DRYAND WINTER CANOLA WATER AND NITROGEN USE

IN EASTERN WASHINGTON

By

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Abstract

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In the low-intermediate rainfall zones of Washington state, a wheat-fallow cropping sequence is dominant. Winter canola is a relatively recent rotational option, boosting subsequent wheat yields due to weed control possibilities, pest cycle disruption, and potential soil health benefits. Little is known about the water and nitrogen (N) requirements of winter canola. Field experiments were conducted to assess the growth and water and N use of winter canola throughout three distinct "seasons": fall (vegetative growth), winter, and harvest (spring regrowth to harvest). Water use varied widely based upon location, though a sigmoidal relationship between fall water use and growing degree days emerged. Canola water extraction patterns were showed water depletion throughout the soil profile. An additional planting date study revealed the influence of seeding date on water use and winter survival. Soil water and N dynamics over winter were tracked, and eventual grain harvest enabled yield-based factors, such as water use efficiency. Nitrogen use efficiency and its components were determined on both a seasonal and total-season basis, with harvest season N metrics similar to spring canola.

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CHAPTER 1

INTRODUCTION AND REVIEW OF LITERATURE

Canola and its place in Washington agriculture

“Canola” is the registered name of an edible rapeseed. Originating in Canada in the 1970s, canola has low erucic acid and glucosinolate contents; the moniker canola was created from “Canada oil low acid” (Kandel and Berglund 2011). It is a member of the *Brassicaceae* family. *Brassica rapa* and *B. napus* are the two most common species, with *B. napus* the most popular due to its higher yield potential (Kandel and Berglund 2011). North Dakota has traditionally led the nation in canola production, with 89% of the domestic crop in 2010.

Canola research and interest in the Pacific Northwest began as early as the 1970s (Divine et al 1977). Acreage remained small, with the USDA not tracking Washington canola plantings until 2011. Production has since increased dramatically, especially in the past few years, with an estimated 45,000 acres planted currently (National Agricultural Statistics Service 2014). Canola cultivation attempts have been mainly in the drier dryland regions of eastern Washington where growers practice a wheat-fallow rotation, though there is some irrigated production. This research focuses on winter canola seeded into fallow, as is typical in the low (<300 mm annual) and intermediate (300-450 mm annual) rainfall areas.

The largest portion of Washington’s arable land falls into the low or intermediate precipitation zones (Sowers et al 2012). This semi-arid climate receives a majority of its rainfall and snow in the winter and early spring. Variety trials have established that winter canola has consistently higher yields than spring-seeded canola in dry areas of eastern Washington (Davis et al 2008, Young et al 2012).

Washington growers have several motives for adopting oilseeds as an alternate crop in their wheat rotations. Wheat following canola has had higher yields and protein contents compared to wheat following wheat (Angus et al 1991, Kirkegaard et al 1997, Larney et al 1994). In the Pacific Northwest (PNW), growers have anecdotally noted a 20-30% yield increase in their subsequent wheat crop (Sowers et al 2012). Canola provides a disease and pest break, reducing wheat pathogens by depriving them of a host for a season (Kirkegaard et al 1997). It is also thought that canola tap roots may improve subsoil structure, finding tiny cracks or weak points in compacted layers and creating macropores; however, scientific evidence has been inconclusive (Cresswell and Kirkegaard 1995). Another attractive aspect is the option of herbicide tolerant or resistant varieties; growers often incorporate genetically modified canola in their rotation as a means to control weeds (Esser and Hennings 2012). The increased market demand and the presence of local PNW processing plants have also made canola production more economically feasible (Sowers et al 2012).

Ultimately, growing canola must generate revenue for famers. The adoption of canola will be driven by its market place and price in relation to winter wheat, as well as reduced production risk from further experience and research. The understanding that rotational benefits may change the break-even point over multiple years will also influence the decision to grow canola (McCraken and Connolly 2013).

Some of the largest challenges of canola production in the PNW are emergence and establishment (Sowers et al 2012, Young et al 2014). A seeding rate of 4.5 kg/ha in the low rainfall areas of Washington is sufficient for acceptable yields (Young et al 2014). In both tilled and no-tilled fields, planting seeds with a drill – as opposed to broadcasting – is common (Young et al 2012). After seedling establishment, large basal rosette leaves form during the autumn vegetative stage. An additional consideration not present with spring canola is that winter canola plants must overwinter; winter-kill can be a major problem some years in some locations (Young et al 2014). In some cases, the plants are too small and don't achieve enough biomass and plant resources to survive harsh winter conditions (Velicka et al 2006, Balodis and Gaile 2011). Conversely, plants that are too large also don't overwinter well; if canola begins to bolt, the vulnerable crown rises above the soil surface and is thus not protected by soil insulation and snow cover. This stem elongation and subsequent winter sensitivity has been observed in several studies (Darby 2013, Balodis and Gaile 2011, Laaniste et al 2007).

Optimal winter survival is seen from canola with 6-8 leaves, a taproot length of 150 cm, and a distance between the terminal bud and the ground of no more than 3 cm (Velicka et al 2006). During winter canola hardening, plants accumulate sugars, proteins, unsaturated fatty acids, and other frost-protective mechanisms (Hurry et al 1995). If development and hardening conditions are favorable, canola can withstand 0-15°C frost without protective snow, and with a snow cover can survive -20°C (Laaniste et al 2007). Plant density, sowing date, and climatic conditions all contribute to the winter preparedness of canola (Velicka et al 2006). Dramatic temperature swings and late frosts (February) are particularly difficult to overcome.

Upon warmer spring temperatures, vegetative growth resumes. Vernalization and subsequent warmer, longer days allow plants to bolt and leads to flowering. Flowering begins on the lowest bud on the stem and lasts for at least 14-21 days (Kandel and Berglund 2011). After flowering initiation, lower leaves are shaded up to 70% and they senesce, translocating any stored carbon (Diependbrock 2000). Like at the seedling stage, canola is vulnerable to drought and heat stress during flowering. Nuttall et al (1992) found that a 3°C increase over the optimum 20°C temperature resulted in a 430 kg ha^{-1} yield decrease. Temperatures above 30°C generally results in flower cessation in eastern Washington (Schillinger 2015).

Open pollinated varieties rely upon wind or insect mediated pollination, and hybrid varieties are becoming popular. Long, thin seed pods form, each of which contains 15-25 seeds (Australian Government 2008). Canola pods, stem, and cauline leaves (upper non-rosette leaves) photosynthesize (Kirkegaard et al 2012). In fact, King et al (1997) found that carbon fixed by the pod can contribute up to 60% of the seed's dry matter. Canola has an indeterminate growth habit, achieving maximum yields with even severe stand reductions (Susko and Superfisky 2009, Young et al 2012). Mature seeds are hard and dark brown or black, and canola is prone to shattering losses (Australian Government 2008). Typically, PNW canola is directly combined, and the seeds are transported to one of several crushing plants.

Seeds have oil contents of 35-45% and are processed for biofuel or food grade oil (Shahidi 1990). The by-product of oil extraction is canola meal, which is a high protein livestock feed supplement (Newkirk 2009). Grazing the vegetative growth of winter canola in the field is also gaining in popularity (Kirkegaard et al 2008).

A closer look at canola development: growing degree days, biomass accumulation, and nitrogen use metrics

In many plant and animal species, temperature is a determining factor in developmental timing. Reaumur introduced the concept of "heat units" in 1730, and many methods of calculating thermal time have since been investigated (McMaster and Wilhelm 1997). In plant studies, growing degree days (GDD) have enabled prediction of development far more accurately than calendar days (Russelle et al 1984). The formula for daily GDD depends upon subtracting a species-specific base temperature from the day's average temperature. The base temperature (T_b) is the minimum temperature required for development to proceed.

In canola, some studies have assumed a T_b of 5°C (Morrison et al 1989, Wilson et al 1992). However, germination and seedling growth does occur – albeit slowly – at temperatures ranging from 0 to 5°C, and more recent research has pinpointed 0°C as a more accurate T_b (Kondra et al 1983, Robertson et al 2002, Vigil et al 1997).

There have been very few GDD modeling studies for canola; most pertain to spring seeded canola and have been developed in Canada. Table 1.1 integrates spring *B. napus* GDD data from S. Brandt and P. Miller, presented in the Canola Council of Canada's growers manual (Thomas 2014). Similar values have been echoed in other studies as well (Malhi et al 2007, Miller et al 1998).

Table 1.1. Canola growth stage and corresponding growing degree day accumulation.

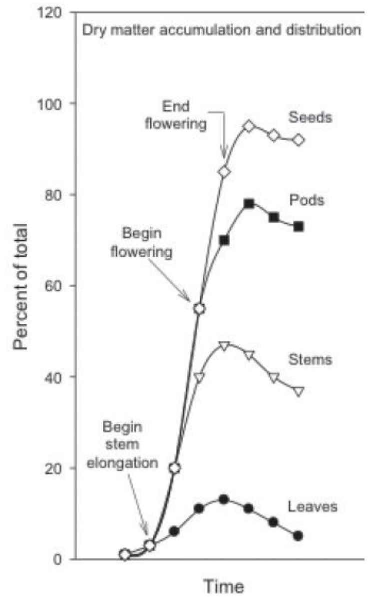
Description of Growth Stage	Growing Degree Days
Cotelydons completely unfolded	152-186
Two leaves unfolded	282-324
Four leaves unfolded	411-463
Flowering initiation	582-666
Flowering 50% complete	759-852
Seed fill begins (10% of seeds full)	972-1074
Seed begins to mature (10% of seeds mature)	1326-1445
40% seeds mature	1432-1557

Canola in Canada is often swathed at approximately 40% maturity for uniform dry-down and easier harvest, rather than direct combining after total pod dry-down as is the practice in Washington. Growing degree days to this full maturity point were quantified by Nanda et al (1996), who noted an average of 1060 GDD from flowering to complete maturity. They also saw progressively fewer GDDs required for later planting dates in colder temperatures, which was attributed to a vernalization-like response (Nanda et al 1996). Tesfamariam et al (2010) observed stress effects on GDD progression; water stress during flowering delayed maturity by 114 GDD. On the other hand, moisture stress during seed fill resulted in maturity 127 GDD earlier than the well-watered comparison (Tesfamariam et al 2010).

Harvest index (HI) is a useful measure that quantifies the percent of above-ground dry matter present in seed. Dryland spring canola HI ranges from 20-30% (Gan et al 2009b, Hocking et al 1997a, Robertson and Kirkegaard 2005). A greater proportion of above-ground biomass is harvested in wheat production, as wheat HI is around 40% (Stapper and Fischer 1990).

Very high positive correlations exist between biomass accumulation and yield, indicating that plant size is important in determining plant seed yield (Campbell and Kondra, 1978). Under dryland conditions, carbon allocation by spring canola to grain:straw:root:rhizodeposits is: 0.13:0.53:0.21:0.13 respectively (Gan et al 2009b). Gan et al (2009b) found a carbon mass of 1371 kg/ha in straw and 534 kg/ha in roots. Malhi et al (2007) observed that maximum biomass was reached during the middle/end of the pod forming stage (750-973 GDD). Maximum rate of biomass accumulation was 146-190 kg/ha and occurred during the bud forming stage (390-498 GDD). Dry matter accumulation generally follows a sigmoidal pattern during the spring growing season (Figure 1.1). Amounts and distribution patterns of biomass accumulation depend upon growth stage and environmental conditions (Malhi 2007).

Figure 1.1. Canola dry matter accumulation and distribution. From Koenig et al 2012.



Nutrient accumulation is also influenced by these factors. For example, seed nitrogen (N) content is higher in non-water-stressed canola (Gan 2010). Nitrogen is the most important agronomic nutrient and is often the most limiting for growth. The critical N curve, which models the minimum N concentration (N) required to reach maximum above-ground biomass (W), is $N = 4.48W^{-0.25}$ for winter canola (Colnenne et al 1998).

Maximum nutrient uptake occurs at flower initiation to early ripening (597-945 GDD) (Malhi et al 2007). The highest rate of nutrient uptake, however, takes place earlier, from branching to early budding (142-399 GDD) (Malhi et al 2007). Berry et al (2010) found that N taken up after flowering was the most important in determining yield differences. Other studies have confirmed that canola N uptake during and after flowering can be up to 33% of total (Hocking et al 1997a, Malagoli et al 2005). In contrast, other research has noted very little N uptake after flowering (Rossato et al 2001, Malagoli et al 2004). In general, the uptake curve follows a pattern similar to Figure 1.1 (Malhi et al 2007, Hocking et al 1997a).

Canola accumulates more N (as well as phosphorus, potassium, and sulfur) than wheat, when an equivalent yield is considered (Koenig et al 2011). In the PNW, canola base N requirements are 6-10 kg N per 100 kg yield (Koenig et al 2011, Wyosocki et al 2007, Maher and Guy 2002).

During autumn growth, winter canola accumulates 25-30% of its total N uptake, around (40-80 kg N ha^{-1}) (Rathke et al 2006). Some of the nitrogen initially present in autumn leaves and stems appears to be recycled to spring growth and is later remobilized during reproduction (Malagoli et al 2005, Rossato et al 2001). Endogenous N flow analysis shows a complicated dynamic, with remobilization to the pods originating from leaves (36%), stem (34%), inflorescences (22%) and taproot (8%) (Malagoli et al 2005).

Nitrogen use efficiency (NUE) is commonly defined as the seed yield per unit N use (Moll et al 1982). There is much discussion regarding agronomic management techniques to maximize NUE, such as early sowing to prevent N losses from leaching (Rathke et al 2006). Canola NUE decreases as fertilizer rates increase (Gan et al 2008, Erley et al 2011, Hocking 1997a).

Though its ability to scavenge N from the soil is high, canola has a low NUE compared to wheat. This is partially due to the fact that canola seeds are high in lipids and require 45% more assimilate per kilogram than starch-rich wheat grains (Sinclair and de Witt 1975). Also, canola has a greater seed N concentration and a higher ratio of seed

N:total biomass N than wheat (Dreccer et al 2000). Finally, a significant portion of N remains in canola crop residues and a significant portion of N (up to 15%) is lost to the soil due to leaf death during the growth cycle (Erley et al 2011, Schjoerring et al 1995, Hocking et al 1997a, Rossato 2001). Abscised leaves retain an N content of 3-4%, compared to less than 1% for wheat (Malagoli et al 2005).

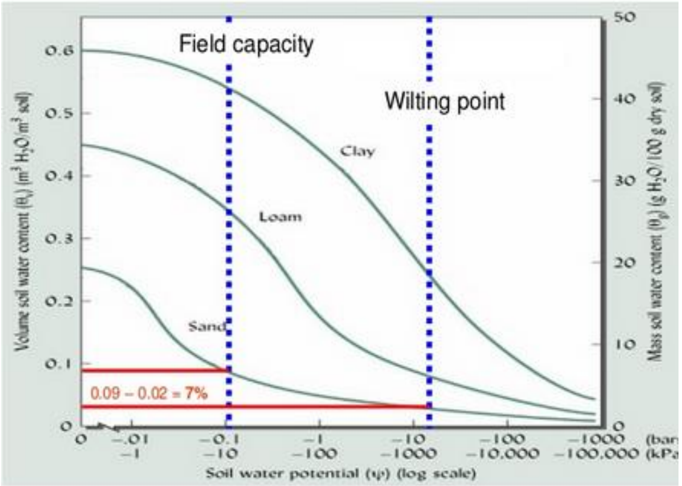
Soil water, canola rooting, and water use efficiency

When compared to the vast quantities of water cycling through the earth and its atmosphere, the amount of water stored in soil is miniscule, approximately 0.05% (Dingman 2002). However, this small pool is immensely important to plant life. Many methods have been devised to quantify soil moisture content. The standard technique is to oven dry a sample at 105°C (cool enough to avoid loss of organic materials) until water loss ceases, generally around 24 hours (ASTM 1979, Robinson 2008). Capacitance sensors, time domain reflectometry, and heat pulse sensors are examples of soil moisture technology (Evett and Parkin 2005, IAEA 2008).

In actuality, gravimetric or volumetric water content (VWC) measurements are not very helpful in understanding the moisture status of a soil. VWC quantifies the amount of water present but does not provide any information about the energy status of that water. Soil water potential provides this key piece of information in discerning the water status of a soil. Water potential is the difference between energy levels of pure water at a reference state and the soil water (Brady and Weil 2010). In most soil situations, water potential is a function of gravitational, matric (adhesive forces and capillarity), and osmotic (solute presence) forces (Brady and Weil 2010). The relationship between soil water potential and soil water content is termed a water release characteristic curve.

Soil texture and structure influence the water characteristic curve. For example, at a given potential, a clay soil holds much more water than a sandy soil (Figure 1.2). Also, water is held much tighter in clay soils at a given water content. A compacted soil can hold less water and it will be held tightly in small pores (Brady and Weil 2010).

Figure 1.2. Soil water characteristic curves for representative mineral soils, from Brady and Weil 2010



Water characteristic curves for specific soils are determined via laboratory analysis. One technique to relate water potential and moisture content is the dew point method. A soil sample is placed in an instrument such as the WP4C (Decagon Devices, Pullman WA), and an internal mirror is chilled until condensation is formed. This dew point, along with the sample's temperature, is used to calculate relative humidity which can then be converted to water potential through the Kelvin equation (Campbell and Norman 1998). Water content of the sample is then determined gravimetrically. This technique works well in drier soils, from -0.1 to -300 MPa. For the wetter portion of the curve, another method must be used, such as tensiometer readings. The UMS Hyprop is an example of a machine that employs natural drying; it integrates two tensiometers at different heights in a cylinder of undisturbed soil with an electronic base that sits on precision scale. The water potential gradient within the soil samples, along with the change in mass from evaporation, allow for determination of hydraulic conductivity (Schindler and Müller 2006). The range of this technique is limited, as tensiometers will cavitate in dry situations (<-0.08 MPa).

The soil water characteristic curve is very useful once established. Field water content measurements are easily made, and the water characteristic curve gives these values more practical meanings. There are several noteworthy soil moisture conditions. In a saturated soil, all the pore spaces are filled with water. After the downward force of gravity has drained water, the remaining soil water content is termed field capacity, FC (Veihmeyer and Hendrickson 1931). The physical characterization of FC is commonly the soil water content at -33 MPa matric potential for fine or moderately course soils (Richards and Weaver 1944). Richards and Weaver (1943) also determined that -1.5 MPa potential generally corresponds to the permanent wilting point (PWP). PWP is the water content at which plants wilt and fail to recover upon rewatering (Briggs and Schantz 1912). The difference between soil water contents at FC and PWP is deemed plant available water (PAW).

Some researchers have contested the -33 and -1.5 MPa standards for FC and PWP respectively by asserting that field measurements are more accurate than laboratory evaluations (Ratliff et al 1983). However, a laboratory-created soil water characteristic curve remains the literature standard for relating potentials to water contents and establishing FC and PWP.

The rooting system is the plant organ that interacts with soil water, utilizing PAW. Rooting architecture is dependent upon both root genetic code and environmental factors (Yu et al 2007). In semiarid environments, a deep exploratory rooting system is ideal for yield stabilization (Gregory and Brown 1989). Unlike the fibrous, multiple-axis growth of cereal roots, canola exhibits a taproot architecture. One main root radical grows vertically and lateral branches progress horizontally. At the base, winter canola taproots can be 2.54 cm in width, tapering to 1 mm at 0.33 m depth (Pan et al 2013).

Spring canola root growth progresses rapidly from emergence to flowering, achieving maximum root surface area in late flowering (Cutforth et al 2013, Lui et al 2011a, Gan et al 2011). Canola's root growth rates are comparatively higher than other oilseeds and legumes (Lui et al 2011b, Angadi et al., 1999). Root length density and associated parameters decline during pod filling and maturation (Lui et al 2011a). This temporal growth pattern seems to hold true regardless of soil moisture status (Merrill et al 2002, Lui et al 2011a).

Spatially, canola's root length density decreases with depth (Lui et al 2011b); about 44% of roots are concentrated in the top 20 cm of soil and 70% in 0-40 cm (Gan et al 2011). Over 75% of root carbon is contributed by roots in the top 40 cm (Gan et al 2009b). Using standard minirhizotrons, Merrill et al (2002) found that dryland spring canola has an average greatest root length density of 25 $km \cdot m^{-2}$, which occurs around 45 cm depth. Conversely, Lui et al (2011b) found canola's greatest root length density to occur in the top 10 cm, consistent with other observations (Cutforth et al 2013). Yet compared to other crops, canola has a higher percentage of roots below 60 cm, ranging from 18% - 25% of total plant roots (Gan et al 2011, Cutforth 2013). Canola can obtain 45% of its total water use from water stored in soil below 60 cm, leaving more water in the upper soil profile than cereals especially in the wetter summers of North Dakota (Merrill 2004).

Canola has been observed to increase total root growth in drier years (Gan et al 2011, Merrill et al 2002). However, Lui et al. (2011a) saw that roughly doubling the amount of soil water increases root length density by 70%, root surface area by 67%, and the number of root tips by 79%. Canola's response was much more drastic than other oilseeds, pulses, or wheat. However, canola had a larger root system than the other oilseeds compared (flax and mustard) even under the limited water condition, making it potentially more resilient to drought conditions (Lui et al 2011b).

