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OPTIMIZING CORN SEEDING DEPTH BY SOIL TEXTURE TO ACHIEVE UNIFORM STAND

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Abstract. *Corn (Zea mays L.) yield potential can be affected by uneven emergence. Corn emergence is influenced by both management and environmental conditions. Varying planting depth and rate as determined by soil characteristics could help improve emergence uniformity and grain yield. This study was conducted to assess varying corn seeding depths on plant emergence uniformity and yield on fine- and coarse-textured soils. Research was conducted on alluvial soil adjacent to the Missouri river with contrasting soil textures (fine sand and silty clay loam) in close proximity to each other. Treatments included four seeding depths (38, 51, 64, and 76 mm), at three population rates (62000, 74000, and 86000 seeds per hectare), and no starter vs. starter fertilizer (46.7 L ha^{-1} 6-24-6). Emergence uniformity and grain yield were measured within a portion of all plots. Initial results from the first year (2017) of the three year project showed that corn emerged quicker at the shallowest depth (38 mm) on the coarser soil. However, planting depth did not influence final yield. However corn yield and emergence in the fine-textured soil was influenced by planting depth. Planting Seed at the 76 mm planting depth resulted in a 0.6 Mg ha^{-1} yield increase over the 38 mm depth. Not surprisingly, corn emerged more evenly at the 76 mm depth. Preliminary results suggest that corn planted deeper in fine-textured soils have improved emergence uniformity and higher yield potential. Planting depth may have little influence on corn yield in coarser-textured soils. These results indicate that variable seeding depth may be beneficial on fields with large variations in soil texture.*

Keywords. *Variable seeding depth; Corn; Uniform stand, Yield components.*

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INTRODUCTION

A uniform planting environment promotes timely emergence and maintains yield potential for corn. The immediate surroundings of a corn seed determine the performance of two vulnerable plant phases, germination and emergence. The immediate seedbed environment is comprised of multiple factors and determines seedling establishment. Variations in soil properties and conditions often exist over small distances within fields. These variations affect how a planter behaves as it is used to plant seed within a field. These variations can reduce the likelihood of achieving uniform seed placement. Therefore, differences in soil properties could justify variable planting management specific to the conditions at any given location in order to homogenize germination. Understanding the agronomic processes involving corn emergence and establishment under variable within-field soil conditions may be necessary to achieve maximum productivity.

Factors Impacting Corn Germination and Emergence

The initial phases of plant growth are the most vulnerable stages in the production season. Germination is initiated by involuntary water imbibition. The rate of water uptake and probability for successful germination is dependent on temperature (Hayhoe et al. 1996). Both temperature and moisture have a range hospitable for germination, including optimum values where germination rate is maximized. Maximum percent germination occurs when environmental conditions are equivalent to optimal values in temperature and moisture (Hadas et al. 2004). Plant available water, determined by soil matrix potential and hydraulic conductivity, is more important than the volume of soil water present (Knappenberger & Köller 2008). Minimum values for mean soil temperature and matrix potential enabling corn germination are 10^{o}C and -1.5 MPa, respectively (Knappenberger & Köller 2008).

As corn seed/seedlings uptake water they become less tolerant to cold stress. Although moisture is important, germination initiated by the imbibition of chilled water reduces seedling vigor (Stoll & Saab 2016). Avoiding injury from cool temperature is essential in achieving uniform stand establishment. Ensuring that seeds are planted into soil temperature of ≥10^{o}C accompanied with a favorable weather forecast for at least 24-48 hr after planting will avoid cold injury (Stoll & Saab, 2016). Cool temperatures and excessively wet or dry moisture conditions can lead to slow germination, physiological deformities, or seedling death (Hoeft et al. 2000).

