CANOLA ROOTS OF WATER AND NITROGEN USE EFFICIENCY: NEW LESSONS FOR PNW WHEAT GROWERS

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ABSTRACT

The semi-arid inland Pacific Northwest (iPNW) has primarily produced wheat for 125 years due to favorable climate, soils, economics and policy drivers. Shifting drivers over the past decade related to energy, climate change, regional and global markets have created new opportunities for the integration of canola into iPNW wheat-dominated rotations. Traditional wheat grower mindsets required an agronomic reboot, forged by an understanding of canola vs. wheat physio morphology, an explosion of variety x herbicide options, evidence of canola-facilitated rotational benefits, and considerations of agroecological-zone specific rotational fits. Water and N use efficiencies (WUE and NUE) and management are key factors that relate to the energy and climate change drivers. Responses to N rates, yield potentials, and NUEs across 12 site-years were modeled using a modified Mitscherlich's Law of Diminishing Returns which predicted a range of water-related unit N requirements (UNRs). Shallower root activity with lower water supply resulted in decreased NUEs and increased UNRs. Lower N uptake and N utilization efficiencies both contributed to lower NUEs. Canola has higher UNRs than wheat, yet more aggressive root systems in terms of lateral and vertical expansion of root axes, and elongated root hairs are likely responsible for canola's ability to recover soil water and N more aggressively, unless poor subsoil quality limits root development. Differences in root architecture of canola relative to wheat also require a different approach to 4R N management, such as changing fundamental approaches in direct seed fertilization.

INTRODUCTION

The dryland cereal producing region of the inland Pacific Northwest is dominated by wheat production with limited diversification with cool-season legumes. Canola production constitutes less than 1% of the crop acreage, in contrast to fully integrated wheat-canola rotations in western Canada and Australia (Pan et al., 2016a), where rotational benefits of these integrated systems have been realized (Kirkegaard et al., 2008a and b). Shifts in U.S. farm policy, public/government interest in biodiesel production (Long et al., 2016), and elevated canola food oil demands and prices have encouraged increased canola research, extension and production in the iPNW. The 125 years of regional cereal grain farming have fine-tuned farmers' knowledge, experience, equipment technologies towards the implementation of regional wheat best management practices.

The basic physiological and morphological differences between wheat and canola (Beard et al., 2017), and the contrasting N uptake and partitioning (Table 1) define basic differences in water and nutrient use and management requirements and recommendations between the two crops (Pan et al., 2016b). Therefore, a shift in farmer mindsets and crop management was needed to integrate canola into these rotations. The 4Rs are critical components of an overall nutrient management strategy for improving nitrogen use efficiency (Norton, 2013). The purpose of this paper is to overview some of these physiological traits that have lead to a better understanding of water and N use and management of canola in iPNW production systems.

PHYSIOLOGY MATTERS

Root system architecture. Root system architecture plays a role in canola water and N use efficiency. Stress impacted depth of rooting, extensiveness of branching and root hair development, and differences in seminal vs. tap root structures all are influencing factors in constructing 4R recommendations. Changing nutrient management mindsets in transitioning from cereal to oilseed management starts with the recognition that while small grain cereals have seminal axes, oilseeds are taprooted crops. This basic architectural difference dictates different 4R N management approaches. For example, while wheat seedlings sprout 5-7 seminal axes at germination, canola sprouts a single taproot, which sets up differential sensitivity to fertilizer placement, rate and form. Ammonia toxicity from banded ammonium fertilizers like urea, whether seed or deep-placed, can severely damage root apical development, causing immediate root necrosis (Pan et al., 2016c). While the multi-axes wheat root system ensures that some axes grow past a deep band at safe distances, there is an increased probability of canola taproots to directly intercept deep bands, causing root and seedling dieback (Figure 1). The gaseous toxicity zone expansion will be dictated by soil pH and water content (Madsen, 2017). The greater sensitivity of canola roots to banded ammonia sources suggests that other placement and timing strategies are warranted compared to traditional wheat N management, particularly in direct seed systems where the bulk of N fertilizer is banded at planting (Veseth et al., 1986).