Several studies, whether by direct observation or water extraction patterns, have confirmed spring canola maximum rooting depth between 1.14 – 1.3 m (Merrill et al 2002, Cutforth et al 2013, Johnson et al 2002). Nielson et al (1997) found that canola extracted water at a depth of 1.65 m, though 92-95% of the water use originated in the top 1.19 m. Maximum root depth is achieved during late flowering to late pod stages (Cutforth et al 2013, Lui et al 2011a, Gan et al 2011). Furthermore, canola tends to send roots deeper as water content at depth increases (Merrill et al 2002, Cutforth et al 2011).

While the most densely rooted soil layer may be more important than maximum root length in soil water use (Yu et al 2007), water deep in the soil profile is used later in the growing season during seed filling (Passioura 2006, Kirkegaard et al. 2007). This deep soil water may make a large contribution to grain yield (Passioura 2006). The water use efficiency of the water deeper in the soil profile can be up to three times greater than the season WUE (Kirkegaard et al 2007).

Water withdrawal patterns are consistent regardless of soil moisture availability (Gan et al 2009). Cutforth et al (2013) found the following spring canola water use (delineated by wheat growth phases): emergence to early boot 29.9 mm, early boot to anthesis 52.2 mm, anthesis to ripe 61.6 mm, for a total water use of 145.4 mm. This total water use was 13 mm less than wheat yet more than pulses, which are common rotational crops in the higher rainfall zones of the PNW. Similarly, Gan et al (2009) found spring canola used 10 fewer mm of water than wheat, with a total water use of 296 mm.

However, five years of data in the Pacific Northwest show that winter canola uses statistically the same amount of water as winter wheat, and post-harvest winter soil recharge is the same for winter canola and winter wheat fields (Schillinger 2012). Canola withdraws a larger portion of its water requirement earlier in the growing season compared to pulses and cereals (Cutforth et al 2013). Canola has been observed to extract water below the soil's theoretical permanent wilting point (Gan et al 2009). Water use and soil water depletion depends upon precipitation and growing season length, not necessarily root growth parameters (Merrill et al 2004).

The relationship of water use to plant production is: $B = mT/E_0$, where biomass (B) depends upon a crop-specific constant (m) and crop transpiration (T) divided by free water evaporation (E_0) (de Wit 1958). Agronomy and breeding efforts focus on these parameters when aiming to increase production under water stress (Passioura 2006). Capturing the maximum amount of water supply, exchanging CO_2 and water more efficiently, and converting more biomass into harvestable organs are the main areas of water use research (Passioura 2006).

Crop water use efficiency (WUE) is a commonly quantified parameter, one that relates the grain yield to plant evapotranspiration (often estimated by water use). A crop with higher WUE may not translate to a more drought-tolerant one (Blum 2009). More effective use of water, and not necessarily WUE, should be the target of breeding. Nevertheless, WUE serves as a useful benchmark and is still widely used. See Table 1.2 for *B. napus* WUE values.

Table 1.2. Canola WUE ratios from various studies.

Source and Location	**Notes**	**WUE ($kg \cdot ha^{-1} mm^{-1}$)**
Tesfamariam et al 2010, South Africa	Winter canola, water stress during flowering	4.45
	Winter canola, water stress during seed fill	5.3
	Winter canola, well watered	7.09
Anderson et al 2003, Mandan ND	Spring canola, no difference in WUE between wet and dry years	4.5
Gan et al 2009a, Saskatchewan	Spring canola, rainfed	2.89
	Spring canola, irrigated	3.1
Azooz and Arshad 1998, British Columbia	Spring canola, no till	3.61
	Spring canola, conventional tillage	4.16
Cutforth et al 2006, Saskatchewan	Spring canola, no till into tall stubble	5.76
	Spring canola, conventional tillage	4.2

Cocks et al (2001) proposed a maximum WUE of 13 $kg \cdot ha^{-1} mm^{-1}$. Hocking et al (1997b) calculated a very similar WUE frontier of 12.5 $kg \cdot ha^{-1} mm^{-1}$. Actual WUE values observed in both these studies varied widely across location and year, from 3 – 18 $kg \cdot ha^{-1} mm^{-1}$. Robertson and Kirkegaard (2005) evaluated 42 datasets of dryland spring canola for WUE and they found the middle 60% to have WUE values between 8.5 – 14 $kg \cdot ha^{-1} mm^{-1}$. The lowest observed was 3.8 $kg \cdot ha^{-1} mm^{-1}$, and the highest was 18.3 $kg \cdot ha^{-1} mm^{-1}$. Crops sown late and crops with low yields and HI tended to have lower WUE. Roberson and Kirkegaard (2005) fit an upper WUE limit of 15 $kg \cdot ha^{-1} mm^{-1}$, comparable to the two aforementioned studies.

WUE can be thought of as the slope of the line between yield and water use (or seasonal water supply) (Robertson and Kirkegaard 2005). The intercept of this line is essentially the threshold of water supply for any yield to occur, though it is often interpreted as water evaporation from the soil surface (Robertson and Kirkegaard 2005, Angus and van Herwaarden 2001). In a well-known paper, French and Schultz (1984) quantified this intercept as 110 mm, and many studies use this baseline (Hocking et al 1997b). Robertson and Kirkegaard (2005) fitted a slightly higher intercept of 120 mm. Soil evaporation is lower for varieties with early vigor and in early-sown crops (Robertson and Kirkegaard 2005).

Management practices affect WUE, with problems like poor fertility or disease pressure lowering WUE values. Even in well-managed situations, unfavorable timing of precipitation and water losses can negatively impact WUE (Robertson and Kirkegaard 2005). WUE varies between species as well. In general, wheat displays higher WUE values compared to canola; wheat's WUE frontier is around 20 - 25 $kg{\cdot}ha^{-1}mm^{-1}$ (Passioura 2006, Angus and van Herwaarden 2001).

OBJECTIVES

Field based experiments will:

1) Determine total water and nitrogen use of winter canola seeded into fallow in low-intermediate rainfall regions of eastern Washington state
2) Monitor water content at depth increments throughout the soil profile to clarify where and when canola uses water, as well as the maximum root depth
3) Use biomass, yield, and water use to calculate water use efficiency parameters
4) Ascertain nitrogen use efficiency throughout seasonal growth based upon periodic soil and biomass nitrogen content measurements
5) Relate growing degree days to biomass accumulation, nitrogen uptake, and water use

Multiple Washington locations will allow for comparisons of these factors across varied landscapes and environments. The planting date study can reveal any differences in these factors due to sowing time. Taken together, this information can lead to a better understanding of canola's fit in Mediterranean dryland wheat-fallow cropping system rotations.

LITERATURE CITED

Anderson, R.L, D.L. Takana, and S.D. Merrill. 2003. Yield and water use of broadleaf crops in a semiarid climate. Agri. Water Manag. 58: 255-266.

Angadi, S.V., B.G.McConkey, D. Ulrich, H.W. Cutforth, P.R.Miller, M.H. Entz, S.A. Brandt, and K.Volkmar. 1999. Developing viable cropping options for the semiarid prairies. Project Rep. Agric. and Agri-Food Can., Swift Current, SK.

Angus, J.F., A.F. van Herwaarden, and G.N. Howe. 1991. Productivity and break crop effects of winter-growing oilseeds. Aust. J. Exp. Agric.. 31: 669-677.

Angus, J.F. and A.F. van Herwaarden. 2001. Increasing water use and water use efficiency in dryland wheat. Agron. J. 93: 290-298.

ASTM. 1979. Standard method of laboratory determination of moisture content of soil: Procedure D2216-71. *In* Annual book of ASTM standards.Am. Soc. Test. Mater., Philadelphia, PA: 290-291.

Azooz, R. H. and Arshad, M. A. 1998. Effect of tillage and residue management on barley and canola growth and water use efficiency. Can. J. Soil Sci. 78: 649–656.

Australian Government. 2008. The biology of *Brassica napus* L. (canola). Department of Health and Aging, Office of the Gene Technology Regulator.

Balodis, O. and Z. Gaile. Winter oilseed rape (*Brassica napus* L.) autumn growth. Research for Rural Development - International Scientific Conference Proceedings. 1: 6-12

Berry, P.M., J. Spink, M.J. Foulkes, and P.J. White. 2010. The physiological basis of genotypic differences in nitrogen use efficiency in oilseed rape (Brassica napus L.). Field Crops Res. 119: 365–373.

Blum, A. 2009. Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. Field Crops Res. 112: 119-123.

Brady, N.C. and R.R. Weil. 2010. Elements of the Nature and Properties of Soils. Pearson Education, New Jersey.

Briggs, L.J. and H.L. Shantz. 1912. The wilting coefficient and its indirect determination. Bot Gazette. 53: 20-37.

Campbell, D. C. and Z. P. Kondra. 1978. Relationships among growth patterns, yield components and yield of rapeseed. Can. J. Plant Sci. 58: 87–93.

Campbell, G.S. and J.M. Norman. 1998. An introduction to environmental biophysics. Springer, New York.

Chen, C. G. Jackson, K. Neill, D. Wichman, G. Johnson, and D. Johnson. 2005. Determining the feasibility of early seeding canola in the Northern Great Plains. Agron. J. 97:1252–1262.

Cocks, B., M.J. Roberson, and S. Cawley. 2001. Water extraction and water use efficiency of canola in the north. *In* Proceedings of the Australian Research Assembly on Brassicas.

Colnenne, C., J.M. Meynard, R. Reau, E. Justes, and A. Merrien. 1998. Determination of a critical nitrogen dilution curve for winter oilseed rape. Ann. Bot. 81: 311–317.

Cresswell, H.P. and J.A. Kirkegaard. 1995. Subsoil amelioration by plant roots: the process and the evidence. Aust. J. Soil Res. 33: 221-39.

Cutforth, H. W., S.V. Angadi, and B.G. McConkey. 2006. Stubble management and microclimate, yield and water use efficiency of canola grown in the semiarid Canadian prairie. Can. J. Plant Sci. 86: 99–107.

Cutforth, H.W., S. V. Angadi, B. G. McConkey, P. R. Miller, D. Ulrich, R. Gulden, K. M. Volkmar, M. H. Entz, and S. A. Brandt. 2013. Comparing rooting characteristics and soil water withdrawal patterns of wheat with alternative oilseed and pulse crops grown in the semiarid Canadian prairie. Can. J. Soil Sci. 93: 147-160.

Darby, H. 2013. 2012-2013 Winter Canola Survival. University of Vermont Extension.

Davis, J.B., M. Lauver, J. Brown, and D. Wysocki. 2008. Pacific Northwest winter canola variety trial results. University of Idaho.

Divine, T.E., D.P. Alzheimer, J.W. Currie, K.A. McGinnis, and D.J. Wiggins. 1977. Research on the potential impact of advanced oilseeds processing technology on Pacific Northwest Agriculture. Batelle Pacific Northwest Laboratories.

Dejoux, J.F., S. Recous, J.M. Meynard, I. Trinsoutrot, and P. Leterme. 2000. The fate of nitrogen from winter-frozen rapeseed leaves: mineralization, fluxes to the environment, and uptake by rapeseed crop in spring. Plant and Soil. 218: 257-272.

de Wit, C.T. 1958. Transpiration and Crop Yields. Institute of Biological and Chemical Research on Field Crops and Herbage, Wageningen, The Netherlands, 64(6): 24.

Diepenbrock, W. 2000. Yield analysis of winter oilseed rape (Brassica napus L.): a review Field Crops Res. 67(1): 35-49.

Dingman, S.L. 2002. Physical hydrology. 2nd ed. Prentice Hall, Upper Saddle River, NJ.

Dreccer, M.F., A. H. C. M. Schapendonk, G. A. Slafer, and R. Rabbinge. 2000. Comparative response of wheat and oilseed rape to nitrogen supply: absorption and utilisation efficiency of radiation and nitrogen during the reproductive stages determining yield. Plant Soil. 220: 189–205.

Erley, G.S., T. Behrens, A. Ulas, F. Wiesler, and W.J. Horst. Agronomic traits contributing to nitrogen efficiency of winter oilseed rape. 2011. Field Crops Res. 124: 114-123.

Esser, A., and R. Hennings. 2012. Winter canola feasibility in rotation with winter wheat. Washington State University Extension Fact Sheet FS068E.

Evett, S.R. and G. W. Parkin. 2005. Advances in soil water content sensing: the continuing maturation of technology and theory. Vadose Zone Journal 4: 986–991.

French, R.J. and J.E. Schultz. 1984. Water use efficiency of wheat in a Mediterranean type environment. 1. The relation between yield, water use and climate. Aust. J. Agric. Res. 35: 743-764.

Gan, Y., S. S. Malhi, S. Brandt, F. Katepa-Mupondwa, and C. Stevenson. 2008. Nitrogen use efficiency and nitrogen uptake of *juncea* canola under diverse environments. Agron. J. 100: 285–295.

Gan, Y.T., C.A. Campbell, L. Liu, P. Basnyat, and C.L. McDonald. 2009a. Water use and distribution profile under pulse and oilseed crops in semiarid northern high latitude areas. Agric. Water Manage. 96: 337-348.

Gan, Y.T., C.A. Campbell, H.H. Janzen, R.L. Lemke, P. Basnyat, and C.L. McDonald. 2009b. Carbon input to soil from oilseed and pulse crops on the Canadian prairies. Agri., Eco., and the Envir. 132: 290-297.

Gan, Y.T., C.A. Campbell, H.H. Janzen, R.L. Lemke, P. Basnyat, and C.L. McDonald. 2010. Nitrogen accumulation in plant tissues and roots and N mineralization under oilseeds, pulses, and spring wheat. Plant Soil 332:446–451.

Gan, Y., L. Liu, H. Cutforth, X. Wang, and G. Ford. 2011. Vertical distribution profiles and temporal growth patterns of roots in selected oilseeds, pulses and spring wheat. Crop Pasture Sci. 62: 457-466.

Gregory, P.J. and S.C. Brown. 1989. Root growth, water use and yield of crops in dry environments: what characteristics are desirable? Aspects Appl. Biol. 22: 235-243.

Hocking, P.J., P.J. Randall, and D. DeMarco. 1997a. The response of dryland canola to nitrogen fertilizer: partitioning and mobilization of dry matter and nitrogen, and nitrogen effects on yield components. Field Crops Research 54:201-220.

Hocking, P.J, J.A. Kirkegaard, J.F. Angus, A.H. Gibson, and E.A. Koetz. 1997b. Comparison of canola, Indian mustard and Linola in two contrasting environments. I. Effects of nitrogen fertilizer on dry-matter production, seed yield and seed quality. Field Crops Res. 49(2-3): 107-125.

Hulbert, S., W.L. Pan, T. Paulitz, and D. Huggins. 2010. Potential of biennially grown canola and canola grown in other dryland PNW environments. *In:* Washington Biofuels Cropping Systems Annual Report.

Hurry, V.M. A. Strand, M. Tobiaeson, P. Gardestrom, and G. Oquist. 1995. Cold hardening of spring and winter wheat and rape results in differential effects on growth, carbon metabolism, and carbohydrate content. Plant Physiol. 109: 697-706.

Johnston, A.M., D.L. Tanaka., P.R. Miller, S.A. Brandt, D.C. Nielson, G.P. Lafond, and R.R. Riverland. 2002. Oilseed crops for semiarid cropping systems in the northern Great Plains. Agron. J. 94, 231–240.

Kandel, H., and D.R. Berglund. 2011. Introduction. *In* Canola Production Field Guide. North Dakota State Extension A-1280.

King, S.P., J.E. Lunn, and R.T. Furbank. 1997. Carbohydrate content and enzyme metabolism in developing canola siliques. Plant Phys. 114: 153–160.

Kirkgaard, J.A., P.J. Hocking, J.F. Angus, G.N. Howe, and P.A. Gardener. 1997. Comparison of canola, Indian mustard, Linola in two contrasting environments. II. Break-crop and nitrogen effects on subsequent wheat crops. Field Crops Res. 52: 179-191.

Kirkegaard, J. A., L.M. Lilley, G.N. Howe, and J.M. Graham. 2007. Impact of subsoil water use on wheat yield. Aust. J. Agric. Res. 58: 303-315.

Kirkegaard, J.A., S.J. Sprague., H. Dove, W.M. Kelman, S.J. Marcroft, A. Lieschke, G.N. Howe, and J.M. Graham. 2008. Dual-purpose canola—a new opportunity in mixed farming systems. Aus. J. Agri. Res. 59: 291–302.

Kirkegaard, J.A.., S.J. Sprague, J.M. Lilley, J.I. McCormick, J.M. Virgona, M.J. Morrison. 2012. Physiological response of spring canola (Brassica napus) to defoliation in diverse environments. Field Crops Res. 125: 61–68.

Koenig, R. 2011. Canola growth, development, and fertility. Washington State University Extension. FS045E.

Kondra, Z.P., D.C. Campbell, and J.R. King. 1983. Temperature effects on germination of rapeseed (*Brassica napus* L. and *B. campestris* L.). Can. J. Plant Sci. 63(4): 1063-1065.

Laaniste, P., J. Joudu, V. Eremeev, and E. Maeorg. 2007. Sowing date influence on winter oilseed rape overwintering in Estonia. Acta Agriculturae Scandinavica Section B - Soil and Plant Science. 57: 342-348.

Larney, F.J., and C.W. Lindwall. 1994. Winter wheat performance in various cropping systems in southern Alberta. Can. J. Plant Sci. 74:79–86.

Lui, L.P., Y.T. Gan, R. Bueckert, and K. Van Rees. 2011a. Rooting systems of oilseed and pulse crops. I. Temporal growth patterns across the plant developmental periods. Field Crops Res. 122: 256–263.

Lui, L.P., Y.T. Gan, R. Bueckert, and K. Van Rees. 2011b. Rooting systems of oilseed and pulse crops II: vertical distribution across the rooting zone. Field Crops Res. 122: 248-255.

Malhi, S.S., A. M. Johnston, J. J. Schoenau, Z. H. Wang, and C. L. Vera. 2007. Seasonal Biomass Accumulation and Nutrient Uptake of Canola, Mustard, and Flax on a Black Chernozem Soil in Saskatchewan. J. Plant Nut. 30: 641–658.

Malagoli P, P. Laine, E. Le Deunff, L. Rossato, B. Ney, and A. Ourry. 2004. Modeling N uptake in Brassica napus L. cv Capitol during a growth cycle using influx kinetics of root nitrate transport systems and field experimental data. Plant Phys. 134: 388–400.

McCracken, V.A. and J.R. Connolly. 2013. Economic returns to canola rotations in eastern Washington. *In:* Dryland Field Day Abstracts: Highlights of Research Progress. Washington State University Extension.

McMaster, G.S. and W.W. Wilhelm. 1997. Growing degree days: one equation, two interpretations. Agri and Forest Meteorology. 87: 291-300.

Miller, P.R., A. M. Johnston, S. A. Brandt, C. L. McDonald, D. A. Derksen, and J. Waddington. 1998. Comparing the adaptation of sunola, canola and mustard to three soil climatic zones of the Canadian prairies. Can. J. Plant Sci. 78(4): 565-570.

Miller, P., W. Lanier, and S. Brandt. 2001. Using growing degree days to predict plant stages. Montana State University Extension Factsheet 200103.

Merrill, S. D., D.L. Tanaka, and J.D. Hanson. 2002. Root length growth of eight crop species in Haplustoll soils. Soil Sci. Soc. Am. J. 66: 913-923.

Merrill, S. D., D.L. Tanaka, J.M. Krupinsky, and R.E. Ries. 2004. Water use and depletion by diverse crop species on Haplustoll soil in the northern Great Plains. J. Soil Water. Conserv. 59: 176-183.

Moll, R.H., E.J. Kamprath, and W.A. Jackson. 1982. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. Agron. J. 74: 562–564.

Morrison, M.J., P.B.E. McVetty, and C.F Shaykewich. 1989. The determination and verification of a baseline temperature for the growth of Westar summer rape. Can. J. Plant Sci. 69:455-464.

National Agricultural Statistics Service. 2014. Prospective Plantings. Agricultural Statistics Board, United States Department of Agriculture.

Newkirk, R. 2009. Canola meal: feed industry guide. Canola Council, Canadian International Grains Institute.

Nielsen, D.C. 1997. Water use and yield of canola under dryland conditions in the central Great Plains. J. Prod. Agric. 10:307–313.

Nuttal, W.F., A.P. Moulin, and L.J. Townley-Smith. 1992. Yield response of canola to nitrogen, phosphorus, precipitation and temperature. Agron. J. 84: 765–768.

Pan, W., A. Hammac, T. McClellan, I. Madsen, L. Graves, K. Sowers, and L. Young. 2013. Oilseed root characteristics: implications for water and nutrient management. *In:* Dryland Field Day Abstracts: Highlights of Research Progress. Washington State University Extension.

Passioura, J. B. 2006. Increasing crop productivity when water is scarce - from breeding to field management. Agric. Water Manage. 80: 176-196.

Rathke, G.W., T. Behrens, and W. Diepenbrock. 2006. Integrated nitrogen management strategies to improve seed yield, oil content and nitrogen efficiency of winter oilseed rape (Brassica napus L.): A review. Agri., Eco., and Envir. 117: 80-108.

Ratliff, L.F., J.T. Ritchie, and D.K. Cassel. 1983. Field-measured limits of soil water availability as related to laboratory-measured properties. Soil Sci. Am. J. 47: 770-775.

Richards, L.A. and L.R. Weaver. 1943. Fifteen-atmosphere percentage as related to the permanent wilting percentage. Soil Sci. 56: 331–339.

