TOWARDS OPTIMIZATION OF ALTERNATE-SOURCE POTASSIUM APPLICATIONS IN CONSERVATION TILLAGE SYSTEMS FOR MAIZE PRODUCTION

by

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A Thesis

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Master of Science

Department of Agronomy

West Lafayette, Indiana

December 2020

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ACKNOWLEDGMENTS

First, I wish to express my deepest appreciation to Dr. Tony Vyn for his mentorship and the opportunity to learn from him over the past several years. I am sincerely grateful to have had the chance to join Purdue University and work within the Agronomy Department. I would also like to thank my committee members, Dr. T. Scott Murrell and Dr. Corey Gerber, for their invaluable guidance and support.

Thank you to the entire Cropping Systems lab from 2016 to 2019 for their diligent and thoughtful work, with special appreciation to my fellow graduate students, Lia Olmedo Pico, Nicholas Thompson, and Garrett Verhagen, for their roles in collecting/ processing samples, answering my many questions and keeping work light-hearted. Additionally, field and sample processing work would not have been possible without the staffs at ACRE (Mr. Jim Beaty), PPAC (Mr. Gary Tragesser), and ICSC (Mr. Jason Adams).

I also want to acknowledge Eric Galdi for his encouragement and guidance since working as an intern with Corteva Agriscience.

To my parents, Kurt and Julie Schwarck, and sister, Emma Schwarck, thank you for your tireless support and encouragement. I am sincerely indebted to my parents for instilling in me a work ethic and ambition that has led me to a career I truly enjoy.

Finally, thank you to my friends at both Iowa State University and Purdue University for your support in reaching this achievement.

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ABSTRACT

Adoption of conservation tillage systems is known to result in increased soil K stratification. Yet, there have been few investigations into the optimization of K management in these tillage systems, particularly regarding the placement and timing of K-based fertilizer applications. Additionally, there are many unknowns regarding the influence of tillage timing with/ without K fertilizer application. Increased availability of fertilizers containing both macro- and micro-nutrients, such as Aspire™ (which includes both K and B), has coincided with new questions about potential micronutrient deficiencies in maize (*Zea mays* L.) production. Previous research has investigated the influence of K and B individually; however, few university studies utilize multi-nutrient fertilizer sources. These knowledge gaps prompted a series of field investigations into the impacts of alternative tillage/ placement of Aspire™ on maize growth and development. Because K stratification is thought to potentially limit K availability to maize, tillage/fertilizer placement treatments involving no till (NT), fall strip-till (FST), spring strip-till (SST), and fall chisel (FC) were compared with at least two application rates of Aspire™ (ranging from 0 to 108 kg K ha^{-1}) from 2016 to 2019 on Indiana soils with moderate exchangeable K concentrations. Maize was grown in rotation with unfertilized soybean (*Glycine max* L) planted after strip-till.

Although tillage systems, other than no-till, were intended to decrease stratification, little change in vertical stratification for in-row samples was observed in the strip-till systems when Aspire™ was band applied at the time of strip-till (indicating fertilizer application was limited to the top several centimeters of soil). Few interactions were evident in maize response between tillage/placement and Aspire™ applications; however, superior V6-stage growth/nutrition responses to Aspire™ application occurred in fall tillage systems (FST or FC). The latter was especially true when comparing the two strip-till timings (FST and SST) at three rates. In addition

to early season plant nutritional benefits, plant stature also benefited from Aspire™ across tillage/ placement systems (e.g., ~20% increase in height at V8, plus a leaf area index (LAI) gain at V14 of ~10%) reflecting on the potential to increase the source capacity of fertilized maize plants. By R1, there was little synergism between treatments in the tested parameters, indicating little difference among the tillage/ placement methods (and strip-till timing), and few immediate consequences from 50% rate reduction for Aspire™ in the strip-till systems. Although grain yield increases of 4-8% were common when Aspire™ was applied, yield component analysis showed little interaction between tillage/placement and Aspire™. Grain yields were shown to be more highly correlated and had significant relationships to earleaf K at R1, and less so with minor changes in B concentrations at R1.

Aspire™ application at the full and 50% rate commonly benefited plant nutrition and grain yield, but little synergism between Aspire™ application and tillage/ placement system was evident. Although rate reduction did not show immediate consequences to plant nutrition in either strip-till timing, longer-term research is necessary to better understand future consequences from this management practice. The lack of differences in response to strip-till timing (fall vs. spring) shows the potential for flexible timing when optimum tillage conditions are present. This research confirmed the importance of K fertilization to maize performance, but the efficient management of K requires further inquiry.

CHAPTER 1. REVIEW OF AGRONOMIC LITERATURE IN POTASSIUM (K) AND BORON (B) MANAGEMENT IMPACTS ON SOIL AND PLANT COMPOSITION

1.1 Introduction

Understanding the nutritional requirements for maize (*Zea mays* L.) to reach maximum yield potential has become of great importance worldwide; however, questions remain regarding nutrient management and fertilizer source influence on maize growth and development. New fertilizer sources allow farmers to apply multiple nutrients simultaneously but frequently are not used in research. This literature review will focus on previous plant nutrition research (primarily in maize) related to potassium (K) and boron (B). Both nutrients play pivotal roles in maize growth and development but are rarely investigated within the same study. To further the knowledge for farmers wanting to utilize multi-nutrient fertilizer sources, research must describe how these specialized fertilizers impact maize. An overview of current K and B knowledge are presented in separate sections in this chapter due to the lack of research describing their co-application. Some ideas on how these nutrients influence one another within the plant are also presented. Research must evaluate how management needs to adapt because of the continual development of new fertilizer technologies and emerging deficiencies from increasingly intensive crop production practices. To effectively create recommendations, researchers must utilize modern genetics and capture treatment responses under a range of environmental conditions. The objectives for this chapter are to (i) summarize previous studies and review papers related to how K and B are affected by management (i.e., tillage, fertilizer placement, fertilizer application rate, etc.), (ii) identify the importance of research related to K and B for maize growth and development, (iii) recognize future research needs related to K and B nutrition in maize, and (iv) introduce a new fertilizer available to producers that applies both nutrients.

1.2 Potassium (K)

K is an essential macronutrient to maize development and is involved in a multitude of internal processes (i.e., enzyme activation, water regulation, photosynthesis, assimilate transport, etc.) (Pettigrew, 2008). Potassium influences multiple systems within the plant to improve tolerance to stresses, both abiotic and biotic (Armstrong & Griffin, 1998; Wang et al., 2013). Low soil temperatures are of concern to Midwest agriculture at the beginning of the growing season following planting. Armstrong and Griffin (1998) reference an Indiana study looking at mitigating frost damage from low soil and air temperatures early in the growing season by adding K fertilizer and reported a 1.6 Mg ha^{-1} increase in maize yield. Increasing the concentration of K in plant cells lowers the freezing point within the cell, protecting cellular integrity (Wang et al., 2013).

Previous research shows the importance of K to help a crop adapt to a range of moisture regimes. The role of K in drought response is tied to the conservation of water (stomatal aperture and internal water movement) and the regulation of sugar transport (previous research has shown K to have importance in the regulation of sugar transport and the accumulation of sugars within the plant) (Wang et al., 2013). Under conditions of excess moisture, increasing K concentration in plant tissues has improved nutrient uptake, photosynthate production, and plant growth (Wang et al., 2013).

In addition to abiotic stresses that have the potential to limit the growth and development of a plant, biotic stresses (infection or damage from pests and disease) pose a threat experienced across all environments. Low levels of plant-available K in the soil leads to the development of plants more susceptible to infection from pests in the environment due to thinner cell walls, weaker stalks, reduced root mass, sugar accumulation in leaves, and accumulation of unused N (Armstrong & Griffin, 1998; Wang et al., 2013). Increasing plant-available K in the soil can lead to plants better able to resist infection or damage from biotic stresses.

1.2.1 Leaf Area and Plant Stature

Because of the importance of K across systems within the plant, a lack of K can lead to reductions in plant stature and leaf area. Pettigrew (2008) summarizes studies from Cassman et al. (1989), Ebelhar and Varsa (2000), Heckman and Kamprath (1992), Mullins et al. (1999), and Pettigrew and Meredith (1997), which all documented limitations in K leading to reductions in leaf area and stature in a variety of crops [i.e., corn, alfalfa (*Medicago sativa* L.), cotton (Gossypium hirsutum L.), etc.]. Interestingly, the Cassman et al. (1989) study utilizing cotton found significant increases in plant stature following K application, revealing increases of 14% in leaf area index (LAI), 3% increase in node number, and 2% increase in plant height. Reduction in leaf area, in particular, can be caused through either a decrease in number of leaves, leaf size, or both (Pettigrew, 2008). A similar study was conducted in maize by Jordan and Pellerin (2004), evaluating leaf area and plant architecture. From this study, the authors found the control (0 K) plants had reduced LAI due to slower leaf emergence and smaller final leaf size. Reductions in leaf area impact plant photosynthetic capacity, thereby lowering the capacity of the source tissue. Several studies by Pettigrew investigated specific leaf weight changes in cotton following fertilization with K. Fertilized plants had decreased specific leaf weight when compared to the control (0 kg K ha^{-1}) treatment, with one study finding a 12% decrease in specific leaf weight when compared to the 112 kg K ha^{-1} K application (Pettigrew, 1999, 2008; Pettigrew & Meredith, 1997). Decreases in specific leaf weights could indicate improved translocation of sugars to sinks, creating a more efficient system within the plant. Differences between maize and cotton are likely, but the importance of K to leaf development and plant stature is evident. Adequate K availability is vital at the start of the growing season to ensure leaf area development for maximum photosynthetic potential. Maximizing photosynthetic potential can lead to increased yield through increasing source capacity, promoting kernel fill.

1.2.2 K Uptake

Similar to other essential nutrients, maize uptake of K has been documented in past research. A more recent study utilizing modern transgenic hybrids by Bender et al. (2013) tracked the cumulative uptake of K in maize and found the uptake pattern of K was a sigmoidal curve with a majority of uptake occurring before anthesis. By R1, approximately 63% of total K uptake was completed, evident in Figure 1.1. A majority of K accumulation occurred before flowering, unique from other essential nutrients (Bell, Mallarino, et al., 2021; Ciampitti et al., 2013; Pettigrew, 2008). The maximum suggested accumulation rate for K in maize is suggested to be approximately 5.8 kg day^{-1} (Bender et al., 2013), with maximum uptake generally believed to occur between V5 and V15 (Ciampitti et al., 2013). Flowering and ear development have been shown in previous research to be impacted by the availability of K. Additions of K have allowed for earlier and improved synchronization of pollen shed and silk emergence, potentially allowing for an extended grain filling period (Armstrong & Griffin, 1998). Past research has suggested that a higher moisture content at harvest reflected a longer grain filling period following K applications relative to untreated controls (Armstrong & Griffin, 1998). Figure 1.1, from Bender et al. (2013), shows uptake continuing through R6 with no losses, while other studies (Ciampitti et al., 2013; Karlen et al., 1988) captured a decrease in K close to the end of the growing season, possibly from leaching of K from senescing tissues. Due to the potential for K loss as the plant senesces, the timing of dry matter sampling to capture true K uptake is critical, and sampling K content at physiological maturity may underestimate the maximum K uptake achieved.

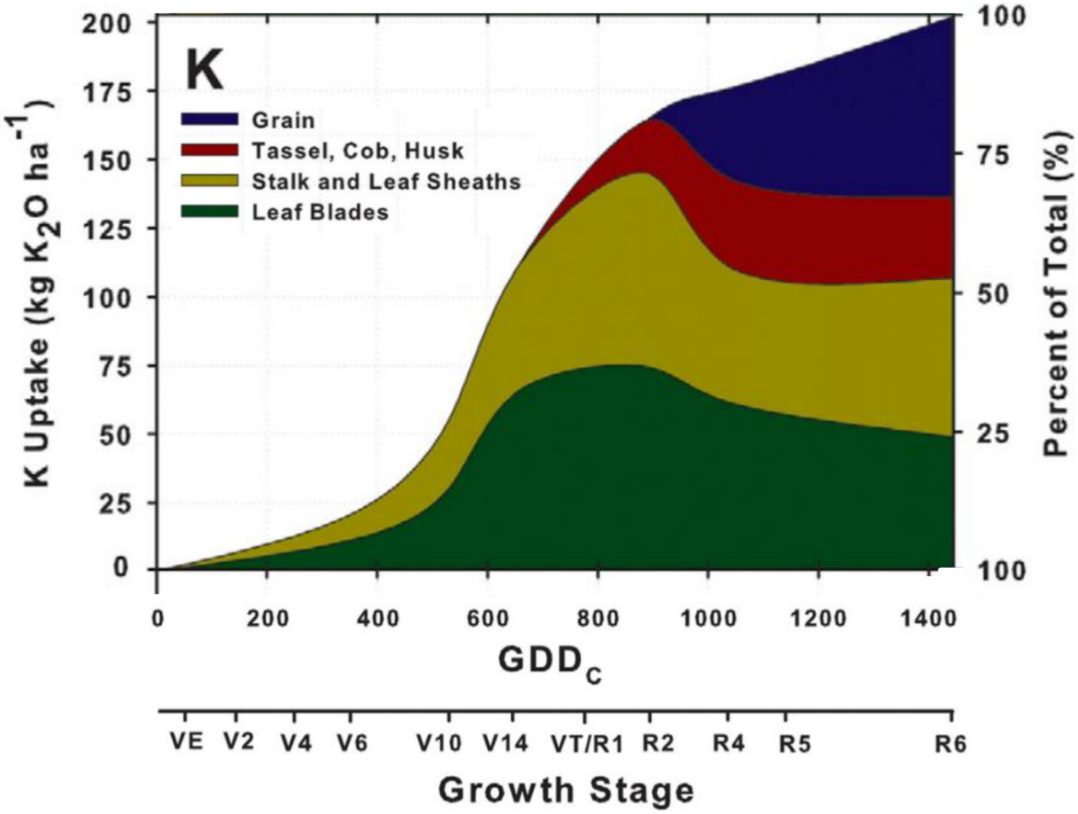

Figure 1.1. Cumulative maize K uptake (kg K_2O ha^{-1}) and percent of total uptake for various stages of development, divided into respective plant components (Bender et al., 2013)

Plant-available K is influenced by the plant itself (root architecture and rhizosphere (Hinsinger et al., 2021), management system (fertilizer applications, tillage, crop rotation, fertilizer placement, and fertilizer source), and environmental conditions (moisture, soil type, and rainfall). Testing the status of soils to provide K for plant growth in the soil has become an established management practice and consists of determining the concentration of K in the exchangeable and soil solution pools (Bell, Ransom, et al., 2021). This method of soil K status analysis has become standard across the agricultural industry today but only accounts for 1-2% of the total soil K that is thought to be available to plants (Bell, Ransom, et al., 2021). It is important to acknowledge that plants likely have access to more K than is detected in conventional soil tests.

1.2.3 Soil K Availability and Distribution

In most soils, K is seen as an immobile nutrient, but there are cases where K can be lost through leaching or can become unavailable through movement into clay interlayers. Potential for loss due to leaching increases when fertilizer application rates are in excess of soil holding capacity, along with low demand from plants (Goulding et al., 2021). Leaching, commonly seen on sandy soils more so than those with high clay content, can lead to crop growth limitations if K moves out of the rooting zone (Rosolem et al., 2021). It should be noted K can be lost from high clay textured soils when preferential flow occurs (Alfaro et al., 2004). Leaching losses of K vary greatly depending not only on soil type but also the weather during the growing season. Fixation is a process whereby hydrated K ions become trapped between 2:1 silicate layers of phyllosilicate minerals (Bell, Ransom, et al., 2021; Franzen et al., 2021). The ability for clay to fix K can be altered over time, depending on the environment and management strategies, but is primarily influenced by clay structure (Franzen et al., 2021). Previous research summarized by Franzen et al. (2021) has documented K fixation in micas, vermiculites, and smectites with little information about how to estimate the loss of available K due to fixation (Barshad, 1951, 1954; Martin & Sparks, 1985; Ranjha et al., 1990; Rich, 1968). K fixation can influence the amount of K available for uptake and is not detectable through a standard soil test, leading to further difficulty estimating the amount of K available for plant uptake. As research continues to understand how to calculate the soil supplying power of K and the processes influencing availability, recommendations for farmers in the future will better capture the true plant-available K in the soil.

Because K is considered immobile in most soils, stratification with depth commonly becomes more prominent where plants grow. In general, K stratification in row crop systems consists of high levels of K present in the surface centimeters, while concentration dramatically decreases with depth. Change in K distribution over time is common, as K is moved from deep in the soil profile to the surface through plant uptake and subsequent surface deposition in plant residue. The phenomenon of K accumulation in the surface centimeters is commonly referred to as 'uplift' in the literature and occurs over time as a greater amount of K accumulates at the surface than is returned (Jobbágy and Jackson, 2004). The movement of K varies with texture, but previous research has shown a general increase in the concentration of K in the top of the soil when plants are present in the system. Jobbágy and Jackson (2004) reference a previous study, Jobbágy and Jackson (2003), which looked at the change in K distribution for fallow sand dunes when trees were introduced into the system. Following 15 years of growth, the authors noted increased K concentrations in the surface soil, with maximum concentrations occurring in the top 20 cm of the 4 m depth measured (Jobbágy & Jackson, 2003). The extent of K uplift specifically in a row crop system, could be manipulated by the cropping sequence (rooting depth, deposition on the soil surface, etc.) and the tillage system utilized over time.

1.2.4 Tillage Impacts on Soil K

Aggressive soil mixing from tillage operations influences the distribution of K in the soil. Increasing tillage intensity mixes the soil more and allows for a more even distribution of K with depth. The impact of common tillage systems on the distribution of K has been investigated in various cropping systems. Authors have noted conservation tillage systems (ex: no-till, chisel plow, etc.) experience significant stratification of K with depth and even in reference to the crop row position (Howard et al., 1999; Robbins & Voss, 1991; Varsa & Ebelharar, 2000; Vyn et al., 2002), and in previous studies were shown to have more extreme stratification than conventional tillage systems (Deubel et al., 2011; Franzluebbers & Hons, 1996; Holanda et al., 1998; Karlen et al., 1991). In previous research by Varsa and Ebelharar (2000), the no-till treatment had higher levels of K in the 0-5 cm depth than the chisel plow treatment, but K concentrations in the 5-10 cm depth were higher in the chisel plow compared to the no-till. The no-till treatment allows for the near-surface accumulation of K from plant dry matter and also broadcast applied K. The inclusion of the chisel plow treatment showed a slight change in soil K distribution from tillage action. Some authors have noted differences in K concentration based on row position (comparing in row and between row) in low disturbance tillage systems over time (Holanda et al., 1998; Robbins & Voss, 1991; Yibirin et al., 1993). An experiment by Howard et al. (1999) investigated the change in exchangeable K concentration by row position (in-row and between row) after six years of no-till cotton production. Across three soils used for this experiment, the in-row surface sample (0-8 cm) had consistently greater soil K concentration than between row (Howard et al., 1999). Varsa and Ebelharar (2000) and Holanda et al. (1998) found similar results with higher K concentrations near the row than between rows for broadcast treatments. Holanda et al. (1998) utilized a detailed sampling procedure that allowed them to create schematics showing the distribution of plant-available K levels with depth and across the row for conservation (fall chisel and no-till) and conventional (moldboard plow) tillage systems) (Figure 1.2). Tillage can be used for incorporating not only K fertilizer but also residue, which contains a large amount of the K taken up by the plant throughout the season. Holanda et al. (1998) attributed the impact of rotation in the no-till system in Figure 1.2 to the large amount of dry matter from a continuous maize system compared to a maize-soybean (*Glycine max*) rotation. Because of the frequent stratification of conservation tillage systems, researchers have investigated advantages to K placement through tillage.

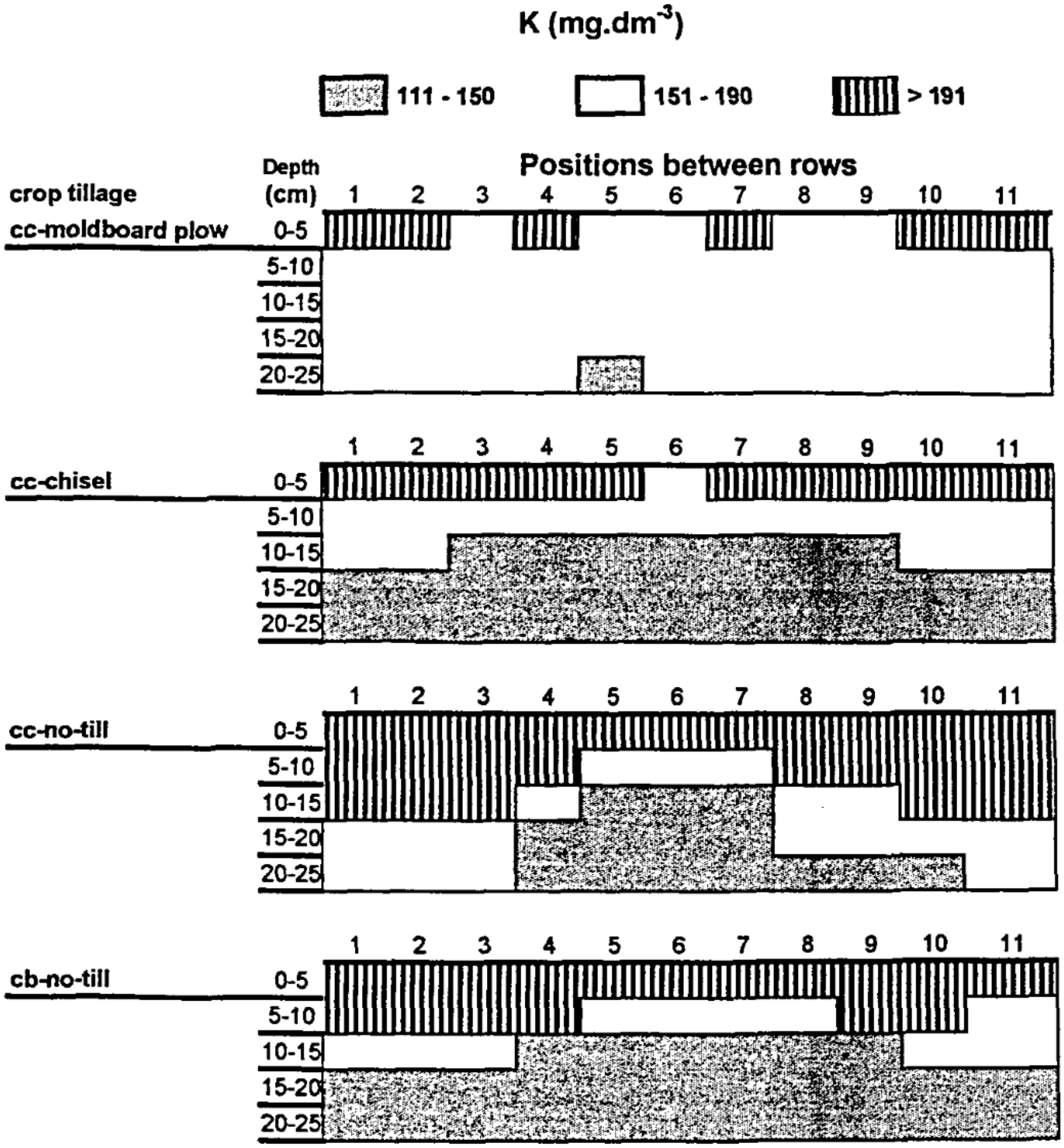

Figure 1.2. Distributions of plant-available K, measured by the Mehlich III extractant, at various depths across the crop row for combinations of crop rotation (cb = maize-soybean, cc= maize-maize) and tillage systems. Position 1 is in the reference row, position 6 is midway between rows, and position 11 is in the adjacent row (Holanda et al., 1998).

1.2.5 K Fertilizer Placement

Past reviews by researchers have suggested a potential advantage to K placement at depth in the soil rather than conventional broadcast treatments. Previous research has investigated alternative fertilizer placement; however, some of these experiments studied the co-application of phosphorus (P) and K. Randall and Hoeft (1988) acknowledged in a review the variability in response to P and K placement due to soil conditions (lack of precipitation, reduced tillage, etc.), lack of response in root growth from K alone, and inherent soil K levels. From the evaluation of previous studies, soil test K levels greater than 240 mg kg^{-1} seldom show differences between banded and broadcast placements (Randall & Hoeft, 1988). Previous research has suggested rate can interact with placement; for example, low rates in a band application generally have greater nutrient uptake efficiency than a high rate broadcast application (Randall & Hoeft, 1988).

Trials in Iowa studied the influence of K placement in a no-till system in several long term study locations using the placement treatments of broadcast, planter banded (5x5 cm), and deep banded (15-20 cm depth) (Bordoli & Mallarino, 1998; Mallarino et al., 1999). The fields used for this experiment were considered optimum to high in soil test K (160 mg kg^{-1}, average of 0-15 cm across experiment locations). Due to the high-testing K levels from the soil, the authors were surprised when several yield responses from the addition of K occurred from deep banding. Some locations saw an increase in early season uptake of K from deep-banded K fertilizer, indicating an advantage to the deep-banded placement when compared to broadcast (Mallarino et al., 1999). At the end of the growing season, deep banding frequently proved to have higher grain yields compared to other placement systems. Still, the yield increases were relatively small, raising concerns for the cost-effectiveness of this system (increase in yield was 0.245 Mg ha^{-1}) (Bordoli & Mallarino, 1998). A later study by Buah et al. (2000) in Iowa compared the rate and placement of K in a no-till system. From this study, tissue measurements were taken early and mid-season did not show a consistent advantage to a specific placement; however, K applications consistently increased tissue K concentrations (showing the importance to the general K management). At the end of the growing season, no grain yield increase was seen for banding in a no-till system, and the authors concluded placement did not play a prominent role in response to K, even on K stratified soil (Buah et al., 2000).

In Ohio, Yibirin et al. (1993) also looked at the impact of K fertilizer placement [broadcast vs. banded (5x5 cm)] in a no-till system. Still, they only saw an increase in earleaf K concentration and grain yield with banding when the soil test K levels were low (< ~85 mg K kg^{-1} average soil K level to see a response to placement across mulch treatments at 85 to 90% relative grain yield), but the level of surface mulch can impact this. A recent study in Illinois, published by Yuan et al. (2020), investigated placement of P and K but looked at no-till (broadcast) and strip-till [broadcast and deep banded (banded 15cm deep)] systems. According to Illinois recommendations, the 8-year field experiment's location was above the critical level (217 mg K kg^{-1}). Placement of P or K did not appear to affect maize or soybean yield in strip-till, but when comparing tillage systems, the strip-till system was superior yielding to no-till (Yuan et al., 2020). Several placement studies utilizing only K have been conducted and looked at combinations of placement and tillage systems. Vyn and Janovicek (2001) examined maize response to tillage and placement effects using experiment locations with no-till histories in Ontario, Canada. This experiment looked at tillage treatments with specific application positions for each tillage system [broadcast in continued no-till, deep banding (15cm depth) in fall strip-till, and with broadcast followed by incorporation by fall moldboard plow]. Most fields had a soil test K <120 mg K kg^{-1} (1 field had a concentration of around 160 mg K kg^{-1}), and soils in most site years were considered stratified. An additional component of this experiment was the effect of adding K to the starter fertilizer. Considerable variability among site years made for difficult interpretation of tillage/placement recommendations. From this study, Vyn and Janovicek (2001) suggested adding K to a starter fertilizer program for no-till and zone-till could be advantageous to producers. Although moldboard plowing of long-term, no-till fields commonly did increase earleaf concentration and dry matter at R1, there was no difference in grain yield compared to no-till with high starter K rate (except for a high fall K application rate) (Vyn & Janovicek, 2001). Vyn et al. (2002) also compared tillage system [no-till, strip-till, and mulch tillage (2-3 passes with a field cultivator)] and placement [broadcast, deep banding below row, and half broadcast with half shallowly banded (5x5 cm) within each tillage system] combinations on soils considered to have low soil test K (<60 mg K kg^{-1}) in Ontario, Canada. Placement and tillage influenced early-season plant nutrition, but this separation was commonly not seen in grain yield (Vyn et al., 2002). Application of K did increase grain yield for the no-till and strip-till system, but no response was documented in the mulch tillage system.

The danger of salt toxicity (both for the seed and developing root) due to the high salt content when using banding methods have led some authors to question the use of in-row banding. Because response in root growth to K banding is not frequently documented unless other nutrients are also incorporated, mixing K fertilizers into a more significant proportion of the soil volume may benefit maize (Bell, Mallarino, et al., 2021; Ebelhar & Varsa, 2000; Kovar & Barber, 1987; Randall & Hoeft, 1988). A review by Bell, Mallarino, et al. (2021) acknowledges that interest in placement has increased in maize production to improve K fertilizer use efficiency, but further investigation into how/if these management strategies improve K fertilizer use efficiency is still needed.

1.2.6 K Efficiency Measurements

Farmers want to continue improving the structured use of nutrients, but K efficiency measures are adapted from those used for evaluating nutrient use efficiencies for other nutrients. Because of the residual effects from K following application and the influence of inherent K levels, metrics for the efficiency of K application can be challenging to track. A review article by Bell, Mallarino, et al. (2021) commented that few research studies in the area of crop production have focused on fertilizer recovery efficiency or the utilization efficiency for K. Popular metrics published by researchers include K recovery efficiency and K harvest index. The goal of measuring components necessary for K recovery efficiency is to understand the difference between K uptake for a fertilizer treatment and an unfertilized control for a given fertilizer application rate, followed by dividing this value by the amount of fertilizer K applied to quantify the amount of fertilizer recovered following application. The K recovery efficiency in maize typically ranges between 30-50% (Bell, Mallarino, et al., 2021; Xu et al., 2015), but this measurement can range from a negative value to exceeding 100%. A negative K recovery efficiency results from more K accumulated in the control treatment as compared to when K was applied. A K recovery efficiency above 100% would indicate the treatment could accumulate all the fertilizer K applied and additional K from the soil compared to the control treatment. Actual K recovery efficiency depends on the application rate of K, as seen in the published study by Qui et al. (2014) where K recovery efficiency decreased by 8.8% when increasing the application rate from 113 kg K ha^{-1} to 225 kg K ha^{-1}, indicating the importance of not exceeding the needs of the crop. A study in China by Niu et al. (2011) observed a range of K recovery efficiencies from -11.9% to 37.9% under varying K rates and management systems. A more recent study by Song et al. (2020) looked at K recovery efficiency under the influence of cropping pattern (monocrop vs. relay intercropping) and row width. Interestingly, this experiment had recovery efficiency measures consistently above 100% (range across years and locations of 129-353%) for both maize and soybean (Song et al., 2020). Values above 100% for K recovery can indicate the plant had access to more K than was supplied from the fertilizer and could potentially be luxury consumption.

The wide range of values for K recovery efficiency reported in the literature implies that it is difficult to quantify the influence of a fertilizer application due to environmental and internal plant mechanisms. A presentation by Michael Bell of the paper, "Soil characteristics and cultural practices that influence potassium recovery efficiency and placement decisions," suggested that recovery efficiencies may be underestimating the recovery of K fertilizer (Bell, Mallarino, et al., 2021; International Plant Nutrition Institute, 2017; Varsa & Ebelharar, 2000). The idea of underestimated K recovery efficiency has been investigated in the past. During his presentation, Bell utilized unpublished work using Rubidium (Rb) enriched fertilizer, suggesting previously reported K recovery efficiencies might have reported values lower than what is being taken up by the plant (International Plant Nutrition Institute, 2017).

In addition to K recovery efficiency, the K harvest index is another important metric for understanding K allocation to the grain in maize and optimum K fertilizer rates for farmers trying to maintain soil exchangeable K levels. The harvest index for maize is calculated as the proportion of grain produced per unit above-ground dry matter. K harvest index indicates the plant's efficiency at partitioning K from the vegetative to reproductive portion (Bender et al., 2013; Hütsch & Schubert, 2017). Past research from Sayre (1948), Hanway (1963), and Karlen et al. (1988) was summarized by Bender et al. (2013) who determined an average harvest index for K of approximately 25%, slightly lower than the range of K harvest index found in the previous studies (27-37%). Similarly, a study by Ciampitti & Vyn (Ciampitti et al., 2013) reported an average K harvest index of 28%. Similar to the slight increase in harvest index commonly seen in modern hybrids, the K harvest index could have increased slightly as well. Improved methods for nutrient use efficiency measurements are needed for farmers to best capture K fertilizers in the plant when applied.

1.2.7 Nutrient Balance with K

Balanced nutrient uptake is vital to reaching maximum grain yield potential for maize. The importance of balance between N and K begins early and can improve early season growth (Armstrong & Griffin, 1998). The importance of balance between N and K depends not only on the plant's ability to take up these nutrients but also on the plant's supply. Armstrong and Griffin (1998) describe how N and K depend on one another to increase dry matter and yield; for example, when N is sufficient, crops will likely respond to increased K and vice versa. Similarly, Niu et al. (2011) suggested that a response to K application can be influenced by the level of N supplied to the plant, further strengthening the idea these nutrients must be kept in balance to see vigorous plant growth. In a synthesis analysis of previous maize experiments by Ciampitti and Vyn (2014), the authors assessed nutrient balance trends between N and K at the end of the growing season. The ideal ratio for N to K for high yield achievement was suggested to be close to 1:1 (N:K) at R6. The N:K ranged from 2.5 to 0.25:1 according to the authors, yet when yield levels were greater than 18 Mg ha^{-1}, the ratio of N:K narrowed (range of 0.6 to 1.3) (Ciampitti & Vyn, 2014). The importance of balance between N and K has been suggested to improve N use efficiency throughout the growing season and lead to higher grain yield (Armstrong & Griffin, 1998). The increase in N use efficiency and uptake with proper K fertility can positively influence the environment by limiting the potential N losses from the maize cropping system during the growing season.

1.3 Boron (B)

Boron (B) was first discovered as an essential nutrient for growth and development in maize by Mazé in 1915 and remains the only non-metal of the micronutrients (Berger, 1949; Umesh C. Gupta, 1980, 1993; Swanback, 1927). Although B is recognized as an essential nutrient in maize, few states have recommendations for B management in maize because of more prevalent B deficiencies in dicotyledonous crops. Dicots commonly require considerably more B than monocots (Bradford, 1966; Mozafar, 1987), yet it remains unclear how maize requirements compare to other monocot species. Research by Mozafar (1987) suggests maize requires the most B out of all grass species, while a recent study by Lordkaew (2011) claims maize has the lowest B requirement out of all cereals. The difference in results between Mozafar (1987) and Lordkaew (2011) could be due to the change in hybrid performance from progress in breeding programs or the shift in management intensity. B requirement for growth and development is well established; however, the physiological roles of B remain less understood than other nutrients (Umesh C. Gupta, 1980). Research with various plant species has shown reproductive growth is highly dependent on adequate B levels (Dell & Huang, 1997). The role of B within maize is continually developing as new techniques and technologies become available to detect and describe its functions.

1.3.1 Nutrient Balance with B

Similar to other essential nutrients in maize, nutrient balance is thought to be important for B. Previous literature has described interactions among B and several cations [calcium (Ca) and K], but most focus on the ratio of Ca to B. Antagonism among cations has been commonly documented within maize [among magnesium (Mg), Ca and K]. When applying high rates of K, a decrease in uptake of Ca, Mg, or both are typically documented. Some previous studies have focused on the impact of K and Ca management on B in various species. Previous research and reviews have reported several scenarios from the additions of Ca, K, and B. The addition of Ca has been shown to increase the severity of B deficiency, but Ca has also reduced the toxic effects of excess B (Bradford, 1966; Fleming, 1980; Mortvedt et al., 1973; Reeve & Shive, 1944). Because of the inverse relationship in the uptake of K and Ca, K additions can lead to increased severity of B deficiency or toxicity (Fleming, 1980; Mortvedt et al., 1973; Reeve & Shive, 1944). Foundational work by Reeve and Shive (1944) and Berger (1949) suggested the Ca:B ratio is important within plants and that high Ca and/or K applications can alter this ratio. Woodruff (1987) conducted a study looking at the impact of combinations of applications of K, B, N, and lime in maize to evaluate the effects of treatment combinations on maize yield and earleaf concentration. Interestingly, in a low B soil where a high amount of K was applied, and plant populations ranged from 70-80,000 plants per hectare, an application of B was necessary to avoid yield penalties (Woodruff et al., 1987). As agriculture continues to intensify and as fertilizer use continues to rise, maintaining optimum balance to B will become more important (Woodruff et al., 1987)

1.3.2 B Importance to Flowering

Adequate B levels are crucial for flower development and pollination in maize. Extensive greenhouse research has documented the detrimental effects of low B levels, but little is understood on the specific role of B in flower initiation and development (Dell & Huang, 1997; Umesh C. Gupta, 1993). Although the tassel and silks are both affected by B limitations, the silks appear to be more sensitive (Dell & Huang, 1997). The influence of B on the anthesis-silking interval in maize is poorly documented in the literature. In a greenhouse study by Lordkaew et al. (2011) plants developed fewer and shorter silks when no B was supplied. Silk number was reduced from an average of 406 silks per ear for the 20 B fertilized treatment (solution concentration 20 µM B) to 30 silks per ear for the control 0 B (solution concentration 0 µM B). In addition to lower silk number, the authors also observed an average reduction in silk length by 7.9 cm for the 0 B treatment compared to the 20 B treatment. Silk emergence from the husk in the 0 B treatment was low due to reduced length and contributed to reduced kernel set.

Although silks appear to be more severely affected by B limitations, tassel and pollen development are also negatively impacted. In addition to documenting damage to silk development, Lordkaew et al. (2011) also evaluated the effects of no B on tassel and pollen development. Lordkaew et al. (2011) documented not only smaller tassels but also tassels that emerged from the whorl appearing dead for the 0 B treatment. Pollen germination and pollen grain number per anther were significantly reduced in the 0 B treatment. Pollen grains from 0 B plants had a lower germination percentage than the 20 B plants, with most 0 B pollen grains lacking starch granule deposits.

Severely limiting B availability throughout the growing season will continue to affect the plant from flowering until the end of the growing season. From the reduction in silk development due to lack of B, ear size and kernel development will also be severely compromised (Umesh C. Gupta, 1980; Lordkaew et al., 2011). The Lordkaew et al. (2011) study saw considerable reductions in kernel set from a lack of B, the average kernel set for the 0 B treatment was 0.4 kernels ear^{-1} while the 20 B treatment had 410 kernels ear^{-1}. Although the Lordkaew et al. (2011) study provides a large amount of insight into the consequences of extreme B deficiency, few field-scale studies show the same dramatic increases in grain yield from the application of B.

1.3.3 B Uptake

Similar to other essential nutrients, plant uptake of B has been evaluated in maize. Bender et al. (2013) tracked the uptake of B in maize and found B uptake occurs throughout the entire growing season. In Figure 1.3, the uptake pattern of B can be described as two sigmoidal curves, with high uptake occurring during both the vegetative and reproductive phases (Bender et al., 2013). Upon reaching R1, Bender et al. (2013) determined that approximately 63% of B uptake was completed and suggested a maximum accumulation rate for B in maize to be about 3.3 g day^{-1}. Figure 1.3 (Bender et al. (2013) shows a slight decline in leaf and stalk content around R1, suggesting some remobilization to the reproductive organs (Karlen et al., 1988). Bender et al. (2013) also suggests the harvest index is approximately 23% (range 17-31%) (B removed with

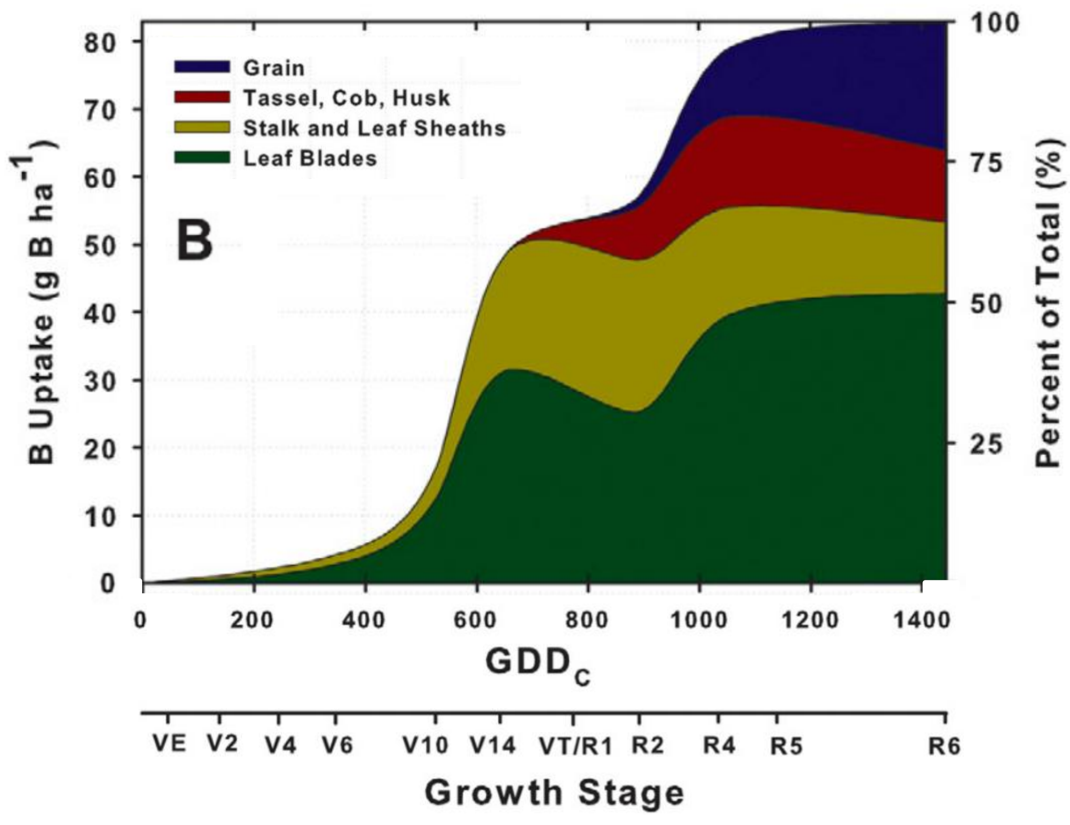

Figure 1.3. Cumulative maize B uptake (g B ha^{-1}) and percent of total uptake for various stages of development, divided into respective plant components (Bender et al., 2013).

grain divided by the total B uptake), but B uptake has been suggested to vary with hybrid, soil condition, and agronomic management (Bender et al., 2013; Umesh C. Gupta, 1993; Mozafar, 1987).

Several greenhouse studies have evaluated the implications of disrupting B supply, showing the importance of a continuous supply throughout the growing season. A sand culture experiment by Mozafar (1989) looked at the implications of interrupting B supply to two maize hybrids a week before flowering at B concentrations ranging from 0.01 to 0.166 mmol L^{-1}. Interruption of B supply to all of the maize plants caused significant reductions to grain development no matter the prior B accumulated by the plants (Mozafar, 1989). The range for ear yield across B concentrations supplied continuously for the Mutin hybrid was 91 to 120 g $plant^{-1}$ versus 18 to 53 g $plant^{-1}$ for interrupted B supply, while for the Carlos Semu 201 hybrid, the continuous supply ranged from 133 to 141 g $plant^{-1}$ versus 86 to 129 g $plant^{-1}$ for the interrupted supply. Mozafar (1989) highlights the drastic impact of B supply interruption on grain yield in maize and the variation in hybrid response to B limitations (some hybrids are more severely affected by lack of B than others). Documenting the impact of B supply interruption in a field-scale trial would be difficult and likely would be inconsistent because of environmental and soil conditions. The study by Mozafar (1989) serves as a foundational study to show the importance of this nutrient throughout the growing season, especially during the critical period. Although the studies presented in this section help understand B, these experiments do not guide farmers struggling with B management.

1.3.4 B Variability with Environmental Conditions

Because B is commonly present (below pH 7) in the soil as an uncharged ion ($H_3BO_3^0$), once B is released into the soil solution, it has the potential to be easily leached (Umesh C. Gupta, 1993). Leaching of B is commonly prevalent in sandy soils and is frequently correlated with clay content and organic matter (Berger et al., 1957; Bradford, 1966; Fleming, 1980; Umesh C. Gupta, 1993; Mortvedt et al., 1973; Rehm et al., 1993; Reisenauer et al., 1973). Managing B on high silt and clay soils is concerning to farmers because of the potential for residual effects from over-applying B, which negatively impacts crop development and yield (Martens & Westermann, 1991; Mortvedt et al., 1973). With the little release of nutrients into the soil solution during drought conditions, B deficiency can intensify or develop during times of limited water availability (Bradford, 1966; Fleming, 1980; Martens & Westermann, 1991; Mozafar, 1989).

1.3.5 B Fertilizer Application

Variability in climatic and soil conditions (fertility and texture) can lead to variability in plant response to B applications (Martens & Westermann, 1991; Reisenauer et al., 1973). Tissue concentration responses were common in field experiments evaluating B application, but yield responses were more variable. A study in Georgia by Touchton and Boswell (1975a) only evaluated broadcast and foliar applications. The authors observed a significant increase in B concentration in the earleaf of maize from a broadcast treatment applied at 1.12 kg ha^{-1} but did not see significant increases in B concentration following the application of 0.56 kg ha^{-1}. The authors did not document grain yield improvement following the broadcast application. Alternatively, Berger et al. (1957) in Wisconsin conducted a field-scale study to document the frequency of response to B application. Sodium borate fertilizer was spread in a 46 cm wide band between rows when maize was approximately 30 cm tall at a rate of 2.3 kg B ha^{-1}, with plant populations above 42,000 plants ha^{-1}. According to the authors, out of the 54 fields harvested, only six fields showed a significant yield increase. Yield improvements were suggested to come from the reduction of barren stalks and improved development of ears (better kernel fill and ear development) (Berger et al., 1957). Later reviews by other authors have cited similar results, suggesting a reduction in barren stalks and improved quality from B applications in maize depends on environmental conditions (Martens & Westermann, 1991; Mortvedt et al., 1973).

1.3.6 B Fertilizer Placement

Several field-scale trials have investigated the impact of placement and rate on B uptake, with little to no investigation into application timing (fall versus spring application). Past research of B application placement in maize has focused on comparing broadcast and foliar applications, where work in other crop species has compared broadcast and banded applications. One of the first field investigations into B placement in a maize system was by Peterson and MacGregor (1966) in Minnesota. The authors compared B uptake and grain yield for granular broadcast, granular in-row surface broadcast, and foliar application. The placement (broadcast and in-row) of the fertilizer did not lead to differences in grain yield at the end of the growing season. However, the in-row B application generally led to higher B concentrations in the upper leaves than broadcast. From this experiment, the authors concluded that B application for achieving maximum maize yield was unnecessary because B levels in the soil were sufficient. Later, a Canadian study by Gupta and Cutcliffe (1978) of rutabaga (*Brassica napobrassica*) investigated the impact of sodium borate fertilizer placement on yield and tissue nutrient concentration, utilizing the following placements: broadcast incorporation, banded near the seed-row, and foliar application. Results from this experiment were that banding of B at 1.12 kg B ha^{-1} and broadcasting at a rate of 2.24 kg B ha^{-1} both controlled brown-heart. This experiment highlights the increased recovery efficiency of B in sampled tissue for the banded application when compared to the standard broadcast incorporation.

Although band applications have been shown to increase tissue B concentration, the likelihood of creating toxic concentrations in close proximity to seeds and roots from a band application also increases (Mahler, 1981; Robertson et al., 1976). Because maize is sensitive to high B applications, utilizing a band treatment with a high B application rate could be seen as a risk by farmers. The adverse residual effects later in the growing season would also play a role in the decision-making process. The study by Gupta and Cutcliffe (1978) incorporated placement technologies farmers utilize for applying fertilizer that had not been used in previous B fertilizer studies. The responsiveness to applications of B have been variable and heavily influenced by environment and management. Previous B experiments with maize and soybean, by Touchton and Bosewell (1975a, 1975b), did not increase total yield, but at times improved crop quality and economic yield. Because of the common lack of yield response, B management is commonly a not great concern to farmers.

1.4 Aspire™

Past crop production research has utilized alternative sources of K [fertilizers containing additional nutrient(s) with K]. Since 2014, a granular K fertilizer with B incorporated has been produced and sold as a product called Aspire™ (The Mosaic Company, Tampa, FL), with an approximate analysis of 0-0-48(K)-0.5 (B). This product is commonly available to producers through agricultural supply retailers across the country. A new formulation of the product was utilized in 2018, incorporating 2 forms of B, calcium hexaborate pentahydrate and sodium tetraborate with potassium chloride (KCl) (The Mosaic Company, 2020). The addition of calcium borate could potentially extend B availability into more of the growing season because calcium borate is considered more recalcitrant than sodium borate. Research utilizing Aspire™ is minimal, with only a few research reports using this product. A report out of Arkansas by Slaton et al. (2019)

compared the use of Aspire™ and MicroEssentials®SZ® (MESZ) to the traditional application of muriate of potash (MOP) and monoammonium phosphate (MAP). This study was unable to look at the individual contributions of each fertilizer because control treatments were not incorporated. Additionally, the Aspire™ application for this study was a 50:50 mix of MOP and Aspire™, not allowing for the full rate of B to be applied. At the conclusion of the study, the authors found that end-of-season maize grain yield was increased significantly following the application of Aspire™ and MESZ compared to MOP and MAP (Slaton et al., 2019). This study does not allow for the separation of the effects of Aspire™ from MESZ or MOP from MAP, therefore not allowing the authors to compare Aspire™ to MOP. Without the direct comparison of these fertilizer sources, farmers will not know what fertilizer contributed to the yield increase. Few studies in the current literature have looked at applying an alternative K source with B in maize systems, such as Aspire™, likely due to the more common B deficiencies in dicotyledonous crops.

1.5 **Conclusion**

Both K and B provide important functions within maize and influence grain yield at the end of the growing season. The influence of these nutrients on maize growth and development have been documented separately; however, the impact of these nutrients when both are applied remains to be documented in modern maize production systems. Management of K has seen some updates to recommendation methodology in the past several decades, but there remains to be more investigation into how fertilizer placement can influence growth, development, and efficiency in modern agricultural systems. Boron especially has not seen changes to nutrient recommendations in maize production, even with intensifying management. Little research has documented maize responses to B application in the Midwest, but with the shift to less diverse rotations, increasing removal, and increasing plant densities, farmers' maize crops could be demanding more B resources throughout the growing season (potentially limiting kernel development). Today, farmers are unsure if the needs of B by maize are being met using available recommendations or how to best apply fertilizers to satisfy these needs. Research into optimal tillage and fertilizer placement has been documented more frequently in K compared to B, with sparse research into the co-application using a single fertilizer product. This thesis examines the effects of co-application of K and B utilizing a recently developed fertilizer source (Aspire™) under a series of conservation tillage systems in the Midwest.

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CHAPTER 2. STRIP-TILL TIMING AND ASPIRE™ FERTILIZER APPLICATION INFLUENCE ON MAIZE GROWTH AND DEVELOPMENT

2.1 Abstract

The development of coulter-based strip-tillage equipment with the capability to apply banded fertilizer on-the-go has raised questions about fertilizer placement consequences on plant nutrition and grain yield responses in maize (*Zea mays* L.). Some researchers suggest enrichment of the tilled zone is a more efficient placement for potassium (K) fertilizers compared to broadcast. Nevertheless, few researchers have investigated this concept utilizing an alternative K source or alternate strip-till operation timings. A five site-year field-scale experiment involving rotation maize production was conducted at the Agronomy Center for Research and Education (ACRE Farm) near West Lafayette, IN by alternating between two fields (from 2016 to 2019), and at the Pinney Purdue Agriculture Center (PPAC Farm) near Wanatah, IN in 2019. Utilizing a coulter driven strip-till implement, the fertilizer Aspire™ (0-0-48(K)-0.5(B)) was incorporated into the tilled strip at rates of 0, 54, or 108 kg K ha^{-1} in the fall (FST) and spring (SST). Treatments (tillage timing and fertilizer rate) were applied before only maize in a maize-soybean (*Glycine max L.*) rotation. Responses were observed for maize year 1 (MY1) and maize year 2 (MY2) maize at ACRE and only first-year maize at PPAC. A series of measurements evaluating both physical and nutritional dynamics were documented for maize during crucial growth stages.

Early in the growing season, FST appeared to have an advantage over SST for both MY1 and 2, as seen by the increased dry matter accumulation at V6 in FST compared to SST (MY1 = 19% and MY2 = 15%). Nutrient accumulation was only significantly increased (by 16%) in MY1 when following FST instead of SST. However, at later sampling times, few differences in nutrient

concentration and content resulting from strip-till timing were observed. Grain and total plant dry matter at R6 did not vary significantly due to tillage timing or Aspire™ rate. However, total grain K uptake increased 10% for SST compared to FST in MY1, and the high rate of Aspire™ (108 kg K ha^{-1}) increased grain K uptake by 15% in MY2 while the 54 kg K ha^{-1} rate didn't impact grain K content. Total plant K uptake, averaged across FST and SST, was 29% and 22% higher for Aspire™ applied at the 108 kg K ha^{-1} rate compared to the 0 and 54 kg K ha^{-1} rates, respectively.

The structure of maize years for this experiment did not allow for the direct comparison of MY1 and 2 to conclude if the maize years behaved differently from one another. However, maize responses to the 54 kg K ha^{-1} rate were similar to the 108 kg K ha^{-1} rate in MY1. Positive responses to the Aspire™ application at R1 were detected despite soils being close to or above critical plant-available K levels at each site/year. Average grain yield increases of 0.4 and 0.6 Mg ha^{-1} occurred in response to the 54 and 108 kg K ha^{-1} Aspire™ rates in MY1, respectively, while the same rates of Aspire™ led to average grain yield increases of 0.9 and 1.3 Mg ha^{-1} in MY2. The subset of treatment data considered in this chapter indicates that following V6, little response to strip-till timing was evident, but Aspire™ application increased grain yield and K uptake even on soils considered close to optimum in plant-available K.

2.2 Introduction

In recent decades, efficiency has grown to be a common buzzword in the agricultural industry. Utilizing management tactics that pay for creating and protecting yield has become increasingly important as the cost of production and market prices continually fluctuate. Equipment options for tillage continue to evolve, but foundational questions regarding tillage timing and efficient placement of fertilizer in the context of modern agricultural systems requires further investigation. Additionally, fertilizer products incorporating multiple nutrients continue to be released with minimal publicly-available research investigating their impact on maize plant growth and development.

In recent decades, strip-till has increased in adoption among Midwest farmers as they endeavor to decrease soil disturbance and maintain their current production level. Strip-till offers benefits of both no-till (as over half of soil surface remains undisturbed and retains residue cover) and conventional tillage systems (by faster soil warming in intended crop row and by clearing residue from the previous crop for improved stand establishment) (Demander et al., 2013; Nowatzki et al., 2017). Past research has shown that surface residue displacement through strip-till allowed soil temperature to increase in the top 5 cm of the soil profile, creating improved conditions for germination (Al-Kaisi & Hanna, 2008). Increased surface temperature following tillage has been recorded by other authors in strip-till systems (Licht & Al-Kaisi, 2005; Wall & Stobbe, 1984).

A study conducted in Iowa by Licht and Al-Kaisi (2005) investigated how the tillage system (no-till, strip-till, and fall chisel) influenced soil temperature, soil moisture, and compaction. Licht and Al-Kaisi (2005) did not find significant differences in soil moisture to a depth of 1.2m (increments of 0-15, 15-30, 30-60, 60-90, 90-120cm) among the tillage systems, but no-till and strip-till were commonly numerically higher in moisture content compared to fall chisel plow throughout the growing season. Although benefits exist for strip-till, it is still frequently only recommended in areas with relatively flat topography, and where poor soil drainage constrains no-till adoption (Al-Kaisi & Hanna, 2008). Steep slopes can potentially lead to increases in erosion with strip-till because of the loosened and exposed berms in the zones where the seed will be planted. Strip-till has soil management advantages, but the investment in equipment limits some farmers from adopting it. To effectively use the tilled strips, farmers typically utilize real-time kinematic (RTK) global positioning system (GPS) to align seed rows within the tilled strips.

Strip-till is performed utilizing a coulter- or shank-based soil loosening system, creating a disturbed strip into which the crop row will be later planted. The strip width is approximately 15 to 25cm (Demander et al., 2013; Tarkalson et al., 2015). Both coulter- and shank-based strip-till systems can apply fertilizer simultaneously with tillage, but they vary in their placement of the fertilizer. Coulter driven systems cannot penetrate as deeply into the soil as a shank system, but coulters generally allow for the incorporation of fertilizer into a greater proportion of the soil volume in comparison to a shank system (Bergman, 2020). Compaction is more easily corrected in a shank-based strip-till system because of its deeper penetration into the soil.

The timing of strip-till is an essential consideration for all farmers. Tilling under wet soil conditions will develop clods, resulting in poor seed to soil contact following planting and smearing of sidewalls limiting root growth (Demander et al., 2013). Wet soil conditions are commonly prevalent in the spring, leading some institutions to recommend that strip-till be performed only on coarse-textured soils with low organic matter (Nowatzki et al., 2017). Although limiting tillage to a specific season would be ideal, weather conditions or labor availability at harvest may not allow farmers to perform all or any strip-till in the fall.

Some previous studies have evaluated consequences to tillage timing (fall versus spring), but few have explicitly looked at strip-till utilizing current management practices. A study in Ontario by Vyn and Raimbault (1993) used a series of tillage treatments (fall moldboard + spring secondary, fall chisel + spring secondary, spring moldboard, spring moldboard + secondary, and no-till) to compare fall versus spring timing of tillage. From this study, the authors found no differences in grain yield between the fall moldboard + spring secondary and spring moldboard + secondary, suggesting that timing did not matter for these tillage systems. Some variation was present in the results from year to year and those were attributed to soil structure in the seedbed zone (Vyn &

Raimbault, 1993). Variation in the seedbed structure is expected when comparing fall (conservation or conventional) to spring tillage. Fall-tilled soil has additional time to settle from freeze-thaw and wetting-drying cycles (sometimes referred to as ‘mellowing’). Particle size may be larger in the spring and prevent ideal seed-to-soil contact, leading to reduced stands. Although the Vyn and Raimbault (1993) study did not incorporate a strip-till treatment, the use of an aggressive tillage system provides some insight into tillage timing impacts on seedbed quality and subsequent maize growth and development.

More recent studies have investigated the timing of tillage utilizing strip-till systems in sugarbeet and maize. Tarkalson et al. (2015) evaluated a series of tillage systems (moldboard plow, chisel plow, and strip-till) in both the fall and spring [which also contained a nitrogen (N) rate component] for sugarbeet production in the Northwest US. No differences in recoverable sucrose or root yields were observed between the fall and spring tillage timing (for any of the evaluated tillage systems). Based on their study, Tarkalson et al. (2015) suggested flexibility in tillage timing for sugarbeet farmers in the Northwest US.

An on-farm trial conducted by Iowa State University investigated strip-till timing (fall, spring, and fall + spring), where a coulter driven strip-till implement (Environmental Tillage Systems, Faribault, MN) in maize was utilized (Bergman, 2019). While performing tillage, phosphorus (P) and K were incorporated into the tillage zone. Measurements within this experiment were limited to grain yield, not providing any insight into the influence of tillage timing on maize growth and development during the growing season. Bergman (2019) noted grain yield varied across locations, but there was no difference from tillage timing (average grain yield difference in timing across three field locations equaled just ~131.8 kg ha^{-1}). Results from that demonstration research suggested no benefit or limitation based on the timing of tillage.

The timing of nutrient application has become a more common question by farmers today because of the need to increase the efficient recovery of applied fertilizers. For example, recent changes to N management have involved more split N applications during the growing season. Several studies have investigated the impacts of K fertilizer timing (fall versus spring application) on nutrient dynamics in several crops (maize, cotton, and forage grasses). In contrast, no studies have recorded the impact of timing on boron (B). Previous research in Alaska has investigated the effects of K fertilizer timing (fall versus spring) in timothy (*Phleum pratense* L.) and smooth bromegrass (*Bromus inermis* Leyss.). Laughlin (1964) utilized smooth bromegrass and found no difference between the fall and spring applications of K (each timing incorporated rates of 0, 74, 149 kg K ha^{-1}). A follow-up study on timothy by Laughlin (1965) found that a spring application of K (range of application rates each year, year 1 (0 to 149 kg K ha^{-1}) and year 2 (0 to 298 kg K ha^{-1})) increased K uptake when compared to a fall application but frequently did not improve dry matter yield.

Studies regarding K timing in row crop systems have been conducted more commonly in cotton (*Gossypium hirsutum* L.) and, to a lesser extent, maize. Boswell (1971) studied fertilizer applications (containing both P and K) in a series of timings (fall, winter, and spring) in both maize and cotton. They concluded that timing treatments had no impact on maize response in one location, but winter and spring applications improved maize over fall timing in the other site (Boswell, 1971). At the cotton location, the spring application managed to produce higher lint yields than fall or winter applications (Boswell, 1971). While this study provides valuable information regarding the timing of fertilizer application, P and K were never applied separately, making the influence of the individual nutrients impossible to determine. A later study in Alabama by Mullins et al. (1999) evaluated four K application rates (0, 55, 111, 167 kg K ha^{-1}) with three application timings (fall, spring, and fall + spring) in cotton. Lint yield was increased for 6 out of 9 years following K application, but the timing did not lead to a lint yield difference (Mullins et al., 1999). Overall, the influence of K fertilizer timing on crop performance has been variable across years of research. Sometimes no yield differences were found due to timing, or if differences were found, the same timing was not always the highest yielding. Such variability suggests environment or soil may play a factor in the optimal timing.

Past crop production research has generally employed a single K fertilizer source, typically potassium chloride (KCl). Alternative sources of K, some with additional nutrients, also need to be tested. Since 2014, The Mosaic Company™ has produced a fertilizer product called Aspire™. This product incorporates B and K into a granular fertilizer with an approximate analysis of 0-0-48(K)-0.5 (B). This product is commonly available to farmers through agricultural supply retailers. A new formulation of Aspire™ was introduced in 2018, incorporating two forms of B, calcium hexaborate pentahydrate ($Ca_2B_6O_{10}\cdot 5H_2O$) and sodium tetraborate ($Na_2B_4O_7$) with KCl (The Mosaic Company, 2020). Calcium borate is considered more recalcitrant than sodium borate, potentially either limiting the release of plant-available B or extending potentially plant-available B further into the growing season. Research utilizing Aspire™ is minimal, with no known refereed literature available (only research reports were found). A research report from Arkansas by Slaton et al. (2019) compared the use of Aspire™ and MicroEssentials®SZ® (MESZ) to the traditional application of KCl and monoammonium phosphate (MAP). This study did not incorporate control treatments to look at the individual responses to each fertilizer, making this study unable to separate the impacts of each fertilizer. Their Aspire™ application was a 50:50 mix of KCl and Aspire™, reducing the B rate to half of what would have been applied if Aspire™ had been the only product used to meet the full rate of K. The authors concluded that maize grain yield was increased significantly following the application of Aspire™ and MESZ compared to KCl and MAP (Slaton et al., 2019). Few studies in the current literature have looked at applying an alternative K source with B in maize systems, such as Aspire™, likely due to the more common B deficiencies that occur in dicotyledonous crops or to the generally sufficient levels of B in soils. Because of the limited literature utilizing this fertilizer source, this chapter will primarily refer to studies using a fertilizer with a single nutrient (K or B) in discussing our new findings relative to the literature.

