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Impact of a Foliar Applied Silicate Product on the Observed and Measured Stalk Strength of Inbred Maize

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Impact of a Foliar Applied Silicate Product on the Observed and Measured Stalk Strength of Inbred Maize.

by

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Figures, Tables, and Graphs

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Introduction

Rationale

Hybrid maize *(Zea mays)* is one of the most valuable crops grown in modern agriculture. With uses that range from feeding livestock to fueling vehicles, maize has become a part of everyday life. The production of hybrid maize seed occurs in the United States as well as several countries around the globe. The value of the United States maize production from 2007 to 2015 averaged $58.9 billion per growing season (National Corn Growers Association, 2017). The volume of maize produced in the United States was 384,778 metric tons for the 2016 growing season. This makes the United States the global leader in maize production by greater than 150,000 metric tons.

China had the second highest production at 219,554 metric tons, followed by Brazil and the European Union (Global corn production, 2019).

The seed maize industry faces many challenges in growing hybrid seed maize. In many cases, the inbred maize used to grow hybrid seed is itself one of the primary challenges that must be managed. Tall spindly stalks, weak root systems, poor pollination and many other challenges plague growers of inbred maize. One issue dealt with in many seed lines is poor standability/strength of the stalks and the impact this has on achieving the maximum potential yield and pollination purity. Standability, is an agronomic measure of stalk integrity to resist lodging or breakage throughout the growing season. While hybrid maize plants tend to stand well for the end user, poor standability of the inbred lines that are used to produce the hybrid seed can be problematic.

In seed production, many fields are grown as a maize on maize rotations. The more productive the soil, the more likely this situation will occur. Hybrid seed can end up on or in the soil profile after the current year production, affecting the management of the seed field the following season. Hybrid seed that is left in the field can germinate and become a weed or source of pollen contamination during the following production year. Reducing the amount of seed lost due to poor stalk strength can significantly reduce the time and manpower needed to maintain the fields next season. Identifying management opportunities to enhance inbred stalk strength has great potential to reduce management time and manpower, while increasing hybrid seed yield.

Each stalk of maize that breaks prior to or during the detasseling operation, as well as prior to or during harvest has a negative impact on the hybrid seed offered to farmers. The theory that silicate could have effects on the strength of the stalks comes from research that has been done in rice and sugarcane and the impact a silicate application had on these crops. (Alvarez and Datnoff, 2001; Ashraf, et al. 2009). If a silicate application can increase stalk strength in maize inbreds, it could dramatically improve the management processes of hybrid maize production. Coupling the value of pure quality seed with the high cost associated with managing green snap/lodging and seed loss prior to harvest is a compelling argument for investigating the potential value of including a silicate treatment in the management system.

A positive return on investment (ROI) from this research could have a profound effect on the seed production industry. Seed loss could be reduced, more efficient management strategies for seed maize hectares could be formulated, and an increase to seed producers bottom line are all possibilities. The ultimate goal is that positive results can be carried over into commercial maize production as a means to increase yield or at least reduce the loss for every hybrid seed producer and farmer.

Objectives

1. Determine whether a foliar silicate application has a positive impact on stalk strength in maize.
2. Determine the relative return on investment (ROI) of a silicate application versus the cost of a ground crew working to manage green snap or lodging events.

Background

Before diving into what silicon (silicate) does in plants, a brief description of what silicate is and where it is found is provided. Silicon, Si on the periodic table of elements with an atomic weight of 14, is an element thought to be present throughout the galaxy and is a main component of meteorites known as aerolites (Winter, 2016). This element composes a large portion of the earth's crust. With a concentration of 25.7% by weight, silicon is the second most abundant element on earth exceeded only by oxygen. Most of the silicon on earth is contained in silicon oxides; these include sand, quartz, flint, opal, and others. Silicon is also found in asbestos, feldspar, clay and mica. Constituting such a large portion of the earth's crust, it could be assumed that silicon is an essential nutrient needed for the lifecycle of a plant, yet this is not the case.

Silicon in plants is considered a value-added nutrient rather than an essential nutrient. For a nutrient to be considered essential for plant growth, it must be required by the plant to complete its lifecycle (Tucker, 1999). The lifecycle of a plant consists of germination, vegetative growth, reproductive growth, and senescence. The nutrients that have been identified as essential include carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, boron, chlorine, copper, iron, manganese, molybdenum, nickel, and zinc (Barak, 2003).

Since silicon has not yet been found to be essential to plant growth, most do not consider it a valuable component in plant development. Silicon constitutes approximately 0.05% of the total dry matter of di-cotyledon plant tissue and 5-10% of the dry matter of mono-cotyledon plant tissue (Deren, 2001). This large amount of silicon suggests it plays a more significant role in mono-cots than di-cots. The exact role of silicon in plant tissue is unclear, although some research has shown plant responses to the application of fertilizers that contain silicon.

The effects from silicate fertilization vary among species and potentially even between varieties. Responses to silicon application include a greater ability to resist damage from abiotic and biotic pests as well as from salinity issues. Silicon applications can increase stem and flower diameter of greenhouse grown cut flowers and decrease transpiration, which would suggest it might be helpful under drought conditions (Navarra, 2018). Importantly, this study shows that silicon has a strengthening effect on plant cell wall tissue. This plant response is of particular interest in this research project. Some more specific examples of silicon's role in monocot plants tissues are described below.

Rice *(Oryza sativa)*

Rice is the 2nd most important crop globally in terms of hectares harvested. The harvested area is estimated at 146 million hectares, trailing wheat which is estimated at 211 million hectares (World Food Crops CSS330, 2004). In terms of total global metric ton production, rice is second only to maize with 579 million metric tons harvested annually. Maize global production is approximately 602 million metric tons annually.

The effect of silicate applications on rice has been studied by several researchers. Some have found evidence that a foliar silicate application is substantial in this crop. The impact of silicon on rice yield has been vital to improving yield with decreasing available land. It has been estimated that the use of silicon fertilization could reduce the land needed by 22.2 million hectares and still satisfy global needs (Alvarez and Datnoff, 2001). The annual ROI associated with the use of silicate fertilizer on rice ranged from $50.22 to $271.85/ha.