Richards, L.A. and L.R. Weaver. 1944. Moisture retention by some irrigated soils and related to soil-moisture tension. J. of Agri. Res. 69(6): 215-235.

Robertson, M.J, S. Asseng, J. A. Kirkegaard, N. Wratten, J. F. Holland, A. R. Watkinson, T. D. Potter, W. Burton, G. H. Walton, D. J. Moot, and I. Farre. 2002. Environmental and genotypic control of time to flowering in canola and Indian mustard. *Aus. J. Agri. Res.* 53(7): 793–809.

Robertson, M.J., and J.A. Kirkegaard. 2005. Water-use efficiency of dryland canola in an equi-seasonal rainfall environment. Aus. J. of Agri. Res. 56: 1373-1386.

Rossato, L., P. Laine, and A. Ourry. 2001. Nitrogen storage and remobilization in Brassica napus L. during the growth cycle: nitrogen fluxes within the plant and changes in soluble protein patterns. J. Exp. Bot. 52 (361): 1655–1663.

Russelle, M. P., W. Wilhelm, R.A. Olson, and J.F. Power. 1984. Growth analysis based on degree days. Crop Sci. 24: 28-32.

Schillinger, W.F. 2012. Dryland and irrigated cropping systems research with camelina, winter canola, and safflower. *In:* Washington Biofuels Cropping Systems Annual Report.

Schillinger, W.F. 2015. Personal communication.

Schindler, U., and L. Müller. 2006. Simplifying the evaporation method for quantifying soil hydraulic properties. J. of Plant Nut. and Soil Sci. 169 (5): 623-629.

Schjoerring, J.K., J.G.H. Bock, L. Gammelvind, C.R. Jensen, and V.O. Mogensen. 1995. Nitrogen incorporation and remobilization in different shoot components in field-grown winter oilseed rape (Brassica napus L.) as affected by rate of nitrogen application and irrigation. Plant Soil, 177: 255–264.

Sinclair, T.R., and C.T. de Witt. 1975. Photosynthate and nitrogen requirements for seed production by various crops. Science. 189: 565–567.

Sowers, K., D. Roe, and W.L. Pan. 2012. Oilseed production case studies in the eastern Washington low-to-intermediate rainfall zone. Washington State University Extension EM048E.

Stapper, M., and R.A. Fischer. 1990. Genotype, sowing date and plant spacing influence on high-yielding irrigated wheat in southern New South Wales. II. Growth, yield and nitrogen use. Aust. J. Agric. Res. 41: 1021-1041.

Susko, D.J., and B. Superfisky. 2009. A comparison of artificial defoliation techniques using canola (Brassica napus). Plant Eco. 202: 169–175.

Tesfamariam, E.H., J.G. Annandale, and J. M. Steyn. 2010. Water stress effects on winter canola growth and yield. Agronomy J. 102(2): 658-666.

Thomas, P. 2014. Grower’s Manual. Canola Council of Canada, Lacombe, AB.

Tolk, J.A. 2003. Soils, Permanent Wilting Point. *In* Encyclopedia of Water Science. Marcel Dekker, Inc, New York: 927-929.

Veihmeyer, F.J and A.H Hendrickson. 1931. The moisture equivalent as a measure of the field capacity of soils. Soil Sci. 32(3): 181-194.

Velicka R., A. Marcinkeviciene, S. Raudonis, and M. Rimkeviciene. 2006. Integrated evaluation of rape readiness for overwintering. Acta Agriculturae Scandinavica Section B - Soil and Plant Science. 56: 110-116.

Vigil, M.F., R. L. Anderson, and W. E. Beard. 1997. Base Temperature and Growing-Degree-Hour Requirements for the Emergence of Canola. Crop Sci. 37:844-849.

Wilson, R.E., B.A. Jensen, and G.C. Fernandez. 1992. Seed germination response to eleven forage cultivars of Brassica to temperature. Agron. J. 84:200-202.

Young, F.L., D.K. Whaley, W.L. Pan, R.D. Roe, and J.R. Alldredge. 2014. Introducing winter canola to the winter wheat-fallow region of the Pacific Northwest. Crop Manage.

Young, F.L., D.S. Long, and J.R. Alldredge. 2012. Effect of planting methods on spring canola (*Brassica napus* L.) establishment and yield in the low-rainfall region of the Pacific Northwest. Crop Manage.

Yu, G.R., J. Zhuang, and K. Nakayama., 2007. Root water uptake and soil water profile as affected by vertical root distribution. Plant Ecol. 189: 15–30.

CHAPTER 2

WINTER CANOLA WATER USE AND PLANTING DATE EFFECTS IN RITZVILLE, WA

ABSTRACT

Winter canola is a potential alternative crop for the low precipitation farming areas of Washington State, which typically follow a winter wheat – fallow rotation. Because canola is a fairly new crop in Washington's dryland regions, the body of conclusive agronomic research is relatively small and farmers have many production-related questions and issues. For example, seasonal canola water use in this region is unknown. Additionally, stand establishment is a large impediment to winter canola growth. Planting earlier than the traditionally recommended August window may provide cooler and moister seed bed conditions. A study in Ritzville, WA was initiated in summer 2013 to address both water use and planting date. Winter canola was seeded June 10, June 26, August 5, and August 12, along with a fallow check. Soil water content was measured biweekly to a depth of 180 cm by neutron probe and gravimetric cores, and laboratory tests were conducted to determine permanent wilting points. Over the course of five months (June – October), fallow plots lost an average of 7.27 cm due to evaporation. Clear graduated differences in water use due to planting date were observed; the earliest date used 15.82 cm of available water before winter dormancy, compared to 7.94 cm by the latest date. The middle two planting dates, June 26 and August 5, used 15.58 cm and 14.2 cm respectively. The first two planting dates extracted all available water during fall growth, while the August 12 planting date water use was

not statistically different than the evaporative losses seen in fallow plots. Water use correlated with growing degree day accumulation in a sigmoidal fashion. Canola extracted moisture to a depth of at least 180 cm, though water was first accessed in the top 30 cm. High amounts of winter kill were observed, and no spring data were collected. Greater winter mortality correlated to both higher fall water use and increased crown height due to premature bolting. The earliest planting date had the least amount of soil water after winter, while the latest planted canola had the highest spring soil water content.

INTRODUCTION

Overview

Literature contains many canola planting date studies, but they generally focus on spring canola and are highly location dependent (Homayounifar et al 2013, Nanda et al 1996, Miralles et al 2001, Pavlista et al 2011, Kirkland and Johnson 2000, Angadi et al 2004). Planting date affects growth rate and pattern (Nanda et al 1996, Nanda 1995), winter survival (Laaniste 2007), flowering date (Balodis and Gaile 2011), yield, and oil content (Chen et al 2005). Planting date choice must account for good germination conditions, optimization of seed yield, and avoidance of unfavorable conditions such as disease or drought (Balodis and Gaile 2011). In the low and intermediate precipitation regions of Washington, Young et al (2014) have determined August 5 to 25 as the best planting window, with the caveats of a visible moisture line within 10 cm of the surface and forecasted upcoming cooler weather (no warmer than 30°C).

Recently, some researchers have examined the idea of planting canola earlier in the summer fallow period, to capture cooler temperatures and moister seed beds (Hulbert et al 2010, Wysocki 2015). One of the largest barriers to canola growth in the PNW is emergence and establishment (Sowers et al 2012, Young et al 2014). Even experienced winter canola farmers in the low precipitation area encounter 20% or greater establishment failure rate (Painter and Roe 2007). Canola exhibits epigeal emergence, so the cotyledons and growing point are exposed to environmental stresses (Koenig et al 2011). Often it is hot, dry seed bed conditions that lead to stand failures. Interestingly, there may be varietal differences in winter canola's ability to germinate under low soil moisture (Huggins et al 2008).

A study conducted in Pendleton, OR, examined planting winter canola in June, July, and late August/early September windows (Wysocki 2015). In 3 of 4 years, the early planted canola yielded higher than the other plantings. The researchers attribute the increased yield to better stand establishment (44 – 78 plants·m^{-2} vs ≤ 12 plants·m^{-2}) in the cooler and wetter seed zone. In terms of water consumption, the early-planted canola used 4.5 cm of water by the time canola was planted in the later traditional window. However, all plantings used about the same amount of available water by the end of the season. In the year that early-seeded canola yielded less, an unusually dry March couldn't sufficiently increase the water content of the depleted soil profile of the early plantings (Wysocki 2015).

Measurement of Soil Water Content

A technique to measure soil water content by neutron scattering was introduced in 1950 by Blecher. The neutron probe includes a source of fast neutrons (mean energy 5 MeV), often a radioactive mixture including beryllium (IAEA 2008, McHenry 1963). About 10^9 neutrons per second are emitted, and these neutrons repeatedly collide with nuclei of atoms in the soil (Johnston 1992). The common soil components aluminum and silicon redirect neutrons with little energy loss (Robinson et al 2008). However, a collision with hydrogen generally halves the energy of the neutron due to their similar radius. Nineteen collisions on average will thermalize a neutron, or reduce its speed (IAEA 2008). The neutron probe also contains a detector for these slow neutrons (Johnson 1992). This estimate of hydrogen nuclei in the soil is calibrated to determine volumetric water content; calibration of the probe is essential and is based on a linear relationship between count ratio values and independently determined volumetric water content (Hodnett 1986). The sphere sampled depends upon water content and can range from 0.15 m to 0.5 m (Robinson et al 2008).

Advantages of the neutron attenuation method include highly accurate, in-situ, non-destructive, repeatable measurements (Hodnett 1986). Aluminum access tubes in the soil allow the probe to be lowered incrementally, leading to a profile-wide description of soil water content. Because neutrons escape from the soil surface causing significant error, some other form of soil moisture monitoring must be employed for the upper 0.3 m of soil.

A neutron probe, along with gravimetric methods, was utilized to quantify soil water content in a study that examined the water use of winter canola seeded in both early and traditional planting windows. The results are presented in this chapter.

MATERIALS AND METHODS

2013-2014 (2013 season)

The 2013 season study was on the Ron Jirava farm located 8 km west of Ritzville, WA. The winter canola variety Falstaff was used. Twenty 30 m by 2.5 m plots, surrounded by a spring wheat crop, were planted with four replicates. Four planting dates and a fallow check were replicated in a randomized completed block design. The planting dates were June 10, June 26, August 5, and August 12. Canola was seeded into no-till fallow with a John Deere HZ deep furrow drill, with a target depth of 3 cm into moisture. Seeding rate was 6 kg/ha, with a row spacing of 40 cm. Two 1-m row sections in each plot were assessed to determine winter survival (plant counts in the late fall and again in the spring) and crown heights.

Soil moisture measurements were obtained at the time of the first planting on June 10 and then on a bi-weekly basis from August 2 to December 2, 2013. The initial water content of the June 26 planting was assumed to be the same as June 10. Permanent aluminum access tubes were installed in early August to a depth of 180 cm in the center of each plot, and a Hydroprobe (Campbell Pacific Nuclear Model 503DR, Raleigh, NC) was used to measure volumetric water content at 0.15 m intervals. The top 0.3 m of soil was sampled with a lined AMS slide-hammer hand probe (American Falls, ID) rather than the neutron probe. These cores were divided into 0.15 m samples in the laboratory for gravimetric moisture analysis. Wet weights were obtained, and the samples were then dried in a 105°C oven for 24 hours for an oven-dry weight.

Soil bulk density was determined in 0.15 m increments. A ring of known volume was used to collect soil to be dried and weighed. A dewpoint hygrometer (Decagon

Devices WP4C, Pullman, WA) was used to determine matric potentials in the -0.1 – -300 MPa range. At least 10 soil samples from each 0.15 increment were brought to varying moisture contents and measured. A power law function was used to fit the curves and determine water content at -1.5 MPa for each depth increment. Preliminary tests with a HYPROP (UMS, Munich Germany), which characterizes the wetter portion of the soil water characteristic curve, were compared with total water content values measured in the fall of the 2013 season. Because the soils were never at field capacity during this time, it is assumed that available water is water content above the permanent wilting point as determined by the WP4C. If measured water content was below the determined permanent wilting point, it was assumed available water was zero.

Results were analyzed using SAS PROC GLM (SAS 9.3, Cary NC). The assumptions of normality, equal variance, and independence were verified. Multiple comparison was accomplished using the Tukey-Kramer method with alpha of 0.05, and Tukey HSD was also used.

2014-2015

Several planting dates in Ritzville were attempted with a Cross Slot no-till drill in the same plot arrangement as the 2013 season. Although excellent stands were achieved, plants died soon thereafter. It was discovered that a sulfonylurea herbicide with a long soil-residual life used to kill broadleaf weeds had been inadvertently applied to the plot area. Thus, no planting date data in Ritzville was obtained for the 2014 season.

2015-2016

Average precipitation occurred during the winter of 2014-2015, but spring and summer were abnormally dry. An excellent stand was achieved from the first planting on

May 28. However, air temperatures over 35°C for several days beginning June 8 resulted in complete stand kill. The site received no rain from May 14 to August 30. No other planting dates were possible.

Calculations

$$\text{gravimetric water content } \left(\frac{\text{g water}}{\text{g soil}}\right) = \frac{\text{soil wet weight} - \text{soil oven dry weight}}{\text{soil oven dry weight}}$$

$$\text{volumetric water content } \left(\frac{\text{cm}^3\text{ water}}{\text{cm}^3\text{ soil}}\right) = \text{gravimetric water content} \times \text{soil bulk density}$$

$$\text{centimeters of water in increment measured} = \text{volumetric water content} \times \text{length of increment (cm)}$$

growing degree days (GDD):

$$\tau_n = \sum_{i=1}^{n} (T_{i\ ave} - T_b)\Delta t$$

Where:

τ_n = cumulative thermal time or GDD
$T_{i\ ave}$ = average daily temperature during day i, $\frac{Tmax + Tmin}{2}$
T_b = species-specific base temperature, 0°C for canola
Δt = time increment, 1 day
Note: if $T_{i\ ave}$ - T_b is negative for a particular day, a value of zero is imposed.

available soil water = total volumetric water content – permanent wilting point

water use = extracted available soil water + precipitation

RESULTS AND DISCUSSION

Ritzville received an unusually high amount of rainfall in June 2013 (Figure 2.1). An accordingly high moisture content in the topsoil allowed for planting and successful establishment in June.

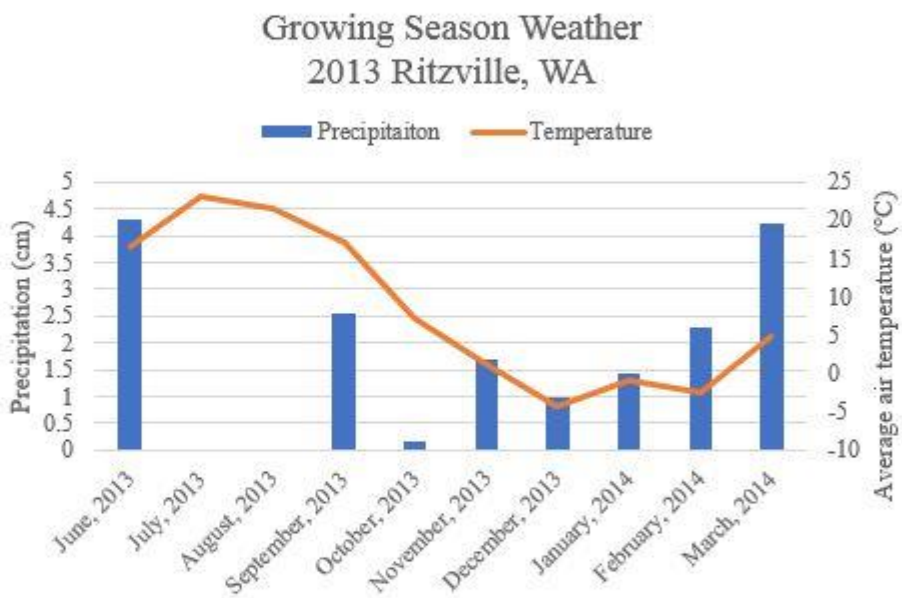


Figure 2.1. Monthly precipitation and mean ambient temperature for the 2013-2014 growing season in Ritzville, WA. Data obtained from AgWeatherNet station on site.

Data from fall vegetative growth confirmed that planting date affects seasonal moisture in the soil profile. At its lowest water content, the earliest planting date's soil profile (June 10) contained only 50% of its initial water content at planting. The lowest water content of August 12's soil profile (the latest planting date) was 80% of its initial. The results were even more dramatic when comparing available water contents instead of total water. The two June planting dates depleted over 96% of the initial available water, while the latest planting date used 37% of initial. These total and available initial vs. final water contents for all planting dates are shown in Figure 2.2. Fallow plots lost 3.77 cm of initial available soil water from August 12 to November 4 due to evaporation.

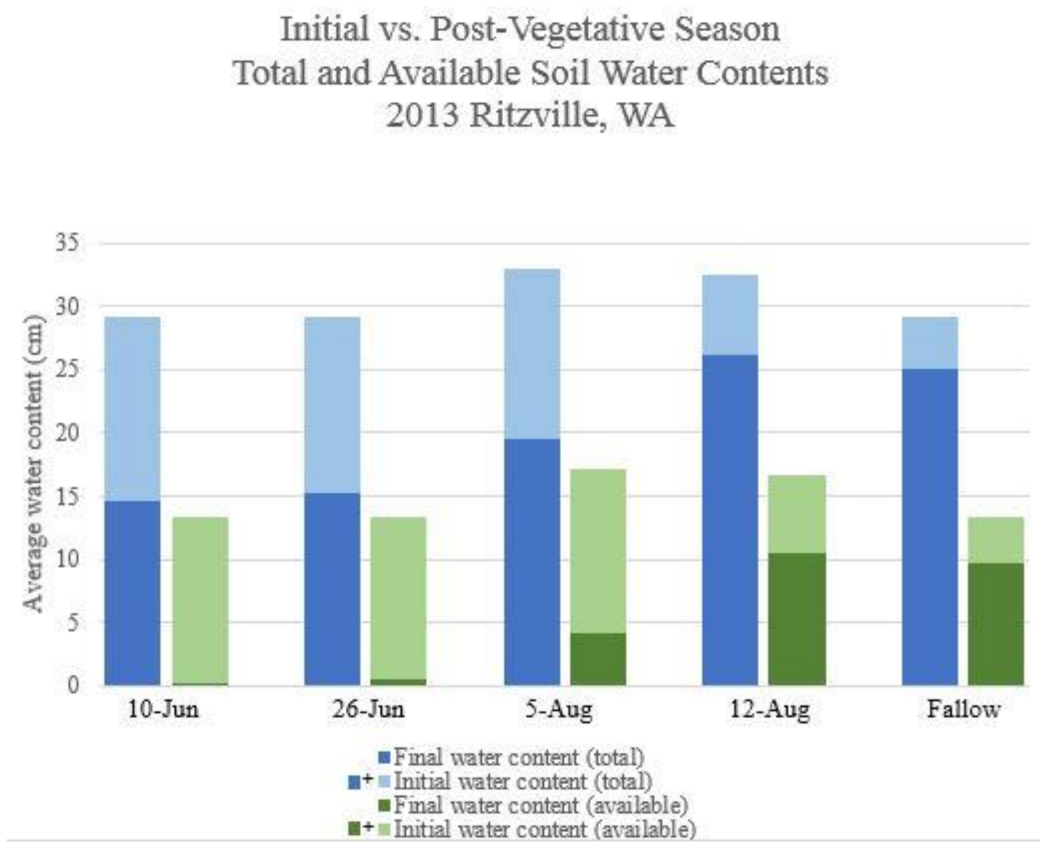


Figure 2.2. Mean water contents in 1.80 m soil profiles for four winter canola planting dates and a fallow check in 2013. Total water amounts are shown in blue, with available water in green. The upper limit of the light colors indicate values at planting, while darker colors signify the lowest water contents during the fall growing season (see Table 2.2 for dates). The fallow initial baseline value was obtained on June 10.

These water content values do not directly reflect precipitation, however. A better parameter is crop water use, defined as the composite value of precipitation and soil water extraction (Table 2.1, Figure 2.3).

Table 2.1. Mean available water use and corresponding standard deviations for each planting date in 2013. Values followed by the same letter indicate no significant difference, as determined by Tukey-Kramer method with α = 0.05.

Planting Date	Mean Available Water Use (cm)	Standard Deviation
June 10	15.82a	0.05
June 26	15.58a	0.71
August 5	14.20a	0.96
August 12	7.94b	1.76
Fallow	7.27b	3.44

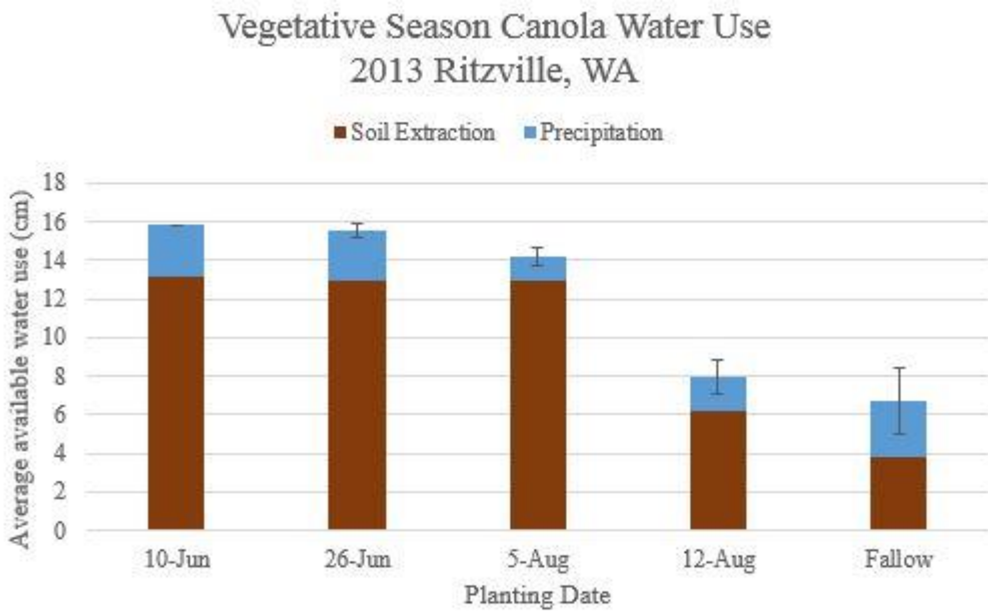


Figure 2.3. Mean available water use (or water loss, in the fallow check) for each planting date and the fallow check, with precipitation and soil water extraction factors shown. Standard error bars are included.