Spring canola roots grow 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), and they are more extensive than other oilseeds and legumes (Lui et al 2011b). Root length density and associated parameters decline during reproductive growth phases (Lui et al 2011a). Depth of rooting also influences the effective soil water and N supply. Root length densities decrease with depth (Lui et al 2011a); with about 70% in 0-1.3 ft, yet up to 25% below 2 ft (Gan et al 2011).

Canola taproots develop wide diameters and are very geotropic, allowing nutrient and water extraction to depths of 6 ft or more (Figure 2; Reese, 2015). In addition, water infiltration and storage improves through the continuous macropores they create (Norton et al., 1999). Soil compaction, however, can be an impediment to vertical root system development, visually detected as characteristic “J hooking” (Figure 3). Soil physical impedance due to long-term tillage or from genetic origins (Figure 3) can restrict rooting system depth, nutrient and water extraction.

The density and extensiveness of root hairs also plays a potential role in water and nutrient efficiencies. Root hairs of canola tap and lateral roots have been shown to be longer and less dense than other crops (Hammac et al., 2011). Root hairs have been recognized for their contributions to increased absorptive surface area, and may help account for observed soil water drawdown to soil water contents corresponding to soil water potentials regarded as permanent wilting point (Figure 2).

Stems, leaves, leaves and silques. Canola also differs from wheat in relative proportions of grain N to total above ground N, resulting in lower N harvest indices and more vegetative biomass and N that is returned to the soil (Table 1). A 3.000 lb grain/acre winter canola crop will produce more than 17,000 lb/acre total dry matter and accumulate more than 225 lb N/acre (Wysocki et al., 2007). Winter canola accumulates 25-30% of its total N uptake during autumn growth, around (35-70 lb N/acre. (Rathke et al 2006). Even higher N accumulation is obtained by early seeded winter canola, where above-ground canola can accumulate up to 3,000 lb dry biomass/acre and 135 lb N/acre between emergence and winter freezing (Reese, 2015). The thorough extraction of root profile soil water by early planted canola has resulted in early shutdown of above ground canola growth and leaf senescence, compared to later planted canola that was not water stressed (Figure 4). During mild winter conditions and/or with sufficient snow cover, this vegetation can survive and continue to grow the following spring (Wysocki et al., 2015), while self-induced drought stress and/or severe freezing conditions will cause dieback of above-ground biomass, likely releasing the N to both air and soil (Reese, 2015). Field surveys have demonstrated roughly 1/3 recovery of biomass N contributions to subsequent soil N mineralization (Reese, 2015).

Similar to comparisons of winter and spring cereals, winter canola typically has higher yield potential than spring canola if winter survival is good (Brown and Davis, 2015). Regrowth of winter canola in spring advances ahead of typical spring canola developmental time, attributable to having an established root system entering the spring regrowth period. Otherwise, growth stages are similar between winter and spring canola. Interestingly, canola leaf senescence and abscission occurs during grain filling more prominently than in cereal crops, which tend to retain their senesced leaves through grain maturity. Dropped canola leaves can still exhibit moderate N concentrations, but does not contribute to N residue carryover as stem and silque N (McClellan, 2014). The proportions of these vegetative N components relative to harvest grain N decreases with increased water stress, causing a decrease in N harvest indices (Maaz et al., 2016). Residual soil N from over-fertilization of canola represents the largest contributor to N carryover in canola-wheat rotations in semiarid systems (Maaz et al., 2016).

