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**Above:** Photo of canola courtesy of Karen Sowers. **Inset:** Images of the same canola root exposed to deep-banded urea 0.67 inches below the root apex, showing arrested root elongation and rapid development of ammonia/ammonium toxicity symptoms between three (left) and four (right) days after planting. Source: Isaac Madsen.

# 4R nitrogen management when integrating canola into semi-arid wheat

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Canola is a new crop for many inland Pacific Northwest U.S. wheat growers to consider for integration into their wheat-dominated systems. Both crops have winter and spring varieties that can fill niches in different precipitation zones across the region, and they both efficiently extract available water to depths of 4 to 6 ft if soil depth allows. Yet, physiological and morphological differences dictate necessary changes in 4R N management approaches and recommendations when transitioning from wheat to canola. Additional differences in water and N use efficiency are also key factors that contribute to region-specific N recommendations. And so, the saying goes in the inland Pacific Northwest that canola "is not your father's wheat." Earn 1 CEU in Nutrient Management by reading this article and taking the quiz at www.agronomy.org/education/classroom/classes/410

Canola production currently constitutes less than 1% of the crop acreage in the inland Pacific Northwest (iPNW), in contrast to fully integrated wheat–canola rotations in western Canada and Australia (Pan et al., 2016c), where rotational benefits of these integrated systems have been realized (Kirkegaard et al., 2008a, 2008b). Shifts in U.S. farm policy, public/government interest in biodiesel production (Long et al., 2016), establishment of regional processing facilities, and elevated food oil demands and prices have encouraged increased canola research, extension, and production in the iPNW. The 135 years of regional cereal grain farming have fine-tuned farmers' knowledge, experience, and equipment technologies toward the implementation of regional wheat best management practices. Fortunately, the same basic seeding, harvesting, and fertilization equipment can be used for canola production.

The basic shoot and root physiological and architectural differences between wheat and canola (Beard et al., 2017) and the contrasting N uptake and partitioning (Table 1) define differences in water and nutrient use and management requirements and recommendations between the two crops (Pan et al., 2016a). Therefore, a shift in farmer mindsets about N fertilizer management is needed to integrate canola into regional rotations. The 4Rs (right rate, timing, source, and placement) are critical components of an overall nutrient management strategy for improving nitrogen use efficiency (Norton, 2013).

## Root system and N placement, source

Root system architecture dictates altered canola N *placement, timing, and source* strategies compared with cereal N recommendations. While small-grain cereals have seminal axes, oilseeds are taprooted crops (Fig. 1), and while wheat seeds sprout five to seven seminal axes at germination, the canola seed sprouts a single vertically oriented taproot, which sets up differential sensitivity to fertilizer placement, rate, and form. Ammonia gas toxicity from banded ammonium fertilizers like urea, whether seed or deep-placed, can severely damage root apical development, causing immediate root necrosis, altered lateral branching, and in extreme cases, seedling death (Pan et al., 2016b). The multiple seminal axes of wheat quickly spread out horizontally and downward, which ensures that some axes grow past a deep band at safe distances. In contrast, there is an increased probability of canola taproots directly intercepting deep bands below the seed, causing root and seedling dieback (Fig. 1). The gaseous

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) | Dark northern spring wheat (14% protein) |
|---|---|---|---|
| | lb N/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 |
| | % removed | | |
| N Harvest Index | 59 | 70 | 80 |

