.41). The increased root activity at this depth may be due to lower amounts of precipitation during the growing season at these sites compared to the Winnipeg 2000 site. The increased water extraction at this depth may have also contributed to greater net soil water extraction by the oat cultivars at these two sites compared to the Winnipeg 2000 site. This depth of soil water extraction may play a role in cropping systems when sub-soil moisture or nitrate-N is present.

Among wheat cultivars, no significant ($p<0.05$) effect of cultivar on soil water extraction patterns at the three soil depths at maturity were observed at the Carman and Winnipeg 2000 sites (Tables 4.42 and 4.43). At the Carman 1999 site, AC Taber extracted significantly more water in the 30-90 cm soil depth than AC Barrie (Table 4.41). However, the greater water extraction at this depth did not translate into greater net water extraction. Lupton et al. (1974), Cholick et al. (1977), Entz et al. (1992), and Richards (1992) all observed few significant differences in soil water extraction patterns between tall and semidwarf wheat cultivars.

Significant ($p<0.05$) differences in soil water extraction patterns between oat and wheat were observed at maturity in the 30-90 cm increment at the Carman 1999 site where Triple Crown extracted more water than both wheat cultivars (Table 4.41); at the Carman 2000 site where both oat cultivars extracted more water than AC Taber (Table 4.42); and at the Winnipeg 2000 site where both oat cultivars extracted more water than both wheat cultivars (Table 4.43). Greater soil water extraction by oat compared with wheat in the 30-90 cm increment indicates greater root activity for oat than wheat in this soil increment.

At two of the three sites, the oat cultivars extracted more water from the 90-130 cm depth in the profile than the wheat cultivars (Appendix Tables A.4.15, A.4.18, and A.4.21). These results suggest deeper root activity for oat compared with wheat. Water extraction by oat cultivars at this depth may play a role in cropping systems where subsoil moisture is available. The data from the present study indicate that the majority of water extracted by maturity from the soil profile occurred in the top 90 cm by both oat and wheat. However, the oat cultivars had higher net water extraction in comparison to the wheat cultivars at all three sites due to greater water extraction deeper in the soil profile, therefore resulting in higher production (i.e. yield).

No significant ($p<0.05$) effects of nitrogen rate on soil water extraction pattern up to 90 cm were observed at either Carman sites (Tables 4.41 and 4.42). At the Winnipeg 2000 site, an increase in N rate led to a significant increase in soil water extracted up to 90 cm (Table 4.43). No significant effect of N rate on water extraction in the 90-130 cm increment was observed at maturity for two of the three sites (Tables 4.42 and 4.43). At the Carman 1999 site (Table 4.41), an increase in N rate led to a significant ($p<0.05$) decrease in water extraction in the 90-130 cm soil depth.

No significant ($p<0.05$) effect of previous crop, or interactions between cultivar and N rate or previous crop on soil water extraction patterns in the three soil depths at maturity were observed at any of the three sites (Tables 4.41 to 4.43). The lack of effects indicate there was no influence of either pea green manure or flax on water extraction, and that all cultivars responded similarly to high and low N supply.

4.4.3.4 Soil water extraction patterns summary

At two of the three site years, oat cultivar had no significant effect on water extraction patterns, indicating the semidwarf trait did not strongly influence where in the soil profile water was being extracted. Similar results were reported by others (Lupton et al. 1974; Cholick et al., 1977; Entz et al., 1992) who concluded that plant height does not play a role in soil water extraction patterns. However, significant differences in soil water extraction patterns were observed at the Winnipeg 2000 site where Triple Crown had greater water extraction compared to AC Ronald up to 90 cm. Under high soil moisture conditions, as was observed at Winnipeg, the conventional oat cultivars may be able to extract more water in the soil profile than semidwarf cultivars.

Both oat and wheat cultivars extracted the majority of soil water from the top 90 cm of the profile at both anthesis and maturity. Within the top 90 cm, the majority of water extracted by both oat and wheat occurred in the 30-90 cm increment. However, oat cultivars generally extracted more water from the entire soil profile than wheat because the oat cultivars were extracting more water at deeper depths in the soil profile (90-130 cm). Therefore, oat may play a role in cropping systems where excess sub-soil moisture or nitrate-N levels exist due to inclusion of short-rooted crops in rotation which do not access these subsoil levels, or cropping systems where deep drainage occurs.

4.4.4 Water use efficiency

Water use efficiency, defined as yield per unit of evapotranspiration, is an important factor in improving the productivity of cereal grains. No previous studies have examined the differences of WUE of grain and biomass yield between semidwarf and conventional oat cultivars. The effect of N supply from N fertilizer and crop rotation on WUE was also examined.

4.4.4.1 Grain WUE

Among oat cultivars, cultivar had a significant ($p<0.05$) effect on oat grain WUE at the Carman 1999 site (Table 4.44), where AC Ronald had a higher WUE than Triple Crown. Similar results were reported in wheat (Entz and Fowler, 1989a) where the semidwarf cultivar Norwin had a greater WUE than the conventional cultivar Norstar. In pot experiments, Ehdaie (1995) reported that modern, short cultivars had higher WUE than old, tall cultivars. It is interesting to note that the higher WUE of AC Ronald coincides with a significantly higher yield for AC Ronald versus Triple Crown at the Carman 1999 site (Table 4.20). At the remaining two site years in the present study, there was no significant difference in grain WUE between AC Ronald and Triple Crown, although AC Ronald consistently had higher WUE (Table 4.44). Among wheat cultivars, no significant ($p<0.05$) cultivar effect on grain WUE was observed at any of the three site

Table 4.44. Grain and dry matter water use efficiency response of oat and wheat to cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

Main Effect	Carman 1999				Carman 2000				Winnipeg 2000			
	Water Use Efficiency kg ha^{-1} mm^{-1} ET				Water Use Efficiency kg ha^{-1} mm^{-1} ET				Water Use Efficiency kg ha^{-1} mm^{-1} ET			
		Dry Matter				Dry Matter				Dry Matter		
	Grain	Stem	Anthesis	Maturity	Grain	Stem	Anthesis	Maturity	Grain	Stem	Anthesis	Maturity
Previous Crop												
Pea	13.1	17.8	29.8	33.0	14.9	82.2	57.9	44.7	8.3	21.6*a*	32.7*a*	27.0
Flax	13.6	19.1	30.8	34.4	15.1	56.1	55.0	39.7	7.0	17.4*b*	28.6*b*	22.9
LSD (0.05)	1.2	7.9	5.2	2.8	2.8	28.8	6.4	9.7	2.2	2.2	2.4	4.2
Cultivar												
AC Ronald	17.3*a*[z]	18.5*b*	33.5*ab*	38.9*a*	18.4*a*	73.1	57.2	42.1	10.1*a*	19.3	29.6	24.9
Triple Crown	14.6*b*	22.2*a*	34.5*a*	39.0*a*	17.4*a*	75.3	62.6	43.6	9.7*a*	19.2	30.4	26.5
AC Taber	10.1*c*	15.4*c*	24.2*c*	28.0*b*	11.8*b*	79.6	56.0	42.7	5.1*b*	18.7	30.2	23.9
AC Barrie	11.1*c*	17.7*bc*	29.0bc	28.8*b*	12.9*b*	48.8	49.9	40.3	5.7*b*	20.6	32.3	24.4
LSD (0.05)	1.6	2.9	5.1	4.8	2.6	30.2	9.3	9.3	0.8	2.2	2.8	2.0
N Rate (kg ha^{-1})												
0	13.2	16.2*b*	27.4*b*	30.9*b*	14.7	63.1	54.0	39.7*b*	7.0*b*	18.1*b*	27.5*b*	22.8*b*
80	13.5	20.7*a*	33.2*a*	36.5*a*	15.4	75.3	58.9	44.6*a*	8.3*a*	20.8*a*	33.7*a*	27.1*a*
LSD (0.05)	1.1	2.6	1.9	2.5	1.5	14.3	5.9	4.5	0.6	1.2	1.8	1.5
Source of Variation	ANOVA (P>F)											
Previous Crop (PC)	0.2917	0.6457	0.5581	0.2059	0.9822	0.0623	0.2459	0.1991	0.1631	0.0084	0.0120	0.0509
Cultivar (Cvr)	<.0001	0.0013	0.0018	<.0001	<.0001	0.1725	0.0742	0.8983	<.0001	0.3524	0.2524	0.0755
PC x Cvr	0.1482	0.0026	0.3665	0.1935	0.4365	0.6743	0.2562	0.8734	0.7085	0.1501	0.1313	0.1951
N Rate	0.5509	0.0012	<.0001	0.0001	0.1532	0.0907	0.0992	0.0334	<.0001	<.0001	<.0001	<.0001
PC x N Rate	0.5892	0.3109	0.0907	0.5175	0.7314	0.5609	0.9007	0.9173	0.0359	0.6375	0.0600	0.0553
Cvr x N Rate	0.9497	0.9223	0.0458	0.3101	0.2084	0.5026	0.4716	0.0751	0.8494	0.9062	0.1423	0.5915
PC x Cvr x N Rate	0.5452	0.3359	0.4161	0.6314	0.1925	0.1140	0.4991	0.1821	0.6889	0.4767	0.2529	0.7408

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P<0.05$).

years (Table 4.44).

At all three site years, AC Ronald and Triple Crown had a significantly greater ($p<0.05$) grain WUE than AC Taber and AC Barrie (Table 4.44). At the Carman 1999, Carman 2000, and Winnipeg 2000 sites, the oat cultivars had an average grain WUE of 16.0, 17.9, and 9.9 kg ha^{-1} mm^{-1} ET at each site, respectively, while wheat cultivars had an average grain WUE of 10.6, 12.4, and 5.4 kg ha^{-1} mm^{-1} ET at each site, respectively. Higher WUE for oat indicates greater efficiency of ET use for oat versus wheat, which translated into greater productivity, i.e. yield (Appendix Table A.4.0).

Nitrogen rate had a significant ($p<0.05$) effect on grain WUE at the Winnipeg 2000 site, where the higher N rate led to a greater WUE (Table 4.44). Nitrogen also increased ET at the Winnipeg site, so the positive effect of N on WUE was due to an increase in yield/ET ratio (Tables 4.40 and 4.44). Entz and Fowler (1989a) reported contrary results in wheat where N did not increase ET, and therefore the increased WUE with N additions was not due to greater water use. Entz and Fowler concluded in order for N to increase WUE, N must increase the proportion of ET that passes through the plant. At the Carman 1999 and 2000 sites, an increase in N did not result in an increase in WUE, indicating that N did not increase the proportion of ET that passed through the plants (Table 4.40). However, the lack of response of N rate on WUE was probably due to high soil nitrogen levels present at the Carman sites compared to the Winnipeg 2000 site (Table 3.2).

