Canola has lower erucic acid content (<2%) in its oil and low glucosinolate (<30 μmol g⁻¹) content in its defatted meal (Lin et al., 2013; Mag, 1983). Canola is the second-largest oil crop produced in the world, its meal is the second-largest protein meal source for animal rations, and its oil is the third-most produced vegetable oil in the world (USDA Economic Research Service, 2012). Canola oil is the second-most widely consumed vegetable oil in the United States (ERS, 2012), but a large portion of it is imported from Canada, which drives demand for more domestic production.

Successful winter canola production creates diversity and crop rotation alternatives for producers. Stand establishment and winter survival are among the main determinants of success in winter canola production. The objective of this research was to investigate the impact of environment, crop management, genetics and their interactions on canola stand establishment, survival, yield, and oil and protein content. Two datasets were analyzed: results from the National Winter Canola Variety Trials conducted from 2003 to 2012 and data from experiments conducted for 3 yr (2010–2012) in Manhattan, KS, to assess the impact of planting date, tillage, and cultivar on canola yield and survival. Canola has the potential to yield up to 7 Mg ha⁻¹; however, actual yields were usually in the range of 0 to 4 Mg ha⁻¹. The average oil content of canola seeds was 40%, but the potential extended to 47%. Environment, defined as a combination of year and location, was responsible for the majority of variation in yield, oil content, stand establishment, and survival of winter canola. Planting in mid to late August and early September benefited yield most of the time compared with planting late in September or October in the Great Plains and Midwestern United States. Only with extremely early or late planting did tillage improve winter survival and yield compared with no-till. Crown height of canola was greater in no-till treatments compared with conventional tillage treatments, but a significant relationship was not observed between crown height and winter survival or yield. Cultivars differed significantly in yield, survival, and crown height, but no cultivars were consistently superior in no-till conditions or with plantings outside of the recommended time frame.

Canola has low erucic acid content (<2%) in its oil and low glucosinolate (<30 μmol g⁻¹) content in its defatted meal (Lin et al., 2013; Mag, 1983). Canola is the second-largest oil crop produced in the world, its meal is the second-largest protein meal source for animal rations, and its oil is the third-most produced vegetable oil in the world (USDA Economic Research Service, 2012). Canola oil is the second-most widely consumed vegetable oil in the United States (ERS, 2012), but a large portion of it is imported from Canada, which drives demand for more domestic production.

Successful winter canola production creates diversity and crop rotation alternatives for producers. Incorporating canola into crop rotations with wheat (Triticum aestivum L.), as opposed to continuous wheat production, has proven to have economic benefits as well as to break weed and pest cycles (Bushong et al., 2012). Because canola is a broadleaf crop, effective and less-expensive herbicides can be used to control grass weeds compared with controlling these weeds in cereal crops (Norton et al., 1999; Zollinger, 2013). Several canola cultivars possess glyphosate resistance, which makes control of glyphosate-susceptible grass and broadleaf weed populations relatively easy because these weeds can be effectively controlled by applying glyphosate without fear of harming the canola crop (Green, 2009; O’Donovan et al., 2006). In addition, possible allelopathic effects of the breakdown of glucosinolates into isothiocyanates or thiocyanates from canola plant residue have been demonstrated to prevent weed}


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germination and inhibit growth (Al-Khatib et al., 1997; Vasilakoglou et al., 2010).

The approval of canola oil by the U.S. Food and Drug Administration is relatively recent (1985), and breeding and agronomic research activities are young; therefore, little information is available regarding winter canola's actual and potential yield in the United States. Major determinants of winter canola survival and yield have not been well characterized. Stand establishment and winter survival have been suggested as among the main limitations to canola production (Conley et al., 2004; Holman et al., 2011). Planting date and crop management practices such as tillage, planting density, nitrogen fertilizer rate, and cultivar selection have received attention to improve survival and yield of canola (Christmas, 1996; Conley et al., 2004; Holman et al., 2011; Song and Copeland, 1995).