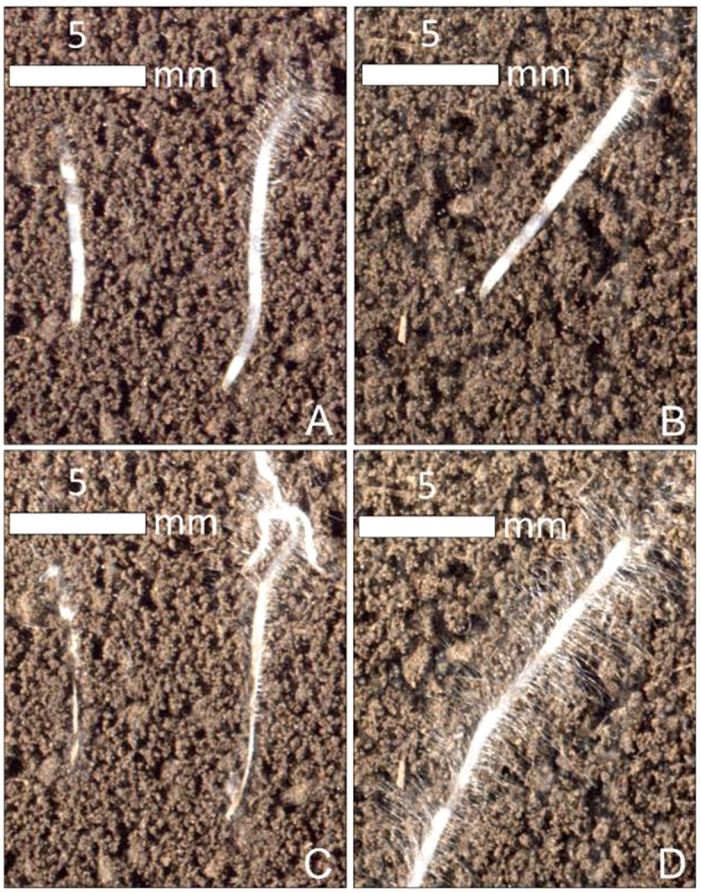


**Fig. 1.** Canola root development in the high deep-banded urea treatment (A and C) and the no-urea control (B and D). At 49 hours after planting, roots in both the treated (A) and control (B) are healthy. By 110 hours after planting, the high treatment (C) shows stunted apical growh, shrinkage of root 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. (2016c).

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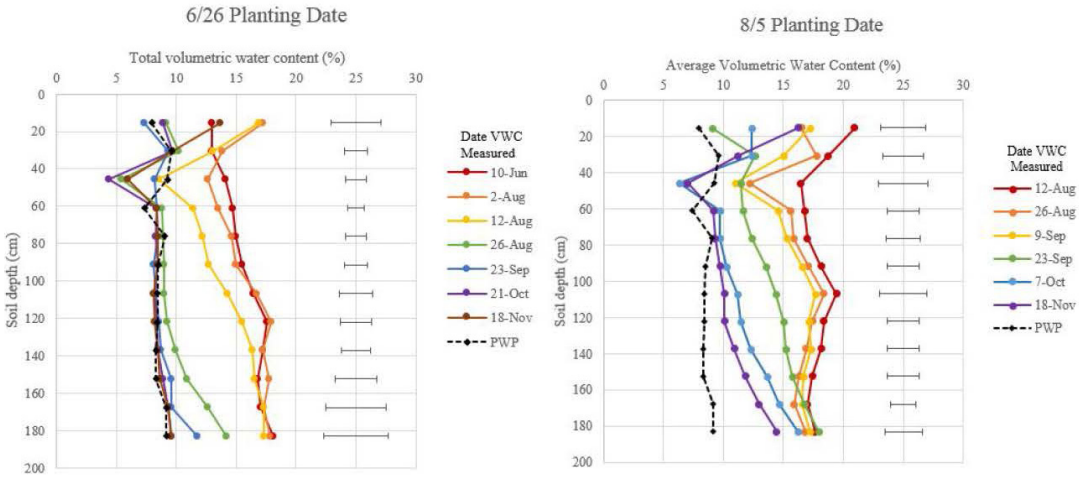
Abbreviations: iPNW, inland Pacific Northwest; NUE, nitrogen use efficiency; UNR, unit N requirement.

toxicity zone expansion will be dictated by soil pH and water content that controls the equilibrium between ammonia gas and ammonium ions, a less toxic N form that mostly resides on cation exchange sites (Madsen, 2017). The greater sensitivity of canola roots to banded ammonia sources suggests that other placement and timing strategies are warranted compared with cereal N management, particularly in direct seed wheat systems where the bulk of N fertilizer has been traditionally deep-banded at planting since its earliest days of adoption (Veseth et al., 1986). Banded ammonia/ammonium toxicity potential should be judged by the localized concentration set by the rate of fertilizer per acre and the seed row spacing, similar to the way in which salt toxicity of fertilizer bands is evaluated (Madsen, 2017).

