FACTORS IMPACTING CORN ESTABLISHMENT AND THE ROLE OF UNIFORM STAND ESTABLISHMENT ON YIELD

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Factors Impacting Corn Establishment and the Role of Uniform Stand Establishment on Yield

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MASTER OF SCIENCE

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ABSTRACT

Information from actual farm fields can help corn producers understand the value and importance of establishing uniform plant emergence and within row plant spacing. Thirty-eight fields planted with corn (*Zea mays L.)* by North Dakota producers were evaluated to determine effects of uneven plant emergence timing and within-row plant space variability, as well as identifying contributing factors. Rows within a planter's width with the most variability yielded 6% less than the least variable. Individual ear weights decreased as the number of days after normal emergence (date when 50% of plant stand emerged) increased. Ears next to within-row gaps weighed 11% more than the normally spaced plants. Combined ears from both plants situated <5.1 cm apart weighed 36% more than the normal emerged. Residue impacted stand establishment variability more than other factors measured. Producers should assess each field environment individually in order to identify best practices to achieve uniform stand establishment.

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INTRODUCTION

There are many farming practices that contribute to maximum yield in corn (*Zea mays* L.) production. Planting high yielding hybrids, applying fertilizer and pest control are common practices. However, there is one major practice affecting corn yield that many overlook-establishing a uniform plant stand. Uniform plant stand establishment includes plant emergence timing and within-row plant spacing variability. Previous studies have shown 6 to 22% yield reduction when corn plantings have uneven emergence. Within-row plant spacing variability also has an impact on individual plant yield, however, the significance of overall yield reduction can be variable.

Stand establishment can be adversely affected by planting in cool, wet soils that are common during the recommended planting season in North Dakota. Management practices that may affect stand establishment include planting date and previous crop, as well as the amount of residue, tillage methods, planter type, planting speed and seeding rate.

Little research on this topic has been conducted specifically in North Dakota. There is a need for local data on this topic in order to assist producers in understanding the importance of establishing uniform plant emergence and within-row plant spacing.

OBJECTIVES

The objectives of this research were to quantify the variability in plant emergence timing and within-row plant spacing within to measure its effects on yield. Additionally, this research will attempt to determine the factors that contribute to uneven emergence and within-row plant spacing variability in corn fields planted by North Dakota producers. From the data collected and reported, producers will better understand the importance of uniform stand establishment and the best practices to achieve it.

LITERATURE REVIEW

The yield potential of recently developed corn hybrids has increased substantially through continual plant breeding (Troyer, 1995). The obvious factors to consider when breeding for top yielding hybrids are tolerance to environmental stress, response to inputs and yield per individual plant. Since the 1930s, corn hybrid breeding has increased yield performance due to stress tolerance and more efficient use of inputs. Newer hybrids have also shown increased tolerance to higher plant densities with improved use of inputs (Troyer, 1995). Interestingly, when compared with older hybrids in a low plant density environment, the yield of the newer hybrids was not greater, indicating the need for high plant density in order to achieve greater yields (Duvik, 1997). In another study, three hybrids from the eras of 1970s, 1980s and 1990s were examined at differing plant densities. The newer hybrids had increased yield in a higher plant density environment, but yielded 10% less than the older hybrids when planted at a lower plant density. This suggests the ability of individual plants to yield did not increase in the newer hybrids (Sangoi et al., 2002). These studies show that the yield potential of an individual plant has not increased over the years when grown at traditional plant density and explains the importance of establishing higher plant density.

These results indicate hybrid selection is not the only important factor to consider when trying to achieve optimum yield, but to also consider plant density and uniform stand establishment. It is hypothesized that variability in stand establishment will decrease yield potential in corn. There are various field and environmental conditions as well as planting methods that contribute to stand establishment variability.

Stand Establishment Variability

Stand establishment variability for the purpose of the research reported here includes uneven plant emergence timing and within-row plant spacing variability. The optimum scenario for corn stand establishment is rapid, uniform emergence timing without within-row occurrences of gaps and crowded plants (Nielsen, 2015). The germination percentage of corn typically ranges from 90 to 95%. Therefore, perfect stands are not possible regardless of planting conditions and equipment. Nevertheless, the environment and planting method can have a significant impact, over and above the impact of the presence of non-viable seeds in the seed lot planted.

Uneven Plant Emergence Timing

Uneven plant emergence timing is defined as plants within a row that emerge from the soil at different dates causing plants to be in different growth stages. Earlier emerging plants are often larger with more developed root systems than those emerging later. The later emerging plant must compete for sunlight, moisture and nutrients with the neighboring earlier emerging plants, which are large and more developed. The presence of smaller, late emerging plants may also result in a competitive effect that is similar to weeds in the canopy, especially if they fail to produce a cob of any size. A study of interplant competition in corn explains plant competition as an early onset of decreased biomass production and plant growth rates, causing a decrease in the allocation to reproductive structures of the smaller plant. These delayed or smaller plants remain stunted, resulting in a smaller to no harvestable ear (Maddonni and Otegui, 2004). Carter et al., (2001), reported that when emergence of 1:4 plants is delayed by 10 to 12 d, a 6 to 9% yield decrease can be expected. A delay of over 21 d in 1:4 plants can result in a 10 to 12% yield decrease. When 3:6 plants have a delay of 21 d a 20 to 22% yield loss is expected. Liu et al., (2004b) found a 4 to 8% yield reduction when one in six plants had late emergence in 12 d and 21 d respectively. Both studies were conducted using hand planting to simulate late emergence. Late-emerged plants bordered by normal-emerged plants will yield less when compared with late-emerged plants bordered by a late-emerged plant. Some yield compensation by the normal emerged plant may occur when placed next to a late emerged plant (Nafziger, et al., 1991).

Variability in time or dates when individual plants emerge is rarely monitored by producers. However, observing differences in growth stages between plants within a given area is relatively easy. When a plant has two or more leaves compared with neighboring plants, the smaller neighboring plants will almost always yield less. In a study comparing the yields of plants with differing growth stages, plants with a two-leaf emergence delay yielded 35% less while plants with a four-leaf delay yielded 72% less (Liu et al., 2004b). The neighboring plant yield increase was 2 to 7%, not large enough to compensate for the loss. Yield reductions for the late emerged plants were associated with reductions in plant height and leaf area (Liu et al., 2004b).

Within-row Plant Spacing Variability

Within-row plant spacing variability is caused by long gaps, referred to as skips, or crowed plants, referred to as doubles. Plants that are next to skips often produce larger ears, but generally do not compensate enough for the missing plant (Nielsen, 2001). Although doubles will generally produce a much smaller ear from the less dominating plant, the combination of the two ears involved in the double will yield comparably to the single ear of the normal-emerged plant. Skips are obviously the most important source of yield loss, but doubles are a wasteful source of seed. Liu et al. (2004b) found plants next to skips achieved a 10 to 19% yield increase over the normal emerged plant ear. Certainly not enough to compensate for the missing plant's ear. The two plants situated as doubles individually resulted in a 0 to 44% decrease in yield when compared with the normal-emerged plant ear. However, when the two ears were combined, an increase of 20 to 83% was found. When comparing whole plot yields, Liu et al. (2004b) did not find a significant relationship between yield reduction and within-row plant spacing variability. Doerge et al. (2015) summarized that within-row plant spacing variability does impact individual ear yields, however, most studies reviewing whole-field yields decreased only by 1 to 2%.

Calculating the standard deviation of within-row plant spacing is another way to observe within-row plant space variability. A standard deviation of 5 cm is the target threshold considering typical germination percentages and planter performance (Nielsen et al., 2001). Standard deviation generally will increase as the target plant density increases. Nielsen et al. (2001) observed 350 fields and found the majority obtained an average standard deviation of 10 to 12 cm. Averaged over five fields, corn yields decreased by 4% for every 2.5 cm increase in standard deviation. Conversely, Liu et al. (2004b) concluded a standard deviation of 2.5 cm to 17.5 cm did not cause severe interplant competition. It is obvious that conclusions regarding within-row plant spacing standard deviation have been mixed. Lauer et al. (2004) suggested that standard deviation alone is not a good means of predicting yield due to the differing effects skips and doubles have on yield and that standard deviation should not be used for comparisons unless row spacing and seeding rates are similar.