The objectives of this study were to investigate the responses of maize to the timing of strip-tillage, the application rate of Aspire™, and the interaction between them.

2.3 Materials & Methods

A five site-year field-scale experiment was conducted at the Agronomy Center for Research and Education (ACRE Farm) near West Lafayette, IN, alternating between two fields (40.493°N, 86.996°W and 40.501°N, 87.000°W) from 2016 to 2019 and conducted for a single year (2019) at the Pinney Purdue Agriculture Center (PPAC Farm) near Wanatah, IN (41.447°N, 86.940°W). The trials were conducted in a series of three fields, all following a maize-soybean rotation. Two fields (ACRE Farm locations) had the study repeated following the soybean year with the treatment positions fixed for data collection during maize years. The ACRE Farm location for 2016 (Maize Year 1 = MY1) and 2018 (Maize Year 2 = MY2) (40.493°N, 86.996°W) was a combination of a Drummer, silty clay loam, 0-2 percent slope (Fine-silty, mixed, superactive, mesic Typic Endoaquolls) and a Raub-Brenton complex, silty clay loam, 0-1 percent slope (Fine-silty, mixed, superactive, mesic Aquic Argiudolls). The ACRE Farm location for 2017 (MY1) and 2019 (MY2) (40.501°N, 87.000°W) was a combination of a Drummer, silty clay loam, 0-2 percent slope (Fine-silty, mixed, superactive, mesic Typic Endoaquolls) and a Toronto-Millbrook complex, silt loam, 0-2 percent slope (Fine-silty, mixed, superactive, mesic Udollic Epiaqualfs). The PPAC Farm location (2019) was mostly composed of Sebewa loam, shaly sand substratum, 0-2 percent slope (Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Argiaquolls) with a small portion of Pinhook loam, 0-2 percent slope (Coarse-loamy, mixed, superactive, mesic Mollic Endoaqualfs).

Daily weather information for each growing season was gathered from weather stations registered with the National Weather Service in West Lafayette, IN (NWSLI = LFYI3) and Wanatah, IN (NWSLI = WANI3).

Soil fertility sampling was completed within two weeks following planting for all site years. Detailed soil sampling was conducted across all site years to understand the variability of soil nutrients with regard to row position and depth. Samples were divided into three depth increments (0-5cm, 5-10cm, and 10-20cm) and two sampling positions: in-row (IR) and between-row (BR). Average fertility levels for the 0-20cm depth for each respective field location are presented in Table 2.1. Analysis of soil samples was completed by A&L Great Lakes Laboratories (Fort Wayne, IN) for 2016, 2017, 2018, and 2019 (ACRE). Suretech Labs (Indianapolis, IN) was used for the analysis of soil for 2019 (PPAC) and pH for 2019 (ACRE). Analysis by A&L Great Lakes Laboratories and Suretech Labs both utilized Mehlich III for extraction to determine CEC, P, K, Mg, and Ca, and both utilized the loss by the ignition method for organic matter determination.

Table 2.1. Soil fertility means of soil samples taken to a depth of 0-20 cm for pH, organic matter (OM), cation exchange capacity (CEC), P, K, Mg, and Ca for each site year, with minima and maxima presented in parentheses.

	MY1[1]			MY2[1]	
Year	2016	2017	2019	2018	2019
Field	ACRE 111	ACRE 131	PPAC F-West	ACRE 111	ACRE 131
pH (1:1)	6.1 (5.4, 6.7)	6.4 (6.0, 6.8)	6.5 (6.0, 6.8)	6.2 (5.4, 7.0)	6.7 (6.3, 7.0)
OM (%)	2.7 (2.2, 3.0)	3.0 (2.5, 3.7)	2.6 (1.8, 4.2)	2.6 (2.2, 3.3)	3.5 (2.9, 4.3)
CEC (meq $100g^{-1}$)	15.6 (12.1, 18.2)	17.6 (13.6, 23.4)	13.2 (10.4, 16.2)	15.6 (11.8, 20.7)	18.1 (14.7, 22.7)
P (mg kg^{-1})	47 (22, 73)	25 (17, 46)	40 (12, 79)	45 (23, 91)	31 (16, 77)
K (mg kg^{-1})	151 (116, 193)	106 (79, 135)	134 (94, 205)	126 (87, 176)	105 (85, 133)
Mg (mg kg^{-1})	516 (325, 687)	594 (467, 803)	476 (349, 590)	527 (331, 807)	625 (529, 772)
Ca (mg kg^{-1})	1615 (1019, 2088)	2056 (1613, 2786)	1805 (1412, 2218)	1698 (1113, 2284)	2143 (1788, 2743)

[1] MY = maize year

Both laboratories used a slurry and electrode to determine soil pH, but calcium chloride was utilized in the Suretech pH measurements.

In total, ten treatments were investigated each year in a randomized complete block design; however, to allow for mean comparisons, only six treatments [those utilizing strip-till in the fall (FST) or spring (SST)] will be discussed in the analysis for this chapter. The source of fertilizer for this experiment was Aspire™ (The Mosaic Company, Tampa, FL) [0-0-48(K)-0.5(B)], a potassium-based fertilizer infused with B. Because of the product formulation change, the sodium borate formulation was used in 2016-2017 and the sodium borate plus calcium borate formulation was utilized for 2018 and both 2019 locations. Aspire™ rates corresponding to 0, 54, and 108 kg K ha^{-1} were applied using a six-row SoilWarrior® (Environmental Tillage Systems, Faribault, MN).

This coulter-based strip-till tool allowed for fertilizer placement to a depth of approximately 5cm while performing tillage. Coulter action mixed fertilizer into a wider band (and possibly more soil volume) than might have been realized with a deep shank placement. In contrast to the specific placement of fertilizer into the crop row with strip-till, the NT and FC treatments (which will have results presented in Chapter 3) had Aspire™ applied across the surface (applying fertilizer both in-row and between row), with FC incorporating fertilizer. In locations repeated for a second year, strip-till was intentionally offset 15 inches. Offsetting avoided enriching the same zone in the soil. This experiment was conducted following a maize-soybean rotation, with treatments and measurements only during maize years. Fall strip-till between the former maize rows preceded soybean planting in the rotation year, but no K or B was applied.

Table 2.2. MY1 (2016, 2017, and 2019 (PPAC)) dates for planting, strip-till, N sidedress, and herbicide regimine (presented as product rate applied) during respective growing seasons.

Maize Year	MY1[1]		
Year	2016	2017	2019
Field	ACRE 111	ACRE 131	PPAC F-West
Planting Date	4/19/2016	4/18/2017	6/5/2019
Fall Strip Tillage Date Spring Strip Tillage Date	11/4/2015 4/18/2016	11/1/2016 4/13/2017	12/6/2018 6/5/2019
Sidedress Date	05/16/2016	05/23/2017	07/02/2019
Pre-Emergence	Glyphosate [N-(phosphonomethyl)glycine], (Bayer Crop Science, Rhein, Germany) at 1543 g ha^{-1}	Glyphosate [N-(phosphonomethyl)glycine], (Bayer Crop Science, Rhein, Germany) at 1543 g ha^{-1} 2, 4-D [Dimethylamine Salt of 2,4-Dichlorophenoxyacetic Acid] at 1122 g ha^{-1}	Durango {Glyphosate [N-(phosphonomethyl)glycine, dimethylamine salt]} (Corteva Agriscience, Wilmington, DE) at 2.3 L ha^{-1} Fultime {Acetochlor [2-chloro- N-ethoxymethyl-N-(2-ethyl6-methylphenyl)acetamide], Atrazine[1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine]} (Corteva Agriscience, Wilmington, DE) at 7.0 L ha^{-1}
Post-Emergence	Callisto {Mesotrione [2-(4-(Methylsulfonyl)-2-nitrobenzoyl)cyclohexane-1,3-dione]} (Syngenta, Basel, Switzerland) at 210 g ha^{-1}	Bicep II {S-metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(1-methoxypropan-2-yl)acetamide], Atrazine [1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine]} (Syngenta, Basel, Switzerland) at 4.8 L ha^{-1} Calisto {Mesotrione [2-(4-(Methylsulfonyl)-2-nitrobenzoyl)cyclohexane-1,3-dione]} (Syngenta, Basel, Switzerland) at 210 g ha^{-1}	Callisto Xtra {Atrazine [1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine], Mesotrione [2-(4-(Methylsulfonyl)-2-nitrobenzoyl)cyclohexane-1,3-dione]} (Syngenta, Basel, Switzerland) at 1402 g ha^{-1}

[1] MY = maize year

Table 2.3. MY2 (2018 and 2019 (ACRE)) dates for planting, strip-till, N sidedress, and herbicide regimin (presented as product rate applied) during respective growing seasons.

Maize Year	MY2[1]	
Year	2018	2019
Field	ACRE 111	ACRE 131
Planting Date	4/26/2018	5/16/2019
Fall Strip Tillage Date Spring Strip Tillage Date	11/10/2017 4/26/2018	10/18/2019 5/15/2019
Sidedress Date	05/21/2018	06/02/2019
Pre-Emergence	Glyphosate [N-(phosphonomethyl)glycine], (Bayer Crop Science, Rhein, Germany) at 1543 g ha^{-1} Bicep II {S-metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(1-methoxypropan-2-yl)acetamide], Atrazine [1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine]} (Syngenta, Basel, Switzerland) at 4.8 L ha^{-1} 2, 4-D [Dimethylamine Salt of 2,4-Dichlorophenoxyacetic Acid] at 1122 g ha^{-1}	Glyphosate [N-(phosphonomethyl)glycine], (Bayer Crop Science, Rhein, Germany) at 1543 g ha^{-1} Bicep II {S-metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(1-methoxypropan-2-yl)acetamide], Atrazine [1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine]} (Syngenta, Basel, Switzerland) at 4.8 L ha^{-1}
Post-Emergence	Glyphosate [N-(phosphonomethyl)glycine] (Bayer Crop Science, Rhein, Germany) at 1543 g ha^{-1} Atrazine [1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine] at 1122 g ha^{-1} Callisto Mesotrione [2-(4-(Methylsulfonyl)-2-nitrobenzoyl)cyclohexane-1,3-dione] (Syngenta, Basel, Switzerland) at 210 g ha^{-1}	Glyphosate [N-(phosphonomethyl)glycine] (Bayer Crop Science, Rhein, Germany) at 1543 g ha^{-1} Callisto {Mesotrione [2-(4-(Methylsulfonyl)-2-nitrobenzoyl)cyclohexane-1,3-dione]} (Syngenta, Basel, Switzerland) at 210 g ha^{-1}

[1] MY = maize year

Experimental plots were 12-rows wide (0.76m row spacing) and ~36.6m in length. All site years were planted with a 6-row John Deere 1780 planter (Moline, IL) except for the 2019 (PPAC) location, which utilized a 12-row Case IH planter (Racine, WI). Planting and strip-till dates are presented in Tables 2.2 (MY1) and 2.3 (MY2). The same hybrid was used for all site years, Pioneer P1311AM or AMXT (Corteva Agriscience, Willmington, DE), except for the 2019 PPAC, which utilized Pioneer P0574AM (Corteva Agriscience, Wilmington, DE). All locations were planted to a population of 84,000 plants ha^{-1} with final average plant populations of 82,500, 83,000, 78,900, 80,000, and 82,400 plants ha^{-1} for 2016, 2017, 2018, 2019 (ACRE), and 2019 (PPAC) respectively (Appendix A, Table A1). At planting, starter fertilizer (placed 5 cm to the side and 5 cm below seed) at the ACRE locations (2016, 2017, 2018, and 2019) utilized ammonium polyphosphate (APP, 10-15(P)-0) with total nutrients applied of 19.6 kg N ha^{-1} and 29.1 kg P ha^{-1}. Starter fertilizer at the 2019 PPAC site was a mixture of urea ammonium nitrate (UAN, 28-0-0), APP, and ammonium thiosulfate [ATS, 12-0-0-26(S)] banding total nutrient amounts of 30.6 kg N ha^{-1}, 9.7 kg P ha^{-1}, and 16.2 kg S ha^{-1}. Upon reaching V5-V6, side-dress UAN was applied as a midrow band at 196 kg N ha^{-1} for all ACRE site years and 188 kg N ha^{-1} for 2019 (PPAC) (Refer to Tables 2.2 and 2.3 for information related to N side-dress date). Total N applied was 216 kg N ha^{-1} to all ACRE site years and 219 kg N ha^{-1} to PPAC in 2019. Herbicide (pre- and post-emergence) applications varied with each year and location; refer to Tables 2.2 and 2.3 for detail regarding applications (i.e., product, rate, date). Before the 2018 growing season at ACRE, an application of lime was broadcast applied to the entire experiment area at a rate of 6.7 metric tons ha^{-1} on 8 November 2017. Due to brown marmorated stink bug (*Halyomorpha halys* Stål) damage in 2019 ACRE, an application of Warhawk [chlorpyrifos [O,O-diethyl-O-(3,5,6-trichloro-2-pyridinyl) phosphorothioate] (Loveland Products, Greeley, CO) at a product rate of 4.7 L ha^{-1} and Headline

AMP {pyraclostrobin [carbamic acid, [2-[[[1-(4-chlorophenyl)-1H-pyrazol-3-yl]oxy]methyl]phenyl]methoxy-,methyl ester)], metconazole [5-[(4-chlorophenyl)methyl]-2,2-dimethyl-1-(1H-1,2,4-triazol-1-ymethyl)cyclopentanol]} (BASF, Research Triangle Park, NC) at the product rate of 0.73 L ha^{-1} was made on 19 June 2019.

2.3.1 In-Season Maize Tissue and Physical Measurements

For all years of this experiment, measurements were always collected in rows 3 and 4, and/or 9 and 10 out of the 12-row plots to avoid any border effects and to minimize the influence of wheel traffic. Following emergence, final plant populations were recorded for each location (replications sampled for MY1 = 14 and MY2 = 8, no differences in plant population across treatments, Table A.2). Zones with consistent plant-to-plant spacing and size were marked for ten consecutive plants (used for later dry matter sampling) and 20 consecutive plants (used for silking observations). A series of tissue samples were collected throughout the growing season. A full suite of macro- and micro-nutrients were measured for all tissue samples, but only the nutrients N, P, K, Calcium (Ca), Magnesium (Mg), and B are presented here. Data from other nutrients can be found in Appendix A. Once plants reached V5-6, whole-plant aboveground dry matter samples were collected for each plot. Samples consisted of 10 consecutive plants cut to ground level with leaves collected from the ground and length of row sampled (number of replications sampled MY1 = 9 and MY2 = 8). Samples were all dried at a temperature of 60°C for 4-7 days until constant weight. Once dry, samples were then weighed (for use in dry matter and nutrient uptake calculations) and ground to pass through a 1mm sieve.

Anthesis-silking notes were collected daily from a pre-selected set of 20 consecutive plants in each plot for all site years except for 2016 (replications sampled MY1 = 7 and MY2 = 8). Anthesis was reached when ten anthers (50% of the plants) were visible from the tassel. To be considered silked, plants had to display at least 1cm of silks extending from the husk. With the use of the planting date and the daily anthesis-silking notes, the anthesis-silking interval was calculated. Earleaf (the leaf opposite and below the ear) samples were collected at R1 (once plots reached 50% silking) from 10 consecutive plants in all years except 2019 ACRE, where ten leaves were collected randomly from plants along the plot length within the same row (replications sampled MY1 = 9 and MY2 = 8). Beginning in 2018, the leaf area of the earleaf was collected using a LI-3000C (LI-COR Biosciences, Lincoln, NE) to calculate the specific leaf area and specific leaf nutrient content (Eq. 1 and 2), using the method from DeBruin et al. (2013) (total replications sampled MY1 = 4 and MY2 = 7). During the growing season, non-destructive leaf area index measurements were taken at V14 (only taken in 2016, 2017, and 2019 ACRE, total reps measured MY1 = 8 and MY2 = 3)) and R2 (only taken during 2016, 2017, and 2018, total reps measured MY1 =8 and MY2 = 4)) utilizing a LAI-2200C (LI-COR Biosciences, Lincoln, NE). Five readings were taken per plot with datapoints collected while moving down and across the crop row; from these readings, an average for the plot was calculated. In 2019 at the ACRE location, visual height differences early in the season prompted height measurements at V8 and R1 (to top leaf collar in both timings).

Once all treatments had reached maturity (R6), ten plants from pre-determined zones were collected to determine final whole plant and component dry matter and nutrient uptake (total reps sampled, stover [MY1= 7, MY2 = 9], grain [MY1= 6, MY2 = 9], and cob [MY1= 6, MY2 = 9]). Plants were separated into three components, dried at 60°C for approximately a week until a constant weight was achieved: stover (husks, leaves, and stems), cobs, and grain. An additional sequential ten ears were collected from each plot, typically immediately following R6 dry matter sample zones, for yield component analysis. Dry matter ears (10 ears) were shelled individually with grain weight and kernel number recorded on a per-plant basis. Once all dry matter ears had been recorded for a plot, 200 kernels were taken from the total grain for the plot (grain was mixed before sampling) and dried at 140°C for 24 hours to ~0% moisture to determine mean kernel weights. All other plant components were dried at 60°C, weighed, and ground to pass through a 1mm sieve. Only one replication of cobs was submitted for nutrient analysis due to resource constraints and known low variability among treatments in cob nutrient composition. From the single replication of cob concentrations, treatments were matched with other reps and used to calculate nutrient content based on known cob weights in each rep. Nutrient analysis was performed for all site years and components at A&L Great Lakes Laboratories (Fort Wayne, IN). Due to mold growth on ears during 2017, no grain or cobs were analyzed for nutrient concentration or content. All ACRE site years were harvested with a Kincaid 2-row combine (Haven, KS) with two passes (4 rows) for the 4 to 6 reps present in each field. Grain harvest for 2019 PPAC was completed with an Allis Chalmers Gleaner 3-row combine (AGCO, Duluth, GA). Due to significant lodging and planting difficulties, 3 to 6 rows from each plot were used for determining the average grain yield per plot for four reps (rows 3-5 or 8-10 were harvested). From the K nutrient contents for each plant component, the K recovery efficiency was calculated (Eq. 3).

Eq 1. $$\text{Specific Leaf Area} = \frac{\text{Leaf area (m}^2\text{)}}{\text{Leaf mass (g)}}$$

Eq 2. $$\text{Specific Leaf Content} = \frac{\text{Tissue Nutrient Concentration}}{(\text{Specific Leaf Area (m}^2\text{g}^{-1}))}$$

Eq 3. $$\text{K Recovery Efficiency (\%)} = \frac{\text{K Uptake}_{\text{Applied K}} - \text{K Uptake}_{\text{No Applied K}}}{\text{K Fertilizer Applied}}$$

2.3.2 Statistical Analysis

Statistical analysis was performed using SAS 9.4 (SAS Institute Inc., 2016) utilizing the GLIMMIX and MIXED procedures (Stroup et al., 2018). Due to the potential for the effects of the addition of Aspire™ to influence a field for several years, site years were divided by maize year (MY1= initial year in the field for the experiment, MY2 = returning to the field following soybean). Because Field ID had few interactions with Tillage, Aspire™, or Tillage x AspireTM (majority had $p>0.05$), only the means for each Maize Year are presented for the plant-related measurements (Carmer et al., 1969). Because of the lack of balance between MY1 and 2 (MY1 having three site years, while MY2 had two site-years), a BY statement in SAS code was used to analyze MY1 and MY2 separately. For analysis, Field ID, Aspire™ rate, and tillage were treated as fixed effects, while hybrid (only for MY1) and block nested within Field ID were treated as random effects. Analysis of variance was conducted using the MIXED procedure, and mean separation was performed with the LSMEANS statement in the GLIMMIX procedure using a Tukey's Honest Significant Difference test. For both methods, a Kenward-Rogers adjustment was used (Stroup, 2015). Fixed variables and mean separation were considered significant at an $\alpha = 0.05$. Because of the variability in interactions between Tillage and Aspire™, the tables present the means for Tillage, Aspire™, and Tillage x Aspire™ along with p-values. Because only one replication of cob concentration data was collected each site year, the model for this parameter assumed the fixed effects of tillage and Aspire™ and random effects of year and hybrid.

Soil data were analyzed using several models to look at the stratification and variation among treatments. Each site year varied in the level of soil test K, so each site year is presented separately for all analyses. The Kenward-Rogers adjustment was used to analyze soil data (Stroup, 2015), and the LSMEANS statement for all analyses of soil utilized the Tukey Honest Significant Difference test. Figures 2.9 through 2.13 utilized the GLIMMIX procedure and used a BY statement to separate analyses by Field ID, treatment, and sampling position to look at individual soil depth increments. Depth increment was a fixed effect while block was treated as a random effect, and the LSMEANS statement was used for mean separation of soil depth increments. To compare sampling position within a treatment for each site year (i.e., bold letters next to the y-axis), a BY statement was also used to separate Field ID and treatment. Row position and depth were fixed effects, and block was random. The LSMEANS statement was used to calculate differences in sampling position. Soil data were also analyzed for significant differences in Aspire™ rate and row position by sampling depth. A BY statement was used to separate by Field ID and sampling depth. The GLIMMIX procedure was used for analysis using the fixed variables of tillage, Aspire™ rate, and row position, and random variable of block. The LSMEANS statement presented the differences in Aspire™ rate and sampling position.

A similar analysis was used to look at differences in K concentration among treatments within a specific depth increment using the GLIMMIX procedure and the LSMEANS statement with a Kenward Rogers Adjustment. A BY statement separated Field IDs and sampling depth; the fixed effects for this experiment consisted of tillage, Aspire™, and row position. Block was considered a random variable.

The ratios of plant-available K concentration in the 0-5cm depth to 5-10cm and 0-5cm to 10-20cm depth were calculated and tested against one another. Similar to the previous analyses, the GLIMMIX procedure was used. The BY statement was used to separate each field ID. The fixed variables for the model were Tillage, Aspire™, and Row Position with Block as a random variable. The LSMEANS statement calculated differences for Aspire™ rate and row position.

2.4 Results and Discussion

2.4.1 General Considerations

Constraints in the presentation and interpretation of our results need to be acknowledged. There are no prior studies that have simultaneously investigated Aspire™ and the timing of strip-till. Furthermore, the lack of additional treatments for separation of the individual influences of K and B makes it challenging to attribute cause and effect in maize response or to compare our findings to previous research. This Results and Discussion section will therefore refer to potentially relevant past K or B research (but only rarely to both).

2.4.2 Weather

Weather information [i.e., high temperature (°C), low temperature (°C), and accumulated precipitation (cm))] for each site year are presented in Figures 2.1 through 2.5. Figure 2.6 displays monthly precipitation from the weather station located at ACRE versus the 30-year normal (1981-2010). Cumulative precipitation in 2016 was approximately normal, but rainfall was relatively low in May. Overall, 2017 saw excess precipitation throughout the growing season, with July alone having nearly twice the normal precipitation. In 2018, the weather was initially normal, but below-normal precipitation in July was followed by above-normal rainfall for the August through October period. In most of the 2019 growing season, rainfall quantities were near normal, except for low precipitation during July. At the PPAC location (2019), Figure 2.7 shows that July through August had below-normal accumulated rainfall, while September was nearly double the 30-year normal (1981-2010). The lack of precipitation during the critical period (~2 weeks prior and following flower initiation) may have limited kernel retention and kernel weights at PPAC during 2019.

The monthly accumulated growing degree days (GDDs) for each location (utilizing temperature limits of 50 and 86°F) are shown in Fig. 2.8. All site years followed a similar rise and fall for monthly GDDs, but several differences existed among the site years. The 2018 year had an unusually high accumulation of GDDs in May, improving early season growing conditions alongside the adequate moisture. Both locations for 2019 (ACRE and PPAC) had a similar accrual pattern for monthly GDDs, but 2019 at PPAC had lower monthly accumulations throughout the growing season than 2019 at ACRE.

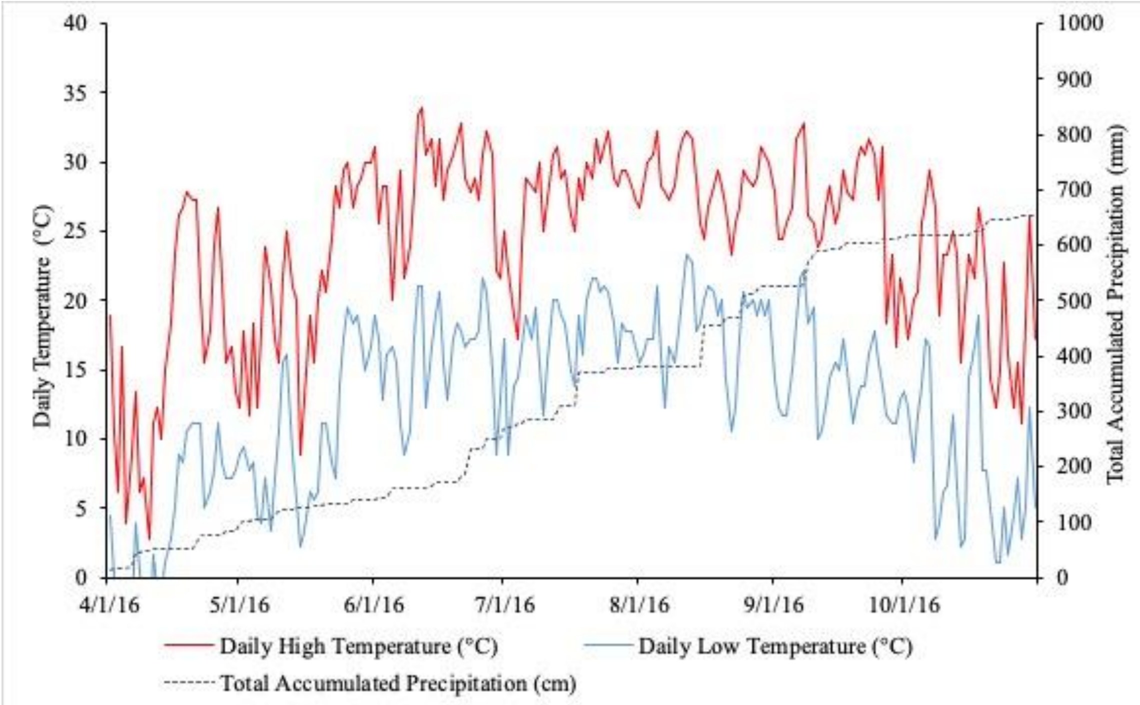

Figure 2.1. Weather at ACRE from 1 April 2016 to 30 November 2016 showing daily high (°C) and low temperatures (°C) with accumulated precipitation (mm).

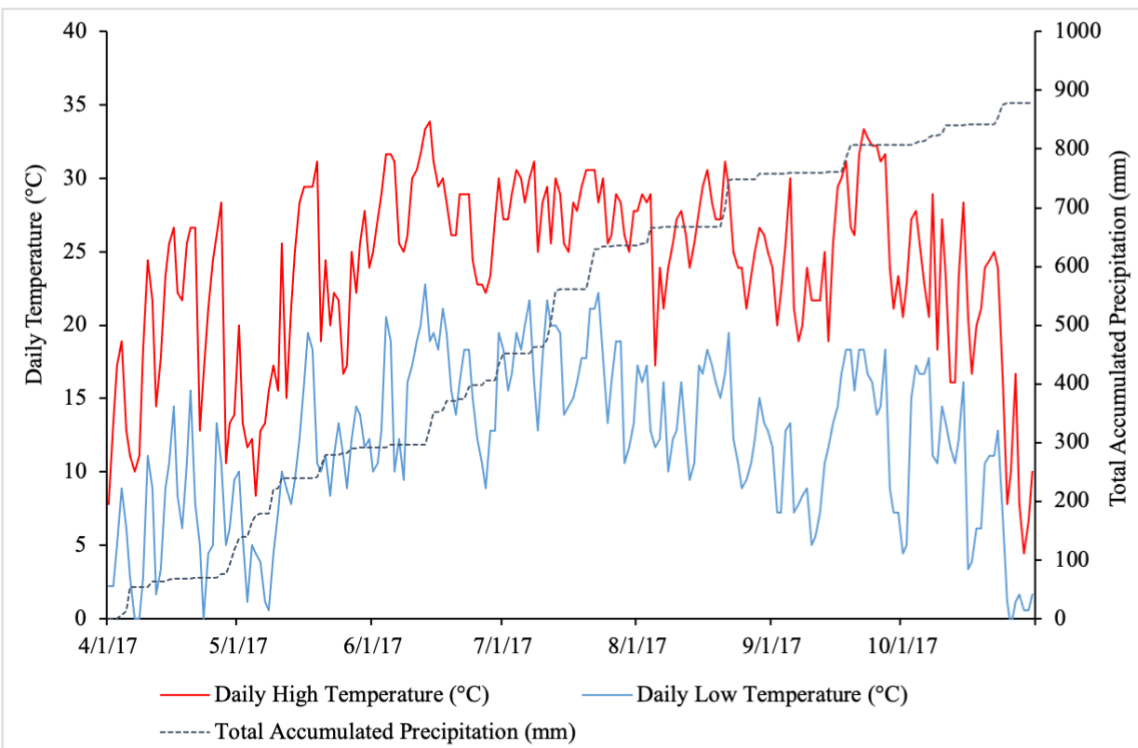

Figure 2.2. Weather at ACRE from 1 April 2017 to 30 November 2017 showing daily high (°C) and low temperatures (°C) with accumulated precipitation (mm).

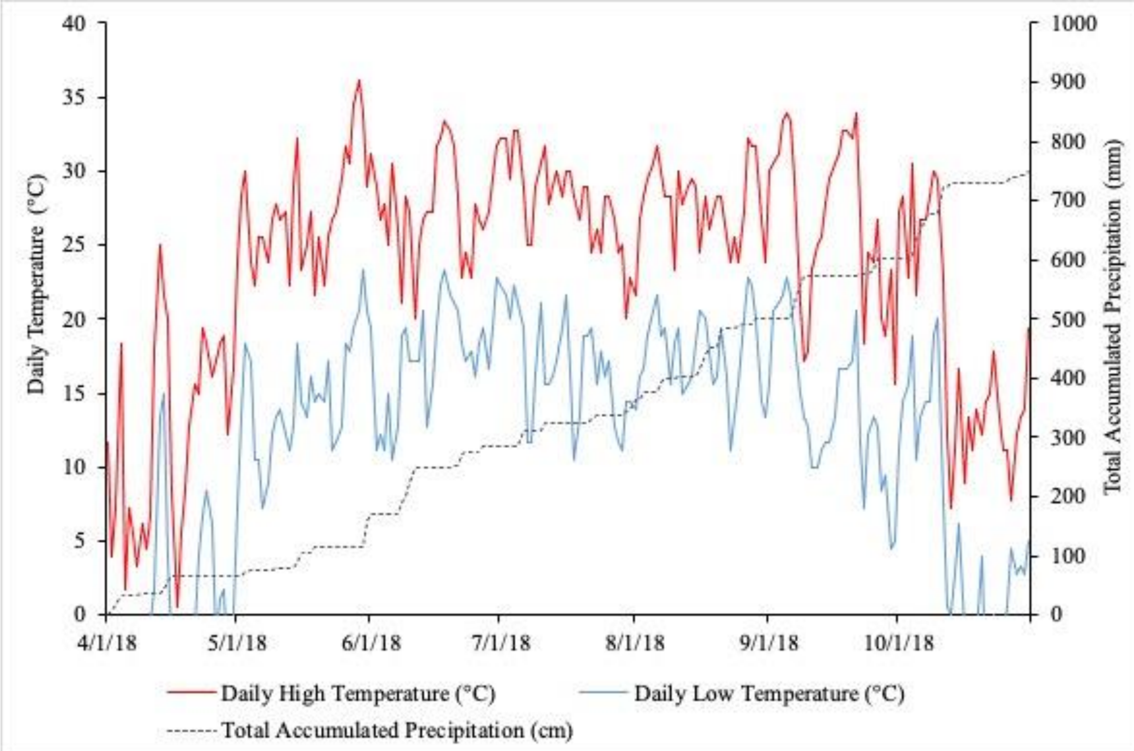

Figure 2.3. Weather at ACRE from 1 April 2018 to 30 November 2018 showing daily high (°C) and low temperatures (°C) with accumulated precipitation (mm).

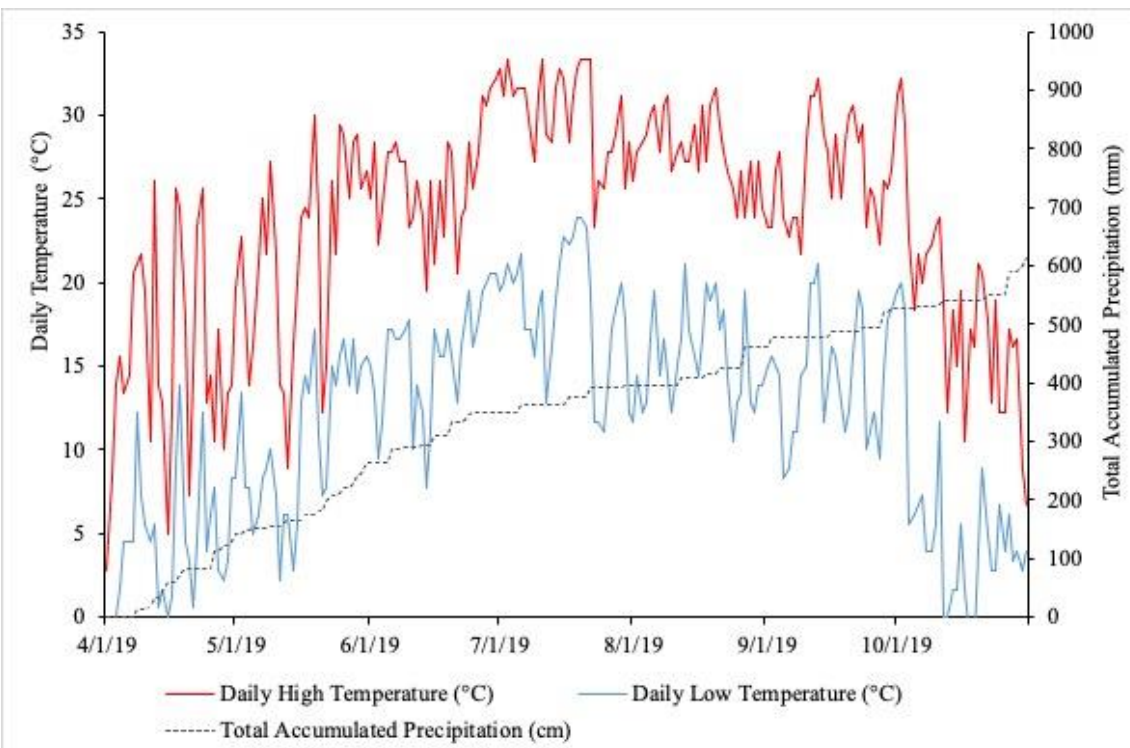

Figure 2.4. Weather at ACRE from 1 April 2019 to 30 November 2019 showing daily high (°C) and low temperatures (°C) with accumulated precipitation (mm).

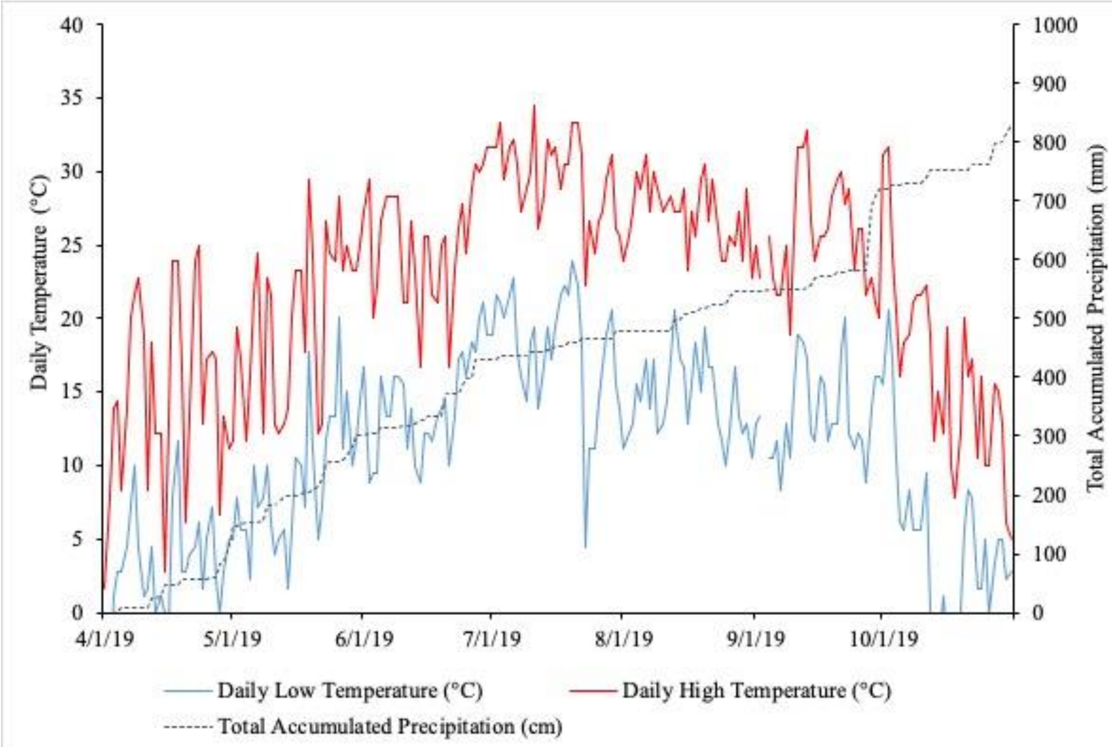

Figure 2.6. Weather at PPAC from 1 April 2019 to 30 November 2019 showing daily high (°C) and low temperatures (°C) with accumulated precipitation (mm).

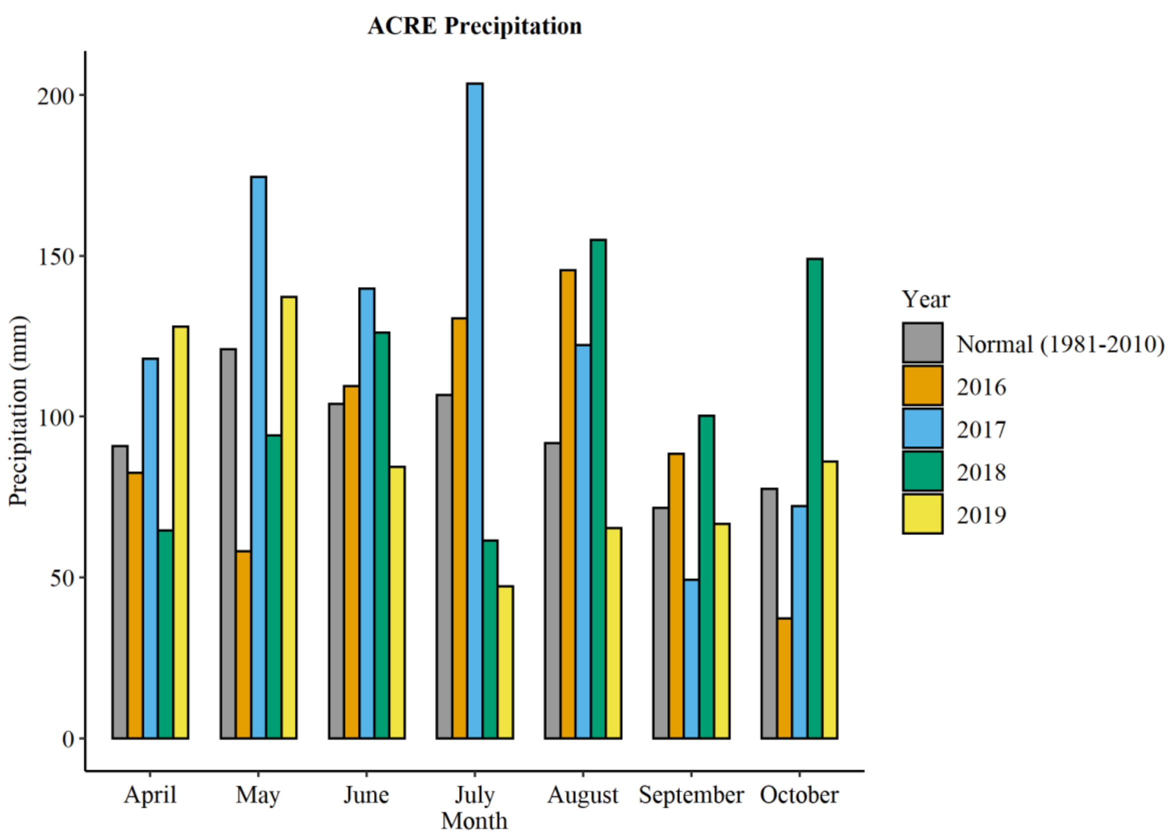

Figure 2.5. Monthly accumulated precipitation (mm) at the ACRE location for 2016, 2017, 2018, and 2019 compared to a 30-year normal (1981-2010).

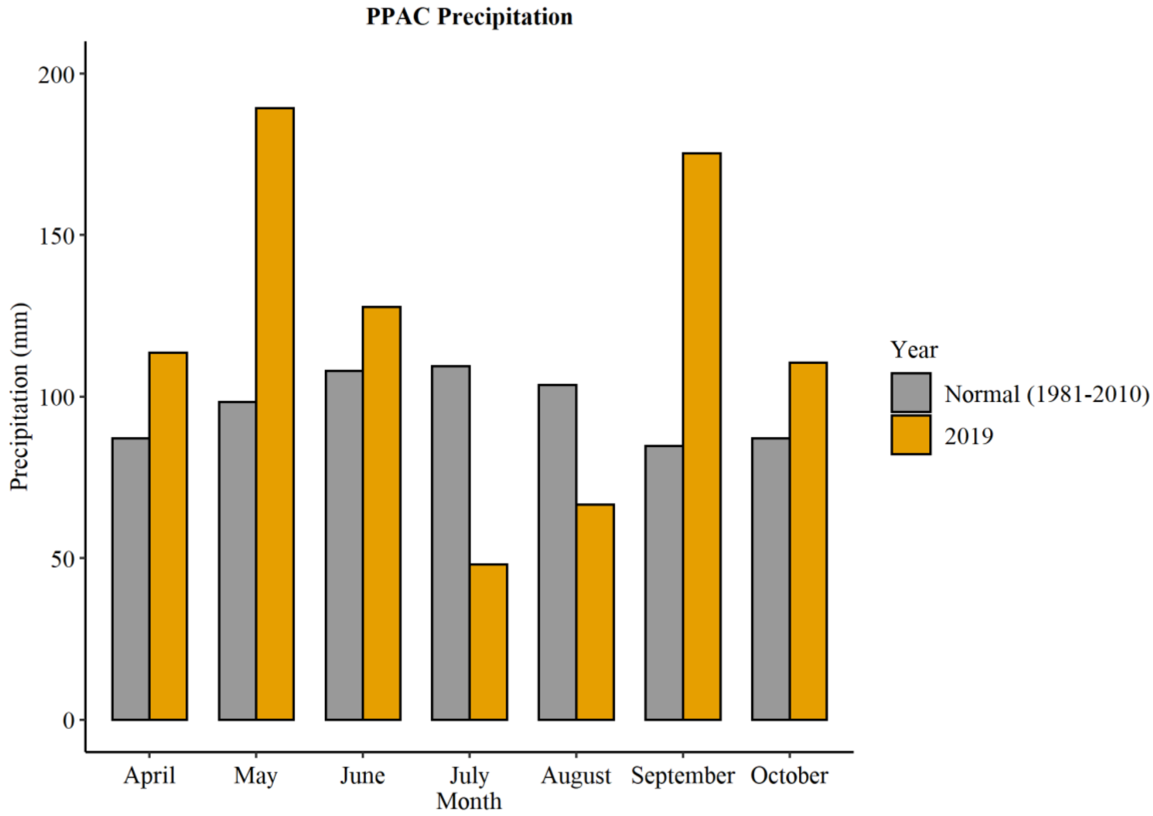

Figure 2.8. Monthly accumulated precipitation (mm) for PPAC in 2019 compared to 30-year normal (1981-2010).

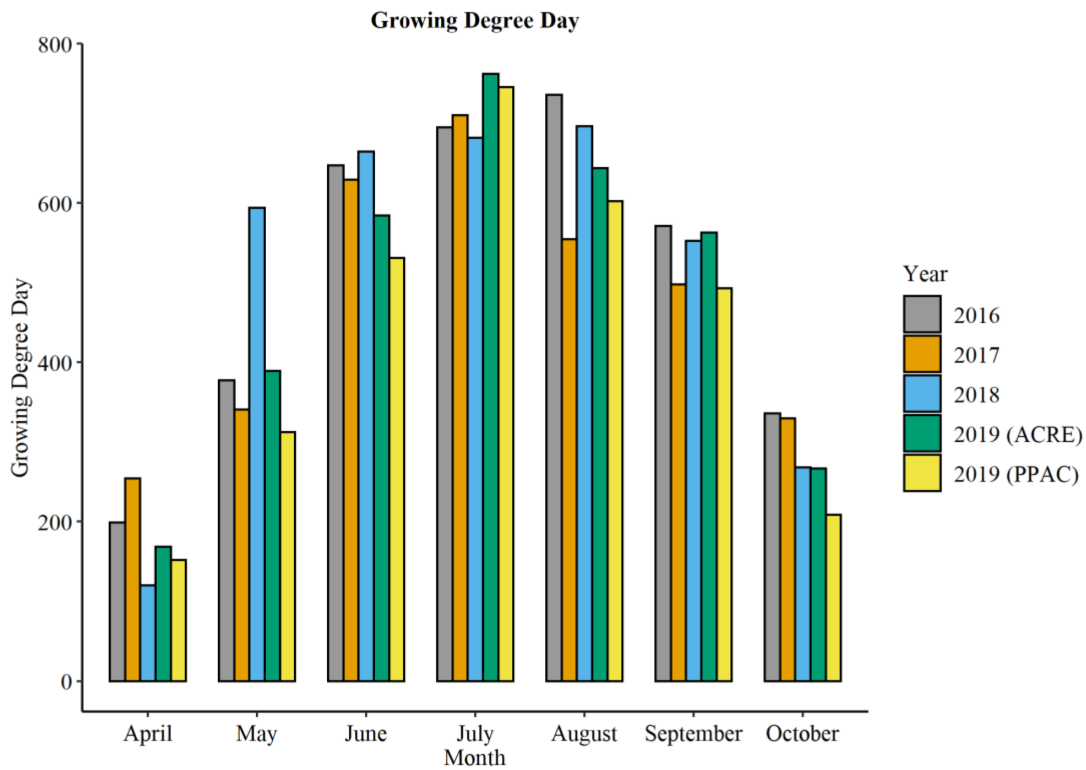

Figure 2.7. Growing degree days accumulated per month for ACRE (2016, 2017, 2018, and 2019) and PPAC (2019). Using limits of 50 and 86°F.

2.4.3 Soil Measurements for Plant-available K

Using Tri-State Fertilizer Recommendations (Vitosh et al., 1995), the critical soil K concentrations were calculated to be 114, 119, 114, 121, and 108 mg K kg^{-1} for 2016, 2017, 2018, 2019 (ACRE) and 2019 (PPAC), respectively. Table 2.1 presents the average plant-available K concentration (from a depth of 0-20cm) for each site year, looking at only the 0 (control) treatments across all tillage systems used in the overall field experiment. Because of the inherent variability of soil over the trial area, some areas of the field would have been classified below the critical level (indicated by the minimum value presented in Table 2.1). However, when looking only at the average for each location, most plant-available K levels were above the critical level, except for 2017 and 2019 (ACRE), which were 13 and 16 mg K kg^{-1} below the critical level, respectively.

Collection of soil samples by depth increment and position is not a new concept, but utilizing this sampling method following the use of a coulter driven strip-till implement while incorporating fertilizer on-the-go, has not yet been documented. Soil sampling in depth increments both in the crop row (IR) and between the crop row (BR) produced Figures 2.9 through 2.18 that show K distribution within the soil following strip-till and Aspire™ applications. Each site-year is presented separately due to the variability in stratification and plant-available K concentration (mg K kg^{-1}) across years within the same field.

There were consistently higher concentrations of plant-available K (mg K kg^{-1}) in the 0-5cm depth compared to the deeper sampling depths (5-10cm and 10-20cm) within a specific treatment (Figures 2.9 to 2.13). The 10-20cm depth frequently was not significantly different than the 5-10cm depth. Accumulation of K close to the surface and the continual deposition of K close to the surface, through both residue and past fertilizer applications, have been shown by other researchers to lead to stratification with depth in other conservation tillage systems (Howard et al., 1999; Mallarino & Ul-Haq, 1997; Robbins & Voss, 1991; Varsa & Ebelharar, 2000; Vyn et al., 2002).

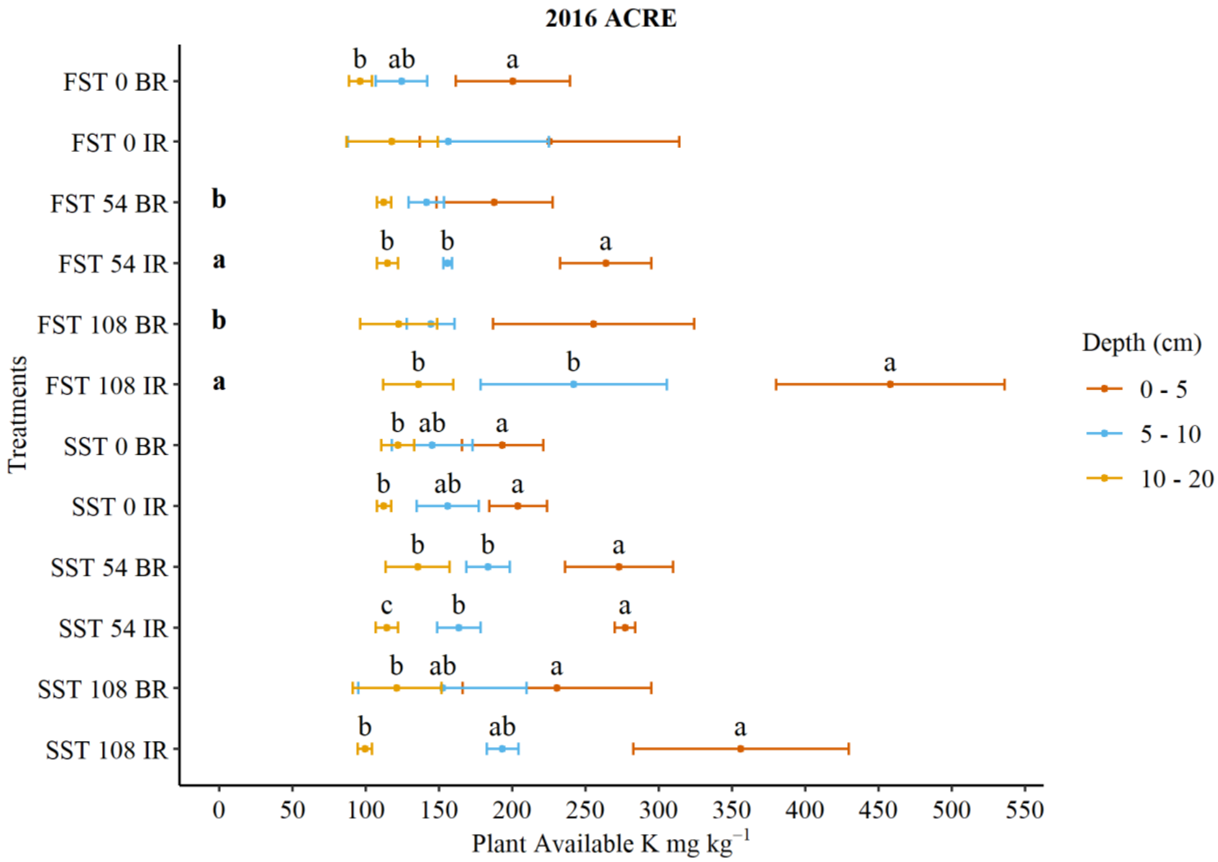

Figure 2.9. Soil sampling results for plant-available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth increment. Dot indicates average for depth increment representing 2 replications. Error bars represent the standard deviation for the individual depth measured. Bold lower-case letters indicate significant differences between sampling position with a treatment at a significance level of $p<0.05$. Letters above dots (representing average) indicate significant differences in plant-available K concentration within a specific treatment and sampling position at a significance level of $p<0.05$.

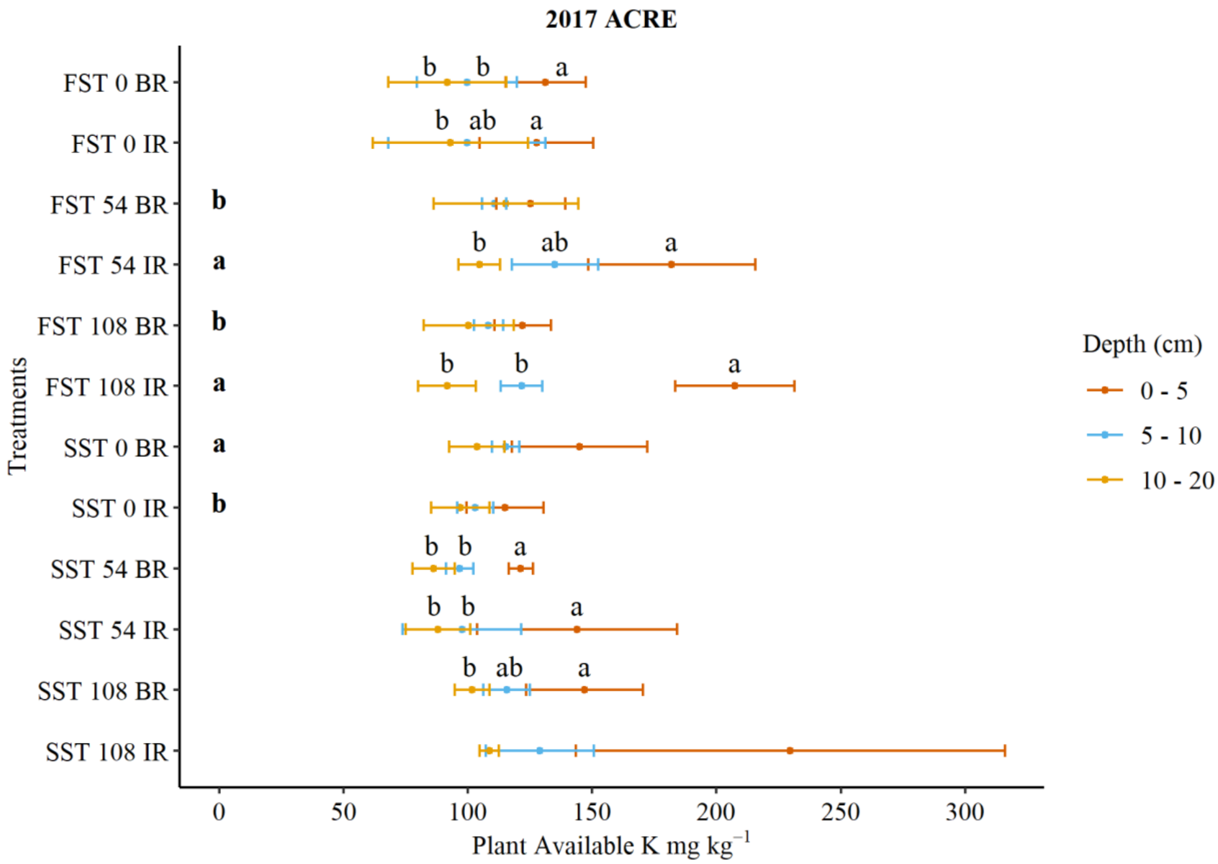

Figure 2.10. Soil sampling results for plant-available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth. Dot indicates average for depth increment representing 3 replications. Error bars represent the standard deviation for the individual depth measured. Bold lower-case letters indicates significant differences between sampling positions with a treatment at a significance level of $p<0.05$. Letters above dots (representing average) indicates significant differences in plant-available K concentration within a specific treatment and sampling position at a significance level of $p<0.05$.

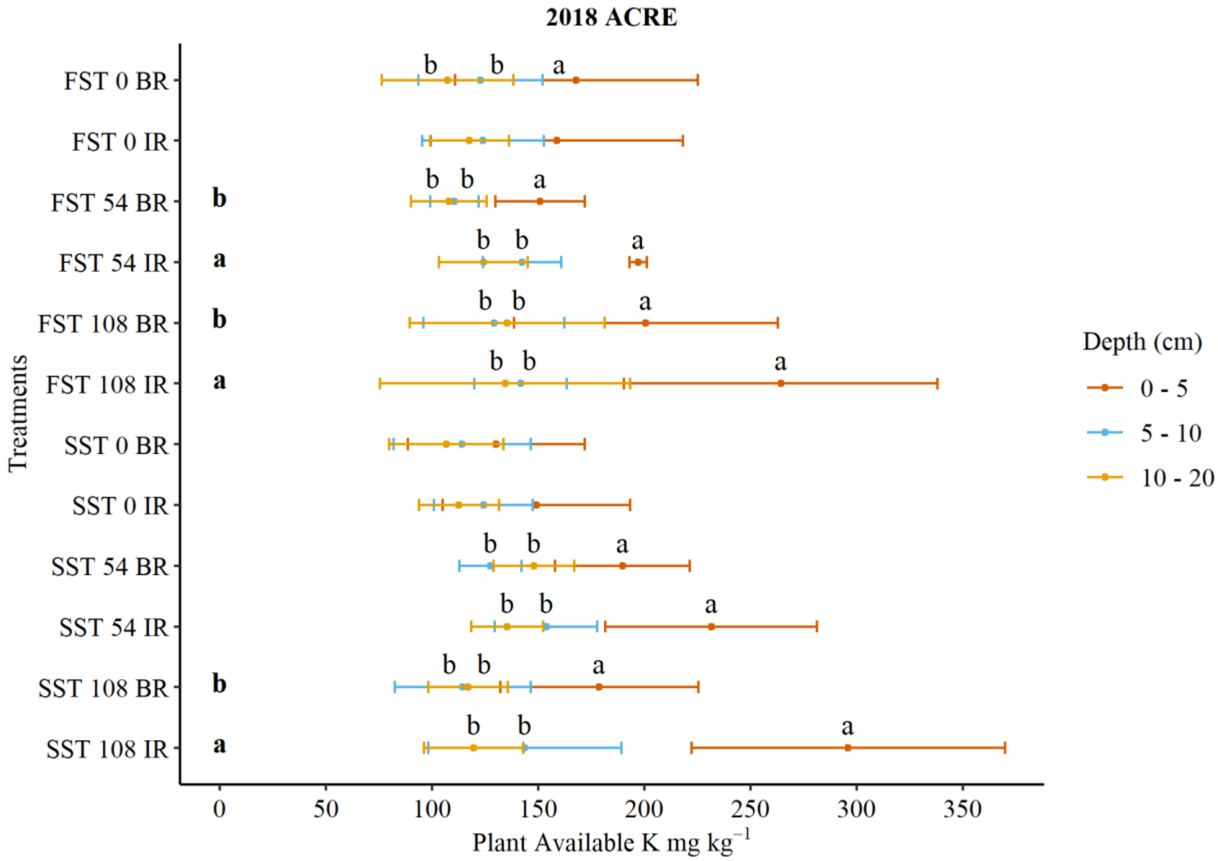

Figure 2.11. Soil sampling results for plant-available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth. Dot indicates average for depth increment representing 4 replications. Error bars represent the standard deviation for the individual depth measured. Bold lower-case letters indicate significant differences between sampling positions with a treatment at a significance level of p<0.05. Letters above dots (representing average) indicates significant differences in plant-available K concentration within a specific treatment and sampling position at a significance level of p<0.05.

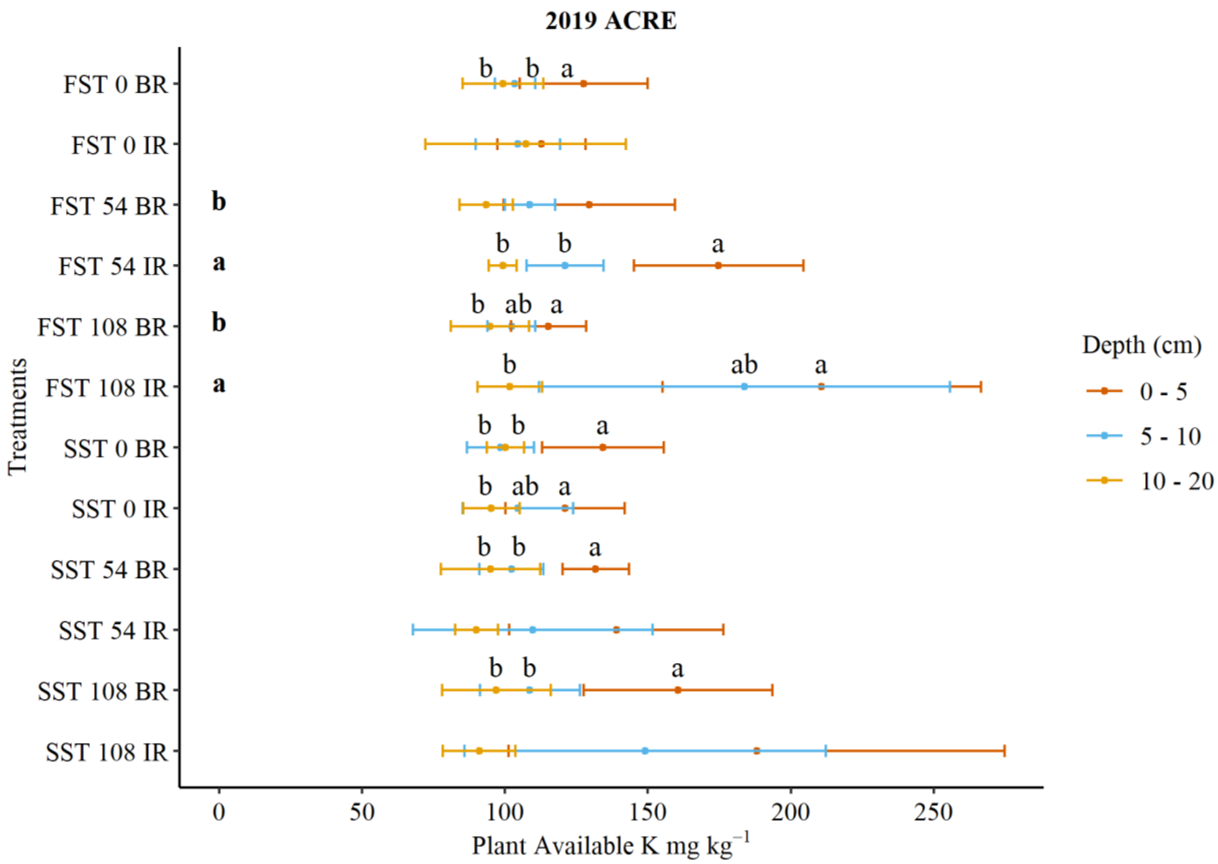

Figure 2.12. Soil sampling results for plant-available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth. Dot indicates average for depth increment representing 4 replications. Error bars represent the standard deviation for the individual depth measured. Bold lower-case letters indicate significant differences between sampling positions with a treatment at a significance level of p<0.05. Letters above dot (representing average) indicates significant differences in plant-available K concentration within a specific treatment and sampling position at a significance level of p<0.05.