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% within 0–1.3 ft, yet up to 25% below 2 ft (Gan et al., 2011).

Winter canola taproots develop wide diameters and are very geotropic, allowing nutrient and water extraction to depths of 6 ft or more (Fig. 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" (Fig. 3). Soil physical impedance due to long-term tillage or from genetic horizons (Fig. 3) can restrict rooting system depth as well as nutrient and water extraction. Where canola relies on stored subsoil water in the iPNW, detection of unused soil water within the 6-ft root profile at the end of the growing season can be a good indication that there was either chemical or physical restrictions on the root system growth and uptake potential.



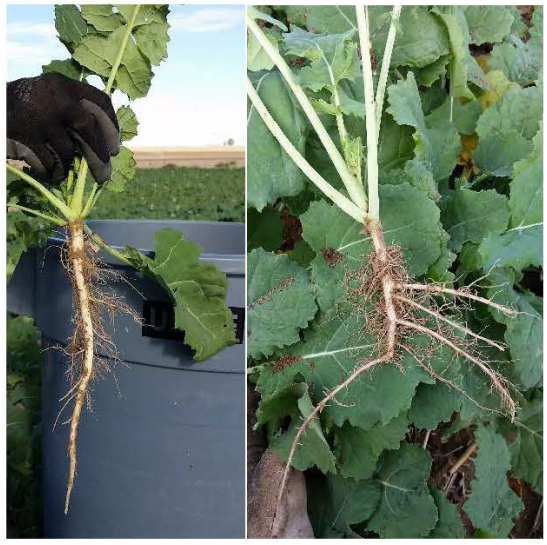



**Fig. 2 (above).** Soil water profiles to 6 ft (180 cm) of late June-planted (left) and early August-planted (right) winter canola near Ritzville, WA in 2014 (Reese, 2015).
**Fig. 3 (left).** Fully extended canola taproot (left) and J-hooked canola root due to soil compaction (right). Photos by K. Sowers.

The density and extensiveness of root hairs also plays a likely role in improving 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 and even below soil water contents regarded as the permanent wilting point (Fig. 2).

## Biomass and N accumulation

Canola also differs from wheat in relative proportions of grain N to total aboveground 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/ac winter canola crop will produce more than 17,000 lb/ac total dry matter and accumulate more than 225 lb N/ac (Wysocki et al., 2007). Winter canola accumulates 25 to

30% of its total N uptake during autumn growth, around 35–70 lb N/ac (Rathke et al., 2006). During mild winter conditions and/or with sufficient snow cover, this vegetation can survive and continue to grow the following spring (Fig. 4; Wysocki et al., 2007). Without loss of vegetative tissue rich in N, the unit N requirement (UNR = lb N supply/100 lb grain) recommendation is similar to high-yielding spring canola, 7 lb N/100 lb grain (Wysocki et al., 2007). Even higher N accumulation is obtained by early seeded winter canola where aboveground canola can accumulate up to 3,000 lb dry biomass/ac and 135 lb N/ac between emergence and winter freezing (Reese, 2015). The thorough extraction of root profile soil water by early planted canola (Fig. 2) resulted in early shutdown of aboveground canola growth and leaf senescence compared with later planted canola that was not water limited. Self-induced drought stress and/or severe freezing conditions will cause dieback of aboveground biomass (Fig. 5), likely releasing the N to both air and soil (Reese, 2015). Field surveys have demonstrated roughly one-third recovery of biomass N contributions to subsequent soil N mineralization (Reese, 2015). This apparent loss or immobilization of vegetative N may result in higher UNR for winter canola that suffers winter dieback in order to compensate for the lost N.