The main objective of our research was to investigate the impact of environment (location and year), crop management (planting date and tillage), genetics (cultivar), and their interactions on canola stand establishment, survival, yield, and oil and protein content. Two datasets were assembled and analyzed separately. The first dataset was extracted from National Winter Canola Variety Trials conducted from 2003 to 2012 across many states. The second dataset was from a 3-yr experiment conducted in Manhattan, KS, to assess the influence of planting date, tillage, and cultivar combinations on canola survival and yield.

**MATERIALS AND METHODS**

**National Winter Canola Variety Trial Data Assembly and Analysis**

National Winter Canola Variety Trials were conducted at different locations in 26 states in the United States from 2003 through 2012 (Kansas State University, 2003–2012). The objectives of the trials were to evaluate performance of varieties released across states, determine areas of adaptation for new cultivars, and increase visibility of winter canola across the country. Canola yield, protein and oil content, stand establishment, winter survival, and weather data were extracted from these trial reports. In total, data were included from 205 environments (combinations of year and location), in which 282 winter canola genotypes were tested.

The distributions of response variables were studied and results were plotted using the R statistical package (R Development Core Team, 2012). The variability in yield, protein, and oil content of winter canola that was explained by environment, genetics, and other factors was studied using PROC VARCOMP in SAS (SAS Institute, 2012). Superior-yielding environments, where yields were 5 Mg ha⁻¹ and greater, and low-yielding environments, where yields were 0.5 Mg ha⁻¹ and less, were extracted from the variety trial data to examine the relationship between yields and environmental conditions. Monthly rainfall and temperature for these two groups of environments were compared for the entire growing season.

A model was fitted using PROC MIXED in SAS to study yield trends for year, location, and the interaction of these factors with random genetic (canola lines) and replication factors. The interaction between year and location was significant; therefore, we used the four subdivisions of the United States from the national trial to study yield trends. The four subdivisions were (i) Great Plains (CO, KS, MO, NE, NM, OK, and TX), (ii) Midwest (KY, IL, IN, OH, and TN), (iii) Northern (MN, MT, OR, VT, WA, and WY), and (iv) Southeast (AL, AR, GA, MS, NC, NJ, and VA). In addition to yield trends, coefficient of variation (ratio of standard deviation over mean yield) was calculated for each region to determine yield variability within each region. Correlation analysis between planting date and yield was conducted for each region using PROC CORR in SAS.

**Planting Date, Tillage, and Genetic Effect Study: Design and Analysis**

This study was conducted in Manhattan, KS, for three harvest years: 2010, 2011, and 2012. Selected environmental conditions (monthly rainfall, maximum and minimum temperature) for the three growing seasons are depicted in Fig. 1. The experimental design was a randomized complete block with treatments arranged in a split-split plot structure. The main plot treatment was planting date, the first split treatment was tillage, and the second split treatment was cultivar, with each treatment factor randomized within the superseding factor and within blocks. Each cultivar plot was drilled using a plot drill equipped with a precision cone seed-metering system in six rows spaced 25.4-cm apart, resulting in a plot width of 1.5 m and length of 9.1 m. In each year, there were four planting dates (13–31 August, 30 August–9 September, 13–22 September, and 20 September–3 October), two tillage practices (conventional tillage [one shallow disking] and low-disturbance no-till), and eight cultivars. Varieties were selected on the basis of differences in agronomic factors such as yield potential, winter survival, herbicide tolerance, hybrid vs. open pollinated, and crown height. The varieties were DKW46–15 (Roundup Ready), Griffin (Kansas State University release with prostrate growth habit), HyCLASS115W (Roundup Ready), HyCLASS154W (Roundup Ready and hybrid), Kadore (winter hardy), Sitro (hybrid), Virginia (national variety trial check), and Wichita (national variety trial check). Chrome (hybrid) replaced Kadore in 2012. There were four replications of the experiment each year. For conventional tillage plots, shallow disking was performed 2 wk before planting. Planting dates were not consistent from year to year because of precipitation and seedbed moisture variability from year to year.