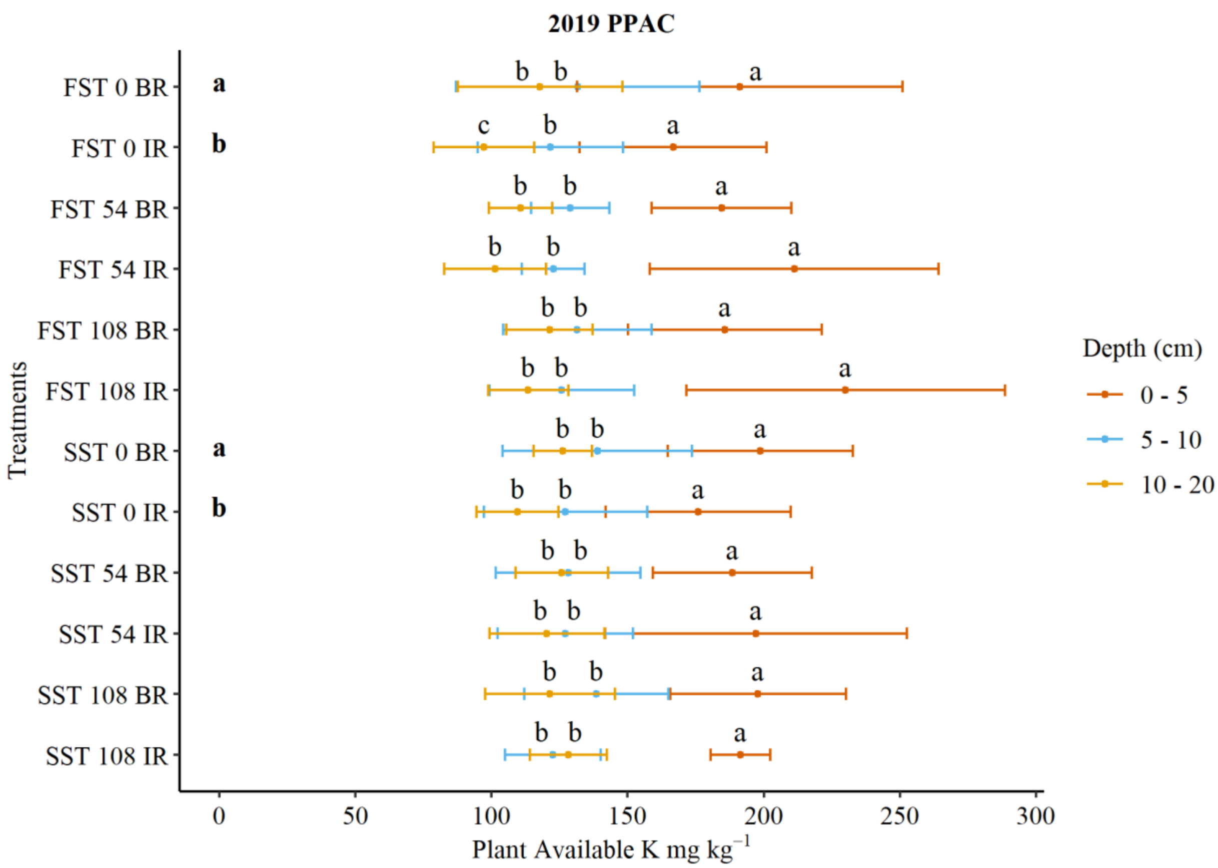

Figure 2.13. Soil sampling results for plant-available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth. Dot indicates average for depth increment representing 6 replications. Error bars represent the standard deviation for the individual depth measured. Bold lower-case letters indicates significant differences between sampling positions with a treatment at a significance level of $p<0.05$. Letters above dot (representing average) indicates significant differences in plant-available K concentration within a specific treatment and sampling position at a significance level of $p<0.05$.

Even after mixing and incorporating fertilizer for some treatments, there were still significant differences among the depth increments for both IR and BR positions. These results show that, even with the mixing from strip-till in the crop row, stratification was not overcome.

Across most site years, plant-available K levels differed significantly between IR- and BR –positions in FST. In all years at ACRE, IR concentrations of K in FST were higher than BR concentrations when Aspire™ had been applied. Others working in conservation tillage systems have documented higher K concentrations in IR than BR positions (Howard et al., 1999; Varsa & Ebelharar, 2000). However, at PPAC, the only difference between row positions was where no Aspire™ had been applied, and K levels in the row were lower than K levels between rows.

Fewer differences between row positions were observed in SST. In both 2017 at ACRE and 2019 at PPAC, K levels in the rows were lower than K levels between the rows when no Aspire™ had been applied. In one site-year, 2018, at ACRE, IR K concentrations were greater than BR K concentrations when the highest rate of Aspire™ had been applied. The lack of differences between sampling positions in the SST treatments fertilized with Aspire™ could be due to multiple factors but likely occurred due to low moisture levels between application and sample collection, limiting the time for fertilizer prills to dissolve and release K into the soil solution. After completing all tillage and nutrient applications, collecting samples provided some indication that Aspire™ required more than a couple of weeks after application to increase soil test K levels.

Another analysis of the soil data looked exclusively at the impact of Aspire™ rate and sampling position for each field ID because tillage timing resulted in little to no influence on differences in plant-available K concentration in the soil (data not shown). Figures 2.14 to 2.18 present differences among Aspire™ rate and row position within a sampling depth for each field

ID. Across most field IDs for the 0-5cm depth sample, the specific combination of 108 kg K ha^{-1} for the IR sample was significantly higher than most other combinations of Aspire™ rates and row positions.

The results for 0-5cm from the 108 kg K ha^{-1} treatment in field 111 at ACRE was significantly higher than all other Aspire™ rates and sampling positions, by 176 mg K kg^{-1} in 2016 and 105 mg K kg^{-1}in 2018 (Figures 2.14 and 2.16). Samples from that same field at ACRE in 2018 showed that all IR sampled treatments were different from one another, and the 54 kg K ha^{-1} IR concentration was 63 mg K kg^{-1} higher than the 0 kg K ha^{-1} and 66 mg K kg^{-1} lower than the 108 kg K ha^{-1} (Figure 2.16).

Field 131 at ACRE also had a significant increase in plant-available K concentration for the 0-5cm depth for the 108 kg K ha^{-1} Aspire™ rate IR sample, with increases in 2017 of 89 mg K kg^{-1} and 70 mg K kg^{-1} higher in 2019 (Figure 2.15 and 2.17).

The concentration of plant-available K for 2019 at PPAC only detected a difference between 108 kg K ha^{-1} and 0 kg K ha^{-1} in the IR position, with all other treatments not considered different (Figure 2.18).

From this analysis, the soil K concentration was influenced most by the 108 kg K ha^{-1} rate only in the crop row. This analysis shows fertilizer applied within the crop row commonly affected the concentration of the 0-5cm depth at the 108 kg K ha^{-1} rate, with the 54 kg K ha^{-1} having less influence on in-row concentrations. There was little overall influence on the concentration of plant-available K at the 5-10cm depth from the Aspire™ application and no influence at the 10-20cm depth.

Plant-available K distribution after performing tillage and applying fertilizer is not frequently documented in the literature; most studies (especially in maize and soybean) collect baseline soil fertility data before any tillage or fertilizer applications occur. The initial distribution of plant-available K is commonly presented to show the K stratification that has developed over time to evaluate how fertilizer placement can mitigate this problem; however, only a few select studies have documented the change in K distribution following several fertilizer rate applications over time. Similar to the results from Mallarino et al. (1991), the high application rate of Aspire™ increased the concentration of K for IR samples. The moderate rate of Aspire™ did not show notable concentration changes between the first- and second-year locations; however, the 0 kg K ha^{-1} treatment also did not show a noticeable decline in plant-available K over the two field season interval.

Calculating the ratio of plant-available K ratios from two different soil depths gives an indication of the degree of stratification at shallow soil depths. Figures 2.19 and 2.20 show the ratio of plant-available K for several of the sampling depths. Figure 2.19 shows the addition of Aspire™ and sample row position influenced 0-5cm:5-10cm plant-available K ratios for the IR position in both MY1 and MY2, and little change for BR. More separation in the stratification ratio was evident among the application rates for the 0-5cm: 10-20cm ratio. As expected, greater ratios of soil exchangeable K concentration were recorded for 0-5cm:10-20cm compared to 0-5:5-10cm. Other authors have documented similar K stratification ratios of plant-available K near the surface (Canepa, 2007; Holanda et al., 1998; Vyn et al., 2002). The high ratio for the IR position for soil exchangeable K ratios at both paired depths reflects the consequence of the 108 kg K ha^{-1} IR samples, because fertilizer is deposited in the top 5cm and only in the crop row.

Soil sampling position relative to the crop row is a critical consideration in a strip-till system. Elevated soil test K levels near the soil surface occur in the row as a result of applying high rates of K to a small volume of soil. Sampling in the fertilizer band gives a much higher

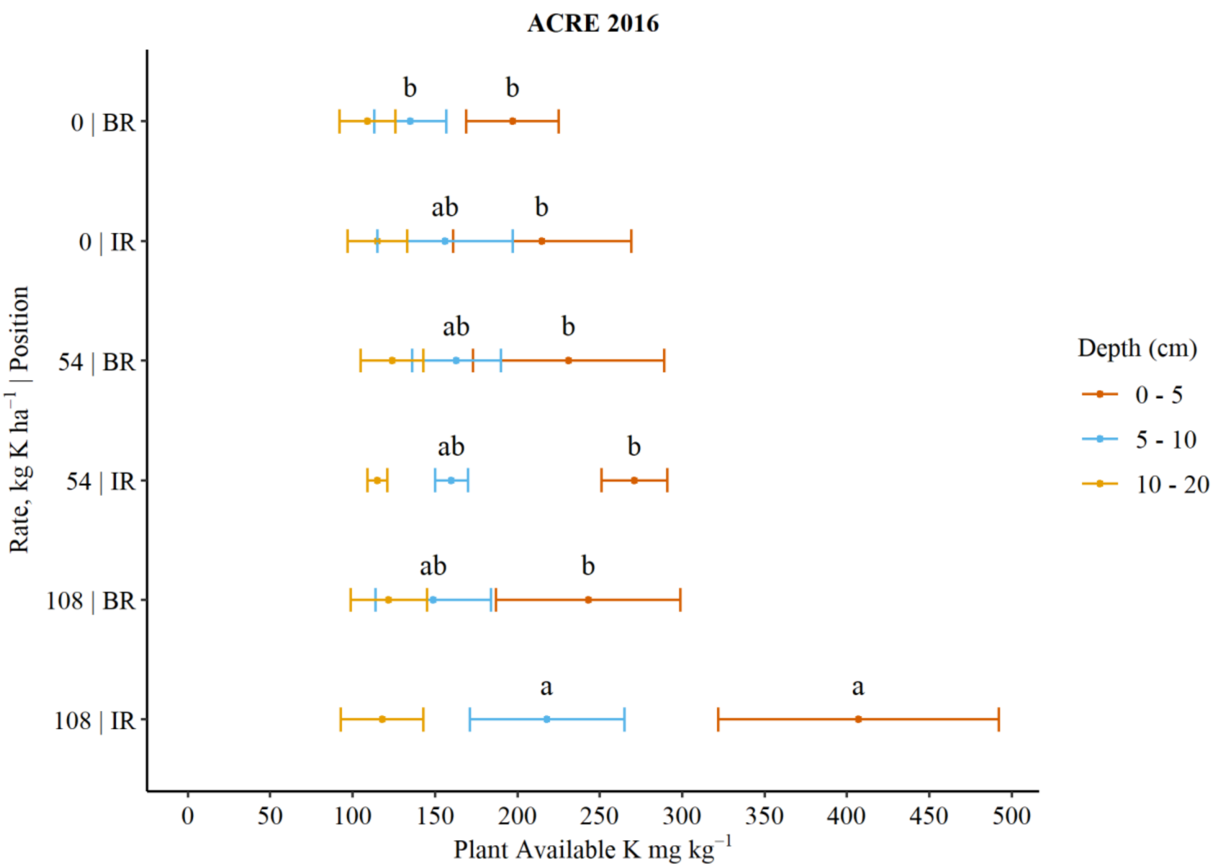

Figure 2.14. Soil sampling results for plant-available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth for 2016 at ACRE. Dots indicate averages for a depth increment representing 2 replications. Error bars represent the standard deviation for the individual depth measured. Letters above dots indicate significant differences in plant-available K concentration within a specific depth across Aspire™ rate and sampling position combinations at a significance level of $p<0.05$.

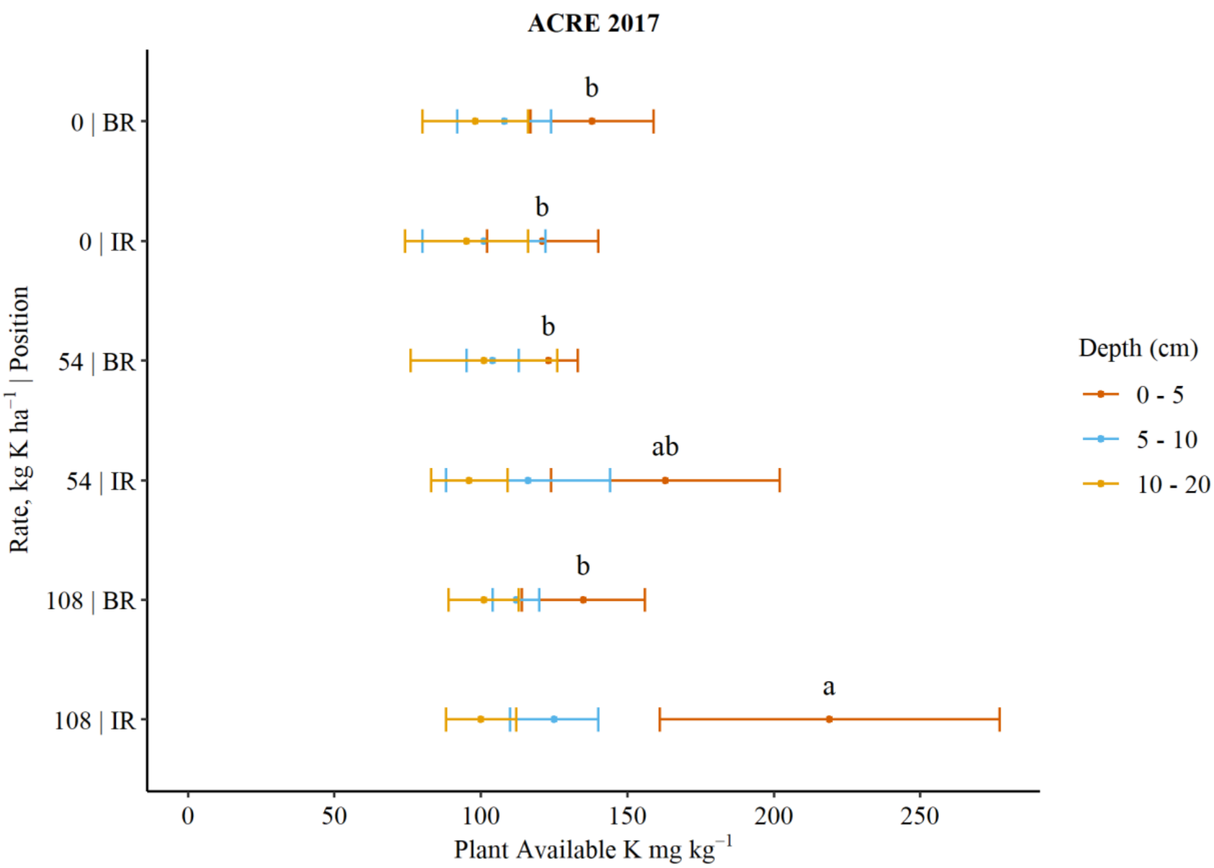

Figure 2.15. Soil sampling results for plant-available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth for 2017 at ACRE. Dots indicate averages for a depth increment representing 3 replications. Error bars represent the standard deviation for the individual depth measured. Letters above dots indicate significant differences in plant-available K concentration within a specific depth across Aspire™ rate and sampling position combinations at a significance level of $p<0.05$.

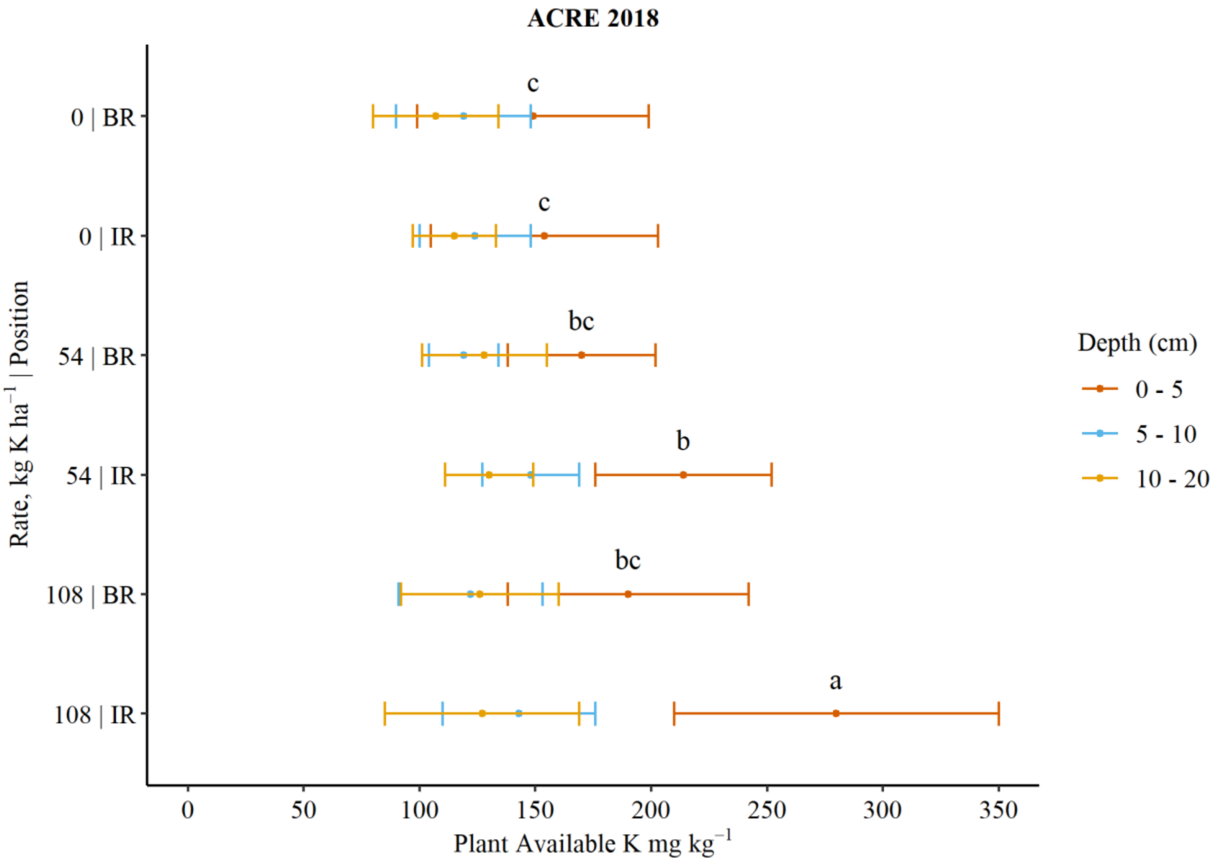

Figure 2.16. Soil sampling results for plant-available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth for 2018 at ACRE. Dots indicate averages for a depth increment representing 4 replications. Error bars represent the standard deviation for the individual depth measured. Letters above dots indicate significant differences in plant-available K concentration within a specific depth across Aspire™ rate and sampling position combinations at a significance level of $p<0.05$.

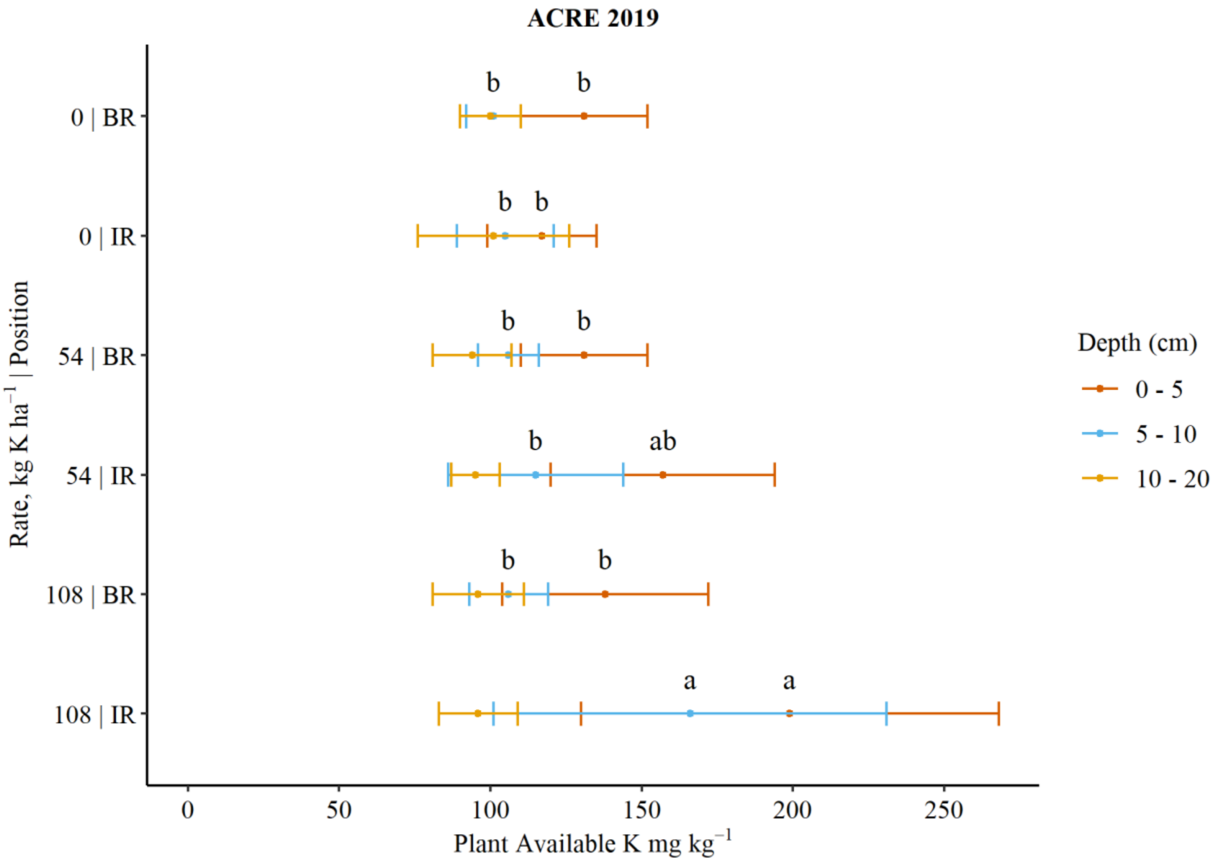

Figure 2.17. Soil sampling results for plant-available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth for 2019 at ACRE. Dots indicate average for a depth increment representing 4 replications. Error bars represent the standard deviation for the individual depth measured. Letters above dots indicate significant differences in plant-available K concentration within a specific depth across Aspire™ rate and sampling position combination at a significance level of $p<0.05$.

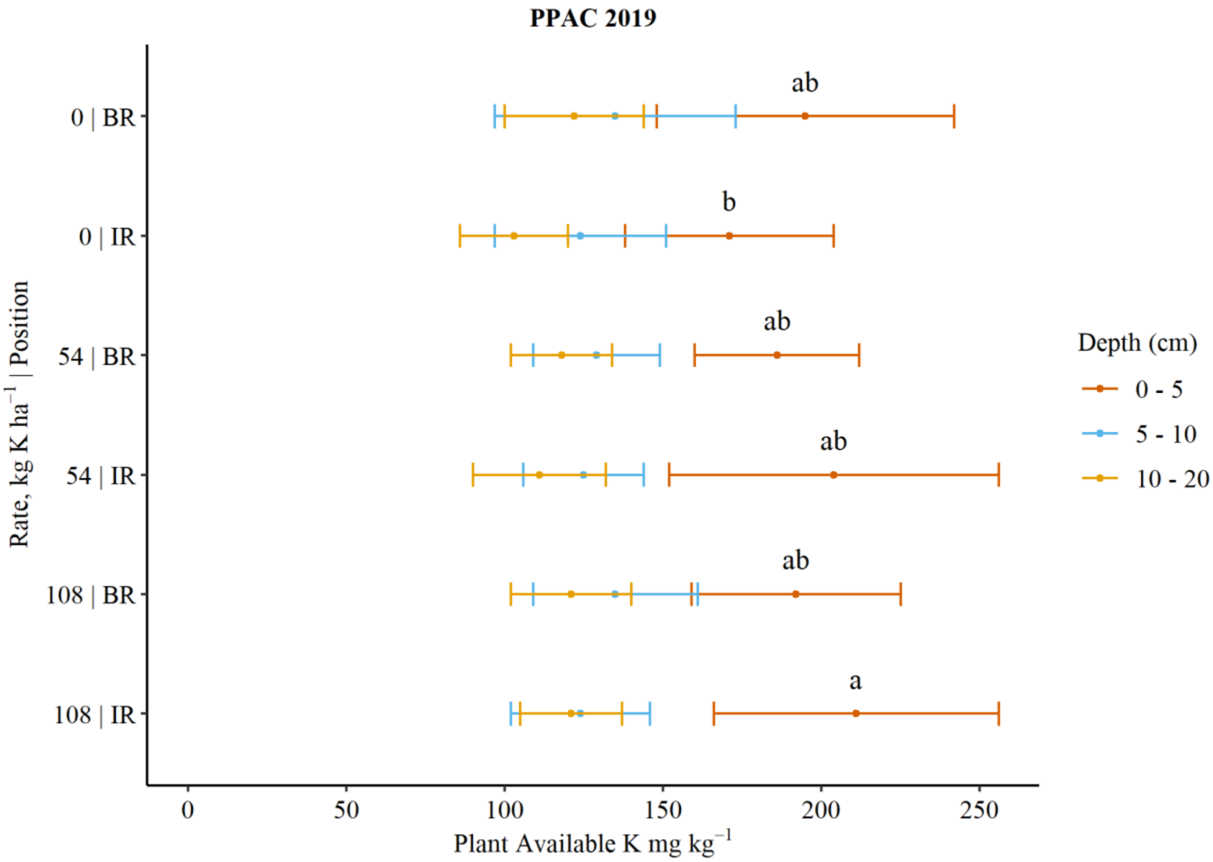

Figure 2.18. Soil sampling results for plant-available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth for 2019 at PPAC. Dots indicate averages for a depth increment representing 6 replications. Error bars represent the standard deviation for the individual depth measured. Letters above dots indicate significant differences in plant-available K concentration within a specific depth across Aspire™ rate and sampling position combination at a significance level of $p<0.05$.

nutrient concentration than in the rest of the soil volume, which could change management decisions. Unknowingly collecting most soil samples from the fertilizer band could potentially lead to cutting fertilizer rates and limiting maize growth and development. The dataset from this chapter also shows that although Aspire™ was incorporated with tillage, the increase in concentration was mostly contained in the top 5cm of the soil. The coulter-based strip-till system used for this chapter places fertilizer mostly near the surface and had little short-term impact below 5cm.

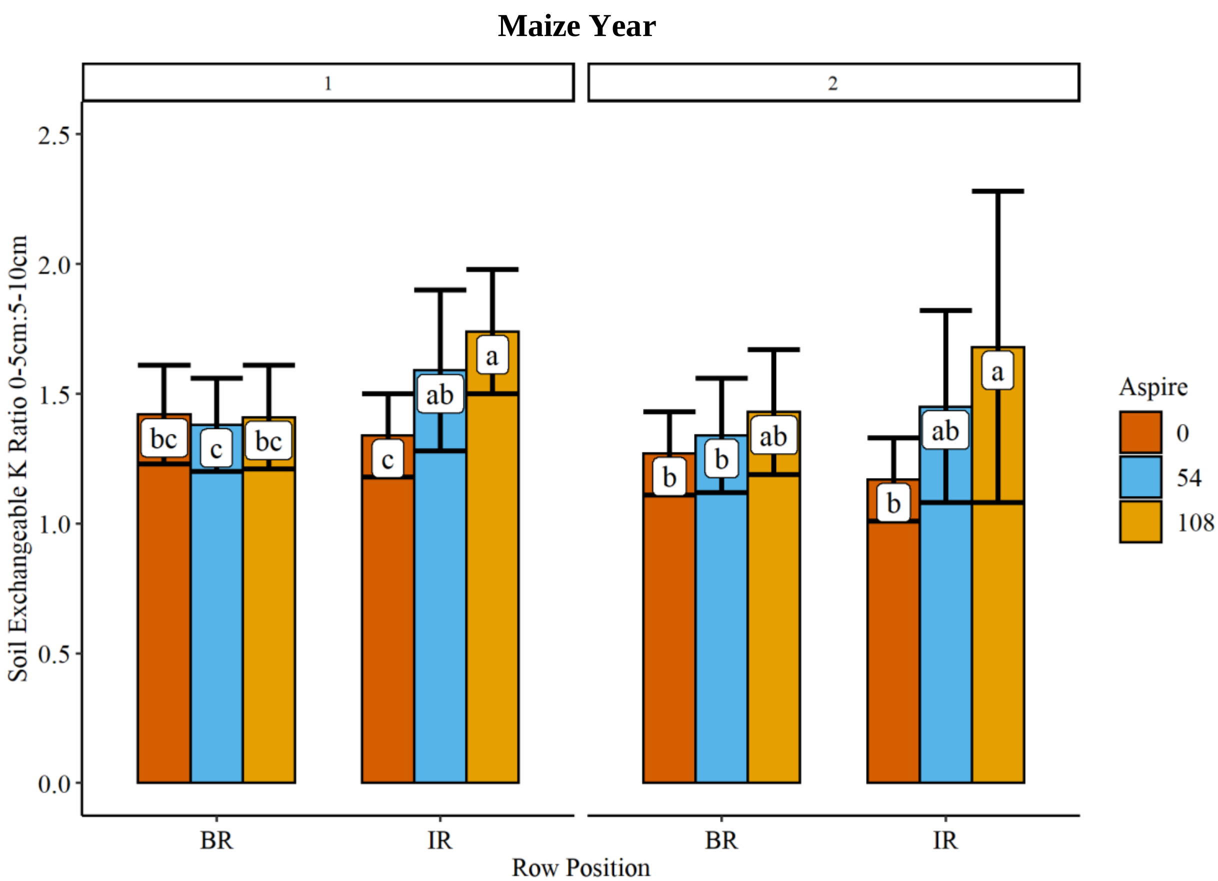

Figure 2.19. Aspire™ rate and row position (IR = in-row, BR = between row) impacts on the ratio of 0-5cm to 10-20cm soil exchangeable K concentration for each maize year (1 = 2016, 2017, and 2019 (PPAC) 2 = 2018 and 2019 (ACRE)). Mean separations for row position and Aspire™ rate were performed for individual maize years. Error bars represent the standard deviation for the depth ratio. Different letters indicate significant differences at $p<0.05$.

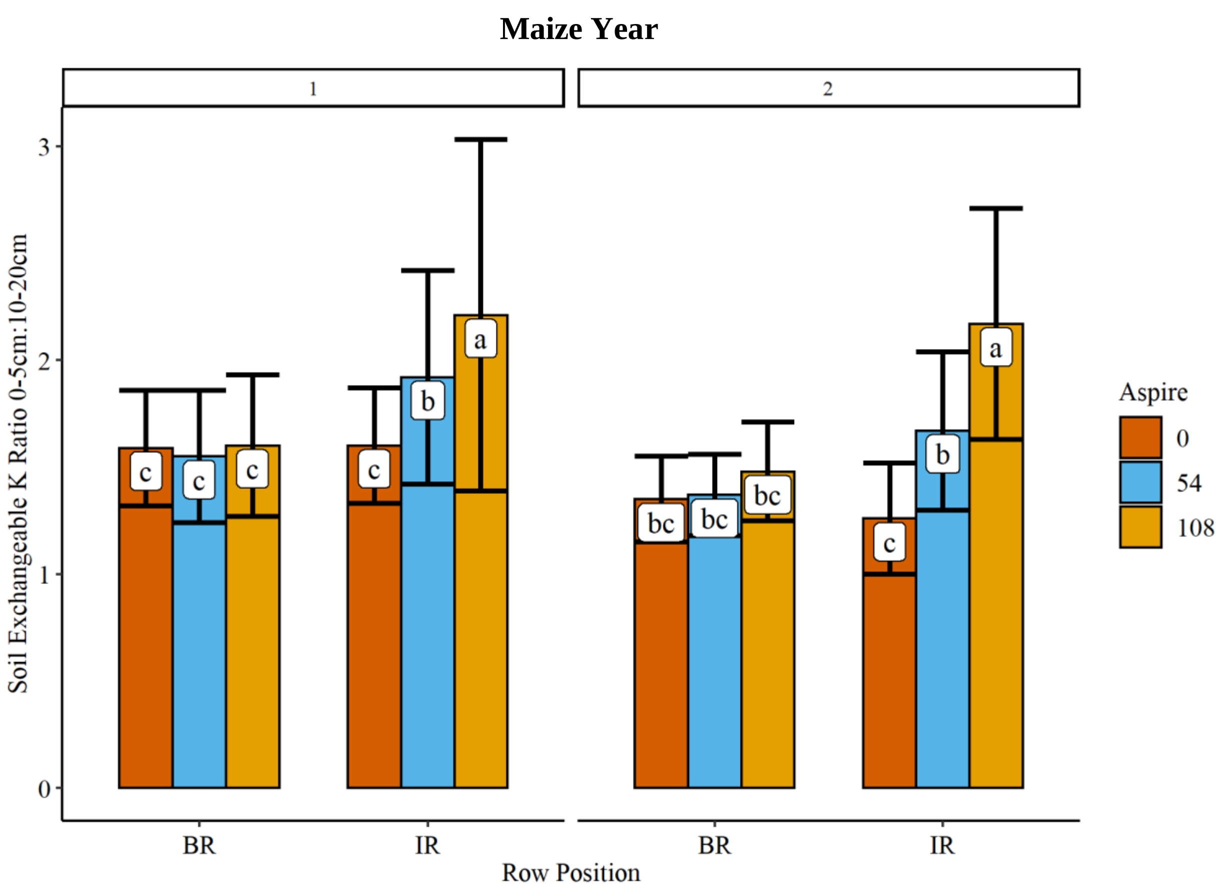

Figure 2.20. Aspire™ rate and row position (IR = in-row, BR = between row) impacts on the ratio of 0-5cm to 10-20cm soil exchangeable K concentration for each maize year (1 = 2016, 2017, and 2019 (PPAC) 2 = 2018 and 2019 (ACRE)). Mean separations for row position and Aspire™ rate were performed for individual maize years. Error bars represent the standard deviation for the depth ratio. Different letters indicate significant differences at $p<0.05$.

2.4.4 V6 Nutrient Concentration and Uptake

Across the strip-till timing and Aspire™ rate treatments, maize responses for both maize years were documented for nutrient concentration (Table 2.4: MY1 and Table 2.5: MY2) and above-ground dry matter and nutrient content (Tables 2.6: MY1 and Table 2.7: MY2) at the V6 growth stage.

Treatments produced several differences in tissue K concentration at the V6 growth stage. For both fall and spring strip-till, the 108 kg K ha^{-1} application rate of Aspire™ resulted in the highest tissue K concentration in both maize years (Tables 2.4 and 2.5). The 54 kg K ha^{-1} rate was not significantly different than either of the other rates in MY1 (Table 2.4). In contrast, K concentrations for all Aspire™ rates were distinct from one another in MY2 (Table 2.5). Increases in K concentration of 6.7 g kg^{-1} for the 108 kg K ha^{-1} Aspire™ rate occurred in MY1 (Table 2.4), with a slightly higher increase in concentration in MY2 of 14.4 g kg^{-1} (Table 2.5). Similar to other studies that utilized KCl, the concentration and content of K appeared to increase after Aspire™ applications early in the growing season (Heckman & Kamprath, 1992; Mallarino et al., 1999; Vyn et al., 2002). The K concentrations recorded in this work are similar to levels published by others (Borges & Mallarino, 1998; Walker & Peck, 1975). No critical K concentration has been established for maize at V6 due to the unreliability of predicting grain yield from nutrient concentrations at this growth stage (Mallarino & Higashi, 2009).

Plant K content was significantly increased following Aspire™ application for both maize years. Both application rates of Aspire™ produced similar K uptake at V6 in MY1. In MY2, K contents were increased more at the 108 kg K ha^{-1} rate than the 54 kg K ha^{-1} rate. The V6 K content of FST was significantly higher than SST (16%) in MY1, but no difference due to timing was detected in MY2.

The concentrations of other plant nutrients were also impacted. Ca and Mg concentration at V6 were higher in SST than FST by an average of 0.5 g kg^{-1} for Ca and 0.75 g kg^{-1} for Mg across both maize years (Tables 2.4 and 2.5). A decrease in concentration for both Ca and Mg as the application rate of K was increased was only documented in MY2. The B concentration showed some response to the application of Aspire™, and concentrations were noticeably higher in MY1 compared to MY2. Only the highest Aspire™ rate of 108 kg K ha^{-1} increased B concentration in MY1, and that increase occurred for both fall and spring strip-till. In MY2, increased tissue B concentration in both tillage timings resulted from both the 54 kg K ha^{-1} and 108 kg K ha^{-1} Aspire™ rates. Little has been published about the critical B concentration necessary for maize. Gupta (1983) suggests that before tassel, maize should have a B concentration of 9 mg kg^{-1}, but there is no indication of the specific growth stage associated with this concentration. Utilizing the 108 kg K ha^{-1} application rate of Aspire™ led to concentrations at or slightly above 9 mg kg^{-1} in MY1, but all treatments for MY2 were at or below 5 mg B kg^{-1}. The low B concentrations for 2018 and 2019 locations could be due to the Aspire™ formulation change described in the methods section. Instead of only sodium borate, a combination of sodium and calcium borate was introduced, potentially delaying B release into the soil solution leading to low concentrations. However, the lack of soil moisture could have led to low availability and uptake as well.

Little to no differences in N and P concentration or content were apparent among treatments within the same site-years. Tillage timing affected dry matter accumulation and content of some nutrients at growth stage V6. Greater above-ground dry matter for the FST timing occurred across both maize years, and a similar trend was also evident for N content (Tables 2.6: MY1 and Table 2.7: MY2)]. In MY1, FST increased N content 19%, P content 16%, K content 16% and B content 33%. In MY2, FST increased N content by 17% but not P, K, or B contents. Tillage timing produced no differences in Ca and Mg contents in the above-ground dry matter in either MY1 or MY2. FST had higher B content both in individual treatments and overall tillage response than SST in MY1. An increase of 1 g ha^{-1} in B content was recorded only when the highest application rate of Aspire™ was applied. The timing also influenced B content with FST with a 1 g B ha^{-1} advantage over SST. MY2 had consistently lower B content compared to MY1, with both 54 and 108 kg K ha^{-1} rates significantly increasing B content for both FST and SST. A consistent decrease in the N:K ratio following the application rates of 54 kg K ha^{-1} and 108 kg K ha^{-1} was documented each maize year.

Table 2.4. Strip-till timing and Aspire™ rate impacts on V6 whole plant nutrient concentration for N, P, K, Ca, Mg, B, and the N:K ratio for MY1 (2016, 2017, and 2019 (PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]						
Tillage[1]	Aspire™		N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	——— g kg^{-1} ———					mg kg^{-1}	1:1
FST	0	0	36.8	4.4	27.9 c	5.0 ab	5.1 ab	7 c	1.56 a
	54	0.5	33.7	4.4	31.5 abc	4.7 ab	4.8 ab	7 c	1.15 abc
	108	1.1	34.4	4.3	34.7 ab	4.4 b	3.9 b	10 a	1.06 c
SST	0	0	34.5	4.5	29.0 bc	4.8 ab	5.3 ab	7 c	1.47 ab
	54	0.5	35.3	4.4	32.0 abc	5.6 a	5.7 a	8 bc	1.30 abc
	108	1.1	35.3	4.6	35.7 a	5.4 a	5.0 ab	9 ab	1.10 bc
FST			34.9	4.4 b	31.4	4.7 b	4.6 b	8	1.26
SST			35.1	4.5 a	32.2	5.3 a	5.4 a	8	1.29
	0	0	35.7	4.5	28.5 b	4.9	5.2	7 b	1.52 a
	54	0.5	34.5	4.4	31.7 ab	5.1	5.3	7 b	1.23 b
	108	1.1	34.9	4.5	35.2 a	4.9	4.5	9 a	1.08 b
Site Year			ns	****	***	***	***	***	***
Tillage			ns	ns	ns	**	*	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	***	ns	ns	****	***
Site Year*Aspire™			ns	ns	ns	ns	ns	***	*
Tillage*Aspire™			ns	ns	ns	*	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table 2.5. Strip-till timing and Aspire™ rate impacts on V6 whole plant nutrient concentration for N, P, K, Ca , Mg, B, and N:K ratio for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]						
Tillage[1]	Aspire™		N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	——— g kg^{-1} ———					mg kg^{-1}	1:1
FST	0	0	39.1	4.0 b	21.0 b	5.1 a	6.0 ab	3 cd	2.26 a
	54	0.5	39.3	4.1 ab	27.8 ab	4.7 ab	5.1 bc	4 bcd	1.53 b
	108	1.1	39.4	3.9 b	33.4 a	4.2 b	4.1 c	4 abc	1.24 b
SST	0	0	39.9	4.5 a	19.9 b	5.2 a	6.7 a	2 d	2.38 a
	54	0.5	36.9	4.1 ab	28.2 ab	5.2 a	5.8 ab	5 ab	1.52 b
	108	1.1	39.2	4.0 ab	36.3 a	4.8 ab	5.0 bc	5 a	1.17 b
FST			39.3	4.0 b	27.4	4.7 b	5.1 b	3 b	1.68
SST			38.7	4.2 a	28.1	5.1 a	5.8 a	4 a	1.69
	0	0	39.5	4.2	20.5 c	5.2 a	6.3 a	2 b	2.32 a
	54	0.5	38.1	4.1	28.0 b	5.0 a	5.4 b	4 a	1.52 b
	108	1.1	39.3	4.0	34.9 a	4.5 b	4.6 c	5 a	1.21 b
Site Year			*	ns	**	**	**	*	***
Tillage			ns	*	ns	**	**	*	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	****	**	****	****	****
Site Year*Aspire™			ns	**	ns	ns	ns	ns	***
Tillage*Aspire™			ns	*	ns	ns	ns	*	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001

Table 2.6. Strip-till timing and Aspire™ rate impacts on V6 whole plant dry matter (kg ha^{-1}) and nutrient content for N, P, K, Ca, Mg, B, and N:K ratio for MY1 (2016, 2017, and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]							
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	——— kg ha^{-1} ———						g ha^{-1}	1:1
FST	0	0	400 ab	14.72	1.78	11.00 b	2.02	2.10	3 b	1.56 a
	54	0.5	456 ab	15.69	2.07	14.57 ab	2.14	2.19	3 b	1.15 abc
	108	1.1	463 a	15.85	1.99	15.53 a	2.13	1.96	4 a	1.06 c
SST	0	0	364 ab	12.54	1.65	10.63 b	1.73	1.92	2 b	1.47 ab
	54	0.5	384 ab	13.53	1.70	12.02 ab	2.19	2.29	3 b	1.30 abc
	108	1.1	364 b	12.82	1.69	12.85 ab	2.00	1.87	3 b	1.10 bc
FST			440 a	15.42 a	1.95 a	13.70 a	2.10	2.09	4 a	1.26
SST			371 b	12.96 b	1.68 b	11.83 b	1.97	2.03	3 b	1.29
	0	0	382	13.63	1.72	10.82 b	1.88	2.01	3 b	1.52 a
	54	0.5	420	14.61	1.88	13.29 a	2.16	2.24	3 b	1.23 b
	108	1.1	414	14.34	1.84	14.19 a	2.06	1.92	4 a	1.08 b
Site Year			***	**	***	****	**	**	**	***
Tillage			**	**	*	*	ns	ns	**	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	**	ns	ns	***	***
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	*
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	*	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table 2.7. Strip-till timing and Aspire™ rate impacts on V6 whole plant dry matter (kg ha^{-1}) and nutrient content for N, P, K, Ca, Mg, B, and N:K ratio for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]							
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	———— kg ha^{-1} ————						g ha^{-1}	1:1
FST	0	0	560 ab	21.95 abc	2.22	10.96 cd	2.91	3.48	1 b	2.26 a
	54	0.5	654 ab	25.87 ab	2.65	16.83 bc	3.17	3.46	3 ab	1.53 b
	108	1.1	682 a	26.91 a	2.66	22.14 a	2.94	2.91	3 ab	1.24 b
SST	0	0	532 b	21.44 bc	2.38	10.28 d	2.81	3.62	1 b	2.38 a
	54	0.5	611 ab	22.81 abc	2.50	16.44 bc	3.26	3.61	3 a	1.52 b
	108	1.1	503 b	19.70 c	2.02	17.98 ab	2.42	2.52	3 ab	1.17 b
FST			632 a	24.91 a	2.51	16.64	3.01	3.28	2	1.68
SST			549 b	21.32 b	2.30	14.90	2.83	3.25	2	1.69
	0	0	546	21.69	2.30	10.62 c	2.86	3.55 a	1 b	2.32 a
	54	0.5	633	24.34	2.58	16.64 b	3.22	3.54 a	3 a	1.52 b
	108	1.1	593	23.30	2.34	20.06 a	2.68	2.72 b	3 a	1.21 b
Site Year			*	*	ns	ns	**	**	**	***
Tillage			**	**	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	****	ns	**	***	****
Site Year*Aspire™			*	*	ns	ns	ns	ns	ns	***
Tillage*Aspire™			ns	*	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

2.4.5 Physical Measurements and Anthesis-Silking Interval

Physical measurements can differentiate plant architecture changes caused by treatments. Data from physical measurements (including height and LAI) and data related to the flowering are presented for both maize years in Tables 2.8 and 2.9.

At the 2019 ACRE (MY2) location, a height difference was noticed early in the season (~V8); this prompted collection of height measurements that found the 0 kg K ha^{-1} treatment was ~5.5cm shorter than other Aspire™ application rates (17.7% shorter). Final heights were collected from different plants at R1, and the 0 kg K ha^{-1} plots were still significantly shorter than the other Aspire™ rates (~17cm shorter, or 8% shorter). Other authors have documented height reductions from lack of K application in maize as well as other species. Pettigrew and Meredith (1997) reported a 3% increase in cotton height following K application when flowering and vegetative growth began to slow, not as high as the recorded values in this experiment, but there was a height advantage when K was applied across species.

Differences in LAI were present at R2 for MY1 and V14 for MY2 only for overall mean comparison of Aspire™ rates (Table 2.8). An increase of ~0.73 in LAI at V14 when Aspire™ was applied at either the 54 or 108 kg K ha^{-1} rates (20% increase) was significant in MY2. The R2 LAI measurements showed a ~0.28 advantage over the 0 kg K ha^{-1} treatment when Aspire™ was applied for MY1 at either rate (7% increase). Reductions in leaf area were seen when no Aspire™ was applied compared to when Aspire™ was added (at either rate) for both maize years and LAI timings, but it was difficult to detect significant differences. In addition to the increased height, the same study by Pettigrew and Meredith (1997) reported a 14% increase in cotton plant LAI from a K application. Pettigrew (2008) reviewed several papers (i.e., those from Jordan-Meille and Pellerin 2004, Kimbrough et al. 1971, and Pettigrew and Meredith 1997) and reported that a K deficiency typically led to reduced leaf area, similar to the results from this study. Although the studies show reductions in LAI, it is difficult to know what impact this had on the final grain yield.

Days to anthesis and silking provides context to the time from planting to visible reproductive stages (Table 2.9). Significant differences were evident due to strip-till timing, but Aspire™ application did not influence anthesis or silking timing. In both maize years, FST reached 50% anthesis and 50% silking a day before SST. Although FST did have a significant advantage in reaching 50% anthesis and silking earlier, this would have little impact on the aversion to stress or lengthening the grain-filling period. The interaction among site year, tillage, and Aspire for silking to 50% in MY1 is expanded in Appendix A, Table A.29 for further information.

The anthesis silking interval (ASI) is important to maize for receptive silks to be available during pollen shed (data are presented in Table 2.9). Strip-till timing appeared to slightly impact the anthesis-silking interval to 50%, with FST having a slightly longer (0.5 days) time to silk than SST in MY1. Silking occurred prior to anthesis in MY2, resulting in negative ASI values). Although not significant when applying Aspire™ (either at 54 or 108 kg K ha^{-1}), ASI appeared to get slightly closer to 0 for both maize years 1 and 2 when K was applied. Previous literature has noted adequate K supply to be important during hot, dry weather for the synchronization of pollen shed and silking (Armstrong & Griffin, 1998). When silking happens close to pollen shed, the resultant earlier silking can help lengthen the grain filling period, leading to potentially higher kernel weights (Armstrong & Griffin, 1998).

Table 2.8. Strip-till timing and Aspire™ rate impacts on V14 leaf area index (LAI) for MY1 (2016 and 2017) and MY2 (2019 (ACRE)), and R2 LAI for MY1 (2016 and 2017) and MY2 (2018). V8 height and final height at R1 were performed exclusively in 2019 (ACRE). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]		MY2[2]			
Tillage[1]	Aspire™		V14 LAI	R2 LAI	V8 Height	R1 Height	V14 LAI	R2 LAI
	kg K ha^{-1}	kg B ha^{-1}			cm	cm		
FST	0	0	3.43	4.02	32 bc	205 bc	3.70	4.88
	54	0.5	3.83	4.19	36 ab	216 abc	3.99	4.97
	108	1.1	3.83	4.11	39 a	228 a	4.32	4.90
SST	0	0	3.55	3.90	30 c	202 c	3.40	4.71
	54	0.5	4.27	4.38	36 ab	217 abc	3.71	5.02
	108	1.1	3.99	4.22	36 abc	224 ab	4.00	5.35
FST			3.69	4.11	36	216	4.00	4.92
SST			3.94	4.17	34	214	3.70	5.03
	0	0	3.49	3.96 b	31 b	204 b	3.55 b	4.79
	54	0.5	4.05	4.28 a	36 a	216 a	3.85 ab	5.00
	108	1.1	3.91	4.16 ab	37 a	226 a	4.16 a	5.13
Site Year			**	*				
Tillage			*	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns				
Aspire™			***	ns	ns	***	*	ns
Site Year*Aspire™			**	ns				
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns				

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table 2.9. Strip-till timing and Aspire™ rate impacts on anthesis and silking for MY1 (2017 and 2019 (PPAC)) and MY2 (2018 and 2019 (ACRE)), and calculated anthesis-silking interval (ASI to 50%). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]			MY2[2]		
Tillage[1]	Aspire™		Anthesis to 50%	Silking to 50%	ASI to 50%	Anthesis to 50%	Silking to 50%	ASI to 50%
	kg K ha^{-1}	kg B ha^{-1}			Days			days
FST	0	0	72 ab	70 c	2.0	67 ab	68 ab	-1.0
	54	0.5	71 b	70 c	1.7	67 ab	67 ab	-0.4
	108	1.1	71 b	70 c	1.6	66 b	67 b	-0.4
SST	0	0	72 ab	70 bc	1.6	68 a	68 ab	-0.4
	54	0.5	73 a	72 a	1.1	68 a	68 a	-0.6
	108	1.1	72 ab	71 ab	1.0	68 a	68 a	-0.4
FST			71 b	70 b	1.8 a	67 b	67 b	-0.6
SST			72 a	71 a	1.2 b	68 a	68 a	-0.5
	0	0	72	70	1.8	67	68	-0.7
	54	0.5	72	71	1.4	67	68	-0.5
	108	1.1	72	70	1.3	67	67	-0.4
Site Year			****	****	***	****	****	**
Tillage			***	****	*	***	**	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	*	*	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	*	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

2.4.6 R1 Nutrient Concentration and Specific Leaf Content

Data from nutrient concentration measurements of the earleaf for each maize year are presented in Tables 2.10 (MY1) and 2.11 (MY2). Earleaves from 0 kg K ha^{-1} were below the 19 g kg^{-1} critical level for K, published in the nutrient recommendation guide (Vitosh et al., 1995), while those treated by either Aspire™ rate were at or above the critical level in both maize years (Tables 2.10 and 2.11). Similar critical concentrations of K were also determined by Walker and Peck (1975) and Armstrong and Griffin (1998). SST produced higher K concentrations than FST in MY1, but no difference in tillage timing for MY2. When comparing rates across both tillage systems, there was no detectable difference in K concentration between the 54 kg K ha^{-1} and 108 kg K ha^{-1} Aspire™ rates for either year. When applying Aspire™ (at either the 54 or 108 kg K ha^{-1} rate), K concentrations increased by ~3.3 g kg^{-1} when averaged over both maize years. The increase in plant K concentration following application suggests levels of plant-available K in the soils at these sites may not be adequate to fully supply K needs for modern hybrids. The experimental field locations were close to or above the critical level for soil K for maize published in current nutrient recommendation guidance (Vitosh et al. 1995).

Earleaf N concentrations were above optimum in MY1, but a majority of the samples were close to and below the critical level for N in MY2, according to (Vitosh et al., 1995). Numerical decreases occurred in earleaf Ca concentrations when Aspire™ was applied, although they were not statistically significant. Statistically significant reductions occurred in earleaf Mg concentrations when Aspire™ was applied at the 108 kg ha^{-1} rate. Both rates of Aspire™ increased earleaf B concentration similarly in both maize years. Earleaf B concentration was not affected by the difference in strip-till timing. The control treatments (0 kg K ha^{-1}) had earleaf B concentrations above the published critical level (Mozafar, 1987; Vitosh et al., 1995) in MY1, but the control treatments were at or below suggested critical levels for MY2. Following the application of Aspire™ (averaged across rates), B concentration increased by ~1.5 mg kg^{-1} in MY1 and ~2.5 mg kg^{-1} in MY2.

Specific leaf area (SLA) and specific leaf nutrient content data for MY1 were collected in only one year (2019 PPAC), likely leading to a lack of means separation (Table 2.12). Two site years (2018 and 2019 (ACRE)) were utilized for presenting the specific leaf nutrient content data in MY2 (Table 2.13). Strip-till timing and Aspire™ rate influences on specific leaf K content (SLK) were not detectable in MY1, but there was a numerical increase of approximately 0.15 g m^{-2} of SLK following Aspire™ application (across both rates within MY1). Following the application of 108 kg K ha^{-1} of Aspire™ in MY2, a significant increase of 0.27 g m^{-2} in SLK was seen across both strip-till timings. Despite the increase of 0.14 g m^{-2} in SLK, the 54 kg K ha^{-1} rate was not significantly different than the 0 or 108 kg K ha^{-1} rates.

No significant individual treatment differences were apparent for SLA, but after applying Aspire™ at either the 54 or108 kg K ha^{-1} rates, average SLA increased numerically by ~0.0005 m^2 g^{-1}. Specific leaf contents of both Ca (SLCa) and Mg (SLMg) at R1 declined in the presence of Aspire™ in MY2. The addition of Aspire™ showed varying effects on the specific leaf B content (SLB), with no difference among rates in FST, but in SST as Aspire™ rate increased specific leaf B content also increased in MY2. When comparing overall rates, the 54 and 108 kg K rates resulted in 0.14 mg B m^{-2} higher compared to the control treatment. Little information is available regarding optimum specific leaf content for nutrients other than N. In an article by Debruin et al. (2013), the authors suggest an SLN of 1.5 g m^{-2} is optimum for a yield level greater than 12.5 Mg ha^{-1}. From Tables 2.12 and 2.13, the SLN for each field was above 1.5 g $(m^2)^{-1}$ at R1 with yield also exceeding 12.5 Mg ha^{-1}, suggesting N was not limiting.

Table 2.10. Strip-till timing and Aspire™ rate impacts on maize nutrient concentration of the earleaf at R1 for N, P, K, Ca, Mg, B, and N:K ratio for MY1 (2016, 2017, and 2019 (PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]						
Tillage[1]	Aspire™		N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	——— g kg^{-1} ———					mg kg^{-1}	1:1
FST	0	0	31.8	3.5	17.1 d	4.7	3.6	5 b	1.95 a
	54	0.5	30.1	3.4	19.0 bcd	4.4	3.5	7 ab	1.60 b
	108	1.1	30.8	3.4	19.9 abc	4.5	3.3	6 ab	1.56 b
SST	0	0	30.5	3.6	18.0 cd	4.4	3.7	5 b	1.72 ab
	54	0.5	31.8	3.5	20.8 abc	4.6	3.4	6 ab	1.60 b
	108	1.1	31.3	3.5	21.5 a	4.4	3.2	7 a	1.48 b
FST			30.9	3.4	18.7 b	4.5	3.5	6	1.71 a
SST			31.2	3.6	20.1 a	4.4	3.5	6	1.60 b
	0	0	31.2	3.6	17.6 b	4.5	3.7 a	5 b	1.84 a
	54	0.5	31.0	3.4	19.9 a	4.5	3.5 ab	6 a	1.60 b
	108	1.1	31.1	3.5	20.7 a	4.4	3.3 b	7 a	1.52 b
Site Year			*	*	***	*	*	****	**
Tillage			ns	ns	**	ns	ns	ns	*
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	****	ns	*	**	****
Site Year*Aspire™			*	ns	ns	*	*	ns	ns
Tillage*Aspire™			**	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	*	*	*	**	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table 2.11. Strip-till timing and Aspire™ rate impacts on maize nutrient concentration of the earleaf at R1 for N, P, K, Ca, Mg, B, and N:K ratio for MY2 (2018 and 2019 (ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]						
Tillage[1]	Aspire™		N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	———— g kg^{-1} ————					mg kg^{-1}	1:1
FST	0	0	29.1	3.5 ab	18.4 b	5.0	5.0 ab	4 ab	1.72 ab
	54	0.5	28.5	3.4 b	21.1 ab	5.1	4.9 ab	5 ab	1.39 bc
	108	1.1	29.4	3.4 b	22.8 a	4.7	4.3 b	5 ab	1.33 c
SST	0	0	29.2	3.7 a	17.6 b	5.3	5.7 a	3 b	1.88 a
	54	0.5	28.5	3.5 ab	20.1 ab	4.9	4.8 ab	5 ab	1.52 abc
	108	1.1	28.6	3.4 ab	22.2 a	4.7	4.3 b	7 a	1.37 bc
FST			29.0	3.4 b	20.8	4.9	4.7	5	1.48
SST			28.8	3.5 a	20.0	5.0	4.9	5	1.59
	0	0	29.1	3.6	18.0 b	5.1	5.4 a	3 b	1.80 a
	54	0.5	28.5	3.4	20.6 a	5.0	4.9 ab	5 a	1.46 b
	108	1.1	29.0	3.4	22.5 a	4.7	4.3 b	6 a	1.35 b
Site Year			ns	ns	***	****	***	ns	**
Tillage			ns	*	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	***	ns	**	**	****
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	**
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table 2.12. Strip-till timing and Aspire™ rate impacts at R1 on maize earleaf specific leaf area (SLA) and specific leaf content for N (SLN), P (SLP), K (SLK), Ca (SLCa), Mg (SLMg), B (SLB), and SLN:SLK ratio for MY1 (2019 (PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]							
Tillage[1]	Aspire™		SLA	SLN	SLP	SLK	SLCa	SLMg	SLB	SLN:SLK
	kg K ha^{-1}	kg B ha^{-1}	m^2 g^{-1}	---------------------------- g m^{-2}	----------------------------				mg m^{-2}	1:1
FST	0	0	0.0139	2.21	0.26	1.21	0.30	0.20	0.38	1.84 a
	54	0.5	0.0137	2.22	0.25	1.33	0.33	0.21	0.46	1.68 ab
	108	1.1	0.0145	2.02	0.23	1.34	0.32	0.21	0.52	1.50 b
SST	0	0	0.0138	2.22	0.27	1.28	0.30	0.20	0.38	1.73 ab
	54	0.5	0.0143	2.27	0.24	1.44	0.33	0.21	0.44	1.59 ab
	108	1.1	0.0141	2.16	0.25	1.47	0.32	0.21	0.48	1.47 b
FST			0.0140	2.15	0.24	1.29	0.32	0.21	0.45	1.68
SST			0.0141	2.22	0.25	1.40	0.32	0.21	0.43	1.60
	0	0	0.0139	2.22	0.26	1.25	0.30	0.20	0.38 b	1.79 a
	54	0.5	0.0140	2.25	0.25	1.39	0.33	0.21	0.45 ab	1.64 ab
	108	1.1	0.0143	2.09	0.24	1.41	0.32	0.21	0.50 a	1.49 b
Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns	**	**
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table 2.13. Strip-till timing and Aspire™ rate impacts at R1 on maize earleaf specific leaf area (SLA) and nutrient concentration for N (SLN), P (SLP), K (SLK), Ca (SLCa), Mg (SLMg), B (SLB), and SLN:SLK ratio for MY2 (2018 and 2019 (ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]							
Tillage[1]	Aspire™		SLA	SLN	SLP	SLK	SLCa	SLMg	SLB	SLN:SLK
	kg K ha^{-1}	kg B ha^{-1}	m^2 g^{-1}	——— g m^{-2} ———					mg m^{-2}	1:1
FST	0	0	0.0148	1.98	0.24 ab	1.24 ab	0.34	0.34 ab	0.25 ab	1.72 ab
	54	0.5	0.0150	1.90	0.22 ab	1.40 ab	0.34	0.33 ab	0.31 ab	1.39 bc
	108	1.1	0.0152	1.95	0.22 b	1.50 a	0.31	0.29 b	0.35 ab	1.33 c
SST	0	0	0.0145	2.03	0.26 a	1.20 b	0.37	0.40 a	0.18 b	1.88 a
	54	0.5	0.0152	1.88	0.23 ab	1.32 ab	0.32	0.32 ab	0.35 ab	1.52 abc
	108	1.1	0.0149	1.92	0.23 ab	1.48 a	0.32	0.29 b	0.44 a	1.37 bc
FST			0.0150	1.94	0.23	1.38	0.33	0.32	0.31	1.48
SST			0.0149	1.94	0.24	1.33	0.34	0.34	0.33	1.59
	0	0	0.0146	2.00	0.25 a	1.22 b	0.36 a	0.37 a	0.22 b	1.80 a
	54	0.5	0.0151	1.89	0.23 ab	1.36 ab	0.33 ab	0.32 ab	0.33 a	1.46 b
	108	1.1	0.0151	1.93	0.23 b	1.49 a	0.32 b	0.29 b	0.39 a	1.35 b
Site Year			*	ns	ns	**	****	****	ns	**
Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	*	**	ns	**	**	****
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	**
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

2.4.7 Grain Yield and Yield Components

Grain yield varied across individual treatments, with differences due to Aspire™ application rate and not to strip-till timing (Tables 2.14). Similar to an extension article by Bergman (2019) from Iowa State University, there was no difference in grain yield associated with strip-till timing. Although the Bergman (2019) experiment did not utilize the same fertilizer sources, the authors observed the same lack of differences from strip-till timing. A lack of differences between strip-till timing shows the potential for more flexibility for farmers. It is still essential to consider that, no matter the timing, field conditions must be suitable for strip tillage (optimal moisture range) to avoid grain yield penalties.