Previous crop had no significant ($p<0.05$) effect on grain WUE at any of the three site years, indicating the increased N supply from the pea system did not result in an increase in WUE (Table 4.44). On the other hand, Forster (1999) observed that addition of legume N from alfalfa residue increased wheat WUE in five of seven site years. There were also no interactions between cultivar and N rate or previous crop in the present study, indicating both cultivars responded similarly to high versus low N supply.

4.4.4.2 Dry matter WUE at stem elongation

At stem elongation, cultivar had a significant ($p<0.05$) effect on oat dry matter (DM) WUE at the Carman 1999 site, where Triple Crown had a higher WUE than AC Ronald. For wheat, no significant ($p<0.05$) effect of cultivar on DM WUE was observed at any of the three site years (Table 4.44). The similar WUE for the semidwarf and conventional wheat cultivars indicates that the semidwarf character did not influence efficiency of ET use early in the growing season. There were no consistent differences in the WUE of oat compared with wheat at any of the three sites (Table 4.44).

A significant ($p<0.05$) effect of cultivar between oat and wheat on DM WUE at stem elongation was observed at the Carman 1999 site (Table 4.44) where Triple Crown had greater DM WUE than AC Ronald and both wheat cultivars. This may indicate under lower soil water levels (Carman 1999), Triple Crown was more using water more efficiently early in the growing season versus AC Ronald and the wheat cultivars. At the remaining two sites, there was no difference in DM WUE between oat and wheat (Table 4.44).

Nitrogen rate had a significant ($p<0.05$) effect on WUE at stem elongation at the Carman 1999 and Winnipeg 2000 sites, where an increase in N increased DM WUE (Table 4.44). The increase in WUE was due to the significant increase in DM accumulation (Table 4.23) with increasing N rate at these sites, possibly resulting in an increased proportion of water going through the plant (Entz and Fowler, 1989a).

Previous crop had a significant ($p<0.05$) effect on DM WUE at stem elongation at the Winnipeg 2000 site (Table 4.44), where the oat crop following pea had a greater WUE versus the oat crop following flax. The increase in WUE was due to an increase in oat DM accumulation following pea, which again would increase transpiration as a fraction of ET (Entz and Fowler, 1989a).

There were no consistent interactions between cultivar and N rate or previous crop on WUE of DM accumulation at stem elongation at all three site years, indicating both cultivars responded similarly to high and low N supply.

4.4.4.3 Dry matter WUE at anthesis

Among oat cultivars, the cultivar effect was not significant ($p<0.05$) for anthesis DM WUE at any of the three site years (Table 4.44), indicating AC Ronald and Triple Crown used pre-anthesis ET at the same efficiency. Similar results were observed among wheat cultivars.

WUE of the oat cultivars were generally greater than the wheat cultivars (Table 4.44). However, the only significant ($p<0.05$) difference between cultivars occurred at the Carman 1999 site where Triple Crown had significantly higher WUE than AC Taber and AC Barrie. Greater WUE of the oat cultivars can be attributed to an increase in the ratio of DM to ET of oat versus wheat and again illustrates why oat is more competitive than wheat.

Nitrogen rate had a significant ($p<0.05$) effect on anthesis DM WUE at Carman 1999 and Winnipeg 2000 sites (Table 4.44), where increasing N rate increased WUE. The present study suggests that N rate increased biomass at a greater rate than ET. Similar results in wheat were reported by Entz and Fowler (1989a).

Previous crop had a significant ($p<0.05$) effect on anthesis DM WUE at the Winnipeg 2000 site (Table 4.44), where the cultivars following pea had a greater WUE versus the cultivars following flax. The present study suggests that under high N supplying systems (pea), oat and wheat used pre-anthesis ET more efficiently than under low N supplying systems (flax). A significant difference of previous crop on DM WUE at anthesis was only observed at the Winnipeg site. A possible explanation may due to denitrification of nitrate-N in the soil as a result of excessive moisture conditions at that site, which led to lower indigenous N levels present compared to the Carman sites.

There was also no consistent cultivar by N rate or previous crop interactions on DM WUE at anthesis at all three sites (Table 4.44), indicating all cultivars used pre-anthesis ET at the same efficiency in high and low N supply.

4.4.4.4 Dry matter WUE at maturity

Among oat cultivars, no significant ($p<0.05$) effect of cultivar on maturity DM WUE was observed at any of the three site years (Table 4.44), indicating AC Ronald and Triple Crown used seasonal ET at the same efficiency. Similar results were observed among the wheat cultivars in the present study.

WUE for oat was generally greater than for wheat (Table 4.44), indicating oat was more efficient at utilizing seasonal ET for DM production than wheat. The only significant ($p<0.05$) difference in WUE of DM production at maturity between oat and wheat occurred at the Carman 1999 site where Triple Crown and AC Ronald had significantly ($p<0.05$) greater WUE than AC Barrie and AC Taber. Dry matter is proportional to transpiration (deWit, 1958), so DM can only increase if a higher proportion of ET is used as transpiration, i.e., less soil evaporation. Therefore, in the present study, higher DM production of oat resulted in greater transpiration, which means a higher proportion of ET is lost as transpiration, not soil evaporation.

Nitrogen rate had a significant ($p<0.05$) effect on WUE at maturity at all three site years (Table 4.44), where an increase in N increased WUE. The higher WUE was attributed to N increasing DM at a greater rate than ET. Similar results were reported for wheat by Entz and Fowler (1989a).

There was no significant ($p<0.05$) effect of previous crop on WUE at maturity at all three site years, indicating no influence of pea or flax in rotation. There was also no interaction between cultivar and N rate or previous crop, indicating both oat and wheat responded similarly to high and low N supply.

4.4.4.5 WUE summary

The present study demonstrated that higher grain yield of AC Ronald at the Carman 1999 site was partially attributed to its significantly ($p<0.05$) higher WUE (Table 4.20). At the Carman and Winnipeg 2000 sites, cultivar had no significant effect on WUE, resulting in no significant ($p<0.05$) difference in yield between AC Ronald or Triple Crown (Tables 4.21 and 4.22). A possible explanation could be AC Ronald was utilizing seasonal ET more efficiently than Triple Crown under the drier conditions that were seen at the Carman 1999 site compared to the other sites. However, the limited data presented in the present study does not allow for an in-depth analysis of this point.

At the Carman 1999 site, DM WUE was generally greater for oat than wheat. This was a result of oat having greater ET and DM production than wheat which decreased soil evaporation losses and increased the proportion of ET used as transpiration. However, this trend was not observed across all sites studied.

5.0 GENERAL DISCUSSION

The development and registration of the first semidwarf oat cultivar AC Ronald in Western Canada prompted new research into the yield physiology, grain quality, and soil water dynamics of a semidwarf and how it compared to a conventional height oat cultivar. Reduced lodging incidence associated with the semidwarf trait was thought to lead to a higher yield potential due to the ability to increase N supply without risking lodging. However, results from the present study indicate AC Ronald had a greater yield potential than Triple Crown due to greater kernel number, panicle density, and harvest index. Hamill (2002) reported similar results with OT288, a non-registered semidwarf, under Manitoba growing conditions. The benefit of the semidwarf trait in increasing yield due to decreased lodging incidence may not be as important as previously thought.

It is difficult to evaluate the effect of lodging on grain yield and quality as lodging can be affected by interactions among several management and environmental factors and lodging severity can vary throughout the field (Pinthus, 1973). Further investigation of how lodging influences oat grain yield and quality under field conditions is needed.

AC Ronald had higher grain quality than Triple Crown in terms of hectolitre weight. However, previous researchers (Zavitz, 1927; Atkins, 1943; Humphreys et al., 1994; Zhou et al., 1998; Hamill, 2002) have reported hectolitre weight may not be an adequate indicator of milling quality. Instead, plump kernel percentage may better indicate milling quality (Hamill, 2002). In the present study, AC Ronald had significantly higher plump kernel percentage than Triple Crown at Carman in 1999, while Triple Crown had significantly higher plump kernel percentage at Winnipeg in 2000. Therefore, if plump kernel percentage was an accurate indicator of milling quality, AC

Ronald may not have the highest quality in all growing environments. However, in order for quality standards to change, further investigation of quality parameters that correlate with milling yield is required. From this research, new standards for quality parameters, such as plump kernel percentage, must be determined. As well, plant breeders must focus their research on developing cultivars that have high yield potential with high quality (i.e. hectolitre weight, plump kernel percentage, groat percentage). AC Ronald was developed with high hectolitre weight because it is the current industry standard. However, if plump kernel percentage became part of the selection criteria, breeders would have to develop cultivars which consistently produced higher plump kernel percentage. However, it is important to keep in mind the milling industry considers consistency in quality more important than a single quality parameter due to their equipment calibrations.

A minimum hectolitre weight of 245 g 0.5 L^{-1} is the current industry standard. AC Ronald had higher grain quality in terms of hectolitre weight as a result of smaller kernels with a lower kernel weight. However, the lower kernel weight of AC Ronald suggested that incomplete grain filling associated with higher post-anthesis sink size (kernel number) resulted in smaller kernels and therefore higher hectolitre weight. This observation suggests that raising yield potential in oat may be to the detriment of physical quality parameters because of the inverse relationship between KNO and KWT. Hamill (2002) observed similar results with OT288, which produced fewer plump kernels and a larger number of smaller sized kernels, having greater hull percentage. Therefore, perhaps more emphasis needs to be placed on higher post-anthesis photosynthetic capacity so that high grain number required for high yield potential also have a large enough mass to qualify as high quality oats. Plant breeders must keep in mind that yield increases should not come at the expense of high quality, and that perhaps there is a "yield limit" of oat production that also ensures high quality grain. The application of fungicides may play a larger role in management strategies of oat to increase higher post-anthesis grain filling to ensure high grain quality. The higher post-anthesis grain filling may result if fungicide delay disease spread and increase the length of time biomass is able to photosynthesize, as well as preventing disease from weakening the culms which could result in increased lodging incidence.

AC Ronald did not require different N rates compared to Triple Crown to optimize grain yield or quality. Based on results from this study, Manitoba producers can use similar fertilizer rates for these two oat cultivars. The high residual soil nitrate-N in the present study may have obscured our ability to detect differences in N requirements, however. In the future, evaluation of N response differences between cultivars should be done on sites with a range of N supplying capability. Perhaps under low N supply, differences in N requirements of semidwarf and conventional oat cultivars would become apparent.