Plant density data were collected twice each growing season, in fall and in spring. From these two data points, winter survival was calculated for each plot as the ratio of the number of plants in spring to the number of plants in fall and multiplied by 100 to express it as a percentage. Crown height was measured from soil surface to base of the crown for five randomly selected plants in each plot at 4 to 6 wk after planting. At harvest, seed yield was determined using a Massey 8XP plot combine (Kincaid Manufacturing, Haven, KS). Additional indicators of crop performance included test weight, percentage of pods that had reached maturity before harvest, and a visual estimate of the percentage of seed shattered before harvest.

The influence of planting date, tillage, cultivars, years, and their interaction on the response variables yield, crown height, and...
RESULTS

National Winter Canola Variety Trial 2003 to 2012

Yield of canola from national variety trials ranged from a minimum of 0 to a maximum of 7 Mg ha\(^{-1}\) with a negative skewed frequency distribution (Fig. 2a; Kansas State University, 2009). However, 94% of yields were between 0 and 4 Mg ha\(^{-1}\), and in this range, yield was approximately normally distributed, with mean yield of 2 Mg ha\(^{-1}\) and SD of 0.9 Mg ha\(^{-1}\) (Fig. 2b). This result indicates that with optimal weather conditions, best crop management practices, and the best available genetics, canola has a potential yield of at least 7 Mg ha\(^{-1}\).

Environment explained about 73% of the variability in canola yield (Table 1). The majority of the remaining 27%
of the variability was due to either genetics or the interaction between genetics and environment. The amount of rainfall differed in almost all months of the growing season between superior-yielding (>5 Mg ha\(^{-1}\)) and low-yielding (<0.5 Mg ha\(^{-1}\)) environments (Fig. 3). Low-yielding environments had greater rainfall in July through November but relatively less rainfall during the rest of the growing season. In addition, low-yielding environments were characterized by relatively higher temperatures from November through June compared with superior-yielding environments.

Modeling of yield from all trials as a function of the components of environment (i.e., year, location, and their interaction) showed that the interaction was significant, suggesting that trends of canola yield over the time period should be studied at a smaller geographic scale. Therefore trials across the United States were separated into four regional divisions, and yield trends for each region were characterized for the time period from 2003 through 2012 (Fig. 4). Year-to-year variations in canola yield were large, reflecting the overwhelming influence of environment, as is the case for most crops. The variation in yield was relatively less in the Great Plains (CV = 0.20), greater for the Northern region (CV = 0.39), and moderate for the Midwest (CV = 0.22) and Southeast (CV = 0.25) regions. Despite the high year-to-year variation, a positive yield gain in the range of 107 to 138 kg yr\(^{-1}\) for Great Plains and Northern regions of the United States was detected.

In the analysis of the national trials, environment embodied not only climatic conditions, but also factors such as planting date and other management factors that varied between years and locations. Because planting date data are available from the national variety trials, a correlation analysis between yield and planting date was conducted for each U.S. region. Significant (\(\alpha = 0.01\)) negative correlations were obtained between planting date, expressed as number of days after January first, and canola yield for the Great Plains (\(R = -0.14\)) and Midwest (\(R = -0.10\)) regions. In those regions, yield declined as planting date was delayed within the range of planting dates considered in the data. On the other hand, positive correlations were obtained for the Northern (\(R = 0.29\)) and Southeast (\(R = 0.08\)) regions.

Protein and oil contents of canola also were measured in most national variety trials. Both the oil and protein contents of canola demonstrated an approximately normal distribution (Fig. 5). The oil content of canola ranged from about 30 to 47% of seed weight, and the mean oil content for canola was about 39% of seed weight. The protein content of canola ranged from 17 to 33%, and mean protein content was about 25% of the seed weight. Similar to yield, most of the variation in oil and protein content was explained by environmental variation (Table 1).