Factors Impacting Emergence Variability

Soil Temperature

Spring planting often does not allow for ideal soil temperature planting conditions as soils are usually below 10^{o}C when planting commences in North Dakota. Changing spring weather conditions are also challenging during planting. Cold rain or snow, which is most likely to occur in the spring, immediately after planting can inhibit ideal stand establishment (Stoll and Saab, 2010). It is important to monitor weather conditions and be aware of upcoming patterns of undesirable weather conditions prior to planting. The presence or onset of cold soil temperatures during imbibition may cause seed injury. More specifically, when a dry seed imbibes cold water, typically 10 ^{o}C or below, injury may occur. This injury results in seed death or abnormal mesocotyl and coleoptile development, injuries that are irreversible (Saab, 2012). Seeds in soils that reach 12 to 13 ^{o}C may begin to emerge in approximately seven days (Nielsen, 2015). However, temperatures that are unevenly distributed through the seed bed will impact variability in germination. Uneven soil temperature around the planted seed can be caused by cool rainfall, soil type, residue cover and seeding depth (Nielsen, 2015).

Soil temperature has a negative effect on number of days to emergence (VE). The VE corn growth stage is defined as when the coleoptile has emerged from the soil's surface (Nielsen, 2014). The number of days to VE50 (growth stage when 50% of the plant density has emerged) when soil temperature is 10 ^{o}C is 35 d. The number of days to VE50 when soil temperature is one degree warmer at 11 ^{o}C decreases to 25 d (Nielsen, 2015).

Soil Moisture

Soil moisture and future rainfall should be considered by producers when determining optimum seeding depth. Uneven soil moisture at the seed zone is a primary cause of uneven emergence (Carter et al., 2001). A 3.8 cm to 5.1 cm depth is normal for seeding corn. In dry soils when rainfall is in the near forecast, 3.8 cm to 5.1 cm depth may be optimum. However, if adequate soil moisture is not available at that level and rainfall is not in the near forecast, seeding depth may need to be increased to 5.1 cm to 7.6 cm for optimum emergence if moisture is available at this deeper depth. Adequate soil moisture can be defined as soil at field capacity (Nielsen, 2015). However, planting when soil moisture is in excess may interfere with row closure by the implement and cause sidewall compaction (Stoll and Saab, 2010). Thereby reducing the seed to soil contact and moisture availability to the germinating seed.

In order for the seed to imbibe moisture, seed to soil contact is crucial. Factors that may cause uneven seed to soil contact are high residue levels, cloddy seed beds, and air contact from open planter furrows when planting into excessively wet soils (Nielsen, 2015). Nafziger et al. (1991) found tillage operations as the primary cause of uneven soil moisture resulting in uneven plant emergence timing.

Soil Compaction

Soil compaction is the process of soil particle rearrangement where soil bulk density increases while porosity decreases (Plaster, 2009). Compaction may be caused by use of heavy machinery during tillage and seeding, pressure from wheels, and plowing at same depth for many years. Even in no-till practices, over 30% of the area has traffic from heavy machinery with one pass during the planting process (Ramazan et al., 2012).

Compaction in the seed zone limits emergence of the coleoptile. Side wall compaction restricts the mesocotyl and emergence of the coleoptile (Nielsen, 2015). Compaction can result in slow or uneven emergence of plants, low plant density, abnormal root growth, and nutrient deficiencies (Hanna et al., 2010). Ramazan et al. (2012) measured three levels of compaction (zero pass, two pass and four passes). Increasing compaction, or passes of the implement, had negative effects on soil bulk density and plant root length. Grain yield decreased with increased soil compaction as well.

Road tires and high axle loads can cause rutting in the field resulting in an uneven soil planting surface. Using flotation tires versus road tires causes less rutting and surface unevenness. The lower tire pressure, 250 kPa, of flotation tires reduces the negative impact of compaction on emergence (Siduh et al., 2006).

Soil Tillage and Crop Rotation

Soil tillage systems affect stand establishment by contributing to various seed bed outcomes. Traffic by tillage machinery, uneven seed bed and residue can all cause poor stand establishment. A study conducted by Boomsma et al. (2006) looked at a subset of 14 years of data from a 30-year data set on how different tillage and crop rotation systems affect plant height and yield in corn. The cropping system treatments included two crop rotations, corn on corn and corn-soybean (*Glycine max L.*), along with four tillage systems, no-till, ridge-till, chisel, and plow. Corn on corn in a no-till (CC-NT) system yielded less than the other treatments in 10 out of the 14 years. The other three treatments did not differ in yield. The CC-NT system also had shorter eight week plant heights, showing that this system did impede corn plant growth. Conversely, in a study comparing conventional tillage, conservation tillage, and no till effects on corn yield, the yield among the systems did not differ (Kosutic et al., 2005).

Planter Type and Planting Speed

Uneven plant spacing is often associated with the ability of a planter to singulate seed from the singulating mechanism down to the furrow (Liu et al., 2004b). Finger pick-up systems may have worn pick-up mechanisms, misadjusted finger tension or worn knock off brushes. Air seeders may have misadjusted air pressure, leaks in the system, worn knock off brushes or wrong disk sizes (Nielsen et al., 2001). Liu et al., (2004a) compared vacuum meter, finger pickup and air seeders for corn stand uniformity and yield. In summary, the air seeder resulted in poor seed singulation and placement capabilities while the finger pick-up had intermediate capabilities. The vacuum meter was the most desired type of planter due to its accurate seed placement. The order of best performance for within-row plant spacing uniformity was vacuum meter, finger pick-up and air seeder. Variability in plant emergence dates did not differ among the vacuum meter and finger pick-up, but were delayed when the air seeder was used.

Lauer and Ramkin (2004) found planting speed can also influence the planter performance. Finger pick-up type seed delivery systems induced higher plant densities at faster planting speeds while air seeder systems had lower plant densities at faster planting speeds. The number of skips and doubles increased as speed increased with both planter types. Regardless of planter type, there was a significant yield loss when planting speed increased from 6 km h^{-1} to 12.9 km h^{-1}. Plant-to-plant standard deviation also increased from 8.4 cm at 6 km $h^{-1}$to 10.7 cm at 12.9 km h^{-1}.

MATERIALS AND METHODS

Field observations were made during the 2013 and 2014 growing seasons to examine the effect of uneven plant emergence timing and within-row plant spacing variability on corn yield. Additionally, field environment and planting methods were examined for their impact on uneven plant emergence timing and within-row plant spacing variability. During these two growing seasons, data were collected from thirty-eight fields planted by North Dakota corn producers. North Dakota State University (NDSU) Extension agents and specialists assisted in this project by conducting the survey observations in their counties. Table 1 lists the counties, region of the state where they are located, and number of fields observed. Prior to the start of the project, an instructional meeting with the agents and specialists was held to explain the step-by-step experimental process. An instructional guide and formatted excel sheets were provided to ensure uniformity in the collection and reporting of the data. Involving these personnel in the project achieved two important goals. First, they allowed for the collection of data from a much larger geographical area. Second, it gave the agents and specialists a way to connect with area producers. A final presentation and video of the experimental results were created for extension agents and specialists to use as an educational resource to present to producers in the state.

Table 1. North Dakota county locations and number of fields observed in 2013 and 2014.