Similar to germination, seedling emergence is impacted by soil properties such as texture, temperature, moisture, aggregate size, and bulk density (Hadas et al. 2004). Seedling emergence is reduced in clay soils when planting is followed by a heavy rain event that reorganizes soil structure. This leads to a compacted or “sealed” soil surface layer that is often referred to as soil crusting. Seeds developing under these conditions encounter less available water and possess insufficient force to emerge through the soil surface (Hadas et al. 2004). When soil becomes compacted and bulk density increases, root development becomes hindered and can lead to loss of photosynthate to soil (Tubeileh et al. 2003). Various cultural practices, including tillage method or inclusion of cover crops, influence the aforementioned soil characteristics (Dam et al. 2005; Haruna et al. 2017). Dam et al. (2005) highlighted that corn emergence was hindered when no-till planted into residue as a result of cool soil temperatures and high moisture content. In addition to cool temperatures, residue can negatively affect emergence by reducing seed-soil contact (Swan et al. 2006). To ensure prompt germination and acceptable emergence, residue should be cleared from row and seeds planted sufficiently deep into adequate moisture. Generally, emergence occurs within 6 to 10 d of planting. However, it may be delayed days or weeks in cool dry or wet conditions. Most corn varieties are capable of emergence from depths of 10 to 13 cm, although planting depth may impact emergence timeliness and uniformity (Hoeft 2000). Current planting recommendations suggest a minimum planting depth of 3.8 to 5.1 cm to ensure crown and nodal roots developing at a soil depth of 2 cm (Thomison et al. 2013). Despite management practices attempting to improve seedling germination and emergence, in-field variability may result in a range of within-field conditions, encompassing both optimal and sub-optimal planting environments. If seedbed conditions differ greatly within field, fluctuations in temperature and moisture availability may cause non-uniform plant establishment and plant to plant variability.

Plant-To-Plant Variability in Emergence Impacts Yield

In corn, plant-to-plant variability (PPV) can significantly reduce yield. PPV considers the relative uniformity in plant spacing, emergence timing, and final yield of neighboring plants (Bos 2012). Non-uniformity of stand establishment and the subsequent PPV can lead to significant yield losses. Fields with multiple landscape positions or several soil textural classes may create large differences in seedbed characteristics leading to undesired PPV.

Neighboring plants compete for resources, and competition increases with increasing variation in plant development. Differences in plant development can be attributed to various factors due to early and mid-season conditions. Early season factors such as in-row spacing or emergence uniformity can cause significant PPV. In-row spacing variation may result from multiple seeds deposited at a single location or areas missed entirely causing a gap. In addition to spatial uniformity, temporal emergence uniformity is required to achieve maximum plant and crop yields. Results from Liu et al. (2004) indicated that maintaining equidistant spacing was important, however greater yield reduction would result from variable plant emergence temporally. The spatial research pointed out that a double or triple seed placement would reduce yield by 6 to 10 %, but if plant populations were equivalent to an equidistant spacing, yield loss would be minimal. Temporal delay in emergence by two or four leaf stages impacted yield by 35 to 47% or 72 to 84%, respectively (Liu et al. 2004). Performances of planter type for uniform germination follow the same trend as maintaining uniform spacing. Ensuring timely emergence is closely correlated with choosing the correct depth.

Within-Field Soil and Landscape Variability

Composition of soil particle size in the form of sand, silt, and clay percentage (i.e., texture) has a considerable influence on the soil temperature and water content (Brady and Weil, 2001). Germination and seed establishment can vary substantially depending on the soil texture composition. The characteristics of the soil particles alter conditions according to their size and interactions between particles. Often particle compositions may improve temperature conditions while providing suboptimal moisture conditions, or vice versa. Due to this tradeoff, planting into soil below field capacity requires consideration of soil particle composition and the associated matrix potential.

Across Missouri landscapes, spatial variability in soil moisture and temperature often exist due to variations in soil texture and landscape position (Sudduth et al. 2001). Many of the productive alluvial soils contain large within-field variation of texture, ranging from soils with high sand to high clay content (Miller and Krusekopf 1918). Similarly, claypan soils in the same region possess landscape position and topsoil depth variations that result in complex hydrologic features (Jamison et al. 1968; Sadler et al. 2015). Drainage characteristics on these soils can cause susceptibility to drought during dry conditions and prolonged saturation during wet conditions. Furthermore, runoff and subsurface lateral flow from upslope positions can result in ponding at low-lying footslope areas. Research has found decreased corn stand and suppressed yield in low lying areas when wet conditions occurred after seeding (Kitchen et al. 1999).

Within field differences in the seedbed environment, including fluctuations in temperature and water content, introduce opportunities for seeding depth and population management. Varying seeding depth and population based on soil conditions could lead to more uniform emergence, uniformity, and yield. The objectives of this analysis were to: i) determine how soil texture impacts the interaction of optimal seeding depth and plant population; and ii) determine how soil moisture and temperature influence optimal seeding depths on coarse- and fine-textured soils.