Lavinski et al. (2016) found that silicon applied to rice during the reproduction stage increased grain yield and increased total photosynthesis. While leaf area and whole-plant biomass did not change, 1000-grain weight increased evidently due to an increase in the strength of the reproductive sink, compared to plants without added silicon. They concluded supplemental silicon had a positive impact on the number and size of the grain, but the exact mechanism by which the silicon affected this response was unknown.

With rice as the second most important crop globally, the positive effects silicon can have on rice yield while reducing the land needed could play a major role in future agronomic decisions in this crop. Greater utilization of silicon on rice crops could impact the global food market, especially those markets that rely heavily on rice as a source of food and income.

Sugarcane *(Saccharum officinarum)*

Sugarcane is one of the two primary sources of sugar in the world; the other being sugar beets (*Beta vulgaris*). Global sugarcane production in 2010 was nearly 1700 million metric tons which was harvested from 24 million hectares (Yara Fertilisers India Pvt. Ltd., 2010). Brazil leads global production by a large margin with 719,157 million metric tons of production in 2010; India was second at 277,750 million metric tons, followed by China, Thailand, and Mexico. The United States was 11th in 2010 with

24,821 million metric tons. The most current data from 2016 show Brazil is still the global leader at 739,300 million metric tons and the United States was 10^{th} globally with 27,900 million metric tons (Sheth, 2017)

Considering the demand for sugar on the global market is notable the impact that silicon has on sugarcane production could be of great value. In fact, sugarcane has been found to absorb more silicon than any other mineral nutrient, with accumulations of approximately 380 kg/ha in a 12-month period (Savant et al., 1999). In addition to the amount of total silicon sugarcane absorbed there were observations that showed yield responses due to “induced resistance to biotic and abiotic stresses” along with “Al, Mn, and Fe toxicity alleviation and increased P availability”. Other observations in sugarcane receiving silicon applications include reduced lodging, improved leaf and stalk erectness, freeze resistance and an improvement in plant water use efficiency (WUE) (Savant et al., 1999). They defined WUE as a measure of the amont of grain produced per unit of water used. Reduced stress allows the plant to utilize water more efficiently for vegetative and reproductive processes rather than protecting them from stress factors. The reduced lodging and leaf and stalk erectness are great observations that we hope to see in maize, and the water economy is similar to some responses seen in rice (Savant et al., 1999).

Reducing stresses is a large part of improving yields and plant health. In this research about maize stalk integrity, one of the products being utilized contains potassium silicate. A study from the *Journal of Agronomy and Crop Science* links the use of these two nutrients to improved yield and juice quality in sugarcane grown under salt stressed conditions (Ashraf et al., 2009). The authors state “cane yield and yield attributes were significantly ($P < 0.05$) higher where K and Si we added.” They also noted that plant tissue concentrations of Na^+ were decreased.

Transferring the results reported in rice and sugarcane to maize has the potential to be a game changer in hybrid maize production. With the value of the crop being grown, small changes to prevent yield loss can have a significant impact on the profitability of seed producers.

Maize (*Zea mays*)

The focus of this research is to qaunitfy the impact of a foliar silicate application on the strength of the stalk of the female inbred maize plants. To date there has been little work done on this specific subject. Silicate applications, as discussed in the previous sections, can have economical impact. That value might also hold true considering related work on silicate applications in maize.

Efficient use of available water for grain production (i.e. Water Use Efficiency, WUE) is critical as many regions of global corn production deal with seasonal and at times long-term drought. Xiaopeng et al. studied how silicon influences WUE in maize. The researchers found that plants treated with “2mmol L^{-1} silicic acid (Si) had 20% higher WUE then that of plants without Si application. The WUE was increased up to 35% when the plants were exposed to water stress (Xiaopeng, et. al., 2006).” Because water stress can have significant impacts on yield, greater WUE might determine how well and farmer can manage their bottom line during a challenging season. Cengiz, Tuna, and Higgs (2006) provided detailed information on the response of water-stressed plants to various levels of silicon application. Their experiment was designed to simulate water stress conditions on greenhouse-grown plants exposed to water stress and 5 concentrations of silicon. The silicon treatments greatly improved total dry matter production, chlorophyll content, and relative water content of the water stressed plants. Although levels were still well below those of the control treatment. Leaf calcium (Ca) and potassium (K) levels were reduced by water stress. The highest concentrations of silicon application, however maintained Ca levels similar to the control treatment with K levels less than the control. The takeaway from these two studies is that silicon application can have a positive impact on the WUE and the concentration of nutrients within the leaves and leaf sheaths of maize plants. Both of these factors support cell turgor and expansion. Because the leaf sheaths that surround the maize stem are the primary structural support for the growing stem internodes, maintaining their turgor is a fundamental physiological process that directly impacts stalk strength.

Applications of silicon during crucial times of growth could have lasting impacts on plant structures and the grain yield they might achieve. Peiffer et. al. (2013), in “The Genetic Architecture of Maize Stalk Strength” discussed several factors that affect maize stalk strength. They stated “Maize stalk strength impacts grain yield and silage quality due to its relationship with stalk lodging and stover quality.” Rind penetrometer resistance (RPR), i.e. the amount of force is takes to pierce a stalk with a spike, was the tool used to measure the RPR of 4,692 recombinant inbreds for stalk strength. An important finding from their study was that 37% of the variation observed in stalk strength was attributed to the growing environment, which could be attributed to a combination of abiotic and biotic stresses.

Crucial points about the impacts of silicon application on maize;

- Silicon application increases WUE by 20-35%, condition dependent
- Water stress reduces [Ca] and [K in leaf sheaths
- Silicon application increases [Ca] back to non-stressed levels
- Silicon application increases [K] but to less than non-stressed levels
- Environment accounts for 37% of the variability in inbred maize stalk strength

Approach

This project was conducted in collaboration with Becks's Hybrids and their production agronomy department located in Atlanta, Indiana. Many resources were made available to the production agronomy team including but not limited to land, capital, equipment, time, knowledge, and market influence. The objectives of this project were aimed at improving the quality of work the agronomy department produces, as well as improving the quality of the hybrid seed available to the end user, the farmer.