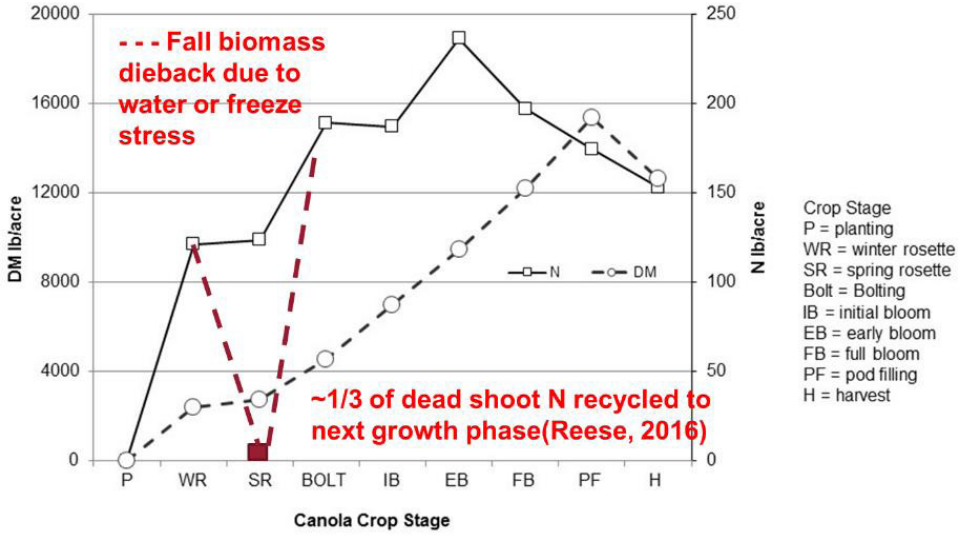



**Fig. 4 (above).** Seasonal biomass and N accumulation of winter canola by crop stage, grown in the 1997–1998 and 1998–1999 crop years following fallow at Pendleton, OR when snow cover insulated and preserved fresh shoot biomass through the winter (black lines). At other locations in Washington, shoot dieback has been observed from frost dieback with no snow cover so that live shoot biomass and N converts to dead residues, a fraction of which can re-mineralize for the spring growing season ( - - - - lines). **Fig. 5 (below).** Early (left)- and late (right)-planted winter canola on Oct. 31, 2014, showing leaf senescence of early planted canola, potentially due to self-imposed drought stress. Photos by Laban Molsee.


## Winter vs. spring canola

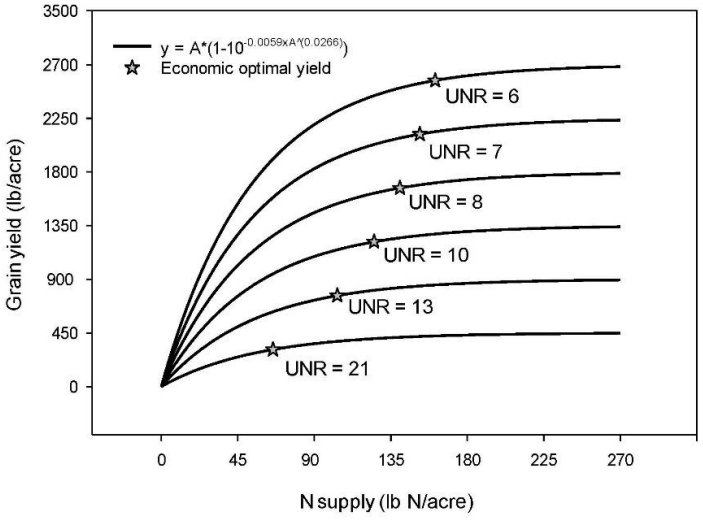
Similar to comparisons of winter and spring cereals, winter canola typically has higher yield potential than spring canola if winter survival is good (Brown and Davis, 2015). Regrowth of winter canola in spring advances ahead of typical spring canola developmental time, attributable to having an established root system entering the spring regrowth period. Otherwise, growth stages are similar between winter canola regrowth 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 (Maaz, 2014), and the proportional increases of vegetative N components relative to harvest grain N with increased water stress and over-optimal fertilization, causing a decrease in N harvest indices (Maaz et al., 2016). Residual soil N from over-fertilization of canola contributes to N carryover in canola–wheat rotations in semiarid systems (Maaz et al., 2016), and high soil N, particularly following fallow, limits canola responses to additional N fertilizer inputs (Pan et