MATERIALS AND METHODS

A plot study was conducted near Claysville, MO on two contrasting soil textures (sand and silty clay loam) on alluvial soil along the Missouri River. The two soil texture sites were in close proximity to each other (<1 km). At each site the treatments consisted of four seeding depths (targeting 38, 51, 64, and 76 mm), three seeding rates (62000, 74000, and 86000 seed drop ha^{-1}), and no starter vs. starter fertilizer (46.7 L ha^{-1} 6-24-6) arranged in a randomized complete block design with starter as a split plot. Each treatment was replicated four times. Each plot was four rows (0.76 m spacing) wide and 9.1 m long. Both sites were planted on 13 April 2017. Both soil moisture and temperature at planting were adequate for corn emergence. No precipitation occurred within one week following planting. All corn was planted into conventionally-tilled soil with soybean as the previous crop.

Soil apparent electrical conductivity (soil EC_a) was measured with a Veris 3100 (Veris Technologies, Salina, KS, USA) across a large area to identify and establish uniform plot areas within each of two contrasting soil textures. Soil ECa values ranged from 10 to 25 on the sandy site and 25 to 50 milliSiemens per meter (mS m^{-1}) on the silty clay loam site, which from this point forward will be referred to as the 'sand site' and 'clay site' respectively. A soil sensor network was installed on the day corn was planted. CS655 (Campell Scientific, Logan, UT, USA) sensors capturing soil moisture and temperature every 15 min were installed at the four seeding depths within each replicate of both soil sites (n = 32). Sensors were placed parallel to the soil surface in trenches two inches away from seed furrows.

All plant measurements were taken from two 1.5 m long sections from adjacent rows in the center of each plot. Plant emergence was monitored and recorded daily or bi-daily for each plant. Leaf stage and initial plant counts were recorded at the third vegetative stage (V3). Also, corn seeding depth for each treatment was determined on a separate, nearby 3 m section due to the destructive nature of the sampling. At R6, a final stand count and stand spacing was measured on the section where emergence was measured. Lost or late emerging plants were recorded. Ears were harvested from each plant and processed individually to determine yield components. The remainder of the plots were harvested with a plot combine. Weights from the plot combine and the hand-harvested plants were added together to determine whole plot yield.

RESULTS AND DISCUSSION

Emergence Uniformity

Clay. At 7 days after planting (DAP), emergence among planting depths were similar. However, at 8 DAP the total number of emerged plants was 22% greater at the 76 mm than the 38 mm planting depth (Fig. 1). The larger percentage may have been caused by insufficient moisture at the 38 mm planting depth, as no precipitation had occurred after planting. Additionally, the 38 mm depth had 4.5 times more late emergers than the deep planting at 76 mm. According to Carter et al. (1990) uneven emergence is most often a result of dry soil. Delayed emergence in shallow planted corn may be attributed to a lack of moisture that delayed emergence until a significant precipitation event occurred. Cloddy soil and poor seed trench closure may have prevented optimal seed-soil contact and accessibility to soil water.

Emergence uniformity influenced plant yield. Plants that emerged between 7 and 8 DAP had the greatest yield potential. This aligns with other recommendations that encourage rapid and uniform emergence to achieve maximum yield (Nielsen, 2001). Plants that emerged between 9 and 14 d yielded similarly. The yield potential of plants that emerged during this timeframe was 13% less than those that emerged 7 to 8 DAP. Not surprisingly, late emergers (>16 DAP) yielded the lowest, where by-plant yield averaged 152.9 g compared to 230.9 g for the earliest emerging plants.

Sand. At 7 DAP the 38 mm planting depth had the greatest percentage of emerged plants (Fig. 1). The following day, the opposite pattern occurred where the deepest planting depth had the greatest number of emerged plants. Collectively, the total number of emerged plants was similar across planting depths at 8 DAP. The emergence uniformity was attributed to high soil temperature, adequate moisture, and low resistance from the coarse-textured soil. Emergence uniformity was very similar across all planting depths on the sand site.