The production agronomist for Beck's in Atlanta, Indiana selected which female inbred lines should be used for this research. He has been with the company for more than 10 years and has extensive background knowledge of each inbred and their strengths and weaknesses. The criteria were to select inbred female lines that had different attributes relative to stalk strength: good stalk strength and late season standability, moderate stalk strength and standability, and poor stalk strength. The intent was to measure the influence of silicon across different genetics. An important goal was to show an improvement across a broad range of genetic lines.

	2017		2018			
Inbred	**E**	**F**	**A**	**B**	**C**	**D**
Inbred Stalk Rating	2*	3*	5*	4*	4*	4*
Tech Sheet Comments	Strong stalk.	Some green snap potential	Brittle stalk	Moderate green snap potential	May green snap	May green snap
	1=Strong Stalk 5=Brittle Stalk *Ratings from Neal Campbell, Senior Production Angronomist, Beck's Hybrids					

Table 1. Inbred stalk ratings and comments. Provided by Neal Campbell, Senior Production Agronomist, Beck's Hybrids.

Silicon Products

Selecting a product that will meet the needs of this research and seed production management was challenging. The primary issue is that many foliar-applied silicon products come in a formulation that contains either calcium, sodium or potassium in addition to the silicon. Readily available forms are calcium silicate, sodium silicate, and potassium silicate. Of these three, sodium silicate and potassium silicate are the most prevalent in the marketplace. Since it was not possible to test the influence of silicate without a confounding influence of potassium, three treatments were imposed: potassium silicate, potassium alone, and a non-treated control. The potassium silicate was the most cost-effective form of silicate product to obtain. And it was simple to apply a potassium product as a second treatment to quantify the direct influence of potassium. The synergy between the potassium and silicate applied together, however, could not be resolved with this simple approach.

Options of potassium silicate products from which a decision was made include. Certis USA (Columbia, MD), who manufactures three potassium silicate products, AgSil® 16H, AgSil® 21 and AgSil® 25(Certis USA, 2017). AgSil® 16H is a hydrous powder available in 22.7 kg. bags (50 pounds). AgSil® 21/25 are both liquid concentrates available in 9.45 to 1039.5-L quantities (2.5 to 275 gallon). Each of the AgSil® products have varying amounts of potassium and silicon, the 16H contains 32% (by weight) K_2O, 52.8% (by weight) SiO_2, and 14.8% (by weight) H_2O. AgSil® 21 contains 12.7% (by weight) K_2O, 26.5% (by weight) SiO_2, and 60.9% (by weight) H_2O. AgSil® 25 contains 8.3% (by weight) K_2O, 20.8% (by weight) SiO_2, and 70.9% (by weight) H_2O (PQ Corporation, 2011).

The second brand of potassium silicate investigated is manufactured by Botanicare LLC (Vancouver, WA). Their potassium silicate product is named Silica Blast™. Silica Blast™ is a liquid concentrate available in amounts from 1.89 to 207.9 L (0.5 to 55 gallons). Silica Blast contains 0.5% (by weight) K_2O and 2.0% (by weight) Silicon (Botanicare, 2017).

AgSil16H™ was selected for this study because it offered the greatest concentration of silicate of the products researched and it was easier to source and most economical to ship. The potassium product was a generic 0-0-50 (NPK) water soluble product (sourced from Organic K^+ Inc. a manufacturer of fertilizers) that allowed for mg/kg calculations to be made accurately and be applied at the same mg/kg of potassium as in the silicate product.

Field Design

The design for this research was a replicated strip trial. This work was applied to commercial fields of inbred plants grown to produce hybrid seed. Each of the inbred lines was planted in a different field. This aspect of the design was out of the researchers' control as nick delays and soil conditions dictated where each hybrid seed field was planted. Thus, the response of each inbred to the silicone treatment is evaluated independently. No inbred by treatment interactions are presented.

Test plots were applied as field strips. Each strip containing three treatments, *Control, 0-0-50* (50% by weight K_2O), *and AgSil16H*. The treatments were replicated four times for each inbred field (Figure 1). The products were applied to both the male and female plants (male and female plants are physiologically the same, each type of plant is called male or female based on the reproductive part of the plant being utilized). Only data from the female plants were collected as green snap in the male rows is insignificant to management decisions.

Figure 1. Map of replicated strip trial for inbred A in 2018. Each treatment is replicated 4 times across the field. Data was collected from each replication in the field.

Field Tests

Two methods of data collection were employed to determine inbred stalk strength: a Push Test, and A Stalk Break Test.

Push test: This is a standard test used throughout the seed industry. This test has been deemed feasible/reasonable by the Beck's Hybrids Practical Farm Research(PFR) team as a close resemblance to the stress the plant experiences during potential green snap events. The data were collected by a 3rd party hired by Beck's for consistent technique. The participating individuals identified the primary ear nodes of the plants to be tested and pushed the plants from this point until the apical portion of the plant touches the adjacent row. They repeat this test on the opposite row. The number of plants that broke or cracked was recorded.

This test involved pushing 40 plants each data collection day. Rep one was sampled first, then rep two and so on.

Treatments were evaluated six times beginning 1 day after application, then every other day until tassel emergence (TE) was reached. This period spanned V10 to TE and included the time prior to and during the first week of detasseling. This test evaluated a total of 1320 plants in 2017, and 2520 plants in 2018.

Stalk Break Test: This test involved harvesting five consecutive plants from each treatment at ground level and evaluated immediately for resistance to stalk breakage under a measured weight load. Harvesting five consecutive plants avoided the bias of collecting the largest plants and excluding the smallest plants.

The stalk break weight device consisted of a metal pole and a digital fishing scale (Berkley, Model BTDFS50-1) rated up to 23kg (50lb.). The pole was used as a horizontal anchor point for the scale (Figure 2). Each stalk was placed into the hook of the digital scale with the primary ear node resting on the scale hook. With hands placed on the nodes on each opposing side of the primary ear node, the stalk was pulled down until the primary ear node snapped. The weight imposed at which the stalk broke was recorded. There were 5 plants per treatment tested daily from one rep. Rep one was sampled first, then rep two and so on. Once the four reps were sampled the sampling was repeated in the same order. Data collection began two days after application and continued every two days until TE was reached. This period spanned V10 to T and included the time prior to and during the first week of detasseling. In total, 480 plants were tested for their stalk breaking point; 165 plants in 2017 , and 315 plants in 2018. As described in the background section this time frame is critical from a quality management perspective.