CANOLA UNR and NUE

A survey of western states canola fertilizer guides revealed a range of unit N recommendations (UNRs) partly due to differences in factors used in estimating non-fertilizer N supply (Table 2), including variable soil nitrate sampling depth, accounting for N mineralization from organic matter, and previous crop straw credits or debits. Another potential explanation for variable UNRs is that they may also be a function of yield (Mahler and Guy, n.d.), which in turn is a function of water supply (Figure 5; Pan et al., 2016b). The UNR expression is the inverse of NUE at economically optimal yields. Mitscherlich relationships between canola grain yield and total N supply were derived from a 12 site-year study (Pan et al., 2016b). Residual and mineralized soil N greatly contributed to total N supply, resulting in minimal or no yield responses to applied fertilizer N in several years. Component analysis (Figure 6) of improved NUE with increasing water-driven yield potentials demonstrates that increasing water supply increases both N uptake efficiency and N utilization efficiency contributions to the increases in NUE and corresponding decreased UNR (Figure 7). In contrast, the N harvest index (G_N/Nt) appears to be more stable across years and environments (Maaz et al., 2016).

SUMMARY

Canola root structure ultimately affects water and N use, which in turn affects canola N supply and placement requirements. Canola nitrogen recommendations will be greater for winter canola than spring canola, due to added biomass production during autumn growth and incomplete overwinter recovery of biomass N. Soil N greatly contributes to total N supply, thereby influencing fertilizer N recommendations, and the factors used to estimate soil N supply and ultimately affects the UNR estimate. Since UNR and NUE are inverse expressions, component analysis of NUE provide insights into soil-plant processes affecting UNRs. In spring canola trials, water supply improved NUE and reduced UNRs. This observation may help explain sliding scales of UNR already established in some of the other western states.

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Table 1. A comparison of average N uptake and removal between canola and wheat. Adapted from Koenig et al., 2011.

Nitrogen	Canola	Soft white winter wheat (10% protein) lbs/100 lb seed	Dark northern spring wheat (14% protein) lbs/100 lb seed
Uptake	5.8	2.2	3.2
Grain N Removed	3.4	1.8	2.5
Biomass N Returned	2.4	0.4	0.7
N Harvest Index (%Removed)	59	70	80

Table 2. Canola unit N supply and factors for estimating soil N supply for determining N fertilizer rate recommendations in west-central U.S.

State	Unit N Req. (lb N/100 lb grain)	N mineralization credit	N Immobilization debit – lbN/A	Nitrate	Ammonium	Reference
ID	7.7-10.5 for 3000 to 1000 lb/A	60 lb for 3-4 % OM Up to 24 lb/A for legume residues	Up to -50 lb N/A w/5 T residues	0-3 ft "or more"	0-2ft	Mahler and Guy, n.d.
KS, OK	5	No	No	1.5-2 ft	No	Boyles et al., 2012
NE, high plains	5.5- 10 for 4000 to 1000 lb/A	+1% OM * 20-30 lbs N	Yes	0-3ft	No	Boyles et al., 2012
OR	6.5-7.5	+20-40 lbN/a in fallow by OM	-45 to 60 wheat stubble	0-2 ft irr 0-3 ft dry	0-2 ft	Wysocki et al., 2007.
WA	6-12 for 3000 to 1000 lb/A	+1% OM*17 lb/A	35 wheat stubble	0-4 ft	0-1 ft	Pan et al., 2016