		2013	2014
County	Region	No. fields	No. fields
Benson	NE	3	-
Eddy	NE	1	1
Foster	NE	2	1
Ramsey	NE	1	-
Steele	NE	-	1
Walsh	NE	1	-
Wells	NE	1	1
Renville	NW	2	2
Ward	NW	3	1
Barnes	SE	3	2
LaMoure	SE	3	-
Stutsman	SE	2	3
Sargent	SE	-	1
Stark-Billings	SW	3	-
Total		25	13

Fields within a county were chosen based on accessibility and their general representativeness of the corn fields in the area. When more than one field within a county was included, some diversity in the type of equipment used for planting was attempted. The following information was obtained from the grower of each field soon after planting: tractor wheel type, corn planter model, planting date, planting rate, hybrid, previous crop, seeding depth, row spacing, planting speed, tillage, tillage time of year and air pressure of tractor tires and seeder. Field locations contained differing hybrid varieties planted as well as seed treatments (data not shown).

Within each field three random areas in each field location were demarcated randomly for detailed measurement. These three areas were referred to as sample unit one, two and three. A minimum of five observational field visits were made to each field site. The closest North Dakota Agriculture Weather Network (NDAWN) station to the field location was used to obtain data on rainfall, soil temperature, and air temperature. Rainfall amount for the periods between the initial field visits were calculated. Average soil and air temperatures were calculated from the previous field visit to that current days field visit. For the purpose of discussing general planting conditions, field locations were categorized by their regional location within the state (NE, NW, SE, SW). For each of these regions air temperature and total rainfall were averaged for 1 May through 31 May. Median planting dates for each region were calculated by referring to the planting date recorded for each field. The soil temperature was averaged for each region using the bare soil temperature at 10 cm below the soils surface for the two weeks after the planting date for that region.

The first field visit occurred at planting. Individual sample units were 9.14 m long and as wide as the number of planter rows on the planter used to plant the field. For example, a twelve-row planter had a sample unit width of 12 rows. In order to decrease the work load for participating extension agents, fields that were planted with planters over 12 rows (e.g. 36 row), only half of the rows were monitored. These rows included the most exterior planted wheel row into the center planted rows. Each row was labeled with a number using wooden stakes which were also used to mark the beginning and the end of the 9.14 m row length. The longitude and latitude coordinates of each sample unit was recorded using any global positioning device the agents had available. Percent residue was estimated once for each sample unit by following the steps listed in the United States Department of Agriculture, Soil Conservation Service, Corn and Soybean Crop Residue Management Guide, USDA (1992). The values from each sample unit were averaged and the average was used to describe the entire field and used in subsequent analysis. Soil moisture was estimated and was categorized as being dry, moist or soggy. Dry soil was defined as soil that did not hold together when trying to form into a ball. Soil that held together when made into a ball was defined as moist, and if water ran out of the formed ball and over the hand, the soil was defined as soggy.

The number of accumulated corn growing degree days (AGDD) needed from time of planting to time of emergence is approximately 120 (Nielsen, 2014). Therefore, the second field visit occurred at least 120 AGDD after planting but no earlier than VE50. VE50 is defined as the growth stage when 50% of the plant density has emerged (Nielsen, 2015). Corn growing degree days were obtained from nearby NDAWN weather stations as calculated using its Corn Growing Degree Day application. The VE corn growth stage is defined as when the coleoptile has emerged from the soil's surface (Nielsen, 2014). During this second field visit, the number of plants in VE were counted and recorded for each row in each of the sample units separately. In sample unit one only, at least three VE plants that also had neighboring plants on both sides, were marked with a red flexible plastic stake. The red stake was dated for that day and identified the plant as a normal emerged (NED) plants. Normal emerged plants are defined as a plant that emerged at the time of 120 AGDD or VE50, therefore representing the plants that emerged most uniformly. These NED plants were used for comparison purposes later in the experiment. At this time, the presence of side wall compaction was investigated by digging away soil at the base of plants in at least one spot in each row. Side wall compaction and rooting restrictions were documented when corn roots were growing horizontally along the soil profile. Seed depth was measured and recorded. A soil compaction tester (DICKEY-john, Auburn, IL) was used to measure penetration resistance in fields located in Sergeant and Stutsman County. At least 10 readings were conducted for each row in all sample units to a depth of 60 cm. The average penetration resistance for each row was recorded.

In 2014, any row planted within a tire track was identified by indicating the type of wheel track associated with that row. Types of wheel tracks included tractor, planter, seed hopper, fertilizer hopper or any combination of the four types.   This step was included in order to identify any increased stand establishment variability associated with planting implement arrangements used by producers.

The third field visit was conducted no less than 7d from the second field visit date. The total number of plants present in each row was counted and recorded for sample units one two and three. In sample unit one, each plant in the VE stage, that also had neighboring plants on both sides, were marked with an orange colored stake and dated for that day.   These plants were identified as late emerged plants.

The fourth field visit occurred no less than 7d from the third field visit date. The total number of plants present in each row and each sample unit were counted and recorded. In sample unit one, each plant in the VE stage that also had neighboring plants on both sides, were marked with and orange colored stake and dated for that day. These plants were identified as late emerged plants. Doubles and skips were counted in all sample units. In sample unit one only, doubles and plants next to skips were marked with an orange stake. Skips were identified as gaps greater than 30.5 cm between two plants and doubles were identified as two plants with a planting space less than 5.1 cm.

In 2013, overall stand establishment variability within-rows was identified by differences in plant emergence over time. The row with the highest change in plant emergence over time (i.e. the row with the largest percentage of plants emerging after the first flush of emergence) was identified as the most variable, the row with the second highest change in plant emergence over time was identified as the second most variable row and so on. Within-row plant spacing was measured on the most and least variable rows in sample unit one only, from which standard deviation was calculated utilizing the built in mathematical function formula in Microsoft Excel.

After the review of the 2013 data and the used method to identify variable rows, changes to the method were made in 2014. The literature contains multiple studies concluding that not only uneven plant emergence timing affects yield, but also within plant spacing variability. Therefore, it was felt that the amount of skips and doubles within-the-row should also be accounted for, as well as the total number of plants in the row, when accessing overall variability in stand establishment and within-row variability. These changes were made to the identification process and were applied in 2014. Relative overall variability within-rows was accessed in 2014 by applying all plant establishment outcome factors into a calculation. These factors included the following for each individual row: final stand count (b_1), first stand count (b_2), total skips (b_3), total doubles (b_4), largest number of plants in a row from all rows in the sample unit (b_5). Each factor was weighted equally based on the total number of plants in that row and were summed together as described in the following equation (Eq.1):

$$V = \{[b_1 - b_2]/[b_1]\} + [b_3/b_1] + [b_4/b_1] + [b_1/b_5]. \quad (1)$$

Equation 1 was applied to each row. The row with the highest value from the calculation was identified as the most variable row for that plot. The row with the second highest value was identified as the second most variable row and so on until the second least and least variable row were also identified. Within-row plant spacing was measured and recorded on the most and least variable rows in sample unit one only.

Harvest took place on the fifth field visit. Harvest occurred any time after the kernels showed black layer and before the producer harvested the field. In all sample units the most, second most, second least and least variable rows were harvested by removing the ear from the husks. The ears (grain and cob) were weighed using an UltraSport V2-30 scale (Jennings Scale, Phoenix, AZ). In order to cut down on hand shelling labor, two representative ears from each of the four variable rows (a total of eight representative ears) were collected for observation and additional measurements. These representative ears were visually identified as the ears that were the average size of all the ears within that variable row. In sample unit one only, at least three individual ears were harvested and individually weighed from the following plants: late emerged from third field visit, late emerged from fourth field visit, plants next to late emerged plants, plants with a normal emergence date, doubles, and skips. Ears next to a skip were harvested from plants on both sides of the skip. Doubles were harvested by taking an ear from both plants situated in the double. These individual variable ears from sample unit one and the eight representative ears from sample unit one, two and three were placed in sealable plastic bags, labeled and transported to the office labs of the participating agents and specialists.

Eight representative ears from each sample unit were hand shelled. The grain collected from the eight representative ears was weighed using the UltraSport V2-30 scale scale (Jennings Scale, Phoenix, AZ).. The empty cobs from the eight representative ears were weighed using the same scale. The grain weight was divided by the whole ear weight to calculate the shelling percentage. Moisture and test weight were measured on the grain and recorded using a mini GAC plus Grain Analysis Computer (DICKEY-John, Auburn, IL). The grain yield was adjusted to 15.5% moisture. The overall grain yield for each of the variable rows from sample unit one, two and three was calculated by applying the shelling percentage, adjusted grain moisture and area harvested.