The present study only compared yield physiology and grain quality of AC Ronald to one conventional height cultivar. Previous studies have shown Triple Crown to perform inconsistently (i.e. low quality) across Manitoba environments (Hamill, 2002). Further research is required to compare the yield potential and quality of AC Ronald to other cultivars available to Manitoba producers. As well, with the future development of both new semidwarf and conventional oat cultivars, ongoing research is required to ensure Manitoba producers are utilizing optimal N rates for grain yield and seed quality.

The semidwarf trait in oat did not consistently influence soil water dynamics in oat or wheat. Under higher than normal precipitation, Triple Crown used more water than AC Ronald due to higher biomass production, suggesting that conventional oat cultivars may be more adapted to higher moisture areas than semidwarfs. This may have implications for where AC Ronald is grown in Manitoba. In areas such as the Red River Valley where high soil moisture conditions can occur, AC Ronald may not be suited. However, decreased straw production of AC Ronald under high moisture conditions may be a benefit to producers in this area.

Our results also suggest that under drier growing conditions, a semidwarf may be able to use water more efficiently (higher grain WUE) than conventional oat cultivars, leading to higher yield potential. This may be important in years or in areas where lower moisture conditions are expected. However, under drier conditions in the present study, AC Ronald and Triple Crown had similar DM production at maturity. These results indicated that the semidwarf trait did not result in less straw production under certain growing conditions and therefore producers would have to find other methods to manage straw residue.

Oat was also able to use more water than wheat early in the growing season, suggesting that oat is more competitive than wheat early in the growing season. This observation may help to explain why oat is regarded as being more competitive with weeds than is wheat. Oat also had higher pre-anthesis and seasonal ET than wheat, especially under high moisture conditions. Oat may have a beneficial role in situations where soil dewatering is important, in wet years for example. It is interesting to note that under higher than normal precipitation, oat extracted only 7% of total ET from soil water present at spring seeding from the soil profile compared to total soil water use. This indicates that although oat uses more water than wheat, under high soil water conditions where the soil profile is saturated during the entire growing season, oat cannot dewater the soil profile.

Oat was able to extract more water from deeper within the soil profile (90-130 cm) than wheat. Deep water extraction may be important where there is an increase in rotation of shallow rooted crops such as beans which do not access subsoil moisture or nitrate-N. Deep water extraction is important in reducing deep drainage and ground water contamination from nitrate-N leaching, as well as helps to reduce soil salinization.

The semidwarf trait in oat influenced grain yield and seed quality at all sites, and soil water dynamics under extremely wet soil conditions. However, it is unclear that these effects were due to the semidwarfing gene *per se*. One effective approach to determine the effect of the semidwarfing gene is to use isogenic lines. Unfortunately, isogenic oat lines for the semidwarf trait have not been developed.

6.0 CONCLUSIONS

The registration of the first semidwarf oat cultivar, AC Ronald, in Western Canada prompted new research into the yield physiology, quality and soil water dynamics of a semidwarf and how it compares to a conventional height oat cultivar. The present study indicated AC Ronald had a greater yield potential than Triple Crown due to greater kernel number, panicle density, and harvest index, not as a result of decreased lodging incidence which is associated with the semidwarf character. Instead, lodging was found to be more influenced by N supply in the present study where high N levels were conducive to increased lodging incidence. Therefore, producers who are concerned with lodging should examine their N application rates first, then cultivar choice.

AC Ronald had higher grain quality than Triple Crown in terms of hectolitre weight due to a greater number of smaller kernels. Lodging played a role in determining grain quality in the present study. Under high levels of lodging, hectolitre weight and plump kernel percentage of both oat cultivars decreased, indicating that perhaps lodging affected translocation of dry matter during grain filling. Results from the present study indicated that cultivar choice and avoiding N application beyond the recommended rate of 115 kg N ha^{-1} are important for optimizing grain quality in Manitoba.

AC Ronald and Triple Crown responded similarly in terms of grain yield and quality to various N fertilizer rates in cropping systems that contained a green manured grain legume and an oilseed. Therefore, the present study suggests Manitoba oat producers can use similar N fertilizer rates for these two semidwarf and conventional oat cultivars to optimize grain yield and quality.

The semidwarf trait did not consistently influence soil water dynamics (ET, net water extraction, soil water extraction patterns, WUE) of oat or wheat. Under higher than normal precipitation, Triple Crown used more water than AC Ronald, suggesting that conventional oat cultivars may be better suited to high moisture growing areas. However, straw management is an important issue for producers in high moisture growing areas, and results from the present study indicated Triple Crown had higher seasonal DM accumulation than AC Ronald under higher than normal precipitation. However, under drier conditions in the present study, AC Ronald and Triple Crown had similar DM production at maturity, indicating the semidwarf trait did not decrease straw production. Therefore, producers must decide which oat cultivar will be best suited to their crop production practices and growing conditions in their areas.

Oat had higher seasonal ET than wheat, especially under high moisture conditions. Greater soil water use by oat may help to explain greater competitiveness of oat with weeds compared to wheat, and indicates producers could include oat in cropping systems where weed pressure is high. As well, higher ET for oat under high moisture conditions suggests that producers could include oat in cropping systems where soil dewatering is important.

Oat and wheat extracted the majority of water from the top 90 cm of the soil profile, although oat extracted water deeper from within the soil profile (90-130 cm) than wheat. Manitoba producers could include oat in cropping systems where deep drainage can lead to potential environmental risks (i.e. groundwater contamination with nitrate-N), or when shallow rooted crops, such as beans, do not access or use subsoil moisture or nitrate-N levels.

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APPENDIX

Appendix Table A.2.0. ANOVA model used in statistical analysis

Main Effect & Interactions	Error Term
Block	Block x Previous Crop
Previous Crop	
Cultivar	Block x Cultivar (Previous Crop)
Previous Crop x Cultivar	
Nitrogen Rate	Block x Nitrogen Rate (Cultivar x Previous Crop)
Previous Crop x Nitrogen Rate	
Cultivar x Nitrogen Rate	
Previous Crop x Cultivar x Nitrogen Rate	

Appendix Table A.3.0. Daily precipitation during May at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

Date	Carman 1999	Carman 2000	Winnipeg 2000
	Precipitation (mm)		
01-May	0.0	0.0	0.0[z]
02-May	0.0	0.0	0.0
03-May	6.6	0.0	0.0
04-May	3.0	0.0[z]	0.0
05-May	12.0	0.0	0.0
06-May	8.2	6.2	5.2
07-May	0.0	0.8	8.1
08-May	0.0	0.4	5.0
09-May	0.0	3.2	0.0
10-May	25.0	6.2	6.0
11-May	1.6	7.6	3.0
12-May	0.0	24.0	34.0
13-May	0.0	0.4	2.7
14-May	11.3	0.0	0.0
15-May	4.3	0.0	0.0
16-May	0.7	0.0	0.0
17-May	0.0[z]	0.0	0.0
18-May	0.0	0.0	0.0
19-May	2.0	0.0	0.0
20-May	26.7	0.0	0.0
21-May	6.3	0.4	1.0
22-May	27.2	0.2	4.2
23-May	0.7	0.0	0.0[y]
24-May	0.0	5.2[y]	0.0
25-May	0.6	0.0	0.0
26-May	0.0	0.0	0.0
27-May	0.6	0.0	0.0
28-May	0.0	0.2	0.0
29-May	0.0	0.0	0.0
30-May	7.0	0.0	0.0
31-May	0.0[y]	0.0	0.0
Total	143.8	49.6	69.2

[z] Seeding date

[y] Initial soil water content determined

Appendix Table A.3.1. Daily precipitation during June at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

Date	Carman 1999	Carman 2000	Winnipeg 2000
	Precipitation (mm)		
01-Jun	0.6	7.4	6.5
02-Jun	0.0	0.2	0.0
03-Jun	0.0	0.0	0.0
04-Jun	7.0	0.0	0.0
05-Jun	0.0	0.0	0.0
06-Jun	7.6	0.2	0.0
07-Jun	0.2	0.0	0.0
08-Jun	0.0	0.8	0.0
09-Jun	16.8	0.0	0.0
10-Jun	0.0	11.4	63.0
11-Jun	0.0	8.4	11.4
12-Jun	0.2	6.2	37.3
13-Jun	0.0	27.4	27.4
14-Jun	1.4	4.2	19.1
15-Jun	0.0	0.0	0.0
16-Jun	0.0	0.2	0.3
17-Jun	0.0	0.2	0.0
18-Jun	0.0	0.0	0.0
19-Jun	0.0	0.0	1.9
20-Jun	0.2	1.4	24.3
21-Jun	0.0	5.6	19.1
22-Jun	1.8	0.0^{z}	0.0
23-Jun	0.8	10.8	8.8
24-Jun	0.0	0.2	0.6
25-Jun	2.4	0.0	4.6
26-Jun	12.0	5.6	1.7^{z}
27-Jun	0.0	0.0	0.0
28-Jun	0.0	0.0	5.8
29-Jun	22.0	0.0	0.0
30-Jun	1.0^{z}	3.4	18.2
Total	73.0	93.6	248.2

^{z} Stem elongation water content determined

Appendix Table A.3.2. Daily precipitation during July at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

Date	Carman 1999	Carman 2000	Winnipeg 2000
	Precipitation (mm)		
01-Jul	0.0	0.0	0.1
02-Jul	2.2	0.2	0.0
03-Jul	2.6	0.0	0.0
04-Jul	0.2	5.8	18.8
05-Jul	9.2	0.0	0.1
06-Jul	0.0	0.0	0.0
07-Jul	0.0	15.8	59.8
08-Jul	20.8	0.0	0.0
09-Jul	2.6	0.0	0.0
10-Jul	0.0	0.4	1.0
11-Jul	0.0	7.0	3.7
12-Jul	1.8	0.0	0.0
13-Jul	19.0	0.0	0.0
14-Jul	0.2	0.0	0.0
15-Jul	17.6	5.6	8.1
16-Jul	0.2	0.0	0.1
17-Jul	0.0	0.0	0.0
18-Jul	0.0	0.0	0.0
19-Jul	0.2	0.0	0.0
20-Jul	0.0[z]	0.0[z]	0.0
21-Jul	0.0	0.0	0.0[z]
22-Jul	3.8	0.0	0.0
23-Jul	0.0	0.0	4.1
24-Jul	0.0	6.4	4.6
25-Jul	2.6	0.4	0.0
26-Jul	0.2	0.0	0.0
27-Jul	0.0	0.0	0.0
28-Jul	0.0	0.0	0.0
29-Jul	0.0	0.0	0.0
30-Jul	0.0	0.0	0.0
31-Jul	0.0	5.2	0.0
Total	83.2	46.8	100.5