Stand establishment and winter survival have been among the main concerns in canola production. Stand establishment data extracted from the national variety trials revealed that when stand establishment ratings were reported, 80% of the values were >7 on a scale of 0 to 10 (10 rating assigned to plots with 100% stand establishment on the basis of visual assessment). When winter survival was reported in the national variety trials, 85% of

### Table 1. Variability explained by the main effects of possible source of variation, environment, genetics, and replication, in National Winter Canola Variety Trial data.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Variance (unit(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield</td>
</tr>
<tr>
<td>Environment (E)</td>
<td>0.94</td>
</tr>
<tr>
<td>Genetics</td>
<td>0.06</td>
</tr>
<tr>
<td>Replication</td>
<td>0.00</td>
</tr>
<tr>
<td>Error</td>
<td>0.28</td>
</tr>
<tr>
<td>Total variance</td>
<td>1.28</td>
</tr>
<tr>
<td>% variance explained by E</td>
<td>73</td>
</tr>
</tbody>
</table>
Figure 3. Total rainfall and maximum and minimum temperatures in superior- (>5 Mg ha\(^{-1}\)) and low-yielding environments in the National Winter Canola Variety Trial.

Figure 4. Winter canola yield trends in the Great Plains, Midwest, Northern, and Southeast regions of the United States, 2003 to 2012.
the values were >80%. Although 100% establishment was reported for only 24% of reported values, once canola was established, 100% survival was possible 53% of the time.

Manhattan Experiment: Planting Date, Tillage, and Genetic Effects on Canola Production

Canola Yield
The four-way interaction between planting date, tillage, genotype, and year was not significant for yield, crown height, and winter survival (Table 2). For yield, the three-way interactions for planting date–tillage year and planting date–genotype year were significant. Therefore, the impact of the interaction of planting date and tillage or planting date and genotype on canola yield in different years of this research will be discussed in the following sections.

Yield as Affected by Planting Date and Tillage
Tillage did not affect yield in any planting date in 2010 (Fig. 6a); however, yield decreased by nearly 75% when planting was delayed until 18 September or later, irrespective of tillage type. In 2011, similar to 2010, yield did not differ between tillage treatments except when planted on 13 September, when no-till treatments yielded less than the conventional tillage treatments. Yield was significantly greater with later planting as opposed to early planting, although severe yield reduction occurred only with the last planting date. The negative impact of no-till on yield was most pronounced in the last planting date compared with the three earlier planting dates, 96% reduction vs. 16 to 26% reduction, respectively (Fig. 6a).

Yield as Affected by Planting Date and Cultivar
The interaction between planting date, cultivar, and year significantly influenced yield (Fig. 6b). In the 2010 crop year at the first planting date, cultivar yields ranked in the order Sitro ≥ Virginia > all the rest > DKW46-15. For the second planting date, yields ranked in order Sitro ≥

Table 2. Type 3 tests of fixed effects for yield, crown height, and winter survival (WS) at Manhattan, KS.

<table>
<thead>
<tr>
<th>Source</th>
<th>Yield</th>
<th>Crown Height</th>
<th>WS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting date (PD)</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Tillage (T)</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>PD × T</td>
<td>*</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Genotype (G)</td>
<td>***</td>
<td>***</td>
<td>*</td>
</tr>
<tr>
<td>PD × G</td>
<td>NS†</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>T × G</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PD × T × G</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Year (Y)</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>PD × Y</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>T × Y</td>
<td>***</td>
<td>***</td>
<td>NS</td>
</tr>
<tr>
<td>PD × T × Y</td>
<td>**</td>
<td>***</td>
<td>**</td>
</tr>
<tr>
<td>G × Y</td>
<td>**</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>PD × G × Y</td>
<td>**</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>T × G × Y</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>PD × T × G × Y</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

* Significant at the 0.06 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† NS, nonsignificant.
Virginia > all the rest > DKW46-15 and HyCLASS115W. In the third and fourth planting dates in 2010, yields were severely reduced and cultivars did not differ, probably due to reduced fall growth and delayed maturity associated with those planting dates.