Figure 2. The Setup for the stalk break test. The fish scale in hung on a metal post between two trucks. The primary node is place on the scale hook and pulled until the stalk broke. The break weight is recorded.

Treatment Applications

Application of foliar treatments occurred at the V10 growth stage with a Hagie Sprayer. The application rate is per label, 1.11 kg AgSil16H per hectare or 3180 mg/kg SiO_2 and 1920 mg/kg K_2O. The application of the potassium occurred at the same mg/kg contained as the label/application rate for the potassium silicate product. The 'strips' were one boom width (i.e. 36.58 m) covering 9 sections; one section is 1 male row and 4 female rows. Measurements were taken from the center section of the boom pass to eliminate the influence of any drift that may have occured from adjacent treatments.

Inbred maize is the crop of focus. The inbreds were being treated with a potassium silicate product (AgSil16H) to determine if there was a measurable impact of this foliar application of a potassium silicate product on plant-stalk strength. In 2017, the test was performed on two inbreds. In 2018, the study was conducted on four inbreds. The 2017 and 2018 trials featured different inbreds due to weather-imposed planting delay. In 2017, it was not possible to apply the products to the desired inbreds due to heavy rain and poor field conditions. Weather conditions were more conducive to applications in 2018 and the original set of target inbred lines were tested.

AgSil16H 53% Silica (SiO_2), 32% Potassium (K_2O), produced by Certis USA, sourced from Nutrien Ag (Loveland, CO) (Certis USA, 2017) was chosen as the appropriate potassium silicate product for this trial due to its cost, concentration of silicon, and ease of tank mixing. In addition to AgSil16H, a water-soluble potassium product (0-0-50, NPK) was included as a treatment to assess the effect potassium ion might have on stalk strength. Potassium (K_2O) fertilizer has been shown to influence the stalk strength by maize in field trials conducted by Pioneer (Pioneer Corporation, 2003) By applying K_20 at the same mg/kg contained in the AgSil16H treatment, a direct comparison between the two treatments should be possible. The data can be analyzed to determine if the silicate had an impact on stalk strength over/above the influence of the K_2O.

Silicate Research									
Field	Total ha	Control ha	AgSil16H ha	0-0-50 ha	AgSil16H Needed	Unit	0-0-50 Needed	Unit
Field 1	31.01	11.02	9.99	10.00	4.50	kg	2.20	kg
Field 2	16.32	6.00	5.14	5.18	2.31	kg	1.14	kg
Field 3	15.66	5.96	4.86	4.84	2.19	kg	1.06	kg

Field	Control	AgSil16H	0-0-50
Field 1 H20 Liters per Treatment	833.1	755.4	755.7
Field 2 H20 Liters per Treatment	453.6	388.4	391.8
Field 3 H20 Liters per Treatment	450.2	367.6	365.8

Figure 3. Visual example of the product calculation sheet developed in Microsoft Word™. This table allows simple figures to be entered then formulas saved within the sheet run calculations telling the user how much water and product they need to apply the mg/kg target for each treatment.

A Microsoft Excel™ workbook was constructed to calculate mg/kg of product (Silicate) per treatment hectare (Figure 3). The number of hectares for each treatment (Control, 0-0-50, and AgSil16H) is entered and kilograms of product needed per hectare is calculated. The first step in using the calculator is to enter the desired nutrient mg/kg. In this example, the target was 3180 mg/kg of silicate. Once this number is entered the calculator tells us that we will also be applying 1920 mg/kg of K_20 with the AgSil16H treatment. Next the user will input 1920 mg/kg into the 0-0-50 row. The calculator generates the amount of 0-0-50 needed per 378 L of water. The user then enters the total field hectares into the total hectare's column. The workbook calculates the number of hectares per treatment, the total gallons of water needed for each treatment, and it will calculate the kilograms of product needed to make the desired application mg/kg.

In 2017, the products were applied at growth stage V10 along with a preventative fungicide package. The control treatment included Headline AMP™ (3.9 mg/kg), Nitamin 20L™ (50 mg/kg), and Pro-Act™ (0.2 mg/kg). The 0-0-50 potassium treatment(1920 mg/kg K_2O) also included Headline AMP™ (3.9 mg/kg), Nitamin 20L™ (50 mg/kg), and Pro-Act™ (0.2 mg/kg) The AGSil16H (3180 mg/kg SiO_2) treatment also contained Headline AMP™ (3.9 mg/kg), Nitamin 20L™ (50 mg/kg), and Pro-Act™ (0.2 mg/kg), and . The application requirements of the Headline AMP™ required that this mixture be applied at 186.73 L per hectare.

In 2018, the products also were applied at growth stage V10 with the preventative fungicide package. The control treatment included Stratego YLD™ (1.56 mg/kg), Nitamin 30L™ (50 mg/kg), and Pro-Act™ (0.2 mg/kg). The 0-0-50 potassium treatment (1920 mg/kg K_2O) also included Stratego YLD™ (1.56 mg/kg), Nitamin 30L™ (50 mg/kg), Pro-Act™ (0.2 mg/kg), and the AGSil16H (3180 mg/kg SiO2) treatment also contained Stratego YLD™ (1.56 mg/kg), Nitamin 30L™ (50 mg/kg), Pro-Act™ (0.2 mg/kg). The application requirements for Stratego YLD™ required that this mixture be applied at 186.73 L per hectare. The switch to Stratego YLD™ was made to better manage gray leaf spot (*Cercospora zeae-maydis*) in the seed production fields.

Statistical Analysis

Each of the six female inbred seed lines (only female seed lines were analyzed for this research) were grown in different fields (6 inbreds, 6 fields) and in different years (2 female inbreds in 2017, 4 female inbreds in 2018). Weather and production time restraints prevented the tests being performed in a complete randomized block design. These factors determine how the data associated with each female inbred will be presented. Each of the six inbred trials being analyzed individually and will be presented as such. The ROI (Return on Investment) calculations will be grouped by year. This is because the ROI require statistical analysis on each inbred, and is intended to provide a generalized assessment of cost/benefits associated with an additional AgSil16H field application.