Following the application of Aspire™, grain yield was increased significantly only in MY2. In MY2, yield increases of 0.9 Mg ha^{-1} and 1.3 Mg ha^{-1} occurred for the 54 and 108 kg K ha^{-1} rates, respectively, although the only significant difference was between the 0 and 108 kg K ha^{-1} Aspire™ rates. There was no difference between the 54 kg K ha^{-1} and 108 kg K ha^{-1} rates in MY1, even though they resulted in numerical increases of 0.4 Mg ha^{-1} and 0.6 Mg ha^{-1}, respectively. Although there was a yield increase due to Aspire™ application, it is difficult to say whether the K or B within Aspire™ led to increased grain yield; however, when Aspire™ was applied, there tended to be an increase in yield.

Yield components are instrumental in understanding the source of a yield difference. Kernel number (kernels (m^2)$^{-1}$) was not significantly influenced by strip-till timing, Aspire™ application, or their interaction in either maize year. Previous research summarized by Armstrong and Griffin (1998) suggests that kernel number is an important factor influenced by plant K concentrations. Data presented here does not support the concept that kernel number would increase with increasing availability of K. Kernel weight (mg kernel^{-1}) was heaviest in the FST 0 kg K ha^{-1} treatment, and the lightest kernel weights were in the FST 54 kg K ha^{-1} and SST 0 kg K ha^{-1} treatments; the other treatments were not considered different in MY1. No treatment consistently had the highest or lowest kernel weight within each field ID or maize year. When looking at the impact of Aspire™ application (average of FST and SST for each Aspire™ rate), no consistent increase in kernel weight was seen. The lower grain yield and kernel weights in 2019 PPAC could be due to dry weather conditions (moisture was severely limited around the critical period) or hybrid change (2019 PPAC used P0574 compared to all other field ID's which used P1311). A review by Pettigrew (2008) summarized an experiment by Varga et al. (2004) and found prolific hybrids responded more than non-prolific maize hybrids under high management (increasing N, P, K fertilization) by increasing kernel weight and grain yield. The increase in kernel weight leading to higher grain yield was not seen among treatments for either maize year when Aspire™ was applied.

Moisture level at harvest appeared to vary slightly due to both timing of strip-till (spring timing had significantly higher moisture levels than the FST) and the application rate of Aspire™ (applying either the 54 or 108 kg K ha^{-1} rates led to higher moisture levels). The application of K based fertilizers commonly leads to extended grain-filling periods. When having a prolonged grain-filling period, harvest moisture will typically be slightly higher. The data in this study suggests there is no difference in grain moisture concentration for the 54 or 108 kg K ha^{-1} rate for either maize year (meaning there was no evidence of changes in the grain-filling period length between these Aspire™ rates).

Table 2.14. Strip-till timing and Aspire™ rate impacts on maize grain yield at 15.5% moisture, harvest moisture (%), kernel number, and kernel weight for MY1 (2016, 2017, and 2019 (PPAC)) and MY2 (2018 and 2019 (ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]				MY2[2]			
Tillage[1]	Aspire™		Grain Yield	Moisture	Kernel Number	Kernel Weight	Grain Yield	Moisture	Kernel Number	Kernel Weight
	kg K ha^{-1}	kg B ha^{-1}	Mg ha^{-1}	%	kernels m^{-2}	mg $kernel^{-1}$	Mg ha^{-1}	%	kernels m^{-2}	mg $kernel^{-1}$
FST	0	0	13.0 bc	19.7 d	4375	307 a	13.2 b	18.0 c	3911	313
	54	0.5	13.3 ab	20.4 bc	4316	272 b	14.3 ab	18.2 c	3920	304
	108	1.1	13.5 ab	20.7 b	4186	288 ab	15.2 a	18.3 bc	4344	325
SST	0	0	12.6 c	19.8 cd	4369	277 b	13.6 b	18.2 c	4392	314
	54	0.5	13.5 ab	21.9 a	4232	293 ab	14.0 ab	18.8 a	3919	312
	108	1.1	13.6 a	21.6 a	4157	288 ab	14.2 ab	18.8 ab	3930	321
FST			13.3	20.2 b	4290	289	14.2	18.2 b	4059	314
SST			13.2	21.1 a	4252	286	13.9	18.6 a	4080	316
	0	0	12.8 b	19.7 b	4372	292	13.4 b	18.1 b	4151	314
	54	0.5	13.4 a	21.1 a	4274	283	14.2 ab	18.5 a	3920	308
	108	1.1	13.6 a	21.1 a	4170	288	14.7 a	18.6 a	4137	323
Site Year			****	****	*	****	***	ns	***	**
Tillage			ns	****	ns	ns	ns	****	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			****	****	ns	ns	**	**	ns	ns
Site Year*Aspire™			ns	**	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	***	ns	**	ns	ns	*	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

2.4.8 R6 Grain and Total Nutrient Uptake

The removal of nutrients via grain harvest is of concern to farmers as this will impact the replacement through fertilizer applications. Grain concentrations are necessary to calculate the removal of nutrients affecting management decisions accurately, and are presented for all nutrients in Appendix A. No detectable changes in grain K concentration due to strip-till timing or Aspire™ application were apparent in MY1, but the K concentration of grain was increased significantly in MY2 (Appendix A, Table A.17 and Table A.18). With increasing Aspire™ rate, the grain concentration of K increased by 0.3 and 0.6 g kg^{-1} for the 54 and 108 kg ha^{-1} rates, respectively. The concentration of K reported by Bender et al. (2013) for maize grain was approximately 4.4 g kg^{-1}, similar to the collected data. Increases in grain K concentration were small and only present in MY1, showing that increases in K concentration following fertilization are not guaranteed with a K application in agreement with Mallarino and Higashi (2009), who also saw several locations increasing in K concentration. Ciampitti et al. (2013) reported slightly higher grain K concentrations with a range of 4.9 to 5.3 g kg^{-1} K (close to the values reported in Tables A.17 and A.18. The B concentrations found in grain are relatively low to begin with and appeared to be unchanged from Aspire application. However, as the detection limits of the lab used for this experiment are likely above what is in the grain, our ability to assess B in the grain accurately is questionable. Bender (2013) reported B concentration of 1.6 mg kg^{-1}, similar to the levels reported in this dataset (Appendix A, Tables A.17 and A.18. The nutrient concentration provides some indication of grain nutritional status but doesn't quantify nutrient removal.

Nutrient contents in the harvested grain did not consistently increase following Aspire™ application (Tables 2.15 and 2.16). No significant increases in grain dry matter or N content were

Table 2.15. Strip-till timing and Aspire™ rate impacts on R6 maize grain dry matter yield (DM) and grain uptake for N, P, K, Ca, Mg, B, and N:K ratio for MY1 (2016 and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]							
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	——— kg ha^{-1} ———						g ha^{-1}	1:1
FST	0	0	11080	112.11	30.05 ab	42.68 ab	0.99	13.17	16.2	2.7
	54	0.5	11183	109.16	27.80 b	39.58 b	0.96	12.84	26.1	2.8
	108	1.1	11412	118.49	32.15 ab	46.76 a	1.04	13.93	22.5	2.6
SST	0	0	11029	113.57	32.41 ab	43.82 ab	1.02	14.97	16.8	2.6
	54	0.5	11781	122.95	35.39 a	49.77 a	1.06	14.65	20.9	2.6
	108	1.1	11533	119.91	35.63 a	47.96 ab	1.02	14.63	16.4	2.5
FST			11225	113.25	30.00 b	43.01 b	0.99	13.31 b	21.6	2.7
SST			11448	118.81	34.48 a	47.18 a	1.03	14.75 a	18.1	2.6
	0	0	11055	112.84	31.23	43.25	1.01	14.07	16.5	2.7
	54	0.5	11482	116.05	31.59	44.68	1.01	13.74	23.5	2.7
	108	1.1	11472	119.20	33.89	47.36	1.03	14.28	19.5	2.6
Site Year			****	**	ns	***	****	**	****	****
Tillage			ns	ns	**	*	ns	*	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	**	*	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	*	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table 2.16. Strip-till timing and Aspire™™ rate impacts on R6 maize grain dry matter yield (DM) and grain uptake for N, P, K, Ca, Mg, B, and N:K ratio for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]							
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	——— kg ha^{-1} ———						g ha^{-1}	1:1
FST	0	0	12020	129.80	33.37	58.40	1.20	13.58	12.0	2.4
	54	0.5	11227	121.57	31.73	56.26	1.12	12.76	11.2	2.2
	108	1.1	12725	138.56	39.72	68.89	1.27	15.35	12.7	2.1
SST	0	0	12930	129.24	35.21	60.80	1.27	14.01	12.7	2.2
	54	0.5	11843	132.54	36.40	63.11	1.18	13.64	11.8	2.2
	108	1.1	12677	142.26	40.39	68.56	1.27	15.82	12.7	2.1
FST			11991	129.98	34.94	61.18	1.20	13.90	12.0	2.2
SST			12483	134.92	37.43	64.30	1.24	14.51	12.4	2.2
	0	0	12475	129.54	34.23 b	59.52 b	1.23	13.78 b	12.3	2.3
	54	0.5	11535	127.06	34.07 b	59.69 b	1.15	13.20 b	11.5	2.2
	108	1.1	12701	140.41	40.06 a	68.72 a	1.27	15.59 a	12.7	2.1
Site Year			**	*	ns	***	**	ns	**	***
Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			*	ns	*	**	ns	**	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

seen across individual treatments, the timing of strip-till, or Aspire™ applications. Grain P contents across individual treatments did have significant differences, but these differences were relatively small and did not show a consistent pattern by treatment in MY1. Both P and Mg contents were significantly higher in SST than FST, with increases of 15% and 11 for P and Mg, respectively. In MY2, grain nutrient contents were influenced only by the rate of Aspire™ with the 0 and 54 kg K ha^{-1} rate resulting in lower P, K, and Mg contents than the 108 kg K ha^{-1} rate. Strip-till timing was found to be significant in MY1, with SST having a 4 kg K ha^{-1} advantage over FST. Grain K uptake was 9.2 and 9.0 kg K ha^{-1} greater for the 108 kg K ha^{-1} Aspire™ rate relative to the average uptake for 0 and 54 kg K ha^{-1} Aspire™ rates, respectively, in MY2. Grain K content was highest at the 108 kg ha^{-1} rate compared to the control (MY1 = +4.11 kg ha^{-1}, MY2 = +9.12 kg ha^{-1}). Using a moderate plant population (79,000 plants ha^{-1}) with a high N rate (224 kg N ha^{-1}), an experiment conducted at Purdue University recorded a mean grain yield of 13 Mg ha^{-1} with a K grain content of 63.5 kg K ha^{-1} (Ciampitti et al., 2013; Ciampitti & Vyn, 2011).

Grain yield in MY1 was comparable; however, the K grain content was lower than the Purdue University experiment (Ciampitti et al., 2013; Ciampitti & Vyn, 2011) for all Aspire™ rate applications (Table 2.15). In contrast, grain yield in MY2 was slightly higher with grain K contents more similar to Ciampitti et al. (Ciampitti et al., 2013; Ciampitti & Vyn, 2011) with increasing Aspire™ application rates (Table 2.16). Bender et al. (2013) observed K removal in grain was ~55 kg K ha^{-1} (range of 47-65 kg K ha^{-1}) for then-current hybrids at yield levels averaging 12 Mg ha^{-1}. Bender et al. (2013) also evaluated the B content of grain at the same grain yield level (12.0 Mg ha^{-1}) and recorded a range of 13 to 32 g ha^{-1} B. The B grain content in MY1 (range = 16 to 26 g ha^{-1}) and 2 (range = 11 to 13 g ha^{-1}) were low, especially when considering the grain yield levels were higher than Bender et al. (2013). Because of naturally low concentrations of B in the grain and laboratory analysis limitations, the values in this chapter should be taken with caution.

Among individual treatments, total plant uptake of K generally increased as the application rate of Aspire™ increased (Tables 2.17 and 2.18). It is crucial from nutrient content results from samples taken at R6 to consider the potential K lost due to cell leakage as the plant begins senescence, meaning plants sampled likely had higher levels before they were sampled (Ciampitti & Vyn, 2014). Evaluating K uptake across rates alone showed an average increase in uptake of ~39.2 kg K ha^{-1} for 108 kg K ha^{-1} treatment compared to the 0 and 54 kg K ha^{-1} treatments. Total K uptake was not affected by individual treatments, strip-till timing, or Aspire™ rates in MY1 (Table 2.17). K uptake for MY1 was low compared to the results from Bender et al. (2013), where the authors reported uptake ranging from 153 to 187 kg K ha^{-1} in total uptake at maturity. However, total uptake was more similar to the range reported by Bender et al. (2013) in MY2, with a treatment average minimum of 146.9 kg K ha^{-1} and maximum of 197.5 kg K ha^{-1} (Table 2.18). Differences were present in MY2 with Aspire™ influencing the total uptake of K but showing some interaction among field ID, strip-till timing, and Aspire.

The contribution of each plant component to total K uptake is represented in Figures 2.21 and 2.22, but differences in total uptake for other nutrients, including K, are presented in Tables 2.17 and 2.18 (Refer to Appendix A for more detail on the nutrient concentration and content of individual components). In MY1, the K content of the grain for FST 54 kg K ha^{-1} treatment was significantly lower than FST 108 kg K ha^{-1} and SST 54 kg K ha^{-1} (Figure 2.21). No significant differences were detected in the stover, but there was a noticeable decrease in stover content for

Table 2.17. Strip-till timing and Aspire™™ rate impacts on R6 maize total above-ground dry matter (DM) and uptake (sum of grain, cob, and stover content) for N, P, K, Ca, Mg, B, and N:K ratio for MY1 (2016 and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]							
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	——— kg ha^{-1} ———						g ha^{-1}	1:1
FST	0	0	19017	186.8	36.6	146.9	22.5	26.8	43.6	1.44
	54	0.5	19199	176.5	33.4	121.9	23.6	30.5	59.2	1.59
	108	1.1	19599	194.2	37.6	147.5	23.9	28.2	56.3	1.48
SST	0	0	19118	179.7	36.5	134.6	20.4	28.8	41.8	1.45
	54	0.5	20388	196.3	41.0	157.4	23.3	30.2	53.2	1.47
	108	1.1	20138	194.8	42.5	160.2	26.4	32.8	49.0	1.29
FST			19272	185.9	35.9	138.8	23.3	28.5	53.0	1.50
SST			19881	190.3	40.0	150.7	23.4	30.6	48.0	1.40
	0	0	19068	183.2	36.6	140.8	21.4	27.8	42.7	1.44
	54	0.5	19793	186.4	37.2	139.6	23.5	30.4	56.2	1.53
	108	1.1	19868	194.5	40.1	153.8	25.1	30.5	52.6	1.38
Site Year			****	****	**	****	****	*	****	****
Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table 2.18. Strip-till timing and Aspire™™ rate impacts on R6 maize total above-ground dry matter and uptake (sum of grain, cob, and stover content) for N, P, K, Ca, Mg, B, and N:K ratio for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]							
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	B	NK
	kg K ha^{-1}	kg B ha^{-1}	——— kg ha^{-1} ———						g ha^{-1}	1:1
FST	0	0	20970	210.8	39.9	156.0 ab	35.7	44.4	55.7	1.5 a
	54	0.5	20341	193.8	37.8	151.6 b	33.4	42.2	51.9	1.3 ab
	108	1.1	22189	220.8	46.0	192.0 ab	33.5	41.8	54.5	1.3 b
SST	0	0	22556	193.8	38.0	146.9 b	36.9	45.2	55.4	1.4 ab
	54	0.5	21062	210.8	43.2	167.5 ab	35.9	44.4	53.4	1.4 ab
	108	1.1	22529	226.7	47.3	197.5 a	36.7	45.3	63.8	1.3 b
FST			21166	208.5	41.3	166.5	34.2 b	42.8	54.0	1.4
SST			22049	210.4	42.8	170.6	36.5 a	45.0	57.6	1.3
	0	0	21763	202.3	39.0 b	151.4 b	36.3	44.8	55.6	1.5 a
	54	0.5	20701	202.3	40.5 ab	159.6 b	34.6	43.3	52.7	1.4 ab
	108	1.1	22359	223.7	46.7 a	194.7 a	35.1	43.6	59.1	1.3 b
Site Year			*	*	ns	****	*	**	*	****
Tillage			ns	ns	ns	ns	*	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	*	ns	ns
Aspire™			ns	ns	*	***	ns	ns	ns	**
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	*	ns	ns	ns	*

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

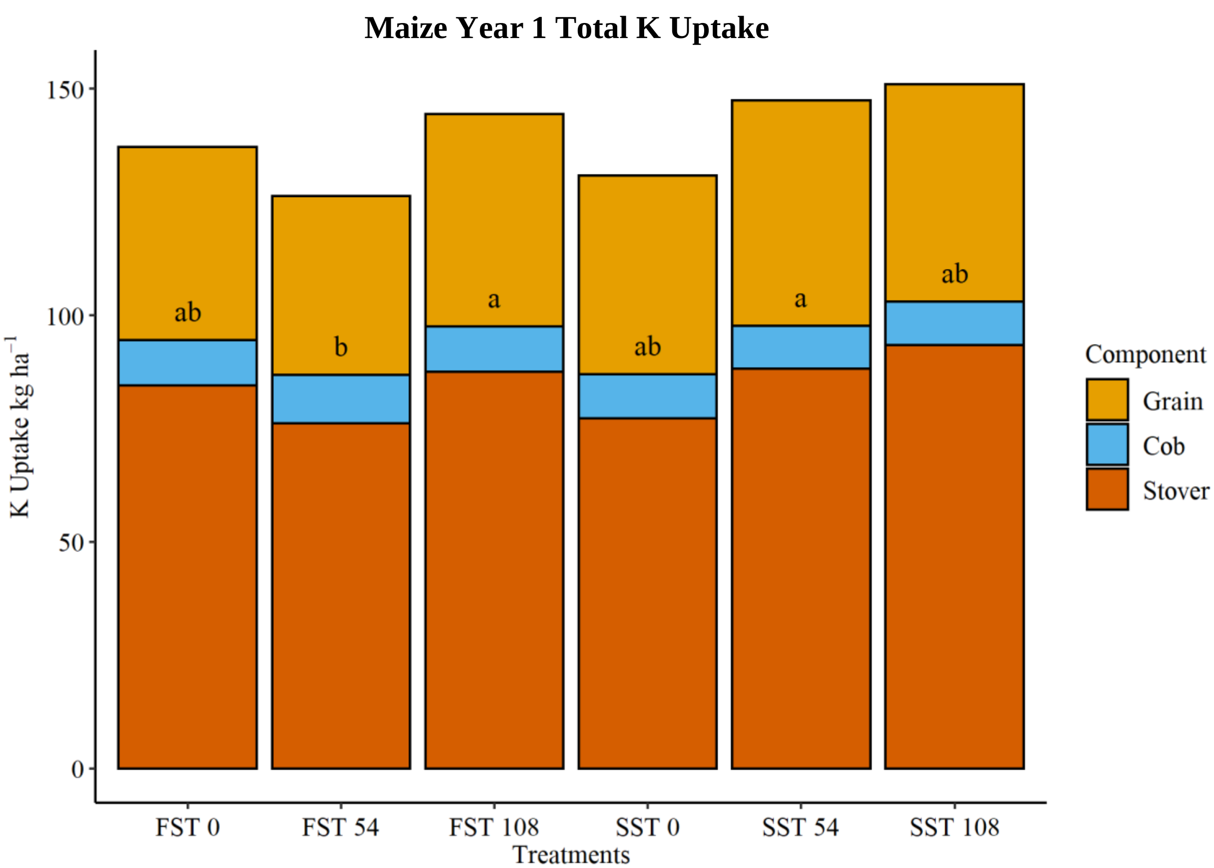

Figure 2.21. Effect of strip-till timing and Aspire™ rate on R6 K uptake within individual plant components and total plant at R6 for MY1 (includes 2016 and 2019 (PPAC)). Bar size represents mean uptake for component with different lowercase letters indicating significant differences in K uptake within a component at $p<0.05$.

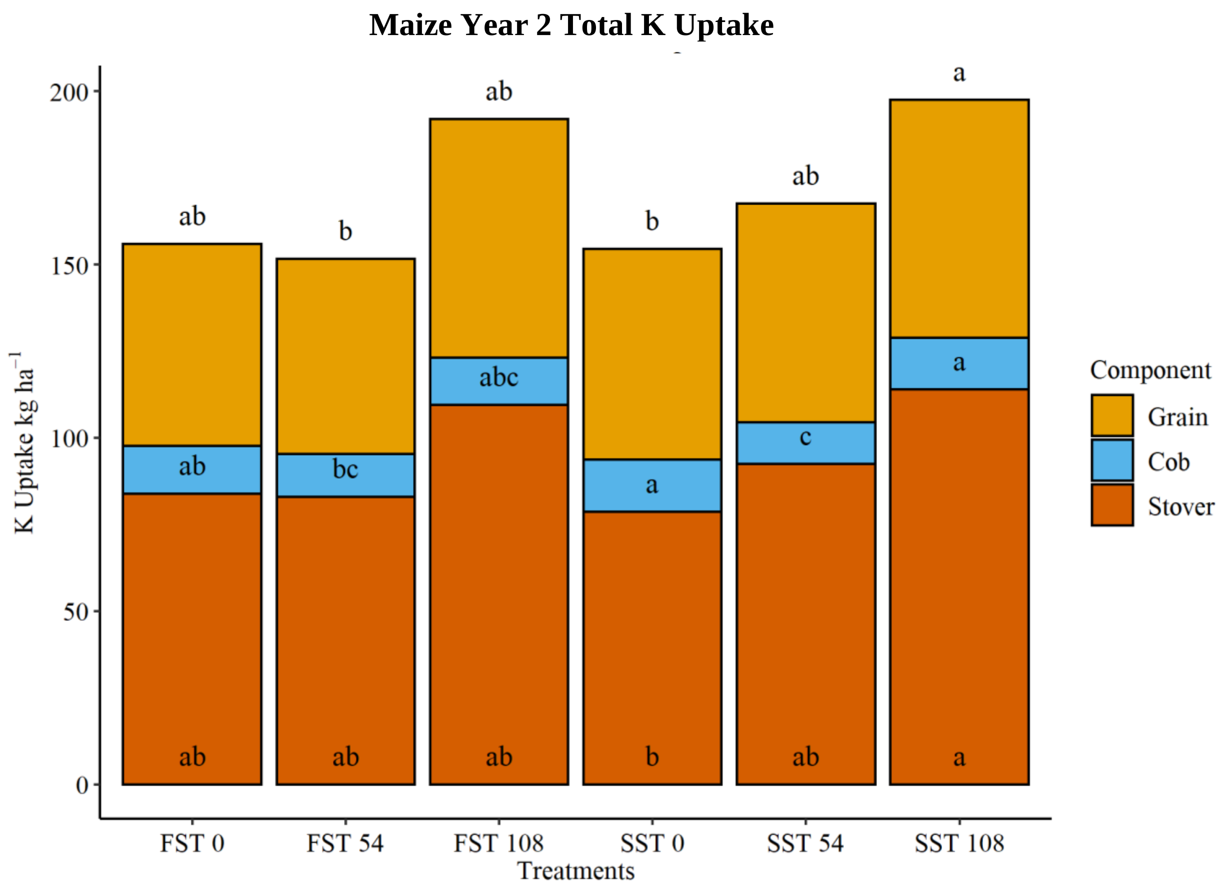

Figure 2.22. Effect of strip-till timing and Aspire™ rate on R6 K uptake within individual plant components and total plant at R6 for MY2 (includes 2018 and 2019 ACRE). Bar size represents mean uptake for component with different lowercase letters indicating significant differences in K uptake within a component at $p<0.05$. Differing lower case letters on top of bars indicates differences in total K uptake at $p<0.05$.

and dry matter for both grain and stover in several plots from 2016 and 2019 (PPAC). In MY2, the highest total content across treatments was recorded in the SST 108 kg K ha^{-1}, with the lowest in the FST 54 kg K ha^{-1} and SST 0 kg K ha^{-1} (Table 2.16). Stover K content increased significantly in SST when 108 kg K ha^{-1} was applied (SST 54 kg K ha^{-1} was not different than either rate), but no differences in FST were detected among the three Aspire™ application rates. The low stover K content for the FST 54 kg K ha^{-1} treatment was due to the combined effects of low DM weights and K concentration in 2018. Collection of more replications or more site years could give a better indication if the low response to FST 54 kg K ha^{-1} is likely to be consistent.

Although not significant, the uptake of B increased following Aspire™ application more so in MY1 than 2 (Figures 2.23 and 2.24). When looking at the overall Aspire™ application rate, the uptake increase was approximately 13.5 g B ha^{-1} (54 kg K ha^{-1} Aspire™ rate) and 9.9 g B ha^{-1} (108 kg K ha^{-1} Aspire™ rate) in MY1, with infrequent increases in B content in MY2 sites. Total B uptake data presented in this chapter was low compared to the average uptake of 83 g B ha^{-1} (range of 67 to 101 g ha^{-1}) documented by Bender et al. (2013) and the 130 g ha^{-1} recorded by Karlen et al. (1988). The low B values recorded in this data compared to previous research could be due to lab limitations (concentration in grain close to detection limit), soil (i.e., soil texture, parent material, etc.), or management factors (i.e., hybrid, fertilization, etc.).

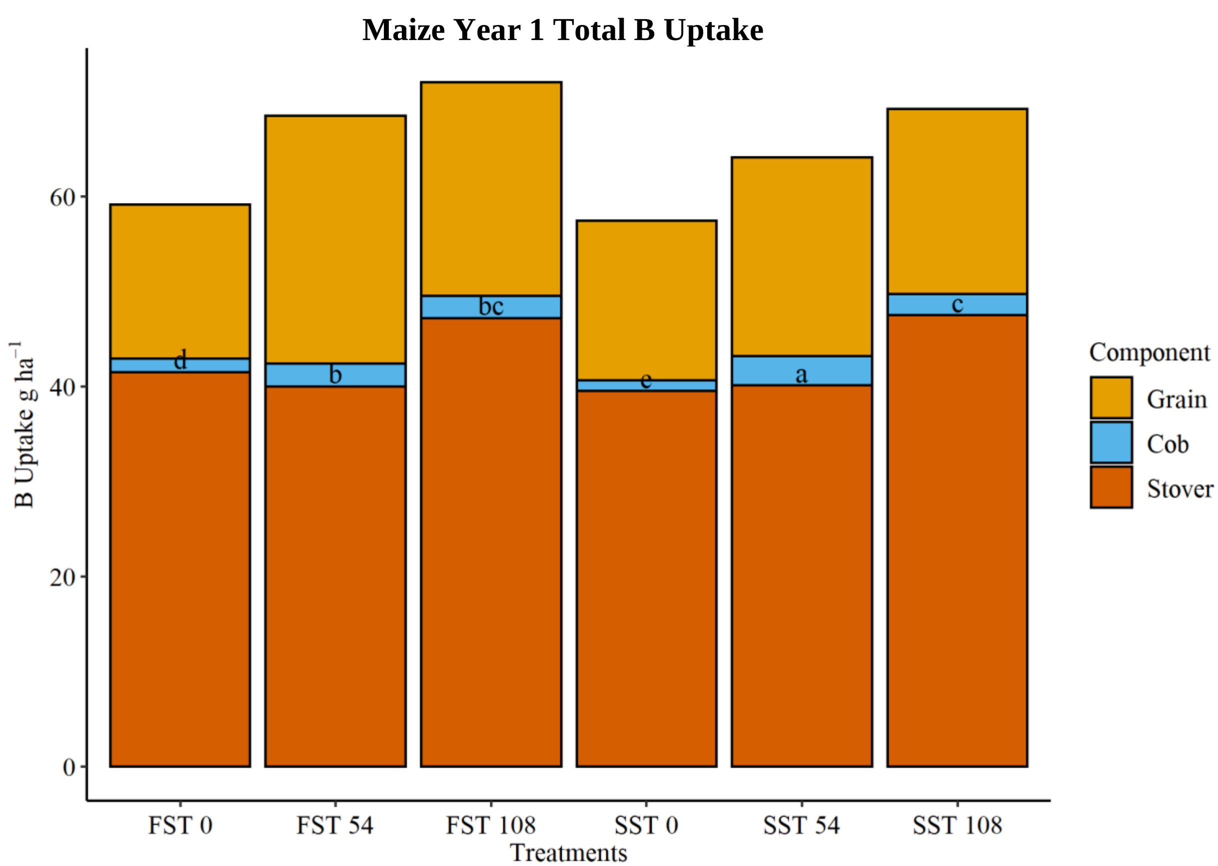

Figure 2.23. Effect of strip-till timing and Aspire™ rate on R6 B uptake within individual plant components and total plant at R6 for MY1 (includes 2016 and 2019 (PPAC)). Bar size represents mean uptake for component with different lowercase letters indicating significant differences in B uptake within a component at $p<0.05$.

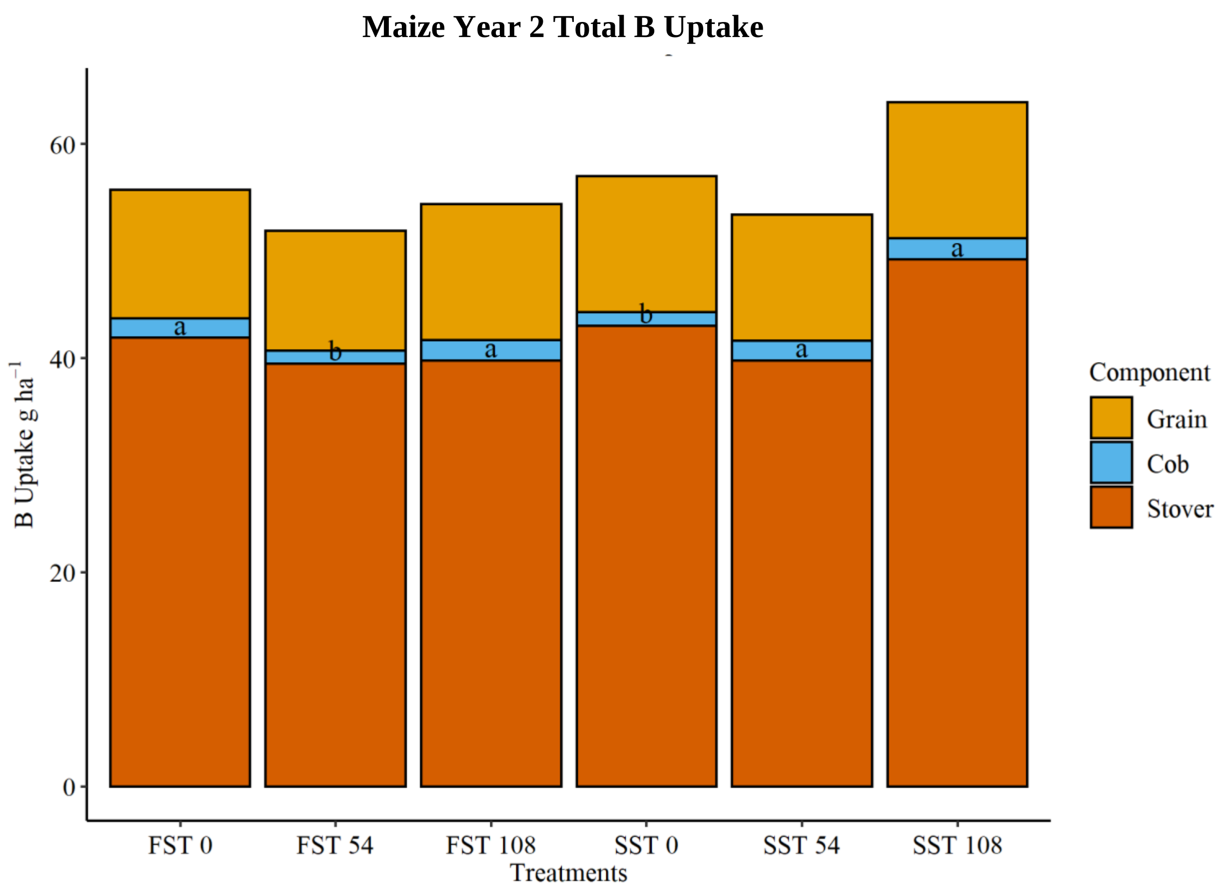

Figure 2.24. Effect of strip-till timing and Aspire™ rate on R6 B uptake within individual plant components and total plant at R6 for MY2 (includes 2018 and 2019 ACRE). Bar size represents mean uptake for each component with different lowercase letters indicating significant differences in B uptake within a component at $p<0.05$.

2.4.9 N:K Ratio Insights

Achieving balance between N and K has been suggested to be an important component for crop growth and development throughout the entire growing season (Armstrong & Griffin, 1998), yet little research looks at this ratio during the season or how it compares to the late season N:K ratio. This ratio is influenced not only by the application of K but also N rate; this means both need to be present in adequate amounts to prevent limiting of maize growth. Ciampitti and Vyn (2014) suggest a ratio of 1:1 for N:K in R6 dry matter for attaining higher yields, but this ratio varies with management and environmental conditions. From this experiment, the N:K ratio for the R6 total dry matter was above 1 for both maize years (Tables 2.17 and 2.18). When Aspire™ was applied at the 108 kg K ha^{-1} rate the N:K ratio was commonly lowered slightly (when looking at overall rate impact). The suggestion of an optimal ratio at the end of the season provides some guidance for fertility management in future growing seasons but does not allow for in-season management. Due to the lack of documentation of N:K ratios during the season, the ratios were calculated for each tissue sample collected to investigate if any similar patterns to the R6 ratios were apparent. Because a majority of K uptake is completed by R1, comparing the N:K from R6 to R1 would likely be more comparable than V6. N:K ratio at R1 was slightly higher than at R6 but showed a similar decrease from Aspire™ application at either sample collection point (Tables 2.10 and 2.11). Overall rate comparison at R1 showed 54 and 108 kg K ha^{-1} had a significantly lower N:K ratio than the control for both maize years. The V6 N:K ratio was not consistently above or below the R6 N:K ratio and those relationships were likely impacted by the very early stages (pre-linear period) of uptake for both nutrients (Tables 2.6 and 2.7).

2.4.10 Harvest Index and Fertilizer Efficiency

The recovery of nutrients in the grain by the farmer is important to understand because this will influence the fertility management used in the future. Harvest index (HI) evaluates the ability of the plant to partition nutrients to the grain (Armstrong & Griffin, 1998; Hütsch & Schubert, 2017), and has shown to be typically higher than 50% in modern maize hybrids (Bender et al., 2013). Grain HI's for all treatments were greater than 50% (Table 2.19) with a range of HI's similar to Bender et al. (2013). Grain HI was slightly lower following the application of Aspire™ in MY2. No significant differences in HI for K were detected in either maize year. The majority of our data for KHI in MY1 were similar to ranges reported by Bender et al. (2013) (ranged from 27 to 37%) and Ciampitti et al. (2013) (ranged from 29 to 33%). KHI values were somewhat higher in MY2. The B HI is presented in Table 2.19 but, due to the uncertainty surrounding the grain content of B, the BHI should be investigated further.

K recovery efficiency has been relatively under-researched due to the lack of negative consequences from over-application (i.e. pollution of air and water resources) (Bell, Mallarino, et al., 2021). In a recent paper by Bell, Mallarino, et al. (2021), the authors discuss the lack of documentation of K recovery efficiency in the literature and the potential for this measurement to help researchers understand the optimum application method for K based fertilizers. From previous research summarized by Bell, Mallarino, et al. (2021), the typical K recovery efficiency is suggested to be between 30 and 50%. However, past research has documented negative K recovery efficiencies and even some above 100%, showing the inherent variability present with this measurement (Niu et al., 2011; Xu et al., 2015). A negative K recovery efficiency can be caused due to higher amounts of K uptake in the control plot than were obtained in the treated plot, lower K uptake in the treated plot, or a combination of these two scenarios. A higher K uptake in the control plot would likely be due to high availability of soil exchangeable K from inherent soil

Table 2.19. Strip-till timing and Aspire™ rate impacts on maize harvest index (HI) (grain, K, and B) and K Recovery Efficiency for MY1 (2016, and 2019(PPAC)) and MY2 (2018 and 2019(ACRE)) from samples collected at R6. Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]				MY2[2]			
Tillage[1]	Aspire™		HI Grain	HI K	HI B	K Recovery Efficiency	HI Grain	HI K	HI B	K Recovery Efficiency
	kg K ha^{-1}	kg B ha^{-1}	%				%			
FST	0	0	58.3	34.8	44.9 ab		57.0	39.7	21.8	
	54	0.5	58.1	37.0	53.3 a	-72.4	55.0	38.0	21.7	-8.1
	108	1.1	58.0	35.9	37.9 b	3.6	57.3	38.4	23.6	33.3
SST	0	0	57.6	35.4	47.4 ab		57.2	41.3	22.7	
	54	0.5	57.7	36.8	47.4 ab	76.8	55.9	40.1	22.5	38.2
	108	1.1	57.1	33.3	38.7 b	21.8	56.2	36.9	20.4	46.8
FST			58.1	35.9	45.3	-34.4	56.4	38.7	22.4	12.6
SST			57.5	35.2	44.5	49.3	56.4	39.4	21.8	42.5
	0	0	58.0	35.1	46.1 a		57.1 a	40.4	22.2	
	54	0.5	57.9	36.9	50.3 a	2.2	55.4 b	39.1	22.1	15.0
	108	1.1	57.6	34.6	38.3 b	12.7	56.7 ab	37.6	22.0	40.1
Site Year			ns	*	*		**	**	ns	ns
Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns		ns	ns	ns	**
Aspire™			ns	ns	**	ns	*	ns	ns	ns
Site Year*Aspire™			ns	ns	ns		*	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns		ns	ns	ns	*

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

properties. Lower K uptake of the treated plots could be in-part to fixation of K from wetting and drying cycles or variability in soil K supplying power. K recovery efficiency was inconsistent overall and did not provide useful insights due to the inconsistency across treatments (Table 2.19). The ability for K to be retained in the soil years after application makes calculating K recovery efficiency difficult (Bell, Mallarino, et al., 2021). The K recovery efficiency was higher in the 108 kg K ha^{-1} Aspire™ rate compared to the 54 kg K ha^{-1} rate in both maize years. Because of the inherent variability in the K recovery efficiency measurement seen throughout this chapter and in previous research, it is difficult to make conclusions regarding anticipated future recovery efficiencies with this fertilizer source. From the data presented in this chapter, SST tended to have higher K recovery efficiency than FST (not significant), but this should be investigated further to better understand timing influence in strip-till.

2.5 Conclusions

The study objectives were to understand the impact of strip-till timing, the application rate of Aspire™, and their combined effects on maize growth and development. Measurements taken during the growing season and at harvest helped us understand these treatment combination effects. Early season growth was advanced with FST timing, but final grain yield showed no statistical difference between the two timings (fall vs. spring). The influence of Aspire™ rate was evident early in the growing season with some separation in V6 K concentrations and contents, but rate had little effect on grain yield. Strip-till timing rarely interacted with Aspire™ for any of the measurements collected throughout the year.

One of the initial hypotheses for this experiment was that FST would be superior to SST because of superior seedbeds and improved early season growth. Growth advantages of FST were evident early in the season but disappeared after the V6 sampling and were not apparent for the remainder of the growing season. In contradiction to the initial hypothesis, this experiment showed that strip-till timing appeared to have little impact on maize growth and development after V6.

The second hypothesis for this experiment was the incorporation of fertilizer into the crop row would allow for reduced fertilizer rates to be utilized and not hinder the growth and development of maize. Enriching a greater portion of soil volume could lead to better access to K fertilizer source by roots, potentially improving recovery efficiency and lowering the amount of fertilizer needing to be applied. The impact of Aspire™ application rate changed both across the growing season and between maize years. The initial maize year did not show any differences between 54 kg K ha^{-1}or 108 kg K ha^{-1}Aspire™ rates in whole-plant K uptake or concentration at V6, but when returning for another maize year, each rate was considered significantly different from one another. This dataset suggests that the initial year of using the 54 kg K ha^{-1} as opposed to the 108 kg K ha^{-1} rate may satisfy plant uptake early in the season, but when utilizing the 54 kg K ha^{-1} a second time, there may be a consequence to plant nutrition. Following the R1 sampling, few differences in nutrient concentration or content were seen between the 54 and 108 kg K ha^{-1}rates. At the end of the growing season, few trends were evident for any of the R6 K content of the whole plant and grain. No significant consequences to applying the 54 kg K ha^{-1}rate on grain yield were observed in MY1, but MY2 grain yield differences hint at the possible negative consequences from using the 54 kg K ha^{-1}(reduced) rate in place of the 108 kg K ha^{-1}(full) rate.

Grain yield in MY2 with the 54 kg K ha^{-1} rate was not different from either the 0 or 108 kg K ha^{-1} rates). The difference in grouping from MY1 to MY2 could be due to the differences in removal and replacement of K. When applying only the 54 kg K ha^{-1}rate, this is replacing approximately the amount of K that is removed by the MY1 maize alone and neglects the substantial K removal from the soybean crop the following year. Because soybeans have a high K demand and almost no K was supplied for the crop, this would likely lead to K mining and potentially limit the K for maize to probably only a portion of what was applied. Continued long-term research is important to understand the impact of lowering fertilizer rates in a strip-till system because few studies have continuously investigated this question or looked at more fertilizer rates. This data suggests that negative consequences of lower than optimum rates on plant health and/or grain yield may not be apparent within the two corn growing seasons documented here. Further inquiry is needed to understand the impacts of fertilizer rate reductions over time in strip-till systems when utilizing alternative K sources. Using alternative fertilizer sources is also necessary to know how these products influence maize growth and development.

2.6 Acknowledgments

Thank you to the Indiana Corn Marketing Council for financial support of this project since its inception in 2016, and especially for the 2018-2019 academic year support via the Gary Lamie MS Graduate Student Assistantship. The Mosaic Company for providing Aspire™ for field trials and sponsored commercial lab costs of soil and plant analyses after sample processing was completed at Purdue. Environmental Tillage Systems generously loaned a 6-row Soil Warrior strip-till unit each year. Also, we give special thanks to Corteva Agriscience for providing seed for trials and financial support for project summarization via their Crop Management Research Award in 2020. Sincere thanks and appreciation to the Vyn Lab field crews from 2016 to 2019 for their diligent work to collect data for this experiment. Field operations and maintenance would not have been possible without Terry West, ACRE field staff, and PPAC field staff.

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CHAPTER 3. CONSERVATION TILLAGE SYSTEM AND PLACEMENT INFLUENCES ON MAIZE NUTRIENT DYNAMICS AND PLANT GROWTH RESPONSES TO ASPIRE™ FERTILIZER

3.1 Abstract

Implementation of conservation tillage systems to reduce soil erosion losses has raised questions regarding K fertilizer placement consequences on plant nutrient uptake and yield responses in maize (*Zea mays* L.). Previous authors have suggested incorporated K fertilizers could be more accessible to plants and positively influence the uptake of other nutrients. Yet few researchers have investigated maize responses to multiple conservation tillage systems, each with effectively unique K placements and timings, while utilizing an alternative K source. The main objective of this study was to document whether maize responses to Aspire™ application varied with the conservation tillage system employed. A five-site year field-scale experiment involving maize in the rotation was conducted by alternating annually between two fields from 2016 to 2019 at the Agronomy Center for Research and Education (ACRE Farm) near West Lafayette, IN and by establishing a single-year study at the Pinney Purdue Agriculture Center (PPAC Farm) near Wanatah, IN in 2019. The conservation tillage systems used for this experiment included fall chisel plow (FC, with spring field cultivating), coulter-driven strip-till [with separate treatments in fall (FST) and spring (SST)], and no till (NT). The alternative K fertilizer source was Aspire™ [0-0-48(K)-0.5(B)], and this source was used in each tillage system at rates of 0 and 108 kg K ha^{-1}. Treatments were only applied before maize in a maize-soybean (*Glycine max* L.) rotation; responses were observed for both first- and second-year maize at ACRE and first-year maize at PPAC. Collectively, the three first-year sites were grouped as maize year 1 (MY1), while the two second-

year sites were grouped as maize year 2 (MY2). A series of measurements were taken to document the nutrient dynamics and growth characteristics during crucial growth stages.

Whole plant sampling at V6 across both maize years showed large positive responses in accumulated dry matter for FST and FC (although not always significant for both), while maize dry matter with SST and NT had neutral or even negative responses to Aspire™. Whole-plant K uptake at V6, when averaged across tillage treatments, was increased by 25% in MY1 and by 84% in MY2 following Aspire™ application, with FST and FC having the largest gains in K uptake from Aspire™ application. At the R1 stage, tillage system differences were insignificant for earleaf K concentrations where Aspire™ was applied. Positive responses to Aspire™ application were observed both years at R1, despite plant-available K soil levels close to or above the critical level at each site/year. At R6, Aspire™ applications increased whole-plant K content (~21%) and B content (~9%) when averaged across tillage systems and both maize years. Differences in grain yield response were not detected within any tillage system following Aspire™ applications in either maize year. In MY1, the addition of Aspire™ led to an average grain yield increase of 0.5 Mg ha^{-1}, with no interaction between tillage system and Aspire™. Grain yields in MY2 were influenced by both Aspire™ and tillage (no interaction); an average grain yield increase of 1.1 Mg ha^{-1} occurred following Aspire™. No tillage system showed a consistent response advantage from the application of Aspire™ for whole-plant nutrient uptake or grain yield, but the application of Aspire™ commonly benefited plant K uptake and overall grain yield.

3.2 Introduction

Optimization of tillage methods that lower erosive soil losses and create an ideal environment for plant growth continues to be a question as tillage tools are developed or modified. Tillage systems with relatively lower surface disturbance are commonly referred to as conservation tillage systems; these can include strip-till, no-till, and chisel plow. Each tillage system changes both physical and chemical (referring to the distribution and abundance of essential plant nutrients) properties of the soil with depth over time. Physical and chemical soil properties can change vertically with depth increments and horizontally (i.e., row position). Position in the landscape (drainage, slope, etc.) also influences tillage system success by controlling soil loss and plant growth conditions. Al-Kaisi and Hanna (2008) provide examples of tillage systems working better than others under specific soil textures. For instance, strip-till could be more advantageous in sandy loam soils compared to moldboard plowing, but strip-till may be less ideal in silt loam and clay loam soils. The determination of success versus failure of a tillage system can be quantified by measuring soil and crop growth properties.

Tillage can change soil physical properties in the short and long term, but few studies have included fall chisel, strip-till, and no-till within the same study. As Global Positioning Systems (GPS) become more accessible to farmers, the need for information about how strip-till compares to other more established conservation tillage systems has become increasingly important. A study conducted in Iowa by Licht and Al-Kaisi (2005) investigated how the physical properties of temperature, moisture, and penetrability varied among strip-till, fall chisel plow, and no-till systems in a short-term experiment (2 years). From the analysis of the temperature data, the authors found chisel plow and strip-till had warmer soil temperatures compared to no-till when air temperature increased, but no differences among tillage systems were detected when cooler weather conditions occurred (Licht & Al-Kaisi, 2005). An important consideration acknowledged in the discussion by Licht and Al-Kaisi (2005) was the influence of water on change in soil temperature. Performing tillage (i.e., strip-till or fall chisel) allows for faster drying, lowering the water content and disturbance of surface residue (exposure of the dark soil reduces surface albedo, increasing heat adsorption) gave fall chisel and strip-till enhanced ability to respond to air temperature change more quickly (Licht & Al-Kaisi, 2005). Because tillage allowed for faster response to temperature changes and higher maximum soil temperatures (due to drier conditions), a slight improvement in the emergence rate and yield under the strip-till and fall chisel systems was observed (Licht & Al-Kaisi, 2005). Within the same study, the authors also looked at the influence of tillage on moisture content distribution both with depth and over time. Although there was variation in moisture content during the growing season, there was no apparent difference in crop water use efficiency among the tillage systems (Licht & Al-Kaisi, 2005).

Efficient drying and warming of the soil profile in the spring is especially imperative for a soil to be considered poorly drained. Not only is crop emergence likely to speed up following the use of fall chisel or strip-till, but there will be less favorable conditions for infection by early-season pathogens (Al-Kaisi & Hanna, 2008). A previous longer-term experiment by Vyn and Raimbault (1993) in Ontario summarized results for a 15-year continuous corn experiment evaluating five tillage systems (fall moldboard + spring secondary, fall chisel + spring secondary, spring moldboard, spring moldboard + secondary, and no-till). Similar to the results from Licht and Al-Kaisi (2005), Vyn and Raimbault (1993) documented variation in days to emergence, with no-till taking approximately two days longer to emerge compared to the other tillage treatments.

The impact of tillage on nutrient distribution is a necessary consideration when addressing crop responses to tillage systems. The extent of soil mixing from tillage operations influences K distribution in soil. Increasing the intensity of tillage (e.g., frequency, depth) and the degree of soil mixing allows for a more consistent distribution of K with depth. The impact of common tillage systems on the distribution of K has been investigated in various cropping systems. Authors have noted conservation tillage systems (e.g., no-till) can experience significant stratification of K with depth (Howard et al., 1999; Mallarino & Ul-Haq, 1997; Robbins & Voss, 1991; Varsa & Ebelharar, 2000; Vyn et al., 2002). Previous studies have also shown conservation tillage can have more extreme stratification than conventional tillage systems (Deubel et al., 2011; Franzluebbers & Hons, 1996; Holanda et al., 1998; Karlen et al., 1991). Varsa and Ebelharar (2000) observed that no-till had higher levels of K in the 0-5 cm depth than the chisel plow treatment, but lower exchangeable K concentrations in the 5-10 cm depth due to soil mixing in chisel systems. The no-till system commonly leads to near-surface accumulation of K from both above-ground plant dry matter decomposition and broadcast applied K fertilizers. Some authors have also noted differences in K concentration based on row position (comparing in-row and between-row) in low disturbance tillage systems over time (Holanda et al., 1998; Robbins & Voss, 1991; Yibirin et al., 1993). Howard et al. (1999) investigated changes in exchangeable K concentration by row position (in-row and between-row) after six years of no-till cotton production and concluded (averaged across three soils) that in-row samples had consistently greater soil K concentration than between-row. Varsa and Ebelharar (2000) and Holanda et al. (Holanda et al., 1998) found similar results with higher K concentrations near the row than between rows after applying broadcast treatments. Tillage incorporates crop residue as well as K fertilizer, and post-maturity residues contain a large amount of the K taken up by the plant. Researchers have investigated advantages to alternate placements of K-based fertilizers because of the frequent occurrence of stratification in conservation tillage systems.

Incorporation of K rather than conventional broadcast treatments has been suggested by some to be a means to overcome limitations due to nutrient stratification. Some of the previous research on alternative fertilizer placements studied the co-application of phosphorus (P) and K. A review by Randall and Hoeft (1988) acknowledges the variability in response to P and K placement due to soil conditions (lack of precipitation, reduced tillage, etc.) and inherent soil K levels. From the evaluation of previous studies, soil plant-available K levels greater than 240 mg K kg^{-1} seldom show crop yield differences between banded and broadcast placements (Randall & Hoeft, 1988). The latter implies the optimal K placement would vary based on the inherent fertility of the soil and moisture conditions. Optimum rate is also suggested to interact with placement, i.e., low rates in a band generally have greater nutrient uptake efficiency than a high-rate broadcast across the surface (Randall & Hoeft, 1988). Root growth responses to K banding are infrequently documented unless other nutrients are also incorporated (Bell, Mallarino, et al., 2021; Ebelhar & Varsa, 2000; Kovar & Barber, 1987; Randall & Hoeft, 1988). However, mixing K fertilizers into a greater proportion of the soil volume may benefit maize (Bell, Mallarino, et al., 2021). A review by Bell, Mallarino, et al. (2021) acknowledges that interest in the use of placement for K has improved K fertilizer use efficiency in maize production, but further investigation into how/if these management strategies improve K fertilizer use efficiency is still needed.

Trials in Iowa looked at the influence of K placement in a no-till system in several long-term study locations using the placement treatments of broadcast, planter banded (5x5 cm), and deep banded (15-20 cm depth) (Bordoli & Mallarino, 1998; Mallarino et al., 1999). The series of fields used for this experiment were rated optimum to high in soil test K (160 mg K kg^{-1}, averaged for the 0-15cm depth across locations) according to Iowa soil fertility standards, surprising the authors when several positive yield responses to K were recorded. Some locations saw an increase in early season uptake of K, commonly showing an advantage to the deep-banded placement when compared to broadcast (Mallarino et al., 1999). At the end of the growing season, grain yield for deep banding proved to have higher yields when compared to the other placement systems, but the yield increases were relatively small, raising the concern about the cost-effectiveness of this system (increase in yield was 0.245 Mg ha^{-1}) (Bordoli & Mallarino, 1998). A later study by Buah et al. (2000) in Iowa compared the rate and placement of K in a no-till system. Tissue measurements (both early and mid-season) showed no consistent advantage to a specific fertilizer placement. Furthermore, no grain yield benefit was observed for banding in their no-till system (Buah et al., 2000).

Previous research in Illinois by Fernández and White (2012) compared the effects of P and K placement in no-till broadcast, no-till deep-banding, and strip-till deep-banding treatments applied to maize from 2007 to 2009 on a soil with an average soil test K of 171 mg K kg^{-1} (critical level of 150 mg K kg^{-1} according to Illinois soil recommendations). Harvest results from 2007 to 2010 showed strip-till utilizing deep banding had superior yield (at average grain yields of 9.4 Mg ha^{-1}, strip-till deep-banding had 7.8% and 7.9% advantage over no-till broadcast and no-till deep-banding, respectively). These grain yields were significantly influenced by the interaction of tillage/placement and fertilization with K. Strip-till deep-banding led to increased P and K accumulation in the grain, while placement did not change grain P and K accumulation in the no-till system. In that study, K led to a yield increase primarily through greater kernel weight. A more recent study from Illinois, published by Yuan et al. (2020), investigated placement of P and K, but looked at no-till (broadcast) and strip-till [broadcast and deep banded (banded 15cm deep)] systems. The soil for their 8-year field experiment tested above the critical level according to Illinois recommendations (217 mg K kg^{-1}). Placement of P or K did not appear to have an effect on maize or soybean yield in strip-till, but they observed the strip-till system was superior to no-till, similar to the results observed by Fernandez and White (2012).

Combined tillage and placement studies utilizing only K have been conducted in Ontario, Canada. Vyn and Janovicek (2001) examined maize response to tillage with varying fertilizer placement effects at locations with histories of no-till and likely highly stratified K. In this experiment, each tillage system had a distinct placement [broadcast in continued no-till, deep banding to 15cm depth in zone-tillage, and broadcast followed by incorporation via fall moldboard plow (conventional)] on fields with soil test K <120mg K kg^{-1}. This study looked at the combined effect of tillage and fertilizer placement (position). The authors found that conventional tillage commonly had higher ear leaf concentrations during the growing season than no-till and zone-tillage, but no-till and zone-tillage typically benefited from shallowly incorporated K applied during the growing season. Vyn et al. (2002) also compared tillage systems [no till, strip-till, and mulch tillage (2-3 passes with a field cultivator)] and varying placements [broadcast, deep banding below row, and ½ broadcast with ½ shallowly banded (5x5cm) within each tillage system] on soils considered to have low soil test K (<60 mg K kg^{-1}) in Ontario, Canada. Early in the growing season differences between tillage and application rates were seen but these were not detectable at R1 (Vyn et al., 2002). Applications of K increased grain yield for the no-till and strip-till system, but no response was documented in the mulch tillage system. No yield differences in deep versus shallow banding were detected (Vyn et al., 2002).

In a long-term tillage experiment initiated in 1992 in Bernburg, Germany, Deubel et al. (2011) looked at the influence of conservation and conventional tillage systems on the distribution of soil nutrients in 2008. Conservation tillage included the processing of stubble from the previous crop and field cultivation (referred to as a ‘grubber’), while conventional included stubble processing with plowing (depth of 20-30cm). This experiment also utilized a diverse crop rotation (grain maize – winter wheat (*Triticum aestivum* L.) – winter barley (*Hordeum vulgare* L.) – winter rape (*Brassica napus ssp. napus*) – winter wheat) which can influence nutrient cycling. Deubel et al. (2011) documented the 0-5cm depth was 275% higher in K concentration compared to the 15-

30cm depth under conservation tillage. Although the soil K levels were high in the soil surface, tillage system treatments did not significantly influence maize yield.

Previous research has rarely utilized alternative sources of K [i.e., fertilizers containing additional nutrient(s) with K]. Since 2014, The Mosaic Company™ produced a fertilizer product called Aspire™. This product incorporates boron (B) and K into a granular fertilizer with an approximate analysis of 0-0-48(K)-0.5(B). This product is available to farmers through agricultural supply retailers throughout the U.S. Midwest. Upon the release of a new formulation in 2018, two forms of B, calcium hexaborate pentahydrate and sodium tetraborate were combined with potassium chloride (KCl) (The Mosaic Company, 2020). Calcium borate is considered more recalcitrant than sodium borate, allowing for potentially extended availability of B. Published research utilizing Aspire™ is minimal. A University of Arkansas report by Slaton et al. (2019) compared the use of Aspire™ and MicroEssentials®SZ® (MESZ) to the traditional application of muriate of potash (MOP) and monoammonium phosphate (MAP). This study did not include control treatments to look at the individual responses to individual fertilizers, so the authors could not separate the influence of each fertilizer. Since Aspire™ was applied in a 50:50 mix of MOP and Aspire™, the full rate of B was not applied. Nevertheless, the authors found final maize grain yield increased significantly following the application of Aspire™ and MESZ compared to MOP and MAP (Slaton et al., 2019). Perhaps the paucity of studies looking at an alternative K source with B in maize systems is understandable given the more common B deficiencies occurring in dicotyledonous crops. In addressing crop responses and differences (due to K and/or B) throughout this chapter, previous research focused on either K or B will be used.

The objectives for this study were to investigate the impact of tillage (system/placement/ timing), the application of Aspire™, and the interaction between them on in-season nutrient dynamics and yield components, grain yield, and nutrient partitioning at maturity to better understand potential differences among tillage systems in the utilization of Aspire™.

3.3 Materials & Methods

A field-scale experiment was conducted for four of five site-years at the Agronomy Center for Research and Education (ACRE Farm) near West Lafayette, IN by alternating between two fields (40.493°N, 86.996°W and 40.501°N, 87.000°W) from 2016 to 2019. The same maize experiment was conducted for a fifth site-year (2019) at the Pinney Purdue Agricultural Center (PPAC Farm) near Wanatah, IN (41.447°N, 86.940°W). Each trial followed a soybean rotation. Two of the fields (ACRE Farm locations) had the maize study repeated following an intermediate (rotational) soybean year. Treatments were applied to the same experimental units in each maize year (repeated measures). The ACRE Farm location for 2016 (MY1) and 2018 (MY2) (40.493°N, 86.996°W) was a combination of a Drummer, silty clay loam, 0-2 percent slope (Fine-silty, mixed, superactive, mesic Typic Endoaquolls) and a Raub-Brenton complex, silty clay loam, 0-1 percent slope (Fine-silty, mixed, superactive, mesic Aquic Argiudolls). The ACRE Farm location for 2017 and 2019 (40.501°N, 87.000°W) was a combination of a Drummer, silty clay loam, 0-2 percent slope (Fine-silty, mixed, superactive, mesic Typic Endoaquolls) and a Toronto-Millbrook complex, silt loam, 0-2 percent slope (Fine-silty, mixed, superactive, mesic Udollic Epiaqualfs). The PPAC Farm location (once again a MY1 site) was mostly composed of Sebewa loam, shaly sand substratum, 0-2 percent slope (Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Argiaquolls) with a small portion of Pinhook loam, 0-2 percent slope (Coarse-loamy, mixed, superactive, mesic Mollic Endoaqualfs). Soil fertility sampling was completed within two weeks following planting for all site years. Detailed soil sampling was conducted to understand the variability of soil nutrients with regard to row position and depth. Ten soil probes were collected per row position (i.e., separately for in-row and between-row) from the middle of each plot. Samples were divided into three depth increments, 0-5cm, 5-10cm, and 10-20cm from both row positions. Average fertility levels for the 0-20cm depth for each respective field location utilizing all 0 kg K ha^{-1} treatments are presented in Table 3.1. Analyses of soil samples were completed by A&L Great Lakes Laboratories (Fort Wayne, IN) for 2016, 2017, 2018, and 2019 (ACRE). Suretech Labs (Indianapolis, IN) was used for the analysis of soil for 2019 (PPAC) and pH for 2019 (ACRE). Analysis by A&L Great Lakes Laboratories and Suretech Labs both utilized Mehlich III for extraction to determine CEC, P, K, Magnesium (Mg), and Calcium (Ca), and both utilized the loss by ignition method for organic matter determination. Both laboratories used a slurry and electrode to determine soil pH, but calcium chloride was utilized in the Suretech pH measurements.

In total, ten treatments were investigated each year in a randomized complete block design; however, to allow for balanced mean comparisons, only eight treatments (those utilizing the application rates of 0 and 108 kg K ha^{-1} rates across four tillage systems) will be discussed in this analysis. The fertilizer source was Aspire™ (The Mosaic Company, Tampa, FL) (0-0-48(K)-0.5(B)), a potassium-based fertilizer infused with B. In 2018, a change in the formulation of Aspire™ incorporated the use of both sodium-borate and calcium-borate instead of only the sodium-borate used in 2016 and 2017. Rates of 0 and 108 kg K ha^{-1} were utilized in all four tillage systems (no-till, strip-till (two timings), and fall chisel plow). No-till (NT) treatments had Aspire™ broadcast applied in the spring before planting. Fall chisel (FC) plowing was performed after broadcast application of Aspire™ and secondary tillage involved a field cultivator the following spring. Strip-till was performed using a six-row SoilWarrior® (Environmental Tillage Systems, Faribault, MN). This coulter-based strip-till tool allowed for fertilizer placement to a depth of approximately 5cm while performing tillage. Strip-till was further divided into two timings the fall

(FST) and spring (SST). Fertilizer placement with coulter-driven strip-till would not be considered a traditional deep band application due to the shallow mixing. Coulter action mixed fertilizer into a wider band (and possibly more soil volume) than might have been realized with a deep shank placement. In contrast to the specific placement of fertilizer into the crop row with strip-till, the NT and FC treatments had Aspire™ applied across surface (applying fertilizer both in-row and between row), with FC accomplishing incorporation of fertilizer in both primary and secondary tillage. For locations repeated for a second year of data collection, strip-till was intentionally offset 37cm to avoid enriching the same zone in the soil in succeeding years.