Data were analyzed using appropriate models in PROC GLM with SAS 9.3 for Windows (SAS Institute, Cary, NC). Environment was considered as a random effect while treatment row was considered a fixed effect. A protected LSD ($p \leq 0.05$) was used to compare means. A stepwise regression model was used to relate stand establishment outcomes as the dependent variables to a set of qualitative and quantitative independent variables. The independent variables that were included were; seeding rate, percent residue, tractor speed, previous crop, tillage type, soil temperature and soil moisture at planting. The entry significance level and stay significance level was set at $p = 0.15$. Each variable and model were given an adjusted R^2 value along with an Akaike's Information Criteria (AIC) value. The adjusted R^2 value represents the percentage of the variability of the dependent variable that is explained by the variation of the independent variable. . The variable or model with the largest adjusted R^2 value was considered to have the best fit. The AIC value measures the model lack of fit and applies a penalty term as the number of independent variables in the model increases. The variable or model with the smallest AIC value is considered the best fit (Beal, 2007).

Relationships between stand establishment variability factors and field environment factors as well as planting methods were identified using a linear correlation model with significance level of $p \leq 0.05$. The independent quantitative variables that were included were: percent residue, planting speed, soil temperature and seeding rate. The regression coefficient slopes were tested using the t-test method.

RESULTS AND DISCUSSION

General Planting Conditions

The median planting dates (Table 2) for fields observed in this research were generally about the middle of May for both years, which was slightly earlier than the date when 50% of all the corn was planted for the state as a whole. However, the planting dates were still behind the states 5- year average by approximately 40% in both years (NASS, 2015).

Table 2. North Dakota Agriculture Weather Network data for air temperature, rainfall and planting date, accumulated growing degree days (AGDD) and average soil temperature for each ND region.

Region	Year	Avg. air temp.†	Total rainfall‡	Planting date§	Avg. time to 120 AGDD¶	Avg. bare soil temp.#
		(°C)	(cm)		(d)	(°C)
NE	2013	11.6	15	5/18	31	13.5
	2014	12.3	6	5/16	14	15.9
NW	2013	11.8	14	5/17	26	13.9
	2014	12.0	6	5/17	16	16.8
SE	2013	13.0	11	5/12	16	14.8
	2014	13.1	5	5/21	12	19.7
SW	2013	12.3	20	5/7	22	16.0

† Average air temperature for 1 May- 31 May recorded by automated weather stations located within the region listed.
‡ Total rainfall for 1 May- 31 May recorded by automated weather stations located within the region listed.
§ Median planting date recorded by participating extension personnel for the locations within the region listed.
¶ Average number of days to 120 AGDD from planting date listed for that region
# Bare soil temperature is the temperature of bare soil with no vegetation at 10 cm below the soil surface, averaged over the two weeks after planting date listed for that region.

Rainfall during the month of May 2013 was substantially greater than the 7 cm average with an average departure from normal of 7 cm, while rainfall conditions during the month of May 2014 was more comparable with only -0.9 cm departure from normal (NDAWN, 2015). In both years, rainfall averages were near normal throughout North Dakota for the remainder of the growing season. For 2013 and 2014, regional field locations had average air temperatures and bare soil temperatures close to the states 5-year average of 12.5^{o}C (Table 2).

The number of accumulated corn growing degree days (AGDD) needed from time of planting to time of emergence is 120 (Nielsen, 2014). The average amount of time to reach emergence in most seasons is approximately 14 d, although in cool-soil conditions emergence can take up to 21 d (Nielsen 2014). The overall average number of days from planting to 120 AGDD in 2013 was 24 d while in 2014 the average number of days to emergence was closer to the expected time with 14 d (Table 2).

Planting Methods and Field Environment

Extension personnel recorded planter type, row spacing, seeding rate and planting speed for each field that was included in this study. Of the 38 fields observed, 31 were planted with a center fill hopper system seeder (Table 3). Fifty-six centimeter row spacing, planting rates of 76,000 to 89,000 seeds/ha^{-1} and planting speeds of 7.3 to 8.0 km h^{-1} were the most frequently recorded planting techniques.

The fields were then evaluated for soil moisture at planting, percent residue, tillage type and previous crop (Table 4). The most frequent previous crop was soybean with 21 fields. Conventional tillage, percent residue of 21 to 30%, and moist soil moisture at planting were the most frequently recorded field environments.

Table 3. Overview of corn planters, planting criteria and field environment for fields evaluated 2013 and 2014.

Factor/Measurement	No. fields
Planter type	
Center fill hopper	31
Individual hoppers	7
Row spacing, cm	
56	9
76	29
Seeding rate, seeds ha^{-1}	
49 500-62 000	4
63 000-75 000	12
76 000-89 000	22
Planting speed†, km h^{-1}	
6.4-7.2	4
7.3-8.0	18
8.3-8.8	7
8.9-12.0	4

† Data were not available for five fields.

Soil Compaction

The presence of side wall soil compaction was investigated by digging away soil at the base of plants in at least one spot within the row. When reviewing data from all rows of all fields and sample units in the experiment, some side wall compaction did occur in five fields, primarily in 2013 when fields were planted in soggy conditions. Nevertheless, when reviewing data from rows that had been identified as being relatively more variable, side wall compaction was present in only two of these rows.

The Stutsman and Sargent County fields were measured for presence of soil compaction with the Soil Compaction Tester. The soil penetrometer resistance is said to mimic the resistance that would be encountered by a root. At 689 kPa, approximately 69% of potential root penetration is expected and is considered to have little to no compaction (Duiker, 2002).

Table 4. Overview of field environment evaluated 2013 and 2014.

Factor/Measurement	No. fields
Previous crop	
Hordeum vulgare L. (Barley)	4
Brassica napus L. *(*Canola)	1
Zea mays L. (Corn)	1
Phaseolus vulgaris L. (Dry bean)	2
Triticum aestivum L. (Hard red spring wheat)	7
Triticum aestivum L. (Hard red winter wheat	1
Pisum sativum L.(Pea)	1
Glycine max L. (Soybean)	21
Tillage type	
Conventional	21
Minimum	2
No-Till	8
Vertical	5
Residue, %	
0-10	3
11-20	8
21-30	12
31-40	6
41-50	1
51-60	2
61-70	3
71- >80	3
Soil moisture†	
Dry	1
Moist	31
Soggy	6

†Dry- soil that did not hold together when trying to form into a ball; Moist- soil that held together when made into a ball; Soggy- water from soil ran out of the formed ball and over the hand.

The soil penetrometer readings from the rows with most variability had an average penetration resistance of 696 kPa while the least variable rows had an average penetration resistance of 689 kPa. Therefore, it would seem soil compaction within the range encountered in these locations did not play a major role with the evenness of emergence or within-row plant spacing variability.

In 2014, any row planted within a tire track was documented in an attempt to identify any increased stand establishment variability associated with planting implements and implement arrangements used by producers. Of the rows identified as having the greatest variability in emergence timing or within-row plant spacing variability, most came from rows not associated with any wheel track, regardless of type. If a wheel track was involved in a variable row, tracks made by the tractor or the planter were the most common. Wheel tracks made by a center-fill seed hopper, fertilizer hopper, or a combination of two or more wheel track type were the least commonly reported (data not shown).

Stand Establishment Variability

Stand establishment variability was defined as the occurrence of uneven plant emergence timing and within-row plant spacing variability. Equation 1 was used to determine which rows within a sample unit/field were most, second most, second least, and least variable in stand establishment variability.