Treatment effects on each female inbred line are analyzed by a one-way ANOVA. The significant level was set to $P=0.1$.

Results

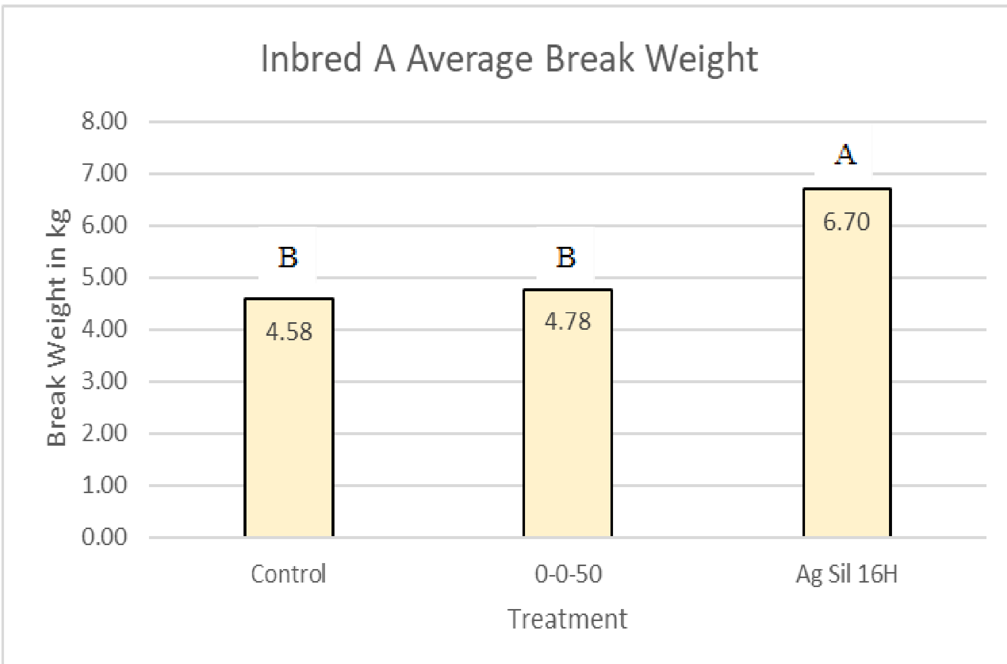
The results are divided into four sections for comparison and to draw general conclusions. First is the ANOVA, average break weight and the percent of broken plants for each individual female inbred seed line. A separate ANOVA is needed for the Push Test results and the Stalk Breakage results. Next is the measured trend in break weights for the individual female inbred lines from day 1 of data collection (Day 1 of data collection is 2 days post application). Third is the percent gain when comparing the control versus the AgSil16H and is referenced with the stalk rating chart on page 10.

Last is an ROI (Return on Investment), the ROI is calculated by year, the inbreds are grouped and the percent broken plants observed is used to find the figures presented. The ROI was not calculated on a per inbred base due to the positive effect observed across each inbred. The respective ROI's represent each growing season and support, along with the ANOVA's, what was observed in each female inbred.

Inbred A Stalk Breakage - ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***Significance[B]***
Between Groups	338.98	2	169.49	32.43	<.001	Y*
Within Groups	376.27	72	5.23			
Total	715.25	74				

[B]Significance level set to 0.1; *data supports field observations

Figure 4. Stalk Breakage ANOVA table for inbred A, supporting field observations.



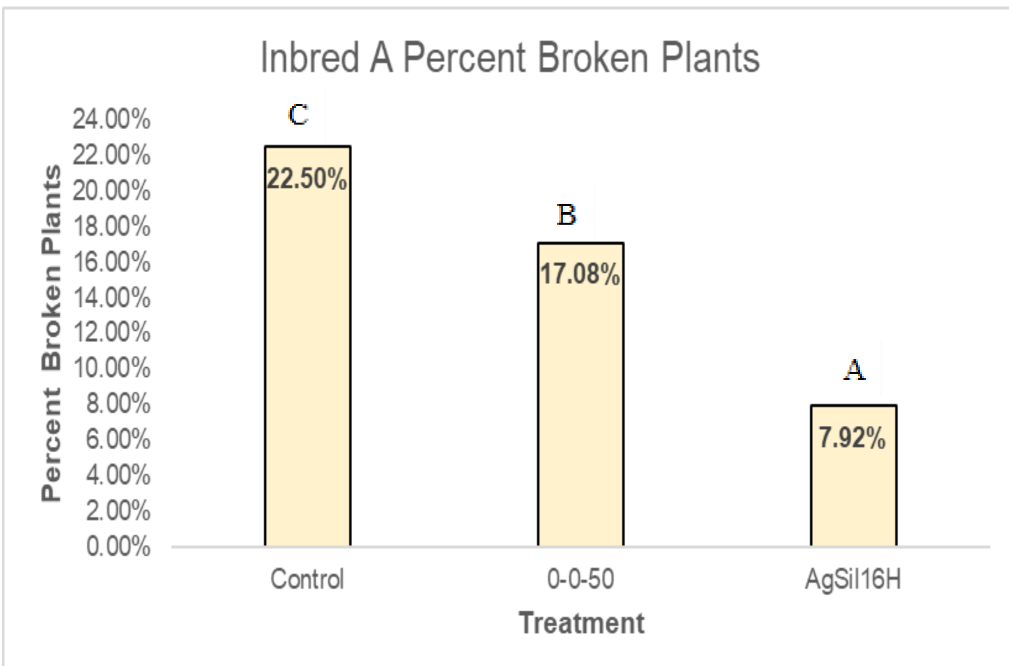
Graph 1. Inbred A graph showing the average breaking point between treatments. Data from the stalk breakage measurements. Columns with a different letter indicate values significantly different at P=0.1

Inbred A Push Test - ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*Significance* [B]
Between Groups	75.60	2	37.80	5.91	0.02	Y*
Within Groups	76.80	12	6.40			
Total	152.4	14				

[B]Significance level set to 0.1; *data supports field observations

Figure 5. Push Test ANOVA table for inbred A, supporting field observations.