Contrary to the clay site, differences in by-plant yield were less obvious in the sand site. However, the general trend was the same (Fig. 2). Plants that emerged by 9 DAP achieved the greatest yield. Delayed emerging plants again yielded lower than the earliest emerging plants. Unlike the cloddy aggregates that exist at the clay site the soil at this location was a fine sand that likely improved seed-soil contact. Despite moisture sensors indicating relatively lower volumetric water content at the sand site than the clay site (Table 1, 2), the aggregate structure characteristics of the coarse soil likely improved row closure and moisture availability.

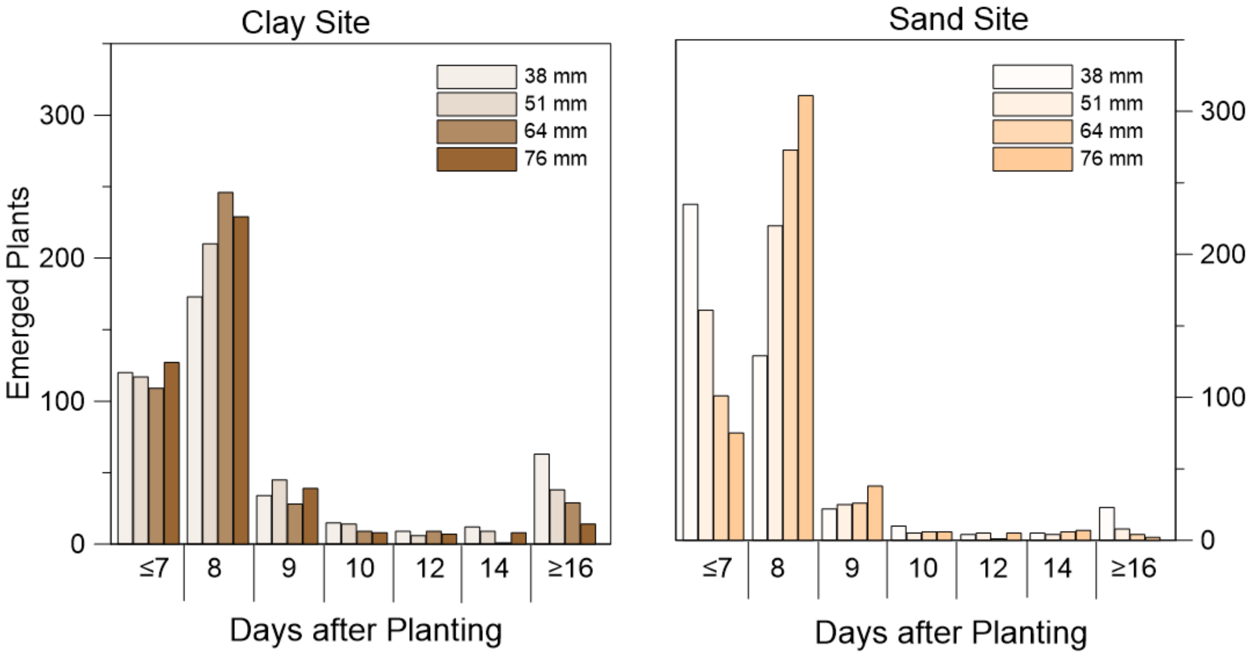

Figure 1: Corn plant emergence (%) relative to days after planting showed that deep planting on fine textured soil (left) resulted in greater emergence eight days after planting than shallow planting. Days to emergence on the coarse textured soil (right) was similar over planting depths.