It was expected that the least variable row would have the highest plant density with the least amount of change relative to the target population, most uniform with regards to timing of emergence, least number of uneven plant emergence timing and least occurrences of within-row plant spacing variability. The most variable row on the other hand would have the lowest plant density with the greatest amount of change relative to the target plant density, most uneven plant emergence timing and greatest within-row plant spacing variability. These expected outcomes did occur when reviewing general plant density characteristics of each variable row type (Table 5). However, in 2013, the second least and second most variable rows had the highest plant density. This unexpected outcome was attributed to the way variability was calculated in 2013, as it did not take into account the number of skips and doubles, or the total number of plants within the row. The least variable rows had the lowest average percent change (-2) in target plant density compared with all other variable rows. The least variable row also had the lowest average plant-to-plant spacing (19.5 cm) and average standard deviation (7 cm).

Across all fields and sample units the average number of plants in a 9.14 m row was 44. The most variable rows averaged across years had 19 occurrences of either within plant spacing variability or late emerged plants (Table 5) while the least variable row had an average of 10 occurrences. Second most variable and second least variable rows resulted in an average of 18 and 11 occurrences, respectively. The type of stand establishment variability outcome that occurred the most often per row were plants that emerged 5 to 10 d after NED plants (LEearly) with 4 to 14 plants row^{-1}, followed by skips (1 to 5 plants/row^{-1}). Doubles occurred the least often with an average of 1 plant/row^{-1}.

In 2013, uneven plant emergence timing had greater occurrences than within-row plant spacing variability. In 2014, within-row plant spacing variability had more occurrences than uneven plant emergence timing. The explanation for the differences between the two years could be attributed to soil moisture and rainfall. Rainfall during the planting season was considerably higher in 2013 than in 2014 (Table 2). It was also the only year for which soggy soil planting conditions were recorded. The presence of high soil moisture may have caused inadequate seed to soil contact due to poor planting conditions, therefore inhibiting seed emergence (Nielsen, 2015). Reduced rainfall during the planting season in 2014 may have encouraged increased planting speeds. Producers often view dry weather conditions as an optimum planting window and set goals to complete as much planting as possible. Lauer and Rankin, (2004), found an increase in within-row plant spacing standard deviation when speeds increased from 6 to 13 km h^{-1}.

Table 5. Average number of within-row plant spacing variability occurrences, late emerged plants, and plant density outcomes for each variable row type.

Variability†	Year	Skip‡	Double§	LEearly¶	LElate#	Total variability occurrences	Avg. plant density	Avg. change from planting rate	Avg. plant spacing	Avg. standard deviation
		no.					plants ha^{-1}	%	cm	cm
Most	2013	2	1	13	4	20	71182	-8	20	8
	2014	5	1	9	2	17	70605	-7	21	9
Second most	2013	2	1	14	3	20	72757	-7	NM††	NM
	2014	5	1	9	1	16	72579	-5	NM	NM
Second least	2013	1	1	9	1	12	74936	-5	NM	NM
	2014	2	1	5	1	9	76670	-1	NM	NM
Least	2013	1	1	9	1	12	72207	-5	19	7
	2014	2	1	4	1	8	77938	+1	20	7

† See Eq. 1 for calculation of variability,

‡ Skip, plant spacing >30.5cm,

§ Double plant spacing <5.1cm,

¶ LEearly, emerged 5 to 10 days after normal emerged plant,

LElate, emerged 11 to 17 days after normal emerged plant,

†† Not measured.

Impact of Uneven Emergence Timing and Within-row Plant Spacing Variability on Individual Plant Yields

Ears from plants with delayed emergence dates, or within-row plant to plant spacing were harvested and weighted to quantify the effects of emergence timing and spacing on individual plant yield. It is understood that late-emerged plants must compete with larger neighboring plants for resources, often resulting in smaller ears (Maddonni and Otegui, 2004). Past studies have shown that individual plants situated next to a skip or double have a difference in individual ear weight, but the impact on overall plot yield is minimal (1 to 2%) (Doerge et al., 2015; Liu et al., 2004b).

Data from all locations and both years shows uneven plant emergence timing and within-row plant spacing variability does affect individual ear weight (p= <.0001). However, the effect on individual ear weight changed depending on the type of emergence timing or within-row plant spacing variability (Table 6).

Table 6. Weight of an individual ear as affected by plant spatial arrangement and emergence timing expressed as a percent of the mean weight of the ear from a normal emerged plant over both years

Individual ear†	
	Relative weight, %
Next to skip	111 a‡
Next to late emerged plant	105 a
Normal emergence date	100 ab
Double1	86 b
LEearly	65 c
LElate	59 cd
Double2	50 d
LSD (p≤0.05)	15

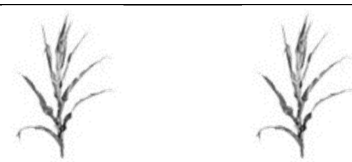
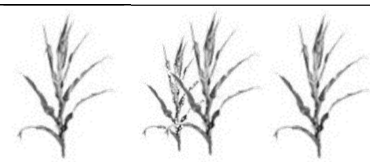
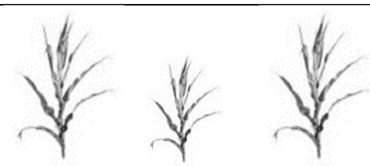
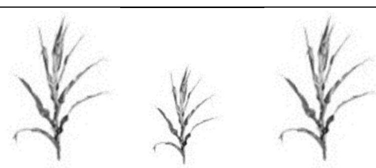
† Skip, > 30.5cm; Double1, < 5.1cm, ear from largest plant; LEearly, emerged 5-10 days after normal emergence date; LElate, emerged 11-17 days after normal emergence date; Double2, < 5.1cm, ear from smallest plant,

‡ Means followed by the same letter in the same column are not significantly different according to LSD (0.05).

Individual ears with delayed plant emergence, LEearly and LElate (11 to 17 d delay), had significantly less yield when compared with the plants that emerged at the normal dates (NED) (Table 6). Plants that were considered LEearly were approximately two leaves behind normal plants (data not shown). These ears weighed 35% less, than the average weight of NED ears. Ears from LElate plants, which were approximately 4 leaves behind the normal emerged plants, weighed 41% less than the average weight of NED ears. These results are consistent with the yield decline Liu et al. (2004b) found with 2-leaf and 4-leaf emergence delay. Both values are significantly different than the weight of the NED ($p \leq 0.05$). Weight reductions of the late-emerging plants were only moderately offset by neighboring plants that emerged normally. Plants next to late-emerged plants (NLE) had ears that weighed 5% greater than plants with a NED. This was a non-significant difference in weight when compared with NED. Ears from plants situated next to a 30.5 cm skip had an average weight of 11% more than the NED ears. However, this increase was not enough to compensate for the missing plant and is not significantly different than the NED ears. The two plants situated as doubles, individually weighed substantially less than the NED, but together, the ears weighed an average of 36% more than the NED. This increase does contribute to an increase in yield. The results for percent weight of within-row spacing variable ears is similar to the findings reported by Liu et al. (2004b) and Doerge et al. (2015).

Table 7 provides a visual aid for various stand establishment outcomes and the individual ear weight loss or gain estimated for the particular plant stand arrangement along with the percent weight of individual ears compared with normal emerged plants. The table clearly shows uneven emergence timing and skips decrease individual ear weight and overall yield.

Table 7†. Percent yield of normal emergence date and individual ear weight loss or gain for various stand establishment outcomes.

Stand establishment outcome‡	Plant spacing			Loss/gain in ear weight§
				—— % ——
Ideal spacing¶				0
Yield, %#	100	100	100	
Skip				-78
Yield, %	111	0	111	
Double				36
Yield, %	100	50 86	100	
LEearly				-45
Yield, %	105	65	105	
LElate				-51
Yield, %	105	59	105	

† Figure format, Doerge et al., 2015.

‡ Skip, plant spacing >30.5 cm; Double, < 5.1cm; LEearly, emerged 5-10 d after normal emerged plant; LElate, emerged 11-17 d after normal emerged plant.

§ The average percent gain or loss of individual ear weight of the plant groupings depicted in Table 7 compared with ideal spacing.