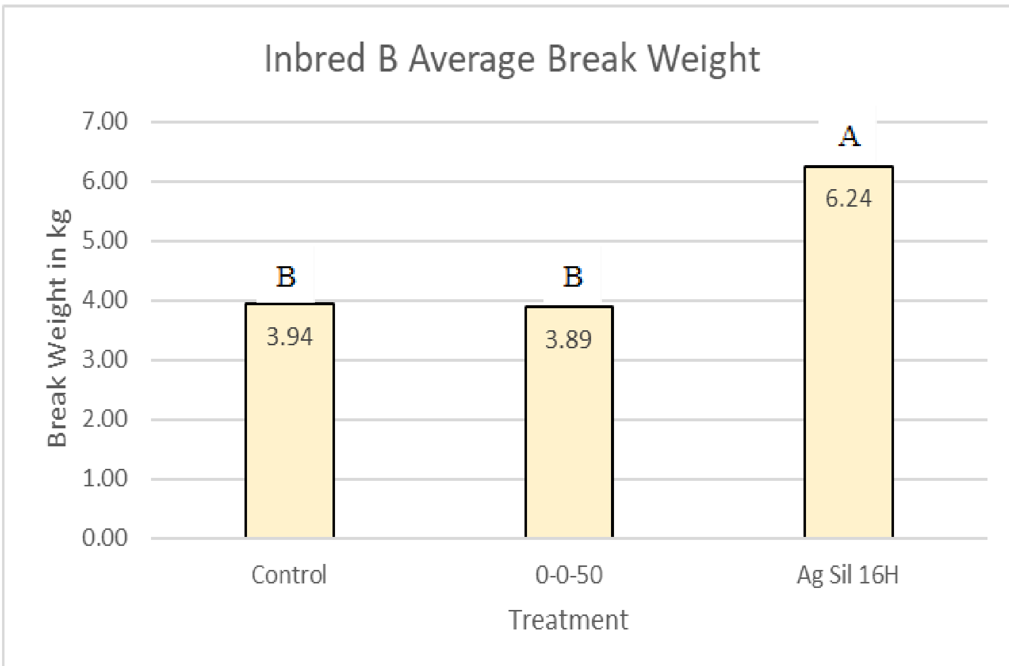
Graph 2. Inbred A graph showing the percent of broken plants measured during the push test. Columns with a different letter indicate values significantly different at P=0.1

Inbred B Stalk Breakage - ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*Significance*[B]
Between Groups	536.17	2	268.09	33.69	<.001	Y*
Within Groups	692.24	87	7.96			
Total	1228.42	89				

[B]Significance level set to 0.1; *data supports field observations

Figure 6. Stalk Breakage ANOVA table for inbred B, supporting field observations.



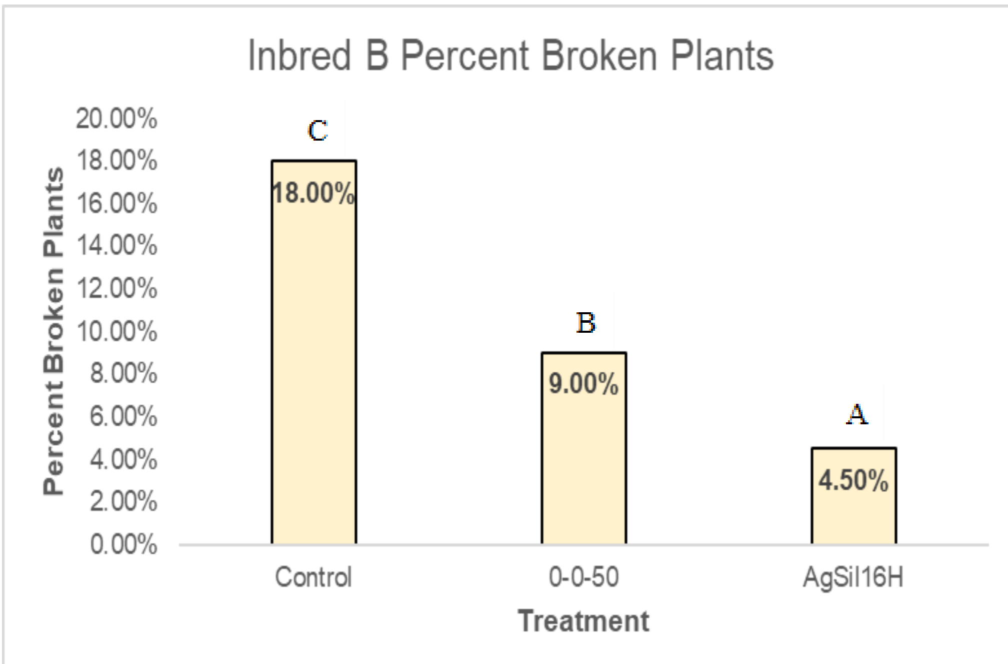
Graph 3. Inbred B graph showing the average breaking point between treatments. Data from the stalk breakage measurements. Columns with a different letter indicate values significantly different at P=0.1

Inbred B Push Test - ANOVA

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***Significance*** [B]
Between Groups	104.33	2	52.17	4.78	0.02	Y*
Within Groups	163.67	15	10.91			
Total	268	17				

[B]Significance level set to 0.1; *data supports field observations

Figure 7. Push Test ANOVA table for inbred B, supporting field observations.