The earliest two planting dates, though they captured more after-planting rainfall, used a significant amount of water, nearly 16 cm. By the time of the latest seeding on August 12, the June 10 planting date had used 10 cm of available water, and June 26 planting date had consumed 4.5 cm. Somewhat surprisingly, canola in the August 5 planting date did not use statistically more water in the fall than the first plantings, though planted 5 to 8 weeks later. It did continue growth longer than the earlier plantings (Table 2.2), which may partially explain the similar water use. Canola in the August 12 planting date utilized only 7.94 cm of water, not statistically different from the evaporative water loss seen in fallow plots.

For all planting dates, increased thermal time correlated with more canola water use in a sigmoidal fashion (Figure 2.4). The earlier planting dates accumulated more growing degree days before the onset of winter. Within each planting date, water use eventually decreased – soil water content increased – signifying soil profile refilling by precipitation and the end of plant growth. Canola in the first two June planting dates ceased growth in October, while the August planting dates continued growth well into November (Table 2.2).

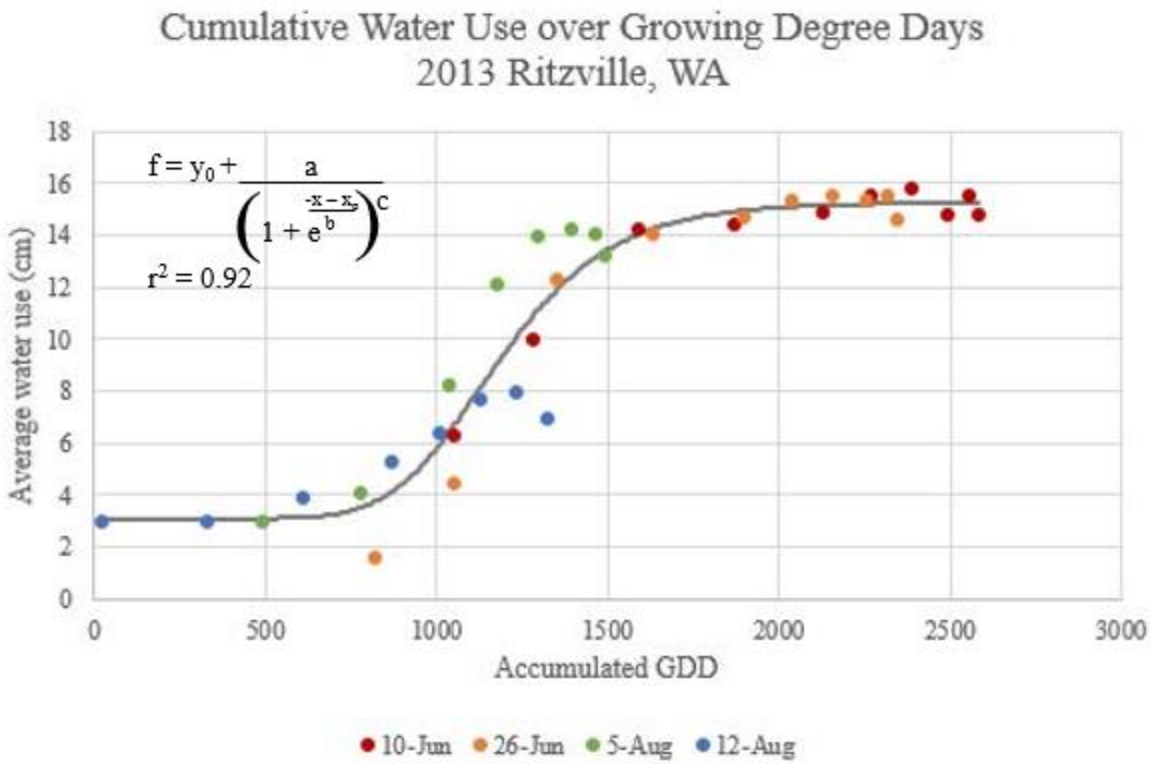


Figure 2.4. Mean water use for each planting date (signified by different colors) as growing degree days accumulate. Five-parameter sigmoidal regression equation is shown, with an R^2 of 0.92.

Table 2.2. Approximate end date of soil water extraction for each planting date. After this sampling date, total soil water content increased, indicating plant growth termination and precipitation refill.

Planting Date	Termination of Fall Soil Water Extraction
10-Jun	October 21 (2386 GDD)
26-Jun	October 21 (2152 GDD)
5-Aug	November 4 (1396 GDD)
12-Aug	November 18 (1293 GDD)

To examine canola water extraction, the total volumetric water content) at several different sampling dates for each planting date is shown in Figure 2.5. This pattern of water extraction is common to other PNW locations as well as other studies (see Chapter

3, Figure 3.5, Cutforth et al 2013, Gan et al 2009). Canola initially uses water in the top 30-60 cm of soil, then utilizes water stored deeper in the profile. Winter canola plants continue to use deep stored water while precipitation recharges some moisture in the top 30 cm, evident in the August 5 planting date, November 18 sampling date. Eventually, fall growth and water extraction ceases, allowing winter precipitation to be added to the profile.

Winter canola is extremely efficient in accessing available water (Figure 2.5). The first two planting dates in particular extracted all available water and reached permanent wilting point (values shown in Table 2.3) by the beginning of September. This observation was also seen by Gan et al 2009.

There was a consistent pattern of volumetric water contents below the permanent wilting point for the 30 – 45 cm depth increment (Figure 2.5). A possible explanation for this phenomenon is that this measurement was the first to be quantified by the neutron probe; above this depth measurements were gravimetric. There is a risk of neutron loss to the surface, which would cause a low value, although this error should be minimal at 30 cm. An additional explanation may be a preponderance of roots at this level. Gan et al 2011 quantified 70% of canola roots above 40 cm, and Merrill et al 2002 found the highest root length density at 45 cm. If indeed the Ritzville canola roots were concentrated around 30 - 45 cm, this zone of soil would be more depleted of water. However, other Washington sites surveyed gravimetrically did not display marked canola water use at this depth (see Chapter 3, Figure 3.4, Figure 3.5).

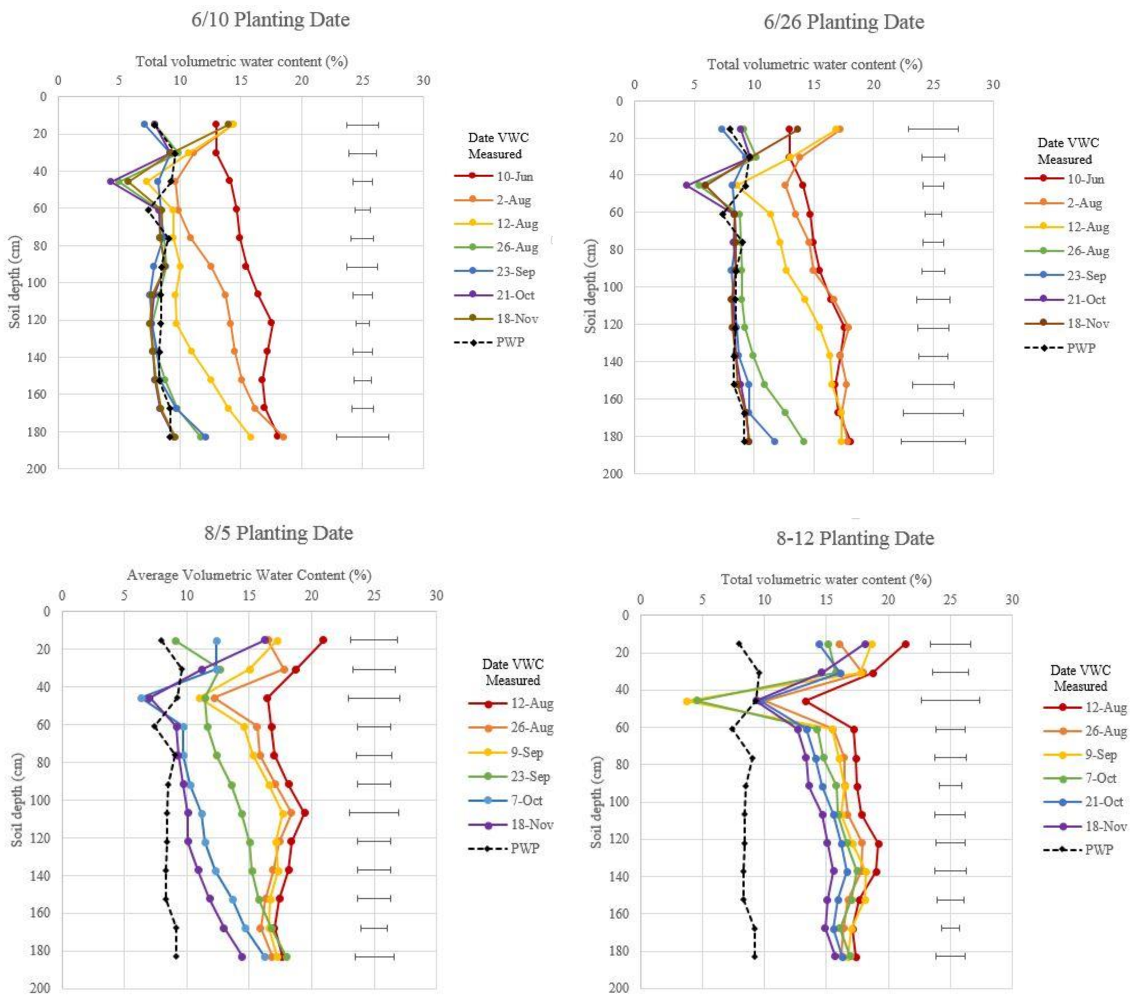


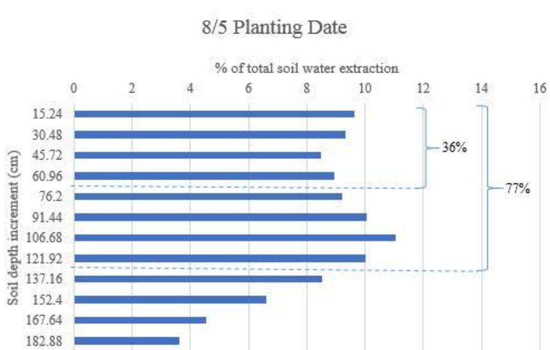
Figure 2.5. Mean volumetric water content graphed as soil depth increases for each planting date. Several sampling dates are shown, as well as permanent wilting point at each depth. Tukey HSD at each depth is also plotted.

Table 2.3. Permanent wilting point in volumetric water content at each soil depth increment.

Soil Depth (cm)	Permanent Wilting Point (% water by volume)
0 – 15	7.93
15 – 30	9.59
30 – 45	9.26
45 – 60	7.36
60 – 75	9.05
75 – 90	8.46
90 – 120	8.43
120 – 150	8.43
150 – 180	8.32

Soil in the first planting date showed a decrease in volumetric water content from 18.1% on June 10 to 9.5% on October 21 at the 180 cm depth (based on average values). Soil in the second planting date – June 26 – decreased from an average of 17.9% water on August 2 to 9.6% water on October 21. This clear extraction of nearly half the total water indicates that the early-planted canola's effective rooting depth was past 180 cm, deeper than other studies have measured to or found (Merrill et al 2002, Cutforth et al 2013, Johnson et al 2002, Nielson et al 1997).

Figure 2.6 shows the percentage of total water extracted at each depth during the fall season for the later two planting dates. These two plantings show very similar patterns of water use by depth. About 55% of the amount of water extracted during the season was pulled from 91 cm and above. Around 75% of total soil water extraction occurred at or above 122 cm, meaning that a quarter of the fall water use – even in these later plantings – originated from deep subsoil reserves. Merrill et al (2004) also reported that a significant portion of canola's water is accessed from deep portions of the soil profile.



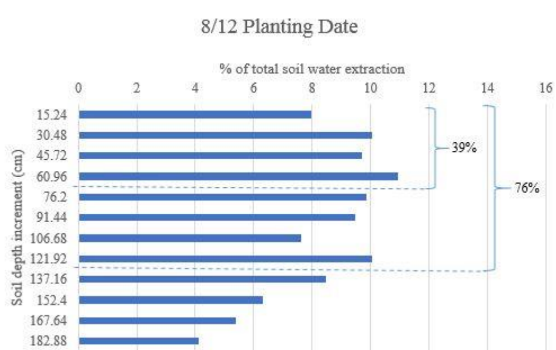


Figure 2.6. Percentage of the total soil water extraction that occurred at each soil depth increment measured for 5-Aug and 12-Aug planting dates.

The winter of 2013-2014 was fairly harsh, with two sub- -18°C events and minimal snow cover. These conditions resulted in high amounts of winter-kill in this experiment (Table 2.4), and no spring data was collected.

Table 2.4. Mean percentage of plants in each planting date that survived the winter to regrow in the spring of 2014.

Planting Date	**Average Percent Winter Survival**
June 10, 2013	0
June 26, 2013	0
August 5, 2013	31
August 12, 2013	55

High water use and plant bolting both correlated with the observed winter kill. It was noted that plants of the two earlier planting dates had begun to bolt before the onset of winter. This phenomenon was quantified by crown height measurements, which are shown in figure 2.7 plotted against winter survival percentages. The stem elongation may have reduced the insulating properties of soil proximity and eliminated the shielding effect of snow cover. This result has been cited in literature (Darby 2013, Balodis and Gaile 2011, Laaniste et al 2007), with Topinka et al (1991) in particular noting very similar planting date effects on stem elongation and winter survival. There was also a correlation between vegetative season water use and winter kill (Figure 2.8). Later-planted canola that used less water had higher survival rates.

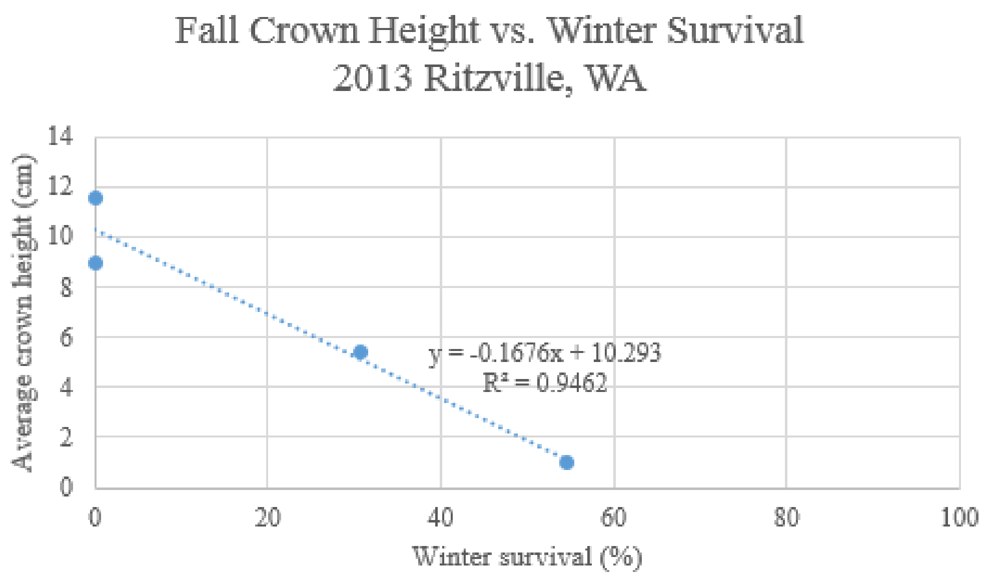


Figure 2.7. Mean crown heights for each planting date, plotted against the corresponding percentage of plants that survived winter. A linear regression line is shown.

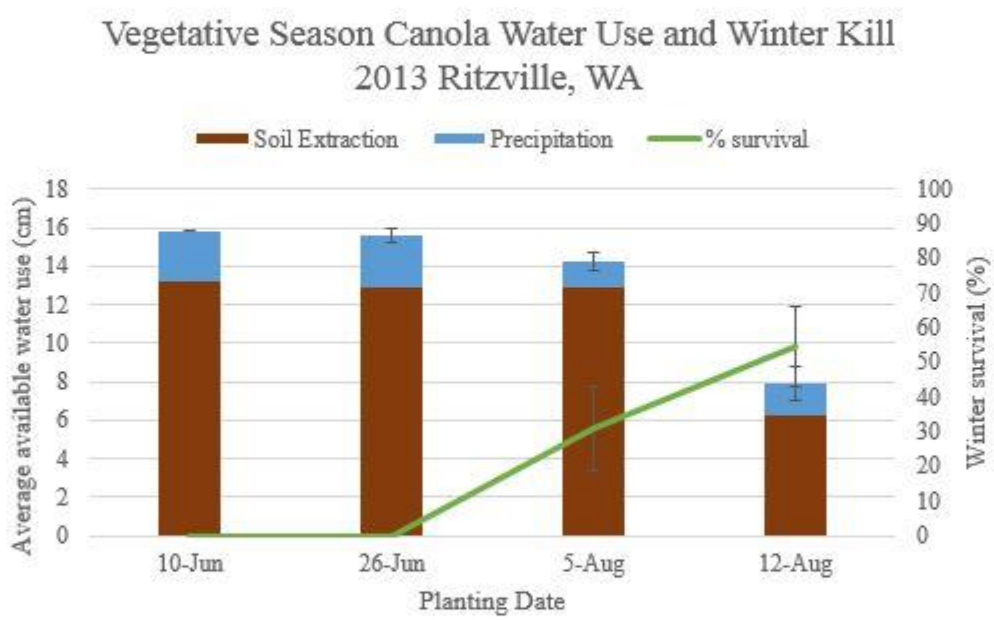


Figure 2.8. Mean available water use (cm) during the fall vegetative growing season is shown by the bars and corresponds to the left axis. The mean winter survival percentage of each planting date is represented by the line and relates to the right axis.

Producers in water-limited areas worry that winter precipitation will not provide enough moisture to refill the depleted soil profiles of early-planted canola. Early-planted canola (June 10) had less soil water in early spring, while the soil profile under the latest seeded canola contained the most water (Figure 2.9). This observation was supported statistically (Table 2.5). The differences seem to occur in the mid-lower portions of the measured profile (Figure 2.9).

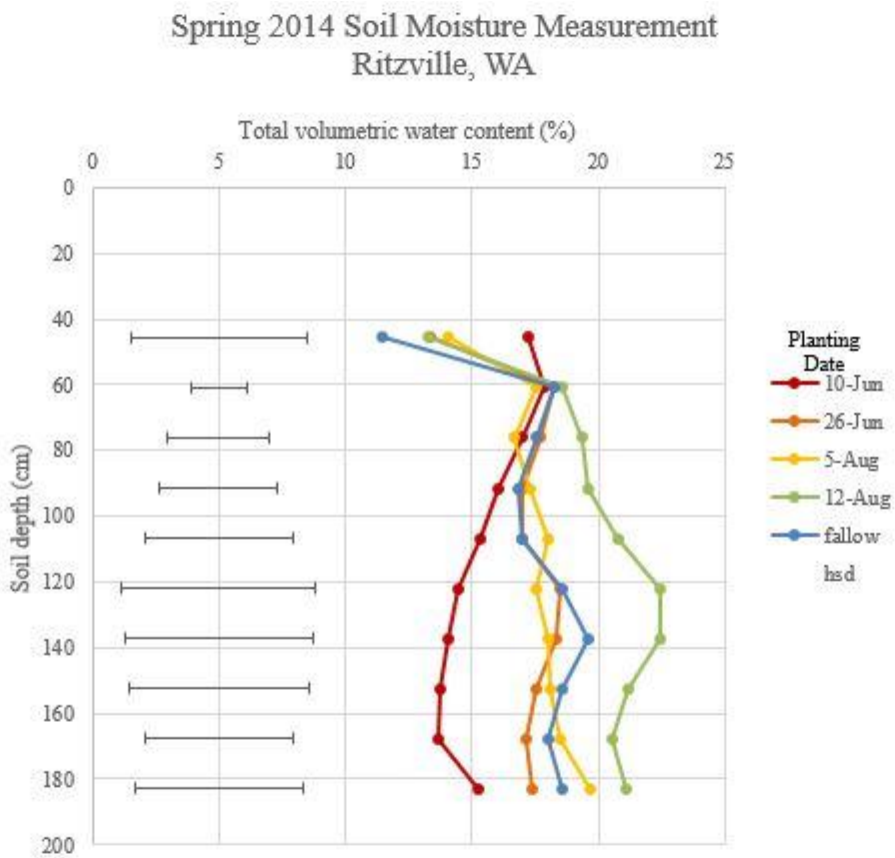


Figure 2.9. Mean volumetric water content as measured on March 31, 2014 as soil depth increases for four planting dates and a fallow check. Tukey HSD is also plotted.