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

| State | Unit N req. (lb N/100 lb grain) | N mineralization credit | N immobilization debit (lb N/ac) | Nitrate | Ammonium | Reference |
|---|---|---|---|---|---|---|
| ID | 7.7–10.5 for 3,000 to 1,000 lb/ac | 60 lb for 3–4 % OM † Up to 24 lb/ac for legume residues | Up to –50 lb N/ac with 5 tons of residues | 0-3 ft "or more" | 0-2ft | Mahler and Guy, 2005 |
| MT | 5.4 (3.0–10.3) | 15–20 lb N * 1% >2% soil OM 10 to 20 lb for grain legume; 30 lb for alfalfa | –10 lb/1,000 lb cereal residue up to –40 lb | Yes, soil depth? | __ | Jones et al., 2016 |
| KS, OK | 5 | No | No | 1.5–2 ft | No | Boyles et al., 2012 |
| NE, High Plains | 5.5–10 for 4,000 to 1,000 lb/ac | +1% OM * 20–30 lb N | Yes | 0–3 ft | No | Boyles et al., 2012 |
| OR | 6.5–7.5 | +20–40 lb N/ac in fallow by OM | –45 to 60 wheat stubble | 0–2 ft irrigated 0–3 ft dryland | 0–2 ft | Wysocki et al., 2007 |
| WA | 6–12 for 3,000 to 1,000 lb/ac | +1% OM * 17 lb/ac | 35 wheat stubble | 0–4 ft | 0–1 ft | Pan et al., 2016b |

† OM, organic matter.

al., 2016a). Total soil N supply (nitrate N + ammonium N + N mineralization) over 12 site-years ranged from 127 to 260 lb N/ac in the 0- to 4-ft root zone after wheat–fallow and 39 to 83 lb N/ac after wheat re-cropping. Four of the five site-years of fallow–spring canola sequence showed no N fertilizer response (Pan et al., 2016a). The prominence of residual and mineralizable soil N in semi-arid soils, particularly following fallow, emphasizes the value in soil testing for determining soil N contributions to total N supply in making fertilizer N recommendations.



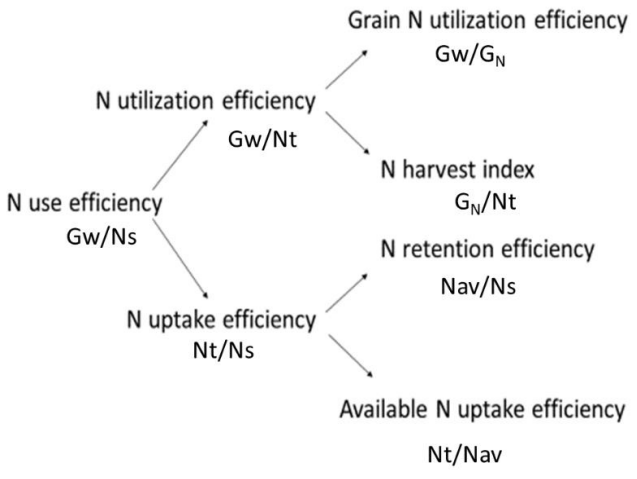




**Fig. 6 (left).** Decreasing unit N requirements (UNRs) with increasing water-dependent economic yield potentials of spring canola (adapted from Pan et al., 2016b). **Fig. 7 (right).** Nitrogen use efficiency and its components, modified from Maaz et al. (2016). Gw = grain weight, Nt = total plant N, $G_N$ = grain N, Ns = total N supply, Nav = total available soil N.