[z] Anthesis water content determined

Appendix Table A.3.3. Daily precipitation during August at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

	Carman 1999	Carman 2000	Winnipeg 2000
Date	Precipitation (mm)		
01-Aug	0.0	0.0	0.0
02-Aug	0.0	0.0	0.0
03-Aug	0.0	0.0	0.0
04-Aug	0.0	0.0	0.0
05-Aug	0.6	11.2	3.7
06-Aug	10.2	2.4	12.4
07-Aug	0.2	7.6	0.0
08-Aug	0.0	0.8	10.3
09-Aug	2.0	0.0	0.3
10-Aug	1.4	6.8	0.1
11-Aug	10.6	30.2	8.4
12-Aug	0.0	0.6	6.7
13-Aug	0.0	0.2	0.0
14-Aug	0.0	0.0[z]	0.0[z]
15-Aug	3.4	0.0	0.0
16-Aug	3.4	0.2	6.1
17-Aug	1.0	0.0	0.9
18-Aug	0.0	0.0	0.0
19-Aug	0.0	0.6	0.3
20-Aug	0.0	6.2	9.3
21-Aug	0.0	0.0	3.3
22-Aug	0.0	0.0	0.0
23-Aug	6.0	0.0	0.0
24-Aug	0.0	0.0	0.0
25-Aug	0.0	0.0	0.0
26-Aug	0.0	0.0	0.0
27-Aug	0.0	0.4	0.0
28-Aug	0.0	3.0	12.4
29-Aug	0.0	0.0	0.0
30-Aug	0.0	15.8	35.6
31-Aug	0.0[z]	0.0	0.0
Total	38.8	86.0	109.7

[z] Maturity water content determined

Appendix Table A.4.0. Oat and wheat yield and dry matter accumulation response to cultivar, nitrogen fertilizer (N) rate, and previous crop treatment effects at Carman, MB (1999 and 2000) and Winnipeg, MB (2000).

	Carman 1999				Carman 2000				Winnipeg 2000			
	Yield	Dry Matter Accumulation			Yield	Dry Matter Accumulation			Yield	Dry Matter Accumulation		
		Stem	Anthesis	Maturity		Stem	Anthesis	Maturity		Stem	Anthesis	Maturity
Main Effect	kg ha^{-1}		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
Previous Crop												
Pea	3938	1581	5527	10093	3677	2921*a*	9305	11087	3438*a*	4037*a*	10560*a*	11399*a*
Flax	3992	1623	5469	10155	3909	2116*b*	8567	10288	3109*b*	3308*b*	9692*b*	10036*b*
LSD (0.05)	276	508	747	1154	326	425	891	821	198	124	360	717
Cultivar												
AC Ronald	5309*a*^{z}	1673*b*	5955*b*	11884*a*	5022*a*	2883*a*	9584*a*	11651*a*	4408*a*	3516*b*	9668*b*	10833*b*
Triple Crown	4534*b*	1960*a*	6597*a*	12173*a*	4541*b*	3058*a*	10061*a*	12033*a*	4177*a*	3739*ab*	10156*ab*	12083*a*
AC Taber	2898*c*	1243*c*	4277*d*	8172*b*	2789*c*	2038*b*	7981*b*	9233*b*	2172*b*	3487*b*	9900*b*	100223*b*
AC Barrie	3083*c*	1532*b*	5162*c*	8266*b*	2903*c*	2096*b*	8119*b*	9834*b*	2329*b*	3959*a*	10721*a*	10255*b*
LSD (0.05)	351	198	527	1030	449	234	744	736	322	289	696	840
N Rate (kg ha^{-1})												
0	3971	1374*b*	4943*c*	9326*b*	3701	2353*b*	8371*b*	10019*b*	2829*c*	3360*b*	8658*b*	9158*c*
40	3986	1684*a*	5552*b*	10391*a*	3752	2492*b*	9005*a*	10800*a*	3174*b*	3583*b*	10456*a*	10511*b*
80	3940	1748*a*	5999*a*	10655*a*	3816	2777*a*	9418*a*	10784*a*	3503*a*	3837*a*	10710*a*	11291*a*
120	n/a	n/a	n/a	n/a	3902	2453*b*	8950*ab*	11147*a*	3604*a*	3903*a*	10685*a*	11905*a*
LSD (0.05)	316	163	308	634	182	275	596	566	288	225	526	688
Source of Variation	ANOVA (P>F)											
Previous Crop (PC)	0.5496	0.8629	0.8302	0.8952	0.0794	0.0091	0.0778	0.0533	0.0111	0.0003	0.0044	0.0091
Cultivar (Cvr)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0094	0.0272	0.0021
PC x Cvr	0.2923	0.0006	0.0208	0.0784	0.3779	<.0001	0.0792	0.5017	0.4695	0.0899	0.3149	0.7354
N Rate	0.9531	<.0001	<.0001	0.0003	0.1039	0.0205	0.0091	0.0017	<.0001	<.0001	<.0001	<.0001
PC x N Rate	0.5084	0.8738	0.7656	0.8122	0.0045	0.0045	0.1827	0.0036	0.0254	0.2349	0.0063	0.0319
Cvr x N rate	0.8601	0.4287	0.4853	0.1625	0.6960	0.1814	0.7170	0.3472	0.4589	0.6275	0.4940	0.7330
PC x Cvr x N rate	0.2599	0.8106	0.8210	0.4094	0.4646	0.0803	0.4234	0.6576	0.4135	0.6718	0.7378	0.3645

[z] Means followed by the same letters are not significantly different according to Fisher's protected Least Significant Difference test ($P<0.05$).

Appendix Table A.4.1. Soil water content in the soil profile increments (0-130 cm) at seeding stage as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999).

	Soil Water Content (mm)							
	Depth (cm)							Total
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**	**0-130**
Previous Crop								
Pea	28.8	48.3	46.5	48.7	57.5	71.2	79.8	380.8
Flax	27.7	50.1	50.0	52.6	61.4	74.3	79.4	395.6
LSD (0.05)	1.3	9.5	10.7	8.8	9.7	15.5	12.0	36.6
Cultivar								
AC Ronald	28.9	49.8	48.5	50.0	58.1	69.6	76.2	381.2
Triple Crown	28.3	49.2	48.9	50.8	59.3	71.8	80.4	388.5
AC Taber	27.8	47.8	46.8	49.3	60.4	77.1	83.2	392.4
AC Barrie	28.1	50	48.9	52.6	60.1	72.4	78.7	390.7
LSD (0.05)	1.4	4.1	4.7	6.3	8.3	7.3	5.2	24.4
N Rate (kg ha^{-1})								
0	28.2	49.2	48.2	50.4	59.5	72.4	79.4	387.2
80	28.3	49.2	48.3	50.9	59.5	73	79.8	388.2
LSD (0.05)	0.7	1.3	1.4	1.4	2.2	2.4	1.7	6.6
Source of Variation	ANOVA (P>F)							
Previous Crop (PC)	0.0745	0.5882	0.3675	0.5212	0.2923	0.5687	0.9215	0.2913
Cultivar (Cvr)	0.4279	0.6528	0.7507	0.7185	0.9375	0.2140	0.0698	0.7816
PC x Cvr	0.5827	0.5002	0.2055	0.2694	0.3480	0.3892	0.6936	0.1680
N Rate	0.7185	0.9065	0.7821	0.4857	0.9536	0.6025	0.6008	0.5386
PC x Nrate	0.9105	0.5242	0.7271	0.0775	0.3132	0.7185	0.0927	0.4634
Cvr x N Rate	0.6081	0.1629	0.0946	0.0615	0.4564	0.2587	0.1033	0.0238
PC x Cvr x N rate	0.9716	0.8775	0.7049	0.0535	0.8282	0.5043	0.1486	0.3359

Appendix Table A.4.2. Soil water content in the soil profile increments (0-130 cm) at stem elongation stage as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999).

	Soil Water Content (mm)							
	Depth (cm)							Total
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**	**0-130**
Previous Crop								
Pea	32.1	41.0	41.8	45.9	55.6	70.7	81.1	368.2
Flax	31.6	44.8	45.6	49.0	59.8	74.4	80.4	385.5
LSD (0.05)	2.8	10.5	8.4	7.3	7.0	15.4	10.0	28.4
Cultivar								
AC Ronald	31.4	43.3	44.3	47.2	55.9	68.4	77.3	367.8
Triple Crown	32.3	40.9	41.7	46.1	57.4	71.5	81.5	371.5
AC Taber	32.0	44.3	43.8	47.0	59.5	77.8	84.1	388.4
AC Barrie	31.6	43.1	44.8	49.4	58.0	72.4	80.2	379.7
LSD (0.05)	1.5	3.9	3.9	6.4	9.6	8.6	5.3	26.6
N Rate (kg ha^{-1})								
0	31.9	43.2	43.5	47.2	57.7	72.1	80.3	375.8
80	31.7	42.3	43.8	47.8	57.8	73.0	81.2	377.8
LSD (0.05)	0.7	2.7	1.7	1.6	2.5	2.6	1.9	8.4
Source of Variation	ANOVA (P>F)							
Previous Crop (PC)	0.5932	0.3290	0.2458	0.2718	0.1551	0.5005	0.8240	0.1480
Cultivar (Cvr)	0.6091	0.3678	0.3947	0.7307	0.8873	0.1821	0.0939	0.3957
PC x Cvr	0.1218	0.3473	0.1688	0.1780	0.3913	0.4858	0.7459	0.2589
N Rate	0.5864	0.6407	0.7613	0.4427	0.9220	0.4491	0.3529	0.6222
PC x Nrate	0.5384	0.7327	0.6929	0.1099	0.8601	0.9761	0.0385	0.9324
Cvr x N Rate	0.1561	0.1961	0.0854	0.0652	0.2722	0.0796	0.3079	0.0194
PC x Cvr x N rate	0.0871	0.2315	0.5082	0.1060	0.7891	0.6573	0.1101	0.6184

Appendix Table A.4.3. Soil water content in the soil profile increments (0-130 cm) at anthesis stage as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999).