This experiment was conducted following a maize-soybean rotation, with treatments and measurements only completed during maize years. Strip-till between the former maize rows preceded soybean planting in the rotation year, but no K or B was applied. Experiment plots were 12-rows wide (0.76m row spacing) and ~36.6m in length. All site years were planted with a 6-row John Deere 1780 planter (Moline, IL) except for the 2019 (PPAC) location, which utilized a 12-row Case IH planter (Racine, WI). Planting and tillage dates are presented in Tables 3.2 (MY1) and 3.3 (MY2). The same hybrid, Pioneer P1311AM or AMXT (Corteva Agriscience, Willmington, DE), was used for all site years at ACRE, and Pioneer P0574AM was planted on the PPAC farm in 2019. All locations were planted to a population of 84,000 plants ha^{-1} with final average plant populations of 82,500, 83,000, 78,900, 80,000, and 82,400 plants ha^{-1} for 2016,

Table 3.1. Soil fertility means for pH, organic matter (OM), cation exchange capacity (CEC), P, K, Mg, and Ca parameters for for each site year (2016, 2017, 2018, 2019(ACRE), 2019(PPAC)), with minima and maxima presented in parentheses to a depth of 20cm. Average was calculated using all tillage system control systems.

	MY1[1]			MY2[1]	
Year	2016	2017	2019	2018	2019
Field	ACRE 111	ACRE 131	PPAC F-West	ACRE 111	ACRE 131
pH (1:1)	6.1 (5.4, 6.7)	6.4 (6.0, 6.8)	6.5 (6.0, 6.8)	6.2 (5.4, 7.0)	6.7 (6.3, 7.0)
OM (%)	2.7 (2.2, 3.0)	3.0 (2.5, 3.7)	2.6 (1.8, 4.2)	2.6 (2.2, 3.3)	3.5 (2.9, 4.3)
CEC (meq 100g^{-1})	15.6 (12.1, 18.2)	17.6 (13.6, 23.4)	13.2 (10.4, 16.2)	15.6 (11.8, 20.7)	18.1 (14.7, 22.7)
P (mg kg^{-1})	47 (22, 73)	25 (17, 46)	40 (12, 79)	45 (23, 91)	31 (16, 77)
K (mg kg^{-1})	151 (116, 193)	106 (79, 135)	134 (94, 205)	126 (87, 176)	105 (85, 133)
Mg (mg kg^{-1})	516 (325, 687)	594 (467, 803)	476 (349, 590)	527 (331, 807)	625 (529, 772)
Ca (mg kg^{-1})	1615 (1019, 2088)	2056 (1613, 2786)	1805 (1412, 2218)	1698 (1113, 2284)	2143 (1788, 2743)

[1] MY = maize year

Table 3.2. MY1 (2016, 2017, and 2019 (PPAC)) dates for planting, tillage, N-sidedress and herbicide (presented as product rate applied) regimine during respective growing season.

	MY1[1]		
Year	2016	2017	2019
Field	ACRE 111	ACRE 131	PPAC F-West
Planting Date	4/19/2016	4/18/2017	6/5/2019
Fall Strip Tillage	11/4/2015	11/1/2016	12/6/2018
Fall Chisel Plow / Spring Secondary	11/3/2015 4/18/2016	11/3/2016 4/17/2017	NA 6/5/2019
Spring Strip Tillage	4/18/2016	4/13/2017	6/5/2019
N Sidedress	05/16/2016	05/23/2017	07/02/2019
Pre-Emergence	Glyphosate [N-(phosphonomethyl)glycine], (Bayer Crop Science, Rhein, Germany) at 1543 g ha^{-1}	Glyphosate [N-(phosphonomethyl)glycine], (Bayer Crop Science, Rhein, Germany) at 1543 g ha^{-1} 2, 4-D [Dimethylamine Salt of 2,4-Dichlorophenoxyacetic Acid] at 1122 g ha^{-1}	Durango {Glyphosate [N-(phosphonomethyl)glycine, dimethylamine salt]} (Corteva Agriscience, Wilmington, DE) at 2.3 L ha^{-1} Fultime {Acetochlor [2-chloro- N-ethoxymethyl-N-(2-ethyl6-methylphenyl)acetamide], Atrazine[1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine]} (Corteva Agriscience, Wilmington, DE) at 7.0 L ha^{-1}
Post-Emergence	Calisto {Mesotrione [2-(4-(Methylsulfonyl)-2-nitrobenzoyl)cyclohexane-1,3-dione]} (Syngenta, Basel, Switzerland) at 210 g ha^{-1}	Bicep II {S-metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(1-methoxypropan-2-yl)acetamide], Atrazine [1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine]} (Syngenta, Basel, Switzerland) at 4.8 L ha^{-1} Calisto {Mesotrione [2-(4-(Methylsulfonyl)-2-nitrobenzoyl)cyclohexane-1,3-dione]} (Syngenta, Basel, Switzerland) at 210 g ha^{-1}	Callisto Xtra {Atrazine [1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine], Mesotrione [2-(4-(Methylsulfonyl)-2-nitrobenzoyl)cyclohexane-1,3-dione]} (Syngenta, Basel, Switzerland) at 1402 g ha^{-1}

[1] MY = maize year

Table 3.3. MY2 (2018 and 2019(ACRE)) dates for planting, tillage, N-sidedress, and herbicide regimine (presented as product rate applied) during respective growing season.

	MY2[1]	
Year	2018	2019
Field	ACRE 111	ACRE 131
Planting Date	4/26/2018	5/16/2019
Fall Strip Tillage	11/10/2017	10/18/2019
Fall Chisel Plow / Spring Secondary	11/3/2017 4/26/2018	10/25/2018 5/15/2019
Spring Strip Tillage	4/26/2018	5/15/2019
N Sidedress	05/21/2018	06/02/2019
Pre-Emergence	Glyphosate [N-(phosphonomethyl)glycine], (Bayer Crop Science, Rhein, Germany) at 1543 g ha^{-1} Bicep II {S-metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(1-methoxypropan-2-yl)acetamide], Atrazine [1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine]} (Syngenta, Basel, Switzerland) at 4.8 L ha^{-1} 2, 4-D [Dimethylamine Salt of 2,4-Dichlorophenoxyacetic Acid] at 1122 g ha^{-1}	Glyphosate [N-(phosphonomethyl)glycine], (Bayer Crop Science, Rhein, Germany) at 1543 g ha^{-1} Bicep II {S-metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(1-methoxypropan-2-yl)acetamide], Atrazine [1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine]} (Syngenta, Basel, Switzerland) at 4.8 L ha^{-1}
Post-Emergence	Glyphosate [N-(phosphonomethyl)glycine] (Bayer Crop Science, Rhein, Germany) at 1543 g ha^{-1} Atrazine [1-Chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine] at 1122 g ha^{-1} Callisto Mesotrione [2-(4-(Methylsulfonyl)-2-nitrobenzoyl)cyclohexane-1,3-dione] (Syngenta, Basel, Switzerland) at 210 g ha^{-1}	Glyphosate [N-(phosphonomethyl)glycine] (Bayer Crop Science, Rhein, Germany) at 1543 g ha^{-1} Callisto {Mesotrione [2-(4-(Methylsulfonyl)-2-nitrobenzoyl)cyclohexane-1,3-dione]} (Syngenta, Basel, Switzerland) at 210 g ha^{-1}

[1] MY = maize year

2017, 2018, 2019 (ACRE), and 2019 (PPAC), respectively. At planting, starter fertilizer (Position: 5 cm to the side of the seed and 5 cm below seed) at the ACRE site years [2016, 2017, 2018, and 2019 (ACRE)] consisted of ammonium polyphosphate [APP, 10-15(P)-0] with total nutrients app of a mixture of urea ammonium nitrate (UAN, 28-0-0), APP and ammonium thiosulfate [ATS, 12-0-0-26(S)] applying total nutrient amounts of 30.6 kg N ha^{-1}, 9.7 kg P ha^{-1}, and 16.2 kg S ha^{-1}. Upon reaching V5-V6, a side-dress application of N, applied as a midrow band of UAN, was completed at a rate of 196 kg N ha^{-1} for all site years except 2019 (PPAC), which applied 188 kg N ha^{-1}. Following side-dress, the total N applied was 215.6 kg N ha^{-1} to all ACRE site years and 218.6 kg N ha^{-1} at PPAC. Herbicide (pre- and post-emergence) applications varied each year and at each location, refer to Tables 3.2 and 3.3 for details regarding applications. Before the 2018 growing season, an application of lime was broadcast applied to the entire experiment area at a rate of 6.7 metric tons ha^{-1} on 08 November 2017. An insecticide was applied on 19 June 2019 (see Chapter 2 for details).

3.3.1 In-Season Tissue and Physical Measurements

For all years of this experiment, measurements were always collected in rows 3 and 4, and/or 9 and 10 out of the 12-row plots to avoid any border effects and minimize the influence of wheel traffic from planting. Following emergence, final plant populations were recorded for each location (total replications sampled for MY1 = 14 and MY2 = 80), but no treatment differences in population were detected in any site-year (Appendix B, Table B.2). Zones for later dry matter samplings were selected (with relatively consistent plant-to-plant spacing and size) at an early growth stage in each plot for ten consecutive plants (used for later dry matter sampling at V6 and R6) and a 20-plant zone (used for flowering observations). A series of tissue samples were collected throughout the growing season. Once plants reached V5-6, whole plant dry matter samples were collected by cutting ten consecutive plants per plot at ground level and recording the length of row (total replications sampled for MY1 = 9 and for MY2 = 8). Samples were all dried at a temperature of 60°C for 4-7 days. Once dry, samples were then weighed (for use in dry matter and nutrient uptake calculations) and ground to pass through a 1mm sieve.

Anthesis-silking notes were collected daily from a pre-selected set of 20 consecutive plants in each plot for all site years, except for 2016 (replications sampled MY1 = 7 and MY2 = 8). Anthesis was reached when ten anthers were visible from the tassel. To be considered silked, plants had to display at least 1cm of silk extending from the husk. With the use of the planting date and the daily anthesis-silking notes, the anthesis-silking interval could be calculated. Earleaf samples were collected at R1 (once a majority of plots had reached 50% silking) from 10 consecutive plants in all years except 2019 ACRE, where ten leaves were collected randomly from plants along the plot length within the same row (replications sampled MY1 = 9 and MY2 = 8). Beginning in 2018, the leaf area of the earleaf was collected using a LI-3000C (LI-COR Biosciences, Lincoln, NE) to allow for calculation of the specific leaf area and specific leaf nutrient content (Eq. 1 and 2) using the method from DeBruin et al. (2013) (total replications sampled MY1 = 4 and MY = 8). During the growing season, non-destructive leaf area index measurements were taken at V14 (only taken in 2016, 2017, and 2019 ACRE, total replications measured MY1 = 8 and MY2 = 3) and R2 (only taken during 2016, 2017, and 2018, total replications measured MY1 =8 and MY2 = 4) utilizing a LAI-2200C (LI-COR Biosciences, Lincoln, NE). Five readings were taken per plot with data points collected while moving down and across the crop row; from these readings a plot average was calculated. In 2019 at the ACRE location, a height difference was noticed early in the season, prompting the collection of height data at V8 (to the top leaf collar) and final heights at R1 (to top leaf collar).

Once all treatments had reached maturity (R6), 10 plants from pre-determined zones were collected to determine final whole plant and component dry matter (total reps sampled, stover [MY1= 7, MY2 = 9], grain [MY1= 6, MY2 = 9], and cob [MY1= 6, MY2 = 9]). Immediately following removal from the field, plants were separated into three components: stover (husks, leaves, and stems), cobs, and grain. All components were dried, weighed, and ground to pass through a 1mm sieve. An additional ten ears were collected from the field for yield component analysis. Dry matter ears (10 ears) were shelled individually with grain weight and kernel numbers recorded on a per-plant basis. Once all ears had been recorded for a plot, a random sub-sample of 200 kernels were taken from the total grain for the plot and dried at 140°C for 24 hours to ~0% moisture to determine individual dry kernel weights. The nutrient concentrations within plant tissues and nutrient content values are reported at the moisture content remaining after drying to 60°C. Only one replication of cobs was sent for nutrient analysis due to resource constraints and known low variability among treatments in cob nutrient composition. Cob nutrient concentrations were matched with cob weights from respective treatments in remaining replications. Cob nutrient content was calculated as the product of dry matter and nutrient concentration. Nutrient analysis was performed for all site years and components at A&L Great Lakes Laboratories (Fort Wayne, IN). Similar to Chapter 2, all nutrients were measured for each tissue sampling, but only the nutrients N, P, K, Ca, Mg, and B are presented in the main chapter tables (refer to Appendix B for additional nutrients). Due to mold growth on ears during 2017, no grain or cobs could be analyzed for nutrient concentration or content. For grain harvest, a Kincaid 2-row combine (Haven, KS) was used to harvest two passes (4 rows) for the 4-6 reps present at all ACRE sites (2016, 2017, 2018, 2019 (ACRE)). The 2019 (PPAC) site was harvested using an Allis Chalmers Gleaner 3-row combine (AGCO, Duluth, GA) and, due to significant lodging and planting difficulties, 3 to 6 rows from each plot were used for determining the average grain yield per plot for four reps (rows 3-5 and/or 8-10 were harvested in a majority of plots). The K recovery efficiency was calculated for plots that received Aspire™ (Eq. 3) based on the nutrient contents for each plant component.

Eq 1. $\text{Specific Leaf Area} = \frac{\text{Leaf area (m}^2\text{)}}{\text{Leaf mass (g)}}$

Eq 2. $\text{Specific Leaf Content} = \frac{\text{Tissue Nutrient Concentration}}{\text{Specific Leaf Area (m}^2\text{g}^{-1}\text{)}}$

Eq 3. $\text{K Recovery Efficiency (\%)} = \frac{\text{K Uptake}_{\text{Applied K}} - \text{K Uptake}_{\text{No Applied K}}}{\text{K Fertilizer Applied}}$

3.3.2 Statistical Analysis

Statistical analysis was performed using SAS 9.4 (SAS Institute Inc., 2016) utilizing the GLIMMIX and MIXED procedures (Stroup et al., 2018). Due to the potential for Aspire™ to influence a field for several years following application, site years were divided by maize year (MY1 = initial experiment year in the field, MY2 = returning to the field following soybean) for all analyses. Because site year had little interaction with tillage, Aspire™, or tillage x Aspire™, only the means for each maize year are presented (p-values for interaction with site year had a majority $p>0.05$) (Carmer et al., 1969). Because of the lack of balance between maize years 1 and 2 (MY1 having three site years, while MY2 had two site years), a BY statement was used to analyze maize years 1 and 2 separately. For analysis, site year, Aspire™ rate, and tillage were treated as fixed effects, while hybrid and block nested within site year were treated as random effects. Analysis of variance was conducted using the MIXED procedure, and mean separation was performed with the LSMEANS statement in the GLIMMIX procedure using a Tukey's Honest Significant Difference test. For both methods, a Kenward-Rogers adjustment was used (Stroup, 2015). Significance and mean separation were considered significant at an $\alpha = 0.05$. Because of the variability in interactions between tillage and Aspire™ rate, the tables present the means for tillage, Aspire™, and tillage x Aspire™ with the results of p-values shown. Because only one replication of cob concentration data was collected each site year, the model for this parameter assumed the fixed effects of tillage and Aspire™ and random effects of year and hybrid.

Soil analysis was completed using several different methodologies. The initial analysis used for Figures 3.4 through 3.8 tested differences in concentration of soil plant-available K in the soil with depth and across row position to better understand soil K stratification. Each site year varied in the initial level of soil-test K, so each site year is presented separately. A BY statement allowed for separating individual treatment and sampling position to look at only one set of soil depths. The model for the GLIMMIX procedure had depth increment as a fixed effect while block was treated as a random effect, and the LSMEANS statement was used for mean separation of soil depth increments using a Tukey's Honestly Significant Difference test. When comparing sampling position within a treatment, a BY statement was also used to separate treatments, and the model treated position and depth as fixed effects and block as a random effect. The LSMEANS statement presented the differences in sampling position using a Tukey Honestly Significant Difference test.

A similar analysis was used to look at differences in K concentration among treatments within a specific depth increment using the GLIMMIX procedure and the LSMEANS statement with a Kenward Rogers Adjustment. A BY statement separated Field IDs and sampling depth; the fixed effects for this experiment consisted of tillage, Aspire, and row position. Block was considered a random variable.

The ratios of plant-available K concentration in the 0-5cm depth to 5-10cm and 0-5cm to 10-20cm depth were calculated and tested against one another to evaluate stratification. Similar to the previous analyses, the GLIMMIX procedure was used and a BY statement separated the MY's.

Significance and mean separation were considered significant at an $\alpha = 0.05$. The fixed variables for the model were Tillage, Aspire, and Row Position with Block as a random variable. The LSMEANS statement calculated differences for Aspire™ rate and row position using a Tukey Honestly Significant Difference test, and a Kenward-Rogers adjustment was also utilized (Stroup, 2015).

3.4 Results and Discussion

3.4.1 General Considerations

As stated in Chapter 2, the lack of research investigating the impact of Aspire™ alone and the undetectable effects of co-applying K and B (not having control K and B treatments) make it difficult to compare this experiment to previous research. Additionally, only the combined effects of both tillage and fertilizer placement can be considered due to the experimental design.

3.4.2 Weather

Chapters 2 and 3 present data from the same experiment but utilize different subsets of treatments for mean comparisons. Detailed weather information for each site year is presented in Chapter 2 and is the same for this chapter. This chapter only presents the monthly cumulative precipitation (mm) and growing degree days (GDDs). Figure 3.1 displays the precipitation from the weather station located at ACRE across each month for all site years, including the 30-year normal (1981-2010). Figure 3.2 depicts the precipitation at the PPAC location for 2019 compared to the 30-year normal (1981-2010); a mix of limited and excessive precipitation is seen during this growing season. In addition to precipitation, Figure 3.3 shows the monthly accumulated GDDs for each location (utilized temperature limits of 50 and 86°F). Together, precipitation and GDDs can provide insight into the growing conditions for each site year.

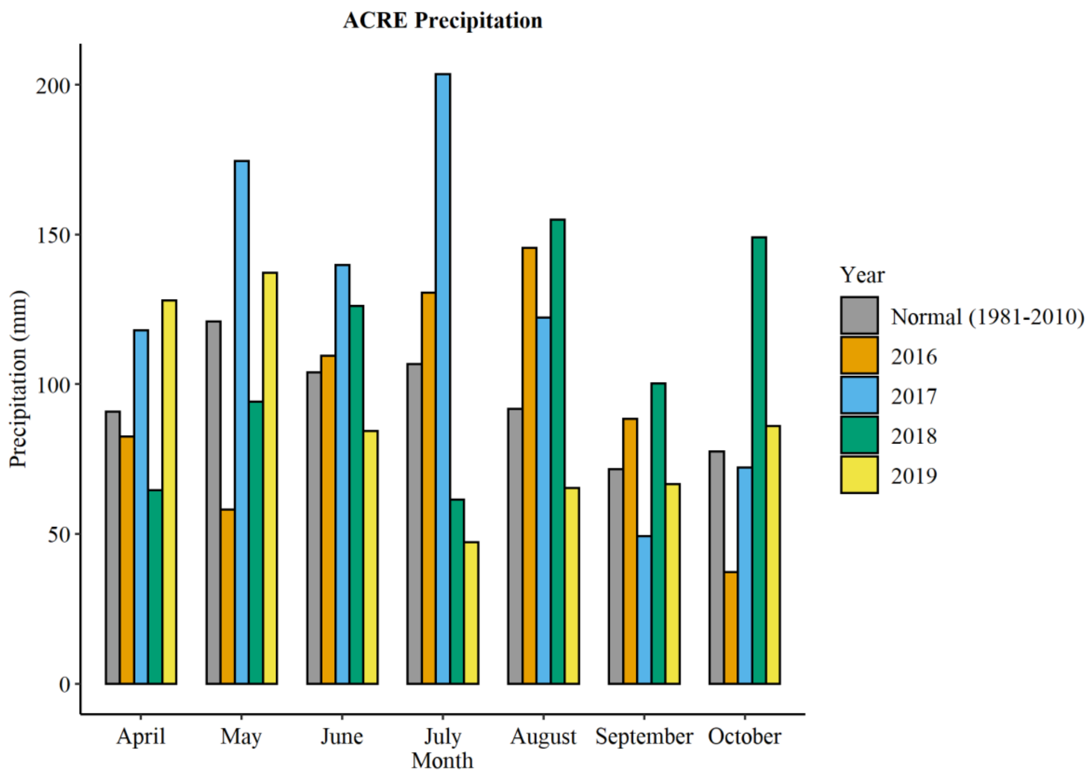

Figure 3.2. Monthly accumulated precipitation (mm) at the ACRE location for 2016, 2017, 2018, and 2019 compared to a 30-year normal (1981-2010).

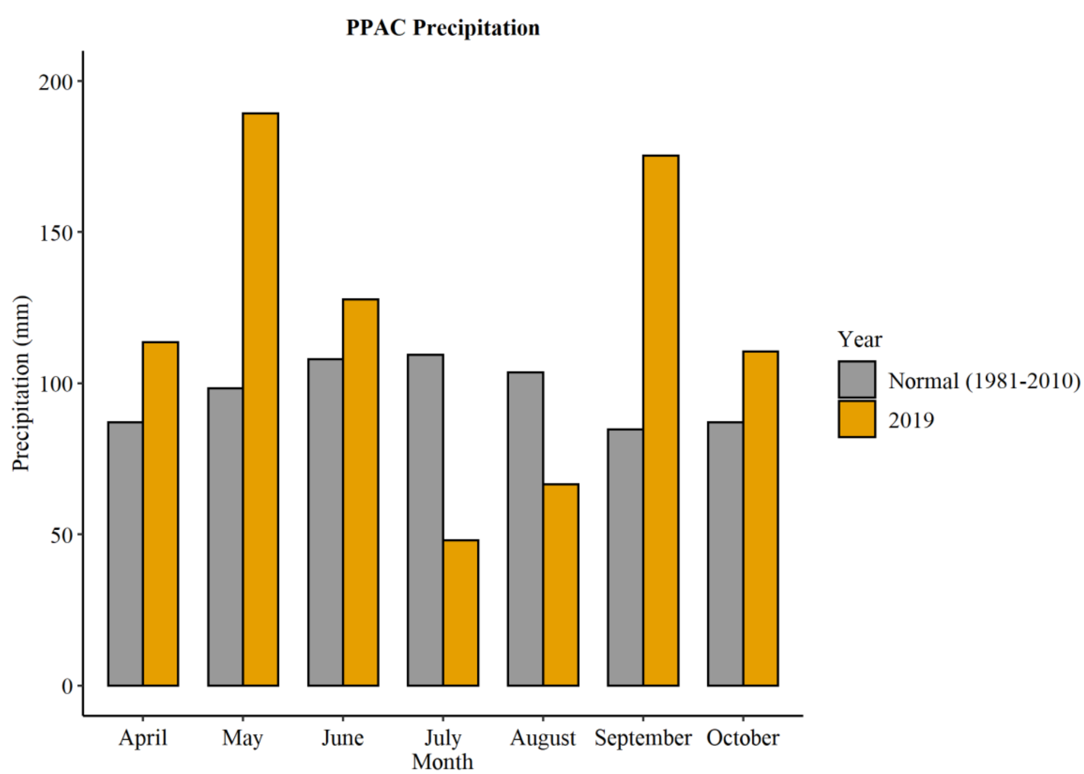

Figure 3.1. Monthly accumulated precipitation (mm) for PPAC in 2019 compared to 30-year normal (1981-2010).

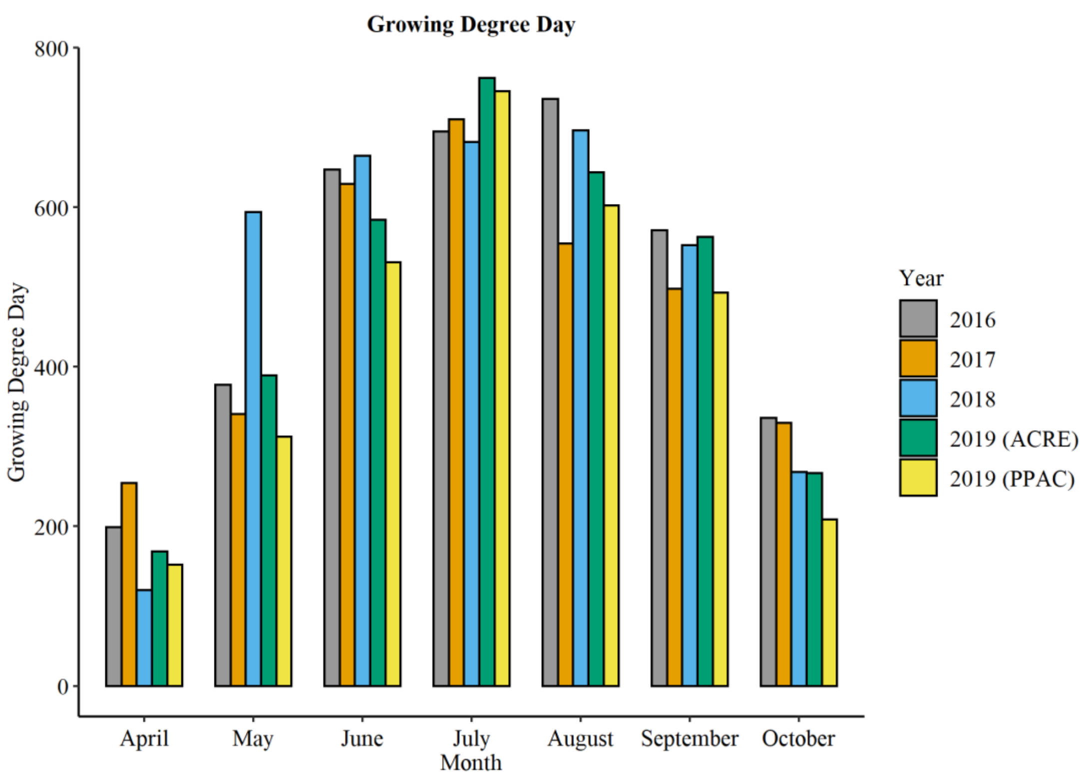

Figure 3.3. Growing degree days accumulated per month for ACRE (2016, 2017, 2018, and 2019) and PPAC (2019). Using limits of 50 and 86°F.

3.4.3 Soil Measurements for Plant-Available K

Average soil fertility nutrient concentrations for the locations used for this experiment are presented in Chapter 2 (Table 2.1), as well as the calculated critical soil exchangeable K concentrations for each site according to the Tri-State Fertilizer Recommendations (Vitosh et al., 1995) and interpretation.

As mentioned in Chapter 2, soil sample collection by depth increment and position is not a new concept. Soil sampling in depth increments both in the crop row (IR) and between the crop row (BR) (Figures 3.4 through 3.8) measured the distribution of K within the soil for each tillage and Aspire™ combination. Figures 3.4 to 3.8 show consistently higher concentrations of plant-available K (mg K kg^{-1}) in the 0-5 cm depth compared to the deeper sampling depths (5-10cm and 10-20cm). Error bars (showing the standard deviations for each depth) show the variability in concentration with each sampling depth across the trial area. When comparing figures for locations used for MY1 and MY2 [Field 111 = 2016 and 2018, Field 131 = 2017 and 2019 (ACRE)], it is interesting to note the higher amount of separation in concentration among sampling depths within a treatment for MY1 compared to MY2 (MY2 appears to have more overlap among the K concentrations with depth).

In MY1 location, Aspire™ led to an increase in the concentration of the 0-5cm depth increment IR of 99 and 67 mg K kg^{-1} when compared to the 0-5cm depth with 0 kg K ha^{-1} for FST and SST when averaged across MY1 locations, respectively (Figures 3.4, 3.5, and 3.8). The increase in the concentration of IR from the application of Aspire™ appeared to be similar for MY2 with increases of 102 mg K kg^{-1} and 107 mg K kg^{-1} when comparing 0 kg K ha^{-1} to 108 kg K ha^{-1} for the IR position for FST and SST. The placement of Aspire™ within the row was evident from the small change in concentration of the BR position comparing the 0-5cm depths of

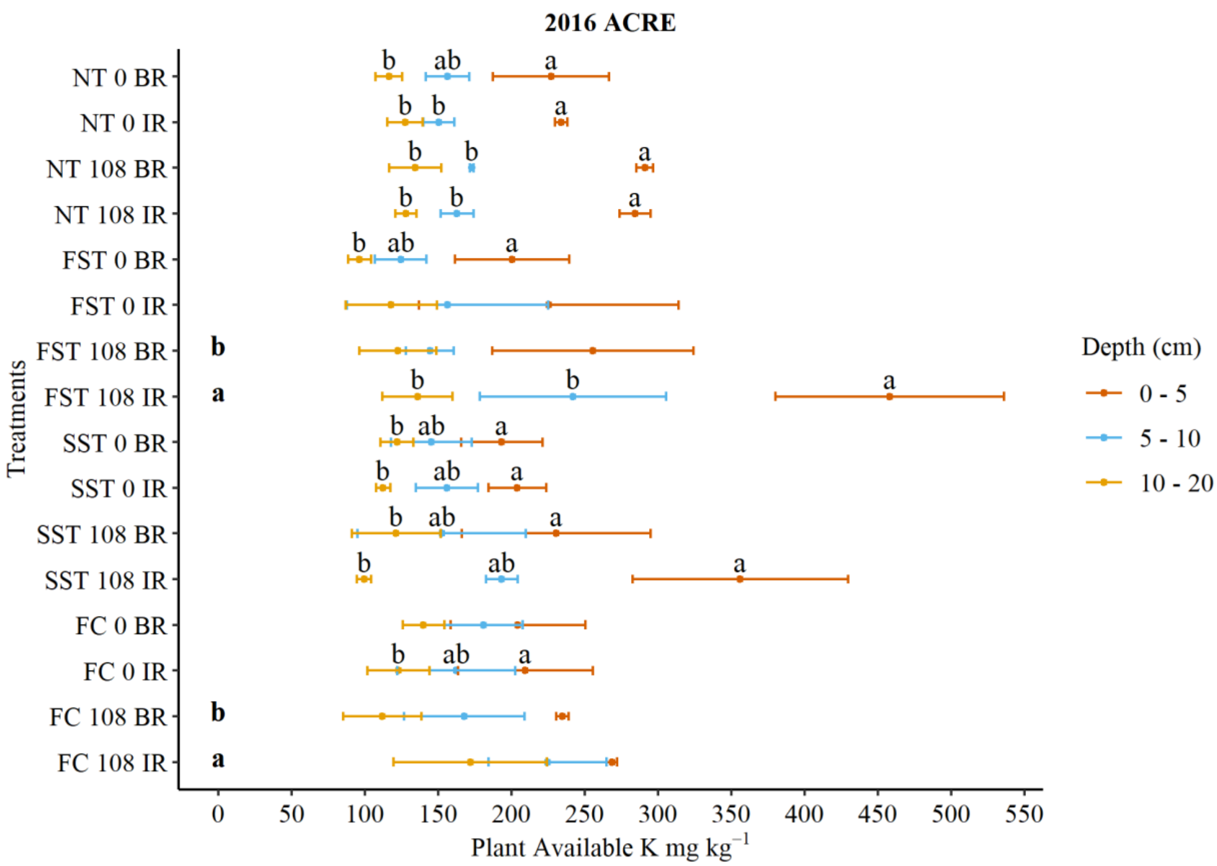

Figure 3.4. Soil sampling results for plant available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth. Dot indicates average for depth increment representing 2 replications. Error bars represent the standard deviation for the individual depth measured. Bold lower-case letters indicate significant differences between sampling position within a treatment across all depths at a significance level of $p<0.05$. Letters above dots (representing average) indicates significant differences in plant available K concentration within a specific treatment and sampling position at a statistical level of $p<0.05$.

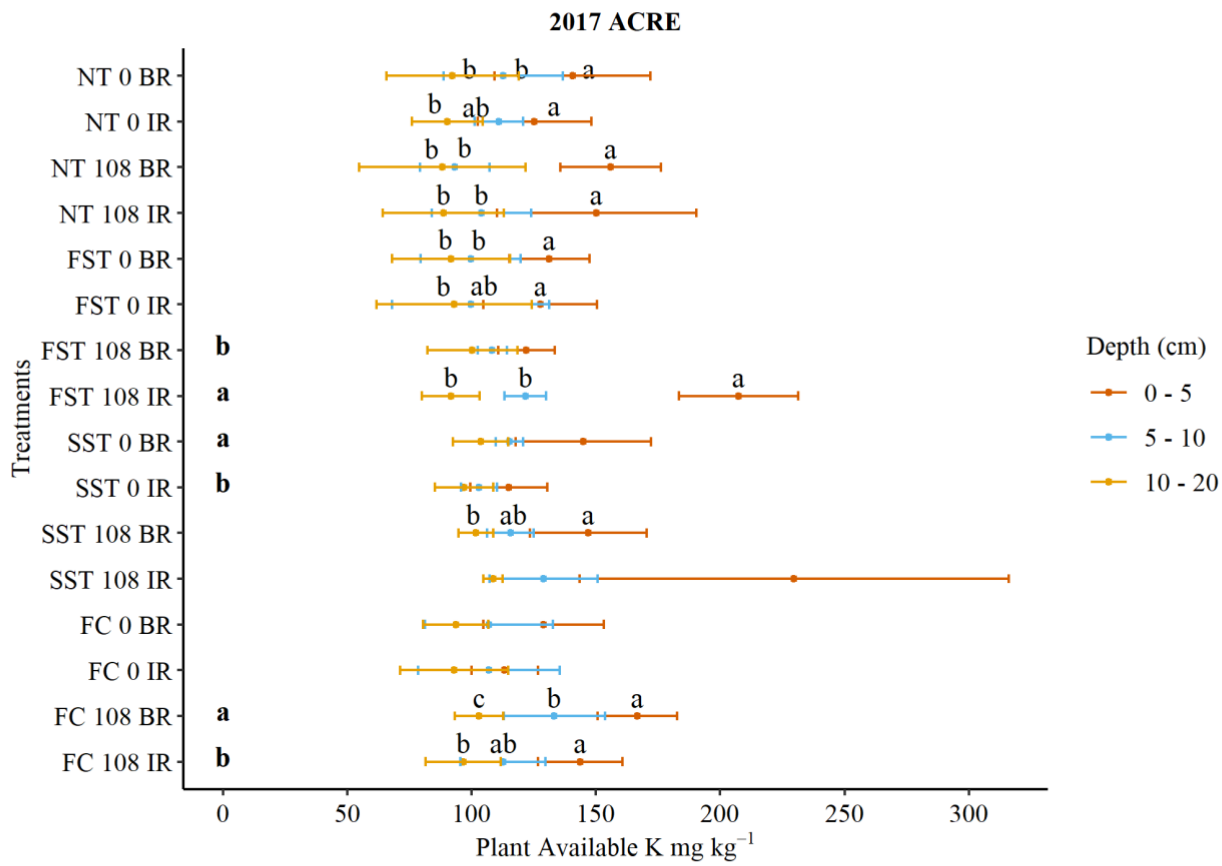

Figure 3.5. Soil sampling results for plant available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth. Dot indicates average for depth increment representing 3 replications. Error bars represent the standard deviation for the individual depth measured. Bold lower-case letters indicate significant differences between sampling position within a treatment across all depths at a significance level of p<0.05. Letters above dots (representing average) indicates significant differences in plant available K concentration within a specific treatment and sampling position at a statistical level of p<0.05.

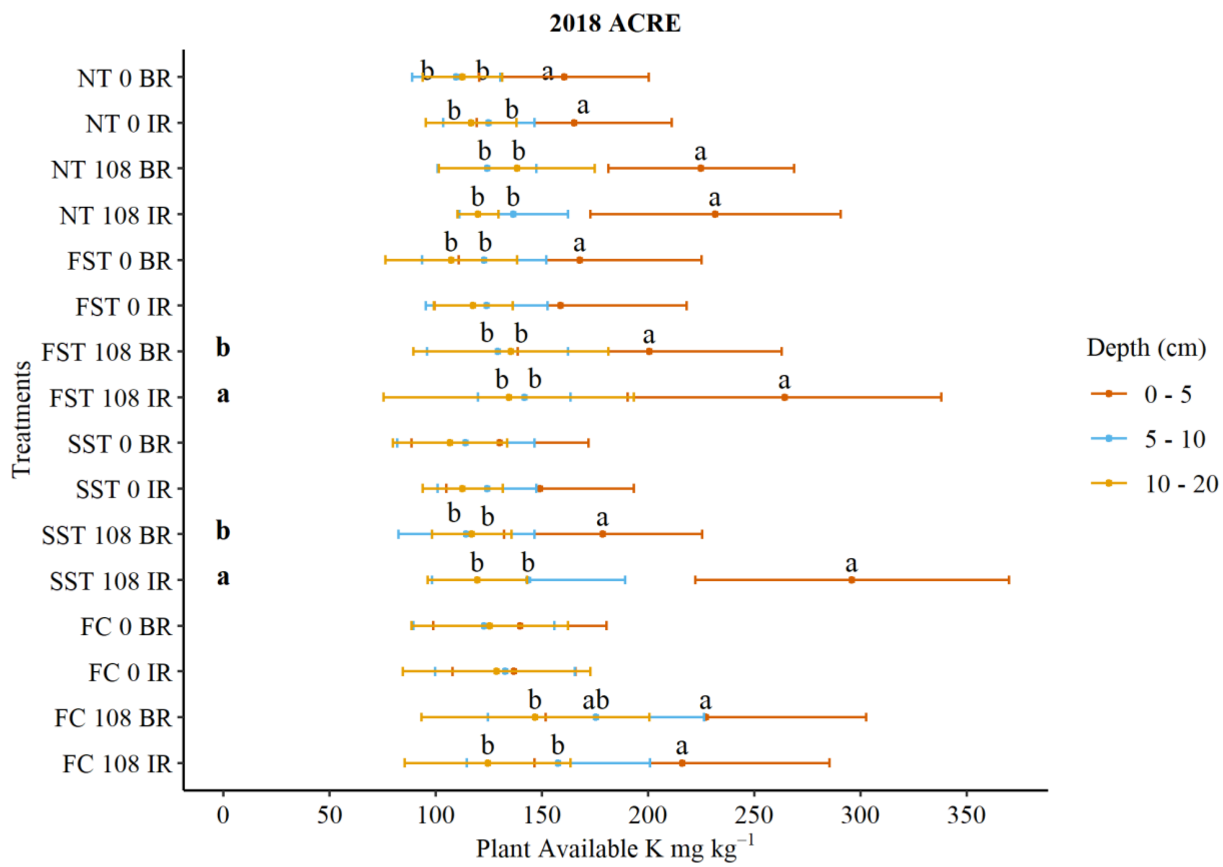

Figure 3.6. Soil sampling results for plant available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth. Dot indicates average for depth increment representing 4 replications. Error bars represent the standard deviation for the individual depth measured. Bold lower-case letters indicate significant differences between sampling position within a treatment across all depths at a significance level of $p<0.05$. Letters above dots (representing average) indicates significant differences in plant available K concentration within a specific treatment and sampling position at a statistical level of $p<0.05$.

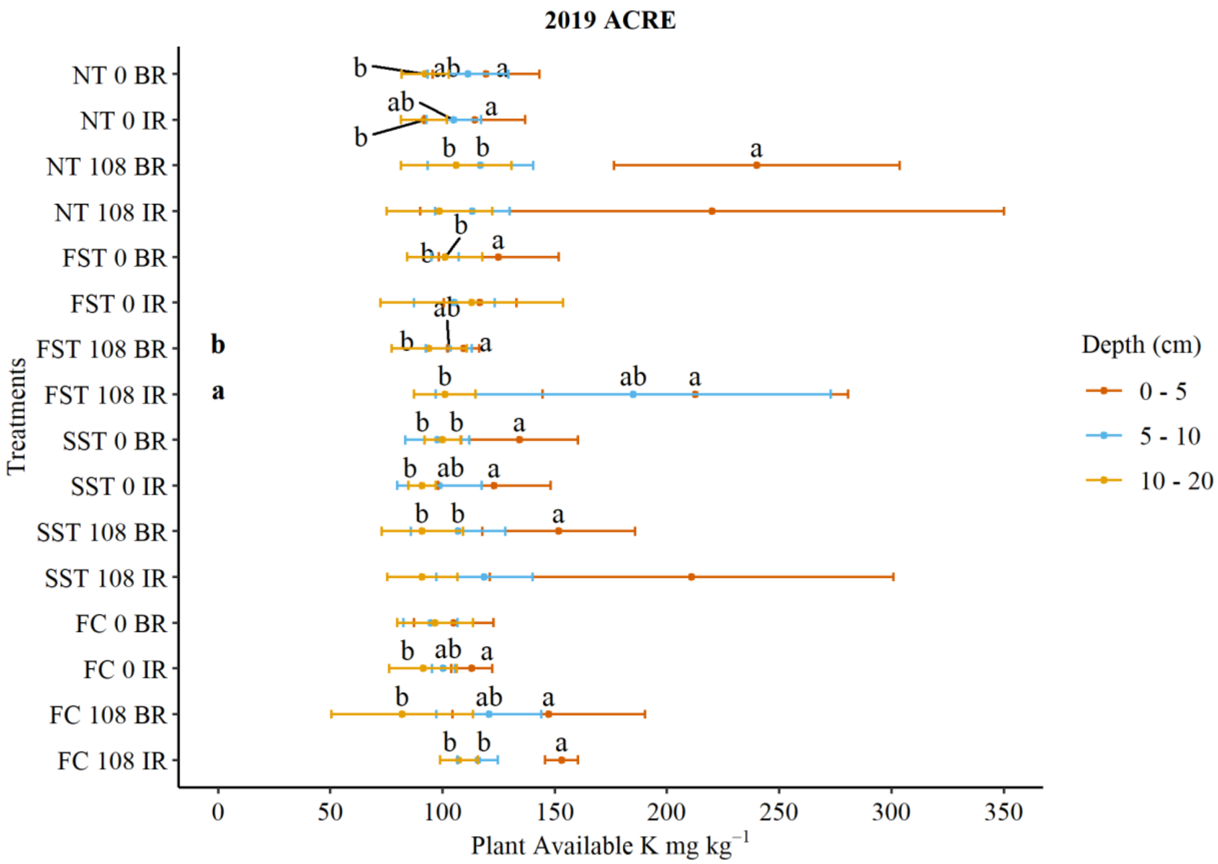

Figure 3.7. Soil sampling results for plant available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth. Dot indicates average for depth increment representing 4 replications. Error bars represent the standard deviation for the individual depth measured. Bold lower case letters indicate significant differences between sampling position within a treatment across all depths at a significance level of p<0.05. Letters above dot (representing average) indicates significant differences in plant available K concentration within a specific treatment and sampling position at a statistical level of p<0.05.

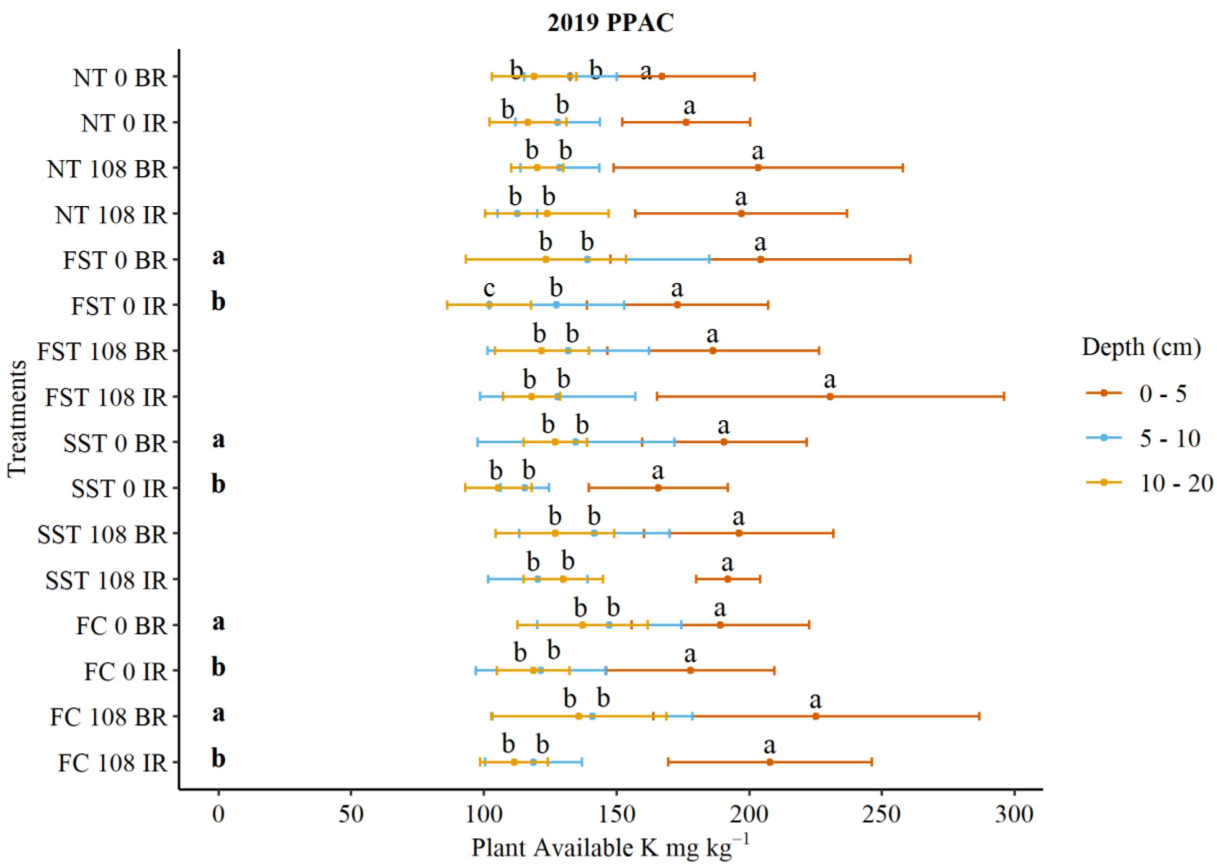

Figure 3.8. Soil sampling results for plant available K stratification by sampling position (IR = In-Row, BR = Between Row) and depth. Dot indicates average for depth increment representing 6 replications. Error bars represent the standard deviation for the individual depth measured. Bold lower-case letters indicate significant differences between sampling position within a treatment across all depths at a significance level of $p<0.05$. Letters above dots (representing average) indicates significant differences in plant available K concentration within a specific treatment and sampling position at a statistical level of $p<0.05$.

the 0 and 108 kg K ha^{-1}, where an increase of 4 and 7 mg K kg^{-1}(FST and SST) were recorded in MY1. When returning to the same field location for MY2, a slightly larger difference was present when comparing the BR position for the 0 and 108 kg K ha^{-1} with concentration differences of 10 and 37 mg K kg^{-1}. The impact of row position on K distribution for the individual strip-till treatments varied in significance, as seen in Figures 3.4 to 3.8, with both the 0 and 108 kg K ha^{-1} rates having some significant differences between row positions.

Unlike the strip-till treatments, and as expected because of the broadcast application, the FC and NT treatments had similar increases in the concentration of the 0-5cm depth following the Aspire™ application for both sampling positions. In the 0-5cm depth for MY1, the FC treatment increased concentrations by 39 and 38 mg K kg^{-1} (BR and IR) following the application of Aspire™, while NT treatments increased by 38 and 32 mg K kg^{-1} (BR and IR) following the application of Aspire™. Concentration differences for both row positions in MY2 were higher than MY1 for the 0-5cm depth for both FC and NT when Aspire™ was applied. The larger differences between MY1 and MY2 for the 0-5cm difference from Aspire™ application could be due to the drawdown of K concentration in the 0 kg K ha^{-1} treatments, the influence of residual K from the Aspire™ applied the initial year, or the influence of both. When comparing the distribution of plant-available K concentration within NT, there was no significant difference between the distribution of IR or BR for any field; however, there was frequently a difference in plant-available K distribution by row position for FC in the 108 kg K ha^{-1} treatments in MY1. The lack of difference in the distribution for FC 108 kg K ha^{-1} in MY2 could be due in part to using a tillage system that mixed across row positions and the residual effects of Aspire™ from MY1.

The vertical distribution of plant-available K among the four tillage systems varied due to the timing (both of tillage and Aspire™ applications) and the amount of residue incorporation. The deposition of crop residue on the surface impacts the K levels as a large amount of K is accumulated in the maize stalk and leaves. Differences in harvest index (HI) influence the amount of K returned to the soil. For example, the HI of maize is slightly above 50% (Bender et al., 2013; Mueller et al., 2019), while the mean soybean HI is ~40% (Bender et al., 2015). Potentially of greater importance is the uptake of K and the location of K within the plant. It is estimated that ~25-45% of total K accumulated in the above-ground portion of maize is removed as grain, while more than 50% of total K uptake accumulated by soybean is removed in the seed (Bender et al., 2015; Rosolem et al., 2021). It should be acknowledged that the amount of K returned to the soil and removed in the grain is variable with cultivar/hybrid, soil K status, and growing conditions (Rosolem et al., 2021). With high amounts of K returned to the soil in residue for maize, soil K stratification will be exacerbated if residue is continually deposited on the soil surface, even though the actual stratification can also vary with the actual mobility of exchangeable K within the soil (Oltmans & Mallarino, 2015).

No-till systems have so little disturbance that crop residue and fertilizer's continued accumulation on the surface frequently leads to more pronounced plant-available K stratification. However, other tillage systems within this experiment (FST, SST, and FC) also frequently showed significant accumulation of K in the top 5cm of soil. Accumulation of K close to the surface and the continual deposition of K close to the surface has been shown by other researchers to lead to stratification with depth in other conservation tillage systems (Howard et al., 1999; Mallarino & Ul-Haq, 1997; Robbins & Voss, 1991; Varsa & Ebelharar, 2000; Vyn et al., 2002; Vyn & Janovicek, 2001). An important consideration when comparing our results to other experiments evaluating change in soil K status is the time span of the study [Howard et al. (1999) = six years compared to our year of establishment or two years following establishment]. Because our experiment took place over a relatively short time (1 or 2 rotations) and row positions were moved, there may not have been enough time or consistent positioning for the difference in row position to develop. Locations used for MY2 had soil samples collected in relation to the rows for the current year and did not consider the location of rows previously used.

A second analysis method of the soil data looked at the difference in plant-available K concentration within a specific soil depth across all tillage/Aspire™ treatments and sample positions (Figures 3.9 to 3.13). The graphics for this analysis show the impact of the strip-till placement on plant-available K concentration and how the shallow fertilizer placements compare to all treatments in the first year of application and the second year of maize following a year of soybean. From this analysis, it was evident the application of Aspire™ significantly increased K concentration mostly in the 0-5cm depth in MY1, but the MY2 locations both showed increases in K concentration in both the 0-5 and 5-10cm depths. The 108 IR FST and 108 IR SST treatments commonly had the highest mean plant-available K concentrations in all site years, but this was frequently not considered different than other tillage, Aspire™, or row position combinations.

Calculating the ratio of plant-available K for 0-5cm:5-10cm (Table 3.4) and 0-5cm:10-20cm (Table 3.5) can provide context regarding the degree of K stratification. A large ratio indicates more K in the surface layer of the soil compared to the lower depths. Stratification ratios for 0-5cm:5-10cm frequently had higher stratification ratios following the application of Aspire™, but no consistent increase in plant-available K concentration was found for a specific row position and tillage combination. The ratios of 0-5cm:10-20cm depth showed a much higher degree of stratification with the highest ratio of 3.56 recorded, compared to a maximum of 2.10 for 0-5cm:5-10cm. The ratio of 0-5cm:10-20cm showed higher amounts of stratification likely due to the high removal of K by roots from the 10-20cm depth and the K being moved to the surface with little reincorporation at that depth. Stratification ratios from Canepa (2007), Holanda et al. (1998), and

Vyn et al. (2002) have similar ranges of ratios to the treatments in this study. Documenting soil status through collecting samples in relation to row position and sample depth provides context for not only the site-specific changes in exchangeable K stratification with or without Aspire™ application.

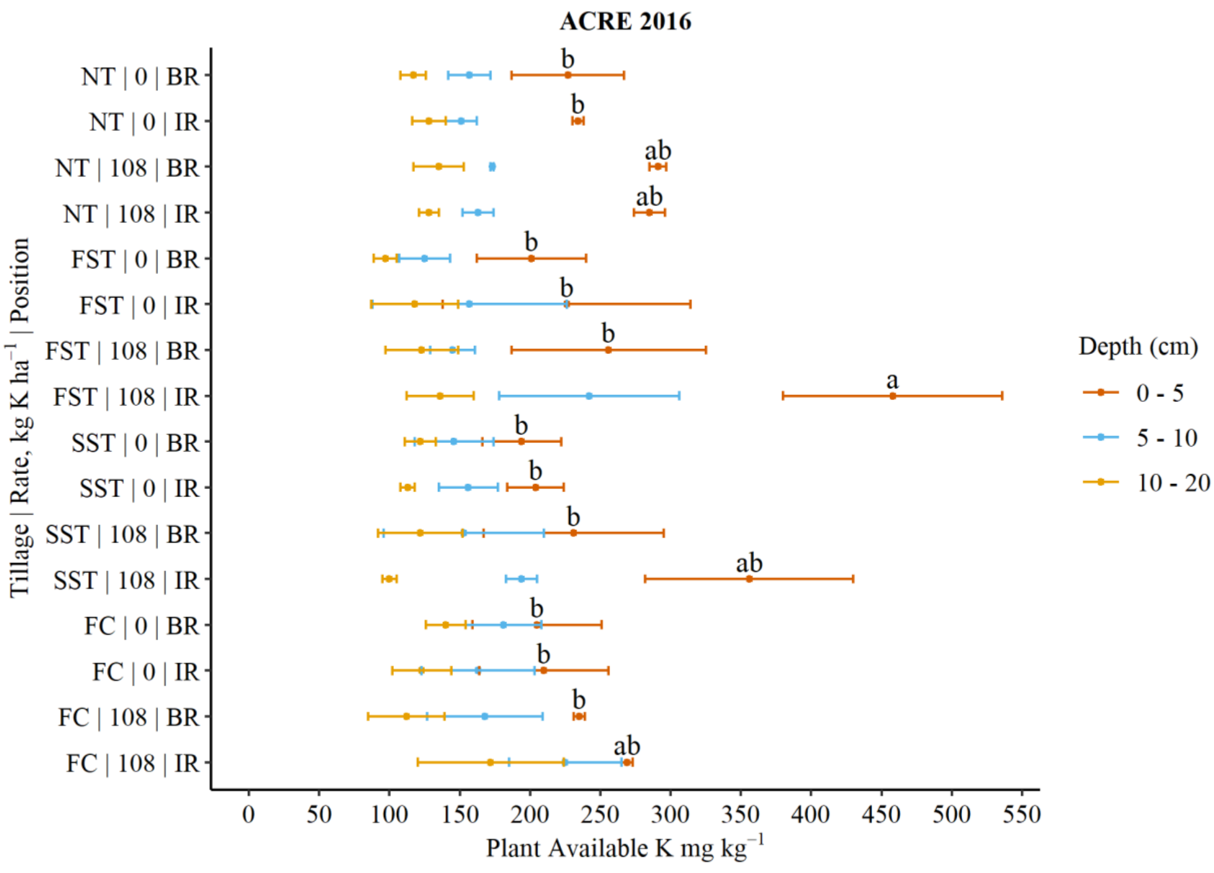

Figure 3.9. Plant available K concentration results for 2016 showing concentration distributions among treatments, sampling position, and sampling depth. Dots indicate averages for depth increment representing 2 replications. Error bars represent the standard deviation for the individual sample depth. Lower-case letters indicate statistical differences among tillage | Aspire™ | row position at a specific sampling depth for statistical significance of $p<0.05$.

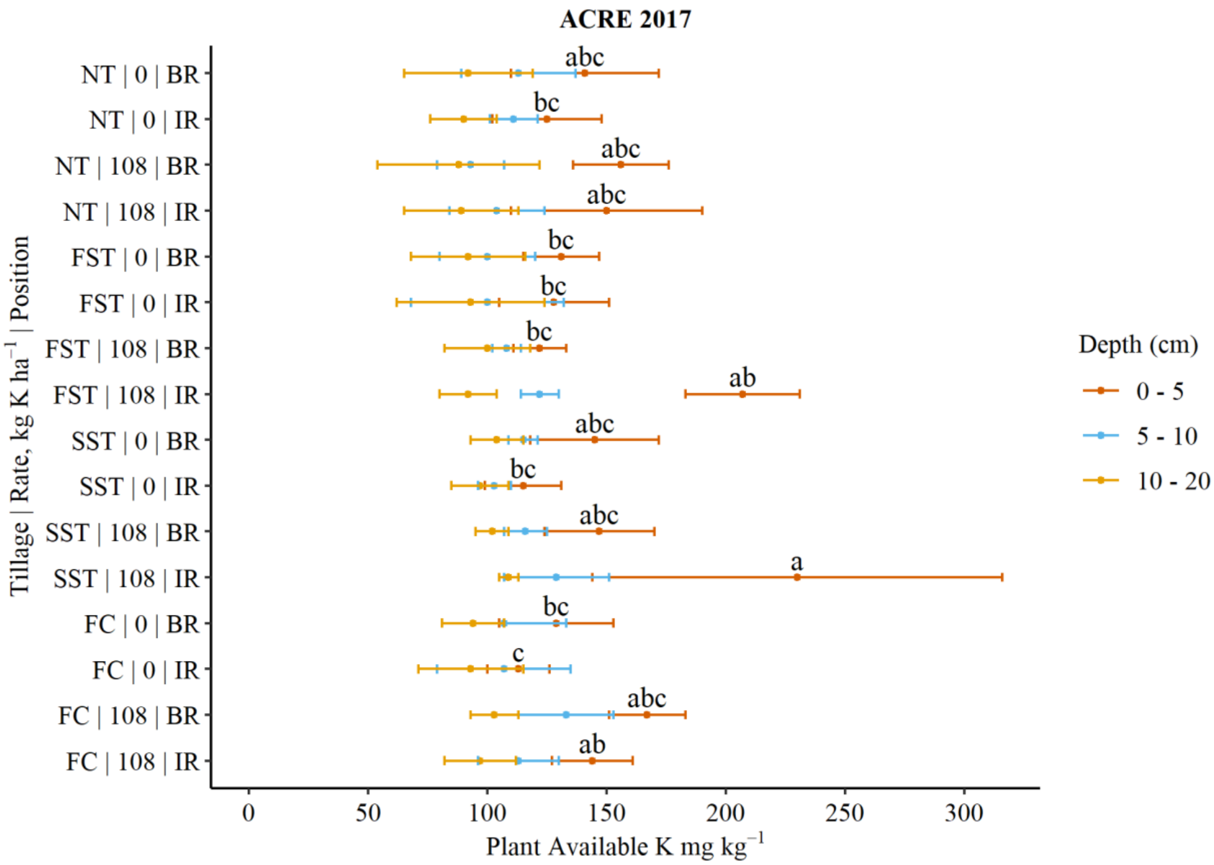

Figure 3.10. Plant available K concentration results for 2017 showing concentration distributions among treatments, sampling position, and sampling depth. Dots indicate average for depth increment representing 3 replications. Error bars represent the standard deviation for the individual sample depth. Lower-case letters indicate statistical differences among tillage | Aspire™ | row position at a specific sampling depth for statistical significance of $p<0.05$.

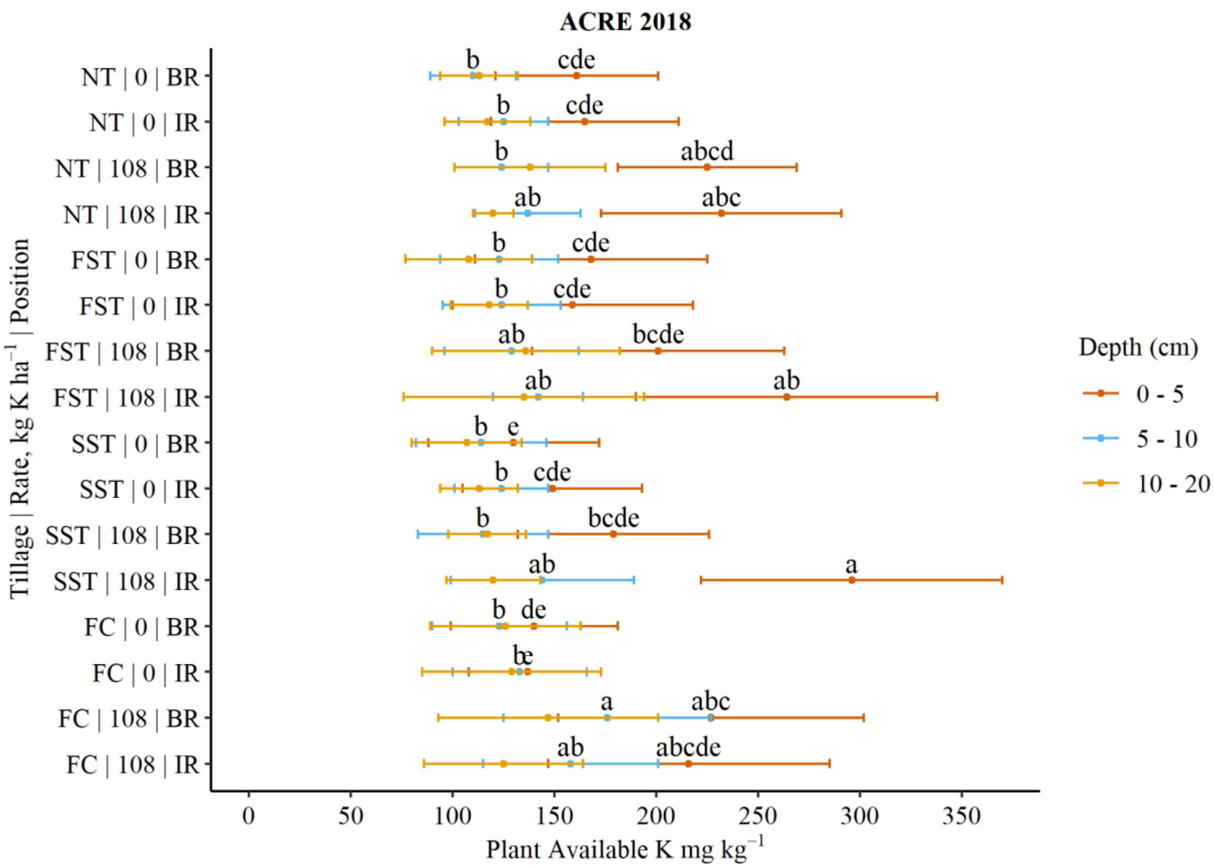

Figure 3.11. Plant available K concentration results for 2018 showing concentration distributions among treatments, sampling position, and sampling depth. Dots indicate average for depth increment representing 4 replications. Error bars represent the standard deviation for the individual sample depth. Lower-case letters indicate statistical differences among tillage | Aspire™ | row position at a specific sampling depth for statistical significance of $p<0.05$.