A significant genotype by planting date interaction was observed in 2011; however, with the exception of a few cultivars varying in yield at the upper or lower yield range, most cultivars had similar yields within a planting date (Fig. 6b). In the two earliest planting dates (23 and 30 August), for example, Griffin, DKW46-15, and Sitro had yields among the top and HyCLASS115W and Wichita were among the lowest-yielding cultivars, with other cultivars in between. For the two later planting dates, 13 and 20 September, yield did not differ among cultivars, with the exception of HyCLASS115W, which was notably less than most of the others.

In 2012, the composition of the cultivars was different, as explained in the Materials and Methods. The newly introduced cultivar, Chrome, had the greatest yields for the first three planting dates (22 September and earlier), followed by Sitro, HyCLASS154W, and Griffin. Cultivars HyCLASS115W and DKW46-15 yielded notably less for these three early planting dates. In the last planting date (3 October), yields of all cultivars were significantly less than for the previous planting dates, with little differentiation among cultivars, although Chrome again ranked at the top.

**Winter Survival**

The three-way interaction between planting date, tillage, and year and the main effect of genotype were significant for winter survival (Table 2). The effect of tillage on winter survival was significant only for the earliest planting date in 2010 (Fig. 7a), where conventional tillage resulted in better winter survival than no-till. In all others, no significant differences were observed due to tillage within a planting date. Planting date, however, affected winter survival in almost all years. In 2010, the three early planting dates resulted in better winter survival than the last planting date (2 October). In 2011, planting after 30 August resulted in better survival, possibly due to excessive fall growth with the early plantings and because the latest planting was only 20 September. In 2012, winter survival was almost uniform across all planting dates except for the latest (3 October) no-till planting, which had less winter

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**Figure 6.** (a) Canola yield response to planting dates and tillage in 2010, 2011, and 2012 at Manhattan, KS. (b) Canola yield as affected by different years, planting dates, and canola cultivars at Manhattan, KS.
survival compared with the 9 September planting and the 22 September planting with the disk treatment. The main effect of genotype was significant for winter survival, but none of the interactions between genotype and other sources of variability were significant. We used two approaches for mean separation between genotypes. First, we conducted mean separation of genotypes for winter survival on a year-by-year basis rather than comparing genotype averages across the years because of the change in one cultivar in the third year of the experiment. In this analysis, winter survival differed between cultivars only in 2011 when Sitro had less survival than DKW46-15 and HyCLASS115W (Table 3). Sitro was among the most consistently high-yielding hybrids, but its 2011 yield was less (Fig. 6b) than expected for planting dates 2 and 4, perhaps as a result of this relatively poorer survival. In the second analysis of winter survival data, Chrome was removed (included only in the last year) and the other genotypes were averaged across years. In this case, no significant differences in winter survival were detected among genotypes.

**Crown Height**

The three-way interaction between planting date, tillage, and year was significant for crown height. In 2010, crown heights for the two early planting dates were higher than for the two later planting dates (Fig. 7b). In the same year, no-till plots had higher crown height compared with conventional tillage plots except for the third planting date. In 2011, the effect of tillage on crown height was more pronounced than the effect of planting date. The crown heights of plants in conventional tillage were all close to 1 cm, significantly shorter than their no-till counterparts at all planting dates. Unlike in 2010, the crown heights of the no-till early planted plots were shorter than the late-planted plots. In 2012, no-till plots had greater crown heights for the years when these variables differed among cultivars.