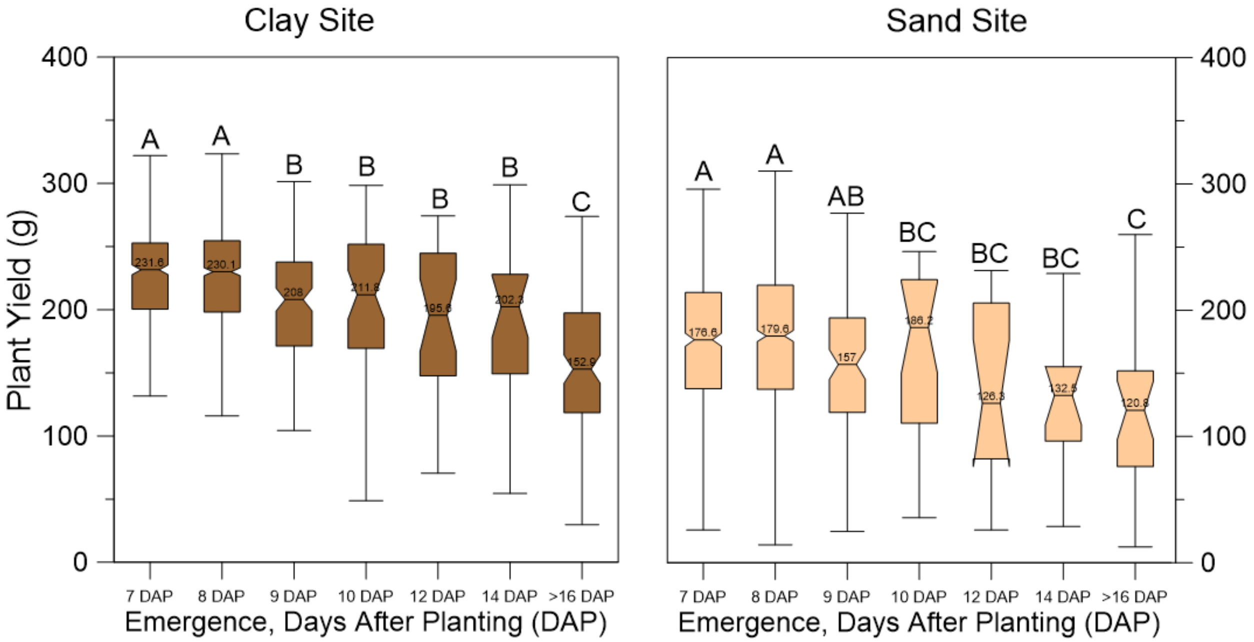

Figure 2: Corn yield per plant for fine textured soil (left) and coarse textured soil (right) displayed similar trends in yield reduction by delayed emergence. The box midline represents the median, the box notch represents the 95- confidence interval around the median, the upper and lower edges of the box represent the 25 to 75 percentiles, and the whiskers represent the range.

Yield

Clay. In 2017 yields were 0.6 Mg ha^{-1} greater at the 76 mm depth than the 38 mm depth (Fig. 3). No differences were found between the 38 mm, 51 mm, and 64 mm depth. Soil temperatures at planting were between 20 to 25 °C (Table 1). At these temperatures results from Gupta et al. (1988) indicated that emergence differences were minimal given sufficient moisture. The yield difference between the 38 mm and 76 mm depth may have been caused by soil moisture, which averaged 29.2% greater at the 76 mm than the 38 mm depth across replications over the first 8 d after planting (Table 1). Additionally, the more even emergence observed at the 76 mm depth likely positively influenced grain yield. These results are similar to those reported by Cox and Cherney (2015) which considered shallow planting depths to pose a greater risk of reduced yields. Interestingly, yield at the 64 mm depth had the least variation in yield, suggesting greater yield stability and supporting the aforementioned research that showed reduced risk with greater planting depths. These results suggest that planting deeper (>76 mm) may lead to increased yield and greater yield stability.

Sand. No difference in yield was observed on the coarse-textured soil across planting depth treatments. This response is reflective of the emergence uniformity and by-plant yield data from this site. Since the majority of plants emerged in the period that achieved the greatest by-plant yield, it is not surprising that yield was not affected by planting depth. Similar to the fine-textured site, there was a reduction in yield variability at the 64 mm planting depth. The decrease in variability may arise at this planting depth due to: i) potentially less interaction with surface residue; and ii) less impact of large aggregates influencing seed-soil contact that may exist at shallow seeding depths. Differences in moisture were less apparent in the sand textured site compared to clay site (Table 2).