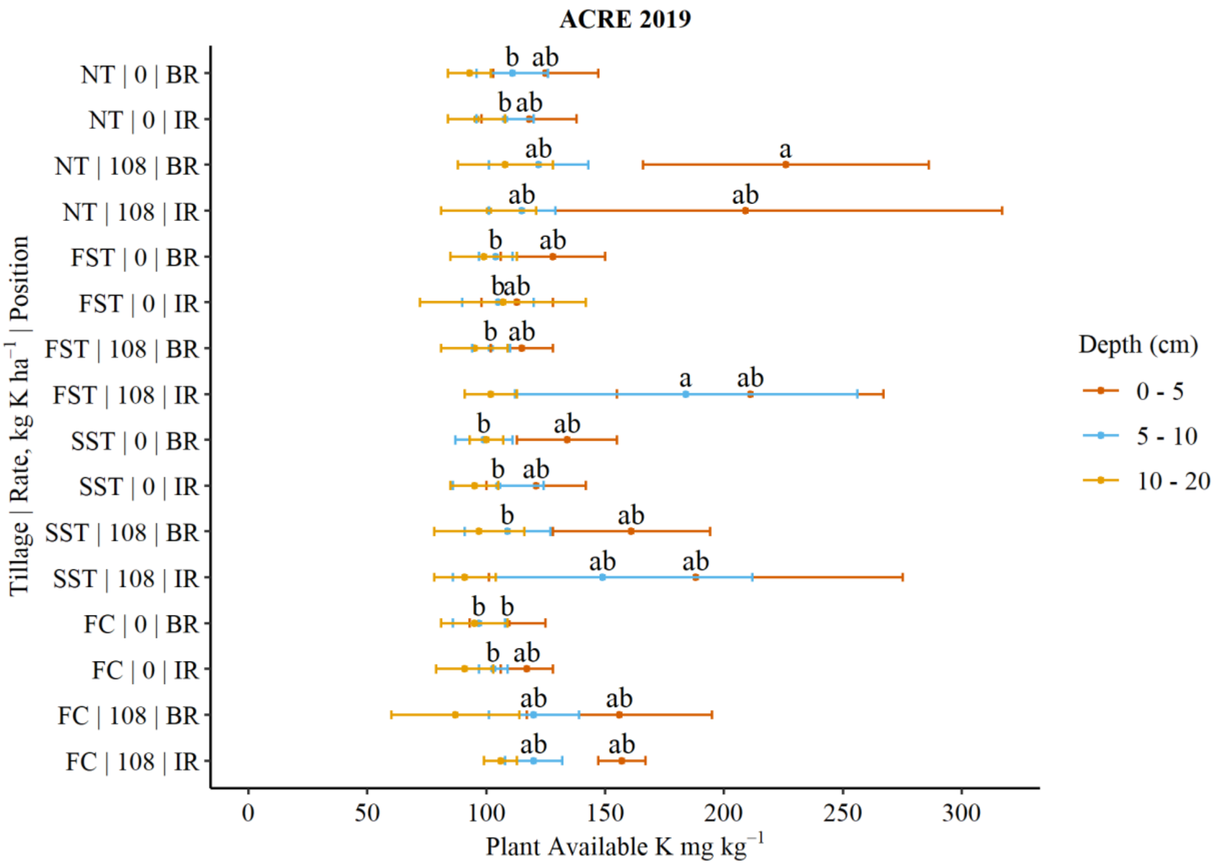

Figure 3.12. Plant available K concentration results for 2019(ACRE) showing concentration distributions among treatments, sampling position, and sampling depth. Dots indicate average for depth increment representing 4 replications. Error bars represent the standard deviation for the individual sample depth. Lower-case letters indicate statistical differences among tillage | Aspire™ | row position at a specific sampling depth for statistical significance of $p<0.05$.

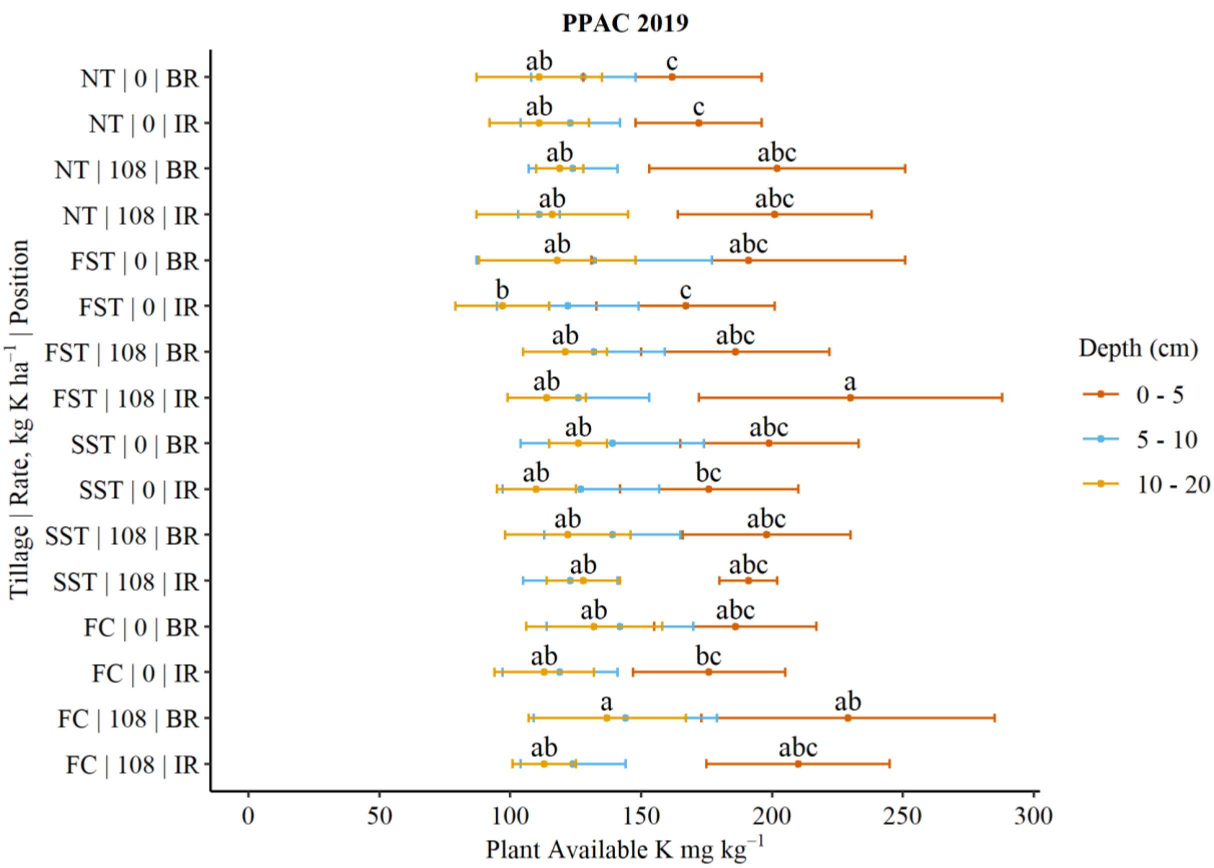

Figure 3.13. Plant available K concentration results for 2019 (PPAC) showing concentration distributions among treatments, sampling position, and sampling depth. Dots indicate average for depth increment representing 6 replications. Error bars represent the standard deviation for the individual sample depth. Lower-case letters indicate statistical differences among tillage | Aspire™ | row position at a specific sampling depth for statistical significance of $p<0.05$.

Table 3.4. Tillage system Aspire™ rate, and row position impacts on the ratio of 0-5cm to 5-10cm soil plant-available K concentration for each year (MY1 = 2016, 2017, 2019(PPAC), MY2 = 2018 and 2019). Mean separation for row position x tillage system x Aspire™ is presented in Table. Different letters indicate statistical differences at $p<0.05$.

				MY1[2]			MY2[2]	
Row Position	Aspire™		Tillage[1]	2016	2017	2019 (PPAC)	2018	2019
	kg K ha^{-1}	kg B ha^{-1}		0-5cm: 5-10cm plant available K concentration ratio				
BR	0	0	NT	1.4 abc	1.3 abc	1.3 d	1.5 bcde	1.1
			FST	1.6 abc	1.3 abc	1.5 abcd	1.4 cdef	1.2
			SST	1.3 abc	1.3 abc	1.5 abcd	1.2 ef	1.4
			FC	1.1 c	1.2 bc	1.3 cd	1.1 ef	1.1
	108	1.1	NT	1.7 abc	1.7 ab	1.6 abcd	1.8 ab	1.9
			FST	1.8 abc	1.1 c	1.4 abcd	1.6 bcd	1.1
			SST	1.5 abc	1.3 abc	1.4 abcd	1.6 bcd	1.5
			FC	1.4 abc	1.3 abc	1.6 abcd	1.3 cdef	1.3
IR	0	0	NT	1.6 abc	1.1 c	1.4 bcd	1.3 cdef	1.1
			FST	1.5 abc	1.3 abc	1.4 cd	1.3 def	1.1
			SST	1.3 abc	1.1 c	1.4 cd	1.2 def	1.2
			FC	1.3 abc	1.1 c	1.5 abcd	1.0 f	1.1
	108	1.1	NT	1.8 abc	1.4 abc	1.8 ab	1.7 bc	1.8
			FST	1.9 a	1.7 ab	1.8 a	1.8 ab	1.4
			SST	1.8 ab	1.7 a	1.6 abcd	2.1 a	1.4
			FC	1.2 bc	1.3 abc	1.7 abc	1.4 cdef	1.3
			Tillage	**	ns	ns	****	ns
			Aspire	***	****	****	****	**
			Tillage*Aspire	ns	ns	ns	**	ns
			Row Position	ns	ns	**	ns	ns
			Tillage*Row Position	ns	**	ns	**	ns
			Aspire*Row Position	ns	**	*	**	ns
			Tillage*Aspire™*Row Position	ns	*	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year

Table 3.5. Tillage system Aspire™ rate, and row position impacts on the ratio of 0-5cm to 10-20cm soil plant-available K concentration for each year (MY1 = 2016, 2017, 2019(PPAC), MY2 = 2018 and 2019). Mean separation for row position x tillage system x Aspire™ is presented in Table. Different letters indicate statistical differences at p<0.05.

				MY1[2]			MY2[2]	
Row Position	Aspire™		Tillage[1]	2016	2017	2019 (PPAC)	2018	2019
	kg K ha^{-1}	kg B ha^{-1}		0-5cm: 10-20cm plant available K concentration ratio				
BR	0	0	NT	1.9 c	1.5 abc	1.5 b	1.4 bcd	1.3 ab
			FST	2.1 c	1.5 bc	1.6 ab	1.6 bcd	1.3 ab
			SST	1.6 c	1.4 bc	1.6 ab	1.2 d	1.3 ab
			FC	1.5 c	1.4 bc	1.4 b	1.1 d	1.2 b
	108	1.1	NT	2.2 c	1.9 abc	1.7 ab	1.7 bcd	2.1 a
			FST	2.1 c	1.3 c	1.5 b	1.5 bcd	1.2 ab
			SST	1.9 c	1.5 bc	1.7 ab	1.5 bcd	1.7 ab
			FC	2.2 c	1.6 abc	1.7 ab	1.6 bcd	1.9 ab
IR	0	0	NT	1.8 c	1.4 bc	1.6 ab	1.4 bcd	1.2 ab
			FST	1.9 c	1.4 bc	1.7 ab	1.3 cd	1.1 b
			SST	1.8 c	1.2 c	1.6 ab	1.3 cd	1.3 ab
			FC	1.7 c	1.2 c	1.6 ab	1.1 d	1.3 ab
	108	1.1	NT	2.2 bc	1.7 abc	1.9 ab	1.9 abc	2.0 ab
			FST	3.4 ab	2.3 a	2.1 a	2.1 ab	2.1 a
			SST	3.6 a	2.1 ab	1.5 b	2.5 a	2.1 a
			FC	1.6 c	1.5 abc	1.9 ab	1.7 bcd	1.5 ab
			Tillage	**	*	ns	ns	ns
			Aspire	****	****	***	****	**
			Tillage*Aspire	ns	ns	ns	ns	ns
			Row Position	**	**	ns	ns	*
			Tillage*Row Position	**	ns	*	ns	ns
			Aspire*Row Position	*	***	**	ns	ns
			Tillage*Aspire™*Row Position	**	ns	*	*	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year

3.4.4 V6 Nutrient Concentration and Uptake

Overall concentration of the nutrients within whole plant V6 samples showed little interaction between tillage systems and Aspire™ applications. Plant N concentrations at V6 for MY2 were decreased overall by 1.1 g N kg^{-1} following the Aspire™ application, and NT overall was at a disadvantage compared to FC (Table 3.7). Tissue P concentrations were highest in the SST treatment and lowest in FST, while both FC and NT were not different than either strip-till timing. Decreased concentration of N or P could be due to dilution associated with a larger amount of above-ground dry matter.

Most tillage systems demonstrated significant positive responses in V6 stage K concentration to the application of Aspire™ in both maize years. Whole plant K concentration was increased by (averaged across the 4 tillage treatments) 5.4 g kg^{-1} and 13.9 g kg^{-1} for MY1 and 2, respectively (Table 3.6 and 3.7). The response to Aspire™ application was consistent in MY2 with all tillage systems having the same significant difference between the 0 and 108 kg K ha^{-1} Aspire™ rates. Interestingly, although tillage and Aspire™ are significant, they do not interact with one another in MY1 (Table 3.6). Various authors have recorded tissue K levels early in the growing season (at V6); some also recommended optimal levels for nutrients at that growth stage. A previous study by Walker and Peck (1975) suggested optimum K concentration for maize at V6 was 39.8 g kg^{-1}, but more recent work by Mallarino and Higashi (2009) emphasized the unreliability of predicting grain yield from K concentration early in the growing season, thus making determination of an optimum level difficult. Although the optimal level of plant tissue K at this early growth stage is debatable, the K concentrations recorded in this work are similar to levels published by other researchers (Borges & Mallarino, 1998; Walker & Peck, 1975).

When applying K, antagonism among positively charged cations (i.e. Ca and Mg) is common and has the potential to influence plant nutrient concentration and content at V6 (as discussed previously in Chapters 1 and 2). The interaction of tillage and Aspire™ in Ca concentration for MY1 is unclear as there was no discernable pattern. MY2 results showed antagonism among K, Mg and Ca following the application of Aspire™, with the overall Ca and Mg concentrations decreasing by 0.5 and 1.4 g kg^{-1} , respectively (Table 3.7). Both Ca and Mg were significantly influenced by tillage in MY2, with Ca having noticeable differences among tillage treatments. The reason for the latter differences are unclear. No interaction was detected between tillage and Aspire™ application, indicating that any reductions of Ca and Mg uptake in the presence of a recent Aspire™ application are unlikely to be impacted by a tillage system.

Because Aspire™ fertilizer contains both K and B, the impacts of its application on B concentration is an important consideration even at V6. Similar to K, an early-season critical concentration for B has also been investigated by previous researchers. Gupta (1983) noted that Neubert (1970) suggested a minimum concentration of total above-ground dry matter of 9 mg B kg^{-1} prior to tassel emergence for maize, but little detail was provided as to the most appropriate vegetative stage for sampling (i.e. it is unclear if this is by V6 or another vegetative stage). Tissue B concentrations at V6 were considerably higher in MY1 (average of all treatments= ~8 mg B kg^{-1}) compared to MY2 (average of all treatments= ~4 mg B kg^{-1}) (Tables 3.6 and 3.7). Overall, Aspire™ applications significantly increased the concentration of B. An interaction between tillage and Aspire™ was detected in MY1, potentially indicating the placement of Aspire™ near the crop row using strip-till may be advantageous for increasing B concentrations early in the growing season. Although MY1 results show some promise of a positive tissue concentration

Table 3.6. Tillage system and Aspire™ rate impacts on whole plant V6 nutrient concentration for N, P, K, Ca, Mg, B, and N:K ratio for MY1 (2016, 2017, and 2019(PPAC)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]						
Tillage[1]	Aspire™		N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}					mg kg^{-1}	1:1
NT	0	0	32.4	4.3	28.5 bc	4.8 ab	4.9 ab	7 c	1.3 abc
	108	1.1	34.3	4.4	31.5 abc	5.5 a	5.4 ab	8 bc	1.2 abc
FST	0	0	36.8	4.4	27.9 c	5.0 ab	5.1 ab	7 c	1.6 a
	108	1.1	34.4	4.3	34.7 ab	4.4 b	3.9 b	10 a	1.1 bc
SST	0	0	34.5	4.5	29.0 c	4.8 ab	5.3 a	7 c	1.5 ab
	108	1.1	35.3	4.6	35.7 a	5.4 a	5.0 ab	9 ab	1.1 bc
FC	0	0	35.2	4.5	31.7 abc	4.8 ab	4.9 ab	7 c	1.2 abc
	108	1.1	34.7	4.6	36.8 a	4.8 ab	4.6 ab	8 bc	1.0 c
NT			33.4	4.3	30.0 b	5.1	5.2	7 b	1.2
FST			35.6	4.3	31.3 ab	4.7	4.5	8 a	1.3
SST			34.9	4.6	32.4 ab	5.1	5.2	8 ab	1.3
FC			34.9	4.6	34.3 a	4.8	4.7	7 b	1.1
	0	0	34.7	4.4	29.3 b	4.9	5.0	7 b	1.4 a
	108	1.1	34.7	4.5	34.7 a	5.0	4.7	9 a	1.1 b
Site Year			ns	***	****	***	***	***	***
Tillage			ns	*	*	ns	ns	**	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	****	ns	ns	****	****
Site Year*Aspire™			ns	ns	ns	ns	ns	****	**
Tillage*Aspire™			ns	ns	ns	**	ns	*	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table 3.7. Tillage system and Aspire™ rate impacts on whole plant V6 nutrient concentration for N, P, K, Ca, Mg, B, and N:K ratio for MY2 (2018 and 2019(ACRE)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY2[2]						
Tillage[1]	Aspire™		N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	———— g kg^{-1} ————					mg kg^{-1}	1:1
NT	0	0	39.2 ab	4.3 ab	21.0 b	5.2 a	6.4 ab	3 bc	2.1 a
	108	1.1	37.2 b	4.1 ab	33.1 a	5.0 a	5.3 abcd	5 a	1.2 b
FST	0	0	39.1 ab	4.0 ab	21.0 b	5.1 a	6.0 abc	3 bc	2.3 a
	108	1.1	39.4 ab	3.9 b	33.4 a	4.2 b	4.1 d	4 ab	1.2 b
SST	0	0	39.9 ab	4.5 a	19.9 b	5.2 a	6.7 a	2 c	2.4 a
	108	1.1	39.2 ab	4.0 ab	36.3 a	4.8 ab	5.0 bcd	5 a	1.2 b
FC	0	0	41.2 a	4.1 ab	23.7 b	5.1 a	5.8 abc	3 bc	1.9 a
	108	1.1	39.3 ab	4.2 ab	38.4 a	4.6 ab	4.5 cd	4 a	1.1 b
NT			38.2 b	4.2 ab	27.0	5.1 a	5.8	4	1.7
FST			39.3 ab	3.9 b	27.2	4.7 b	5.1	3	1.8
SST			39.6 ab	4.3 a	28.1	5.0 ab	5.8	4	1.8
FC			40.3 a	4.1 ab	31.1	4.9 ab	5.2	4	1.5
	0	0	39.9 a	4.2	21.4 b	5.2 a	6.2 a	3 b	2.2 a
	108	1.1	38.8 b	4.1	35.3 a	4.7 b	4.8 b	5 a	1.2 b
Site Year			****	*	**	***	**	**	***
Tillage			*	*	ns	*	*	ns	ns
Site Year*Tillage			ns	*	ns	ns	ns	ns	ns
Aspire™			*	ns	****	****	****	****	****
Site Year*Aspire™			ns	**	ns	ns	ns	ns	****
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

response to optimal placement of B using FST following an Aspire™ application, the MY2 results do not show the same interaction.

Collecting dry matter information can provide additional insight into plant health at V6 by adding the additional dimension of plant size. Fertilization with Aspire™ did not influence V6 dry matter accumulation in either maize year (Tables 3.8 and 3.9). Although there was no interaction between tillage and Aspire™ for accumulated dry matter in either maize year, SST and NT commonly were not different in dry matter accumulation. Several prior studies showed a lack of overall dry matter response to K applications (Heckman & Kamprath, 1992; Mallarino et al., 1999; Vyn et al., 2002). Mallarino et al. (1999) investigated the influence of fertilizer incorporation (i.e., broadcast, shallow banding, and deep banding) on early plant growth and development and concluded from multiple locations that K applications and placement (deep or shallow banding) often did not interact with one another or impact early season growth (similar to the data presented here).

Nutrient content responses at V6 to treatments varied. The uptake of N and P at V6 was predominantly unaffected by interactions between an Aspire™ application and tillage (except for MY2 P content). Aspire™ application didn't increase N and P contents in the SST and NT systems.

Total K uptake at V6 was influenced by both tillage and Aspire™ application (separately) for both MY1 and MY2, but in MY2 there was an interaction between tillage and the Aspire™ application (Table 3.8 and 3.9). Fall tillage systems appeared to have an advantage in K uptake similar to the advantages seen for V6 dry matter. Similar to previous K experiments that utilized muriate of potash, the K concentration and content appeared to increase following an Aspire™ application early in the growing season.

Table 3.8. Tillage system and Aspire™ rate impacts on V6 whole plant dry matter and nutrient content for N, P, K, Ca, Mg, B, and N:K ratio for MY1 (2016, 2017, and 2019(PPAC)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]							
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	——————————— kg ha^{-1} ———————————						g ha^{-1}	1:1
NT	0	0	364 ab	11.8	1.5 ab	10.1 b	1.8	1.8	2 b	1.3 abc
	108	1.1	351 b	12.0	1.5 b	10.7 b	2.0	2.0	3 b	1.2 abc
FST	0	0	400 ab	14.7	1.8 ab	11.0 b	2.0	2.1	3 b	1.6 a
	108	1.1	463 a	15.9	2.0 ab	15.5 a	2.1	2.0	4 a	1.1 bc
SST	0	0	364 ab	12.5	1.7 ab	10.6 b	1.7	1.9	2 b	1.5 ab
	108	1.1	364 b	12.8	1.7 ab	12.9 ab	2.0	1.9	3 b	1.1 bc
FC	0	0	392 ab	13.7	1.8 ab	12.4 ab	1.9	1.9	3 b	1.2 abc
	108	1.1	442 ab	15.3	2.0 a	16.0 a	2.1	2.0	3 b	1.0 c
NT			358 b	11.9 b	1.5 b	10.4 c	1.9	1.9	3 b	1.2
FST			432 a	15.3 a	1.9 ab	13.3 ab	2.1	2.0	4 a	1.3
SST			364 b	12.7 ab	1.7 ab	11.7 bc	1.9	1.9	3 b	1.3
FC			417 ab	14.5 a	1.9 a	14.2 a	2.0	2.0	3 ab	1.1
	0	0	380	13.2	1.7	11.0 b	1.8	1.9	3 b	1.4 a
	108	1.1	405	14.0	1.8	13.8 a	2.0	2.0	3 a	1.1 b
Site Year			***	**	****	***	***	****	***	***
Tillage			**	**	*	***	ns	ns	***	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	****	ns	ns	****	****
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	**
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	*	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table 3.9. Tillage system and Aspire™ rate impacts on V6 whole plant dry matter and nutrient content for N, P, K, Ca, Mg, B, and N:K ratio for MY2 (2018 and 2019(ACRE)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]							
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	——— kg ha^{-1} ———						g ha^{-1}	1:1
NT	0	0	507 ab	19.9 ab	2.2 ab	10.3 d	2.7	3.3	1 bc	2.1 a
	108	1.1	472 b	17.7 b	1.9 b	14.6 cd	2.4	2.6	2 ab	1.2 b
FST	0	0	560 ab	21.9 ab	2.2 ab	11.0 d	2.9	3.5	1 bc	2.3 a
	108	1.1	682 a	26.9 a	2.7 ab	22.1 ab	2.9	2.9	3 a	1.2 b
SST	0	0	532 ab	21.4 ab	2.4 ab	10.3 d	2.8	3.6	1 c	2.4 a
	108	1.1	503 ab	19.7 ab	2.0 b	18.0 bc	2.4	2.5	3 a	1.2 b
FC	0	0	549 ab	22.6 ab	2.2 ab	12.4 cd	2.9	3.3	1 bc	1.9 a
	108	1.1	688 a	27.1 a	2.9 a	25.9 a	3.2	3.2	3 a	1.1 b
NT			489 b	18.8 b	2.0 b	12.5 c	2.5	2.9	2	1.7
FST			621 a	24.4 a	2.4 ab	16.6 ab	2.9	3.2	2	1.8
SST			517 ab	20.6 ab	2.2 ab	14.1 bc	2.6	3.1	2	1.8
FC			619 a	24.9 a	2.6 a	19.2 a	3.0	3.2	2	1.5
	0	0	537	21.5	2.3	11.0 b	2.8	3.4 a	1 b	2.2 a
	108	1.1	586	22.9	2.4	20.2 a	2.7	2.8 b	3 a	1.2 b
Site Year			*	**	ns	ns	**	**	*	***
Tillage			**	**	*	***	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	****	ns	**	****	****
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	****
Tillage*Aspire™			ns	ns	*	**	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Uptake of B is important to the development of maize reproductive organs (discussed in Chapter 1). Similar to B concentration responses, B content in MY1 seemed to be slightly higher than MY2 (Tables 3.6 through 3.9). Both tillage and Aspire™ affected B content, and the tillage x Aspire™ interaction was significant ($p<0.05$) in MY1. Plant B content was increased only in the FST system following the application of Aspire™ in MY1 (Table 3.8). Overall tillage comparisons in MY1 (averaged across Aspire™ rates) showed FST had the highest B uptake, although FST was not different than FC. Relatively consistent increases in uptake following the application of Aspire™ for FST, SST, and FC were seen in MY2, contributing to the significant overall increase in B content (of ~2 g B ha^{-1}) following the application of Aspire™.

3.4.5 Physical Measurements and Flowering Notes

A variety of physical measurements were collected throughout the growing season to better understand if plant morphology or flowering were affected by tillage, Aspire™, or the combination of tillage and Aspire™ (Tables 3.10 and 3.11). Although Aspire™ includes both K and B, similar responses to physical measurements taken in this experiment were recorded by other researchers of those individual nutrients.

Height measurements were taken exclusively in 2019 at the ACRE location after a visual height was noticed at V8. Height measurements collected at V8 showed the 0 kg K ha^{-1} Aspire™ treatment across all tillage systems were 6cm (19.4%) shorter than corresponding treatments fertilized with 108 kg K ha^{-1}; however, there was no interaction between the Aspire™ application and tillage (Table 3.10). Later final plant heights collected from other plants within each plot at R1 confirmed once again that plant heights had no interaction between the application of Aspire™ and tillage system. The treatments that did not receive Aspire™ were still significantly shorter overall by ~19cm (9.3%) across all tillage systems at the final height measurement. The application of K (across all application rates of K) was shown by Pettigrew and Meredith (1997) to increase the height of cotton by ~3% when flowering and vegetative growth began to slow. Our use of an alternative K source retained the consequence of taller plant stature from a K application.

Leaf area index (LAI) differences varied each time measurements were collected (Table 3.10). LAI measurements taken at V14 in MY1 were influenced by both tillage and Aspire™ (no interaction between them). The FC treatment achieved 15% greater LAI compared to FST, although the LAI with NT and SST was not different from either FC or FST. The sources of the differences between the tillage systems are unclear, as the later LAI measurement (R2 stage) and MY2 results do not show any influences of tillage.

The application of Aspire™ consistently increased LAI for V14 and R2 in both maize years (Table 3.10). In MY1, Aspire™ applications increased LAI at V14 by 10% and LAI at R2 by 6%. In MY2, Aspire™ applications increased LAI by 11% at V14 and by 9% at R2. In addition to height differences, Pettigrew and Meredith (1997) also observed a 14% increase in LAI following the application of K upon reaching cutout [reached when the uppermost white flower is 5 nodes down from the terminal bud (Byrd, 2017)]slightly higher than the data presented in this chapter. Our results agree with the review by Pettigrew (2008) of several papers (e.g. Jordan-Meille and Pellerin 2004, Kimbrough et al. 1971, Pettigrew and Meredith 1997) that noted a general reduction in LAI with K deficiency for maize and other species (i.e. cotton and alfalfa).

Tracking of anthesis and silking progression was performed yearly (except for 2016), and these results confirmed the expected delay in reaching 50% anthesis and silking in the NT system (Table 3.11). Tillage and Aspire™ interacted with one another at tassel (only for MY1) and silking (both MY1 and 2), indicating Aspire™ could have influenced the time needed for maize to reach reproductive growth stages differently among tillage systems. MY1 showed an

Table 3.10. Tillage system and Aspire™ rate impacts on V14 LAI for MY1 (2016 and 2017) and MY2 (2019(ACRE)), and R2 LAI for MY1 (2016 and 2017) and MY2 (2018). V8 height and final height at R1 exclusively performed in 2019 (ACRE). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]		MY2[2]			
Tillage[1]	Aspire™		V14 LAI	R2 LAI	V8 Height	R1 Height	V14 LAI	R2 LAI
	kg K ha^{-1}	kg B ha^{-1}			cm	cm		
NT	0	0	3.49 ab	4.12	31 ab	205 ab	4.22	4.44 b
	108	1.1	3.71 ab	4.32	35 ab	222 ab	4.30	4.58 ab
FST	0	0	3.34 b	3.99	32 ab	205 ab	3.79	4.70 ab
	108	1.1	3.41 ab	4.08	39 a	228 a	4.61	4.62 ab
SST	0	0	3.51 b	3.91	30 b	202 b	3.51	4.49 ab
	108	1.1	3.87 ab	4.30	36 ab	224 ab	4.21	4.91 ab
FC	0	0	3.54 ab	4.17	32 ab	207 ab	4.04	4.15 b
	108	1.1	4.17 a	4.36	37 ab	223 ab	4.28	5.36 a
NT			3.60 ab	4.22	33	214	4.26	4.51
FST			3.37 b	4.03	35	217	4.25	4.66
SST			3.69 ab	4.11	33	213	3.86	4.70
FC			3.88 a	4.27	35	215	4.15	4.69
	0	0	3.47 b	4.04 b	31 b	205 b	3.92 b	4.43 b
	108	1.1	3.81 a	4.27 a	37 a	224 a	4.36 a	4.84 a
Site Year			***	**				
Tillage			*	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns				
Aspire™			**	*	***	****	**	**
Site Year*Aspire™			ns	ns				
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns				

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel

[2] MY = maize year

* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

interaction among site year, tillage and Aspire™ which is expanded upon in Appendix B Table B.29.

A short time interval between anthesis and silking (ASI) is essential to ensure that pollen shed occurs when receptive silks have been extruded from the husk. In MY1, neither tillage nor Aspire™ significantly influenced the ASI (Table 3.11). In contrast to MY1, detectable ASI differences due to the tillage systems were observed in MY2. Some values in MY2 were negative, indicating silking occurred before tasseling (such as -1.0 day ASI in the unfertilized control of FST), yet FC demonstrated a positive ASI. The fertilized FC treatment had the shortest ASI of only 0.1 days in MY2. Tillage system, but not Aspire™ fertilization, significantly influenced ASI.

Adequate K supplies have been shown in previous research to be important to synchronizing pollen shed and silk extrusion during hot and dry weather conditions (Armstrong & Griffin, 1998). Silking occurring close to pollen shed helps ensure successful pollination of kernels. Another benefit of K fertility and synchronization of flowering is the potential to lengthen the grain filling period (Armstrong & Griffin, 1998). Extended grain filling periods could potentially lead to higher kernel weights. The dataset presented in this chapter does not provide definitive evidence K additions in any of the conservation tillage systems improved the synchronization of anthesis and silking. Previous Canadian research has shown tillage systems can influence silking timing (similar to the time differences seen among the tillage systems in this experiment) (Vyn & Raimbault, 1992, 1993); however, to our knowledge, no prior research has documented the influence of Aspire™ and tillage on ASI.

Table 3.11. Tillage system and Aspire™ rate impacts on V14 LAI for MY1 (2016 and 2017) and MY2 (2019(ACRE)), and R2 LAI for MY1 (2016 and 2017) and MY2 (2018). V8 height and final height at R1 exclusively performed in 2019 (ACRE). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]			MY2[2]		
Tillage[1]	Aspire™		Anthesis to 50%	Silking to 50%	ASI to 50%	Anthesis to 50%	Silking to 50%	ASI to 50%
	kg K ha^{-1}	kg B ha^{-1}	days			days		
NT	0	0	72 ab	71 bc	1.7	67 ab	68 ab	-0.8 bc
	108	1.1	74 a	73 a	1.2	68 a	69 a	-0.9 bc
FST	0	0	72 b	70 c	2.0	67 ab	68 ab	-1.0 c
	108	1.1	71 b	70 c	1.7	66 b	67 b	-0.3 abc
SST	0	0	72 b	70 bc	1.6	68 ab	68 ab	-0.4 abc
	108	1.1	72 ab	71 ab	1.0	68 ab	68 ab	-0.4 abc
FC	0	0	72 b	70 bc	2.0	68 ab	67 b	0.5 a
	108	1.1	71 b	70 c	1.7	68 ab	67 b	0.1 ab
NT			73 a	72 a	1.4	68 a	69 a	-0.8 b
FST			71 b	70 c	1.8	67 b	67 b	-0.6 b
SST			72 b	71 b	1.3	68 a	68 ab	-0.4 ab
FC			72 b	70 c	1.8	68 a	67 b	0.3 a
	0	0	72	70 b	1.8	67	68	-0.4
	108	1.1	72	71 a	1.4	67	68	-0.4
Site Year			****	****	***	****	****	**
Tillage			****	****	ns	**	***	***
Site Year*Tillage			ns	ns	ns	ns	ns	ns
Aspire™			ns	*	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	**	ns	ns	ns
Tillage*Aspire™			*	*	ns	ns	*	ns
Site Year*Tillage*Aspire™			*	*	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

3.4.6 R1 Nutrient Concentration and Specific Leaf Content

The nutritional status within the maize plant at R1 has been utilized in previous research as a predictor of maize grain yield. Our earleaf sample collection method allowed for both the measurement of nutrient concentrations and specific leaf contents. All earleaf samples from MY1 locations had adequate concentrations of N and P [i.e., N and P concentrations above 29.0 and 3.0 g kg^{-1}, respectively (Vitosh et al., 1995)], with no interactions between tillage and Aspire™ (Table 3.12). In MY2, there was no detectable treatment variation in earleaf N concentration, but overall concentrations were lower, and some treatments appeared deficient (N concentration below 29.0 g kg^{-1}) (Table 3.13). In both years, earleaf P concentrations surpassed the critical level in the Tri-State Fertilizer Recommendations (Vitosh et al., 1995).

Because Aspire™ is predominantly comprised of K, the influence of Aspire™ on K nutrition of the plant at R1 is of most importance. Earleaf K concentration within MY1 was increased 3.3 g kg^{-1} following the application of Aspire™ (19% increase), bringing maize above the recommended critical level of 19.0 g kg^{-1} (Vitosh et al., 1995) (Table 3.12). The earleaf K concentrations in MY2 showed similar trends with a consistent increase following the Aspire™ application across all tillage systems (Table 3.13). Overall, earleaf K concentration increased 4.8 g kg^{-1} for MY2 (a 27% gain), bringing concentrations above the critical level. Response in K concentration to the application of Aspire™ was similar for all tillage systems for both maize years with no interactions between tillage and Aspire™ rate (Tables 3.12 and 3.13), similar to other previous research (Vyn et al., 2002; Vyn & Janovicek, 2001). Soil test levels were close to or above the critical concentration (calculated using the Tri-State Fertilizer Recommendations), therefore not apparently limiting to grain yield (Table 3.1). The consistent response in K concentration to Aspire™ applications suggests the soil K resources alone were not enough to meet potential K

Table 3.12. Tillage system and Aspire™ rate impacts on maize nutrient concentration of the earleaf at R1 for N, P, K, Ca, Mg, B, and N:K ratio for MY1 (2016, 2017, and 2019(PPAC)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]						
Tillage[1]	Aspire™		N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	———— g kg^{-1} ————					mg kg^{-1}	1:1
NT	0	0	31.4	3.6	17.7 bc	4.6	3.6 ab	5 b	1.8 ab
	108	1.1	31.2	3.4	21.4 a	4.6	3.4 ab	8 a	1.5 c
FST	0	0	31.8	3.5	17.1 c	4.7	3.6 ab	5 b	2.0 a
	108	1.1	30.8	3.4	19.9 ab	4.5	3.3 ab	6 ab	1.6 bc
SST	0	0	30.5	3.6	18.0 bc	4.4	3.7 a	5 b	1.7 abc
	108	1.1	31.3	3.5	21.5 a	4.4	3.2 ab	7 ab	1.5 c
FC	0	0	31.7	3.5	18.0 bc	4.3	3.5 ab	5 b	1.8 ab
	108	1.1	31.6	3.5	21.3 a	4.3	3.0 b	6 ab	1.5 c
NT			31.3	3.5	19.6	4.6	3.5	6	1.7 ab
FST			31.3	3.5	18.5	4.6	3.4	6	1.8 a
SST			30.9	3.6	19.8	4.4	3.5	6	1.6 b
FC			31.7	3.5	19.7	4.3	3.3	6	1.7 ab
	0	0	31.4	3.6	17.7 b	4.5	3.6 a	5 b	1.8 a
	108	1.1	31.2	3.5	21.0 a	4.4	3.2 b	7 a	1.5 b
Site Year			**	****	***	**	**	**	**
Tillage			ns	ns	ns	ns	ns	ns	*
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	****	ns	***	***	****
Site Year*Aspire™			ns	ns	ns	**	***	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table 3.13. Tillage system and Aspire™ rate impacts on maize nutrient concentration of the earleaf at R1for N, P, K, Ca, Mg, B, and N:K ratio for MY2 (2018 and 2019(ACRE)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]						
Tillage[1]	Aspire™		N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	——— g kg^{-1} ———					mg kg^{-1}	1:1
NT	0	0	28.3	3.6	18.9 b	5.3	5.1 ab	3 bc	1.6 abc
	108	1.1	28.7	3.4	23.1 a	4.9	4.4 ab	6 ab	1.3 c
FST	0	0	29.1	3.5	18.4 b	5.0	5.0 ab	4 abc	1.7 abc
	108	1.1	29.4	3.4	22.8 a	4.7	4.3 b	5 abc	1.3 c
SST	0	0	29.2	3.7	17.6 b	5.3	5.7 a	3 c	1.9 a
	108	1.1	28.6	3.4	22.2 a	4.7	4.3 b	7 a	1.4 bc
FC	0	0	29.4	3.8	17.6 b	5.3	5.7 a	5 abc	1.8 abc
	108	1.1	29.3	3.5	23.5 a	4.9	4.4 ab	5 abc	1.3 c
NT			28.5	3.5	21.0	5.1	4.8	5	1.4
FST			29.3	3.4	20.6	4.8	4.6	5	1.5
SST			28.9	3.6	19.9	5.0	5.0	5	1.6
FC			29.4	3.6	20.6	5.1	5.1	5	1.6
	0	0	29.0	3.6 a	18.1 b	5.2 a	5.4 a	4 b	1.8 a
	108	1.1	29.0	3.4 b	22.9 a	4.8 b	4.4 b	6 a	1.3 b
Site Year			ns	ns	***	****	***	*	***
Tillage			ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	**	****	**	****	****	****
Site Year*Aspire™			*	*	ns	ns	ns	ns	***
Tillage*Aspire™			ns	ns	ns	ns	ns	*	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

needs of maize plants. Occasional low K testing areas were observed in our experimental field, but exchangeable K concentrations were never substantially below the calculated critical level. The considerable increase in earleaf concentration suggests that either soil K critical levels didn't characterize the true K supplying power of the soil and that the addition of K fertilizer provides earleaf K benefits even when soil tests indicate limited likelihood of a yield gain, or that there was some luxury consumption of K.

The response of Ca and Mg to the increase in K concentration at R1 varied across maize years. In MY1, no treatment variations were observed in Ca concentrations, but Mg concentrations were negatively impacted by Aspire™ applications (Table 3.12). Overall, the application of Aspire™ in MY1 led to a significant 0.4 g kg^{-1} decline in Mg concentration, but there was no interaction between tillage and Aspire™ applications for earleaf Mg. Significant decreases in concentrations of 0.4 g kg^{-1} for Ca and 1.0 g kg^{-1} for Mg were observed following Aspire™ applications in MY2 (Table 3.13). However, the reductions in Ca and Mg concentrations were not influenced by an interaction between tillage and Aspire™.

Earleaf B concentrations at R1 reflected plant ability to take up B from the applied Aspire™ fertilizer. Significant B concentration increases of 2 mg B kg^{-1} following the application of Aspire™ occurred each year (Table 3.12 and 3.13). Within specific tillage systems, B increases were only significant in the NT system (MY1) and SST (MY2). However, it should be noted that tillage and Aspire™ did interact with one another in MY2. Some 0 kg K ha^{-1} treatments in MY2 had earleaf B concentrations below the recommended critical concentration of 4 mg B kg^{-1}. The B deficiencies present in the 0 kg K ha^{-1} treatments may indicate a need for more research into the B status of Indiana soils following decades of row crop production with limited applications of B fertilizers or manure. The difference in concentration for B among site years could have been influenced by the change in the formulation of Aspire™ following 2017, but soil moisture conditions during vegetative growth (and after B applications) may have played a larger role in soil B levels.

Specific leaf nutrient content at R1 may provide more insight into the current maize nutrient status because this trait considers the size and weight of the earleaf in addition to concentration. Because of resource constraints, leaf area and nutrient content determination only occurred in one MY1 site (2019 PPAC, Table 3.14) and two MY2 sites (2018 and 2019, Table 3.15). Data from MY1 showed Aspire™ had a significant relationship with specific leaf contents for P, K, and B, but mean separation did not detect differences among treatments (Table 3.14). No detectable differences due to tillage or Aspire™ for SLA or N occurred in MY2 (Table 3.15), but P content differences were detected both for tillage and Aspire™ (although the variation detected was small) during MY2. The addition of Aspire™ led to an overall increase in specific leaf K content of 0.31 g $(m^2)^{-1}$ in MY2, and the significant increase occurred in all individual tillage systems. Due to the increase in K content, Ca and Mg contents were likely reduced by 0.03 and 0.07 g $(m^2)^{-1}$ during MY2. The specific leaf B content increased by an average of 0.14 mg $(m^2)^{-1}$ following the application of Aspire™, and these content increases were especially evident in NT (65%) and SST (31%) treatments.

Critical levels (minimum values mentioned in the concentration section) have not been established for specific leaf measurements at R1, but some research has been conducted related to specific leaf measurements. N. Debruin et al. (2013) considered a specific leaf N content of 1.5 g $(m^2)^{-1}$ at R1 to be optimum for yield levels greater than 12.5 Mg ha^{-1}. The N specific leaf content reported in MY1 and 2 were above 1.5 g $(m^2)^{-1}$ and grain yields were close to or above 12.5 Mg ha^{-1}, suggesting N was not limiting.

Table 3.14. Tillage system and Aspire™ rate impacts on R1 maize earleaf specific leaf area and content for N, P, K, Ca, Mg, B, and N:K ratio for MY1 (2019(PPAC)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]							
Tillage[1]	Aspire™		SLA	N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	m^2 g^{-1}	——— g $(m^2)^{-1}$ ———					mg $(m^2)^{-1}$	1:1
NT	0	0	0.0142	2.2	0.3	1.2	0.3	0.2	0.4	1.8 abc
	108	1.1	0.0146	2.1	0.2	1.4	0.3	0.2	0.6	1.5 c
FST	0	0	0.0139	2.2	0.3	1.2	0.3	0.2	0.4	1.8 ab
	108	1.1	0.0145	2.0	0.2	1.3	0.3	0.2	0.5	1.5 bc
SST	0	0	0.0138	2.2	0.3	1.3	0.3	0.2	0.4	1.7 abc
	108	1.1	0.0141	2.2	0.2	1.5	0.3	0.2	0.5	1.5 c
FC	0	0	0.0137	2.3	0.3	1.2	0.3	0.2	0.4	1.9 a
	108	1.1	0.0141	2.3	0.3	1.5	0.3	0.2	0.5	1.5 bc
NT			0.0144	2.1	0.2	1.3	0.3	0.2	0.5	1.6
FST			0.0142	2.1	0.2	1.3	0.3	0.2	0.4	1.7
SST			0.0140	2.2	0.3	1.4	0.3	0.2	0.4	1.6
FC			0.0139	2.3	0.3	1.3	0.3	0.2	0.4	1.7
	0	0	0.0139	2.2	0.3	1.2	0.3	0.2	0.4	1.8 a
	108	1.1	0.0143	2.1	0.2	1.4	0.3	0.2	0.5	1.5 b
Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	**	****	ns	ns	***	****
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table 3.15. Tillage system and Aspire™ rate impacts on R1 maize earleaf specific leaf area and content for N, P, K, Ca, Mg, B, and N:K ratio for MY2 (2018 and 2019(ACRE)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]							
Tillage[1]	Aspire™		SLA	N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	m^2 g^{-1}	g $(m^2)^{-1}$					mg $(m^2)^{-1}$	1:1
NT	0	0	0.0151	1.9	0.2 ab	1.2 c	0.4	0.3 ab	0.2 bc	1.6 abc
	108	1.1	0.0152	1.9	0.2 ab	1.5 a	0.3	0.3 ab	0.4 ab	1.3 c
FST	0	0	0.0148	2.0	0.2 ab	1.2 bc	0.3	0.3 ab	0.3 abc	1.7 abc
	108	1.1	0.0152	1.9	0.2 b	1.5 a	0.3	0.3 b	0.3 abc	1.3 c
SST	0	0	0.0145	2.0	0.3 ab	1.2 c	0.4	0.4 a	0.2 c	1.9 a
	108	1.1	0.0149	1.9	0.2 ab	1.5 ab	0.3	0.3 ab	0.4 a	1.4 bc
FC	0	0	0.0147	2.0	0.3 a	1.2 c	0.4	0.4 ab	0.4 abc	1.8 ab
	108	1.1	0.0145	2.0	0.2 ab	1.6 a	0.3	0.3 ab	0.4 abc	1.3 c
NT			0.0152	1.9	0.2 ab	1.4	0.3	0.3	0.3	1.4
FST			0.0150	2.0	0.2 b	1.4	0.3	0.3	0.3	1.5
SST			0.0147	2.0	0.2 ab	1.3	0.3	0.3	0.3	1.6
FC			0.0146	2.0	0.2 a	1.4	0.4	0.3	0.4	1.6
	0	0	0.0148	2.0	0.2 a	1.2 b	0.4 a	0.4 a	0.3 b	1.8 a
	108	1.1	0.0149	2.0	0.2 b	1.5 a	0.3 b	0.3 b	0.4 a	1.3 b
Site Year			*	ns	ns	***	***	***	ns	***
Tillage			ns	ns	*	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	**	****	*	***	***	****
Site Year*Aspire™			ns	ns	*	ns	ns	ns	ns	***
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

3.4.7 Grain Yield and Yield Components

Grain yields and yield components were not significantly influenced by tillage and Aspire™ treatment interactions in either MY1 or 2, suggesting no substantive difference in response to Aspire™ among the tillage systems. Maize grain yield was influenced significantly by the addition of Aspire™ for MY1 and 2, while tillage system differences were also significant in MY2 (Table 3.16). The application of Aspire™ for MY1 led to an overall increase in grain yield of 0.5 Mg ha^{-1}, although the only significant increase in grain yield (at 1 Mg ha^{-1}) with Aspire™ occurred within the SST tillage system. The highest average grain yield achieved in MY1 (13.4 Mg ha^{-1}) was recorded in SST with Aspire™ at 108 kg K ha^{-1}. In MY2, Aspire™ application increased overall grain yield by 1.1 Mg ha^{-1} averaged across all tillage systems, but significantly (at 2 Mg ha^{-1}) only in FST. Unlike MY1 locations, in MY2, tillage impacted grain yield as NT yields were significantly lower than those after FST and FC.

As with other studies that have evaluated the responsiveness to K fertilizer additions, the soil plant-available K levels and environmental conditions can influence plant K access [i.e., positive responses to K application are less likely with high soil plant-available K concentrations (Vyn & Janovicek, 2001)]. Because of the potential influence from inherent soil supplies, the response to placement can be highly variable and often depend on environmental conditions. With adequate and well-distributed rainfall, it is possible that maize in a control K treatment could have access to sufficient K during the growing season and have a similar performance to treatments where K was applied. The unpredictable nature of K availability in the soil and the inability to detect other K pools plants have access to will limit the ability to make reliable recommendations for future crop production.

Table 3.16. Tillage system and Aspire™ rate impacts on maize grain yield at 15.5% moisture, harvest moisture, kernel number, and kernel weight for MY1 (2016, 2017, and 2019(PPAC)) and MY2 (2018 and 2019(ACRE)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]				MY2[2]			
Tillage[1]	Aspire™		Grain Yield	Moisture	Kernel Number	Kernel Weight	Grain Yield	Moisture	Kernel Number	Kernel Weight
	kg K ha^{-1}	kg B ha^{-1}	Mg ha^{-1}	%	kernels (m^2)$^{-1}$	mg kernel^{-1}	Mg ha^{-1}	%	kernels (m^2)$^{-1}$	mg kernel^{-1}
NT	0	0	12.6 bc	20.5 cd	3891	296	12.9 c	18.2 cd	3861	318
	108	1.1	12.8 abc	22.9 a	4060	307	14.1 abc	19.2 a	4077	320
FST	0	0	12.8 abc	19.8 de	3955	307	13.4 bc	18.1 cd	3911	313
	108	1.1	13.0 ab	20.9 c	4023	283	15.4 a	18.5 bcd	4333	325
SST	0	0	12.4 c	19.9 de	4063	277	13.7 bc	18.3 bcd	4392	314
	108	1.1	13.4 a	21.7 b	4081	289	14.4 ab	18.9 ab	3930	321
FC	0	0	12.6 abc	19.4 e	4082	295	14.1 abc	18.0 d	4286	303
	108	1.1	13.3 ab	20.4 cd	4167	295	14.6 ab	18.6 abc	3992	317
NT			12.7	21.7 a	3975	302 a	13.5 b	18.7 ab	3975	319
FST			12.9	20.3 c	3991	296 ab	14.5 a	18.3 b	4135	320
SST			12.9	20.8 b	4072	282 ab	14.1 ab	18.6 a	4161	318
FC			13.0	19.9 c	4127	295 b	14.3 a	18.3 ab	4148	310
	0	0	12.6 b	19.9 b	4001	294	13.5 b	18.1 b	4118	312 b
	108	1.1	13.1 a	21.4 a	4085	294	14.6 a	18.8 a	4090	321 a
Site Year			****	****	**	****	***	ns	**	**
Tillage			ns	****	ns	ns	*	**	ns	ns
Site Year*Tillage			ns	****	ns	ns	ns	ns	ns	ns
Aspire™			****	****	ns	ns	****	****	ns	**
Site Year*Aspire™			ns	***	**	*	ns	ns	ns	ns
Tillage*Aspire™			ns	**	ns	ns	ns	ns	*	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel

[2] MY = maize year

* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

To better understand the source of grain yield differences, yield component measurements are critical (kernel number and weight). Tillage and Aspire application only interacted in MY2 for kernel number while having no significant influence individually for either MY (Table 3.16). No significant differences in kernel number due to tillage or Aspire™ application were observed in either MY1 or 2. Kernel weight was only significantly influenced by Aspire application in MY2 with a 9 mg kernel^{-1} advantage following Aspire™ application in MY2, but Aspire™ had no such benefit in MY1; however, there were differences in the grouping for tillage systems, with NT being significantly higher in kernel weight than FC.

As seen in other studies, when applying fertilizer containing K, grain moisture concentrations tend to be higher at harvest (Armstrong & Griffin, 1998; Vyn et al., 2002). Across all tillage systems, the application of Aspire™ raised the moisture concentration by 1.5% (MY1) and 0.7% (MY2). The higher moisture in treatments where Aspire™ has been applied suggests that the grain-filling period may be extended, potentially influencing final kernel weight.

3.4.8 R6 Grain and Total Nutrient Uptake

Nutrient content of the grain and total above-ground dry matter at R6 is a vital measurement allowing for the calculation of nutrient metrics (i.e., removal, harvest index, etc.) at the grain yield attained. The lack of interaction between tillage and Aspire™ suggests the combined effect of Aspire™ application and a particular tillage system did not influence the accumulation of nutrients in grain (Tables 3.17 and 3.18). In MY1, there was minimal treatment variation in dry matter and grain nutrient accumulation. Grain nutrient content changes were only detectable for Ca and B, and both were influenced by tillage (Table 3.17). Grain B content was significantly higher (by ~5.5 g B ha^{-1}) in NT and FST tillage systems than in FC. Interestingly, the addition of Aspire™ did not always lead to increases in B content in the grain. In MY2, gains in grain nutrient contents were apparent after Aspire™ applications, while grain DM was highest in the SST system and lowest in NT (Table 3.18). Grain contents of N, P, K, and Mg were all increased significantly following the application of Aspire™ by 9.5, 5.0, 7.4, and 1.4 kg ha^{-1}, respectively. Although Aspire™ didn't significantly increase grain DM according to the dry matter samples, nutrient content increased, leading to increased nutrient removal from the system.

Grain harvest removes nutrients from the system. Our grain K contents were similar to those at comparable grain yields in prior studies by Ciampitti et al. (2013), Ciampitti and Vyn (2011) and Bender et al. (2013). Bender et al. (2013) also evaluated the B content of grain at the same grain yield level (12.0 Mg ha^{-1}) and recorded a range of 13 to 32 g ha^{-1} B. Our B grain contents in MY1 (range = 13.2 to 22.7 g ha^{-1}) and 2 (range = 11.3 to 13.4 g ha^{-1}) were low, especially when considering the grain yield levels were higher than Bender et al. (2013). Grain nutrient data in this chapter showed K content increased with increasing grain yield, but this same increase was not detected in B content.

Grain nutrient concentration data are not presented in the main chapter but are reported in Appendix B (Table B.17 and B.18). Data presented in this chapter show a significant increase in K concentration following the application of Aspire™ (MY1 = 0.2 g kg^{-1}, MY2 = 0.6 g kg^{-1} K). Mallarino and Higashi (2009) also saw increases in grain K concentration following K application, but several experiment locations showed no response. Our observed grain K concentration was similar to Bender et al. (2013) but was slightly lower than that reported in Ciampitti et al. (2013). Bender et al. (2013) also presented B concentration in the grain and recorded a 1.6 mg B kg^{-1} concentration. Limitations in lab analysis prevent the reliable detection of grain B concentration in our research because the grain has a much lower concentration than the standards used for machine calibration, making it difficult to form definitive insights.

Table 3.17. Tillage system and Aspire™™ rate impacts on maize R6 grain total dry matter and uptake for N, P, K, Ca, Mg, B, and N:K ratio for MY1 (2016 and 2019(PPAC)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]							
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	——— kg ha^{-1} ———						g ha^{-1}	1:1
NT	0	0	11169	114.0	34.9	46.4	1.0 b	14.5	23 a	2.6
	108	1.1	11345	109.7	32.5	44.9	1.0 b	13.2	18 ab	2.5
FST	0	0	11080	112.1	30.0	42.7	1.0 b	13.2	16 ab	2.7
	108	1.1	11412	118.5	32.1	46.8	1.0 b	13.9	22 a	2.6
SST	0	0	11029	113.6	32.4	43.8	1.0 b	15.0	17 ab	2.6
	108	1.1	11533	119.9	35.6	48.0	1.0 b	14.6	16 ab	2.5
FC	0	0	11518	124.3	35.2	48.3	1.1 ab	16.0	13 b	2.7
	108	1.1	11864	129.5	37.8	52.4	1.3 a	15.8	16 ab	2.6
NT			11257	111.9	33.7	45.7	1.0 b	13.9	20 a	2.5
FST			11246	115.3	31.1	44.7	1.0 b	13.5	19 a	2.7
SST			11281	116.7	34.0	45.9	1.0 b	14.8	17 ab	2.6
FC			11691	126.9	36.5	50.3	1.2 a	15.9	14 b	2.6
	0	0	11199	116.0	33.1	45.3	1.0	14.7	17	2.7
	108	1.1	11539	119.4	34.5	48.0	1.1	14.4	18	2.6
Site Year			****	**	*	****	****	***	**	****
Tillage			ns	*	ns	ns	**	ns	*	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	*	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	*	ns	**	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table 3.18. Tillage system and Aspire™™ rate impacts on R6 maize grain total dry matter (DM) and uptake for N, P, K, Ca, Mg, B, and N:K ratio for MY2 (2018 and 2019(ACRE)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY2[2]							
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	—— kg ha^{-1} ——						g ha^{-1}	1:1
NT	0	0	11305	121.2	32.7	56.3	1.1	13.2	11	2.2 ab
	108	1.1	11769	130.0	38.2	65.1	1.2	14.2	13	2.1 b
FST	0	0	12020	129.8	33.4	58.4	1.2	13.6	12	2.4 a
	108	1.1	12725	138.6	39.7	68.9	1.3	15.3	13	2.1 b
SST	0	0	12930	129.2	35.2	60.8	1.3	14.0	13	2.2 ab
	108	1.1	12677	142.3	40.4	68.6	1.3	15.8	13	2.1 ab
FC	0	0	12156	123.1	33.0	60.1	1.2	13.2	12	2.2 ab
	108	1.1	11555	129.8	35.5	62.1	1.2	14.2	12	2.2 ab
NT			11537 b	125.6	35.5	60.7	1.2	13.7	12	2.1
FST			12372 ab	134.2	36.5	63.6	1.2	14.5	12	2.2
SST			12803 a	136.2	38.0	64.9	1.3	15.0	13	2.1
FC			11856 ab	126.5	34.2	61.1	1.2	13.7	12	2.2
	0	0	12103	125.7 b	33.5 b	58.8 b	1.2	13.5 b	12	2.2 a
	108	1.1	12181	135.2 a	38.5 a	66.2 a	1.2	14.9 a	13	2.1 b
Site Year			**	*	ns	***	*	ns	*	***
Tillage			*	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	*	**	**	ns	*	ns	*
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	*
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Total uptake at R6 should be considered in the context of grain yield and the applications of Aspire™ made before the growing season started. The total uptake for nutrients presented in this chapter are presented in Tables 3.19 and 3.20 (for more information regarding additional nutrients not shown in this main chapter, refer to Appendix B). Each component's contribution to the total content of K and B is further broken down in Figures 3.14 to 3.17. In MY1, the total K content generally increased (but not significantly) following Aspire™ applications for all tillage systems. Total K uptake in MY2 was significantly increased following the application of Aspire™ for NT, SST, and FC. The small increase in K uptake for MY1 when applying 108 kg K ha^{-1} and the significant increase in K content for MY2 shows the variability in response to the application of Aspire™ that could have been impacted by environmental conditions. Increases in total K uptake appear to be mostly due to increases in stover K content

Total dry matter, was slightly increased (but not significantly) following Aspire application for both MY. Nutrient uptake was also commonly increased following Aspire application, but only significantly increased in MY2 for N (+14.3 kg ha^{-1}), P (+5.6 kg ha^{-1}), and K (+44.5 kg ha^{-1}). In MY2, across the tillage systems used as treatments, there was commonly a significant increase in K content. Total K content reported by Bender et al. (2013) was slightly higher than the results presented in this chapter for similar grain yield levels. Ciampitti et al. (2013) reported total K uptake grain yield and total K uptake similar to the results presented in this chapter. No significant interaction between Aspire™ and tillage was detected for B uptake in either maize year with only slight increases in B content from Aspire™ applications.

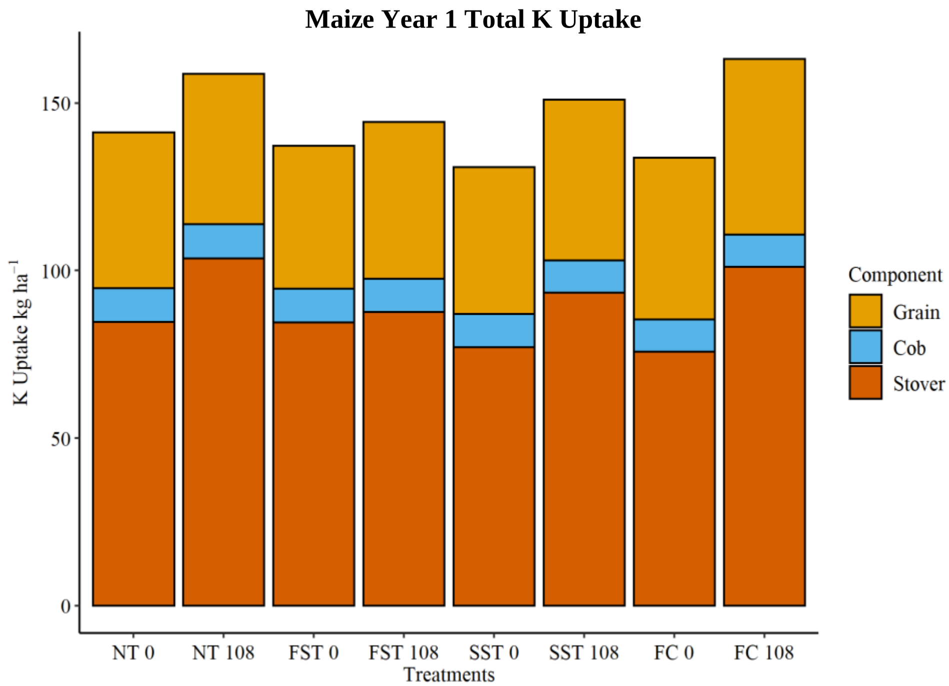

Figure 3.1. Effect of strip-tillage timing and Aspire™ rate on R6 K uptake within individual plant components and total plant at R6 for maize year 1 (includes 2016 and 2019 (PPAC)). Bar size represents mean uptake per component with different lowercase letters indicating significant differences in K uptake within a component at $p<0.05$.

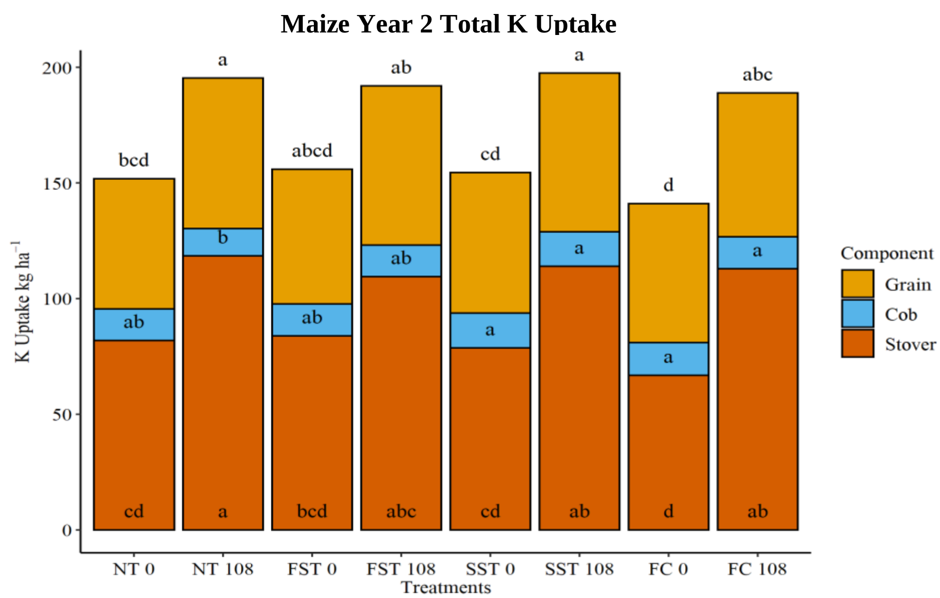

Figure 3.2. Effect of strip-tillage timing and Aspire™ rate on R6 K uptake within individual plant components and total plant at R6 for maize year 2 (includes 2018 and 2019 ACRE). Bar size represents mean uptake per component with different lowercase letters indicating significant differences in K uptake within a component at $p<0.05$. Differing lower case letters on top of bars indicates differences in total K uptake at $p<0.05$.