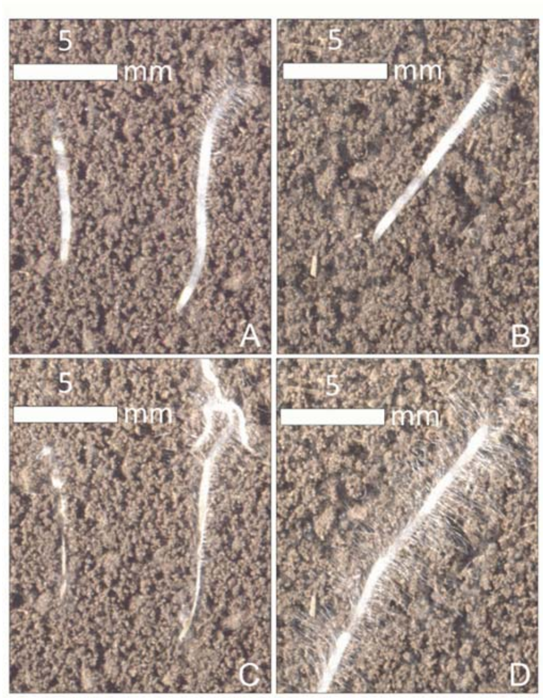

Figure 1. Canola root development in the high deep-banded urea treatment (A and C) and the no urea control (B and D). At 49 hours after planting roots in both the treated (A) and control (B) are healthy. By 110 hours after planting the high treatment (C) shows stunted apical growh, shrinkage of root girth, lateral root emergence, disapearance of root hairs, and browning of root tissue in contrast with the control (D) which has continued to grow and mature out of the image frame. Reprinted from Pan et al. (2016).

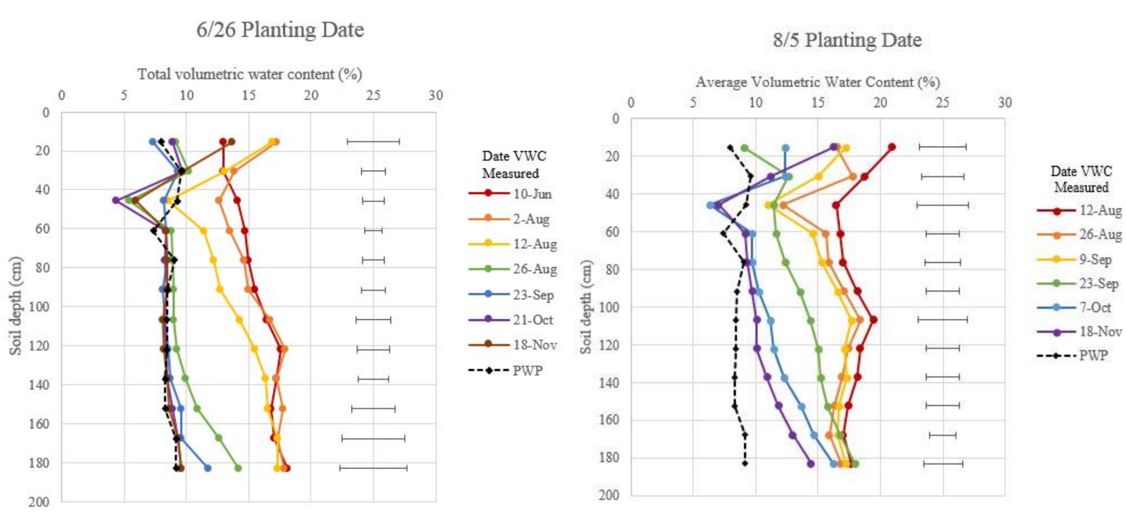

Figure 2. Soil water profiles to 6 ft (180 cm) of late June-planted (left) and early August-planted (right) winter canola near Ritzville WA. 2013 (Reese, 2015).

Figure 3. Fully extended canola taproot (left) and J-hooked canola root due to soil compaction (right). *Photos by K. Sowers.*

Figure 4. Early (left) and late (right) planted winter canola on October 31, 2014, showing leaf senescence of early planted canola, potentially due to self-imposed drought stress.