### Table 3. Mean separation for winter survival and crown height

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Winter survival, 2011</th>
<th>Crown Height, 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>DKW46-15</td>
<td>88.7</td>
<td>4.66</td>
</tr>
<tr>
<td>Griffin</td>
<td>79.8</td>
<td>3.52</td>
</tr>
<tr>
<td>HyCLASS115W</td>
<td>85.5</td>
<td>4.07</td>
</tr>
<tr>
<td>HyCLASS154W</td>
<td>76.0</td>
<td>4.70</td>
</tr>
<tr>
<td>Kadore</td>
<td>84.0</td>
<td>3.79</td>
</tr>
<tr>
<td>Sitro</td>
<td>69.1</td>
<td>4.39</td>
</tr>
<tr>
<td>Virginia</td>
<td>79.8</td>
<td>4.43</td>
</tr>
<tr>
<td>Wichita</td>
<td>80.8</td>
<td>3.91</td>
</tr>
<tr>
<td>HSD†</td>
<td>12.0</td>
<td>0.86</td>
</tr>
</tbody>
</table>

† HSD, Tukey's honest significant difference at P < 0.05. Cultivars that differ in value (winter survival or crown height) in greater number than the respective HSD value are significantly different.
height than conventional tillage plots only in the earliest planting date (31 August). For all other planting dates in 2012, crown height did not differ between no-till and conventional tillage plots. Although it was hypothesized that crown height may be related to winter survival and yield, regression analysis revealed no significant relationships between crown height and either winter survival or yield.

The main effect of genotype was significant for crown height, but interactions with other treatment factors were not significant. Similar to winter survival, we used two approaches to separate genotype means. First, mean separation of genotypes by year revealed significant difference in crown height among cultivars in 2010, but not in 2011 and 2012 (Table 3). Even in 2010, most varieties fell in the same range except Griffin (prostrate growth habit), which was among those that had significantly shorter crown height compared with HyCLASS154W and DKW46-15. In 2010, DKW46-15 yielded less than other varieties, which might suggest a negative relationship between crown heights and yield, but the lack of significant difference in yield between Griffin and HyCLASS154W is further evidence that crown height was not a clear indicator of yield. The second mean separation was conducted by removing cultivar Chrome (present only in 2012) from the data and by comparing the remaining cultivars averaged across years. This analysis produced a result similar to that obtained for crown height cultivar differences in 2010 (Table 3).

**DISCUSSION**

Our analysis of National Winter Canola Variety Trial data indicated that with optimal weather conditions, best crop management practices, and best available genetics, canola has a potential yield of up to 7 Mg ha\(^{-1}\) (Fig. 2a), which is more than double the actual yields reported by many researchers in the United States and Canada (Harker et al., 2012; Nielsen et al., 2012; Stamm et al., 2012). The mean yield of 2.0 Mg ha\(^{-1}\) (Fig. 2a) of the lowest 94% of environments is still greater than the national average yield of 1.6 Mg ha\(^{-1}\) (USDA National Agricultural Statistics Service, 2013). The national variety trial data set includes several years and locations, producing a set of diverse environmental conditions. This diverse sampling of genetics, environment, and their interaction facilitated exploration of the genetic potential of the crop across environments and produced evidence of canola yield potential that could be exploited by combinations of environmental, genetic, and management factors. The mean oil content for canola, about 40% of seed weight, and the mean protein content of about 25% of the seed weight were in line with previous reports (Harker et al., 2012; Mailer et al., 1998). Exceptionally high oil content of about 53% of seed weight, above the maximum recorded from the variety trial data, were previously reported in Alaska (Geier, 2004). Both the national variety trial and the Manhattan experiment showed that environment was responsible for explaining the overwhelming majority of the variability in canola yield, oil, and protein contents. A significant impact of environment on yield and oil content of canola has been previously reported (Farre et al., 2001; Harker et al., 2012; Walton et al., 1999). Similar evidence that environment is responsible for >70% of the variability in dryland and irrigated yields exists for other row crops (Assefa et al., 2014). Rainfall and temperature are environmental variables that might change across years and planting dates. Analysis of weather conditions associated with yield extremes suggested that canola yields were maximized when rainfall during planting and establishment was relatively low (40–60 mm mo\(^{-1}\)) but was greater (50–100 mm mo\(^{-1}\)) from December through June. Relatively wetter but cooler weather during flowering and seed filling stages distinguishes superior canola-yielding environments from low-yielding environments. This result agrees with previous reports of canola yield relationships with these environmental variables (Farre et al., 2002; Kutcher et al., 2010; Nuttall et al., 1992).