	Soil Water Content (mm)							
	Depth (cm)							Total
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**	**0-130**
Previous Crop								
Pea	26.9	41.8	40.8	44.2	53.3	68.8	79.8	357.0
Flax	28.9	44.7	44.2	47.3	57.6	73.8	78.8	373.8
LSD (0.05)	3.8	6.6	7.7	7.4	6.1	11.7	9.8	20.8
Cultivar								
AC Ronald	28.3	43.7	42.9	46.6	54.9	66.6	75.8	358.7
Triple Crown	27.8	41.1	40.6	43.0	53.7	69.0	80.0	358.2
AC Taber	27.0	44.2	42.7	45.1	57.0	77.8	83.0	373.4
AC Barrie	28.3	44.0	43.7	48.4	56.3	71.8	78.8	371.4
LSD (0.05)	1.9	3.1	4.2	6.1	10.0	10.2	5.8	26.1
N Rate (kg ha^{-1})								
0	27.7	43.8	42.5	45.5	55.5	70.9	78.7	362.6
80	28.0	42.7	42.5	46.0	55.5	71.9	80.0	368.2
LSD (0.05)	0.9	1.4	1.6	1.8	2.9	2.7	2.3	7.8
Source of Variation	ANOVA (P>F)							
Previous Crop (PC)	0.1870	0.2587	0.2516	0.2770	0.1095	0.3923	0.8390	0.0651
Cultivar (Cvr)	0.4531	0.1636	0.4489	0.3253	0.9031	0.1285	0.0900	0.3717
PC x Cvr	0.8525	0.0905	0.0957	0.1329	0.4477	0.5482	0.5056	0.2671
N Rate	0.5872	0.1561	0.9774	0.6455	0.9833	0.7908	0.3956	0.4985
PC x Nrate	0.1020	0.9802	0.9915	0.1187	0.7357	0.5220	0.0647	0.9568
Cvr x N Rate	0.0648	0.0464	0.0137	0.1060	0.2053	0.1067	0.1321	0.0109
PC x Cvr x N rate	0.2508	0.8084	0.9303	0.1493	0.8907	0.8374	0.2578	0.4116

Appendix Table A.4.4. Soil water content in the soil profile increments (0-130 cm) at maturity stage as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999).

	Soil Water Content (mm)							
				Depth (cm)				**Total**
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**	**0-130**
Previous Crop								
Pea	20.2	26.7	29.7	33.0	40.3	56.4	71.7	277.9
Flax	21.1	28.5	33.1	36.2	45.7	64.0	71.3	299.8
LSD (0.05)	1.0	5.5	8.7	8.6	6.6	19.0	18.0	27.9
Cultivar								
AC Ronald	20.5	26.9*a*[z]	29.2*a*	33.1*a*	40.7	53.6*b*	64.9	268.9*c*
Triple Crown	20.1	27.8*ab*	29.8*a*	30.9*a*	39.0	51.5*b*	71.5	270.6*bc*
AC Taber	20.3	26.3*a*	31.4*a*	33.7*a*	43.5	70.0*a*	78.7	303.8*ab*
AC Barrie	21.6	29.4*b*	35.1*b*	40.5*b*	48.8	65.6*ab*	71.0	312.0*a*
LSD (0.05)	1.2	2.2	3.7	6.6	10.8	14.6	10.8	34.0
N Rate (kg ha^{-1})								
0	20.5	27.5	31.3	34.0	41.8	58.9	69.7	283.6
80	20.7	27.7	31.5	35.1	44.2	61.5	73.3	294
LSD (0.05)	0.6	1.0	1.4	2.0	3.3	4.5	4.3	11.5
Source of Variation	ANOVA (P>F)							
Previous Crop (PC)	0.0713	0.3829	0.3037	0.3144	0.0815	0.2932	0.9486	0.0880
Cultivar (Cvr)	0.0658	0.0416	0.0147	0.0389	0.2800	0.0417	0.1028	0.0287
PC x Cvr	0.1977	0.2243	0.1184	0.3962	0.4749	0.6742	0.5290	0.6384
N Rate	0.5252	0.7402	0.7115	0.2699	0.1402	0.2408	0.0928	0.0746
PC x Nrate	0.1386	0.5098	0.7994	0.5829	0.6834	0.3758	0.0774	0.3894
Cvr x N Rate	0.0591	0.0837	0.3203	0.6381	0.2878	0.0973	0.2190	0.2221
PC x Cvr x N rate	0.7305	0.4608	0.8838	0.2315	0.4297	0.5823	0.0536	0.1850

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \le 0.05$).

Appendix Table A.4.5. Soil water content in the soil profile increments (0-130 cm) at seeding stage as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (2000).

	Soil Water Content (mm)							
	Depth (cm)							Total
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**	**0-130**
Previous Crop								
Pea	24.4	48.9	50.0	52.2	62.7	74.6	81.8	394.5
Flax	23.4	47.9	47.6	49.6	61.5	78.2	86.6	394.8
LSD (0.05)	2.6	4.5	6.2	8.5	14.3	8.6	5.6	47.1
Cultivar								
AC Ronald	24.2	49.6	50.2	52.7	64.5	76.6	86.9	404.7
Triple Crown	23.6	50.0	49.2	49.4	62.5	77.5	83.3	395.5
AC Taber	24.4	48.4	47.8	51.1	63.7	74.9	81.1	391.4
AC Barrie	23.2	45.6	47.8	50.3	57.6	76.8	85.5	387.2
LSD (0.05)	1.8	4.8	3.1	4.6	6.8	7.7	5.4	23.0
N Rate (kg ha^{-1})								
0	24.1	48.2	49.3	50.2	61.5	76.7	84.0	393.0
80	23.6	48.6	48.3	51.6	62.7	76.2	84.4	396.4
LSD (0.05)	1.0	1.2	1.1	3.2	5.2	4.4	3.7	14.7
Source of Variation	ANOVA (P>F)							
Previous Crop (PC)	0.2997	0.5640	0.3150	0.4081	0.8017	0.2748	0.0727	0.9846
Cultivar (Cvr)	0.5545	0.2288	0.3943	0.4908	0.1811	0.9066	0.1579	0.4422
PC x Cvr	0.4315	0.9017	0.6767	0.8098	0.3260	0.3589	0.2419	0.5019
N Rate	0.2361	0.4940	0.0895	0.3711	0.6170	0.8302	0.8516	0.6383
PC x Nrate	0.5228	0.7571	0.0530	0.2600	0.1409	0.3186	0.3045	0.1449
Cvr x N Rate	0.1587	0.7202	0.9828	0.4237	0.7879	0.6201	0.4844	0.8215
PC x Cvr x N rate	0.3444	0.0425	0.4826	0.5439	0.9222	0.8601	0.1910	0.8038

Appendix Table A.4.6. Soil water content in the soil profile increments (0-130 cm) at stem elongation stage as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (2000).

	Soil Water Content (mm) **Depth (cm)**							**Total**
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**	**0-130**
Previous Crop								
Pea	32.1	52.0	52.8	57.1	68.9	77.4	84.0*b*	424.5
Flax	33.0	51.2	50.7	54.1	67.4	79.9	86.7*a*	422.9
LSD (0.05)	4.3	2.5	3.6	7.5	10.8	4.6	2.4	25.7
Cultivar								
AC Ronald	32.3	51.0	51.9	56.1	69.2*a*^{z}	77.1	85.6	423.1
Triple Crown	31.9	53.0	51.6	53.2	68.9*a*	81.0	84.8	424.4
AC Taber	33.2	52.5	52.2	58.7	71.2*a*	77.8	85.0	430.5
AC Barrie	32.7	51.0	51.3	54.9	63.0*b*	78.7	86.2	416.9
LSD (0.05)	1.7	3.5	2.6	3.9	5.0	5.2	2.0	14.8
N Rate (kg ha^{-1})								
0	32.3	51.6	51.4	55.3	67.9	77.9	85.8	423.2
80	32.8	51.6	52.1	56.2	68.4	78.4	84.9	424.3
LSD (0.05)	1.2	1.0	0.9	2.4	3.6	2.5	1.5	7.7
Source of Variation	ANOVA (P>F)							
Previous Crop (PC)	0.5400	0.3901	0.1536	0.2507	0.6790	0.1815	0.0350	0.8541
Cultivar (Cvr)	0.4450	0.2661	0.9067	0.0554	0.0189	0.4487	0.4177	0.3241
PC x Cvr	0.6369	0.8188	0.1465	0.8318	0.5098	0.5180	0.3961	0.6723
N Rate	0.4539	0.9490	0.1317	0.4364	0.7580	0.6588	0.2211	0.7628
PC x Nrate	0.2925	0.4497	0.8751	0.2670	0.3783	0.7649	0.4838	0.4597
Cvr x N Rate	0.9892	0.8038	0.9298	0.1429	0.7337	0.5541	0.8615	0.3592
PC x Cvr x N rate	0.7058	0.0441	0.9335	0.3868	0.9417	0.5135	0.3346	0.9575

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Appendix Table A.4.7. Soil water content in the soil profile increments (0-130 cm) at anthesis stage as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (2000).

	Soil Water Content (mm)							
	Depth (cm)							Total
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**	**0-130**
Previous Crop								
Pea	21.3	37.0	41.4	45.6	59.5	74.5	82.4*b*[z]	361.7
Flax	21.5	36.1	40.2	44.5	58.9	77.7	85.9*a*	364.8
LSD (0.05)	4.1	3.2	1.7	5.9	17.6	10.3	2.2	32.9
Cultivar								
AC Ronald	22.0	34.7	39.5	45.2	59.5	73.4	83.9	358.1
Triple Crown	21.4	37.1	40.8	41.7	60.4	78.1	83.5	363.0
AC Taber	20.9	38.6	40.8	48.1	63.6	76.7	83.7	373.4
AC Barrie	21.4	35.8	41.1	45.1	53.2	76.1	85.6	358.4
LSD (0.05)	1.9	4.7	3.7	5.5	8.5	6.5	2.3	18.1
N Rate (kg ha^{-1})								
0	21.3	37.2	41.2	44.7	59.1	77.1	84.8	365.3
80	21.6	35.9	40.4	45.4	59.3	75.1	83.5	361.2
LSD (0.05)	0.9	1.6	1.7	2.6	4.8	3.0	1.8	6.9
Source of Variation	ANOVA (P>F)							
Previous Crop (PC)	0.9029	0.4362	0.1178	0.5705	0.9298	0.3994	0.0147	0.7847
Cultivar (Cvr)	0.6415	0.3536	0.6415	0.1463	0.1110	0.5040	0.2136	0.3103
PC x Cvr	0.2613	0.7153	0.3261	0.7921	0.7649	0.5686	0.0715	0.6405
N Rate	0.5815	0.1173	0.3633	0.5469	0.9486	0.1799	0.1784	0.2308
PC x Nrate	0.9862	0.0392	0.1773	0.8705	0.8537	0.7324	0.8329	0.6601
Cvr x N Rate	0.1272	0.7205	0.8210	0.0322	0.3634	0.3949	0.7166	0.1498
PC x Cvr x N rate	0.4876	0.8480	0.9940	0.3621	0.4568	0.7067	0.7351	0.7096

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Appendix Table A.4.8. Soil water content in the soil profile increments (0-130 cm) at maturity stage as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (2000).