¶ Ideal spacing, viewed as normal plant spacing for the desired plant density.

Mean percent weight of individual ear compared with mean weight of the ear from the normal emerged plant (Table 6).

Impact of Uneven Emergence Timing and Within-row Plant Spacing Variability on Overall Yield within a Given Location

As previously described, it was found that uneven emergence and within-row plant-to-plant spacing variability did impact individual plant yield. The next step in the process was to quantify the impact of uneven emergence timing and within-row plant spacing variability on overall yield. This was achieved by measuring yield from the most, second most, second least, and least variable rows from each sample unit. It was expected that the most variable row would yield the least when compared with the other variable rows, while the least variable row would have the greatest yield.

In 2013, averaged across all field locations, the most variable row yielded 9651 kg ha^{-1} and the least variable row yielded 10 002 kg ha^{-1} (Table 5). When data were analyzed using a combined analysis for all locations in 2013, yield was not impacted by uneven plant emergence timing and within-row plant spacing variability ($P = 0.67$) (Table 8). However, this result could be due to how variability was selected in 2013. For that year, variability was identified only by calculating the change in plant density over time and did not include total number of plants, skips, or doubles within the row. This issue was recognized and the method of variable row identification was modified in 2014 and Eq. 1 was implemented. When all data were collected in 2014, yield was significantly impacted by uneven plant emergence timing and within-row plant spacing variability ($p = <.0001$). The most variable row yielded 9% less (9666 kg ha^{-1}) than the least variable row (10 592 kg ha^{-1}) (Table 8).

Table 8. Effect of emergence and within row plant space variability on grain yield

Variability†	Grain Yield 2013	2014	Mean
	kg ha^{-1}		
Most	9651 a‡	9666 a	9658 a
Second most	9810 a	9732 a	9773 a
Second least	9887 a	10 444 b	10 148 b
Least	10 002 a	10 592 b	10 278 b
LSD (p≤0.05)	552	340	341

† See Eq. 1 for definition of variability

‡ Means followed by the same letter in the same column are not significantly different according to LSD (0.05).

When combining both years and all locations, uneven plant emergence timing and within-row plant spacing variability had a significant impact on yield (P = <.0021). The most variable row yielded 6% (9658 kg ha^{-1}) less than the least variable row (10 278 kg ha^{-1}).

The yield decline for the variable rows in all cases can be attributed the increased occurrences of late emerging plants (LEearly and LElate) and skips, all three known to impact the weight of individual ears and overall yield (Table 6). When these individual types of stand establishment outcomes are assessed in a group basis (Table 7) and quantified for differences in yield (Table 8), shows that stand establishment variability causes a decrease in overall yield.

Nafzinger et al. (1991) states the effect on yield is heavily dependent on the proportion of the overall stand that is delayed. This statement could be taken further too also include within-row plant spacing variability. For example, when assessing stand establishment outcomes individually, if the total percentage of plant density (based on 74,100 plants ha^{-1}) has 10, 20 and 30% occurrences of skips, there is an estimated yield loss of 8, 17, and 25% respectively (Table 9). The percentage yield loss results (2 to 6%) for LElate (Table 9) were similar to Nafzinger et al. (1991) findings of a 6% yield decline when 25% of the plant stand had a 10 to 12 d delay in emergence. Liu et al (2004b) reported 4% and 8% yield decline when 17% of the plant stand had a delay in emergence of 12 d and 21 d respectively.

Table 9. Estimated percent overall yield loss or gain for each stand establishment outcome with occurrences of 10, 20, and 30% of the total plant density

Total plant density‡	Stand establishment outcome†			
	Skip	LEearly	LElate	Double
%		yield loss/ gain, %		
10	-8	-1	-2	3
20	-17	-2	-5	7
30	-25	-2	-6	10

† Skip, plant spacing >30.5 cm; Double, < 5.1cm; LEearly, emerged 5-10 d after normal emerged plant; LElate, emerged 11-17 d after normal emerged plant.
‡ Based on 74 100 plants ha^{-1}

However, it is rare to experience only one type of stand establishment outcome in the field, and producers should expect a combination of outcome type. In this experiment, overall yield declined by an average of 4% when an average of 36% (approximately 1 in 3 plants) of the plant density had a combination of all four types of stand establishment variability outcomes occurring.

Factors Impacting Stand Establishment Variability

Since this study has confirmed that stand establishment variability does impact individual ear and overall yield of corn, the next step in the process was to identify factors that might cause greater stand establishment variability and to quantify how they might impact stand establishment variability. However, this proved to be difficult, as very few field environments had the same types or amounts of unfavorable planting conditions at the same time.

Linear prediction models were used to estimate the impact of measure factors on plant stand variability in order to aid producers in understanding what field environments and planting methods impact uneven plant emergence timing and within-row plant spacing variability. However, these were not proposed as a tool to accurately predict stand establishment variability.

Stepwise regression was used to develop the best linear prediction model for overall variability, skips, doubles, LEearly and LElate stand establishment outcomes. Both quantitative and qualitative field environment and planting method variables were included in the model. The following variables were included: previous crop (PC), soil moisture at planting (SM), tillage type (T), percent residue (PR), speed (S), speed by speed (SxS), seeding rate (SR) and soil temperature (ST).

Stepwise regression of overall variability (*V*) with field environment and planting method variables resulted in the following equations for 2013 (Eq. 2), 2014 (Eq. 3) and combined years (Eq. 4):

$V = b_0 + b_1SR + b_2T + b_3ST$ (adj. $R^2 = 0.46$; AIC = -22), (2)

$V = b_0 + b_1ST$ (adj. $R^2 = 0.19$; AIC = -39), (3)

$V = b_0 + b_1PCxT + b_2SxS + b_3S$ (adj. $R^2 = 0.80$, AIC = -81). (4)

The adjusted R^2 values for Eq. 2 and Eq. 4 were quite high, while the AIC values were very low, indicating that most of the variation in overall variability can be explained by the independent variables listed in those best fit models. However, the adjusted R^2 values for Eq. 3 is only 0.19, indicating that most of the variability is not explained by the independent variables included in the model.

Stepwise regression of number of skips (*Sk*) with field environment and planting method variables resulted in the following equations for 2013 (Eq. 5), 2014 (Eq.6) and combined years (Eq. 7):

$Sk = b_0 + b_1T + b_2PR$ (adj. $R^2 = 0.45$; AIC = 7), (5)

$Sk = b_0 + b_1SxS + b_2S + b_3T + b_4PR$ (adj. $R^2 = 0.85$; AIC = 9), (6)

$Sk = b_0 + b_1SM$ (adj. $R^2 = 0.12$; AIC = 52). (7)

The adjusted R^2 values for Eq. 5 and Eq. 6 were quite high, and the AIC values were low, indicating that most of the variation in number of skips can be explained by the independent variables listed in those best fit models. However, the adjusted R^2 values for Eq. 7 is only 0.12, indicating that most is not explained by those independent variables. The AIC is also quite high, indicating the models lack of fit.

Stepwise regression of number of doubles (*D*) with field environment and planting method variables resulted in the following equations for 2013 (Eq. 8) and combined years (Eq.9):

$$D = b_0 + b_1PR \text{ (adj. } R^2 = 0.29\text{; AIC = -7),} \quad (8)$$

$$D = b_0 + b_1PR \text{ (adj. } R^2 = 0.07\text{; AIC = -0.2).} \quad (9)$$

In the combined years (Eq.9) only 7% (adj. $R^2 = 0.07$) of the variation in doubles is explained by PR.