Table 2.5. Mean available water as measured on March 31, 2014 for each planting date and a fallow check. Values followed by the same letter indicate no significant difference, as determined by Tukey-Kramer method with $\alpha = 0.05$.

Planting Date	**Average available water in soil profile (cm)**
June 10	10.5 a
June 26	13.1 b
August 5	13.6 b
August 12	17.2 c
Fallow	13.5 b

CONCLUSION

Stand establishment is a large impediment to winter canola production in the low precipitation zone of east-central Washington and north-central Oregon. Planting early, before the recommended August window, may capture cooler soil temperature and more moisture; however, excessive water use by these early-planted fields is a concern. One year of data from Ritzville showed that ideal stand establishment is possible in June, given adequate moisture. Fall season water use was heavily dependent upon planting date, with plantings on June 10 and 26 using 15.8 cm and 15.6 cm respectively, compared to 14.2 cm and 7.9 cm used by canola planted August 5 and August 12. All canola plantings accessed water to at least 180 cm soil depth and were efficient in scavenging available water. Planting date also appeared to affect winter survival; canola planted in June bolted, stopped growth earlier in the fall, and suffered 100% winter mortality. The earliest planting date depleted all available water in the fall and winter rains did not increase the soil water to the same degree as other planting dates. It had the lowest soil water content after winter, while the August 12 planting date had the highest spring water content. Based on the single year of data, early planting may not be advisable due to soil water depletion and winter kill risk. However, this planting date study should be continued for several seasons to more fully understand the impact of early planting on winter canola water use, growth, and yield. Additionally, weed and insect pressure should be monitored, as these dynamics may change with altered planting times. Techniques to control water use could be explored, such as fall season mowing or grazing.

LITERATURE CITED

Angadi, S. V., H. W. Cutforth, B.G. McConkey, and Y. Gan. 2004. Early seeding improves the sustainability of canola and mustard production on the Canadian semiarid prairie. Can. J. Plant Sci. 84: 705–711.

Balodis, O. and Z. Gaile. Winter oilseed rape (*Brassica napus* L.) autumn growth. Research for Rural Development - International Scientific Conference Proceedings. 1: 6-12

Chen, C. G. Jackson, K. Neill, D. Wichman, G. Johnson, and D. Johnson. 2005. Determining the feasibility of early seeding canola in the Northern Great Plains. Agron. J. 97:1252–1262.

Cutforth, H. W., S.V. Angadi, and B.G. McConkey. 2006. Stubble management and microclimate, yield and water use efficiency of canola grown in the semiarid Canadian prairie. Can. J. Plant Sci. 86: 99–107.

Darby, H. 2013. 2012-2013 Winter Canola Survival. University of Vermont Extension.

Gan, Y.T., C.A. Campbell, L. Liu, P. Basnyat, and C.L. McDonald. 2009. Water use and distribution profile under pulse and oilseed crops in semiarid northern high latitude areas. Agric. Water Manage. 96: 337-348.

Gan, Y., L. Liu, H. Cutforth, X. Wang, and G. Ford. 2011. Vertical distribution profiles and temporal growth patterns of roots in selected oilseeds, pulses and spring wheat. Crop Pasture Sci. 62: 457-466.

Hodnett, M.G. 1986. The neutron probe for soil moisture measurement. Advanced Agricultural Instrumentation, NATO ASI Series 111: 148-192.

Homayounifar, M., H. Ranji, and A. Emami. 2013. Effects of planting date and density on the yield of a winter rapeseed cultivar in West Azarbaijan. Intl. J. Agron. Plant. Prod. 4 (7): 1564-1567.

Huggins, D., S. Hulbert, W.L. Pan, and J. Qiu. 2008. Evaluating seeding date, plant growth regulator, water and temperature effects on winter canola germination, growth, survival and yield. *In:* Washington Biofuels Cropping Systems Annual Report.

Hulbert, S., W.L. Pan, T. Paulitz, and D. Huggins. 2010. Potential of biennially grown canola and canola grown in other dryland PNW environments. *In:* Washington Biofuels Cropping Systems Annual Report.

IAEA. 2008. Field estimation of soil water content: a practical guide to methods, instrumentation and sensor technology. International Atomic Energy Agency Training Course Series 30, Vienna, Austria.

Johnson, A.I. 1992. Methods of measuring soil moisture in the field. US Department of the Interior. US geological survey water supply paper 1619-U.

Johnston, A.M., D.L. Tanaka., P.R. Miller, S.A. Brandt, D.C. Nielson, G.P. Lafond, and R.R. Riverland. 2002. Oilseed crops for semiarid cropping systems in the northern Great Plains. Agron. J. 94, 231–240.

Kirkland, K. J. and E.N. Johnson. 2000. Alternative seeding dates (fall and April) affect *Brassica napus* canola yield and quality. Can. J. Plant Sci. 80: 713–719.

Koenig, R. 2011. Canola growth, development, and fertility. Washington State University Extension. FS045E.

Laaniste, P., J. Joudu, V. Eremeev, and E. Maeorg. 2007. Sowing date influence on winter oilseed rape overwintering in Estonia. Acta Agriculturae Scandinavica Section B - Soil and Plant Science. 57: 342-348.

McHenry, J.R. 1963. Theory and application of neutron scattering in the measurement of soil moisture. Soil Science 95(5): 294-307.

Merrill, S. D., D.L. Tanaka, and J.D. Hanson. 2002. Root length growth of eight crop species in Haplustoll soils. Soil Sci. Soc. Am. J. 66: 913-923.

Merrill, S. D., D.L. Tanaka, J.M. Krupinsky, and R.E. Ries. 2004. Water use and depletion by diverse crop species on Haplustoll soil in the northern Great Plains. J. Soil Water. Conserv. 59: 176-183.

Miralles, D.J., B.C. Ferro, and G.A. Slafer. 2001. Developmental responses to sowing date in wheat, barley and rapeseed. Field Crops Res. 71: 211-223.

Nanda, R., S.C. Bhargava, and H.M. Rawson. 1995. Effect of sowing date on rates of leaf appearance, final leaf numbers and areas in *Brassica campestris, B. juncea, B. napus* and *B. carinata*. Field Crops Res. 42: 125-134.

Nanda, R., S.C. Bhargava, D.P.S. Tomar, and H.M. Rawson. 1996. Phenological development of *Brassica campestris, B. juncea, B. napus* and *B. carinata* grown in controlled environments and from 14 sowing dates in the field. Field Crops Ress 46: 93-103.

Nielsen, D.C. 1997. Water use and yield of canola under dryland conditions in the central Great Plains. J. Prod. Agric. 10:307–313.

Painter, K. and D. Roe. 2007. Economics of canola production in the Pacific Northwest. Working Paper Series, WP 2007-17. Washington State University School of Economic Sciences.

Pavlista, A.D., T.A. Isbell, D.D. Baltensperger, and G.W. Hergert. 2011. Planting date and development of spring-seeded irrigated canola, brown mustard and camelina. Industrial Crops and Products 33: 451–456.

Robinson, D. A., C. S. Campbell, J. W. Hopmans, B. K. Hornbuckle, S. B. Jones, R. Knight, F. Ogden, J. Selker, and O. Wendroth. 2008. Soil moisture measurements for ecological and hydrological watershed scale observatories: A review. Vadose Zone J. 7: 358–389.

Sowers, K., D. Roe, and W.L. Pan. 2012. Oilseed production case studies in the eastern Washington low-to-intermediate rainfall zone. Washington State University Extension EM048E.

Topinka, A.K.C., R.K. Downey, and G.F.W. Rakow. 1991. Effect of agronomic practices on overwintering of winter canola in southern Alberta. Agronomy: Production Factors. GCRIC 1991 Congress, B-53.

Wyosocki, D. 2015. Personal communication.

Young, F.L., D.K. Whaley, W.L. Pan, R.D. Roe, and J.R. Alldredge. 2014. Introducing winter canola to the winter wheat-fallow region of the Pacific Northwest. Crop Manage. DOI: 10.2134/CM-2013-0023-RS.

CHAPTER 3

THREE DISTINCT STAGES OF WINTER CANOLA WATER AND NITROGEN USE IN DRYLAND EASTERN WASHINGTON

ABSTRACT

Growers have noted increased wheat yields following winter canola in the fallow dryland farming regions of Washington State, due to rotational benefits. Farmers have produced canola throughout eastern Washington for many years, but questions regarding best agronomic practices remain. Research was conducted in Okanogan (north-central) as well as Pomeroy and Cloverland (south-east) to characterize winter canola during its major growth periods. Gravimetric water content was measured to a depth of 120 cm or bedrock, and permanent wilting point was determined to estimate available water. Soil nitrogen (N), aboveground dry matter, and plant N accumulation were also monitored.

Data from Cloverland revealed the dependence of water content on soil depth to bedrock. At the other two sites, winter canola growth was analyzed in three seasons: fall vegetative growth, winter, and spring regrowth until harvest. Canola at Pomeroy extracted water to at least 150 cm in the fall and used nearly all available water by harvest. In contrast, canola water use at Okanogan was relegated to the top 90 cm during fall, but then accessed moisture deeper in the soil profile during spring regrowth. Generally, late-summer and early-fall water use constituted 15-25% of total season water use. Soil water content increases over the winter were not consummate with the amount of precipitation received, with retentions under 80%.

Nitrogen supply was determined for both fall and harvest seasons. Pomeroy had a higher N retention efficiency in fall than harvest season, although unaccounted for N did not exceed 30%. A much higher proportion, 75% of the N supply, was unaccounted for during the fall season at Okanogan. Volatilization, immobilization, and ammonium fixation are loss pathways that may explain these discrepancies. However, N in the Okanogan crop and soil at harvest exceeded the estimated fall season supply, which may be due to failure to capture whole-season balance owing to temporal fluctuation. Observed soil N increases during winter were likely because of release from fall-grown leaves. The seasonal timeline of canola biomass and N accumulation followed a sigmoidal pattern, the expected curve as described by Hocking et al (1997). Nitrogen uptake was roughly equal between the fall and harvest seasons, though much more dry matter accumulated in the harvest season.

Yields were much higher in the comparatively water- and N- rich site of Pomeroy, and water use efficiency was also higher, at 4.5 $kg \cdot ha^{-1} mm^{-1}$ compared to Okanogan's 3 $kg \cdot ha^{-1} mm^{-1}$. In both locations, harvest season NUE was greater than total season NUE and corresponded to spring canola expected values. Total season unit N requirements were much higher than those reported in local extension literature.

INTRODUCTION

Wheat has long been the main crop in dryland Washington farmland east of the Cascade mountain range. In the lower precipitation zone, where the winter wheat-fallow rotation is dominant, winter canola is an emerging rotational crop. Touted for its agronomic benefits and impact on subsequent wheat yields, canola was produced on

18,200 Washington hectares in the 2014-2015 season (National Agricultural Statistics Service 2014).

Winter canola, unlike spring varieties, develops a rosette in the fall season. These basal leaves senesce and abscise as winter frosts begin. The growing point at the crown remains viable throughout winter. When temperatures warm in the spring, vegetation regrows and again forms a rosette. Having satisfied its vernalization requirement, the stem elongates during bolting, and profuse branching occurs. Yellow flowers set long, thin seed pods which are eventually harvested.

Yield in much of eastern WA is limited by water, and canola water use is of paramount concern for growers. Seven years of data from Reardon, WA showed that winter canola uses the same amount of water as winter wheat, and post-harvest winter soil recharge is the same for winter canola and winter wheat fields (Schillinger 2012). A relationship between spring canola yield and available water has emerged for the PNW, with a water use efficiency of 3 $kg \cdot ha^{-1} mm^{-1}$ (Pan et al, in review). Wheat grown in this area has a higher WUE, 5.3 – 7 $kg \cdot ha^{-1} mm^{-1}$, but the efficiency is more similar to canola on an energy or protein basis (Pan et al, in review).

Several studies, whether by direct observation or water extraction patterns, have confirmed spring canola maximum rooting depth between 1.14 – 1.3 m (Merrill et al 2002, Cutforth et al 2013, Johnson et al 2002). Nielson et al (1997) found that spring canola extracted water at a depth of 1.65 m, though 92-95% of the water use originated in the top 1.19 m. Canola uses water efficiently, sometimes extracting water below the soil's theoretical permanent wilting point (Gan et al 2009a).

The extensive taproot system of winter canola that enables water extraction also allows for high nutrient recovery. Winter canola N uptake – along with biomass – follows a sigmoidal pattern, with the highest rate occurring from branching to early budding (Malhi et al 2007, Wysocki et al 2007). During autumn growth, winter canola accumulates 25-30% of its total N uptake, around 40-100 kg N ha^{-1} (Rathke et al 2006, Wysocki et al 2007). These vegetative leaves abscise during winter, and around 75% of N in canola residue is non-structural or associated with soluble cell components (Beard 2013). Although up to 15% remains in the soil, around 28% of the nitrogen initially present in autumn leaves and stems appears to be recycled to spring growth and is later remobilized during reproduction (Dejoux et al 2000, Erley et al 2011, Rossato et al 2001). Endogenous N flow analysis shows a complicated dynamic, with remobilization to the pods originating from leaves, stem, inflorescences, and taproot (Malagoli et al 2005). In some cases, over 60% of the N supply may be unaccounted for, not found in crop residue or soil (Maaz 2014).

Current winter canola base N requirements in the PNW are 6-11 kg N supply per 100 kg yield (Koenig et al 2011, Wyosocki et al 2007, Maher and Guy 2002). However, more recent spring canola research has indicated higher N requirements, up to 22 kg N per 100 kg yield in drier areas (375 mm of precipitation annually) (Maaz 2014). Nitrogen use efficiency (NUE) is a common metric that identifies the yield per unit N supply. Spring canola in the PNW has NUE around 4-12 $kg \cdot kg^{-1}$, with lower values in drier regions (Maaz 2014). A component of NUE is nitrogen utilization efficiency, the harvest N uptake per unit of N supply, and for winter canola this value is 25-35 $kg \cdot kg^{-1}$ (Berry et al 2010, Erley et al 2011). Nitrogen harvest index, the seed N per unit N supply, is 60-79% for winter canola (Dreccer et al 2000, Koenig et al 2011).

A possible approach to analyzing winter canola N and water consumption is through three “seasons”: fall vegetative season, winter season, and harvest season (which spans spring regrowth to harvest). Comparatively little is known about fall season growth, especially as spring varieties compose a large majority of Canada’s considerable canola acreage. Changes in winter soil nitrogen and water content have also not been studied in the Pacific Northwest. Finally, questions still remain about total-season water and nitrogen need.

In this study, research was established in Pomeroy, Cloverland, Mansfield, and Okanogan (Table 3.1). Pomeroy, WA, is a high-elevation site that receives an intermediate amount of precipitation (500 cm per year). The soils are loamy with increasing clay content in the subsoil. Cloverland, WA, is within 55 km of Pomeroy, though it receives less rainfall on average. At Cloverland areas within the same field have extremely variable soil depth; basalt is the parent material bedrock, and it is covered by 0.3 – 3 m of topsoil. Several producers near Pomeroy and Cloverland consistently grow winter canola, and some are experimenting with spring canola as well. A few farmers in north-central Washington near Okanogan and Mansfield have also been growing winter canola for over a decade. The Colville Confederated Tribes in this region expressed interest in canola for biofuel, and USDA-ARS/WSU researchers responded by introducing research trials to the area. Their efforts increased winter canola acreage in Douglas and Okanogan counties from 200 acres in 2007 to over 10,000 acres in 2013 (Young et al 2013).

This study tracked the dynamics of winter canola water and N use in both the fall and harvest growing seasons, as well as soil water and N changes over the winter. Analyzing water extraction, N use, and crop biomass in this research contributed to the growing body of literature concerning winter canola in the PNW.

MATERIALS AND METHODS

Winter canola variety trials were planted in late summer 2014 in Pomeroy, Okanogan, and Cloverland. All sites were planted in late August with a hoe-type Ag Pro™ no-till air drill at 40.5 cm spacing and 2 kg seed · $acre^{-1}$. Plots were 3 m by 15 m and arranged in a randomized complete block design, with four replications of each variety. Borders were also seeded to canola. Plots were fertilized with N and sulfur (S) in October, and surviving plots were fertilized again in spring (Table 3.1).

All N and water measurements were sampled in the Croplan 115 (CP115) variety plots at all locations. The Cloverland site was surrounded by a grower's field, planted one month earlier than the plots. Samples were taken both in the plots and in the grower's field at Cloverland to compare planting dates. The field was planted with a Horsh-Anderson 40-15 drill, with a seeding density of 4 $kg{\cdot}ha^{-1}$ at 38 cm row spacing.

At Pomeroy and Cloverland, water data were obtained biweekly from planting to November 20, 2014. At Okanogan, measurements were taken every 3 – 4 weeks. Measurements resumed in early March at both Okanogan and Pomeroy and continued periodically until harvest in late July. In each CP115 plot, soil cores at 30-cm intervals were hand-extracted with a 180-cm, thin closed-wall Veihmeyer (King) tube down to bedrock. Wet weights were obtained, and the samples were then dried in a 105°C oven for at least 24 hours for an oven-dry weight.

At Okanogan and Pomeroy, soil bulk density was determined in 30-cm increments. At least 3 rings of known soil volume per increment were collected, dried, and weighed. A WP4C dewpoint hygrometer (Decagon Devices, Pullman WA) determined water potentials in the -0.1 – -300 MPa range. At least 10 soil samples from each 30-cm increment were brought to varying water contents and measured. A power law function was used to fit the curves and determine water content at -1.5 MPa for each depth increment. It was assumed that available water was water content above the permanent wilting point as determined by the WP4C.

Every time soil water was quantified at each location, canola biomass was sampled in a 1-m linear row. Plants were counted, severed at the soil level, placed in a paper bag, and weighed for a fresh weight. Plant material was dried at 40°C for at least 48 hours, reweighed, and then ground by a Wiley mill (Thomas Scientific, Swedesboro, NJ). Total C and N of subsamples were determined via dry combustion in a LECO Truspec C and N analyzer (St. Joseph, MI).

For soil N analysis, samples were taken in 30-cm increments at planting, first hard frost, upon spring regrowth, and at harvest. Available ammonium and nitrate were extracted with 0.5M KCl and analyzed calorimetrically with a Lachat QuikChem 8000 series FIA+ system and autosampler (Loveland, CO). Weather monitoring stations were located in each field. A Decagon datalogger stored information that was recorded every 2 hours from an ECT air temperature sensor and an ECRN-100 high resolution rain gauge (Decagon Devices, Pullman WA).

At every location, visual establishment ratings were determined on a 1-5 scale (1=poor, 5=excellent). Two 1-m linear rows in each plot were counted in the fall and again in spring to assess winter survival. Canola at Cloverland did not survive for spring growth and was therefore no harvest occurred. In Pomeroy and Okanogan, a Wintersteiger plot combine was used to harvest 1.52 m by 15.2 m in each plot. Additionally, at Okanogan, three sections in the surrounding grower's field, as well as the three border alleys in the trial, were harvested for a yield comparison of N rates. The alleys received no fertilizer, and the grower's field received 56 $kg \cdot ha^{-1}$ N. Seed was cleaned using a 9 mm sieve and wind separation. In unharvested portions of the plots, plants in a 1-m row section were cut at ground level and placed in paper bags. This seed was threshed mechanically, cleaned as described above, and weighed. All chaff and biomass was collected and weighed, and harvest index was computed. Plant material was ground and LECO combustion determined total C and N of subsamples.

Results were analyzed using SAS PROC GLM (SAS 9.3, Cary NC). When applicable, multiple comparison was done using the Tukey-Kramer method with alpha = 0.05 and Tukey honestly significant difference (HSD). The assumptions of normality, equal variance, and independence were verified.

Table 3.1. Location characteristics and field operations for the 2014-2015 season.