	Soil Water Content (mm)							
	Depth (cm)							**Total**
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**	**0-130**
Previous Crop								
Pea	26.4	43.8	39.3	38.9	49.3	66.4	78.3*b*	342.2
Flax	24.9	43.7	38.9	36.9	47.7	70.8	83.3*a*	346.1
LSD (0.05)	7.4	2.0	3.3	8.8	14.8	9.6	3.7	31.5
Cultivar								
AC Ronald	25.7	43.7	37.9	36.8*bc*^{z}	48.9	62.7	80.0	335.8
Triple Crown	25.7	44.6	37.2	32.3*c*	46.1	69.2	78.4	333.4
AC Taber	25.4	43.0	40.6	43.3*a*	55.7	73.2	82.4	364.3
AC Barrie	25.6	43.6	40.5	39.3*ab*	43.1	69.4	82.3	343.2
LSD (0.05)	1.6	4.4	4.4	5.8	9.5	12.1	4.5	29.8
N Rate (kg ha^{-1})								
0	25.8	43.9	39.2	37.0	47.3	68.1	80.9	342.2
80	25.4	43.6	39.0	38.8	49.7	69.1	80.6	343.1
LSD (0.05)	0.7	1.5	1.6	3.5	7.4	6.1	3.6	17.1
Source of Variation	ANOVA (P>F)							
Previous Crop (PC)	0.5522	0.8436	0.7479	0.5376	0.7512	0.2350	0.0233	0.7205
Cultivar (Cvr)	0.9802	0.8939	0.2615	0.0070	0.0662	0.3640	0.2146	0.1555
PC x Cvr	0.9535	0.6951	0.2558	0.9674	0.8212	0.7034	0.1211	0.9873
N Rate	0.2358	0.6770	0.7622	0.2983	0.5091	0.7277	0.8463	0.6422
PC x Nrate	0.8265	0.6310	0.6579	0.2873	0.9144	0.8215	0.9829	0.7349
Cvr x N Rate	0.1790	0.7139	0.3731	0.0728	0.6284	0.2018	0.8588	0.2700
PC x Cvr x N rate	0.0401	0.0948	0.3843	0.1541	0.6680	0.8000	0.1925	0.3393

^{z} Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Appendix Table A.4.9. Soil water content in the soil profile increments (0-130 cm) at seeding stage as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Winnipeg, MB (2000).

	Soil Water Content (mm)							
	Depth (cm)							**Total**
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**	**0-130**
Previous Crop								
Pea	31.7	83.9	86.2*a*^{z}	85.0	85.3	86.3	86.9	545.2
Flax	32.4	83.0	84.9*b*	83.1	84.0	85.1	85.1	537.7
LSD (0.05)	1.5	1.9	1.2	2.2	1.5	2.1	3.0	8.7
Cultivar								
AC Ronald	31.4	83.9	85.6	83.7	85.0	85.7	86.5*a*	541.7
Triple Crown	32.6	84.0	85.3	84.4	84.9	85.7	85.5*c*	542.2
AC Taber	32.0	83.0	85.4	83.9	84.8	85.8	85.8*bc*	540.5
AC Barrie	32.3	83.0	86.0	84.2	84.0	85.7	86.2*ab*	541.3
LSD (0.05)	1.4	2.0	2.1	2.0	1.1	1.0	0.6	6.8
N Rate (kg ha^{-1})								
0	32.0	83.5	85.9	84.3	84.8	85.7	86.2	542.4
80	32.2	83.3	85.2	83.7	84.5	85.6	85.8	540.5
LSD (0.05)	1.2	1.4	0.8	0.8	0.8	0.5	0.9	2.9
Source of Variation	ANOVA (P>F)							
Previous Crop (PC)	0.2177	0.2516	0.0462	0.0665	0.0718	0.1806	0.1611	0.0715
Cultivar (Cvr)	0.3648	0.6026	0.9050	0.8876	0.2422	0.9966	0.0260	0.9593
PC x Cvr	0.0581	0.7450	0.9971	0.9966	0.7298	0.6993	0.1039	0.9680
N Rate	0.7505	0.7735	0.1343	0.1231	0.5248	0.6330	0.3729	0.1774
PC x Nrate	0.9353	0.6809	0.5229	0.9982	0.6379	0.0051	0.4462	0.4072
Cvr x N Rate	0.5342	0.8814	0.9016	0.6577	0.4964	0.8508	0.5694	0.5079
PC x Cvr x N rate	0.4064	0.3332	0.4098	0.7457	0.7386	0.3185	0.2962	0.2386

^{z} Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Appendix Table A.4.10. Soil water content in the soil profile increments (0-130 cm) at stem elongation stage as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Winnipeg, MB (2000).

	Soil Water Content (mm)							
	Depth (cm)							**Total**
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**	**0-130**
Previous Crop								
Pea	37.8	91.7	92.7	92.4	90.3	89.4	89.2	583.5
Flax	40.1	91.3	91.9	90.7	89.6	88.3	88.0	580.0
LSD (0.05)	6.9	4.3	3.6	2.3	1.0	2.6	3.7	20.5
Cultivar								
AC Ronald	37.9	91.6	92.4	91.7	89.9	88.8	88.6	581.0
Triple Crown	38.8	91.6	92.3	91.4	89.7	88.6	87.8	580.3
AC Taber	39.6	91.9	92.5	91.4	90.4	88.8	89.1	583.6
AC Barrie	39.6	90.8	91.9	91.7	89.8	89.1	89.1	582.1
LSD (0.05)	2.8	1.3	1.8	1.2	1.2	1.1	1.3	6.1
N Rate (kg ha^{-1})								
0	39.6	91.6	92.4	91.5	90.0	88.6	88.9	582.5
80	38.4	91.4	92.1	91.6	90.0	89.1	88.4	581.0
LSD (0.05)	1.6	1.0	0.8	0.6	0.7	0.9	0.8	2.8
Source of Variation	ANOVA (P>F)							
Previous Crop (PC)	0.3615	0.7594	0.5375	0.1010	0.1167	0.2574	0.3823	0.6183
Cultivar (Cvr)	0.5393	0.3749	0.9211	0.9006	0.6019	0.8512	0.1479	0.6741
PC x Cvr	0.9197	0.5536	0.4605	0.4487	0.5067	0.3798	0.1678	0.3087
N Rate	0.1540	0.8007	0.4739	0.8517	0.9424	0.3247	0.2089	0.2539
PC x Nrate	0.4361	0.2830	0.0891	0.1655	0.3512	0.9472	0.2921	0.2864
Cvr x N Rate	0.7922	0.8790	0.7585	0.0255	0.8585	0.8584	0.2089	0.4739
PC x Cvr x N rate	0.0675	0.3454	0.9673	0.1665	0.6317	0.7801	0.7579	0.5343

Appendix Table A.4.11. Soil water content in the soil profile increments (0-130 cm) at anthesis stage as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Winnipeg, MB (2000).

	Soil Water Content (mm)							
	Depth (cm)							**Total**
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**	**0-130**
Previous Crop								
Pea	34.4	82.4	90.3	90.5	90.0	90.2	90.4	568.3
Flax	34.3	82.4	89.9	89.6	89.9	89.5	89.5	565.1
LSD (0.05)	1.2	7.2	4.6	2.2	3.0	4.3	3.6	24.2
Cultivar								
AC Ronald	33.9	82.8*a*[z]	90.5	90.2	90.1	90.1	89.8*a*	567.4
Triple Crown	33.9	80.5*b*	88.9	90.0	90.2	90.0	89.1*a*	562.6
AC Taber	34.8	82.6*a*	90.8	89.7	90.1	89.7	90.0*a*	567.4
AC Barrie	34.9	83.6*a*	90.2	90.4	89.5	89.6	91.0*b*	569.3
LSD (0.05)	1.8	2.0	1.7	1.5	1.2	1.2	1.0	5.9
N Rate (kg ha^{-1})								
0	34.6	84.5*a*	90.3	90.3	90.1	89.7	90.1	569.6*a*
80	34.1	80.2*b*	89.9	89.9	90.0	90.0	89.9	563.8*b*
LSD (0.05)	0.9	1.1	0.8	0.9	0.6	0.6	1.0	1.9
Source of Variation	ANOVA (P>F)							
Previous Crop (PC)	0.7655	0.9992	0.7657	0.3067	0.9169	0.6202	0.4881	0.7044
Cultivar (Cvr)	0.4654	0.0295	0.1540	0.7865	0.6395	0.8029	0.0103	0.1407
PC x Cvr	0.0944	0.3009	0.5945	0.6018	0.8763	0.9025	0.0779	0.5570
N Rate	0.2770	<.0001	0.2311	0.3314	0.5451	0.3950	0.6084	<.0001
PC x Nrate	0.5701	0.7209	0.9397	0.3724	0.8728	0.5799	0.8197	0.5694
Cvr x N Rate	0.0057	0.0692	0.0647	0.7179	0.6541	0.3059	0.2714	0.0902
PC x Cvr x N rate	0.0612	0.2032	0.3455	0.4806	0.4274	0.2882	0.4989	0.3254

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Appendix Table A.4.12. Soil water content in the soil profile increments (0-130 cm) at maturity stage as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Winnipeg, MB (2000).