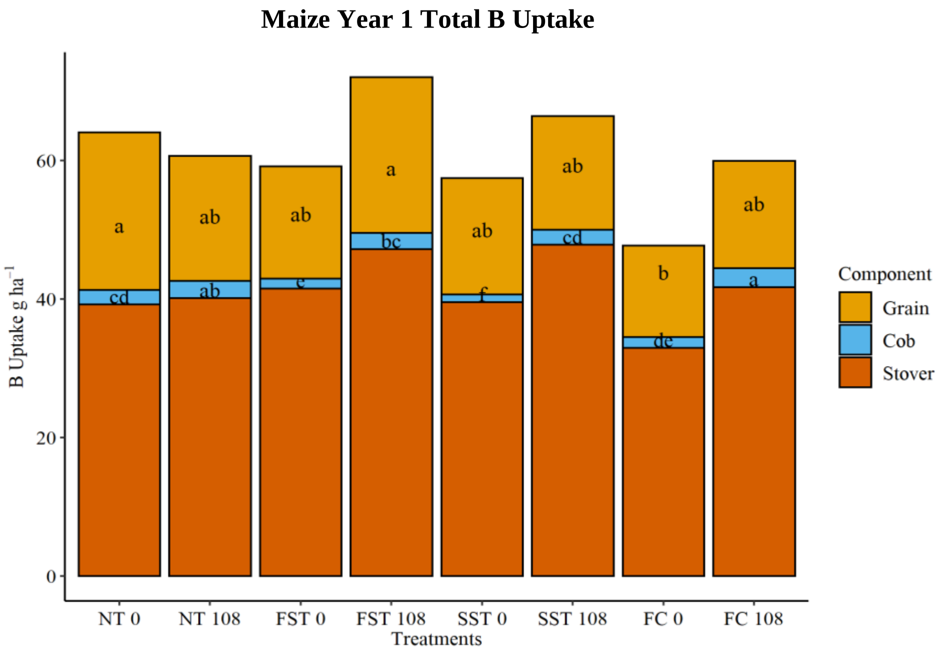

Figure 3.3. Effect of strip-tillage timing and Aspire™ rate on R6 B uptake within individual plant components and total plant at R6 for maize year 1 (includes 2016 and 2019 (PPAC)). Bar size represents mean uptake per component with different lowercase letters indicating significant differences in B uptake within a component at $p<0.05$.

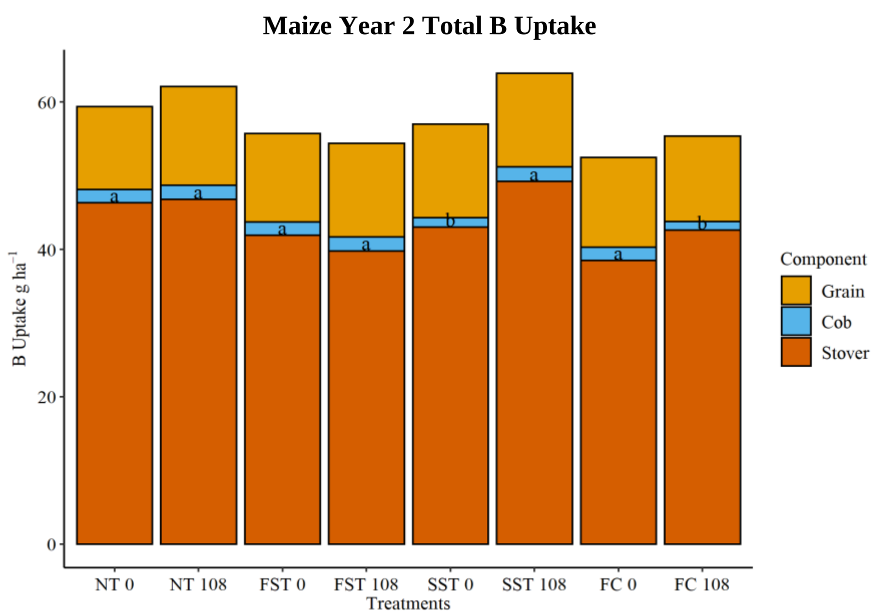

Figure 3.4. Effect of strip-tillage timing and Aspire™ rate on R6 B uptake within individual plant components and total plant at R6 for maize year 2 (includes 2018 and 2019 ACRE). Bar size represents mean uptake per component with different lowercase letters indicating significant differences in B uptake within a component at $p<0.05$.

Table 3.19. Tillage system and Aspire™™ rate impacts on R6 maize total dry matter and uptake (sum of grain, cob, and stover content) for N, P, K, Ca, Mg, B, and N:K ratio for MY1 (2016 and 2019(PPAC)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]							
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	B	N:K
	kg K ha^{-1}	kg B ha^{-1}	—— kg ha^{-1} ——						g ha^{-1}	1:1
NT	0	0	19208	197.5	46.6	151.0	24.1	32.0	57	1.4
	108	1.1	20245	195.5	42.3	168.3	25.4	31.5	46	1.3
FST	0	0	19017	186.8	36.6	146.9	22.5	26.8	44	1.4
	108	1.1	19599	194.2	37.6	147.5	23.9	28.2	56	1.5
SST	0	0	19118	179.7	36.5	134.6	20.4	28.8	42	1.4
	108	1.1	20138	194.8	42.5	160.2	26.4	32.8	49	1.3
FC	0	0	19760	198.8	42.1	143.7	22.5	31.1	31	1.5
	108	1.1	20437	216.9	45.6	165.1	27.3	32.3	42	1.4
NT			19727	196.5	44.5	159.6	24.7	31.7	52	1.3
FST			19308	190.5	37.1	147.2	23.2	27.5	50	1.5
SST			19628	187.2	39.5	147.4	23.4	30.8	45	1.4
FC			20098	207.8	43.8	154.4	24.9	31.7	37	1.4
	0	0	19276	190.7	40.5	144.1	22.3 b	29.7	43	1.4
	108	1.1	20105	200.4	42.0	160.3	25.7 a	31.2	48	1.4
Site Year			****	*	ns	**	****	ns	****	****
Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	*	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = $p<0.001$...

Table 3.20. Tillage system and Aspire™™ rate impacts on R6 maize total dry matter and uptake (sum of grain, cob, and stover content) for N, P, K, Ca, Mg, B, and NT:K ratio for MY2 (2018 and 2019(ACRE)). Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]							
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	B	NK
	kg K ha^{-1}	kg B ha^{-1}	-- kg ha^{-1} --						g ha^{-1}	1:1
NT	0	0	20459	207.0	41.4	151.7 bcd	38.4	44.8	59	1.5 abc
	108	1.1	21348	210.1	45.8	195.4 a	36.7	44.3	62	1.2 d
FST	0	0	20970	210.8	39.9	156.0 abcd	35.7	44.4	56	1.5 ab
	108	1.1	22189	220.8	46.0	192.0 ab	33.5	41.8	54	1.3 cd
SST	0	0	22556	193.8	38.0	146.9 cd	36.9	45.2	55	1.4 bcd
	108	1.1	22529	226.7	47.3	197.5 a	36.7	45.3	64	1.3 cd
FC	0	0	20865	201.5	38.8	141.1 d	36.2	44.4	52	1.6 a
	108	1.1	20959	212.8	41.5	188.9 abc	34.8	42.7	55	1.2 d
NT			20903	208.6	43.6	173.6	37.6	44.6	61	1.3
FST			21579	215.8	43.0	174.0	34.6	43.1	55	1.4
SST			22542	210.2	42.6	172.2	36.8	45.3	60	1.3
FC			20912	207.2	40.2	165.0	35.5	43.5	54	1.4
	0	0	21212	203.3 b	39.5 b	148.9 b	36.8	44.7	56	1.5 a
	108	1.1	21756	217.6 a	45.1 a	193.4 a	35.4	43.5	59	1.2 b
Site Year			**	*	ns	***	ns	*	**	***
Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	*	*	****	ns	ns	ns	****
Site Year*Aspire™			ns	ns	ns	*	*	ns	ns	**
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	*
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

3.4.9 N:K Insights

The change in the N:K ratio throughout the growing season has been infrequently documented in previous research (as reviewed in Chapter 2). The ability to understand how the N:K ratio could be manipulated during the growing season could be important for improving the N utilization and translocation of nutrients to the grain. As described in Chapter 2, Ciampitti and Vyn (2014) recommend a whole-plant ratio of 1:1 for N:K at maturity in maize, but also suggested the ratio was commonly narrower for high yielding locations. In this research, tissue samplings had the N:K ratio calculated and presented to see the impact of Aspire™ application across the tested conservation tillage systems. The R1 ratios seem to be closer to those calculated for the R6 total dry matter than the V6 ratios, similar to Chapter 2 (V6 = Tables 3.8 and 3.9, R1 = Tables 3.12 and 3.13, R6 total dry matter = Tables 3.18 and 3.19). The similarity in ratios between R6 and R1 could be due to the majority of K uptake being completed by R1. Ratios were commonly lowered when Aspire™ was applied (as expected) with no influence from tillage at any crop development stage.

3.4.10 Harvest Index and Fertilizer Efficiency

The proportion of photosynthates and nutrients allocated to the grain versus other aboveground plant tissue at maturity is defined as the harvest index (HI) (Armstrong & Griffin, 1998; Hütsch & Schubert, 2017). In the past, the HI of maize has been assumed to be ~50%; however, modern maize hybrids have shown that HI is typically higher than 50% (Bender et al., 2013; Mueller et al., 2019). Harvest index for grain in the presented dataset was recorded at higher than 50% for both maize years (Table 3.21). No influence from tillage or Aspire™ applications on grain HI was detected in MY1, but MY2 showed variation due to tillage and Aspire™. Overall tillage comparisons showed FST had a 2% higher grain HI than NT, and Aspire™ application decreased overall grain HI by 1.1%. Tillage and Aspire™ application treatments did not change HI in MY1, but Aspire™

applications resulted in lower grain HI in MY2. The decrease in grain HI following the application of Aspire™ was likely due to enhanced leaf stay-green and improved stover plant health near maturity (a factor that was also reflected is more K retained in the stover, lowering K HI). The K HI did have an interaction between tillage and Aspire™ rate, indicating a difference in response to the application of Aspire™ among the tillage systems. Following the application of Aspire™ (across all tillage systems) in MY2, K HI was reduced by 5%. FC was the only tillage system to significantly reduce K HI following the application of Aspire™. The K HI in MY2 had a slightly wider range when compared to MY1 (MY1 had a range from 32 to 38% (6%) while MY2 had a range from 33.8 to 44.2% (10.2%)). Both maize years showed relatively normal K HI values compared to previous work at similar grain yield levels by Bender et al. (2013) (ranged from 27 to 37%) and Ciampitti et al. (2013) (ranged from 29 to 33%), but MY2 was higher than the ranges presented in either study. The HI for B is also shown; however, due to laboratory weakness in detecting B within the grain, any conclusions regarding B HI await further investigation (Table 3.20). Harvest index is not the only metric that is important for understanding uptake and removal of nutrients, but fertilizer efficiencies can provide insight into how a management practice could be influencing nutrient balance.

K recovery efficiency (KRE) has not been thoroughly researched due to the lack of negative consequences from over-application of K-based fertilizers (i.e., pollution of air and water resources) (Bell, Mallarino, et al., 2021). No significant differences in KRE were detected among the tillage systems for either maize year in the data presented (Table 3.20). However, only one year of KRE data was collected at an MY1 location (2019 PPAC), while two years (2018 and

Table 3.21. Tillage system and Aspire™ rate impacts on maize harvest index (HI) (grain, K, and B) and K Recovery Efficiency for MY1 (2016, and 2019(PPAC)) and MY2 (2018 and 2019(ACRE)). 2019(PPAC) was the only year when K Recovery Efficiency data was collected for samples collected at R6. Mean separation for tillage system x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]				MY2[2]			
Tillage[1]	Aspire™		HI Grain	HI K	HI B	K Recovery Efficiency	HI Grain	HI K	HI B	K Recovery Efficiency
	kg K ha^{-1}	kg B ha^{-1}	——— % ———				——— % ———			
NT	0	0	58.0	36.4	48.7		55.1 ab	38.7 abc	19.6	
	108	1.1	56.2	32.0	41.6		55.1 b	34.8 bc	21.7	
FST	0	0	58.3	34.8	44.9		57.0 ab	39.7 abc	21.8	
	108	1.1	58.0	35.9	37.9		57.3 ab	38.4 abc	23.6	
SST	0	0	57.6	35.4	47.4		57.2 ab	41.3 ab	22.7	
	108	1.1	57.1	33.3	38.7		56.2 ab	36.9 bc	20.4	
FC	0	0	58.2	38.0	48.2		58.1 a	44.2 a	23.5	
	108	1.1	58.0	35.7	41.8		54.9 b	33.8 c	21.4	
NT			57.1	34.2	45.2	20.5	55.1 b	36.7	20.6	40.4
FST			58.2	35.3	41.4	3.6	57.1 a	39.0	22.7	33.3
SST			57.4	34.3	43.1	21.8	56.7 ab	39.0	21.5	46.8
FC			58.1	36.8	45.0	31.2	56.5 ab	39.0	22.5	44.2
	0	0	58.0	36.2	47.3 a		56.9 a	41.0 a	21.8	
	108	1.1	57.3	34.2	40.0 b		55.8 b	36.0 b	21.8	
Site Year			ns	*	*		*	**	ns	**
Tillage			ns	ns	ns	ns	*	ns	ns	ns
Site Year*Tillage			ns	ns	ns		ns	ns	ns	ns
Aspire™			ns	ns	**		*	****	ns	
Site Year*Aspire™			ns	ns	ns		ns	ns	ns	
Tillage*Aspire™			ns	ns	ns		ns	*	ns	
Site Year*Tillage*Aspire™			ns	ns	ns		ns	ns	ns	

[1] NT= no till, FST = fall strip-till, SST = spring strip-till, FC = fall chisel
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

2019 ACRE) were collected for MY2. Average recovery efficiencies were favorable for both maize years, showing that ~30% of the fertilizer was recovered. From previous research summarized by Bell, Mallarino, et al. (2021), the typical K recovery efficiency is suggested to be between 30 and 50%. However, past research has documented negative K recovery efficiencies and even some above 100%, showing the inherent variability present with this measurement (Niu et al., 2011; Xu et al., 2015). A negative K recovery efficiency can be caused due to higher K uptake in the control plot than was obtained in the treated plot, a constraint in K uptake in the treated plot, or a combination of these two scenarios. A higher K uptake in the control plot would likely be due to the increased availability of soil exchangeable K from inherent soil properties. Lower K uptake of the treated plots could be due, in part, to K fixation from wetting and drying cycles or variability in soil K supplying power. Bell, Mallarino, et al. (2021) reviewed the literature for a presentation at an international K conference and discussed the lack of documentation of K recovery efficiency and the potential for this measurement to help researchers understand the optimum application method (placement) for K-based fertilizers. Because applied K is retained in the soil long after application, K recovery efficiency can be difficult to both measure and interpret because it is unknown if the K taken up by the plant is from the recent application or if it is derived from natural deposits/plant residues or past fertilizer applications (Bell, Mallarino, et al., 2021).

3.5 Conclusions

The objective of this study was to understand the impact of tillage/placement, the application of Aspire™, and the interaction between these two treatment factors on maize growth and development. Various measurements taken during the season and at maturity helped document treatment impacts and better define recommendations for maize farmers.

The main hypothesis for this experiment was that tillage/incorporation method would influence the response to Aspire™ (i.e., incorporating fertilizer into the soil/ crop row would lead to higher plant nutrition levels than were present in no till when Aspire™ was applied as a broadcast treatment). This experiment included three fertilizer placements/tillage systems (broadcast, incorporation with tillage following the broadcast, and incorporation of fertilizer via tillage limited to the intended row zone). Interactions between tillage and Aspire™ at V6 were rare for maize plant concentrations and contents for most nutrients, and treatment interactions were not detected for K concentrations or contents in either maize year. With earleaf sampling at R1, an interaction between tillage and Aspire™ was only present in MY2 for B. Grain yield was significantly increased following Aspire™ applications for SST (MY1) and NT (MY2), but yields among tillage systems with the 108 kg K ha^{-1} rate of Aspire™ were not different from one another. Significant interactions between tillage and Aspire™ were rare in most plant parameters, but significance was more commonly documented for B than K. From this research, the interaction between tillage and Aspire™ that was evident earlier in the season (~V6) had little bearing on final yield, while the consequences to maize from tillage and Aspire™ treatments were apparent throughout the growing season.

The second hypothesis regarding this experiment was that the overall tillage system and Aspire™ application would influence maize growth and development throughout the growing season. Overall, the effects due to tillage were evident as early as V6. Both FST and FC commonly showed early season advantages in V6 dry matter and K content relative to no-till in both maize years, but SST was generally not different than FST and FC. However, upon reaching R1, there were no detectable differences among tillage systems for K concentration, but there was a significant increase in tissue K concentrations from the application of Aspire™. Although usually insignificant, spring applied Aspire™ commonly had slightly higher B concentrations at R1 compared to fall applications, suggesting there could be some loss from a fall application of Aspire™. In MY2, grain K content was increased by Aspire™ from both an increase in grain yield and K concentration, suggesting that the K removals could also increase with improved K management.

Although the research presented in this chapter does not provide a direct recommendation for farmers, it does highlight the unpredictable nature of crop response to K fertilizers across time. No single tillage system was the best for all site and Aspire™ rate conditions. Advantages from tillage and placement were commonly seen in early season plant growth, but less frequently following V6. Further inquiry is required to understand whether K placement plays a factor in efficient fertilizer recovery and how this can change across tillage systems. Continuing to utilize alternative fertilizer sources is also necessary to understand how these products influence maize growth and development.

3.6 Acknowledgments

Thank you to the Indiana Corn Marketing Council for financial support of this project since its inception in 2016, and especially for the 2018-2019 academic year support via the Gary Lamie MS Graduate Student Assistantship. The Mosaic Company for providing Aspire™ for field trials and sponsored commercial lab costs of soil and plant analyses after sample processing was completed at Purdue. Environmental Tillage Systems generously loaned a 6-row Soil Warrior strip-till unit each year. Also, we give special thanks to Corteva Agriscience for providing seed for trials and financial support for project summarization via their Crop Management Research Award in 2020. Sincere thanks and appreciation to the Vyn Lab field crews from 2016 to 2019 for their

diligent work to collect data for this experiment. Field operations and maintenance would not have been possible without Terry West, ACRE field staff, and PPAC field staff.

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CHAPTER 4. RESEARCH REFLECTION AND DISCUSSION

4.1 Contributions to Science

Soil K stratification commonly develops in conservation tillage systems, and this has raised questions regarding the potential impacts on plant-available K accessibility and optimal K management strategies for maize nutrient uptake and grain yield. Many strip-till implements are now incorporating the ability to supply fertilizer on-the-go, but few studies have examined this technology relative to alternative tillage systems in the context of different soils, different degrees of nutrient stratification levels, and in high crop yield situations. The use of coulter-based strip-till systems for strip-till is a unique feature for this research, as prior studies on nutrient banding have primarily involved shank-based deep banding. This thesis addressed questions regarding K fertility and conservation tillage systems through the use of Aspire™, an alternative K fertilizer source produced by the Mosaic Company containing both K and B.

4.1.1 Chapter 1

The current state of knowledge should ideally be reviewed prior to the design and execution of an experiment. The opening chapter's literature review sought to summarize previous studies and review papers related to how K and B uptake in maize are affected by management (i.e., tillage, fertilizer placement, fertilizer application rate, etc.). These nutrient reviews were conducted separately due to the lack of current research on the co-application of these nutrients.

State recommendations for improved K management have been revised somewhat in the past several decades, but more investigations are needed to account for modern agricultural practices and technologies. The continued high preponderance of low soil K levels within the

Eastern Cornbelt and documented physiological consequences of low K levels to grain crops has increased the need for continued K research.

Plant available K stratification in the soil is a natural phenomenon even without recent broadcast fertilizer applications because of K cycling from plant uptake to deposition on the surface as residue. As conservation tillage has grown in adoption, it is still uncertain if the stratification of soil K is negatively impacting maize production in the Eastern Cornbelt. Ensuring adequate K for crop production involving much higher yield levels and within-field variability (as well as both horizontal and vertical K stratification) requires more fundamental K research in commercially relevant systems.

Even with the intensification of maize production systems throughout the Eastern Cornbelt, little to no changes have been made to B recommendations for decades. Producer uncertainty about whether B needs of maize are met using available recommendations is likely valid because the management practices were developed at lower planting densities, potentially more diverse cropping rotation sequences, much lower B removal at harvest, and with hybrids achieving much lower kernel numbers per unit area. Additionally, B soil testing capabilities remain greatly limited, leaving the plant to be the B deficiency indicator. Research into optimal tillage and fertilizer placement has been documented more frequently in K compared to B. Upon reviewing B related research, I concluded that maize production throughout the Eastern Cornbelt has little information about B management in the context of the current agricultural systems.

Both K and B perform essential functions within maize and influence final grain yield. The influence of these nutrients on maize growth and development have been documented separately; however, the impact of these nutrients when both are applied has not been described in the literature in the context of modern maize production systems. This thesis evaluated the effects of K and B co-application utilizing a recently developed fertilizer source (Aspire™) under a series of conservation tillage systems in the Eastern Cornbelt.

4.1.2 Chapters 2 and 3

Throughout chapters 2 and 3 the amount of data collected and presented is a valuable contribution to science. Soil data collected not only provided information relevant to the plant-available K status of the soil but also soil fertility status. Tissue samples also provided a large amount of data because the majority of plant essential nutrients were measured. The vast amount of nutrient data collected provides information useful to not only the interpretation of data from this experiment but also to other researchers who wish to advance K management.

Although plant-available K status is important, it does not provide information on plant-available K distribution within the soil. Both Chapters 2 and 3 provide detailed information with soil samples divided based on position (relative to the intended crop row) and depth increment. All site years showed stratification across a majority of treatments. In both chapters, in-row placement of Aspire™ in the FST and SST treatments was shallowly incorporated and led to exceptionally high K concentrations within the 0-5cm depth compared to other tillage/ placement treatments. Broadcast placement for NT and FC led to similar plant-available K concentrations for both in-row and between-row positions after broadcast K application, with both having pronounced vertical stratification.

A key contribution to science from the Chapter 2 analysis was the realization of growth and nutrient uptake advantages early in the growing season (at V6) in FST compared to SST, but the lack of final grain yield differences between the two timings. A second contribution from the analysis in Chapter 2 are the results suggesting the initial year of reducing Aspire™ fertilizer rate by 50% may not show a limitation to plant nutrition, but when utilizing the same rate reduction, a second time in maize, there may be a slightly negative consequence to plant nutrient uptake. Across the multiple measurements taken throughout the growing season, the 108 kg K ha^{-1} rate was more frequently considered significantly different from the control than with the 54 kg K ha^{-1} rate. Chapter 3 compared all tillage systems/ fertilizer placements (broadcast, incorporation with tillage following the broadcast, and incorporation of fertilizer and tillage within the intended row), which only included the Aspire™ fertilizer rates of 0 and 108 kg K ha^{-1}. Interactions between tillage and Aspire™ are of most concern in this analysis because this indicates whether a tillage system responds differently to the application of Aspire. Overall, few interactions between tillage and Aspire™ interactions occurred for both maize years. Significant interactions were more common for B (both concentration and content), suggesting there could be more of a benefit to the placement of Aspire™ for B compared to K. Although interactions were more common for B no tillage/ placement combination appeared to have a clear advantage during the whole growing season. The lack of interactions between Aspire™ and tillage for K confirms other research that the placement is not key with K, but the application of fertilizer itself increased grain yield (increases following application of Aspire™, Yr 1 = 4% and Yr 2 = 8%).

Individual site years showed positive relationships between R1 earleaf K concentration and grain yield (with little evidence of a maximum concentration) but little relationship when considering B concentration. From the data collected, some site years even showed continued increases in grain yield with K concentration higher than the recommended 19 g kg^{-1}; this implies higher leaf K concentrations have the potential to continue benefiting grain yield development.

4.2 Implications for Agriculture

This research has implications for the management of K and B under multiple conservation tillage systems. However, this research cannot look at the management of these nutrients separately due to the limited treatment structure.

Producers in the Eastern Cornbelt have asked questions regarding strip-till timing. Due to weather challenges, limited labor, and the need to complete multiple operations in the fall, a farmer needs to understand what can wait until spring without costing potential grain yield if all operations cannot be completed. It was evident across site years that strip-till timing, when performed under optimal conditions, has little negative impact on grain yield. Early in the growing season, FST commonly has an advantage in the above ground dry matter at V6; however, the advantages early in the season were not clear when R1 earleaf samples were collected. The lack of differences in grain yield between FST and SST provides farmers with additional research-derived evidence showing, when conditions are fit and maize planting isn't delayed, that timing of strip-till has little to no impact on crop growth and final yield. The latter suggests farmers may have flexibility in strip-till timing if tillage is conducted under the optimum field conditions at either timing. However, FST and SST were planted the same day, which could have contributed to the lack of differences. FST would likely have an advantage in planting date (i.e., FST planted before SST) on more poorly drained soils as compared to SST.

Few interactions were seen between Aspire™ application and tillage/ placement with plant K nutrient concentrations or contents throughout the growing season, but there were more frequent Aspire™ x tillage/ placement interactions for maize B concentration and content. This data suggests the interaction between Aspire™ application and tillage/ placement for maize may be rare in soils considered to have near optimum soil test K levels. Maize growth or nutrient benefits in the beginning of the growing season from the incorporation of Aspire™ fertilizer were infrequent, and few nutritional or grain yield differences were detected past R1 among fertilized tillage treatments. However, these conclusions were reached for maize in soils considered near optimum for plant-available K. Future research needs to incorporate the use of soils with varying soil K status to improve the understanding of responsiveness to K application placement. Soil recommendations regarding plant-available K have adapted over time but still require further investigation because higher yields were achieved following recent Aspire™ application even though soil K levels were considered adequate. This research adds to previous research by Bordoli and Mallarino (1998) from Iowa that also reported an increase in K uptake and grain yield from K application, even when the plant-available K status of the soil was considered to be above optimum.

The ability for R1 K concentration to explain the change in grain yield varied considerably among the site years. In site years with low r-squared values, it remains unclear what factor led to the poor relationship between R1 K concentration and grain yield. Although this relationship is influenced by K supplied through fertilizer application, the environment (i.e., moisture, K fixation, inherent K levels, etc.) has a large influence that changes each year. The range in values for R1 K concentration was considerable when comparing site years, showing the variability in K status for a single commercial hybrid across a multitude of environmental conditions. Earleaf B concentration at R1 varied considerably across growing seasons and showed only a small ability to explain the measured kernel weight and kernel number, making evident another factor would better explain the variation in grain yield.

4.3 Research Limitations

The field experiments discussed in Chapters 2 and 3 have limitations in their capacity to inform crop consultants about specific nutrient-management conclusions because of K and B co-application. Although increases in plant nutrient uptake following the addition of Aspire™ were common, it remains unclear if the grain yield increases were due to K, B, or both nutrients. Both nutrients are important during the critical period and grain filling, but we cannot know their contributions without separate treatments. Adding treatments with these individual nutrients (instead of only investigating Aspire™) will provide more insight into general fertility recommendations for K and B.

Reducing fertilizer rates in a strip-till system potentially has long-term consequences likely not seen in an experiment conducted only for a few years. Chapter 2 only looked at reduced fertilizer rates in a strip-till system for two maize years over a rotation cycle (maize-soybean), which is likely too short. To improve potential recommendations for farmers, experiments using reduced application rates need to have data collected over a longer period of time and at varying initial soil-test K levels (the overall soil K in the sites used was mostly moderate). A concern with reducing fertilizer rates is the mining of soil K resources and the lack of nutrient replacement upon removal.

Fertilizer rates used within this experiment were largely limited with only a 0 or 108 kg K ha^{-1} rate investigated for most tillage systems, while the intermediate rate of 54 kg K ha^{-1} rate was only employed in strip-till systems. To better understand the impact of Aspire™, more rates need to be included within the study, but high rates need to be monitored closely because of the potential long-term adverse effects from applying excessive amounts of B. By including more Aspire™ rates, identifying an optimum rate would help future management decisions.

In addition to limited fertilizer rates, this experiment was largely limited toda the tillage systems explored and could have incorporated more systems utilized by farmers in the Eastern Cornbelt (e.g., vertical tillage, deep ridging, deep ripping). Each tillage system used in this study had a specific soil disturbance component and fertilizer placement. Ideally, separating the effects of tillage from placement can be most reliably accomplished via the inclusion of distinct placement treatments within each tillage system. Timing of Aspire™ application was not considered within the FC or NT systems, with only a fall application for FC and spring broadcast for NT.rr Including treatments of spring-applied fertilizer before field cultivating in FC and fall broadcast in NT could have been beneficial for a better understanding of the timing effect in tillage systems other than strip-till.

An additional limitation of this research is the few hybrids utilized (i.e., four of five field experiments utilized a single hybrid). Previous research has documented differences in hybrid sensitivity to K and B; however, differences among commercial hybrids for these sensitivities are highly under-researched. Although the relative sensitivity of these hybrids to K and B is unknown, utilizing a multitude of hybrids would allow for improved descriptions of ideal management for maize in Eastern Cornbelt production systems.

4.4 Future Research Focus

Future research to address gaps in knowledge related to the research areas discussed could address a variety of issues. The research in this thesis focused on the co-application of K and B but failed to address the individual influence of the nutrients. Understanding how each nutrient influences maize production in the Eastern Cornbelt would help further management practice development.

With continued interest in reducing fertilizer rates by placing fertilizer within the intended crop-row with coulter-based strip-till, the establishment of long-term research with varied soil K status is necessary to understand future consequences to plant nutrition. Although not directly addressed within this research, the benefit/ consequences of moving tilled and fertilized strips over time is still largely unknown and remains to be investigated. The establishment of long-term experiments would allow for the understanding of the impacts on the cropping system when reducing K fertilizer rates over an extended time. Ideally, the factors controlling exchangeable K release from the soil in those experiments would also be monitored. Support of long-term tillage and fertility experiments needs to continue, as investment in long-term research has been significantly reduced. As with many agronomic questions, too little research documents long-term consequences and/or benefits for a management strategy.

Plant K concentrations provide some context for the potential limitations to growth, but this is commonly assessed near the R1 timing in maize. Future research should continue to strive for interpreting nutrient concentration at earlier growth stages (i.e., V6-10) to allow farmers to make corrective fertilizer applications if possible. An early indication of nutrient limitation is especially important for K as a majority of nutrient uptake in maize occurs prior to R1. K fertilizer efficiency is rarely documented in the current literature but would improve the understanding of how freshly applied K is utilized by the crop. Bell, Mallarino, et al. (2021) acknowledges the common perspective that over-application of K is commonly only a concern due to profitability and not environmental contamination. As farm budgets continue to tighten, understanding the K recovery efficiency and how it can be manipulated will continue to grow in importance. The K recovery efficiency can vary considerably and can be influenced by a variety of environmental conditions. Once again, this calls for the increased investment in K fertility research.

Some of the most practical work in the future could be in B fertility management because plant tissue B is considered a more reliable indicator of nutrient limitations than soil B. Because the silks and tassel depend on B for development and viability, sampling either component to understanding nutrient dynamics could allow for indexing of optimal B levels for improved B management. Measurement of silk number, diameter, or length could also be valuable to understand B influence on maize reproduction in a modern production setting. Management of B will likely increase in need as cropping intensity continues to grow throughout the Eastern Cornbelt. Because of the common inability for lab equipment to reach the low detection limit necessary for B, further inquiry into the effective analysis of B is necessary if field research wants to continue making progress in understanding the actual removal of B and other micronutrients.

Tillage and fertility management continues to be modified as researchers seek more efficient management practices. With the continual change in farming practices, the need for research incorporating relevant management practices (i.e., modern hybrids, plant densities, modern agricultural equipment, crop management, etc.) is of great importance to provide information necessary for continued agricultural advancement.

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APPENDIX A. CHAPTER 2 ADDITIONAL MEASUREMENTS

Table A.1. Example of code used for analyzing in-season measurements data using SAS Version 9.4

```
Proc Mixed Data=  aspire_physical_fstsst ;
By FieldYear;
Class Year Hybrid Block Tillage Aspire;
Model Pop_pph = Year|Tillage|Aspire/ outp=resid_c outpm=resid_m residual vciry ddfm=kr;
Random Block(Year) Hybrid;
run;

Proc GLIMMIX Data= aspire_physical_fstsst ;
By FieldYear;
Class Year Block Tillage Aspire Hybrid;
Model Pop_pph = Year|Tillage|Aspire/ ddfm=kr;
Random Block(Year) Hybrid;
LSMeans Tillage|Aspire / pdiff lines adjust = tukey alpha = 0.05 cl;
run;
```

FieldYear = Maize year
Hybrid = Corn hybrid used for site year
Block = Replications present within field
Tillage = Tillage timing
Aspire = Aspire™ rate
Year = Individual site year

Table A.2. Strip-till timing and Aspire™ rate impacts on final plant populations for MY1 (2016, 2017, and 2019 (PPAC)) and MY2 (2018 and 2019 (ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			Plant Population	
Tillage[1]	Aspire™		Plants ha^{-1}	
	kg K ha^{-1}	kg B ha^{-1}	MY1[2]	MY2[2]
FST	0	0	82400	78300
	54	0.5	83400	80300
	108	1.1	82000	80500
SST	0	0	82600	78700
	54	0.5	82900	79900
	108	1.1	82500	79100
FST			82600	79700
SST			82600	79200
	0	0	82500	78500
	54	0.5	83200	80100
	108	1.1	82200	79800
Site Year			ns	ns
Tillage			ns	ns
Site Year*Tillage			ns	ns
Aspire™			ns	ns
Site Year*Aspire™			ns	ns
Tillage*Aspire™			ns	ns
Site Year*Tillage*Aspire™			ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.3. Strip-till timing and Aspire™ rate impacts on V6 whole-plant nutrient concentrations for S, Zn, Mn, Fe, Cu, and Al for MY1 (2016, 2017, and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}	——————— mg kg^{-1} ———————				
FST	0	0	2.5	30 ab	38	158	12	69
	54	0.5	2.4	29 ab	34	135	13	67
	108	1.1	2.4	29 b	39	172	11	83
SST	0	0	2.3	28 ab	36	149	11	64
	54	0.5	2.3	29 ab	39	141	12	80
	108	1.1	2.4	33 a	41	173	13	88
FST			2.4	29	37	155	12	73
SST			2.3	30	39	155	12	77
	0	0	2.4	29	37	154 ab	12	66 b
	54	0.5	2.3	29	37	138 b	12	74 ab
	108	1.1	2.4	31	40	173 a	12	85 a
Site Year			***	**	**	ns	**	ns
Tillage			ns	ns	ns	ns	ns	ns
Site Year*Tillage			*	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	*	ns	ns
Site Year*Aspire™			*	ns	ns	ns	*	ns
Tillage*Aspire™			ns	**	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	*	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till

[2] MY = maize year

* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.4. Strip-till timing and Aspire™ rate impacts on V6 whole-plant nutrient concentrations for S, Zn, Mn, Fe, Cu, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}	——— mg kg^{-1} ———				
FST	0	0	2.3	30	53	342 ab	14 ab	161 ab
	54	0.5	2.3	31	49	316 b	14 ab	171 ab
	108	1.1	2.3	29	50	290 b	12 b	139 b
SST	0	0	2.4	30	57	601 a	16 a	310 a
	54	0.5	2.3	29	59	489 ab	14 ab	284 ab
	108	1.1	2.4	30	55	471 ab	15 ab	264 ab
FST			2.3	30	50	316 b	13 b	157 b
SST			2.3	30	57	520 a	15 a	286 a
	0	0	2.4	30	55	471	15	236
	54	0.5	2.3	30	54	403	14	228
	108	1.1	2.3	30	52	381	14	201
Site Year			ns	***	ns	*	***	**
Tillage			ns	ns	ns	***	*	****
Site Year*Tillage			ns	ns	ns	ns	*	*
Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.5. Strip-till timing and Aspire™ rate impacts on V6 whole-plant nutrient contents for S, Zn, Mn, Fe, Cu, and Al for MY1 (2016, 2017, and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}	———————— g ha^{-1} ————————				
FST	0	0	1.0	12	14	50 ab	5	23
	54	0.5	1.1	13	15	51 ab	6	25
	108	1.1	1.1	13	17	77 a	5	39
SST	0	0	0.8	10	12	48 ab	4	21
	54	0.5	0.9	11	14	44 b	4	26
	108	1.1	0.9	12	14	51 ab	5	27
FST			1.1 a	13 a	15 a	59 a	6	29
SST			0.9 b	11 b	14 b	48 b	5	25
	0	0	0.9	11	13	49	5	22 b
	54	0.5	1.0	12	14	48	5	25 ab
	108	1.1	1.0	13	15	64	5	33 a
Site Year			***	**	ns	****	**	**
Tillage			**	*	*	*	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	*	ns	*
Site Year*Aspire™			ns	ns	ns	ns	ns	*
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	**	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till

[2] MY = maize year

* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.6. Strip-till timing and Aspire™ rate impacts on V6 whole-plant nutrient contents for S, Zn, Mn, Fe, Cu, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}	——— g ha^{-1} ———				
FST	0	0	1.3 ab	16	30	187 b	8 ab	86 b
	54	0.5	1.5 a	20	30	194 ab	10 a	99 ab
	108	1.1	1.6 a	19	33	190 ab	9 ab	88 b
SST	0	0	1.3 ab	16	29	295 a	8 ab	153 a
	54	0.5	1.4 ab	17	35	279 ab	8 ab	158 a
	108	1.1	1.2 b	15	27	212 ab	7 b	117 ab
FST			1.5 a	18 a	31	190 b	9	91 b
SST			1.3 b	16 b	30	262 a	8	143 a
	0	0	1.3	16	29	241	8	119
	54	0.5	1.5	19	33	236	9	129
	108	1.1	1.4	17	30	201	8	103
Site Year			*	ns	ns	ns	**	*
Tillage			*	*	ns	**	ns	****
Site Year*Tillage			ns	ns	ns	*	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Aspire™			*	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	*	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.7. Strip-till timing and Aspire™ rate impacts on maize nutrient concentrations in the earleaf at R1 for S, Zn, Mn, Fe, Cu, and Al for MY1 (2016, 2017, and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}	——— mg kg^{-1} ———				
FST	0	0	2.1 a	25	52 a	100	11 ab	9
	54	0.5	2.0 b	27	40 ab	98	10 b	10
	108	1.1	2.1 ab	27	50 ab	99	11 a	5
SST	0	0	2.0 ab	24	36 b	97	10 ab	11
	54	0.5	2.1 ab	27	48 ab	99	12 a	8
	108	1.1	2.0 ab	27	46 ab	100	11 ab	8
FST			2.1	26	47	99	11	8
SST			2.1	26	43	99	11	9
	0	0	2.1	25 b	44	99	10	10
	54	0.5	2.0	27 a	44	99	11	9
	108	1.1	2.1	27 a	48	100	11	6
Site Year			ns	**	**	*	****	ns
Tillage			ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	*	ns	ns	ns	ns
Aspire™			ns	*	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	*
Tillage*Aspire™			**	ns	**	ns	**	ns
Site Year*Tillage*Aspire™			ns	ns	*	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.8. Strip-till timing and Aspire™ rate impacts on maize nutrient concentrations in the earleaf at R1for S, Zn, Mn, Fe, Cu, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}	——— mg kg^{-1} ———				
FST	0	0	1.8	24	52	100	10	15
	54	0.5	1.7	24	44	96	10	9
	108	1.1	1.9	25	48	96	11	6
SST	0	0	1.8	24	40	97	10	9
	54	0.5	1.8	24	43	92	10	13
	108	1.1	1.8	24	54	93	10	20
FST			1.8	24	48	97	10	10
SST			1.8	24	46	94	10	14
	0	0	1.8	24	46	99	10	12
	54	0.5	1.7	24	44	94	10	11
	108	1.1	1.8	24	51	95	11	13
Site Year			*	ns	ns	*	ns	**
Tillage			ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	***	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	*
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	*

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.9. Strip-till timing and Aspire™ rate impacts on maize R1 specific leaf nutrient contents for S, Zn, Mn, Fe, Cu, and Al for MY1 (2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	g m^{-2}	——— mg m^{-2} ———				
FST	0	0	0.2	1.9	1.8	7.5	0.7	1.0
	54	0.5	0.2	2.1	1.9	7.7	0.7	1.0
	108	1.1	0.1	2.0	1.9	6.9	0.7	0.8
SST	0	0	0.2	2.0	2.1	7.5	0.7	0.7
	54	0.5	0.2	2.2	2.2	7.2	0.8	0.5
	108	1.1	0.1	2.2	2.4	7.4	0.7	0.7
FST			0.2	2.0	1.9	7.4	0.7	0.9 a
SST			0.2	2.1	2.2	7.4	0.7	0.6 b
	0	0	0.2	2.0	1.9	7.5	0.7	0.8
	54	0.5	0.2	2.1	2.0	7.5	0.7	0.8
	108	1.1	0.1	2.1	2.2	7.1	0.7	0.7
Tillage			ns	ns	ns	ns	ns	**
Aspire™			ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.10. Strip-till timing and Aspire™ rate impacts on maize R1 specific leaf content of S, Zn, Mn, Fe, Cu, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	g m^{-2}	———————— mg m^{-2} ————————				
FST	0	0	0.1	1.6	3.5	6.9	0.7	1.0
	54	0.5	0.1	1.6	2.9	6.4	0.7	0.6
	108	1.1	0.1	1.6	3.2	6.4	0.7	0.4
SST	0	0	0.1	1.6	2.7	6.7	0.7	0.6
	54	0.5	0.1	1.6	2.9	6.1	0.7	0.8
	108	1.1	0.1	1.6	3.6	6.3	0.7	1.3
FST			0.1	1.6	3.2	6.6	0.7	0.7
SST			0.1	1.6	3.1	6.4	0.7	0.9
	0	0	0.1	1.6	3.1	6.8	0.7	0.8
	54	0.5	0.1	1.6	2.9	6.2	0.7	0.7
	108	1.1	0.1	1.6	3.4	6.3	0.7	0.8
Site Year			****	ns	ns	***	ns	**
Tillage			ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	**	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	*
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	*

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.11. Strip-till timing and Aspire™ rate impacts on maize R6 grain nutrient contents for S, Zn, Mn, Fe, Cu, and Al for MY1 (2016 and 2019(PPAC)). Mean separation for strip-till x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}	——— g ha^{-1} ———				
FST	0	0	8.5 ab	192 ab	57	181 b	16	10 b
	54	0.5	8.0 b	181 b	47	187 b	20	44 ab
	108	1.1	9.4 ab	211 a	55	203 ab	25	81 ab
SST	0	0	9.2 ab	208 ab	51	186 b	19	133 a
	54	0.5	9.4 ab	219 a	61	222 ab	24	131 a
	108	1.1	9.8 a	222 a	66	244 a	23	91 ab
FST			8.7 b	195 b	53	190 a	20	45 b
SST			9.5 a	217 a	59	217 a	22	118 a
	0	0	8.9 a	200 a	54	183 b	18	72
	54	0.5	8.7 a	200 a	54	204 ab	22	87
	108	1.1	9.6 a	216 a	61	223 a	24	86
Site Year			*	ns	ns	ns	ns	****
Tillage			*	**	ns	ns	ns	**
Site Year*Tillage			ns	ns	ns	ns	ns	**
Aspire™			ns	ns	ns	**	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table A.12. Strip-till timing and Aspire™ rate impacts on maize R6 grain nutrient content for S, Zn, Mn, Fe, Cu, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}	——— g ha^{-1} ———				
FST	0	0	8.9	224	59 ab	189	16	167
	54	0.5	7.8	223	51 b	187	15	125
	108	1.1	10.1	267	87 a	253	20	75
SST	0	0	9.1	231	52 b	185	18	75
	54	0.5	8.7	237	70 ab	265	16	135
	108	1.1	9.9	263	69 ab	258	18	118
FST			8.9	238	66 a	210	17	122
SST			9.2	244	64 a	238	18	111
	0	0	9.0 ab	227 b	56 b	187	17	124
	54	0.5	8.2 b	230 b	61 b	226	16	130
	108	1.1	10.0 a	265 a	78 a	256	19	97
Site Year			ns	ns	*	ns	ns	***
Tillage			ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns
Aspire™			*	**	**	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	*	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	*	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.13. Strip-till timing and Aspire™ rate impacts on maize total nutrient contents (sum of grain, cob, and stover contents) for S, Zn, Mn, Fe, Cu, and Al for MY1 (2016 and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}	———— g ha^{-1} ————				
FST	0	0	14.7	349	507	910	63	378 b
	54	0.5	13.3	342	283	1139	64	490 b
	108	1.1	15.4	383	501	1049	77	444 b
SST	0	0	14.7	364	329	952	63	508 ab
	54	0.5	15.3	375	392	1318	70	725 ab
	108	1.1	16.0	413	480	1651	74	913 a
FST			14.5	358	430	1033	68	437 b
SST			15.3	384	400	1307	69	715 a
	0	0	14.7	357	418	931	63	443 b
	54	0.5	14.3	359	338	1228	67	607 ab
	108	1.1	15.7	398	490	1350	75	678 a
Site Year			***	****	****	**	*	ns
Tillage			ns	ns	ns	ns	ns	**
Site Year*Tillage			ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	*
Site Year*Aspire™			ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table A.14. Strip-till timing and Aspire™ rate impacts on maize R6 total nutrient content (sum of grain, cob, and stover contents) for S, Zn, Mn, Fe, Cu, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}	——— g ha^{-1} ———				
FST	0	0	15.2	412	488	1759	72	885
	54	0.5	13.0	403	385	1932	62	979
	108	1.1	16.5	445	558	1678	78	836
SST	0	0	14.2	397	379	1990	73	1162
	54	0.5	14.6	413	459	2188	70	1268
	108	1.1	16.7	447	517	2113	80	1266
FST			14.9	420	477	1790	71	900 b
SST			15.2	419	452	2097	74	1232 a
	0	0	14.7 ab	404	433 ab	1875	73 ab	1024
	54	0.5	13.8 b	408	422 b	2060	66 b	1123
	108	1.1	16.6 a	446	538 a	1895	79 a	1051
Site Year			ns	****	**	***	*	****
Tillage			ns	ns	ns	*	ns	**
Site Year*Tillage			ns	*	ns	ns	ns	*
Aspire™			*	ns	*	ns	*	ns
Site Year*Aspire™			ns	ns	*	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.15. Strip-till timing and Aspire™ rate impacts on maize harvest index of N, P, Ca, Mg, S, Zn, Mn, Fe, Cu, and Al for MY1 (2016, and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]									
Tillage[1]	Aspire™		N	P	Ca	Mg	S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	%									
FST	0	0	63.2	86.1	4.9	50.7	61.6	57.9	19.7	21.1	25.3	3.0
	54	0.5	63.6	84.2	4.3	41.9	60.7	54.5	19.8	19.0	33.7	13.4
	108	1.1	63.3	87.3	4.6	47.9	63.1	56.7	16.8	20.1	31.0	16.7
SST	0	0	64.3	86.9	5.4	50.0	64.4	57.0	21.2	18.1	28.4	29.6
	54	0.5	65.3	87.0	4.7	47.0	64.8	59.0	19.6	17.9	33.6	23.0
	108	1.1	63.8	86.9	4.2	45.2	64.8	56.2	17.2	16.9	31.6	13.2
FST			63.4	85.9	4.6	46.8	61.8 b	56.4	18.8	20.0	30.0	11.1
SST			64.4	87.0	4.8	47.4	64.6 a	57.4	19.4	17.6	31.2	21.9
	0	0	63.7	86.5	5.1 a	50.4	63.0	57.4	20.5	19.6	26.8	16.3
	54	0.5	64.4	85.6	4.5 b	44.5	62.7	56.8	19.7	18.4	33.6	18.2
	108	1.1	63.6	87.1	4.4 b	46.6	63.9	56.4	17.0	18.5	31.3	15.0
Site Year			ns	**	ns	***	****	****	****	ns	ns	***
Tillage			ns	ns	ns	ns	*	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	*	ns	ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.16. Strip-till timing and Aspire™ rate impacts on maize harvest index of N, P, Ca, Mg, S, Zn, Mn, Fe, Cu, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY2[2]									
Tillage[1]	Aspire™		N	P	Ca	Mg	S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	------ % ------									
FST	0	0	61.5	84.0	3.5	31.5	58.4	55.3 ab	13.2	12.7	22.4	17.9
	54	0.5	62.6	84.1	3.5	30.7	60.0	56.3 ab	14.6	12.0	24.0	13.6
	108	1.1	63.0	86.3	3.8	38.1	61.5	61.2 a	17.1	16.2	27.3	8.6
SST	0	0	62.0	83.0	3.6	30.8	58.9	54.6 b	15.0	10.9	24.0	9.8
	54	0.5	62.7	84.3	3.5	32.3	59.1	57.6 ab	16.0	14.4	22.7	11.6
	108	1.1	62.9	85.6	3.5	35.7	59.5	59.4 ab	15.6	13.5	23.5	8.9
FST			62.4	84.8	3.6	33.4	60.0	57.6	15.0	13.6	24.6	13.4
SST			62.6	84.4	3.5	33.0	59.2	57.3	15.5	13.0	23.4	10.1
	0	0	61.8	83.5 b	3.5	31.2 b	58.7	55.0 b	14.0	11.8	23.2	14.1
	54	0.5	62.6	84.2 ab	3.5	31.5 b	59.6	57.0 b	15.3	13.2	23.4	12.6
	108	1.1	62.9	86.0 a	3.7	36.9 a	60.5	60.3 a	16.4	14.9	25.4	8.8
Site Year			ns	****	****	ns	**	***	ns	**	****	****
Tillage			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	*	ns	ns	*	ns	ns	ns	ns
Aspire™			ns	*	ns	*	ns	**	ns	ns	ns	ns
Site Year*Aspire™			*	ns	ns	ns	ns	ns	ns	ns	*	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table A.17. Strip-till timing and Aspire™ rate impacts on maize R6 grain nutrient concentrations of N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY1 (2016 and 2019 (PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]											
Tillage[1]	Aspire™		N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	——— g kg^{-1} ———						——— mg kg^{-1} ———					
FST	0	0	11.6	3.1	4.3	0.1	1.4	0.9	20	6	19 b	2	2	1
	54	0.5	11.6	3.0	4.2	0.1	1.4	0.9	20	5	20 ab	2	3	4
	108	1.1	11.6	3.2	4.4	0.1	1.4	0.9	21	6	21 ab	3	2	6
SST	0	0	11.3	3.3	4.3	0.1	1.6	0.9	21	5	19 b	2	2	10
	54	0.5	11.8	3.4	4.7	0.1	1.5	0.9	21	6	22 ab	2	2	10
	108	1.1	12.0	3.6	4.7	0.1	1.5	1.0	22	7	25 a	2	2	8
FST			11.6	3.1 b	4.3	0.1	1.4	0.9	20 b	6	20	2	2	4 b
SST			11.7	3.4 a	4.6	0.1	1.5	0.9	22 a	6	22	2	2	9 a
	0	0	11.4	3.2	4.3	0.1	1.5	0.9	21	6	19 b	2	2 b	6
	54	0.5	11.7	3.2	4.4	0.1	1.4	0.9	20	6	21 ab	2	2 a	7
	108	1.1	11.8	3.4	4.6	0.1	1.5	0.9	22	6	23 a	2	2 ab	7
Site Year			****	****	ns		****	****	***	**	***	*	****	****
Tillage			ns	*	ns		ns	ns	*	ns	ns	ns	ns	**
Site Year*Tillage			ns	ns	ns		ns	ns	ns	ns	ns	ns	ns	**
Aspire™			ns	ns	ns		ns	ns	ns	ns	*	ns	*	ns
Site Year*Aspire™			ns	ns	ns		ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns		ns	ns	ns	ns	ns	ns	ns	ns
Site Year * Tillage * Aspire™			ns	ns	ns		ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.18. Strip-till timing and Aspire™ rate impacts on maize R6 grain nutrient concentration of N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]											
Tillage[1]	Aspire™		N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}						mg kg^{-1}					
FST	0	0	10.8 ab	2.8	4.8	0.1	1.2	0.7	19	5 ab	16	1	1	12
	54	0.5	10.9 a	2.9	5.0	0.1	1.2	0.7	20	5 ab	17	1	1	10
	108	1.1	10.9 a	3.2	5.4	0.1	1.2	0.8	21	7 a	20	2	1	6
SST	0	0	10.2 b	2.8	4.8	0.1	1.1	0.7	18	4 b	15	1	1	5
	54	0.5	11.3 a	3.1	5.3	0.1	1.2	0.7	20	6 ab	22	1	1	10
	108	1.1	11.3 a	3.2	5.4	0.1	1.3	0.8	21	6 ab	21	2	1	10
FST			10.9	2.9	5.0	0.1	1.2	0.7	20	5	18	1	1	9
SST			10.9	3.0	5.1	0.1	1.2	0.7	20	5	19	1	1	9
	0	0	10.5 b	2.8 b	4.8 b	0.1	1.1 b	0.7	19 b	5 b	15 b	1	1	9
	54	0.5	11.1 a	3.0 ab	5.1 ab	0.1	1.2 ab	0.7	20 ab	5 ab	19 ab	1	1	10
	108	1.1	11.1 a	3.2 a	5.4 a	0.1	1.2 a	0.8	21 a	6 a	20 a	2	1	8
Site Year			ns	ns	**		**	****	*	ns	ns	***		***
Tillage			ns	ns	ns		ns	ns	ns	ns	ns	ns		ns
Site Year*Tillage			ns	ns	ns		ns	ns	ns	ns	ns	ns		ns
Aspire™			***	*	**		*	*	**	*	*	ns		ns
Site Year*Aspire™			ns	ns	ns		ns	ns	ns	ns	ns	ns		ns
Tillage*Aspire™			**	ns	ns		ns	ns	ns	*	ns	ns		ns
Site Year*Tillage*Aspire™			ns	ns	ns		ns	ns	ns	ns	ns	ns		ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.19. Strip-till timing and Aspire™ rate impacts on maize stover (includes: stems, leaves, and husk) concentration at R6 for N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY1 (2016, 2017, and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]											
Tillage[1]	Aspire™		N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	——— g kg^{-1} ———						——— mg kg^{-1} ———					
FST	0	0	9.0	0.8	11.0	3.7	2.7	0.8	19	55	147	6	5	78
	54	0.5	8.6	0.8	9.8	3.8	3.2	0.8	20	40	196	6	5	87
	108	1.1	9.0	0.7	11.5	3.7	2.8	0.8	19	58	179	7	6	90
SST	0	0	8.5	0.8	10.5	3.6	2.9	0.7	20	42	155	6	5	73
	54	0.5	8.8	0.7	11.0	3.9	3.3	0.7	19	43	196	6	5	101
	108	1.1	8.7	0.7	11.7	3.9	3.1	0.7	20	49	231	7	6	136
FST			8.9	0.8	10.8	3.7	2.9	0.8	20	51	174	7	5	85
SST			8.7	0.7	11.1	3.8	3.1	0.7	20	45	194	7	5	103
	0	0	8.7	0.8	10.8	3.6	2.8	0.8	20	49	151	6	5	75
	54	0.5	8.7	0.7	10.4	3.9	3.2	0.8	20	41	196	6	5	94
	108	1.1	8.9	0.7	11.6	3.8	2.9	0.8	20	54	205	7	6	113
Site Year			ns	*	****	***	***	****	**	*	****	ns	****	****
Tillage			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns
Site Year*Aspire™			*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.20. Strip-till timing and Aspire™ rate impacts on maize stover (includes: stems, leaves, and husk) nutrient concentrations at R6 for N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY2[2]											
Tillage[1]	Aspire™		N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	——— g kg^{-1} ———						——— mg kg^{-1} ———					
FST	0	0	9.0	0.7	10.4	4.5	4.0	0.7	21	53	210	7	5	95
	54	0.5	7.9	0.7	10.4	4.1	3.7	0.6	19	41	224	5	5	108
	108	1.1	8.5	0.7	12.9	4.0	3.2	0.7	19	55	178	6	5	96
SST	0	0	8.2	0.7	9.6	4.3	3.9	0.7	20	40	216	6	5	130
	54	0.5	8.4	0.8	11.6	4.3	3.8	0.7	19	47	239	6	5	141
	108	1.1	8.5	0.7	12.9	4.2	3.5	0.7	19	50	222	7	6	136
FST			8.5	0.7	11.3	4.2	3.6	0.7	20	50	204	6	5	100 b
SST			8.4	0.7	11.4	4.2	3.7	0.7	20	46	226	6	5	135 a
	0	0	8.6	0.7	10.0 b	4.4	3.9 a	0.7	21	46	213	6	5	113
	54	0.5	8.1	0.7	11.0 ab	4.2	3.7 ab	0.6	19	44	232	6	5	124
	108	1.1	8.5	0.7	12.9 a	4.1	3.4 b	0.7	19	53	200	6	5	116
Site Year			**	***	***	***	***	**	***	*	***	***	ns	***
Tillage			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	**
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
Aspire™			ns	ns	**	ns	*	ns	ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table A.21. Strip-till timing and Aspire™ rate impacts on maize stover (includes: stems, leaves, and husks) dry matter (kg ha^{-1}) and nutrient uptake at R6 for N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY1 (2016 and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]												
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	——— kg ha^{-1} ———							——— g ha^{-1} ———					
FST	0	0	6825	66.7	6.0	84.5	28.1	21.1	5.9	147	448	1119 b	49	42	599 ab
	54	0.5	6927	62.4	5.8	76.2	28.4	24.2	5.6	147	317	1381 ab	47	40	641 ab
	108	1.1	7046	66.4	5.4	87.6	28.2	21.4	5.8	143	454	1328 ab	51	47	697 ab
SST	0	0	6966	60.9	5.9	77.2	26.3	21.9	5.3	145	321	1094 b	45	40	523 b
	54	0.5	7419	68.0	5.7	88.2	30.9	26.3	5.9	152	349	1435 ab	50	40	785 ab
	108	1.1	7466	69.5	6.0	93.4	31.0	25.1	6.0	156	400	1800 a	55	48	1088 a
FST			6933	65.2	5.7	82.8	28.2	22.2	5.8	146	406	1276	49	43	646
SST			7283	66.1	5.9	86.3	29.4	24.4	5.7	151	357	1443	50	42	799
	0	0	6896	63.8	6.0	80.9	27.2	21.5	5.6	146	385	1106 b	47	41	561
	54	0.5	7173	65.2	5.8	82.2	29.6	25.2	5.8	150	333	1408 ab	48	40	713
	108	1.1	7256	68.0	5.7	90.5	29.6	23.2	5.9	149	427	1564 a	53	47	892
Site Year			****	**	**	****	***	***	**	****	**	****	**	***	****
Tillage			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	*	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.22. Strip-till timing and Aspire™ rate impacts on maize stover (includes: stems, leaves, and husks) dry matter (kg ha^{-1}) and uptake at R6 for N (kg ha^{-1}), P (kg ha^{-1}), K (kg ha^{-1}), Ca (kg ha^{-1}), Mg (kg ha^{-1}), S (kg ha^{-1}), Zn (g ha^{-1}), Mn (g ha^{-1}), Fe (g ha^{-1}), Cu (g ha^{-1}), B (g ha^{-1}), and Al (g ha^{-1}) for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]												
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	——— kg ha^{-1} ———							——— g ha^{-1} ———					
FST	0	0	7728	70.2	5.8	83.9 ab	34.3	30.3	5.6 ab	165	421	1546	51	42	702
	54	0.5	7886	62.2	5.3	82.9 ab	32.0	28.9	4.6 b	154	327	1719	42	39	838
	108	1.1	8176	70.5	5.6	109.4 ab	32.0	25.9	5.6 ab	155	460	1402	53	40	757
SST	0	0	8293	68.1	6.2	78.7 b	35.4	32.3	5.5 ab	168	326	1799	52	43	1090
	54	0.5	8007	67.2	6.1	92.4 ab	34.4	30.3	5.2 ab	155	378	1894	48	40	1114
	108	1.1	8534	73.1	6.1	114.0 a	35.1	29.0	6.0 a	164	439	1829	56	49	1117
FST			7930	67.6	5.6	92.1	32.8	28.3	5.2	158	403	1555 b	49	40	766 b
SST			8278	69.5	6.1	95.0	35.0	30.5	5.6	162	381	1841 a	52	44	1107 a
	0	0	8011	69.1	6.0	81.3 b	35.0	31.3 a	5.6 ab	166	373	1672	51 ab	42	896
	54	0.5	7946	64.7	5.7	87.7 b	33.2	29.6 ab	4.9 b	154	353	1806	45 b	40	976
	108	1.1	8355	71.8	5.9	111.7 a	33.6	27.4 b	5.8 a	160	449	1615	54 a	45	937
Site Year			*	**	***	***	*	*	**	***	**	***	****	*	****
Tillage			ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	***
Site Year*Tillage			*	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	**
Aspire™			ns	ns	ns	**	ns	ns	*	ns	ns	ns	*	ns	ns
Site Year*Aspire™			*	*	ns	ns	ns	ns	*	ns	*	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1] FST = fall strip-till, SST = spring strip-till