Location	Soil Type	Elevation (m)	Region Average Precip (mm)	Field History	Planting Date
Cloverland	81% Neissenberg-Pataha Silt Loam 19% Spofmore-Catheen Silt Loam	848	397	No-till fallow	*Trial:* 8/18/2014 *Grower Field:* 7/18/2014
Okanogan	Farrell Fine Sandy Loam	455	301	No-till fallow	8/26/2014
Pomeroy	Palouse Silt Loam	1273	501	Conservation-till fallow	8/19/2014

Location	Field Operations	Harvest Date
Cloverland	*Field* 7/18/14: 12.4 kg/ha N, 22.5 kg/ha P, 11.2 kg/ha K, 11.2 kg/ha S, 2.2 kg/ha Zn, 1.1 kg/ha B *Field* 9/10/14: 4.5 oz/ha glyphosate (Round Up) *Trial* 9/25/14: 22.2 oz/ha quizalofop p-ethyl (Assure II) *Field and trial* 10/31/14: 56.1 kg/ha N, 16.8 kg/ha S	n/a
Okanogan	10/9/14: 56.1 kg/ha N, 5.6 kg/ha S 10/9/14: 22.2 oz/ha quizalofop p-ethyl (Assure II) 3/13/15: 25.8 kg/ha N, 5.6 kg/ha S	7/8/2015
Pomeroy	10/3/14: 22.2 oz/ha quizalofop p-ethyl (Assure II) 10/14/14 89.8 kg/ha N, 5.6 kg/ha S 3/21/15: 33.7 kg/ha N, 16.8 kg/ha S, 0.56 kg/ha B	7/27/2015

Calculations

gravimetric water content $\left(\frac{\text{g water}}{\text{g soil}}\right) = \frac{\text{soil wet weight} - \text{soil oven dry weight}}{\text{soil oven dry weight}}$

volumetric water content $\left(\frac{\text{cm}^3\text{ water}}{\text{cm}^3\text{ soil}}\right) = $ gravimetric water content $\times$ soil bulk density

centimeters of water in increment measured = volumetric water content $\times$ length of increment (cm)

growing degree days (GDD):

$$\tau_n = \sum_{i=1}^{n} (T_{i\,ave} - T_b)\Delta t$$

Where:

τ_n = cumulative thermal time or GDD

$T_{i\,ave}$ = average daily temperature during day i, $\frac{\text{Tmax} + \text{Tmin}}{2}$

T_b = species-specific base temperature, 0°C for canola

Δt = time increment, 1 day

Note: if $T_{i\,ave}$ - T_b is negative for a particular day, a value of zero is imposed.

available soil water = total volumetric water content – permanent wilting point $\left(\frac{\text{cm water}}{\text{cm soil}}\right)$

total water use = fall growth extracted soil water + fall precipitation + spring growth extracted soil water + spring precipitation

water use efficiency $\left(\frac{\text{kg}}{\text{ha mm}}\right) = \frac{\text{seed yield}}{\text{total water use}}$

fall biomass water use efficiency $\left(\frac{\text{kg}}{\text{ha mm}}\right) = \frac{\text{aboveground vegetative biomass}}{\text{fall water use}}$

harvest index $\left(\frac{\text{kg}}{\text{kg}}\right) = \frac{\text{seed yield}}{\text{total aboveground biomass}}$

total mineralized N $\left(\frac{\text{kg}}{\text{ha}}\right) = 15.14\ \frac{\text{kg}}{\text{ha}}$ X soil organic matter content (%)

fall mineralized N $\left(\frac{\text{kg}}{\text{ha}}\right)$ = % total GDD accrued in fall × total mineralized N

fall residue N $\left(\frac{\text{kg}}{\text{ha}}\right) = Nt_f$

fall available N $\left(\frac{\text{kg}}{\text{ha}}\right) = Nav_f = Nt_f$ + soil N after fall growth ceases

fall N supply $\left(\frac{\text{kg}}{\text{ha}}\right) = Ns_f$ = preplant available soil N + fall fertilizer N + fall mineralized N

fall N uptake efficiency = $NupE_f = \frac{Nt_f}{Ns_f}$

fall N retention efficiency = $\text{NretE}_{\text{f}} = \frac{Nav_f}{Ns_f}$

fall available N uptake efficiency = $\text{avNupE}_{\text{f}} = \frac{Nt_f}{Nav_f}$

harvest residue N $(\frac{\text{kg}}{\text{ha}})$ = Nt

harvest available N $(\frac{\text{kg}}{\text{ha}})$ = Nav = Nt + soil N at harvest

grain weight $(\frac{\text{kg}}{\text{ha}})$ = Gw

grain N content $(\frac{\text{kg}}{\text{ha}})$ = Ng

harvest N supply $(\frac{\text{kg}}{\text{ha}})$ = Ns_{h} = available soil N at spring regrowth + spring fertilizer N + spring mineralized N

harvest N use efficiency = $\text{NUE}_{\text{h}} = \frac{Gw}{Ns_h}$

harvest N uptake efficiency = $\text{NupE}_{\text{h}} = \frac{Nt}{Ns_h}$

harvest N retention efficiency = $\text{NretE}_{\text{h}} = \frac{Nav}{Ns_h}$

total season N supply $(\frac{\text{kg}}{\text{ha}})$ = Ns = preplant available soil N + fall fertilizer N + fall mineralized N + spring fertilizer N + spring mineralized N

N use efficiency = $\text{NUE} = \frac{Gw}{Ns}$

N uptake efficiency = $\text{NupE} = \frac{Nt}{Ns}$

N utilization efficiency = $\text{NutE} = \frac{Gw}{Nt}$

N retention efficiency = $\text{NretE} = \frac{Nav}{Ns}$

available N uptake efficiency = $\text{avNupE} = \frac{Nt}{Nav}$

N harvest index = $\text{NHI} = \frac{Ng}{Nt}$

grain N utilization efficiency = grain $\text{NutE} = \frac{Gw}{Ng}$

RESULTS AND DISCUSSION

Fall vegetative season (planting –termination of growth at winter onset)

Excellent stands were achieved, with establishment at Cloverland averaging 4.8, Pomeroy 4.0, and Okanogan 4.3. Soil depth to bedrock at the Cloverland location was extremely variable, even within a single plot. Therefore, water and nitrogen use could not be compared across time or replications. Total soil water content depended upon soil depth in a linear fashion (Figure 3.1).

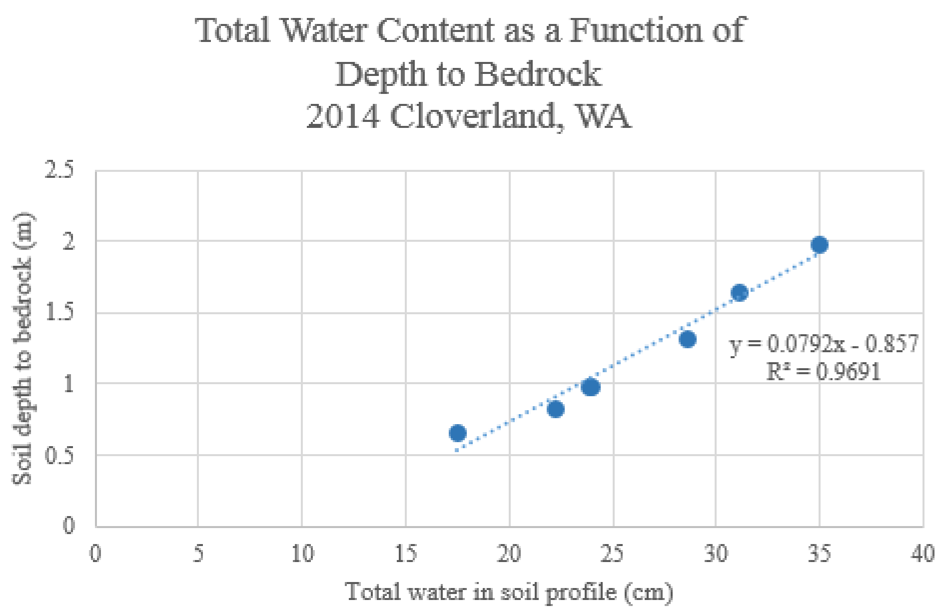


Figure 3.1. Soil depth to bedrock and corresponding total water content at a selected sampling date in Cloverland.

A planting date comparison was seen in Cloverland, as the cooperating farmer planted the surrounding field a month before the plots (Figure 3.2). Within the first 0.6 m, the canola in the grower's field used 13.46 cm of water and terminated growth for winter about October 5. In contrast, the canola in the variety trial used 8.89 cm of water in the top 0.6 m of soil. This later-planted canola continued to extract water long after the early-planted canola had ceased, concluding fall growth around November 4. These observations of early-planted canola using more water and ceasing growth earlier compared to later-planted canola are similar to the findings in Chapter 2.

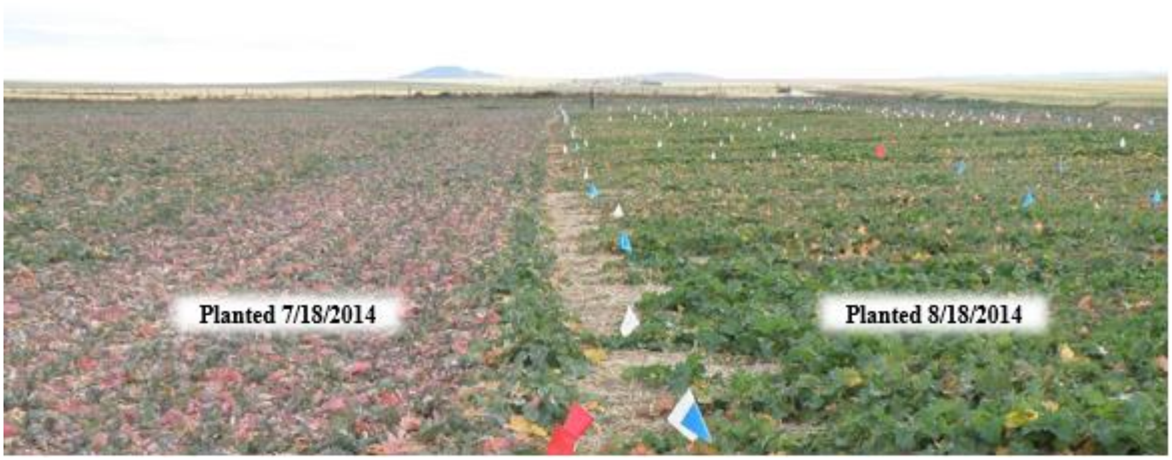


Figure 3.2. Visual comparison of Cloverland plots surrounded by grower's field on October 31, 2014.

Pomeroy soil contained 27 cm of water at planting, nearly twice the initial water content of Okangan (15 cm). Canola at Pomeroy used 13.67 cm of water during the 2014 fall growing season, while canola at Okanogan utilized only 4.25 cm. When combining data for these two sites, cumulative water use appears to increase exponentially (Figure 3.3). Canola water consumption rate may be greater in Pomeroy, perhaps due to greater soil water available initially (Figure 3.4, Figure 3.5).

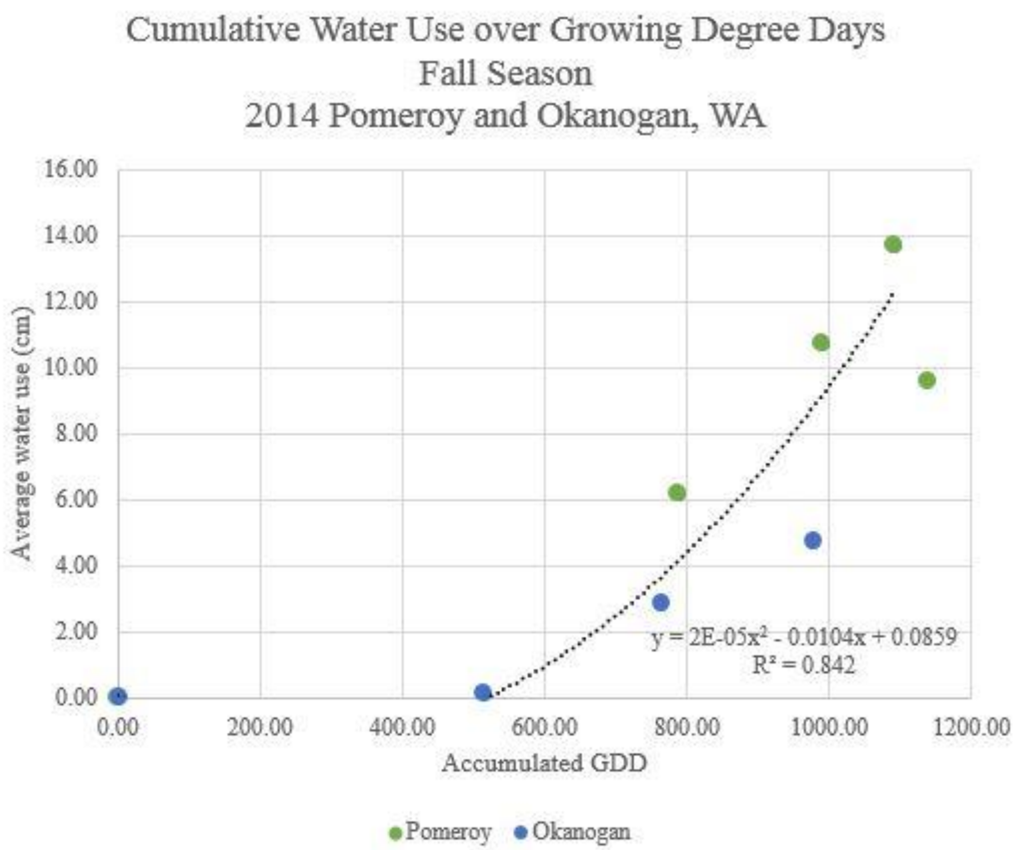


Figure 3.3. Mean available water use by canola as growing degree days progress from planting to winter onset in Okanogan (blue) and Pomeroy (green). Polynomial regression for combined data shown by dashed line.

Water extraction within the soil profile over time showed that canola at Pomeroy first withdrew water from the top 80 cm of soil, particularly above 60 cm (Figure 3.4). By November 4, nearly two and a half months after planting, water extraction was seen at 120 cm. However, precipitation recharged some moisture in the top 30 cm, increasing the water content from the previous measurement on October 22. The November 20 sampling date reflects precipitation further increasing water contents and cessation of plant growth.

Canola in Okanogan did not extract much soil water during fall season growth, and the usage was relegated to the upper 90 cm of the profile (Figure 3.5). A hardpan layer at approximately 20 cm was present at this location, which may have restricted early root growth and subsequent access to water. By early November, water extraction had ceased and precipitation had increased soil water content in the topsoil, similar to the pattern seen at Pomeroy.

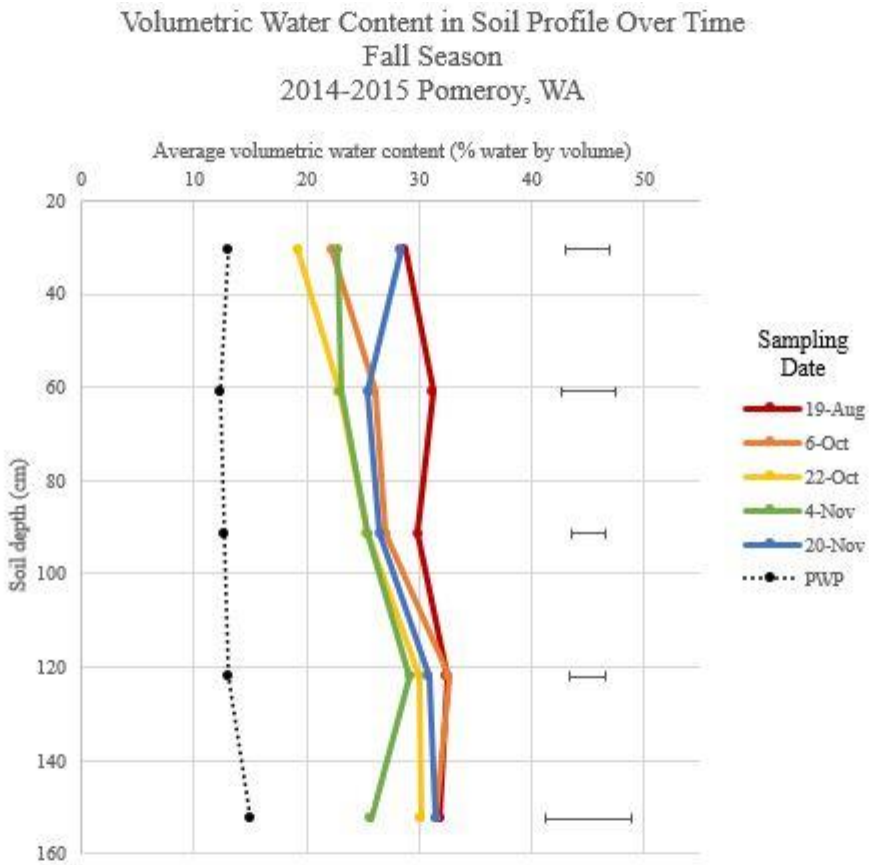


Figure 3.4. Mean volumetric water content in Pomeroy graphed as soil depth increases. Several fall season sampling dates are shown, as well as permanent wilting point at each depth. Tukey HSD at each depth is also plotted.

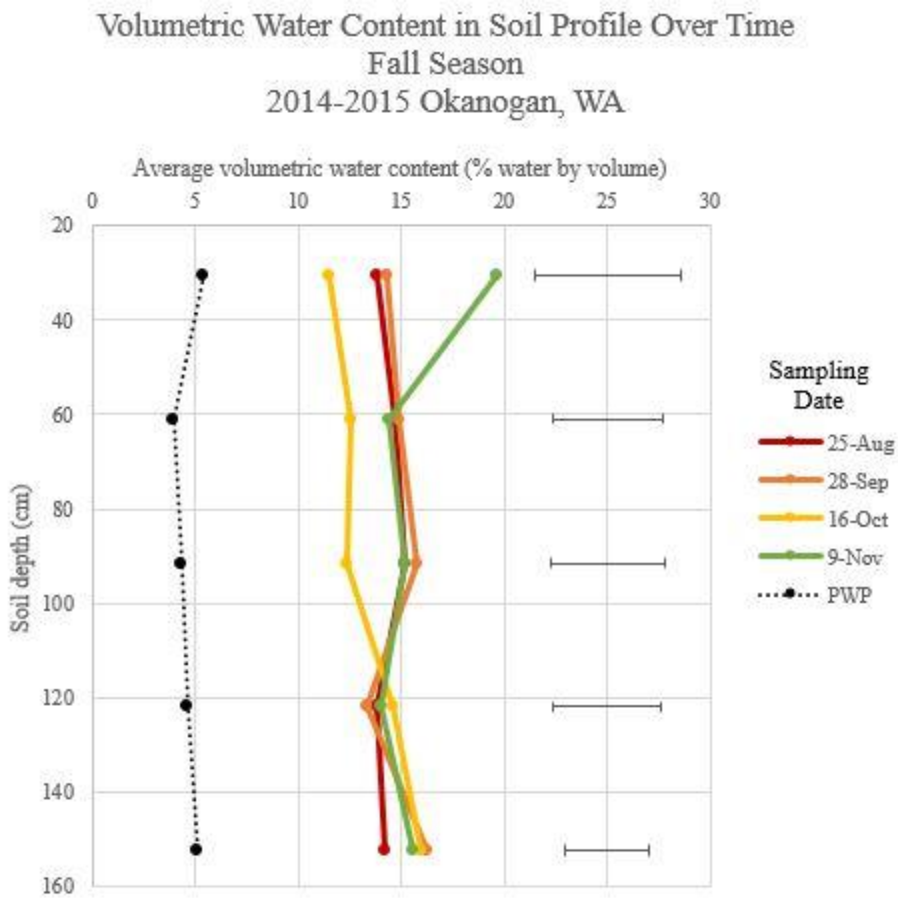


Figure 3.5. Mean volumetric water content in Okanogan graphed as soil depth increases. Several fall season sampling dates are shown, as well as permanent wilting point at each depth. Bars indicate Tukey HSD at each depth.

Based on soil texture analysis by Mastersizer (laser diffraction of dispersed sample), Okanogan contained 15% sand, 70% silt, and 15% clay, and Pomeroy contained 7% sand, 74% silt, and 19% clay (Nunez 2015, unpublished data). The permanent wilting point is highly dependent upon soil texture, as indicated by the comparison of Pomeroy and Okanogan (Table 3.2). The film of water surrounding soil particles is held tightly and not accessible to plant roots. In relation to Okanogan, Pomeroy has more silt and clay. Silt and clay are smaller than sand and have a proportionately larger surface area. Thus, permanent wilting points are higher in the Pomeroy soil. Okanogan has over twice the sand content than Pomeroy; less water adheres to these large particles and therefore permanent wilting point is lower. Additionally, Pomeroy has slightly higher bulk density values on average than Okanogan, probably because of the higher proportion of clay particles.

Table 3.2. Mean values for bulk density and volumetric permanent wilting point at several soil depth increments for the Pomeroy and Okanogan plot locations.

POMEROY, WA		
Soil Depth (cm)	**Bulk Density ($g \cdot cm^{-3}$)**	**Permanent Wilting Point (% water by volume)**
0 – 30	1.17	13.00
30 – 60	1.21	12.26
60 – 90	1.18	12.66
90 – 120	1.34	13.05
120 – 150		15.04
OKANOGAN, WA		
Soil Depth (cm)	**Bulk Density ($g \cdot cm^{-3}$)**	**Permanent Wilting Point (% water by volume)**
0 – 30	1.13	5.39
30 – 60	1.00	3.94
60 – 90	1.18	4.32
90 – 120	1.19	4.60
120 – 150		5.09

Pomeroy had a much higher N supply in the fall than Okanogan due to greater fertilization, mineralization, and initial inorganic soil N content (Table 3.3). Pomeroy soil N was greatest in the upper 30 cm, at approximately 120 $kg \cdot ha^{-1}$ (Figure 3.6). N content generally decreased with soil depth, with only 20 $kg \cdot ha^{-1}$ of N at 90 cm. After fall canola growth, soil N was nearly depleted at 60 cm and below, though a fertilizer application sustained N in the topsoil. Of Pomeroy's fall N supply, 38% was measured in fall vegetation and 33% remained in the soil after fall growth. Only 29% remained unaccounted, some of which was contained in unmeasured root mass (Table 3.4). In addition, N may have been removed from the system by deer, which grazed the plots.