	Soil Water Content (mm)							
	Depth (cm)							Total
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**	**0-130**
Previous Crop								
Pea	33.4	70.0	77.5	80.8	84.0	87.3	88.9	522.0
Flax	33.2	72.1	79.1	82.6	84.8	87.4	88.1	527.1
LSD (0.05)	1.7	7.1	5.9	7.4	6.1	3.9	5.2	34.6
Cultivar								
AC Ronald	33.4	69.2*b*[z]	76.1*c*	80.0*b*	85.0	87.5	88.9	520.0*c*
Triple Crown	32.2	63.6*c*	70.9*d*	77.3*b*	82.6	86.9	87.7	501.2*d*
AC Taber	33.6	73.1*a*	80.7*b*	83.9*a*	84.6	87.3	88.4	531.9*b*
AC Barrie	33.9	78.2*a*	85.6*a*	85.5*a*	85.5	87.6	89.0	545.1*a*
LSD (0.05)	1.9	3.9	3.1	3.4	2.7	1.8	1.3	11.4
N Rate (kg ha^{-1})								
0	33.6	75.1a	81.2*a*	83.4*a*	85.1*a*	87.3	88.6	534.2*a*
80	32.9	66.9b	75.5*b*	80.0*b*	83.8*b*	87.4	88.4	514.9*b*
LSD (0.05)	1.3	2.1	1.2	1.2	0.8	0.9	1.0	3.3
Source of Variation	ANOVA (P>F)							
Previous Crop (PC)	0.7260	0.4175	0.4485	0.5164	0.7163	0.9641	0.6314	0.6667
Cultivar (Cvr)	0.2610	<.0001	<.0001	0.0003	0.1461	0.8311	0.1884	<.0001
PC x Cvr	0.2172	0.9552	0.5332	0.5838	0.5122	0.9128	0.2864	0.6575
N Rate	0.2609	<.0001	<.0001	<.0001	0.0049	0.8166	0.7610	<.0001
PC x Nrate	0.6048	0.1907	0.3820	0.4239	0.2685	0.4738	0.8568	0.5160
Cvr x N Rate	0.7447	0.6326	0.2547	0.6516	0.3647	0.5648	0.7200	0.1172
PC x Cvr x N rate	0.8768	0.9013	0.1894	0.7745	0.7426	0.4269	0.1883	0.9197

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Appendix Table A.4.13. Soil water extraction at stem elongation in the soil profile increments (0-130 cm) as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999).

	Soil Water Use (mm)						
	Depth (cm)						
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**
Previous Crop							
Pea	-3.3	7.3	4.7	2.8	1.9	0.5	-1.3
Flax	-3.9	5.3	4.5	3.6	1.6	-0.1	-0.9
LSD (0.05)	1.9	4.2	3.3	2.3	3.0	1.6	2.2
Cultivar							
AC Ronald	-2.5	6.5	4.2*b*^{z}	2.8	2.2	1.2	-1.0
Triple Crown	-4.1	8.3	7.1*a*	4.7	1.8	0.4	-1.1
AC Taber	-4.2	3.5	3.0*b*	2.3	0.9	-0.7	-0.9
AC Barrie	-3.5	6.9	4.0*b*	3.1	2.1	-0.1	-1.5
LSD (0.05)	2.0	4.2	2.2	2.6	2.3	2.1	2.1
N Rate (kg ha^{-1})							
0	-3.7	6.0	4.6	3.3	1.8	0.4	-0.9
80	-3.4	6.6	4.5	3.2	1.7	0.0	-1.3
LSD (0.05)	1.1	2.6	1.2	1.1	1.4	1.2	1.2
Source of Variation	ANOVA (P>F)						
Previous Crop (PC)	0.3941	0.2147	0.8146	0.3381	0.7977	0.3190	0.6452
Cultivar (Cvr)	0.2968	0.1594	0.0051	0.2881	0.6477	0.3110	0.9356
PC x Cvr	0.6929	0.8018	0.3959	0.5773	0.4668	0.8173	0.8607
N Rate	0.5745	0.5771	0.9116	0.8365	0.9301	0.5373	0.4592
PC x Nrate	0.7538	0.4936	0.3424	0.9971	0.2036	0.4434	0.3391
Cvr x N Rate	0.6664	0.6549	0.0912	0.9382	0.5789	0.2188	0.3435
PC x Cvr x N rate	0.5504	0.1890	0.7208	0.8862	0.4318	0.3456	0.7955

^{z} Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Appendix Table A.4.14. Soil water extraction at anthesis in the soil profile increments (0-130 cm) as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999).

	Soil Water Use (mm)						
	Depth (cm)						
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**
Previous Crop							
Pea	2.0	6.5	5.7	4.5	4.2	4.6	2.5
Flax	-1.2	5.4	5.8	5.3	3.8	0.5	2.8
LSD (0.05)	4.0	3.5	4.3	4.2	4.4	8.6	11.5
Cultivar							
AC Ronald	0.6	6.1	5.6*b*^{z}	3.5*b*	3.2	3.0	0.5
Triple Crown	0.4	8.1	8.2*a*	7.8*a*	5.6	7.2	5.3
AC Taber	0.8	3.6	4.1*b*	4.2*b*	3.5	-0.7	4.9
AC Barrie	-0.2	6.0	5.1*b*	4.2*b*	3.8	0.5	-0.1
LSD (0.05)	1.8	3.1	2.6	2.7	3.0	7.9	10.6
N Rate (kg ha^{-1})							
0	0.5	5.4	5.7	4.9	4.0	1.6	2.9
80	0.3	6.5	5.9	5.0	4.0	3.4	2.4
LSD (0.05)	1.1	1.1	1.2	1.1	1.6	4.6	7.4
Source of Variation	ANOVA (P>F)						
Previous Crop (PC)	0.0842	0.3905	0.9370	0.5815	0.7756	0.2279	0.9350
Cultivar (Cvr)	0.6785	0.0555	0.0192	0.0159	0.3725	0.2017	0.5957
PC x Cvr	0.6526	0.5683	0.0968	0.2561	0.5808	0.4017	0.2562
N Rate	0.8081	0.0511	0.7722	0.8926	0.9668	0.4134	0.8797
PC x Nrate	0.1830	0.4742	0.6689	0.7689	0.0568	0.2089	0.2396
Cvr x N Rate	0.0766	0.2632	0.2313	0.9365	0.2976	0.6544	0.3487
PC x Cvr x N rate	0.2974	0.6982	0.3577	0.9681	0.2693	0.3648	0.5062

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Appendix Table A.4.15. Soil water extraction at maturity in the soil profile increments (0-130 cm) as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (1999).

	Soil Water Use (mm)						
	Depth (cm)						
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**
Previous Crop							
Pea	8.7*a*[z]	21.6	16.8	15.8	17.3	14.8	8.1
Flax	6.6*b*	21.6	17	16.4	15.8	10.3	8.1
LSD (0.05)	1.9	4.5	4.8	6.5	9.6	5.3	6.2
Cultivar							
AC Ronald	8.5	22.9	19.3*a*	16.9*ab*	17.5*a*	16.0*a*	11.3
Triple Crown	8.2	21.4	19.1*a*	19.8*a*	20.3*a*	20.3*a*	8.9
AC Taber	7.5	21.4	15.4*b*	15.6*bc*	17.0*a*	7.2*b*	4.5
AC Barrie	6.5	20.6	13.7*b*	12.1*c*	11.3*b*	6.7*b*	7.7
LSD (0.05)	1.5	2.7	3.2	3.6	4.2	8.3	6.5
N Rate (kg ha^{-1})							
0	7.7	21.6	16.9	16.4	17.7*a*	13.6	9.7*a*
80	7.7	21.5	16.8	15.8	15.3*b*	11.6	6.5*b*
LSD (0.05)	1.0	1.1	1.3	1.4	2.2	3.1	3.2
Source of Variation	ANOVA (P>F)						
Previous Crop (PC)	0.0396	0.9857	0.9131	0.7677	0.6540	0.0738	0.9968
Cultivar (Cvr)	0.0547	0.3929	0.0035	0.0025	0.0028	0.0058	0.2042
PC x Cvr	0.2471	0.3096	0.0498	0.4020	0.9781	0.7887	0.5016
N Rate	0.9968	0.8537	0.9187	0.3831	0.0357	0.1953	0.0479
PC x Nrate	0.4885	0.1654	0.9154	0.2783	0.1148	0.3164	0.1348
Cvr x N Rate	0.3476	0.7574	0.3086	0.2203	0.2166	0.1778	0.0865
PC x Cvr x N rate	0.9497	0.6083	0.6889	0.9128	0.2619	0.7789	0.0807

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Appendix Table A.4.16. Soil water extraction at stem elongation in the soil profile increments (0-130 cm) as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (2000).

	Soil Water Use (mm)						
	Depth (cm)						
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**
Previous Crop							
Pea	-7.7	-3.1	-2.8	-5.2	-6.2	-2.8	-2.2
Flax	-9.6	-3.3	-3.1	-4.4	-5.9	-1.6	-0.2
LSD (0.05)	6.3	2.5	3.6	6.4	6.2	5.2	4.5
Cultivar							
AC Ronald	-8.1	-1.4*a*[z]	-1.7	-3.4*a*	-4.7	-0.4	1.3
Triple Crown	-8.2	-3.0*ab*	-2.5	-3.8*a*	-6.4	-3.5	-1.5
AC Taber	-8.8	-4.1*b*	-4.3	-7.6*b*	-7.5	-3.0	-3.8
AC Barrie	-9.5	-4.3*b*	-3.2	-4.6*a*	-5.5	-1.9	-0.7
LSD (0.05)	2.2	2.1	1.9	2.6	3.2	4.0	4.9
N Rate (kg ha^{-1})							
0	-8.2	-3.4	-3.1	-5.1	-6.4	-2.2	-1.8
80	-9.2	-3.0	-2.8	-4.6	-5.7	-2.2	-0.6
LSD (0.05)	1.4	0.8	1.0	1.5	2.6	3.0	3.1
Source of Variation	ANOVA (P>F)						
Previous Crop (PC)	0.3989	0.8665	0.8566	0.7262	0.8825	0.5450	0.2498
Cultivar (Cvr)	0.5380	0.0302	0.0588	0.0149	0.3116	0.4249	0.2161
PC x Cvr	0.6187	0.3570	0.5942	0.9724	0.4173	0.2573	0.2900
N Rate	0.1615	0.2653	0.6023	0.5019	0.5696	0.9570	0.4287
PC x Nrate	0.6423	0.1517	0.0461	0.5223	0.0870	0.2284	0.3757
Cvr x N Rate	0.3708	0.9566	0.8257	0.9715	0.7842	0.5185	0.2871
PC x Cvr x N rate	0.6203	0.5164	0.6257	0.8181	0.9254	0.2760	0.3550

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \le 0.05$).

Appendix Table A.4.17. Soil water extraction at anthesis in the soil profile increments (0-130 cm) as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (2000).