Yield declined as planting date was delayed in the Great Plains and Midwest regions within the range of planting dates reported in the national variety trial data (early August to late October). In the Manhattan experiments, planting winter canola during the first 3 wk of September provided the most consistent yield response. A similar study conducted in southwest Kansas (Holman et al., 2011) documented the benefit of planting of canola from mid-August to the first week of September, illustrating that optimal planting time can vary across a relatively short geographical distance, largely driven by substantial differences in annual precipitation and elevation. A positive correlation between earlier planting and yield also was obtained for the Northern and Southeast regions in the national variety trial and in the 2011 Manhattan experiment, further evidence that environment dictates the impact of planting date on yield.

In most cases, no-till and conventional tillage produced similar yields, but under some conditions, no-till plots yielded significantly less than conventional tillage plots, most notably with later planting. These experiments used low-disturbance no-till drills to provide the greatest challenge to genetics and planting date management factors; however, other research has demonstrated effective residue-management strategies (e.g., using high disturbance seed openers, increasing seeding rate, ensuring sufficient downward force on row planter units), to improve yields in no-till (Godsey et al., 2013; Holman et al., 2011).

Cultivar yield varied with year, planting date, and tillage, but no cultivars distinguished themselves as consistently superior for no-till planting or for planting date extremes. Some cultivars yielded consistently better or
worse than others in most combinations of year, planting date, and tillage. For example, Sitro (a hybrid) was among cultivars that consistently yielded more, whereas HyCLASS115W (Roundup Ready) was consistently lower yielding in these experiments. Although present in only 2012, Chrome (a hybrid) was notably superior in yield than the other cultivars when planted before late September. High parent heterosis of up to 50% has been reported for canola (McVetty, 1995), and thus hybrids may be able to somewhat overcome the negative effects of residue on canola performance in a no-till production system.

Stand establishment and survival are among the main concerns in winter canola production (Holman et al., 2011). Results from the national variety trials indicated that varieties tested in the last 10 yr have performed well in that regard. Also, our comparison of the genotypes in the Manhattan experiment indicated no significant difference in winter survival in most cases. This agrees with the conclusion of Conley et al. (2004) that in the last decade, stand establishment and winter survival of canola varieties have substantially improved in the United States. Planting date significantly impacted winter survival in our analysis, suggesting early planting can assure sufficient canola plant growth to survive the winter (Darby et al., 2013 Holman et al., 2011), but planting too early also can have negative results. Comparing the two limitations of canola production, stand establishment appears to be a relatively greater problem in canola production than winter survival because 100% establishment was possible in only 24% of reported values, but once canola was established, 100% survival was possible 53% of the time.

CONCLUSION
Analysis of National Trial data revealed that environment (year, location) contributed the greatest percentage of variability in canola yield and oil content. Although both stand establishment and winter survival has exceeded 80% for most genotypes in most trials for the last 10 yr, stand establishment remains a more prominent constraint to canola production than winter survival. The positive impact of early planting on canola yield for the Great Plains and Midwest regions was evident from the analysis of national variety trials, consistent with the 2010 and 2012 results in the current Manhattan experiment and conclusions by Holman et al. (2011). The yield difference between no-till and tillage plots was not large, but yield tended to improve with tillage, and reductions in yield and winter survival associated with very early or very late planting were greater without tillage. Although cultivars responded differently to planting date in each year, the interactions were not consistent, and planting date affected yield more than cultivar differences in any given year. Most cultivars produced similar yields, but some yielded consistently better across years and planting dates than others. Our research indicates that selection of high-performing cultivars for a given environment and planting them at a time that enhances winter survival given tillage considerations maximizes the yield potential of canola. Future research in canola should focus on increasing yield and stand establishment by identifying genotypes and key environmental indicators for planting, among other management factors.

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References


SAS Institute, Cary, NC.


