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Rooting systems of oilseed and pulse crops I: Temporal growth patterns across the plant developmental periods

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ABSTRACT

Oilseed and pulse crops have been increasingly used to diversify cereal-based cropping systems in semiarid environments, but little is known about the root characteristics of these broadleaf crops. This study was to characterize the temporal growth patterns of the roots of selected oilseed and pulse crops, and determine the response of root growth patterns to water availability in semiarid environments. Canola (*Brassica napus* L.), flax (*Linum usitatissimum* L.), mustard (*Brassica juncea* L.), chickpea (*Cicer arietinum* L.), field pea (*Pisum sativum* L.), lentil (*Lens culinaris*), and spring wheat (*Triticum aestivum* L.) were tested under high- (rainfall + irrigation) and low- (rainfall only) water availability conditions in southwest Saskatchewan, in 2006 and 2007. Crops were hand-planted in lysimeters of 15 cm in diameter and 100 cm in length that were installed in the field prior to seeding. Roots were sampled at the crop stages of seedling, early-flower, late-flower, late-pod, and physiological maturity. On average, root length density, surface area, diameter, and the number of tips at the seedling stage were, respectively, 41, 25, 14, and 110% greater in the drier 2007 than the corresponding values in 2006. Root growth in all crops progressed rapidly from seedling, reached a maximum at late-flower or late-pod stages, and then declined to maturity; this pattern was consistent under both high- and low-water conditions. At the late-flower stage, root growth was most sensitive to water availability, and the magnitude of the response differed between crop species. Increased water availability increased canola root length density by 70%, root surface area by 67%, and root tips by 79% compared with canola grown under low-water conditions. Water availability had a marginal influence on the root growth of flax and mustard, and had no effect on pulse crops. Wheat and two *Brassica* oilseeds had greater root length density, surface area and root tips throughout the entire growth period than flax and three pulses, while pulse crops had thicker roots with larger diameters than the other species. Sampling roots at the late-flower stage will allow researchers to capture best information on root morphology in oilseed and pulse crops. The different root morphological characteristics of oilseeds, pulses, and wheat may serve as a science basis upon which diversified cropping systems are developed for semiarid environments.

1. Introduction

Roots are the primary organ for water and nutrient uptake, and play an essential role in the soil–plant continuum (Lynch et al., 2007). Also, plant roots are an important sink of photosynthates and the decomposition of roots contributes carbon to the soil (Gan et al., 2009), thus increasing soil organic matter (Pietola and Alakukku, 2005). In addition, the morphology of roots can greatly influence the capacity of nutrient uptake and water extraction in crop plants (Fageria, 2004), thus, influencing aboveground growth and biomass yield. Root morphology varies widely among plant species, ranging from a dominant taproot system with few lateral roots to highly branched fibrous root systems (Clement et al., 1993). Root morphological traits such as root length, root surface area, root diameter, and the number of root tips directly influence the functionality of the whole root system. For example, roots with a larger surface area absorb a greater amount of phosphorus (Marschner, 1998) and nitrate (Sullivan et al., 2000). However, large variations exist between crop species in terms of the association of root morphological traits and their functionality. For example, in spring wheat (*T. aestivum* L.), root length density was of minor importance for nitrate uptake from soil (Robinson et al., 1994), whereas root length

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Table 1
Crop cultivars and agronomy information for oilseed, pulse, and cereal crops grown in the lysimeter experiment at Swift Current, Saskatchewan, 2006–2007.

Crop	Cultivar	Fungicide			Seeds per tube[a]	Plants per tube[a]
		Trade name	Active ingredient	Rate (ml 100 kg^{-1} seeds)		
Oilseed crop						
Canola	45H21	Helix	Thiamethoxam	1500	11	3
Flax	Vimy	Vitaflo 280	Carbathiin + Thiram	525	12	4
Mustard	Cutlass	Helix	Thiamethoxam	1500	11	3
Pulse crop						
Chickpea	CDC Anna	Crown	Carbathiin + Thiabendazole	600	5	2
Field pea	Eclipse	Apron FL	Metalaxyl	16	5	2
Lentil	CDC Glamis	Crown	Carbathiin + Thiabendazole	600	7	3
Cereal crop						
Wheat	Lillian	Vitaflo 280	Carbathiin + Thiram	330	7	3

[a] Seeds tube^{-1} (or plants tube^{-1}) can be converted into seeds ha^{-1} (or plants ha^{-1}) by multiplying 560,000.

density in corn (*Zea mays* L.) highly influences the depletion of nitrate in the subsoil (Wiesler and Horst, 1994). Roots with greater length or more tips increase nutrient supply to the plant to a greater extent than those with shorter roots or fewer root hairs (Dong et al., 1995).