	Soil Water Use (mm)						
	Depth (cm)						
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**
Previous Crop							
Pea	3.0	11.8	8.6	6.5	3.2	0.1	-0.6
Flax	1.8	11.8	7.5	5.2	2.5	0.6	0.7
LSD (0.05)	2.3	4.1	7.2	7.4	5.3	2.3	3.7
Cultivar							
AC Ronald	2.2	14.9*a*[z]	10.7	7.5	5.0	3.2	3.0
Triple Crown	2.2	12.9*ab*	8.4	7.7	2.1	-0.6	-0.2
AC Taber	3.5	9.8*b*	6.1	3.0	0.1	-1.8	-2.6
AC Barrie	1.8	9.8*b*	7.0	5.2	4.4	0.6	-0.1
LSD (0.05)	2.3	4.2	4.1	4.0	4.0	5.1	4.9
N Rate (kg ha^{-1})							
0	2.8	11.0*b*	7.2	5.5	2.3	-0.4	-0.8
80	2.0	12.7*a*	8.9	6.2	3.5	1.1	0.8
LSD (0.05)	1.3	1.6	2.0	2.1	2.7	2.6	3.4
Source of Variation	ANOVA (P>F)						
Previous Crop (PC)	0.1992	0.9833	0.6425	0.5940	0.7007	0.6033	0.3588
Cultivar (Cvr)	0.4541	0.0493	0.1262	0.0812	0.0681	0.2306	0.1621
PC x Cvr	0.2135	0.8096	0.7288	0.9026	0.2499	0.7207	0.3836
N Rate	0.2199	0.0431	0.0834	0.5236	0.3994	0.2340	0.3558
PC x Nrate	0.6258	0.0244	0.0268	0.1289	0.0159	0.2027	0.3231
Cvr x N Rate	0.6092	0.6450	0.8246	0.5049	0.6332	0.7094	0.4260
PC x Cvr x N rate	0.2632	0.2083	0.8906	0.9991	0.3526	0.2329	0.2645

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Appendix Table A.4.18. Soil water extraction at maturity in the soil profile increments (0-130 cm) as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Carman, MB (2000).

	Soil Water Use (mm)						
	Depth (cm)						
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**
Previous Crop							
Pea	-2.0	5.1	10.7	13.3	13.4	8.3	3.5
Flax	-1.5	4.3	8.8	12.7	13.8	7.4	3.3
LSD (0.05)	5.7	5.8	9.1	10.7	3.4	4.2	3.3
Cultivar							
AC Ronald	-1.5	5.9	12.3	15.9*ab*^{z}	15.6*a*	13.9*a*	6.9
Triple Crown	-2.1	5.4	11.9	17.0*a*	16.4*a*	8.3*ab*	4.9
AC Taber	-1.1	4.8	7.2	7.9*c*	8.0*b*	1.7*b*	-1.4
AC Barrie	-2.4	2.6	7.5	11.1*bc*	14.5*a*	7.4*ab*	3.2
LSD (0.05)	2.4	3.6	4.8	4.9	5.0	8.0	5.9
N Rate (kg ha^{-1})							
0	-1.7	4.3	9.1	13.2	14.2	8.6	3.1
80	-1.8	5.0	10.3	12.8	13.1	7.1	3.8
LSD (0.05)	1.4	1.3	1.7	2.7	3.7	4.5	4.0
Source of Variation	ANOVA (P>F)						
Previous Crop (PC)	0.7843	0.6951	0.5406	0.8628	0.7464	0.5537	0.8390
Cultivar (Cvr)	0.6935	0.2464	0.0642	0.0032	0.0084	0.0397	0.0530
PC x Cvr	0.6801	0.5084	0.6987	0.6946	0.2181	0.7678	0.2496
N Rate	0.8539	0.2785	0.1698	0.7835	0.5305	0.5015	0.7290
PC x Nrate	0.5774	0.7999	0.0989	0.0091	0.0249	0.2014	0.3533
Cvr x N Rate	0.7651	0.5100	0.3508	0.4002	0.5527	0.1761	0.2551
PC x Cvr x N rate	0.0883	0.2249	0.7109	0.5736	0.3735	0.3610	0.9829

^{z} Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Appendix Table A.4.19. Soil water extraction at stem elongation in the soil profile increments (0-130 cm) as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Winnipeg, MB (2000).

	Soil Water Use (mm)						
	Depth (cm)						
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**
Previous Crop							
Pea	-6.1	-7.9	-6.5	-7.4	-5.0	-3.2	-2.3
Flax	-7.7	-8.3	-7.0	-7.7	-5.6	-3.1	-2.9
LSD (0.05)	7.6	4.0	2.6	0.8	1.5	1.6	0.7
Cultivar							
AC Ronald	-6.5	-7.7	-6.8	-8.0	-4.9	-3.2	-2.1
Triple Crown	-6.2	-7.7	-7.0	-7.1	-4.8	-3.0	-2.3
AC Taber	-7.6	-9.0	-7.1	-7.5	-5.6	-3.0	-3.3
AC Barrie	-7.3	-7.8	-6.0	-7.5	-5.9	-3.4	-2.9
LSD (0.05)	3.2	1.9	1.8	1.7	1.4	1.4	1.2
N Rate (kg ha^{-1})							
0	-7.6	-8.0	-6.5	-7.2	-5.2	-2.9	-2.7
80	-6.2	-8.1	-6.9	-7.9	-5.4	-3.4	-2.6
LSD (0.05)	2.3	1.4	1.1	1.0	0.9	0.9	1.1
Source of Variation	ANOVA (P>F)						
Previous Crop (PC)	0.5485	0.7688	0.6127	0.3586	0.2924	0.9820	0.0917
Cultivar (Cvr)	0.7930	0.4384	0.5412	0.6946	0.3096	0.9007	0.1660
PC x Cvr	0.8293	0.3524	0.5913	0.6847	0.4707	0.2492	0.4612
N Rate	0.2385	0.9010	0.5294	0.1918	0.5648	0.1963	0.8122
PC x Nrate	0.6099	0.7412	0.4312	0.3898	0.2664	0.0705	0.1815
Cvr x N Rate	0.8039	0.9679	0.9920	0.4942	0.7343	0.6004	0.8400
PC x Cvr x N rate	0.7303	0.8750	0.7436	0.5366	0.3396	0.3786	0.5068

Appendix Table A.4.20. Soil water extraction at anthesis in the soil profile increments (0-130 cm) as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Winnipeg, MB (2000).

	Soil Water Use (mm)						
	Depth (cm)						
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**
Previous Crop							
Pea	-2.7	1.5	-4.1	-5.5	-4.7	-3.9	-3.5
Flax	-1.8	0.6	-4.9	-6.6	-5.9	-4.3	-4.4
LSD (0.05)	1.3	6.4	3.6	1.7	2.8	3.4	1.2
Cultivar							
AC Ronald	-2.4	1.1*b*[z]	-4.9	-6.5	-5.1	-4.4	-3.3*b*
Triple Crown	-1.3	3.3*a*	-3.6	-5.6	-5.3	-4.3	-3.6*b*
AC Taber	-2.8	0.3*b*	-5.4	-5.8	-5.3	-3.8	-4.1*ab*
AC Barrie	-2.6	-0.5*b*	-4.2	-6.2	-5.5	-4.0	-4.9*a*
LSD (0.05)	2.5	2.2	1.6	1.9	1.2	1.1	1.0
N Rate (kg ha^{-1})							
0	-2.6	-1.0*a*	-4.5	-6.0	-5.3	-4.0	-3.9
80	-1.9	3.1*b*	-4.6	-6.1	-5.4	-4.3	-4.0
LSD (0.05)	1.7	1.2	0.9	1.0	1.1	0.6	0.9
Source of Variation	ANOVA (P>F)						
Previous Crop (PC)	0.1293	0.6994	0.5417	0.1340	0.2840	0.7397	0.0960
Cultivar (Cvr)	0.5988	0.0118	0.1261	0.7654	0.9081	0.6720	0.0326
PC x Cvr	0.7640	0.1312	0.5795	0.7078	0.5426	0.7400	0.6272
N Rate	0.4431	<.0001	0.7181	0.7241	0.8984	0.2518	0.7461
PC x Nrate	0.8208	0.4243	0.6149	0.4507	0.8032	0.0615	0.6199
Cvr x N Rate	0.1195	0.0301	0.2643	0.6464	0.8722	0.2007	0.8859
PC x Cvr x N rate	0.3474	0.0047	0.6678	0.4941	0.8424	0.0279	0.2514

[z] Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).

Appendix Table A.4.21. Soil water extraction at maturity in the soil profile increments (0-130 cm) as affected by cultivar, nitrogen (N) fertilizer rate, and previous crop treatment effects at Winnipeg, MB (2000).

	Soil Water Use (mm)						
	Depth (cm)						
Main Effect	**0-10**	**10-30**	**30-50**	**50-70**	**70-90**	**90-110**	**110-130**
Previous Crop							
Pea	-1.6	13.9	8.7	4.2	1.3	-1.0	-2.0
Flax	-0.7	10.9	5.8	0.5	-0.8	-2.2	-3.0
LSD (0.05)	2.1	5.8	5.7	6.8	5.9	3.3	2.9
Cultivar							
AC Ronald	-1.9	14.7*b*^{z}	9.4*b*	3.6*a*	0.0*b*	-1.8	-2.4
Triple Crown	0.4	20.3*c*	14.4*a*	7.1*a*	2.3*a*	-1.2	-2.2
AC Taber	-1.8	9.8*c*	4.7*c*	-0.1*b*	0.1*ab*	-1.6	-2.5
AC Barrie	-1.3	4.8*d*	0.4*d*	-1.3*b*	-1.5*b*	-1.9	-2.8
LSD (0.05)	2.6	4.5	3.4	3.5	2.2	1.4	1.4
N Rate (kg ha^{-1})							
0	-1.6	8.4*b*	4.7*b*	0.9*b*	-0.3	-1.5	-2.4
80	-0.7	16.4*a*	9.7*a*	3.7*a*	0.7	-1.7	-2.6
LSD (0.05)	1.6	2.5	1.3	1.1	1.1	0.8	1.2
Source of Variation	ANOVA (P>F)						
Previous Crop (PC)	0.2449	0.2064	0.2069	0.1883	0.3516	0.3295	0.3889
Cultivar (Cvr)	0.2266	<.0001	<.0001	0.0004	0.0187	0.6998	0.8072
PC x Cvr	0.1051	0.8599	0.6875	0.5507	0.1805	0.6816	0.5929
N Rate	0.2445	<.0001	<.0001	<.0001	0.0604	0.5849	0.6785
PC x Nrate	0.7132	0.1831	0.7179	0.3653	0.2278	0.3063	0.4614
Cvr x N Rate	0.9874	0.8059	0.2581	0.4000	0.9849	0.3787	0.9065
PC x Cvr x N rate	0.9308	0.8058	0.1244	0.6129	0.5691	0.4831	0.2912

^{z} Means followed by the same letter are not significantly different according to Fisher's protected Least Significant Difference test ($P \leq 0.05$).