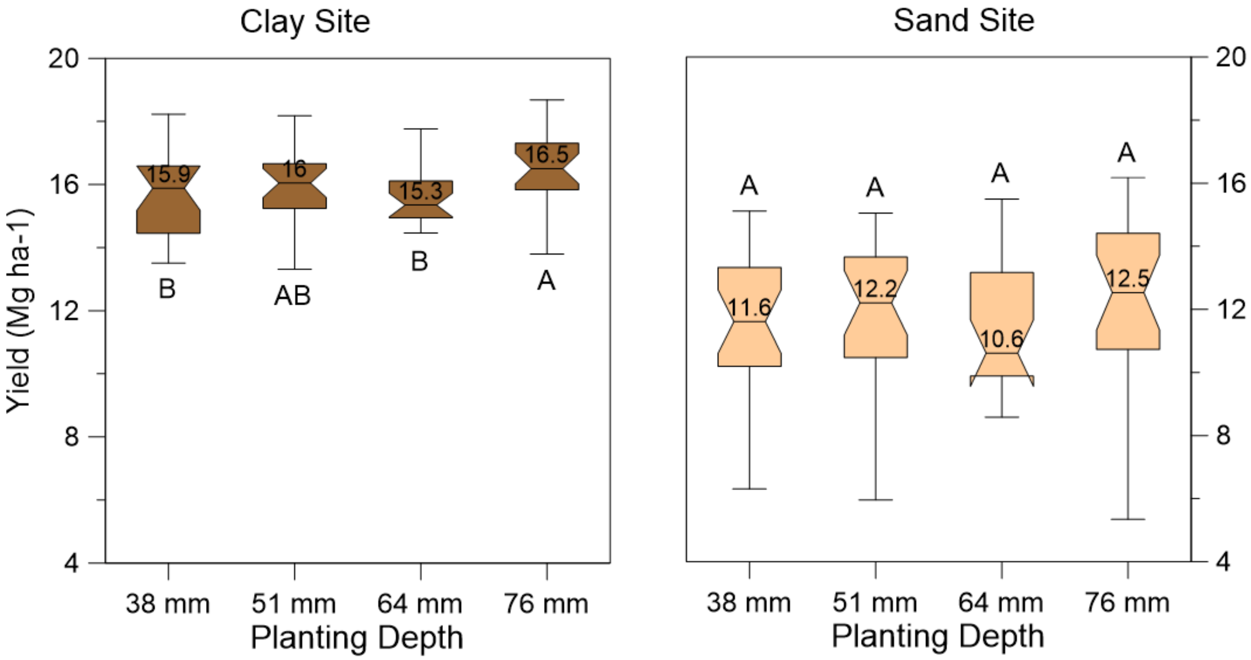

Figure 3: Corn yield grown within a single field on a fine textured soil (left) was influenced by planting depth, but was not when grown on a coarse textured soil. The box midline represents the median, the box notch represents the 95- confidence interval around the median, the upper and lower edges of the box represent the 25 to 75 percentiles, and the whiskers represent the range.

Table 1 Daily cumulative percent emergence of final stand on fine textured soil site following planting on April 13 with cumulative growing degree days in Celsius and average daily volumetric water content. Final emerging plants in each treatment occurred at some point after April 26

Clay Site	**38 mm Planting Depth**			**51 mm Planting Depth**			**64 mm Planting Depth**			**76 mm Planting Depth**		
Date:	Emergence, %	Soil GDD, C	Water Content, % Vol.	Emergence, %	Soil GDD, C	Water Content, % Vol.	Emergence, %	Soil GDD, C	Water Content, % Vol.	Emergence, %	Soil GDD, C	Water Content, % Vol.
19-Apr	28.2	81.7	11.7	26.7	79.1	28.3	25.3	77.1	38.2	29.4	75.2	41.3
20-Apr	68.8	93.0	11.4	74.5	90.3	27.9	82.4	88.2	37.8	82.4	86.4	41.1
21-Apr	76.8	99.7	11.3	84.7	97.2	27.1	88.9	95.3	37.0	91.4	93.8	40.1
22-Apr	80.3	103.7	16.2	87.9	101.6	29.8	91.0	100.1	38.0	93.3	98.9	40.2
24-Apr	82.4	117.7	14.0	89.3	115.2	28.6	93.0	113.5	37.9	94.9	112.4	40.6
26-Apr	85.2	132.9	25.3	91.3	130.4	36.2	93.3	129	41.9	96.8	128.0	43.2

Table 2 Daily cumulative percent emergence of final stand on coarse textured soil site following planting on April 13 with cumulative growing degree days and average daily volumetric water content. Final emerging plants in each treatment occurred at some point after April 26