At initial planting in Okanogan, soil N dramatically decreased with soil depth, ranging from 100 kg·ha^{-1} in the upper 30 cm to only 1.7 kg·ha^{-1} at 150 cm (Figure 3.7). By November, only 6 kg·ha^{-1} (3% of fall N supply) remained in the entire profile. Although much of the available N was taken up by the crop (available NupE at 86%), the N retention efficiency was very low (21%) (Table 3.4). There are several pathways for N loss in these agronomic systems that would contribute to the amount of unaccounted N. Possible losses include: immobilization, when converted from inorganic N to organic forms; volatilization, especially from the surface fertilizer applications; and ammonium fixation, whereby NH_4^+ ions are trapped in the interlayer spaces of 2:1 clays (Hermanson et al 2000). Leaching is another common cause for N loss, but these sites are relatively dry and downward nitrate movement would have been within the sampled depths. Finally, sampling errors and misrepresentation may be inherent issues.

Table 3.3. Total nitrogen supply (kg·ha^{-1}) including contributing components at Pomeroy and Okanogan, WA during the fall season.

	Total Fall Season N Supply (Ns_f)	Initial Soil N at Planting (kg·ha^{-1})	Fall Organic Matter Mineralization Estimate (kg·ha^{-1})	Fall N Fertilizer Application (kg·ha^{-1})
Pomeroy	366 kg·ha^{-1}	262	14	90
Okanogan	197 kg·ha^{-1}	134	7	56

Table 3.4. N uptake efficiency, N retention efficiency, and available N uptake efficiency (kg·ha^{-1}) at Pomeroy and Okanogan, WA during the fall season, as well as component factors.

Fall Season					
	Available N (Nav_f)	**Aboveground Biomass N (Nt_f)**	**$NupE_f$ (Nt_f/Ns_f)**	**$NretE_f$ (Nav_f/Ns_f)**	**$avNupE_f$ (Nt_f/Nav_f)**
Pomeroy	248 kg·ha^{-1}	140 kg·ha^{-1}	0.38	0.71	0.54
Okanogan	41 kg·ha^{-1}	36 kg·ha^{-1}	0.18	0.21	0.86

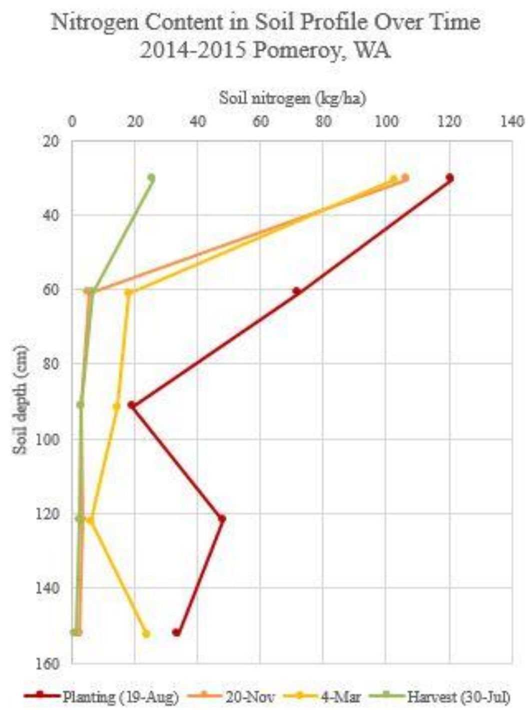


Figure 3.6. Nitrogen content throughout the soil profile at several sampling dates at Pomeroy.

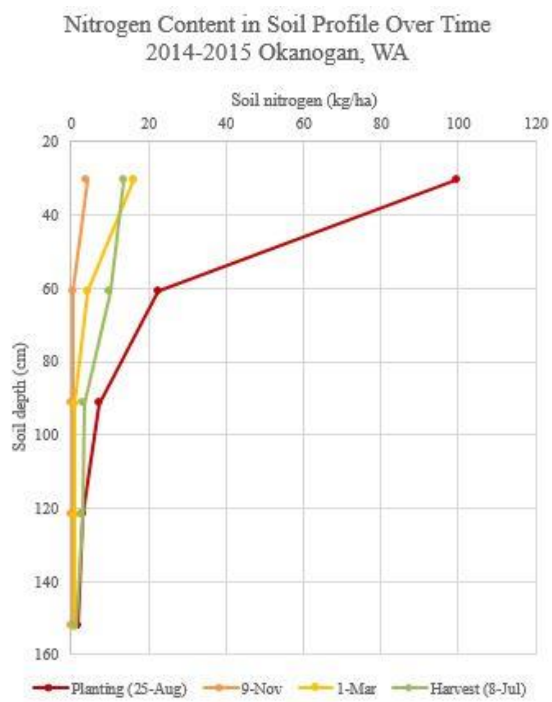


Figure 3.7. Nitrogen content throughout the soil profile at several sampling dates at Okanogan.

Canola above-ground biomass accumulation and N content followed a similar pattern throughout the 2014-2015 growing season (Figure 3.8). Values increased in a sigmoidal fashion during fall vegetative growth, with the last sampling dates at Pomeroy showing growth cessation due to winter onset. The pattern corresponds very closely to research at Pendleton, Oregon, and the biomass values were similar to Pomeroy values, though the N content was higher in Oregon canola (Wysocki et al 2007).

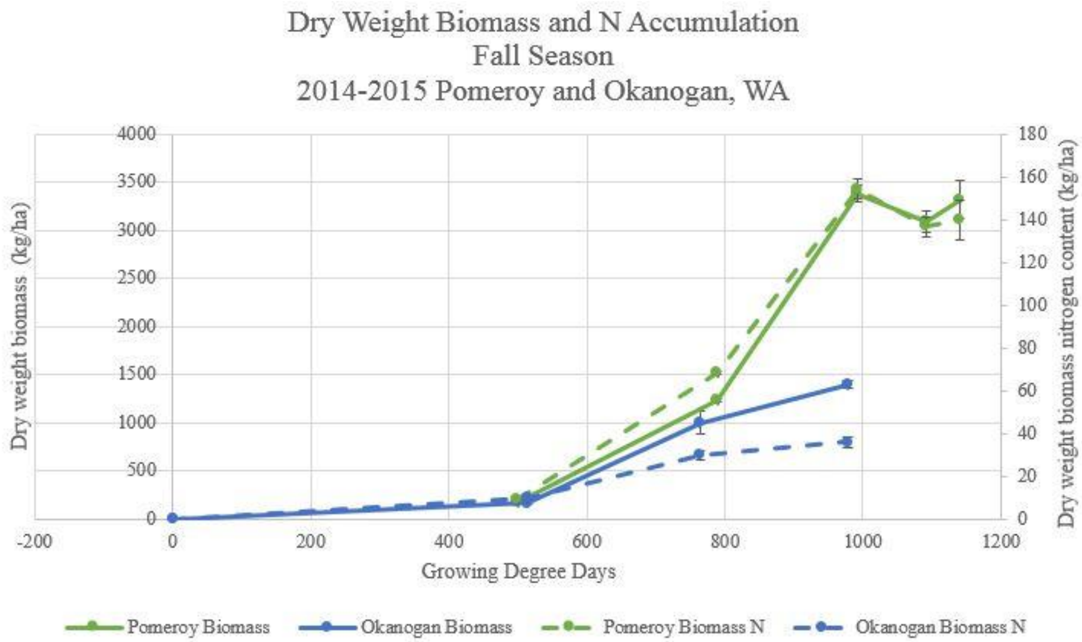


Figure 3.8. Mean biomass and biomass nitrogen accumulation as growing degree days progress in Pomeroy (green) and Okanogan (blue). Canola biomass (solid lines) corresponds to the left axis, while biomass N (dashed lines) corresponds to the right axis. Standard error bars are shown.

Winter season (winter onset – spring regrowth)

Canola at Cloverland was extensively grazed by elk in the fall and suffered complete winter kill. Canola averaged 42% and 69% winter survival at Pomeroy and Okanogan respectively. In terms of the soil profile, nitrogen content changed over the winter. A November sampling date revealed averages of 5 kg N·ha^{-1} in Okanogan and 108 kg N·ha^{-1} in Pomeroy. By early March, these values had increased to 20 kg N·ha^{-1}

and 148 kg N·ha^{-1}. Elevated N levels may be due to some organic matter mineralization. Another contributor is release of N from abscised fall vegetation, as roughly 75% percent of the N in these leaves is non-structural or associated with soluble cell components (Beard 2013). The N increase at Okanogan was relegated to the top 30 cm of the soil profile, but N levels generally increased throughout the entire sub-30 cm profile at Pomeroy, including at 150 cm (Figure 3.6). Leaching of existing soil N, as well as recently mineralized N, is likely the cause for this downward migration in the wetter Pomeroy location.

Although most of the annual precipitation occurred in the winter months at Pomeroy and Okanogan, not all precipitation was directly reflected in the soil profiles' water content. Fifty six percent of Pomeroy's winter precipitation entered and remained in the soil profile, while Okanogan measurements indicate the soil absorbed 78% of its precipitation (Table 3.5). These over-winter precipitation storage efficiency values are similar to those reported for winter wheat. Surface run-off and evaporation are likely causes for the observed incomplete precipitation retention. The increase in soil water remained in the upper 120 cm of soil at Pomeroy and appeared to reach 150 cm at Okanogan (Figure 3.11, Figure 3.12).

Table 3.5. Precipitation during winter months and soil water content increase over the same time period for Pomeroy and Okanogan, WA.

	Winter Precipitation (Late November – Early March)	**Increase in Soil Water Content (Late November – Early March)**	**Precipitation Retention Efficiency**
Pomeroy	22.6 cm	12.6 cm	56%
Okanogan	13.4 cm	10.5 cm	78%

Harvest season (spring regrowth – harvest)

A majority of winter canola water consumption occurred in the harvest season – 86% in Okanogan and 75% in Pomeroy (Figure 3.9). Total water use varied between 55 cm (Pomeroy, higher rainfall site) and 30 cm (Okanogan, drier location).

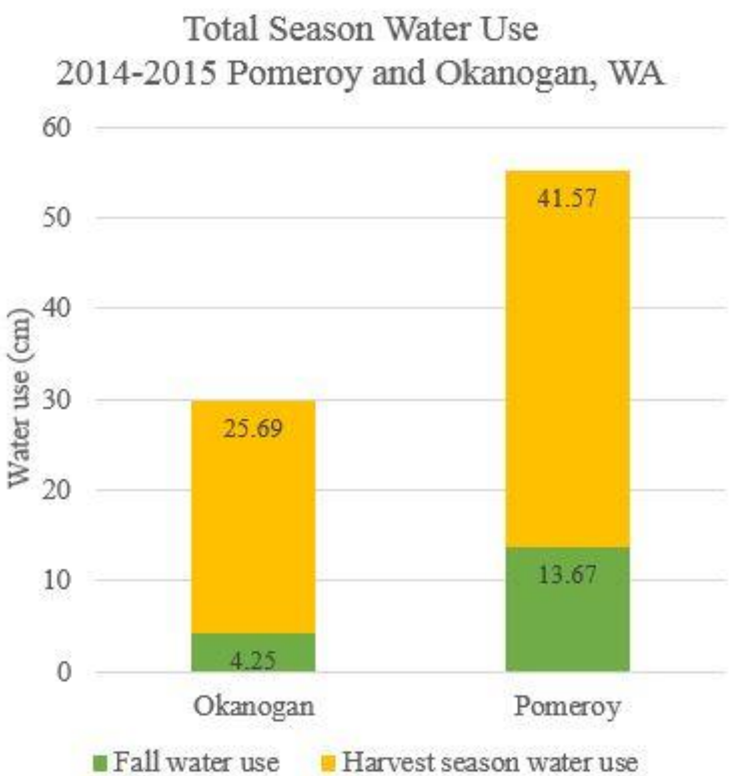


Figure 3.9. Water use in Okanogan and Pomeroy during fall (green) and harvest seasons (yellow). The total height of the column represents total water use (cm).

Compared to the more gradual, exponential water use increase in the fall (Figure 3.3), cumulative water use followed a steeper, linear trend in the harvest season (Figure 3.10). The available soil water contents at spring regrowth were greater than the water contents at planting (27 cm vs. 14 cm in Okanogan, 32 cm vs. 27 cm in Pomeroy). This greater water availability, combined with stored root reserves, allow for a quicker growth flush and accordingly more transpiration.

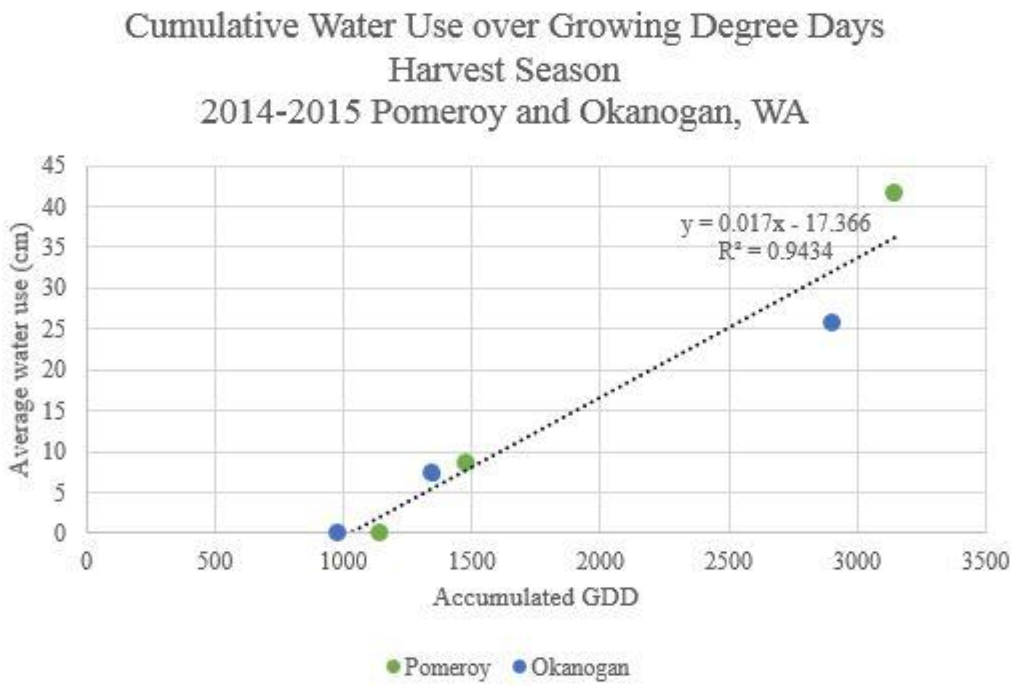


Figure 3.10. Mean available water use by canola as growing degree days progress from spring regrowth to harvest in Okanogan (blue) and Pomeroy (green). A linear regression is shown by the dashed line.

The November 20 sampling date provides a reference for late fall soil water content in Pomeroy, and it appears that winter precipitation increased the water content in the upper 120 cm of soil (Figure 3.11). From early March to the end of April, minimal water extraction occurred, with the plants sustained mainly by precipitation. By harvest, however, the canola roots accessed much of the stored soil water. Essentially all available water in the upper 90 cm was taken up, with water use extending to 150 cm. Root length was at least 150 cm, as the volumetric water content was reduced by 65% at this depth during spring water use. This observation is parallel to data in Chapter 2.

In Okanogan, winter precipitation increased the water content throughout the entire 150 cm profile, particularly in the upper 60 cm (Figure 3.12). The first month and a half of spring growth resulted in extraction from only that top section. By harvest, however, canola roots accessed water throughout the profile. Most of the available water was used within the top 60 cm, with the final soil water content fairly close to the permanent wilting point. Available soil water was left in the soil below 60 cm.

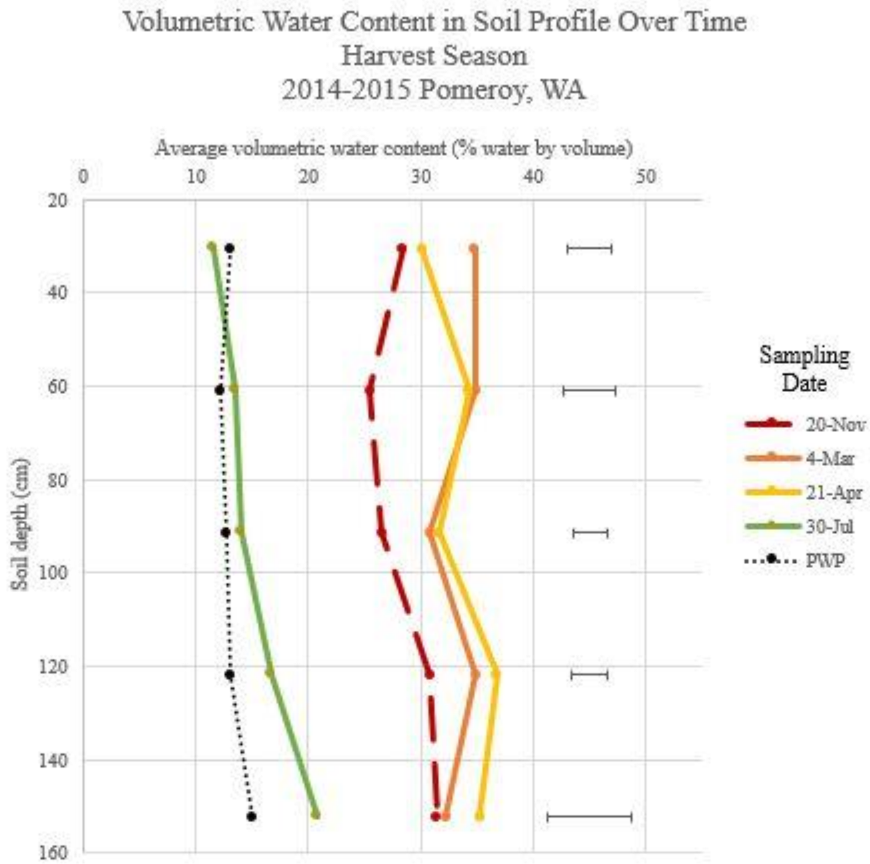


Figure 3.11. Mean volumetric water content in Pomeroy graphed as soil depth increases. The dashed line corresponds to the sampling date just before winter. Several harvest season sampling dates are shown in solid lines, as well as permanent wilting point at each depth. Tukey HSD at each depth is also plotted.

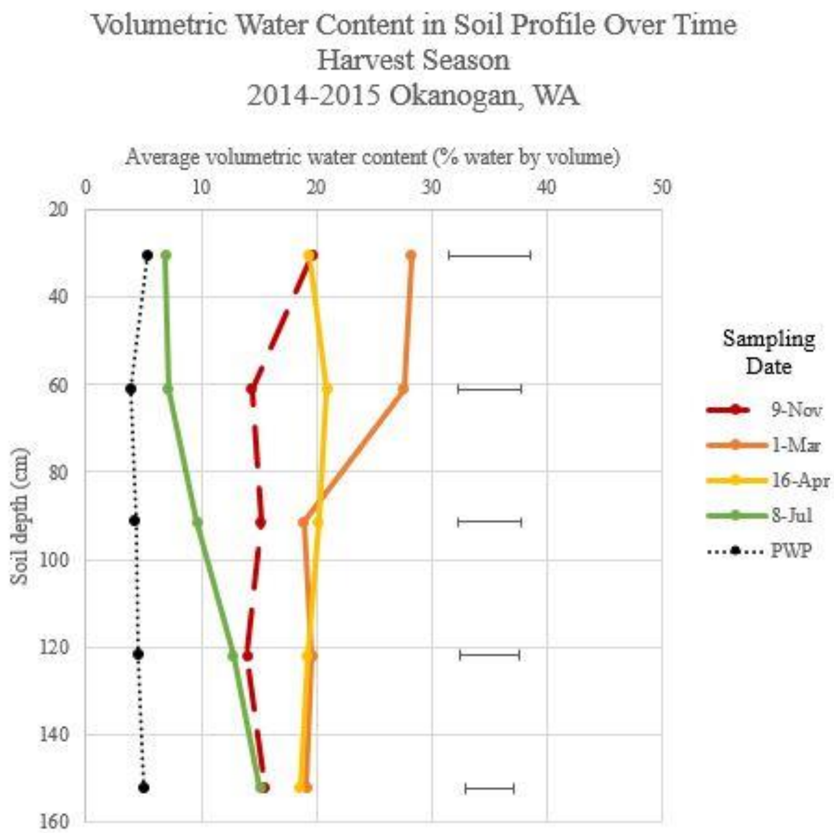


Figure 3.12. Mean volumetric water content in Okanogan graphed as soil depth increases. The dashed line corresponds to the sampling date just before winter. Several harvest season sampling dates are shown in solid lines, as well as permanent wilting point at each depth. Tukey HSD at each depth is also plotted.

In Okanogan canola, harvest season N accumulation was 56% of its fall + harvest season N uptake, while Pomeroy canola's harvest biomass contained 43% of fall + harvest season (Figure 3.13). These numbers are lower than the 70-75% documented in Germany (Rathke et al 2006). Based on these two site-years, it appears that roughly the same amount of N was utilized in the fall as in the harvest season. However, much more biomass was accumulated in the harvest season than in the fall at both sites (Figure 3.14). Pomeroy amassed more biomass in the fall season than Okanogan, 3320 kg·ha^{-1} versus 1397 kg·ha^{-1}. By harvest, canola biomass at Pomeroy (7800 kg·ha^{-1}) was nearly double of the biomass at Okanogan (4006 kg·ha^{-1}).

