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# Camelina growth and yield response to sowing depth and rate in the northern Corn Belt USA

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ABSTRACT

Camelina (*Camelina sativa* L.) is gaining interest as a productive alternative oilseed crop for biofuels, bioproducts, and healthy food-use applications. Developing sound agronomic practices for its production is key to optimizing its seed oil yield potential. Plant stand establishment of camelina has been problematic in some environments, which may be related to its small seed size and current recommendation for shallow sowing. Shallow sowing can diminish seed to soil contact and expose seeds to large soil temperature and moisture fluctuations, which greatly affect germination and seedling emergence. A study was conducted in 2011 and 2012 on a Barnes loam soil in western Minnesota to examine the effects of sowing spring camelina at soil depths of 1, 2, and 4 cm at sowing rates of 2, 3, and 6 kg ha$^{-1}$. Seedling emergence increased with sowing rate, but averaged across depths it had no effect on seed yield. Seedling emergence between the 1 and 2 cm sowing depths did not differ in 2012, while stands were reduced by an average of 29% at the 2 cm depth in 2011, but seed yields did not differ between the two sowing depths in either year. However, averaged across sowing rates, sowing at 4 cm led to a 64% stand reduction and a significant 22% loss of yield compared with the 1 and 2 cm depths. Neither sowing depth nor rate affected seed oil content or harvest index. Results show that camelina has exceptional yield compensation capacity at low plant densities and can be sown deeper than commonly recommended (i.e., ≤1.0 cm) without compromising yield in the northern Corn Belt. Sowing to a depth of 2 cm may be beneficial for certain soils prone to large temperature and moisture fluctuations.

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## 1. Introduction

Camelina is gaining popularity in the U.S. as an alternative oilseed crop useful for both industrial and food-use applications. The seed oil of camelina is high in α-linolenic acid (C18:3) and tocopherol content making it a healthy alternative oil for food applications (Budin et al., 1995; Ní Edhin et al., 2003). However, most current interest in camelina is focused on its development as a feedstock for biofuels and bioproducts (Johnson et al., 2007). Its oil has been shown to be well suited for making biodiesel and renewable aviation fuel (Shonnard et al., 2010), and biofuels derived from camelina have been shown to reduce greenhouse gas emissions by over 60% compared to petroleum based fuels (Petre et al., 2013). Moreover, camelina seed meal may be a valuable coproduct as an animal feed supplement to increase the nutritive value of meat and other animal products (Aziza et al., 2010; Rokka et al., 2002).

Evidence indicates that camelina fits well in crop rotations that include small grains in the western and Great Plains regions of the U.S. (Chen et al., 2015; Guy et al., 2014; Keske et al., 2013). Additionally, winter annual camelina also can be successfully double- and relay-cropped with short-season food and forage crops in the Upper Midwest (Gesch and Archer, 2013; Berti et al., 2015), potentially offering farmers new economic opportunities and environmental benefits (Eberle et al., 2015).

As interest for camelina production grows, and new cultivars are developed (Guy et al., 2014), there is an increasing need to develop and refine best management practices for its production. Plant stand establishment is critical to crop production, and insufficient stands can result in poor resource use efficiency and greater weed competition, as well as reduced yields. Camelina plant stand establishment in some environments has been reported to be highly variable (Schillinger et al., 2012; Lenssen et al., 2012; Gesch, 2014) and in these instances, fluctuations in temperature and precipitation around the time of sowing have been noted to be correlated to this variability.

Camelina seed is relatively small, typically ranging from 1.0 to 1.5 g 1000 seed$^{-1}$ (Gesch, 2014), and current production recommendations suggest sowing it shallow at a depth of ≤1.0 cm (McVay

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and Lamb, 2008; Ehrensing and Guy, 2008; Grady and Nleya, 2010). However, Robinson (1987) reported significant camelina emergence at a sowing depth of 5.0 cm on a tilled silt loam soil in east central Minnesota and commented that camelina can be sown deeper than the size of its seed indicate. Indeed, our field observations in western Minnesota tend to agree with that of Robinson (1987).

Previous studies that have addressed seeding rate and plant densities on camelina production commonly report that its yield is little affected over a wide range of plant populations, primarily due to its growth plasticity (Urbaniak et al., 2008; McVay and Khan, 2011). However, choosing a sowing rate that balances productivity with seed costs is important. Another factor to consider in camelina establishment is weed management. Relatively high densities of camelina have been observed to effectively suppress weeds (Gesch and Cermak, 2011), which is especially important given that there are few herbicides that camelina tolerates.

Sufficient seed to soil contact is vital for good crop emergence and stand establishment. Seeds placed at a shallow depth in the soil are often exposed to large fluctuations in temperature and moisture (Spokas and Forcella, 2009), which greatly influence germination and emergence. The deeper that seeds can be placed in the soil, the better access they generally have to available moisture and the less likely they are to be subjected to large temperature fluctuations. Although a few studies have addressed the effects of sowing method and seeding rate on camelina production, little information exists for considering sowing depth in the field as a factor. The present study was conducted over two growing seasons in west central Minnesota to determine the influence of sowing depth and rate on emergence, plant growth, and seed yield of spring camelina.