Stepwise regression of number of LEearly (*LE*) with field environment and planting method variables resulted in the following equations for 2013 (Eq. 10), 2014 (Eq. 11) and combined years (Eq. 12):

$$LE = b_0 + b_1PR + b_2S + b_3SxS \text{ (adj. } R^2 = 0.69\text{; AIC = 66),} \quad (10)$$

$$LE = b_0 + b_1PR + b_2PC \text{ (adj. } R^2 = 0.41\text{; AIC = 43),} \quad (11)$$

$$LE = b_0 + b_1PR + b_2PCxT + b_3SxS + b_4STxST + b_5SRxPC + b_6SRxSR + b_7ST \quad (12)$$

$$\text{(adj. } R^2 = 0.94\text{; AIC = 62).}$$

Stepwise regression of number of LElate (*LL*) with field environment and planting method variables resulted in the following equation for 2014 (Eq. 13):

$$LL = b_0 + b_1PC \text{ (adj. } R^2 = 0.11\text{; AIC = 32).} \quad (13)$$

The models generated for variation in number of LElate (Eq.13) explains only 11% (0.11) of the variation in number of LElates by previous crop.

Although it was difficult to identify a specific prediction model to calculate expected stand establishment variability, certain field environments and planting method variables have a consistent presence in the models. These independent variables represent a significant contributing factor to overall stand establishment variability, uneven emergence timing, and within plant spacing variability outcomes. The independent variables with the most occurrences were percent residue and tractor speed, followed by previous crop, tillage, and soil temperature.

The majority of the fields in this experiment were planted in fields with residue cover ranging from 21 to 40% (Table 4). The amount of residue cover has the ability to cause other undesirable planting conditions that are known to impact stand establishment variability. Past studies have shown that percent residue induces uneven soil temperatures and soil moisture (Nielsen, 2015). Planting issues of lack of consistent planting depth, reduced ability of planter performance, and reduced seed to soil contact can also occur in high residue fields (Stoll and Saab, 2015).

Studies have shown that increasing planting speed causes a decrease in yield and an increase in within-row plant spacing variability. Lauer and Rankin (2004) found a decrease in yield of 4% when speed increased from 6.4 to 12.8 km h^{-1}, as well as an increase in plant spacing standard deviation when speeds increased from 6.4 to 12.8 km h^{-1}. A study conducted by Liu et al. (2004a) also found an increase of plant spacing standard deviation as planting speed increased. In their research, the greatest effect from speed was under no-till when speeds increased from 7.2 to 11.3 km h^{-1}. In the fields monitored in the research reported here, the majority of planting speeds ranged from 7.3 to 8.8 km h^{-1} (Table 3).

The model for overall variability in combined years (Eq.7) includes an interaction of previous crop with tillage. In this study, there were too few observations of certain previous crop type in order to make a statistical inference on which previous crop has the greatest impact on uneven plant emergence and within-row plant spacing (Table 4). A study conducted by Duvick et al. (2006) found that a corn-corn rotation with no-till had the greatest negative effect on yield and growth when compared with corn-soybean with conventional till.

Soil temperatures at planting are typically below the optimum 29 ^{o}C for corn germination and emergence (Stoll and Saab, 2015). In this experiment, the bare soil temperature averaged over two weeks after the planting date for all locations over both years was 15.8 ^{o}C. Varying soil temperatures can be attributed to physical characteristics of the soil such as color and texture (Nielsen, 2015). However, the amount of residue on the soil surface also plays an important role in soil temperature. Heavy residue areas will be cooler than others, also whole fields can experience reduced soil temperatures in reduced tillage systems (Nielsen, 2015; Carter et al., 2001).

Most research studying the impact of uneven emergence and within-row plant space variability on yield has been conducted on small scale, hand planted plots. Some research has been done to identify factors that impact stand establishment variability. These studies were conducted on fields planted with farming implements in large scale fields. However, even these experiments applied the field environments or planting methods in question as controlled factors to the field, or identified one as the main contributing limiting factor in that field. This type of design aided the researchers to more accurately identify the level of impact the specific field environment or planting method had on stand establishment variability. Future experiments could be conducted locally in order to generate accurate prediction models for stand establishment variability in North Dakota.

Effects of Quantitative Field Environment and Planting Methods on Stand Establishment Variability

Linear correlation was applied to quantitative factors of percent residue, speed, soil temperature and seeding rate, with the goal of identifying the strength and direction of relationships between stand establishment variability factors and field environments and planting methods.

The correlation matrix found few significant relationships between the listed field environment and planting methods with stand establishment outcomes (Table 10). This result could be attributed to the point that no two fields can be expected to have the same amount or combination of non-ideal planting environments or methods and the relatively small number of observations used.

Table 10. Correlation between stand establishment type and quantitative field environments and planting methods using linear correlation.

Stand establishment type†	Percent Residue	Planting Speed	Soil temperature	Seeding Rate
	r value			
Variability	0.42‡	0.33	-0.13	-0.53*
	(0.01)§	(0.06)	(0.43)	(0.001)
Skips	-0.25	-0.08	0.26	-0.12
	(0.17)	(0.70)	(0.16)	(0.52)
Doubles	-0.41*	0.21	-0.09	0.34
	(0.02)	(0.29)	(0.62)	(0.06)
LEearly	0.67*	-0.01	-0.03	-0.29
	(<0.0001)	(0.97)	(0.86)	(0.11)
LElate	0.19	0.18	-0.08	-0.22
	(0.30)	(0.35)	(0.66)	(0.25)

† See Eq. 1 for definition of variability; Skips, plant spacing >30.5 cm; Doubles plant spacing <5.1 cm, LEearly, emerged 5-10 d after normal emerged plant; LElate, emerged 11-17 days after normal emerged plant.

‡Significant at the 0.05 probability level.

§ *P* values.

Linear regression models were built for the significant correlations with slopes greater or less than zero. Positive linear relationships occurred between overall variability and percent residue (Eq. 14) and number of LEearly plants and percent residue (Eq.15). Negative linear relationships occurred between number of doubles and percent residue (Eq.16),

$$y = 1.1309 + 0.0068x, \tag{14}$$

$$y = 0.3114 + 0.1729x, \tag{15}$$

$$y = 0.9607 - 0.0117x, \tag{16}$$

Again, percent residue occurred the most with having a significant effect on stand establishment variability. According to the model (Eq. 14 and Eq. 15), when percent residue increases, overall variability and number of LEearly plants increases. When percent residue increased, the number of doubles decreased (Eq. 16). However, when reviewing the model for each variable relationship (Eq. 14 through 16), for every increase, or decrease, in percent residue there is very little change in the variable. This indicates the producer would need a substantial change in percent residue to see any effect on overall variability, emergence and doubles.

CONCLUSIONS

Uneven plant emergence timing and within-row plant spacing variability effects on corn yield generally followed the expected trends based on results from previous research. Despite the differences in rainfall and rate of AGDD between the two years, corn yield responded similarly to uneven plant emergence timing and within-row plant space variability in both years.

Uneven plant emergence timing and within-row plant spacing variability impacted individual ear weight. The amount of per plant yield loss due to uneven emergence increases (35 to 41%) as the number of days (5 to 17 d) after normal emergence increased. The amount of loss due to within-row plant spacing variability is dependent on the type; skip or double. Plants next to skips had a greater weight by 11% compared with the NED ear, but did not compensate for the missing ear. When two plants situated in the double are combined, there is a 35% increase in ear weight.

The percentage of overall yield loss is dependent on the proportion of the overall stand that is delayed Nafzinger et al. (1991). In this study, LEearly and skips occurred the most often followed by LElate and Doubles. When an average of 36% (approximately 1 in 3 plants) of the plant density had stand establishment variability, overall yield declined by an average of 4%.

Percent residue, planting speed, previous crop, tillage and soil temperature did have a consistent presence in the regression prediction models, indicating their increased ability to impact stand establishment variability. Percent residue was also identified as having significant linear correlation relationships with overall variability, doubles and LEearly stand establishment outcomes. However, whether it was a positive or negative correlation was not consistent.

Past studies have identified specific field environments and planting methods such as soil temperature, soil moisture, tillage type, percent residue, soil compaction, planter type and planting speed to have an effect on uneven plant emergence timing and within-row plant space variability (Boomsma et al., 2006; Carter et al., 2001; Lauer et al., 2004; Liu et al., 2004a; Ramazan et al., 2012; Saab, 2012). It is important that the producer has an understanding that these field environments and planting methods do have an impact on final stand establishment. It is also important the producer understands the presence of uneven emergence and skips will reduce yields. Producers must apply these indications and assess each field individually in order to make best management decisions that will lead to reduced uneven plant emergence timing and within-row plant spacing variability.