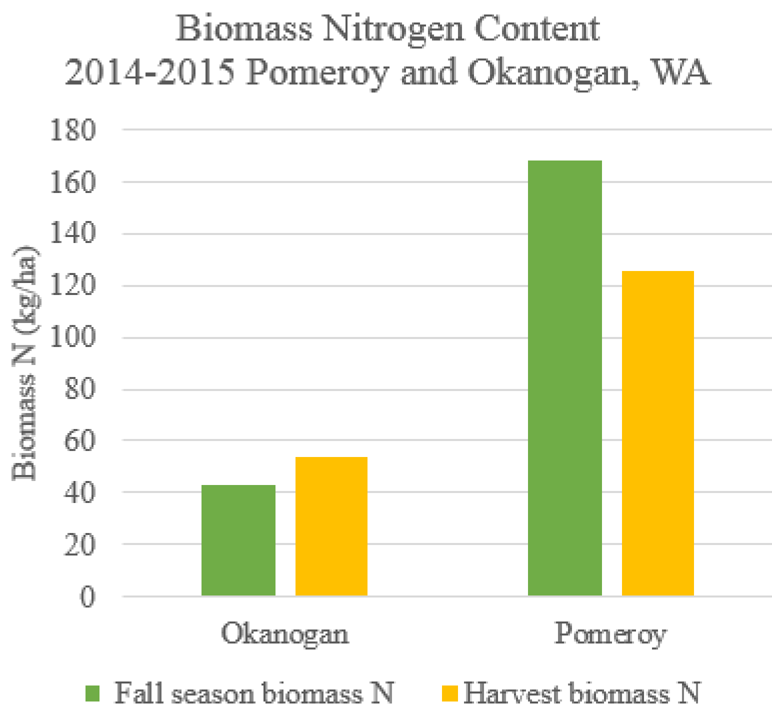


Figure 3.13. Biomass nitrogen accumulation in Okanogan and Pomeroy during fall (green) and harvest seasons (yellow).

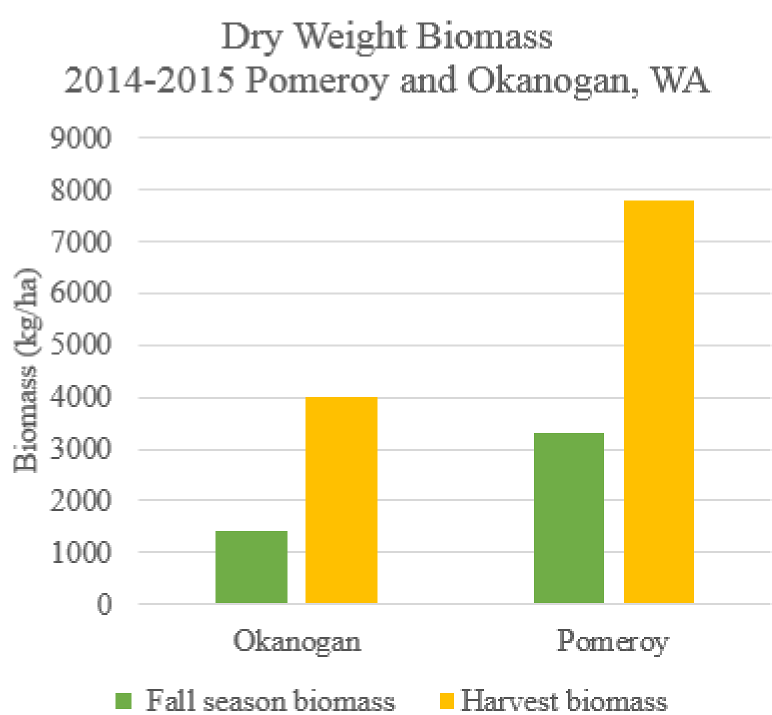


Figure 3.14. Biomass accumulation in Okanogan and Pomeroy during fall (green) and harvest seasons (yellow).

As in the fall, Pomeroy had a much higher harvest season N supply than Okanogan (Table 3.6), and only 26% remained unaccounted (Table 3.8). Compared to the fall N budgets (Table 3.4), this harvest N retention efficiency is higher, and more of the available N was contained in crop biomass. The Pomeroy harvest season unit nitrogen requirement was 8, very near the predicted value for similarly-yielding spring canola in the PNW (Maaz 2014). Harvest season NUE in Pomeroy was lower than Okanogan, which may reflect the fact that NUE generally declines with increasing N supply (Huggins and Pan 1993).

An interesting phenomenon was observed at Okanogan, as more N was present in the biomass or in the soil at harvest than the estimated harvest season supply, generating a harvest N retention efficiency above 1 (Table 3.8). Unrepresentative sampling or underestimation of N mineralization may have partially created this discrepancy. Also, N dynamics are extremely complicated, and sampling at only a few select dates may have illuminated temporal fluctuations but failed to characterize a balance throughout the season; recall that 79% of the fall N supply was unaccounted at winter onset at Okanogan (Table 3.4), while the harvest values exceed the supposed spring season supply. Thirty nine percent of available N was left in the soil at harvest, some of which may have been "stranded" by low volumetric water contents in the upper portion of the soil profile. As soil dries, root activity is curbed and can no longer access N in the soil solution.

Table 3.6. Total N supply ($kg \cdot ha^{-1}$) at Pomeroy and Okanogan, WA during the harvest season, as well as contributing components.

	Total Harvest Season N Supply (Ns_h)	Initial Soil N at Spring Regrowth ($kg \cdot ha^{-1}$)	Harvest Season Organic Matter Mineralization Estimate ($kg \cdot ha^{-1}$)	Spring N Fertilizer Application ($kg \cdot ha^{-1}$)
Pomeroy	207 $kg \cdot ha^{-1}$	148	25	34
Okanogan	59 $kg \cdot ha^{-1}$	20	13	26

Table 3.7. Harvest season available N, biomass N, grain N, and grain weight ($kg \cdot ha^{-1}$) at Pomeroy and Okanogan, WA.

	Available N (Nav)	**Aboveground biomass N (Nt)**	**Grain N (Ng)**	**Grain weight (Gw)**
Pomeroy	154 $kg \cdot ha^{-1}$	114 $kg \cdot ha^{-1}$	87 $kg \cdot ha^{-1}$	2454 $kg \cdot ha^{-1}$
Okanogan	80 $kg \cdot ha^{-1}$	49 $kg \cdot ha^{-1}$	34 $kg \cdot ha^{-1}$	892 $kg \cdot ha^{-1}$

Table 3.8. N use efficiency and contributing components at Pomeroy and Okanogan, WA during the harvest season, as well as the total season, which has an altered Ns.

Harvest Season							
	NUE_h (Gw/Ns_h)	**$NupE_h$ (Nt/Ns_h)**	**NutE (Gw/Nt)**	**$NretE_h$ (Nav/Ns_h)**	**avNupE (Nt/Nav)**	**NHI (Ng/Nt)**	**gNutE (Gw/Ng)**
Pomeroy	12	0.56	21	0.74	0.75	0.76	28
Okanogan	15	0.83	18	1.36	0.61	0.69	26
Total Season							
	NUE (Gw/Ns)	**NupE (Nt/Ns)**	**NutE (Gw/Nt)**	**NretE (Nav/Ns)**	**avNupE (Nt/Nav)**	**NHI (Ng/Nt)**	**gNutE (Gw/Ng)**
Pomeroy	6	0.27	21	0.36	0.75	0.76	28
Okanogan	4	0.21	18	0.34	0.61	0.69	26

Nitrogen use efficiency and its components were also computed across the total season, where N supply was defined as preplant soil N along with mineralized and fertilized N in both fall and harvest seasons (Table 3.8). Total season N supply was higher than the harvest season N supply in Pomeroy and Okanogan, and the losses in fall and spring are compounded. Therefore, the NUE and N uptake efficiencies are lower in total season compared to the harvest season. Total season NUE is higher in Pomeroy than the low-precipitation site of Okanogan, which is expected because low water availability curtails N uptake and efficiency (Pan et al 2007).

Both total season N utilization efficiencies were close to those cited previously in the literature (Berry et al 2010, Erley et al 2011), as were N harvest indices (Dreccer et al 2000, Koenig et al 2011). The total season unit nitrogen requirement was higher than in the drier site of Okanogan (26, versus 17 in Pomeroy). These values are much greater than the 6-11 kg·100 kg seed^{-1} cited for winter canola in local extension publications (Koenig et al 2011, Mahler and Guy 2002, Wysocki et al 2007).

Compared to past Pomeroy variety trial yields, the 2014-2015 harvest (over 2400 kg·ha^{-1}, Table 3.9) was greater than the previous year's but lower than 2012-2013 (Young et al 2013). Yields of 900 kg·ha^{-1} were obtained at Okanogan, less than past Okanogan variety trials, which have ranged from 1575 to 1700 kg·ha^{-1} (Young et al 2014). The yield difference between Pomeroy and Okanogan is likely due to water and N availability, as discussed earlier. Additionally, Okanogan encountered high temperatures, and heat stress probably impacted flowering and seed fill, with a seed N% of 3.8.

Harvest index at Okanogan was 21.9% and at Pomeroy 31.5% (Table 3.9), both within the expected range for canola (Gan et al 2009b, Hocking et al 1997). Pomeroy also had a higher WUE (4.46 kg·ha^{-1}mm^{-}1) compared to Okanogan (2.93 kg·ha^{-1}mm^{-1}). Robertson and Kirkegaard (2005) found much higher WUE in their review of dryland spring canola (most 8.5 – 14 kg·ha^{-1}mm^{-1}), which is likely due to the absence of fall vegetative water use. However, recent research on spring canola in the PNW revealed similar WUE to the results presented here, with an average of 3 kg·ha^{-1}mm^{-1} (Pan et al, in review). In terms of biomass, 23 and 27 kg·ha^{-1} of dry matter in fall was produced per mm of water used at Pomeroy and Okanogan respectively. Because Okanogan canola consumed very little water in the fall, the efficiency was higher than at Pomeroy.

Table 3.9. Mean values for several yield and water relationships for the 2014-2015 season in Pomeroy and Okanogan.

Factor	**Pomeroy**	**Okanogan**
Yield (seed kg · ha^{-1})	2454.06	892.11
Harvest index (seed kg · biomass kg^{-1})	0.32	0.22
Water use efficiency (seed kg · ha^{-1}mm^{-1})	4.46	2.93
Fall biomass water use efficiency (biomass kg · ha^{-1}mm^{-1})	23.30	27.47

A correlation was noted between plant vigor and fertilization levels at Okanogan. The border alleys between the trial replications received no fertilizer and yielded significantly less than the fertilized plots and surrounding field (Figure 3.15).

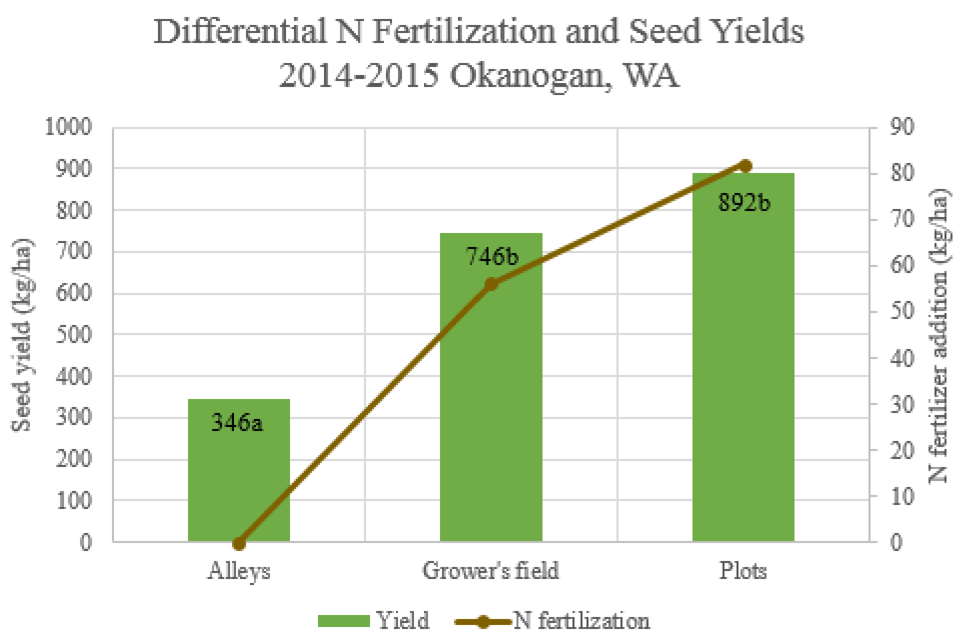


Figure 3.15. Different fertilizer rates (line) at Okanogan, WA and corresponding seed yields (bars). Yield values followed by the same letter indicate no significant difference.

CONCLUSION

Winter canola plots were established at Pomeroy, Cloverland, and Okanogan. Canola growth analysis was approached in three distinct phases: fall vegetative season, winter season, and harvest growth. Soil water, soil N, and plant biomass were monitored periodically throughout the fall and harvest growing seasons. A planting date comparison at Cloverland echoed findings in Chapter 2, as early-planted (July 18) canola extracted more water and terminated growth earlier in the fall compared to late-planted canola (August 18). Fall water use in Okanogan and Pomeroy varied from 4-16 cm, but was 15-20% of total water use. Root activity reached 1.5 m in the fall, though water was first utilized in the upper portions of the soil profile. Similar to water use, fall N use also varied, but was approximately equal to harvest season N accrual. Fall biomass and N accumulation followed a sigmoidal pattern. In both locations, N inefficiencies appeared to occur in the fall season to a greater degree than the harvest season. Observed soil N increases during winter were likely due to organic matter mineralization and release from fall-grown leaves. Soil water content also increased over the winter, though not consummate with the amount of precipitation received. Yield was much higher at Pomeroy, which had greater soil water and N supplies. Water use efficiency values were between 4.5 – 3 $kg \cdot ha^{-1}mm^{-1}$, similar to spring canola in the area (Pan et al in review). Harvest season winter canola N efficiency metrics were comparable to spring canola (Pan et al, in review). The total season NUEs were lower than the harvest season NUE and contributed to regional data sets. Overall, this study proposed a novel approach to analyzing winter crops throughout three distinct seasons. Research should continue in order to build a comprehensive dataset for winter canola water and N use in the PNW.

Additional research questions raised by this study include: optimal timing and rate of N fertilizer, accurate estimate of N mineralization from fall vegetative leaves, and amount of N fixed in these soils.

LITERATURE CITED

Asplund, L., G. Bergkvist, and M. Weih. 2014. Proof of concept: nitrogen use efficiency of contrasting spring wheat varieties grown in greenhouse and field. Plant and Soil. 374: 829-842.

Beard, T.L. Effects of silicon on soil crusting and soil quality. 2013. MS Thesis. Washington State Univ., Pullman.

Berry, P.M., J. Spink, M.J. Foulkes, and P.J. White. 2010. The physiological basis of genotypic differences in nitrogen use efficiency in oilseed rape (Brassica napus L.). Field Crops Res. 119: 365–373.

Cutforth, H.W., S. V. Angadi, B. G. McConkey, P. R. Miller, D. Ulrich, R. Gulden, K. M. Volkmar, M. H. Entz, and S. A. Brandt. 2013. Comparing rooting characteristics and soil water withdrawal patterns of wheat with alternative oilseed and pulse crops grown in the semiarid Canadian prairie. Can. J. Soil Sci. 93: 147-160.

Dawson, J.C., D.R. Huggins, and S.S. Jones. 2008. Characterizing nitrogen use efficiency in natural and agricultural ecosystems to improve the performance of cereal crops in low-input and organic agricultural systems. Field Crops Res. 107: 89-101.

Dejoux, J.F., S. Recous, J.M. Meynard, I. Trinsoutrot, and P. Leterme. 2000. The fate of nitrogen from winter-frozen rapeseed leaves: mineralization, fluxes to the environment, and uptake by rapeseed crop in spring. Plant Soil. 218: 257-272.

Dreccer, M.F., A. H. C. M. Schapendonk, G. A. Slafer, and R. Rabbinge. 2000. Comparative response of wheat and oilseed rape to nitrogen supply: absorption and utilisation efficiency of radiation and nitrogen during the reproductive stages determining yield. Plant Soil. 220: 189–205.

Erley, G.S., T. Behrens, A. Ulas, F. Wiesler, and W.J. Horst. 2011. Agronomic traits contributing to nitrogen efficiency of winter oilseed rape. Field Crops Res. 124: 114-123.

Gan, Y.T., C.A. Campbell, L. Liu, P. Basnyat, and C.L. McDonald. 2009a. Water use and distribution profile under pulse and oilseed crops in semiarid northern high latitude areas. Agric. Water Manage. 96: 337-348.

Gan, Y.T., C.A. Campbell, H.H. Janzen, R.L. Lemke, P. Basnyat, and C.L. McDonald. 2009b. Carbon input to soil from oilseed and pulse crops on the Canadian prairies. Agri. Eco., Envir. 132: 290-297.

Hermanson, R., W. Pan, C. Perillo, R. Stevens, and C. Stockle. 2000. Nitrogen use by crops and the fate of nitrogen in the soil and vadose zone–a literature search. Washington State Univ. and Washington Dept. of Eco. Publication no. 00-10-015.

Hocking, P.J., P.J. Randall, and D. DeMarco. 1997. The response of dryland canola to nitrogen fertilizer: partitioning and mobilization of dry matter and nitrogen, and nitrogen effects on yield components. Field Crops Res. 54:201-220.

Huggins, D.R. and W.L. Pan. 1993. Nitrogen efficiency component analysis: an evaluation of cropping system differences in productivity. Agronomy J. 85: 898-905.

Johnston, A.M., D.L. Tanaka., P.R. Miller, S.A. Brandt, D.C. Nielson, G.P. Lafond, and R.R. Riverland. 2002. Oilseed crops for semiarid cropping systems in the northern Great Plains. Agron. J. 94, 231–240.

Koenig, R.T., W.A. Hammac, and W.L. Pan. 2011. Canola growth, development and fertility. Washington State Univ. Ext. Fact Sheet FS045E.

Mahler, R.L. and S.O. Guy. 2002. Northern Idaho Fertilizer Guide: Spring Canola. Univ. of Idaho Ext. CIS 1012.

Malhi, S.S., A. M. Johnston, J. J. Schoenau, Z. H. Wang, and C. L. Vera. 2007. Seasonal Biomass Accumulation and Nutrient Uptake of Canola, Mustard, and Flax on a Black Chernozem Soil in Saskatchewan. J. Plant Nut. 30: 641–658.

Malagoli P, P. Laine, E. Le Deunff, L. Rossato, B. Ney, and A. Ourry. 2004. Modeling N uptake in Brassica napus L. cv Capitol during a growth cycle using influx kinetics of root nitrate transport systems and field experimental data. Plant Phys. 134: 388–400.

Maaz, T. 2014. Nitrogen uptake and cycling by canola, pea, and wheat: implications for rotational nitrogen use efficiency. PhD Diss. Washington State Univ., Pullman.

Merrill, S. D., D.L. Tanaka, and J.D. Hanson. 2002. Root length growth of eight crop species in Haplustoll soils. Soil Sci. Soc. Am. J. 66: 913-923.

Nielsen, D.C. 1997. Water use and yield of canola under dryland conditions in the central Great Plains. J. Prod. Agric. 10:307–313.

Pan, W.L., T.M. Maaz, W.A. Hammac, and R.T. Koenig. In review. Mitscherlich modeled canola nitrogen requirements influenced by soil N and water in annual and fallow cropping systems. Agron. J.

Pan, W.L., W. Schillinger, D.R. Huggins, R. Koenig, and J. Burns. 2007. Fifty years of predicting wheat nitrogen requirements based on soil water, yield, protein, and nitrogen efficiencies. Proceedings of the Soil Science Society of America.

Rathke, G.W., T. Behrens, and W. Diepenbrock. 2006. Integrated nitrogen management strategies to improve seed yield, oil content and nitrogen efficiency of winter oilseed rape (Brassica napus L.): A review. Agri., Eco., Envir. 117: 80-108.

Robertson, M.J., and J.A. Kirkegaard. 2005. Water-use efficiency of dryland canola in an equi-seasonal rainfall environment. Aus. J. of Agri. Res. 56: 1373-1386.

Rossato, L., P. Laine, and A. Ourry. 2001. Nitrogen storage and remobilization in Brassica napus L. during the growth cycle: nitrogen fluxes within the plant and changes in soluble protein patterns. J. Exp. Bot. 52 (361): 1655–1663.

Schillinger, W.F. 2012. Dryland and irrigated cropping systems research with camelina, winter canola, and safflower. *In:* Washington Biofuels Cropping Systems Annual Report.

Tesfamariam, E.H., J.G. Annandale, and J. M. Steyn. 2010. Water stress effects on winter canola growth and yield. Agron. J. 102(2): 658-666.

Young, et al. 2013. Winter canola production in the low- to intermediate-rainfall zones of the Pacific Northwest. Washington Oilseed Cropping Systems Annual Report.

Young, F.L., D.K. Whaley, W.L. Pan, R.D. Roe, and J.R. Alldredge. 2014. Introducing winter canola to the winter wheat-fallow region of the Pacific Northwest. Crop Manage.

Wysocki, D.J., M. Corp, D.A. Horneck, and L.K. Lutcher. 2007. Irrigated and dryland canola nutrient management guide. Oregon State Univ. Ext. EM8943-E.