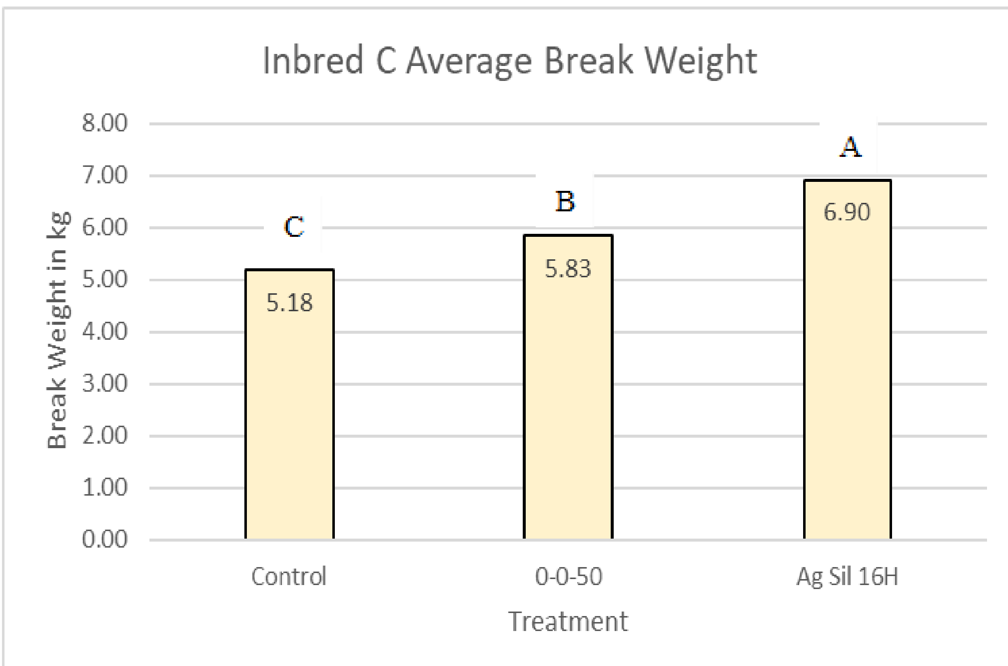
Graph 4. Inbred B graph showing the percent of broken plants measured during the push test. Columns with a different letter indicate values significantly different at P=0.1

Inbred C Stalk Breakage - ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*Significance*[B]
Between Groups	185.90	2	92.95	15.66	<.001	Y*
Within Groups	427.30	72	5.93			
Total	613.20	74				

[B]Significance level set to 0.1; *data supports field observations

Figure 8. Stalk Breakage ANOVA table for inbred C, supporting field observations.



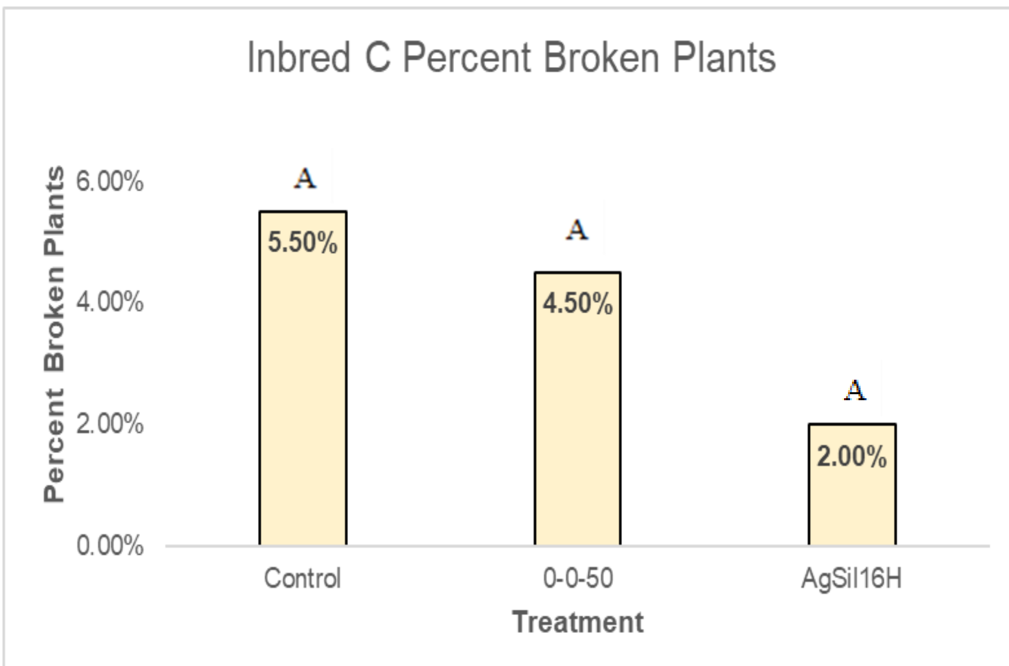
Graph 5. Inbred C graph showing the average breaking point between treatments. Data from the stalk breakage measurements. Columns with a different letter indicate values significantly different at P=0.1

Inbred C Push Test - ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*Significance* [B]
Between Groups	5.20	2	2.60	1.70	0.22	N*
Within Groups	18.40	12	1.53			
Total	23.6	14				

[B]Significance level set to 0.1; *data supports field observations

Figure 9. Push Test ANOVA table for inbred C, supporting field observations.



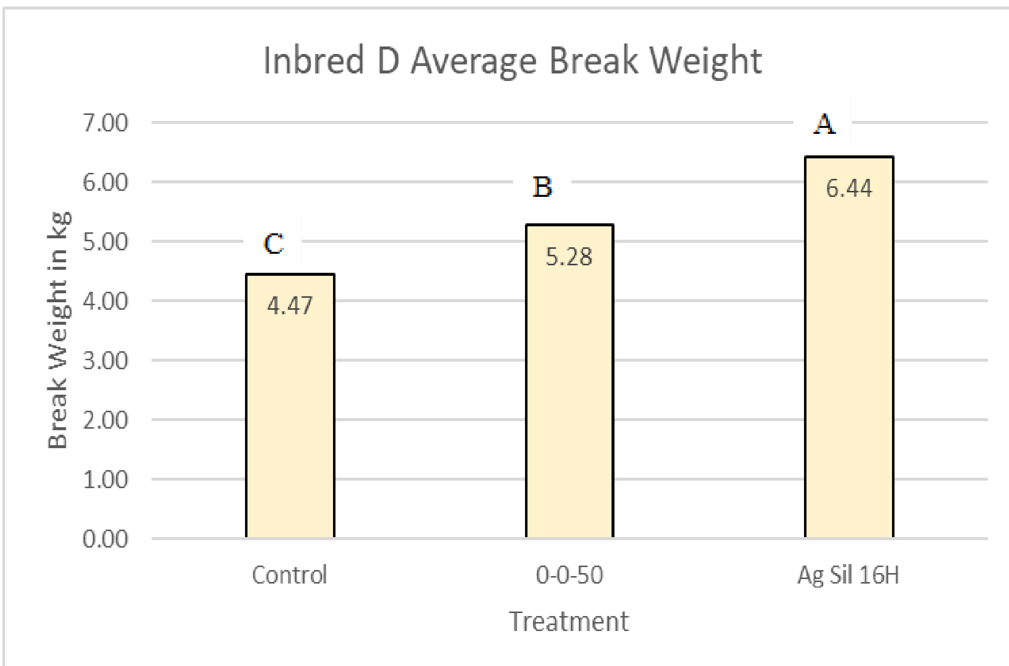
Graph 6. Inbred C graph showing the percent of broken plants measured during the push test. Columns with a different letter indicate values significantly different at P=0.1

Inbred D Stalk Breakage - ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*Significance*[B]
Between Groups	242.65	2	121.32	23.88	<.001	Y*
Within Groups	365.84	72	5.08			
Total	608.49	74				

[B]Significance level set to 0.1; *data supports field observations

Figure 10. Stalk Breakage ANOVA table for inbred D, supporting field observations.