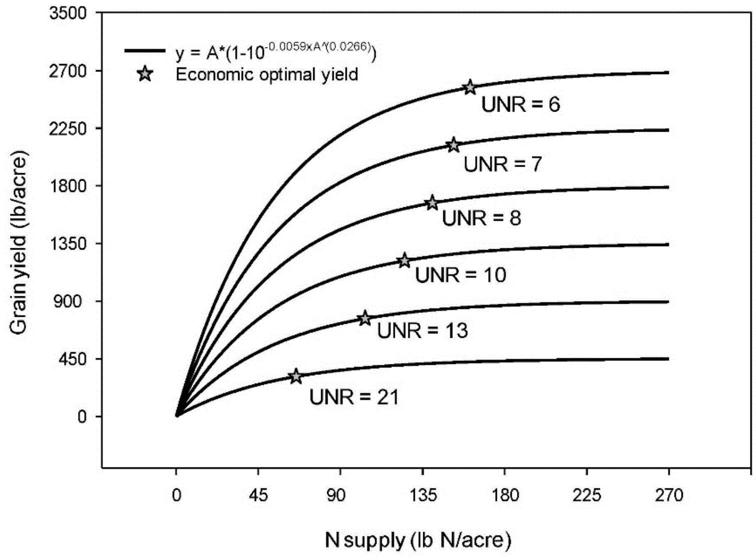

Figure 5. Decreasing unit N requirements (UNRs) with increasing water-dependent economic yield potentials of spring canola (adapted from Pan et al., 2016).

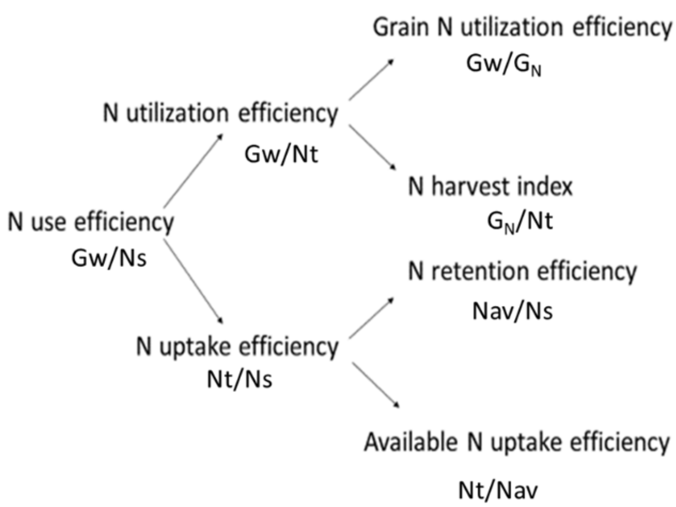

Figure 6. Nitrogen use efficiency and its components, modified from Maaz et al. (2016). Gw=grain weight, Nt=total plant N, GN=grain N, Ns=total N supply, Nav-=total available soil N.

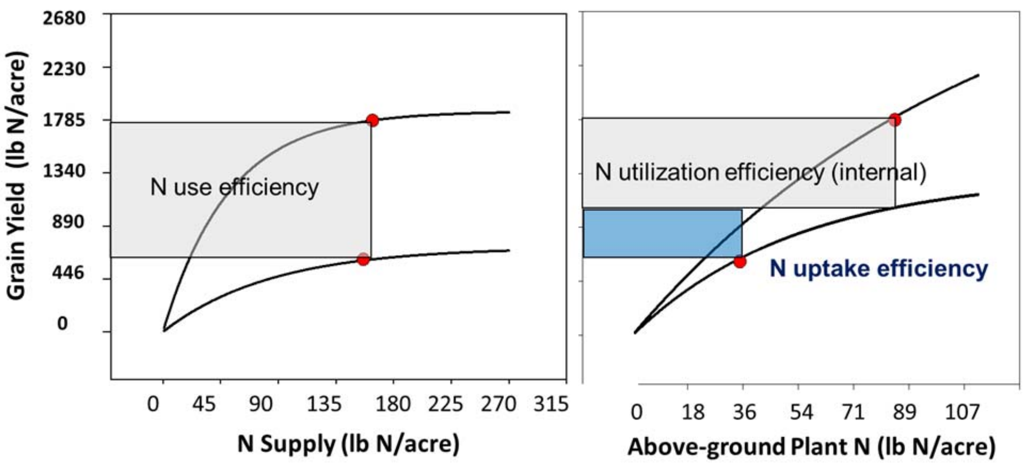

Figure 7. N use efficiency N utilization (Gw/Nt) and N uptake (Nt/Ns) contributions to overall differences in N use efficiency (Gw/Ns) between two locations differing in water supply, adapted from Maaz et al. (2016).