Under water-limited conditions, morphology of crop root systems is extremely crucial in acquisition of available soil water. The development of a vigorous root system earlier in the growth period is particularly important for a crop to be better adapted to semiarid environments (Fageria, 2004). The size of root systems confers drought resistance, as roots are capable of increasing water uptake ability by producing more lateral roots and larger root volume under drought conditions (Ingram et al., 1994). The improved root morphological traits such as increased root length, root diameter, or root-to-shoot ratio can help reduce drought stress in crops (O'Toole and Soemartono, 1981). The semiarid northern Great Plains of North America is an area where drought occurs frequently during the crop growing season, thus knowing the temporal growth patterns of rooting systems is crucial in managing field crops to reduce drought stress.

Oilseed and pulse crops have been widely used to diversify cropping systems on the semiarid northern Great Plains (Johnston et al., 2002; Gan et al., 2010). In western Canada, for example, the area seeded to oilseed crops has increased from 3.46 million hectares in 1990 to 6.57 million hectares in 2006 (Statistics Canada, 2007). Similarly, the area seeded to pulse crops has increased from 257,000 ha in 1990 to 2.33 million hectares in 2006. These crops are playing a significant role in the development of sustainable agricultural systems (Zentner et al., 2001). The use of broadleaf crops to replace conventional summer fallow exhibits great environmental benefits (Gan and Goddard, 2008), mitigating greenhouse gas emissions (Lemke et al., 2007), and lowering carbon footprints for field crops (Gan et al., 2011a,b). Unfortunately, most of the published research on crop rooting systems has focused on cereals (Bolinder et al., 1997), and there is little information available on the root systems of broadleaf crops. Modellers require information on the progress of root growth during the growing season to improve the ability of models to predict crop growth as well as C and N dynamics (Pietola and Alakukku, 2005). The objectives of this study were to (i) determine the temporal growth patterns of selected oilseed and pulse crops in comparison with spring wheat, and (ii) examine the effect of water availability on root morphological characteristics of oilseed and pulse crops in a semiarid environment. We hypothesized that the growth of roots reached a peak when the crop plants were near full blooming or at the early pod stage, and that the development of rooting systems was influenced by water availability. A sister paper from the same study focuses on the vertical distribution patterns of plant roots across various soil depths for the selected oilseed and pulse crops (Liu et al., 2011).

2. Materials and methods

2.1. Experiment design

Field experiments were conducted at the Semiarid Prairie Agricultural Research Centre of Agriculture and Agri-Food Canada, near Swift Current (50°15′N, 107°44′W), Saskatchewan, in 2006 and 2007. The experiment was established on an Orthic Brown Chernozem (Aridic Haploboroll) soil with silt loam texture; the content of sand, silt, and clay was 28%, 49%, and 23%, respectively, and organic matter of 3.0%. Three oilseeds (canola, flax, and mustard), three pulses (chickpea, field pea, and lentil), and spring wheat (as control) were studied under "low-water" (rainfall only) and "high-water" (rainfall plus partial irrigation with an amount equivalent to 2/3 of the long-term average precipitation at the experimental site) conditions. A representative cultivar was selected for each crop species based on their production popularity (Table 1). Irrigation was applied using a portable sprayer with about 1/2 of the water being applied prior to flowering and the other 1/2 applied from flowering to maturity (Table 2). Seven crops with two water treatments were arranged in a factorial, randomized complete block design with two replicates. Each treatment contained five sampling times in each replicate. Thus, the experiment had a total of 140 experimental units (7 crops × 2 water conditions × 5 sampling times × 2 replicates) in each year.

2.2. Seeding, root sampling and data collection

Crop seeds were treated with fungicides to minimize seed- and soil-borne diseases (Table 1). Oilseed crops and wheat received fer-

Table 2
The amounts of water (mm) that crop received during the different growth stages under low- (natural rainfall) and high- (rainfall plus irrigation) water conditions at Swift Current, Saskatchewan, 2006–2007.

Crop stage[a]	2006		2007	
	Low-water[b]	High-water[b]	Low-water	High-water
Seedling	131.0	156.0	98.0	135.7
Early-flower	14.2	41.3	17.2	40.0
Late-flower	21.8	44.8	4.7	21.5
Late-pod	1.0	14.0	0.3	27.5
Maturity	12.0	28.3	10.0	52.0
Total	180.0	284.4	130.2	276.7

[a] For oilseed and pulse crops, the growth stage in 2006 was on Julian days 178 (seedling), 187–199 (early-flower), 207 (late-flower), 214 (late-pod), and 223–233 (physiological maturity); in 2007 the corresponding stages were on Julian days 173–177, 184–193, 193–201, 204–207, and 214–219, respectively; for wheat the corresponding stages were: seedling, boot, anthesis, soft dough, and maturity.

[b] Low-water means natural rainfall only, and high-water means natural rainfall plus irrigation. Long-term (1960–2010) precipitation during the entire growing season (1 May – 31 August) at the experimental site was 215 mm.