[2] MY = maize year

* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.23. Strip-till timing and Aspire™ rate impacts on maize cob nutrient concentration at R6 for N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY1 (2016 and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]											
Tillage[1]	Aspire™		N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	—— g kg^{-1} ——						—— mg kg^{-1} ——					
FST	0	0	6.9 ab	0.4 bc	9.3 b	0.1 b	0.1	0.5 ab	14 ab	6 b	15 bc	4	1 bc	2 b
	54	0.5	7.7 a	0.5 abc	10.4 a	0.2 a	0.2	0.5 a	12 b	7 ab	25 a	4	2 a	2 b
	108	1.1	7.1 ab	0.4 c	8.8 bc	0.2 a	0.1	0.4 c	14 ab	7 ab	19 b	4	2 ab	2 ab
SST	0	0	6.9 ab	0.6 ab	8.7 bc	0.1 b	0.2	0.5 bc	16 a	10 a	16 bc	4	1 c	5 a
	54	0.5	7.4 a	0.6 a	8.2 c	0.2 a	0.2	0.5 bc	16 a	8 ab	19 b	3	3 a	4 ab
	108	1.1	6.6 b	0.5 abc	8.8 bc	0.1 b	0.1	0.4 c	15 a	6 b	13 c	4	2 ab	1 b
FST			7.2	0.5 b	9.5 a	0.1 a	0.1	0.5 a	14 b	7	20 b	4	2	2 b
SST			7.0	0.5 a	8.6 b	0.1 b	0.2	0.5 b	16 a	8	16 a	4	2	3 a
	0	0	6.9 b	0.5 ab	9.0 ab	0.1 c	0.2 ab	0.5 a	15	8	16 b	4	1 c	3
	54	0.5	7.6 a	0.6 a	9.3 a	0.2 a	0.2 a	0.5 a	14	7	22 a	4	3 a	3
	108	1.1	6.8 b	0.4 b	8.8 b	0.1 b	0.1 b	0.4 b	15	7	16 b	4	2 b	2
Tillage			ns	**	****	*	ns	**	****	ns	***	ns	ns	*
Aspire™			***	**	**	****	*	***	ns	ns	****	ns	****	ns
Tillage*Aspire™			ns	ns	****	**	ns	ns	ns	*	**	ns	ns	**

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.24. Strip-till timing and Aspire™ rate impacts on maize cob nutrient concentration at R6 for N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY2 (2018 and 2019 (ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]											
Tillage[1]	Aspire™		N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}						mg kg^{-1}					
FST	0	0	8.9 b	0.7 ab	11.3 a	0.2 c	0.4 b	0.7 a	20 ab	7 c	19 ab	5	2 a	13 ab
	54	0.5	8.3 c	0.6 b	10.2 b	0.2 bc	0.5 ab	0.5 c	21 a	6 c	22 ab	4	1 b	13 ab
	108	1.1	9.1 ab	0.6 b	10.7 ab	0.2 bc	0.5 ab	0.6 b	18 ab	9 ab	18 b	4	2 a	4 b
SST	0	0	9.5 a	0.8 a	11.3 a	0.3 ab	0.5 a	0.6 b	20 a	6 c	23 ab	4	1 b	5 b
	54	0.5	9.1 c	0.6 b	10.0 b	0.3 a	0.4 b	0.6 b	18 ab	10 a	24 a	5	2 a	17 a
	108	1.1	8.6 bc	0.6 b	11.4 a	0.2 bc	0.4 b	0.6 b	16 b	7 bc	20 ab	5	2 a	24 a
FST			8.8 b	0.6	10.7	0.2 b	0.4	0.6 b	19	7	20 b	4	1	10 b
SST			9.1 a	0.6	10.9	0.3 a	0.4	0.6 a	18	7	22 a	4	1	15 a
	0	0	9.2 a	0.7 a	11.3 a	0.2 b	0.5	0.6 a	20 a	6 b	21 ab	4	1 b	9
	54	0.5	8.7 b	0.6 b	10.1 b	0.3 a	0.4	0.6 c	19 a	8 a	23 a	4	1 b	15
	108	1.1	8.9 b	0.6 b	11.0 a	0.2 b	0.4	0.6 b	17 b	8 a	19 b	4	2 a	14
Tillage			**	ns	ns	****	ns	**	ns	ns	*	ns	ns	*
Aspire™			***	****	****	**	ns	****	**	***	*	ns	*	ns
Tillage*Aspire™			****	*	*	**	****	****	ns	****	ns	***	****	****

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.25. Strip-till timing and Aspire™ rate impacts on maize cob dry matter and uptake at R6 for N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY1 (2016 and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]						
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	S
	kg K ha^{-1}	kg B ha^{-1}	——— kg ha^{-1} ———						
FST	0	0	1112	7.4 b	0.5 c	10.1	0.1 b	0.1 b	0.5 ab
	54	0.5	1088	7.8 ab	0.6 b	10.6	0.2 a	0.2 a	0.5 a
	108	1.1	1140	8.1 ab	0.5 c	10.0	0.2 a	0.2 b	0.5 ab
SST	0	0	1122	7.8 ab	0.7 a	9.8	0.1 b	0.2 a	0.5 a
	54	0.5	1188	8.6 a	0.7 a	9.5	0.2 a	0.2 a	0.5 a
	108	1.1	1140	7.1 b	0.5 c	9.6	0.1 b	0.2 b	0.2 b
FST			1113	7.8	0.5 b	10.2	0.2 a	0.2 b	0.5
SST			1150	7.8	0.6 a	9.6	0.1 b	0.2 a	0.5
	0	0	1117	7.6 ab	0.6 b	9.9	0.1 c	0.2 b	0.5 a
	54	0.5	1138	8.2 a	0.6 a	10.0	0.2 a	0.2 a	0.5 a
	108	1.1	1140	7.6 b	0.5 c	9.8	0.2 b	0.2 c	0.2 b
Site Year			****	***	****	****	***	****	****
Tillage			ns	ns	****	ns	*	****	ns
Site Year*Tillage			ns	**	****	ns	**	****	***
Aspire™			ns	*	****	ns	****	****	**
Site Year*Aspire™			ns	*	****	ns	****	****	*
Tillage*Aspire™			ns	**	****	ns	****	****	ns
Site Year*Tillage*Aspire™			ns	ns	****	ns	****	****	**

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.26. Strip-till timing and Aspire™ rate impacts on maize cob uptake at R6 for Zn, Mn, Fe, Cu, B, and Al for MY1 (2016 and 2019(PPAC)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]					
Tillage[1]	Aspire™		Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	g ha^{-1}					
FST	0	0	15 bc	6 d	16 cd	4 b	1 d	2 d
	54	0.5	13 c	7 d	25 a	4 b	2 b	2 d
	108	1.1	16 ab	8 c	21 ab	5 a	2 bc	3 c
SST	0	0	18 a	11 a	18 bc	4 a	1 e	6 a
	54	0.5	18 a	9 b	21 abc	4 ab	3 a	5 b
	108	1.1	17 a	6 d	14 d	4 b	2 c	1 e
FST			15 b	7 b	21 a	4	2	2 b
SST			17 a	9 a	18 b	4	2	4 a
	0	0	16 ab	9 a	17 b	4	1 c	4 a
	54	0.5	15 b	8 b	23 a	4	3 a	3 b
	108	1.1	16 a	7 b	18 b	4	2 b	2 c
Site Year			***	*	***	ns	****	****
Tillage			****	****	***	ns	ns	****
Site Year*Tillage			ns	****	ns	**	ns	****
Aspire™			*	****	***	ns	****	****
Site Year*Aspire™			ns	****	****	*	****	****
Tillage*Aspire™			**	****	***	****	****	****
Site Year*Tillage*Aspire™			****	****	ns	***	****	****

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table A.27. Strip-till timing and Aspire™ rate impacts on maize cob dry matter and nutrient uptake at R6 for N, P, K, Ca, Mg, and S for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]						
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	S
	kg K ha^{-1}	kg B ha^{-1}	——— kg ha^{-1} ———						
FST	0	0	1221	10.9 bc	0.8 b	13.7 ab	0.2 c	0.5 c	0.8 a
	54	0.5	1227	10.1 c	0.7 b	12.5 bc	0.3 b	0.6 bc	0.6 b
	108	1.1	1288	11.7 ab	0.8 b	13.7 abc	0.3 b	0.6 b	0.8 a
SST	0	0	1333	12.6 a	1.0 a	15.0 a	0.3 a	0.7 a	0.8 a
	54	0.5	1212	11.0 bc	0.7 b	12.0 c	0.4 a	0.5 c	0.7 a
	108	1.1	1317	11.3 abc	0.7 b	14.9 a	0.3 b	0.5 bc	0.8 a
FST			1245	10.9 b	0.8 b	13.3 b	0.2 b	0.5	0.7 b
SST			1288	11.7 a	0.8 a	14.0 a	0.3 a	0.6	0.8 a
	0	0	1277	11.7 a	0.9 a	14.4 a	0.3 b	0.6 a	0.8 a
	54	0.5	1220	10.6 b	0.7 b	12.2 b	0.3 a	0.5 b	0.7 b
	108	1.1	1303	11.5 a	0.7 b	14.3 a	0.2 b	0.6 ab	0.8 a
Site Year			ns	ns	ns	ns	***	***	ns
Tillage			ns	**	*	*	****	ns	*
Site Year*Tillage			ns	ns	ns	ns	***	**	ns
Aspire™			ns	**	****	****	****	*	****
Site Year*Aspire™			ns	*	****	ns	****	****	ns
Tillage*Aspire™			ns	*	****	ns	****	****	*
Site Year*Tillage*Aspire™			ns	ns	***	*	****	ns	ns

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.28. Strip-till timing and Aspire™ rate impacts on maize cob nutrient uptake at R6 for Zn, Mn, Fe, Cu, B, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for strip-till timing x Aspire™, strip-till timing, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]					
Tillage[1]	Aspire™		Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	——— g ha^{-1} ———					
FST	0	0	24 abc	8 c	23 bc	5 ab	2 a	16 c
	54	0.5	25 ab	7 d	27 ab	5 b	1 b	15 c
	108	1.1	22 bcd	11 a	23 c	5 b	2 a	4 d
SST	0	0	26 a	7 cd	30 a	5 ab	1 b	6 d
	54	0.5	22 cd	11 a	29 a	5 ab	2 a	19 b
	108	1.1	21 d	9 b	26 bc	6 a	2 a	30 a
FST			24	9 b	24 b	5 b	2	12 b
SST			23	9 a	28 a	6 a	2	18 a
	0	0	25 a	8 c	26 a	5	2 b	11 b
	54	0.5	23 a	9 b	28 a	5	2 b	17 a
	108	1.1	21 b	10 a	24 b	6	2 a	17 a
Site Year			ns	***	**	*	****	****
Tillage			ns	**	****	**	ns	****
Site Year*Tillage			****	**	****	****	ns	****
Aspire™			****	****	***	ns	****	****
Site Year*Aspire™			****	**	****	***	****	****
Tillage*Aspire™			***	****	*	*	****	****
Site Year*Tillage*Aspire™			ns	****	****	ns	****	****

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table A.29. Expanded table details for the Site Year x Tillage x Aspire™ interactions from Tables 2.9, 2.10, and 2.14 Different letters indicate statistical differences at p<0.05.

				MY1[2]			
	Tillage[1]	Aspire™		Silking to 50%	R1 K	R1 B	R6 Grain K Content
Site Year		kg K ha^{-1}	kg B ha^{-1}	days	(g kg^{-1})	(mg kg^{-1})	(kg ha^{-1})
2016	FST	0	0		23.0 abcd	8 abcde	58.34 ab
		54	0.5		21.9 abcde	9 ab	49.69 bcd
		108	1.1		23.8 abc	6 bcdef	66.81 a
	SST	0	0		21.2 abcde	6 abcdef	56.37 abc
		54	0.5		26.7 a	9 abc	66.36 a
		108	1.1		26.1 ab	10 a	57.66 ab
2017	FST	0	0	86 ab	13.6 f	4 f	
		54	0.5	86 ab	18.2 cdef	5 cdef	
		108	1.1	85 b	18.2 cde	5 def	
	SST	0	0	86 ab	16.3 ef	5 cdef	
		54	0.5	87 a	17.3 ef	5 ef	
		108	1.1	87 a	19.6 cde	5 def	
2019 (PPAC)	FST	0	0	61 e	16.9 ef	5 def	34.86 d
		54	0.5	61 e	18.2 cdef	6 abcdef	34.53 d
		108	1.1	61 cde	19.2 cde	8 abcd	36.74 d
	SST	0	0	61 de	17.7 def	5 def	37.55 d
		54	0.5	62 c	20.5 cde	6 abcdef	41.47 cd
		108	1.1	61 cd	20.7 bcde	7 abcdef	43.11 cd

[1] FST = fall strip-till, SST = spring strip-till
[2] MY = maize year

Table A.30. Expanded table details for the Site Year x Tillage x Aspire™ interactions from Table 2.17 in MY2. Different letters indicate statistical differences at p<0.05.

				MY2[2]	
		Aspire™		R6 Total Dry matter K	
Site Year	Tillage[1]	kg K ha^{-1}	kg B ha^{-1}	(kg ha^{-1})	
2018	FST	0	0	218.38	ab
		54	0.5	187.12	abc
		108	1.1	261.16	a
	SST	0	0	173.30	bcd
		54	0.5	226.14	ab
		108	1.1	259.21	a
2019 (ACRE)	FST	0	0	93.58	d
		54	0.5	116.10	cd
		108	1.1	122.82	cd
	SST	0	0	120.52	cd
		54	0.5	108.92	cd
		108	1.1	135.77	cd

[1] FST = fall strip-till, SST = spring strip-till
[2]MY = maize year

APPENDIX B CHAPTER 3 ADDITIONAL MEASUREMENTS

Table B.1. Example of code used for analyzing in-season measurements data using SAS Version 9.4

```
Proc Mixed Data=  aspire_physical_0200 ;
By MaizeYear;
Class Year Hybrid Block Tillage Aspire;
Model Pop_pph = Year|Tillage|Aspire/ outp=resid_c outpm=resid_m residual vciry ddfm=kr;
Random Block(Year) Hybrid;
run;

Proc GLIMMIX Data= aspire_physical_0200 ;
By MaizeYear;
Class Year Block Tillage Aspire Hybrid;
Model Pop_pph = Year|Tillage|Aspire/ ddfm=kr;
Random Block(Year) Hybrid;
LSMeans Tillage|Aspire / pdiff lines adjust = tukey alpha = 0.05 cl;
run;
```

FieldYear = Maize year
Hybrid = Corn hybrid used for site year
Block = Replications present within field
Tillage = Tillage timing
Aspire = Aspire™ rate
Year = Individual site year

Table B.2. Tillage system and Aspire™ rate impacts on final plant population for MY1 (2016, 2017, and 2019(PPAC)) and 2 (2018 and 2019(ACRE)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			Plant Population	
Tillage[1]	Aspire™		Plants ha^{-1}	
	kg K ha^{-1}	kg B ha^{-1}	MY1[2]	MY2[2]
NT	0	0	81900	79700
	108	1.1	81800	79400
FST	0	0	82400	78300
	108	1.1	82000	80500
SST	0	0	82600	78700
	108	1.1	82500	79100
FC	0	0	83500	78100
	108	1.1	83000	80200
NT			81900	79500
FST			82200	79400
SST			82500	78900
FC			83200	79100
	0	0	82600	78700
	108	1.1	82300	79800
Site Year			ns	ns
Tillage			ns	ns
Site Year*Tillage			ns	ns
Aspire™			ns	ns
Site Year*Aspire™			ns	ns
Tillage*Aspire™			ns	ns
Site Year*Tillage*Aspire™			ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.3. Tillage system and Aspire™ rate impacts on whole plant nutrient concentration for S, Zn, Mn, Fe, Cu, and Al for MY1 (2016, 2017, and 2019(PPAC)) at V6. Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}	———— mg kg^{-1} ————				
NT	0	0	2.3	29	38	163	10	98
	108	1.1	2.2	28	37	131	12	55
FST	0	0	2.5	30	38	158	12	69
	108	1.1	2.4	29	39	172	11	83
SST	0	0	2.3	28	36	149	11	64
	108	1.1	2.4	33	41	173	13	88
FC	0	0	2.4	31	44	159	11	69
	108	1.1	2.4	27	34	171	12	74
NT			2.2 b	28	37	147	11	76
FST			2.4 ab	29	39	165	11	76
SST			2.3 ab	30	38	161	12	76
FC			2.4 a	29	39	165	12	71
	0	0	2.4	30	39	157	11	75
	108	1.1	2.4	29	38	162	12	75
Site Year			***	*	**	ns	*	ns
Tillage			*	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	*	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	*	ns	ns	ns	**
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table B.4. Tillage system and Aspire™ rate impacts on whole plant nutrient concentration for S, Zn, Mn, Fe, Cu, and Al for MY2 (2018 and 2019(ACRE)) at V6. Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY2[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}	———— mg kg^{-1} ————				
NT	0	0	2.3	30	48	345 ab	14 ab	167 bc
	108	1.1	2.2	26	40	297 b	13 ab	152 c
FST	0	0	2.3	30	53	342 ab	14 ab	161 bc
	108	1.1	2.3	29	50	290 b	12 b	139 c
SST	0	0	2.4	30	57	601 a	16 a	310 a
	108	1.1	2.4	30	55	471 ab	15 ab	264 abc
FC	0	0	2.4	29	68	534 ab	14 ab	288 ab
	108	1.1	2.4	27	57	470 ab	14 ab	247 abc
NT			2.3 b	28	44 b	321 b	14 ab	159 b
FST			2.3 ab	30	51 ab	316 b	13 b	150 b
SST			2.4 ab	30	56 ab	536 a	15 a	287 a
FC			2.4 a	28	62 a	502 a	14 ab	267 a
	0	0	2.4	30	56	455	15 a	231
	108	1.1	2.3	28	50	382	14 b	200
Site Year			*	***	ns	**	***	**
Tillage			*	ns	ns	***	*	****
Site Year*Tillage			*	ns	ns	ns	*	*
Aspire™			ns	ns	ns	ns	*	ns
Site Year*Aspire™			*	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table B.5. Tillage system and Aspire™ rate impacts on whole plant nutrient content for S, Zn, Mn, Fe, Cu, and Al for MY1 (2016, 2017, and 2019(PPAC)) at V6. Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}	g ha^{-1}				
NT	0	0	0.8	10	13	56 ab	4	36 ab
	108	1.1	0.8	10	12	43 ab	4	19 b
FST	0	0	1.0	12	14	50 ab	5	23 ab
	108	1.1	1.1	13	17	77 a	5	39 a
SST	0	0	0.8	10	12	48 ab	4	21 b
	108	1.1	0.9	12	14	51 ab	5	27 ab
FC	0	0	1.0	12	17	57 ab	5	24 ab
	108	1.1	1.1	12	14	69 ab	5	29 ab
NT			0.8 c	10	13	49	4	27
FST			1.1 a	13	15	63	5	31
SST			0.9 bc	11	13	50	5	24
FC			1.0 ab	12	16	63	5	27
	0	0	0.9	11	14	53	4	26
	108	1.1	1.0	12	14	60	5	29
Site Year			***	**	*	*	**	*
Tillage			**	*	*	*	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	*
Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	*	ns	**
Site Year*Tillage*Aspire™			ns	ns	*	ns	ns	*

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.6. Tillage system and Aspire™ rate impacts on whole plant nutrient content for S, Zn, Mn, Fe, Cu, and Al for maize year 2 (2018 and 2019(ACRE)) at V6. Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY2[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}	——————————— g ha^{-1} ———————————				
NT	0	0	1.2 bc	15 ab	25 ab	172 cd	7 ab	82 bc
	108	1.1	1.0 c	12 b	18 b	132 d	6 b	65 c
FST	0	0	1.3 abc	17 ab	30 ab	187 bcd	8 ab	86 bc
	108	1.1	1.6 ab	19 a	33 ab	190 abcd	9 ab	88 bc
SST	0	0	1.3 abc	16 ab	29 ab	295 ab	8 ab	153 a
	108	1.1	1.2 bc	15 ab	27 ab	212 abcd	7 ab	117 abc
FC	0	0	1.3 abc	15 ab	35 a	262 abc	8 ab	135 ab
	108	1.1	1.6 a	19 a	38 a	312 a	10 a	162 a
NT			1.1 c	14 b	21 b	152 c	7 b	73 b
FST			1.4 ab	18 a	31 a	189 bc	8 ab	87 b
SST			1.2 bc	15 ab	28 ab	254 ab	8 ab	135 a
FC			1.5 a	17 a	36 a	287 a	9 a	149 a
	0	0	1.3	16	30	229	8	114
	108	1.1	1.4	16	29	211	8	108
Site Year			**	ns	ns	*	***	**
Tillage			**	**	***	****	*	****
Site Year*Tillage			ns	ns	ns	ns	ns	*
Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns
Tillage*Aspire™			*	*	ns	ns	*	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till

[2]MY = maize year

* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table B.7. Tillage system and Aspire™ rate impacts on maize nutrient concentration of the earleaf at R1 for S , Zn, Mn, Fe, Cu, and Al for maize year 1 (2016, 2017, and 2019(PPAC)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}	------------------------------ mg kg^{-1} ------------------------------				
NT	0	0	2.1	25	45 ab	104 ab	11	6
	108	1.1	2.0	27	43 ab	99 ab	11	14
FST	0	0	2.1	25	52 a	100 ab	11	9
	108	1.1	2.1	27	50 ab	99 ab	11	5
SST	0	0	2.0	24	36 b	97 b	10	11
	108	1.1	2.0	27	46 ab	100 ab	11	8
FC	0	0	2.1	28	47 ab	101 ab	11	7
	108	1.1	2.1	26	35 b	110 a	11	13
NT			2.0	26	44 ab	101	11	10
FST			2.1	26	51 a	100	11	7
SST			2.0	26	41 b	99	11	9
FC			2.1	27	41 b	105	11	10
	0	0	2.1	25	45	100	11	8
	108	1.1	2.1	27	44	102	11	10
Site Year			ns	**	**	ns	****	ns
Tillage			ns	ns	**	ns	ns	ns
Site Year*Tillage			ns	ns	**	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.8. Tillage system and Aspire™ rate impacts on maize nutrient concentration of the earleaf at R1for S , Zn, Mn, Fe, Cu, and Al for maize year 2 (2018 and 2019(ACRE)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}	——— mg kg^{-1} ———				
NT	0	0	1.6	23	49	94	10	11
	108	1.1	1.7	25	48	106	10	18
FST	0	0	1.8	24	52	100	10	15
	108	1.1	1.9	25	48	96	11	6
SST	0	0	1.8	24	40	97	10	9
	108	1.1	1.8	24	54	93	10	20
FC	0	0	1.9	24	45	105	11	13
	108	1.1	1.9	24	41	100	11	13
NT			1.7 b	24	48	100	10	15
FST			1.8 ab	24	50	98	11	11
SST			1.8 ab	24	47	95	10	15
FC			1.9 a	24	43	103	11	13
	0	0	1.8	24	47	99	10	12
	108	1.1	1.8	24	48	99	11	14
Site Year			ns	ns	ns	ns	ns	****
Tillage			*	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Aspire™			**	ns	ns	**	****	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	*
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	*

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.9. Tillage system and Aspire™ rate impacts on maize specific leaf content for S (g $(m^2)^{-1}$), Zn (mg $(m^2)^{-1}$), Mn (mg $(m^2)^{-1}$), Fe (mg $(m^2)^{-1}$), Cu (mg $(m^2)^{-1}$), and Al (mg $(m^2)^{-1}$) for maize year 1 (2019(PPAC)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	g m^{-2}	———— mg m^{-2} ————				
NT	0	0	0.2	1.9	1.6	7.6	0.7	0.9
	108	1.1	0.1	2.1	1.9	6.9	0.7	1.5
FST	0	0	0.2	1.9	1.8	7.5	0.7	1.0
	108	1.1	0.1	2.0	1.9	6.9	0.7	0.8
SST	0	0	0.2	2.0	2.1	7.5	0.7	0.7
	108	1.1	0.1	2.2	2.4	7.4	0.7	0.7
FC	0	0	0.2	2.3	2.3	8.0	0.8	0.7
	108	1.1	0.2	1.9	1.7	8.1	0.7	1.6
NT			0.1	2.0	1.8	7.2	0.7	1.2
FST			0.2	2.0	1.8	7.2	0.7	0.9
SST			0.2	2.1	2.3	7.4	0.7	0.7
FC			0.2	2.1	2.0	8.1	0.7	1.1
	0	0	0.2	2.0	2.0	7.6	0.7	0.8
	108	1.1	0.1	2.1	2.0	7.3	0.7	1.1
		Tillage	ns	ns	ns	ns	ns	ns
		Aspire™	****	ns	ns	ns	ns	ns
		Tillage*Aspire™	ns	ns	*	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.10. Tillage system and Aspire™ rate impacts on maize specific leaf content of S (g $(m^2)^{-1}$), Zn (mg $(m^2)^{-1}$), Mn (mg $(m^2)^{-1}$), Fe (mg $(m^2)^{-1}$), Cu (mg $(m^2)^{-1}$), and Al (mg $(m^2)^{-1}$) for maize year 2 (2018 and 2019(ACRE)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	g m^{-2}	——— mg m^{-2} ———				
NT	0	0	0.1 b	1.6	3.3	6.3	0.7	0.7
	108	1.1	0.1 ab	1.7	3.2	7.0	0.7	1.2
FST	0	0	0.1 ab	1.6	3.5	6.9	0.7	1.0
	108	1.1	0.1 ab	1.6	3.2	6.4	0.7	0.4
SST	0	0	0.1 ab	1.6	2.7	6.7	0.7	0.6
	108	1.1	0.1 ab	1.6	3.6	6.3	0.7	1.3
FC	0	0	0.1 ab	1.7	3.1	7.2	0.7	0.9
	108	1.1	0.1 a	1.6	2.8	6.9	0.7	0.9
NT			0.1 b	1.6	3.2	6.7	0.7	1.0
FST			0.1 ab	1.6	3.4	6.6	0.7	0.7
SST			0.1 ab	1.6	3.2	6.5	0.7	1.0
FC			0.1 a	1.6	3.0	7.1	0.7	0.9
	0	0	0.1	1.6	3.2	6.8	0.7	0.8
	108	1.1	0.1	1.6	3.2	6.6	0.7	0.9
Site Year			*	ns	ns	*	ns	***
Tillage			*	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Aspire™			**	ns	ns	*	****	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	*

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.11. Tillage system and Aspire™ rate impacts on maize grain nutrient content for S, Zn, Mn, Fe, Cu, and Al for maize year 1 (2016 and 2019(PPAC)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}	––––––– g ha^{-1} –––––––				
NT	0	0	8.9 ab	207	37 b	192 ab	17	158 a
	108	1.1	8.2 b	201	44 ab	198 ab	26	180 a
FST	0	0	8.5 ab	192	57 ab	181 ab	16	10 b
	108	1.1	9.4 ab	211	55 ab	203 ab	25	81 ab
SST	0	0	9.2 ab	208	51 ab	186 b	19	133 a
	108	1.1	9.8 ab	222	66 ab	244 a	23	91 ab
FC	0	0	9.6 ab	235	62 ab	217 ab	24	123 a
	108	1.1	10.5 a	234	49 ab	230 ab	30	77 ab
NT			8.6	204	41 b	195	21	169 a
FST			9.0	201	56 a	192	21	46 b
SST			9.5	215	58 a	215	21	112 ab
FC			10.0	234	55 ab	223	27	100 b
	0	0	9.1	211	52	194 b	19 b	106
	108	1.1	9.5	217	54	219 a	26 a	107
Site Year			****	**	ns	ns	ns	*
Tillage			ns	ns	**	ns	ns	***
Site Year*Tillage			ns	ns	*	ns	ns	***
Aspire™			ns	ns	ns	**	**	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table B.12. Tillage system and Aspire™ rate impacts on maize grain nutrient content for S, Zn, Mn, Fe, Cu, and Al for maize year 2 (2018 and 2019(ACRE)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}	g ha^{-1}				
NT	0	0	7.9	214	58 ab	221	17	126
	108	1.1	8.8	249	64 ab	235	19	160
FST	0	0	8.9	224	59 ab	189	16	167
	108	1.1	10.1	267	87 a	253	20	75
SST	0	0	9.0	231	52 b	185	18	75
	108	1.1	9.9	263	69 ab	258	18	118
FC	0	0	9.0	221	49 b	194	15	89
	108	1.1	9.1	243	69 ab	217	21	87
NT			8.3	232	61	228	18	143
FST			9.5	245	73	221	18	121
SST			9.5	248	61	224	18	98
FC			9.1	232	59	206	18	88
	0	0	8.7 b	222 b	55 b	198 b	16 b	116
	108	1.1	9.5 a	256 a	72 a	241 a	20 a	110
Site Year			ns	ns	*	ns	ns	***
Tillage			ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns
Aspire™			*	***	***	*	*	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	*	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till

[2]MY = maize year

* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.13. Tillage system and Aspire™™ rate impacts on maize total nutrient content (sum of grain, cob, and stover contents) for S, Zn, Mn, Fe, Cu, and Al for maize year 1 (2016 and 2019(PPAC)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}	——— g ha^{-1} ———				
NT	0	0	15.5	412	337	988	64	596
	108	1.1	15.0	396	362	1115	76	708
FST	0	0	14.7	349	507	910	63	378
	108	1.1	15.4	383	501	1049	77	444
SST	0	0	14.7	364	329	952	63	508
	108	1.1	16.0	413	480	1651	74	913
FC	0	0	15.2	410	353	1391	71	692
	108	1.1	17.9	428	512	2015	86	968
NT			15.2	404	350	1052	70	652
FST			15.0	366	504	979	70	411
SST			15.3	389	404	1301	68	710
FC			16.5	419	433	1703	78	830
	0	0	15.0	384	381	1060	65	544
	108	1.1	16.0	405	464	1458	78	758
Site Year			****	**	****	ns	ns	ns
Tillage			ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till

[2]MY = maize year

* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.14. Tillage system and Aspire™™ rate impacts on maize total nutrient content (sum of grain, cob, and stover contents) for S, Zn, Mn, Fe, Cu, and Al for maize year 2 (2018 and 2019(ACRE)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY2[2]					
Tillage[1]	Aspire™		S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}	——— g ha^{-1} ———				
NT	0	0	14.2	429	477	1762	70	902
	108	1.1	15.0	442	480	1858	73	1094
FST	0	0	15.2	412	488	1759	72	885
	108	1.1	16.5	445	558	1678	78	836
SST	0	0	14.2	397	379	1990	73	1162
	108	1.1	16.7	447	517	2113	80	1266
FC	0	0	15.3	394	421	2163	70	1251
	108	1.1	15.3	413	465	2039	77	1101
NT			14.6	436	478	1810	72	998
FST			15.8	428	523	1718	75	861
SST			15.5	422	448	2052	77	1214
FC			15.3	404	443	2101	73	1176
	0	0	14.8	408	441 b	1919	71	1050
	108	1.1	15.9	437	505 a	1922	77	1074
Site Year			ns	**	**	****	*	****
Tillage			ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	*
Aspire™			ns	ns	*	ns	ns	ns
Site Year*Aspire™			*	ns	**	ns	*	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table B.15. Tillage system and Aspire™ rate impacts on maize harvest index of N, P, Ca, Mg, S, Zn, Mn, Fe, Cu, and Al for MY1 (2016, and 2019(PPAC)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]									
Tillage[1]	Aspire™		N	P	Ca	Mg	S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	%									
NT	0	0	63.1	83.7 b	4.7	50.4	63.2	57.0	19.5	20.2	28.3	27.7
	108	1.1	62.1	84.0 ab	4.4	43.2	60.7	56.0	15.5	20.0	34.7	33.4
FST	0	0	63.2	86.1 ab	4.9	50.7	61.6	57.9	19.7	21.1	25.3	3.0
	108	1.1	63.3	87.3 ab	4.6	47.9	63.1	56.7	16.8	20.1	31.0	16.7
SST	0	0	64.3	86.9 ab	5.4	50.0	64.4	57.0	21.2	18.1	28.4	29.6
	108	1.1	63.8	86.9 ab	4.2	45.2	64.8	56.2	17.2	16.9	31.6	13.2
FC	0	0	65.0	87.4 b	5.3	52.9	64.5	60.4	20.1	16.4	32.2	24.4
	108	1.1	64.3	87.6 a	5.4	50.5	63.2	60.5	14.2	16.2	35.8	7.4
NT			62.6 b	83.8 b	4.5	46.8	62.0	56.5	17.5	20.1	31.5	30.6
FST			63.3 ab	86.7 a	4.8	49.3	62.4	57.3	18.3	20.6	28.1	9.9
SST			64.0 ab	86.9 a	4.8	47.6	64.6	56.6	19.2	17.5	30.0	21.4
FC			64.7 a	87.5 a	5.3	51.7	63.9	60.5	17.1	16.3	34.0	15.9
	0	0	63.9	86.0	5.1	51.0	63.4	58.1	20.1	18.9	28.5	21.2
	108	1.1	63.4	86.4	4.6	46.7	63.0	57.3	15.9	18.3	33.3	17.7
Site Year			ns	****	ns	*	****	****	****	ns	ns	*
Tillage			*	**	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	*	ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	ns	*	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.16. Tillage system and Aspire™ rate impacts on maize harvest index of N, P, Ca, Mg, S, Zn, Mn, Fe, Cu, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]									
Tillage[1]	Aspire™		N	P	Ca	Mg	S	Zn	Mn	Fe	Cu	Al
	kg K ha^{-1}	kg B ha^{-1}	%									
NT	0	0	58.6 b	79.7 b	3.0	30.1 b	55.7 b	51.0 b	13.5	14.3	24.5	8.6
	108	1.1	62.0 ab	84.0 ab	3.3	32.8 ab	59.1 ab	57.2 ab	14.4	14.5	26.8	15.1
FST	0	0	61.5 ab	84.0 ab	3.5	31.5 ab	58.4 ab	55.3 ab	13.2	12.7	22.4	17.9
	108	1.1	63.0 ab	86.3 a	3.8	38.1 a	61.5 a	61.2 a	17.1	16.2	27.3	8.6
SST	0	0	62.0 ab	83.0 ab	3.6	30.8 ab	58.9 ab	54.6 ab	15.0	10.9	24.0	9.8
	108	1.1	62.9 a	85.6 a	3.5	35.7 ab	59.5 ab	59.4 a	15.6	13.5	23.5	8.9
FC	0	0	61.2 ab	85.2 a	3.6	31.0 ab	59.1 ab	56.8 ab	12.9	12.7	21.5	10.9
	108	1.1	61.2 ab	85.6 a	3.3	33.4 ab	60.3 ab	59.6 a	16.3	12.6	27.2	10.9
NT			60.3	81.8 b	3.2	31.5	57.4	54.1	13.9	14.4	25.6	11.9
FST			62.3	85.1 a	3.6	34.8	60.0	58.3	15.2	14.5	24.8	13.3
SST			62.5	84.4 ab	3.6	33.4	59.2	57.2	15.3	12.3	23.7	9.3
FC			61.2	85.4 a	3.5	32.2	59.7	58.2	14.6	12.6	24.3	10.9
	0	0	60.8 b	83.0 b	3.4	30.9 b	58.0 b	54.4 b	13.6 b	12.7	23.1 b	11.9
	108	1.1	62.3 a	85.4 a	3.5	35.0 a	60.1 a	59.4 a	15.9 a	14.2	26.2 a	10.9
Site Year			ns	***	**	ns	**	****	*	****	****	****
Tillage			ns	**	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			*	**	ns	**	*	***	*	ns	*	ns
Site Year*Aspire™			*	ns	ns	ns	*	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			*	ns	ns	ns	*	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.17. Tillage system and Aspire™ rate impacts on maize grain nutrient concentration of N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY1 (2016 and 2019(PPAC)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]											
Tillage[1]	Aspire™		N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	——— g kg^{-1} ———						——— mg kg^{-1} ———					
NT	0	0	11.7 ab	3.6	4.6	0.1	1.6	0.9 ab	21	4 b	21 b	2	2 a	12 ab
	108	1.1	11.3 ab	3.4	4.5	0.1	1.4	0.9 b	21	5 ab	21 ab	3	2 abc	14 a
FST	0	0	11.6 ab	3.1	4.3	0.1	1.4	0.9 ab	20	6 ab	19 b	2	2 abc	1 c
	108	1.1	11.6 ab	3.2	4.4	0.1	1.4	0.9 ab	21	6 ab	21 ab	3	2 ab	6 abc
SST	0	0	11.3 b	3.3	4.3	0.1	1.6	0.9 ab	21	5 ab	19 b	2	2 abc	10 ab
	108	1.1	12.0 ab	3.6	4.7	0.1	1.5	1.0 ab	22	7 a	25 a	2	2 abc	8 abc
FC	0	0	11.6 ab	3.3	4.4	0.1	1.5	0.9 ab	22	6 ab	21 b	2	1 c	9 abc
	108	1.1	12.3 a	3.7	4.8	0.1	1.6	1.0 a	22	5 ab	23 ab	3	1 bc	6 bc
NT			11.5	3.5	4.6	0.1	1.5	0.9	21	5 b	21	2	2 a	13 a
FST			11.6	3.2	4.4	0.1	1.4	0.9	20	6 a	20	2	2 a	4 c
SST			11.6	3.4	4.5	0.1	1.5	0.9	22	6 a	22	2	2 ab	9 ab
FC			11.9	3.5	4.6	0.1	1.6	0.9	22	6 ab	22	3	1 b	7 bc
	0	0	11.5 b	3.3	4.4 b	0.1	1.5	0.9	21	5	20 b	2 b	2	8
	108	1.1	11.8 a	3.4	4.6 a	0.1	1.5	0.9	22	6	22 a	3 a	2	9
Site Year			**	*	*		****	**	**	**	***	ns	**	*
Tillage			ns	ns	ns		ns	ns	ns	**	ns	ns	**	***
Site Year*Tillage			ns	ns	ns		ns	ns	ns	*	ns	ns	ns	***
Aspire™			*	ns	*		ns	ns	ns	ns	**	**	ns	ns
Site Year*Aspire™			ns	ns	ns		ns	*	ns	ns	*	ns	ns	ns
Tillage*Aspire™			ns	ns	ns		ns	*	ns	ns	ns	ns	ns	ns
Site Year * Tillage * Aspire™			ns	ns	ns		ns	ns	ns	ns	ns	ns	*	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.18. Tillage system and Aspire™ rate impacts on maize grain nutrient concentration of N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]											
Tillage[1]	Aspire™		N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	——— g kg^{-1} ———						——— mg kg^{-1} ———					
NT	0	0	10.7 ab	2.9	4.9 ab	0.1	1.2	0.7	19	5 ab	19	2	1	9
	108	1.1	11.1 a	3.3	5.5 a	0.1	1.2	0.8	21	5 ab	20	2	1	12
FST	0	0	10.8 ab	2.8	4.8 b	0.1	1.2	0.7	19	5 ab	16	1	1	12
	108	1.1	10.9 ab	3.2	5.4 ab	0.1	1.2	0.8	21	7 a	20	2	1	6
SST	0	0	10.2 b	2.8	4.8 ab	0.1	1.1	0.7	18	4 b	15	1	1	5
	108	1.1	11.3 a	3.2	5.4 ab	0.1	1.3	0.8	21	6 ab	21	2	1	10
FC	0	0	10.2 b	2.7	4.9 ab	0.1	1.1	0.8	18	4 b	16	1	1	7
	108	1.1	11.2 a	3.1	5.3 ab	0.1	1.2	0.8	21	6 ab	19	2	1	7
NT			10.9	3.1	5.2	0.1	1.2	0.7	20	5	19	2	1	11
FST			10.9	3.0	5.1	0.1	1.2	0.8	20	6	18	2	1	9
SST			10.8	3.0	5.1	0.1	1.2	0.8	20	5	18	1	1	8
FC			10.7	2.9	5.1	0.1	1.2	0.8	20	5	17	2	1	7
	0	0	10.5 b	2.8 b	4.8 b	0.1	1.1 b	0.7 b	19 b	5 b	16 b	1 b	1	8
	108	1.1	11.1 a	3.2 a	5.4 a	0.1	1.2 a	0.8 a	21 a	6 a	20 a	2 a	1	9
Site Year			ns	ns	**		*	*	ns	ns	ns	****	ns	***
Tillage			ns	ns	ns		ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns		ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			****	**	****		*	*	****	***	**	*	ns	ns
Site Year*Aspire™			ns	ns	ns		ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			*	ns	ns		ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns		ns	ns	ns	ns	ns	*	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.19. Tillage system and Aspire™™ rate impacts on maize stover (includes: stems, leaves, and husk) concentration for N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY1 (2016, 2017, and 2019(PPAC)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]											
Tillage[1]	Aspire™		N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}						mg kg^{-1}					
NT	0	0	9.4 a	1.0	11.3	3.9	2.9	0.8	21	44	167	7	5	78
	108	1.1	8.5 ab	0.9	12.4	3.8	2.9	0.8	20	44	151	7	5	73
FST	0	0	9.0 ab	0.8	11.0	3.7	2.7	0.8	19	55	147	6	5	78
	108	1.1	9.0 ab	0.7	11.5	3.7	2.8	0.8	19	58	179	7	6	90
SST	0	0	8.5 b	0.8	10.5	3.6	2.9	0.7	20	42	155	6	5	73
	108	1.1	8.7 ab	0.7	11.7	3.9	3.1	0.7	20	49	231	7	6	136
FC	0	0	8.7 ab	0.7	9.9	3.7	2.9	0.7	19	39	197	7	4	104
	108	1.1	8.5 ab	0.7	12.3	3.7	2.5	0.8	19	55	277	7	5	154
NT			8.9	0.9 a	11.8	3.8	2.9	0.8	21	44	159	7	5	75
FST			9.0	0.7 b	11.2	3.7	2.8	0.8	19	57	163	7	6	84
SST			8.6	0.8 b	11.1	3.7	3.0	0.7	20	46	193	7	5	104
FC			8.6	0.7 b	11.1	3.7	2.7	0.7	19	47	237	7	5	129
	0	0	8.9	0.8	10.7	3.7	2.9	0.8	20	45	167 b	7	5	83 b
	108	1.1	8.7	0.8	12.0	3.8	2.8	0.8	20	51	209 a	7	5	113 a
Site Year			ns	*	**	**	**	ns	ns	*	ns	*	****	ns
Tillage			ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	*
Site Year*Aspire™			ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.20. Tillage system and Aspire™™ rate impacts on maize stover (includes: stems, leaves, and husk) concentration for N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]											
Tillage[1]	Aspire™		N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	——— g kg^{-1} ———						——— mg kg^{-1} ———					
NT	0	0	9.3	1.0 a	10.0 cd	4.7 a	4.0 a	0.7	24	50	199	6	6	100
	108	1.1	8.3	0.8 ab	13.9 a	4.3 ab	3.6 ab	0.7	21	48	201	6	6	116
FST	0	0	9.0	0.7 ab	10.4 bcd	4.5 ab	4.0 a	0.7	21	53	210	7	5	95
	108	1.1	8.5	0.7 b	12.9 abc	4.0 b	3.2 b	0.7	19	55	178	6	5	96
SST	0	0	8.2	0.7 ab	9.6 d	4.3 ab	3.9 ab	0.7	20	40	216	6	5	130
	108	1.1	8.5	0.7 b	12.9 abc	4.2 ab	3.5 ab	0.7	19	50	222	7	6	136
FC	0	0	8.9	0.7 b	8.8 d	4.7 a	4.1 a	0.7	20	48	264	7	5	155
	108	1.1	8.7	0.6 b	13.4 ab	4.1 ab	3.5 ab	0.7	18	46	223	6	5	126
NT			8.8	0.9 a	11.9	4.5	3.8	0.7	22	49	200	6	6	108 ab
FST			8.8	0.7 b	11.7	4.2	3.6	0.7	20	54	194	6	5	95 b
SST			8.3	0.7 b	11.3	4.2	3.7	0.7	20	45	219	6	5	133 a
FC			8.8	0.7 b	11.1	4.4	3.8	0.7	19	47	244	6	5	141 a
	0	0	8.9	0.8 a	9.7 b	4.5 a	4.0 a	0.7	21	48	222	6	5	120
	108	1.1	8.5	0.7 b	13.3 a	4.1 b	3.5 b	0.7	19	50	206	6	5	118
Site Year			**	***	**	**	**	**	**	*	****	**	***	****
Tillage			ns	***	ns	ns	ns	ns	ns	ns	ns	ns	ns	**
Site Year*Tillage			ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
Aspire™			ns	*	****	***	****	ns	ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	ns	ns	*	ns	*	ns	*	ns	*	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.21. Tillage system and Aspire™™ rate impacts on maize stover (includes: stems, leaves, and husks) dry matter and uptake for N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY1 (2016 and 2019(PPAC)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]												
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	—— kg ha^{-1} ——							—— g ha^{-1} ——					
NT	0	0	6916	70.0	7.3 ab	84.7	29.9	23.0	6.0	158	354	1210 ab	52	39	586
	108	1.1	7479	70.1	8.0 a	103.6	31.6	24.5	6.4	168	372	1225 ab	56	40	583
FST	0	0	6825	66.7	6.0 ab	84.5	28.1	21.1	5.9	147	448	1119 ab	49	42	599
	108	1.1	7046	66.4	5.4 b	87.6	28.2	21.4	5.8	143	454	1328 ab	51	47	697
SST	0	0	6966	60.9	5.9 ab	77.2	26.3	21.9	5.3	145	321	1094 b	45	40	523
	108	1.1	7466	69.5	6.0 ab	93.4	31.0	25.1	6.0	156	400	1800 ab	55	48	1088
FC	0	0	7036	65.2	5.6 ab	75.8	27.9	22.4	5.5	141	308	1435 ab	49	33	774
	108	1.1	7422	68.1	5.9 ab	101.1	30.3	21.0	6.2	156	466	2168 a	55	42	1241
NT			7197	70.1	7.7 a	94.1	30.7	23.8	6.2	163	363	1217	54	40	585
FST			6936	66.6	5.7 b	86.1	28.1	21.2	5.9	145	451	1224	50	44	648
SST			7216	65.2	6.0 b	85.3	28.7	23.5	5.7	150	361	1447	50	44	806
FC			7229	66.7	5.7 b	88.4	29.1	21.7	5.8	148	387	1802	52	37	1008
	0	0	6936 b	65.7	6.2	80.6 b	28.1	22.1	5.7	148	358	1214 b	49 b	38 b	621 b
	108	1.1	7353 a	68.5	6.3	96.4 a	30.2	23.0	6.1	156	423	1630 a	54 a	44 a	902 a
Site Year			****	**	**	***	***	***	**	**	**	ns	****	****	*
Tillage			ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Aspire™			*	ns	ns	*	ns	ns	ns	ns	ns	*	*	*	*
Site Year*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant

Table B.22. Tillage system and Aspire™ rate impacts on maize stover (includes: stems, leaves, and husks) dry matter and uptake for N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]												
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	kg ha^{-1}							g ha^{-1}					
NT	0	0	7961	74.5	7.9 a	82.0 cd	37.1	31.1	5.6	193	410	1520	48	46	770
	108	1.1	8334	69.0	6.7 ab	118.4 a	35.2	29.6	5.5	172	406	1598	49	47	930
FST	0	0	7728	70.2	5.8 ab	83.9 bcd	34.3	30.3	5.6	165	421	1546	51	42	702
	108	1.1	8176	70.5	5.6 ab	109.4 abc	32.0	25.9	5.6	155	460	1402	53	40	757
SST	0	0	8293	68.1	6.2 ab	78.7 cd	35.4	32.3	5.5	168	326	1799	52	43	1090
	108	1.1	8534	73.1	6.1 ab	114.0 ab	35.2	29.0	6.0	164	439	1829	56	49	1117
FC	0	0	7460	66.9	5.1 b	66.9 d	34.7	30.7	5.5	153	364	1942	50	39	1140
	108	1.1	8165	72.3	5.3 b	112.9 ab	33.4	28.0	5.5	152	384	1797	51	43	1008
NT			8148	71.7	7.3 a	100.2	36.1	30.4	5.6	183	408	1559	49	47	850 ab
FST			7952	70.4	5.7 b	96.7	33.2	28.1	5.6	160	440	1474	52	41	729 b
SST			8414	70.6	6.2 ab	96.4	35.3	30.6	5.8	166	382	1814	54	46	1104 a
FC			7812	69.6	5.2 b	89.9	34.0	29.3	5.5	152	374	1869	50	41	1074 a
	0	0	7861 b	69.9	6.3	77.9 b	35.4	31.1 a	5.6	170	380	1702	50	42	925
	108	1.1	8302 a	71.2	5.9	113.7 a	33.9	28.1 b	5.6	161	422	1657	52	45	953
Site Year			**	**	***	***	*	*	**	***	**	****	**	**	****
Tillage			ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	**
Site Year*Tillage			ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	*
Aspire™			*	ns	ns	****	ns	**	ns	ns	ns	ns	ns	ns	ns
Site Year*Aspire™			ns	*	ns	*	*	ns	**	ns	**	ns	*	ns	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Site Year*Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.23. Tillage system and Aspire™ rate impacts on maize cob nutrient concentration N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, and Al for MY1 (2016 and 2019(PPAC)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at $p<0.05$.

			MY1[2]											
Tillage[1]	Aspire™		N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	——— g kg^{-1} ———						——— mg kg^{-1} ———					
NT	0	0	7.9 ab	0.8 a	9.3 ab	0.2 ab	0.3 a	0.5 a	16 a	7 ab	15 cd	4 a	2 a	14 a
	108	1.1	8.1 a	0.7 ab	9.7 a	0.2 a	0.2 ab	0.5 a	16 ab	7 ab	21 a	4 a	2 a	3 ab
FST	0	0	6.9 c	0.4 c	9.3 ab	0.1 b	0.1 c	0.5 ab	14 b	6 b	15 cd	4 a	1 b	2 b
	108	1.1	7.1 bc	0.4 c	8.8 abc	0.2 ab	0.1 c	0.4 b	14 ab	7 ab	19 ab	4 a	2 a	2 ab
SST	0	0	6.9 c	0.6 bc	8.7 abc	0.1 b	0.2 bc	0.5 ab	16 ab	10 a	16 bc	4 a	1 b	5 ab
	108	1.1	6.6 c	0.5 bc	8.8 abc	0.1 b	0.1 c	0.4 b	15 ab	6 b	13 d	4 a	2 a	1 b
FC	0	0	7.2 abc	0.5 bc	7.9 c	0.1 b	0.2 bc	0.5 ab	15 ab	9 ab	17 bc	3 b	1 b	2 ab
	108	1.1	7.5 abc	0.6 abc	8.5 bc	0.2 ab	0.2 bc	0.5 ab	14 b	7 ab	13 d	4 a	2 a	6 ab
NT			8.0 a	0.8 a	9.5 a	0.2 a	0.3 a	0.5 a	16 a	7	18 a	4 a	2 a	9
FST			7.0 bc	0.4 c	9.1 ab	0.1 b	0.1 c	0.5 b	14 b	7	17 a	4 a	2 bc	2
SST			6.8 c	0.5 bc	8.8 bc	0.1 b	0.2 bc	0.5 b	16 ab	8	15 b	4 a	2 c	3
FC			7.3 b	0.6 b	8.2 c	0.1 b	0.2 b	0.5 b	14 b	8	15 b	3 b	2 b	4
	0	0	7.2	0.6	8.8	0.1 b	0.2	0.5	15	8 a	16	4 b	1 b	6
	108	1.1	7.3	0.6	8.9	0.2 a	0.2	0.5	15	7 b	17	4 a	2 a	3
Tillage			****	****	****	****	****	***	***	ns	****	****	****	ns
Aspire™			ns	ns	ns	****	ns	ns	ns	*	ns	*	****	ns
Tillage*Aspire™			ns	ns	ns	ns	ns	ns	ns	*	****	****	**	*

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.24. Tillage system and Aspire™ rate impacts on maize cob nutrient concentrations of N, P, K, Ca, Mg, S , Zn, Mn, Fe, Cu, B, and Al for MY2 (2018 and 2019 (ACRE)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]											
Tillage[1]	Aspire™		N	P	K	Ca	Mg	S	Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	g kg^{-1}						mg kg^{-1}					
NT	0	0	9.5	0.7 ab	11.3 a	0.2 ab	0.5	0.6	18 abc	8 ab	18 c	5 a	2 a	6 b
	108	1.1	9.0	0.7 ab	9.6 b	0.3 a	0.5	0.6	17 abc	8 ab	21 ab	4 b	2 a	3 b
FST	0	0	8.9	0.7 ab	11.3 a	0.2 b	0.4	0.7	20 ab	7 ab	19 bc	5 a	2 a	13 ab
	108	1.1	9.1	0.6 b	10.7 a	0.2 ab	0.5	0.6	18 abc	9 a	18 c	4 ab	2 a	4 b
SST	0	0	9.5	0.8 a	11.3 a	0.3 a	0.5	0.6	20 a	6 b	23 a	4 ab	1 b	5 b
	108	1.1	8.6	0.6 b	11.4 a	0.2 ab	0.4	0.6	16 bc	7 ab	20 bc	5 a	2 a	24 a
FC	0	0	9.2	0.6 b	11.3 a	0.2 ab	0.4	0.6	17 abc	6 b	22 a	4 ab	2 a	19 a
	108	1.1	8.7	0.6 b	11.2 a	0.2 ab	0.5	0.6	15 c	9 a	21 ab	4 ab	1 b	5 b
NT			9.2	0.7	10.4 b	0.2 a	0.5	0.6	18 ab	8	19 b	4	2 a	4 b
FST			9.0	0.6	11.0 a	0.2 b	0.4	0.6	19 a	8	19 b	4	2 a	8 ab
SST			9.1	0.7	11.3 a	0.2 a	0.5	0.6	18 ab	6	21 a	4	1 b	14 a
FC			8.9	0.6	11.3 a	0.2 ab	0.4	0.6	16 b	8	22 a	4	1 b	12 ab
	0	0	9.3 a	0.7 a	11.3 a	0.2	0.4	0.6	19 a	6 b	20	4 a	1	10
	108	1.1	8.8 b	0.6 b	10.7 b	0.2	0.4	0.6	16 b	8 a	20	4 b	1	9
Tillage			ns	ns	****	**	ns	ns	*	ns	****	ns	**	**
Aspire™			**	**	****	ns	ns	ns	**	****	ns	*	ns	ns
Tillage*Aspire™			ns	*	****	**	**	ns	ns	ns	****	****	****	****

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.25. Tillage system and Aspire™ rate impacts on maize cob dry matter and uptake for N, P, K, Ca, Mg, and S for MY1 (2016 and 2019(PPAC)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]						
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	S
	kg K ha^{-1}	kg B ha^{-1}	---- kg ha^{-1} ----						
NT	0	0	1123	8.5 abc	0.9 a	10.1	0.2 bc	0.3 a	0.6 ab
	108	1.1	1421	8.6 ab	0.8 ab	10.3	0.2 a	0.3 bc	0.6 ab
FST	0	0	1112	7.4 bc	0.5 c	10.1	0.1 d	0.1 d	0.5 b
	108	1.1	1140	8.1 abc	0.5 c	10.0	0.2 ab	0.2 d	0.5 b
SST	0	0	1122	7.8 abc	0.7 b	9.8	0.1 d	0.2 c	0.5 ab
	108	1.1	1140	7.1 c	0.5 c	9.6	0.1 d	0.2 d	0.5 b
FC	0	0	1206	8.7 abc	0.6 b	9.5	0.1 cd	0.2 c	0.6 ab
	108	1.1	1151	8.6 a	0.8 a	9.7	0.2 ab	0.2 ab	0.6 a
NT			1272	8.6 a	0.8 a	10.2	0.2 a	0.3 a	0.6 a
FST			1126	7.7 b	0.5 c	10.0	0.2 b	0.2 c	0.5 b
SST			1131	7.5 b	0.6 b	9.7	0.1 c	0.2 b	0.5 b
FC			1179	8.6 a	0.7 a	9.6	0.2 b	0.2 a	0.6 a
	0	0	1141	8.1	0.7	9.9	0.1 b	0.2	0.6
	108	1.1	1213	8.1	0.6	9.9	0.2 a	0.2	0.5
Site Year			ns	****	****	****	**	****	****
Tillage			ns	***	****	ns	****	****	***
Site Year*Tillage			ns	**	****	ns	****	****	***
Aspire™			ns	ns	ns	ns	****	ns	ns
Site Year*Aspire™			ns	ns	***	ns	****	*	ns
Tillage*Aspire™			ns	ns	****	ns	*	****	ns
Site Year*Tillage*Aspire™			ns	**	****	ns	ns	****	**

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.26. Tillage system and Aspire™ rate impacts on maize cob dry matter and uptake for Zn, Mn, Fe, Cu, B, and Al for MY1 (2016 and 2019(PPAC)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY1[2]					
Tillage[1]	Aspire™		Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	---------- g ha^{-1} ----------					
NT	0	0	18 a	8 b	16 bc	4 a	2 cd	16 a
	108	1.1	17 ab	7 bc	22 a	4 ab	3 ab	3 d
FST	0	0	15 b	6 bc	17 bc	4 ab	1 e	2 ef
	108	1.1	16 ab	8 b	21 a	5 a	2 bc	3 de
SST	0	0	18 a	11 a	18 abc	5 a	1 f	6 c
	108	1.1	17 ab	6 c	14 c	4 ab	2 cd	1 f
FC	0	0	18 ab	10 a	20 ab	3 b	2 de	3 de
	108	1.1	16 ab	8 bc	15 bc	4 a	3 a	8 b
NT			17 a	8 b	19 a	4 ab	2 a	10 a
FST			16 b	7 b	19 a	4 a	2 b	2 d
SST			17 ab	9 a	16 b	4 a	2 c	3 c
FC			17 a	9 a	17 ab	4 b	2 a	5 b
	0	0	17	9 a	18	4	2 b	7 a
	108	1.1	17	7 b	18	4	2 a	4 b
Site Year			****	****	***	*	****	****
Tillage			*	****	*	**	****	****
Site Year*Tillage			**	****	ns	ns	****	****
Aspire™			ns	****	ns	ns	****	****
Site Year*Aspire™			*	****	ns	ns	ns	****
Tillage*Aspire™			ns	****	****	****	*	****
Site Year*Tillage*Aspire™			**	****	**	**	***	****

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.27. Tillage system and Aspire™ rate impacts on maize cob dry matter and uptake for N, P, K, Ca, Mg, and S for MY2 (2018 and 2019(ACRE)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]						
Tillage[1]	Aspire™		DM	N	P	K	Ca	Mg	S
	kg K ha^{-1}	kg B ha^{-1}	------ kg ha^{-1} ------						
NT	0	0	1193	11.3 ab	0.8 b	13.5 ab	0.2 b	0.5 bc	0.7
	108	1.1	1245	11.2 ab	0.8 b	11.9 b	0.3 a	0.6 bc	0.8
FST	0	0	1221	10.9 b	0.8 b	13.7 ab	0.2 c	0.5 c	0.8
	108	1.1	1288	11.7 ab	0.8 b	13.7 ab	0.3 b	0.6 b	0.8
SST	0	0	1333	12.6 a	1.0 a	15.0 a	0.3 a	0.7 a	0.8
	108	1.1	1317	11.3 ab	0.7 b	14.9 a	0.3 b	0.5 bc	0.8
FC	0	0	1248	11.5 ab	0.8 b	14.1 a	0.3 b	0.5 bc	0.8
	108	1.1	1240	10.8 b	0.8 b	13.9 a	0.3 b	0.6 bc	0.7
NT			1219 b	11.2	0.8 ab	12.7 c	0.3 ab	0.6 b	0.7
FST			1255 ab	11.3	0.8 b	13.7 bc	0.2 c	0.5 b	0.8
SST			1325 a	12.0	0.9 a	15.0 a	0.3 a	0.6 a	0.8
FC			1244 ab	11.1	0.8 b	14.0 ab	0.3 b	0.5 b	0.8
	0	0	1249	11.6	0.8 a	14.1	0.3 b	0.6	0.8
	108	1.1	1273	11.2	0.8 b	13.6	0.3 a	0.6	0.8
Site Year			ns	ns	ns	ns	****	***	ns
Tillage			ns	ns	**	****	****	**	*
Site Year*Tillage			ns	***	****	*	****	****	**
Aspire™			ns	ns	**	ns	*	ns	ns
Site Year*Aspire™			ns	*	****	ns	**	****	ns
Tillage*Aspire™			ns	*	****	ns	****	****	ns
Site Year*Tillage*Aspire™			ns	ns	**	ns	****	ns	***

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.28. Tillage system and Aspire™ rate impacts on maize cob dry matter and uptake for Zn, Mn, Fe, Cu, B, and Al for MY2 (2018 and 2019(ACRE)). Mean separation for tillage x Aspire™, tillage system, and Aspire™ rate were performed separately. Different letters indicate statistical differences at p<0.05.

			MY2[2]					
Tillage[1]	Aspire™		Zn	Mn	Fe	Cu	B	Al
	kg K ha^{-1}	kg B ha^{-1}	——— g ha^{-1} ———					
NT	0	0	21 bc	9 cd	21 d	5 ab	2 a	7 d
	108	1.1	21 bc	10 bc	25 bc	4 c	2 a	3 f
FST	0	0	24 ab	8 de	23 cd	6 ab	2 a	16 c
	108	1.1	23 b	12 a	23 cd	5 b	2 a	4 ef
SST	0	0	27 a	7 e	30 a	5 ab	1 b	6 de
	108	1.1	21 bc	9 c	26 bc	6 a	2 a	30 a
FC	0	0	21 bc	8 e	27 ab	5 bc	2 a	22 b
	108	1.1	19 c	11 ab	26 bc	5 bc	1 b	6 de
NT			21 bc	10 a	23 b	5 c	2 a	5 d
FST			23 ab	10 a	23 b	5 ab	2 a	10 c
SST			24 a	8 b	28 a	6 a	2 b	18 a
FC			20 c	9 a	27 a	5 bc	2 b	14 b
	0	0	23 a	8 b	25	5	2	13 a
	108	1.1	21 b	10 a	25	5	2	11 b
Site Year			*	*	***	ns	****	****
Tillage			****	****	****	****	****	****
Site Year*Tillage			****	****	ns	***	****	****
Aspire™			****	****	ns	ns	ns	****
Site Year*Aspire™			****	****	***	ns	ns	***
Tillage*Aspire™			**	****	***	****	****	****
Site Year*Tillage*Aspire™			ns	****	***	****	****	****

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = p<0.05, ** = p<0.01, *** = p<0.001, **** = p<0.0001, ns = not significant

Table B.29. Expanded table detailing the Site Year x Tillage x Aspire™ interactions from Table 3.11 and 3.16 found in main chapter tables. Different letters indicate statistical differences at $p<0.05$.

				MY1[2]		
Site Year	Tillage[1]	Aspire™		Anthesis at 50%	Silking at 50%	R6 Grain B Content
		kg K ha^{-1}	kg B ha^{-1}	Days from planting		g ha^{-1}
2016	NT	0	0			46 a
		108	1.1			25 bcdef
	FST	0	0			32 abcd
		108	1.1			41 ab
	SST	0	0			33 abc
		108	1.1			31 abcd
	FC	0	0			21 bcdef
		108	1.1			29 abcde
2017	NT	0	0	87 ab	86 abc	
		108	1.1	89 a	89 a	
	FST	0	0	86 b	85 bc	
		108	1.1	85 b	84 c	
	SST	0	0	86 b	86 bc	
		108	1.1	87 ab	87 ab	
	FC	0	0	86 b	86 bc	
		108	1.1	85 b	85 bc	
2019(PPAC)	NT	0	0	62 c	59 de	11 ef
		108	1.1	62 c	61 d	15 bcdef
	FST	0	0	61 c	58 e	8 f
		108	1.1	61 c	59 de	13 def
	SST	0	0	61 c	59 de	9 f
		108	1.1	61 c	60 de	9 f
	FC	0	0	61 c	58 e	10 f
		108	1.1	61 c	58 de	9 f

[1]NT = no till, FST = fall strip-till, SST = spring strip-till, FC = fall strip-till
[2]MY = maize year
* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$, **** = $p<0.0001$, ns = not significant