Sand Site	**38 mm Planting Depth**			**51 mm Planting Depth**			**64 mm Planting Depth**			**76 mm Planting Depth**		
Date:	Emergence, %	Soil GDD, C	Water Content, % Vol.	Emergence, %	Soil GDD, C	Water Content, % Vol.	Emergence, %	Soil GDD, C	Water Content, % Vol.	Emergence, %	Soil GDD, C	Water Content, % Vol.
19-Apr	54.9	84.7	8.8	24.2	81.9	13.0	37.6	80.3	15.7	16.9	78.2	16.2
20-Apr	85.0	96.2	8.8	89.7	93.4	12.9	89.0	91.9	15.5	86.9	89.7	16
21-Apr	90.2	102.3	12.0	95.9	99.8	15.8	94.9	98.4	17.7	95.5	96.5	17.7
22-Apr	92.5	105.6	10.2	97.4	103.5	13.9	96.0	102.2	16.5	96.8	100.5	16.6
24-Apr	93.5	120.8	9.6	97.6	118.2	13.3	97.2	116.7	16.0	98	114.6	16.4
26-Apr	94.6	136.6	17.1	99.0	128.9	21.1	98.1	127.0	22.0	99.5	124.6	21.8

Population Rate and Starter

No interaction was present between population rate and seeding depth treatments. Yield was greater in both textures when planting population increased from 62 to 82,000 seeds ha^{-1} (Fig. 4). Good growing conditions throughout 2017 allowed for high yield potential. Therefore the largest population was able to generate the greatest yield in both the fine and coarse textured soil. The clay and sand site yield increased 13% and 19% respectively, when population increased from 62 to 82 0000 seeds ha^{-1}. Starter fertilizer did not influence yield on either soil texture (Fig. 5). Limited effect from starter fertilizer can be attributed to adequate soil test levels with additional fertilizer incorporated prior to planting.

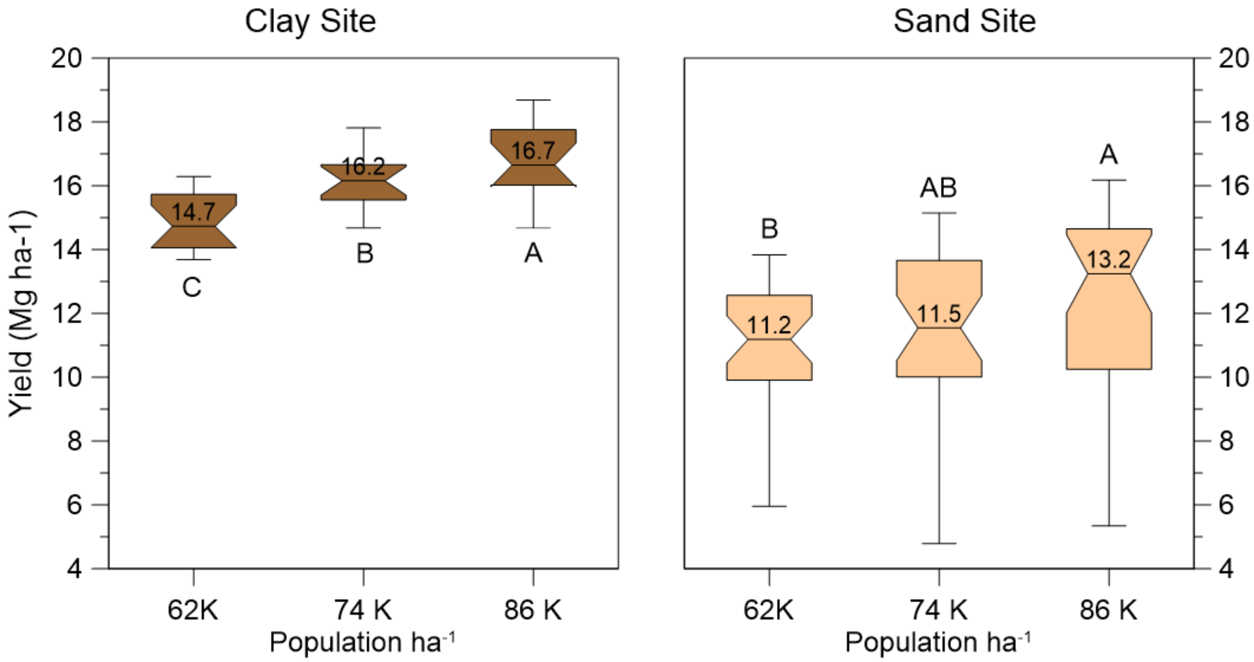

Figure 4: Corn yield across three population rates grown in fine textured soil (left) and coarse textured soil (right) displayed increased yield with increasing population. The box midline represents the median, the box notch represents the 95- confidence interval around the median, the upper and lower edges of the box represent the 25 to 75 percentiles, and the whiskers represent the range.