## 2. Materials and methods

### 2.1. Experimental design and cultural practices

This study was conducted over two growing seasons during 2011 and 2012 at the USDA-ARS Swan Lake Research farm near Morris, Minnesota (45°35′ N, 95°54′ W) on a Barnes loam soil (fine-loamy, mixed, superactive, frigid Calcic Hapludoll). The experimental design was a split-plot randomized complete block with four replications. The main plots were sowing rate (2, 3, and 6 kg seed ha$^{-1}$) and subplots were sowing depth (1, 2, and 4 cm). Individual plot size was 3.7 × 7.6 m.

A spring cultivar of camelina (cv. 'CO46′) was used in both years of the study. Its germination rate was tested under controlled conditions prior to the study and found to be >90%. At a seed weight of 1.1 mg seed$^{-1}$ for CO46 camelina, approximately 910,000 seeds were sown per kg of seed.

Camelina was sown on 18 May in 2011 and 6 June in 2012 on 30 cm spaced rows using a plot drill (Wintersteiger, Model PDS 12R) with double-disk openers. In both years of the study, the previous crop was spring wheat (*Triticum aestivum* L.). The study area was chisel plowed the previous fall and then again in the spring prior to sowing and packed twice with a roller packer to create an even and firm sowing surface. Prior to packing the soil surface, N, P, and K fertilizer were broadcast at rates of 78, 34, and 34 kg ha$^{-1}$, respectively, as urea, diammonium phosphate, and potash. Additionally, trifluralin at a rate of 1.1 kg ai. ha$^{-1}$ was applied for weed control, and then both herbicide and fertilizer were incorporated by cultivation to an approximate depth of 15 cm. This fertility regime has been found to be sufficient for producing camelina on the given soil type for the study without limiting growth and yield (Johnson and Gesch, 2013). To verify sowing depth, in soil adjacent to the study plots that was similarly worked, trial runs were made with the planter using coated forage sorghum (*Sorghum bicolor* L.) seed that was red in color. Soil was carefully excavated within sown rows to uncover seeds and determine sowing depth. This was done after each adjustment to the planter to verify sowing depth.

**Table 1**
Monthly average air temperature and cumulative precipitation in 2011 and 2012 including the 30-year average of air temperature and precipitation at the study site near Morris, MN.

| | [a]Mean air temperature (°C) | | | | Precipitation (mm) | | |
|---|---|---|---|---|---|---|---|
| Month | 2011 | 2012 | 30-yr Avg. | | 2011 | 2012 | 30-yr Avg. |
| May | 14.1 | 16.2 | 13.9 | | 107 | 91 | 76 |
| June | 20.0 | 21.1 | 19.1 | | 44 | 66 | 98 |
| July | 24.1 | 24.9 | 21.6 | | 142 | 63 | 100 |
| August | 20.8 | 20.5 | 20.1 | | 61 | 56 | 84 |
| Mean | 19.8 | 20.7 | 18.7 | Total | 354 | 276 | 358 |

[a] Air temperature (2 m height) and precipitation were measured by an automated weather station located at the study site.

### 2.2. Plant sampling and harvest

Plant population density was measured on two randomly selected 1-m strips of row in each plot while avoiding the two border rows on each side of a plot. Once plants began emerging, plant population density was measured weekly from the same area until counts were stable at which time the counts were used for analysis of emergence.

Camelina was harvested with a plot combine (Model 160, Hege) on 26 July in 2011 and 15 August in 2012 when approximately 90% or more of silicles had dried and seed were a reddish brown color. To measure seed yield, a 1.5 m wide section from the center of each plot was harvested. In rows adjacent to the harvest area, a 1-m row of plants was harvested for determining total dry biomass and seed yield per plant as well as harvest index after drying plant material at 65 °C in a forced air oven to constant weight. Seed yield samples were dried at 65 °C to constant weight before cleaning and yield was reported on a dry weight basis.

A 5 g subsample of seed for each treatment replicate was used for determining seed oil content by nuclear magnetic resonance (NMR, Minispec mq10, Bruker, The Woodlands, TX) using a previously described procedure (Forcella et al., 2005). Samples were dried for 4 h at 130 °C in a forced air oven and cooled for 15 min in a desiccator before making oil measurements. Prior to measurements, the instrument was calibrated with pure camelina oil.

### 2.3. Statistical analysis

All data were statistically analyzed with the Mixed Procedure of SAS (SAS for Windows 9.2, SAS Inst., Cary, NC). Sowing rate and depth were analyzed as fixed effects and year of experiment was treated as a random effect. When treatment effects were significant, mean differences were separated by Least Significant Differences (LSD) at the $P = 0.05$ level.

## 3. Results

### 3.1. Climate conditions

On average, both 2011 and 2012 were 1 to 2 °C warmer than the 30-year average for the study site (Table 1). Most notable was that mean air temperature in July was 2.5 °C warmer in 2011 and 3.3 °C warmer in 2012 than the 30-year average. Total precipitation between May and August of 2011 was comparable to the 30-year average, but was 82 mm lower in 2012. In June 2011 precipitation was 57 mm below average but was 42 mm above average in July. Despite the drier conditions in 2012, rainfall was relatively evenly distributed throughout the growing season with the exception of

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