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APPENDIX

Table A1. ANOVA for average weight of individual ears for 2013-2014

SOV	Df	MS	*F*
Env	28	0.03175924	8.40*
Trt	6	0.09018114	23.84*
Env x Trt	111	0.00460121	1.22
Error	365	0.00378221	

* Significant at ($p \leq 0.05$).

Table A2. ANOVA for percent of the mean weight of the ear from a normal emerged plant for 2013-2014

SOV	df	MS	*F*
Env	22	2268.6807	4.04*
Trt	6	20656.8058	36.77*
Env x Trt	97	1250.1614	2.23*
Error	325	561.8080	

* Significant at ($p \leq 0.05$).

Table A3. ANOVA average yield of variable rows for 2013

SOV	df	MS	*F*
Env	14	109514221	121.09*
Trt	3	805435	0.89
Env x Trt	42	1573061	1.74
Error	81	904433	

* Significant at ($p \leq 0.05$).

Table A4. ANOVA average yield of variable rows for 2014

SOV	df	MS	*F*
Env	11	73276805.7	103.96*
Trt	3	8298310.0	11.77*
Env x Trt	33	517838.1	0.73
Error	75	704874	

* Significant at ($p \leq 0.05$).

Table A5. ANOVA average yield of variable rows for 2013-2014

SOV	df	MS	*F*
Env	26	90193217	111.56*
Trt	3	6196980	7.66*
Env x Trt	78	1159506	1.43*
Error	156	808491	

* Significant at ($p \leq 0.05$).

Table A6. Field environment and planting methods for fields in the NE and NW regions observed in 2013

County	Region	Planting date	Seeding rate	Planting speed	Corn planter type†	Tractor wheel type	Previous crop‡	Percent residue	Tillage type§	Row spacing	Soil moisture¶
			seeds ha^{-1}	km h^{-1}				%		cm	
Benson	NE	5/15	76 570	8.4	CH	Wheel	Barley	30	Con	76	Moist
Benson	NE	5/28	79 040	8.0	CH	Wheel	Barley	30	Con	76	Moist
Benson	NE	5/20	78 546	9.7	CH	Wheel	Barley	15	Con	76	Moist
Eddy	NE	5/14	74 100	7.0	IH	Wheel	Barley	20	MT	76	Moist
Foster	NE	5/16	74 100	8.0	CH	Wheel	HRSW	48	Con	76	Moist
Foster	NE	5/24	86 450	8.5	CH	Wheel	Soybean	29	Con	76	Moist
Ramsey	NE	5/25	79 040	9.6	CH	Wheel	Dry bean	NA#	Con	76	Soggy
Walsh	NE	5/15	86 450	7.0	CH	Track	Soybean	30	Con	56	Moist
Wells	NE	6/02	88 920	NA	CH	Wheel	Dry bean	17	Con	76	Moist
Renville	NW	NA	71 630	NA	CH	NA	HRSW	68	Con	76	Soggy
Renville	NW	NA	71 630	NA	CH	NA	HRWW	64	NT	76	Soggy
Ward	NW	5/11	70 395	8.8	IH	Wheel	HRSW	30	Con	76	Moist
Ward	NW	5/17	79 040	9.6	CH	Wheel	Canola	30	Con	76	Moist
Ward	NW	5/25	49 400	8.8	CH	Wheel	Pea	30	Con	76	Soggy

† CH,central fill hopper; IH, individual fill hopper.

‡ HRSW, hard red spring wheat; HRWW, hard red winter wheat.

§ Con, conventional; MT, minimum tillage; NT, no tillage.

¶ Dry, soil that did not hold together when trying to form a ball; Moist, soil that held together when made into a ball; Soggy, water from soil ran out of the formed ball and over the hand.

NA, not available.

Table A7. Field environment and planting methods for fields in the SE and SW regions observed in 2013

County	Region	Planting date	Seeding rate	Planting speed	Corn planter type†	Tractor wheel type	Previous crop‡	Percent residue	Tillage type§	Row spacing	Soil moisture¶
			seeds ha^{-1}	km h^{-1}				%		cm	
Barnes	SE	5/16	75 335	8.0	IH	Wheel	Soybean	10	Con	56	Moist
Barnes	SE	5/17	82 745	8.0	CH	Wheel	Soybean	17	NT	76	Moist
Barnes	SE	5/13	83 980	8.0	CH	Wheel	Soybean	17	NT	76	Moist
LaMoure	SE	5/09	83 980	NA	CH	Wheel	Corn	40	Con	76	Moist
LaMoure	SE	5/10	83 980	7.0	CH	Track	Soybean	70	Con	76	Moist
LaMoure	SE	5/12	76 570	8.0	CH	Wheel	Soybean	35	Con	76	Moist
Stutsman	SE	5/07	79 040	7.7	CH	Wheel	Soybean	40	Con	56	Moist
Stutsman	SE	5/12	74 100	8.8	CH	Wheel	Soybean	36	Con	76	Moist
Stark-Billings	SW	5/07	59 280	NA	CH	NA	Soybean	82	NT	76	Moist
Stark-Billings	SW	5/13	51 870	8.8	CH	Wheel	HRSW	75	MT	76	Moist
Stark-Billings	SW	5/06	51 623	8.0	CH	Wheel	HRSW	75	NT	76	Moist

† CH,central fill hopper; IH, individual fill hopper.

‡ HRSW, hard red spring wheat.

§ Con, conventional; MT, minimum tillage; NT, no tillage.

¶ Dry, soil that did not hold together when trying to form a ball; Moist, soil that held together when made into a ball; Soggy, water from soil ran out of the formed ball and over the hand.

NA, not available.

Table A8. Field environment and planting methods for each field observed in 2014

County	Region	Planting date	Seeding rate	Planting speed	Corn planter type†	Tractor wheel type	Previous crop‡	Percent residue	Tillage type§	Row spacing	Soil moisture¶
			seeds ha^{-1}	km h^{-1}				%		cm	
Eddy	NE	5/20	74 100	7.2	CH	Wheel	Soybean	21	Con	76	Moist
Foster	NE	5/16	86 450	8.0	CH	Wheel	Soybean	18	Con	56	Moist
Steele	NE	5/17	86 450	8.0	CH	Wheel	Soybean	10	Con	56	Moist
Wells	NE	5/15	76 570	7.6	CH	Wheel	HRSW	58	Con	76	Moist
Renville	NW	5/17	69 160	8.9	CH	Wheel	Soybean	28	NT	76	Soggy
Renville	NW	5/24	69 160	8.0	CH	Wheel	Soybean	28	NT	76	Soggy
Ward	NW	5/17	65 455	7.6	IH	Wheel	HRSW	10	Vertical	76	Moist
Barnes	SE	5/20	81 510	8.0	IH	Wheel	Soybean	37	Vertical	56	Moist
Barnes	SE	5/18	76 570	8.0	IH	Wheel	Soybean	35	Vertical	76	Moist
Stutsman	SE	5/21	71 630	7.4	CH	Wheel	Soybean	20	Vertical	56	Moist
Stutsman	SE	5/22	84 923	8.0	IH	Wheel	Soybean	53	NT	76	Moist
Stutsman	SE	5/21	71 630	7.4	CH	Wheel	Soybean	12	Vertical	56	Moist
Sargent	SE	5/28	79 040	12.0	CH	Track	Soybean	25	Con	56	Dry

† CH,central fill hopper; IH, individual fill hopper.

‡ HRSW, hard red spring wheat.

§ Con, conventional; MT, minimum tillage; NT, no tillage.

¶ Dry, soil that did not hold together when trying to form a ball; Moist, soil that held together when made into a ball; Soggy, water from soil ran out of the formed ball and over the hand.