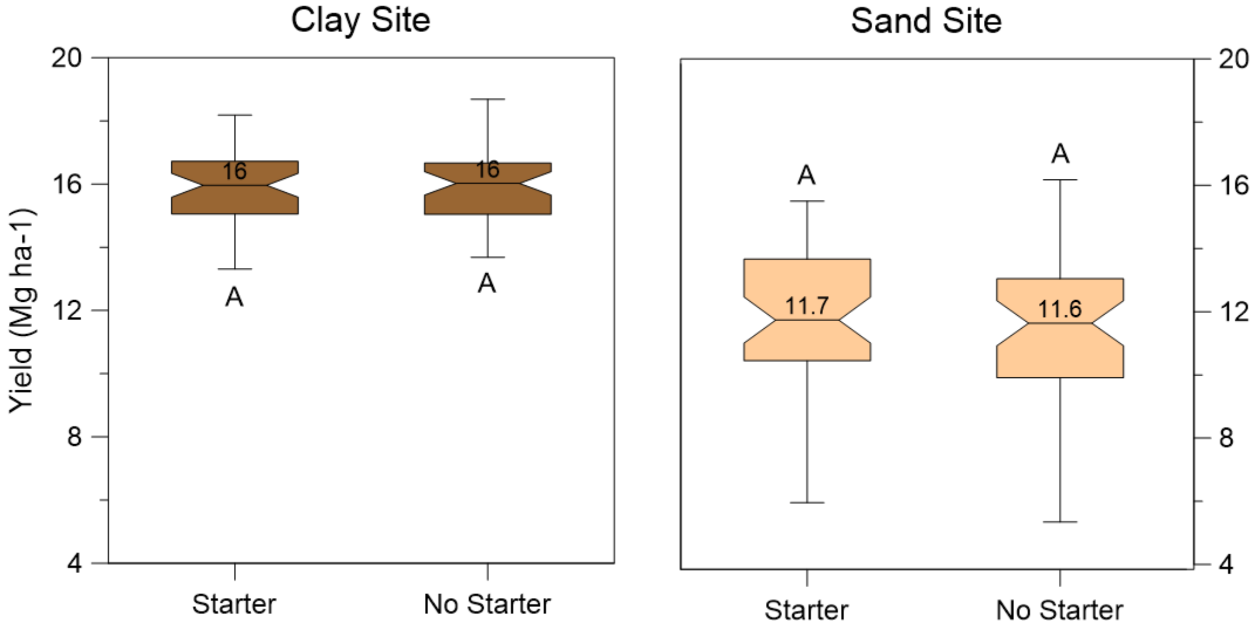

Figure 5: Corn yield grown with and without starter fertilizer in fine textured soil (left) and coarse textured soil (right) showed no effect of starter fertilizer on yield. The box midline represents the median, the box notch represents the 95- confidence interval around the median, the upper and lower edges of the box represent the 25 to 75 percentiles, and the whiskers represent the range.

Summary

These preliminary results suggest that deeper planting is more advantageous than shallow planting, aligning with observations from Cox and Cherney (2015), especially on fine-textured soils. Data also suggests that ideal emergence requires all plants to emerge within 48 hr to maintain maximum yield potential. Additionally, soil texture did influence soil moisture and temperature, which in turn influenced impacts of soil texture on emergence, uniformity, and yield. The largest impact of seeding depth was that yield increased by 4% on the clay site with 76 vs.

38 mm seeding depth. This indicates that variable seeding depth across fields with soil texture variations may be beneficial to growers. Additionally, population rate and starter fertilizer does not affect optimum seeding depth of corn in either coarse or fine textured soil. Understanding field variability is crucial to implementing effective management practices. Specific seeding depth of corn has the potential to homogenize stands and increase corn yield on variable-soil textures. Additional research is needed to determine whether results are consistent in different temperature and moisture conditions. This research will be conducted two more years on similar soils to ascertain if these results will be similar across growing seasons.

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