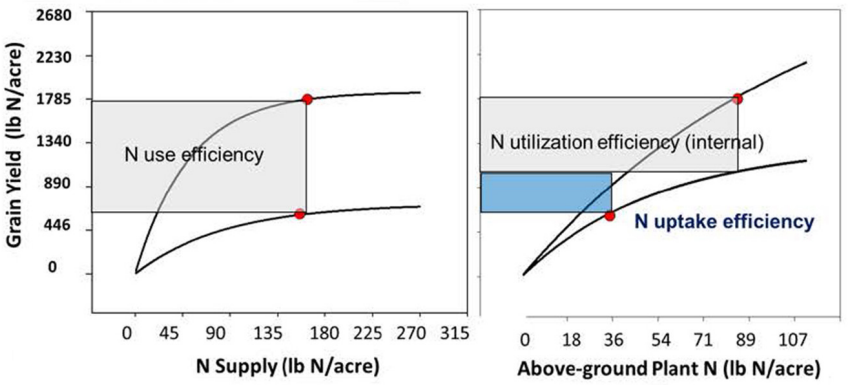



**Fig. 8.** Nitrogen use efficiency N utilization (Gw/Nt) and N uptake (Nt/Ns) contributions to overall differences in N use efficiency (Gw/Ns) between two locations differing in water supply, adapted from Maaz et al. (2016).

## Canola N supply recommendations

In the inland Pacific Northwest, the total N supply requirement of canola in semi-arid systems is determined by multiplying yield potential by the unit N. The UNR (N supply/100 lb grain) is the amount of N supply needed to yield 100 lb grain, which is the inverse of N use efficiency (NUE; grain yield/total N supply) at economically optimal yields. A survey of Western states' canola fertilizer guides revealed a range of 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 (Pan et al., 2016a). Another potential explanation for variable UNRs is that they may also be a function of yield (Mahler and Guy, 2005), which in turn, is a function of water supply (Fig. 6). Mitscherlich relationships between canola grain yield and total N supply were derived from a 12 site-year study across a range of water-limited yields. A decreasing scale of UNRs corresponded to increasing NUEs driven by increased water availability was revealed (Fig. 6). A yield component analysis of improved NUE (Fig. 7) with increasing water-driven yield potentials demonstrates that increasing water supply increases both N uptake efficiency (bigger, deeper root systems) and N utilization efficiency (more pods, seeds) contributions to the increases in NUE (Maaz et al., 2016) and corresponding decreased UNR at economic optimal yields (Fig. 8).

## Canola N timing

In field studies, Hammac (2015) found that fall N application at high rates (120 and 160 lb/ac) and fall–spring split N application at low rates (40-40 lb/ac) outperformed split application with high spring rates and single-rate spring application. Declines in grain and oil yield may have resulted from damage to taproot growth and development as observed by Pan (2016b). Spring-timed application may be ideal to minimize N loss in terms of 4R nutrient management, but placement and source will need rethinking in that scenario to maximize profitability.

Davis et al. (2014) observed that broadcast-tilling all urea and ammonium phosphate fertilizer at planting of winter canola reduced yields and winter survival compared with 25% at planting with the remainder applied later as split fall: spring topdress applications. Similarly, Wysocki (unpublished data from 2013 and 2014 crop years) also found that applying all 140 lb N/ac at winter canola planting as urea resulted in yields similar to the 0 N control while 0 to 25% of the total N fertilizer applied at planting resulted in higher yields. In summary, field studies confirm the root studies that caution against the application of high ammonia-based fertilizers at canola planting, particularly when placed with and below the seed.

## Summary

Canola root and shoot structure ultimately affects overall water and N use, and reactivity to N fertilizer, which in turn affects canola N rate, source, timing, and placement requirements. Canola N 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 ultimately affect the UNR estimate. Since UNR and NUE are inverse expressions at economic optima, the NUE component analysis provides insights into soil-plant processes affecting UNRs. In spring canola trials, water supply improved NUE and reduced UNRs. Direct-seeded wheat is more tolerant of deep-placed N due to its multiseminal axes root architecture while the single canola taproot is more sensitive and requires modifying N source, placement, and split N timing strategies to move away from placing high rates of ammonia-based fertilizers in deep bands. &

*See the Reference section on page 66*

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