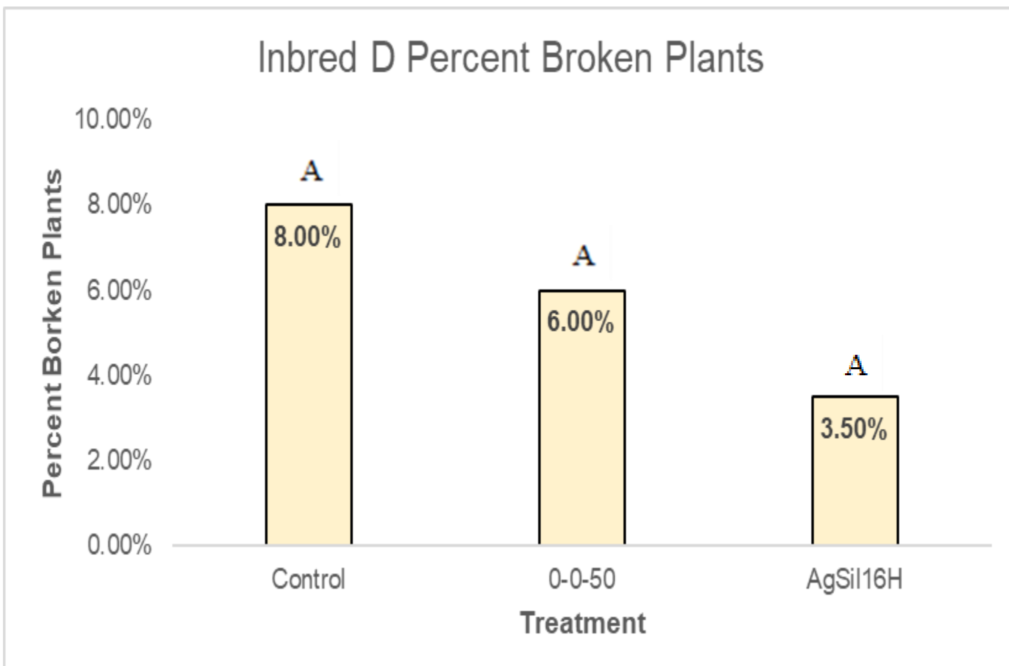
Graph 7. 2018 Inbred D graph showing the average breaking point between treatments. Data from the stalk breakage measurements. Columns with a different letter indicate values significantly different at P=0.1

Inbred D Push Test - ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*Significance* [B]
Between Groups	3.73	2	1.87	0.66	0.54	N*
Within Groups	34.00	12	2.83			
Total	37.73	14				

[B]Significance level set to 0.1; *data supports field observations

Figure 11. Push Test ANOVA table for inbred D, supporting field observations.



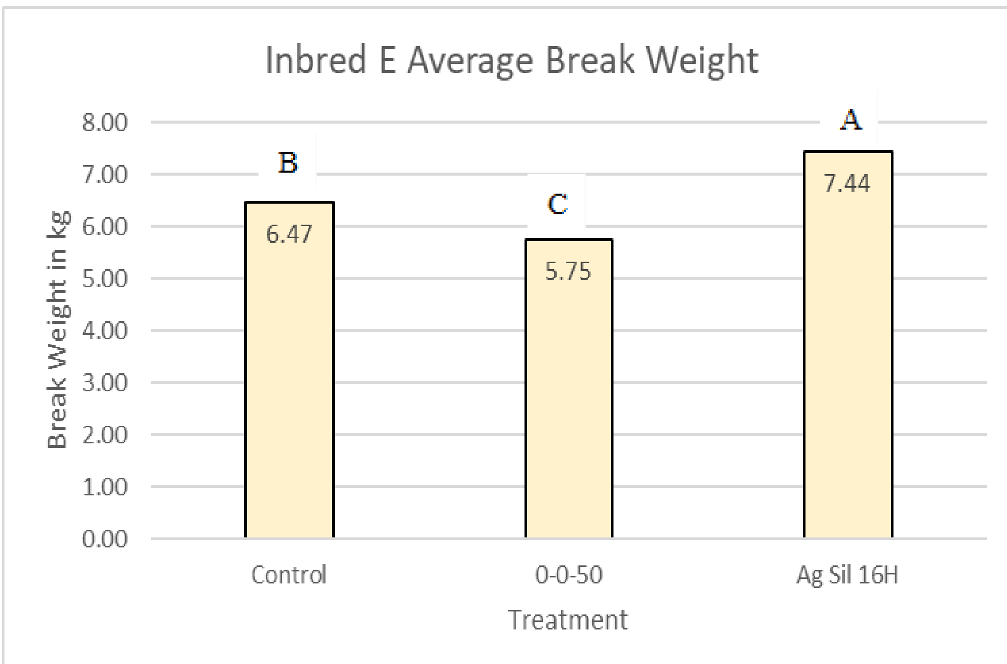
Graph 8. Inbred D graph showing the percent of broken plants measured during the push test. Columns with a different letter indicate values significantly different at P=0.1

Inbred E Stalk Breakage - ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*Significance* [B]
Between Groups	212.45	2	106.23	4.90	0.009	Y*
Within Groups	1885.15	87	21.67			
Total	2097.60	89				

[B]Significance level set to 0.1; *data supports field observations

Figure 12. Stalk Breakage ANOVA table for inbred E, supporting field observations.



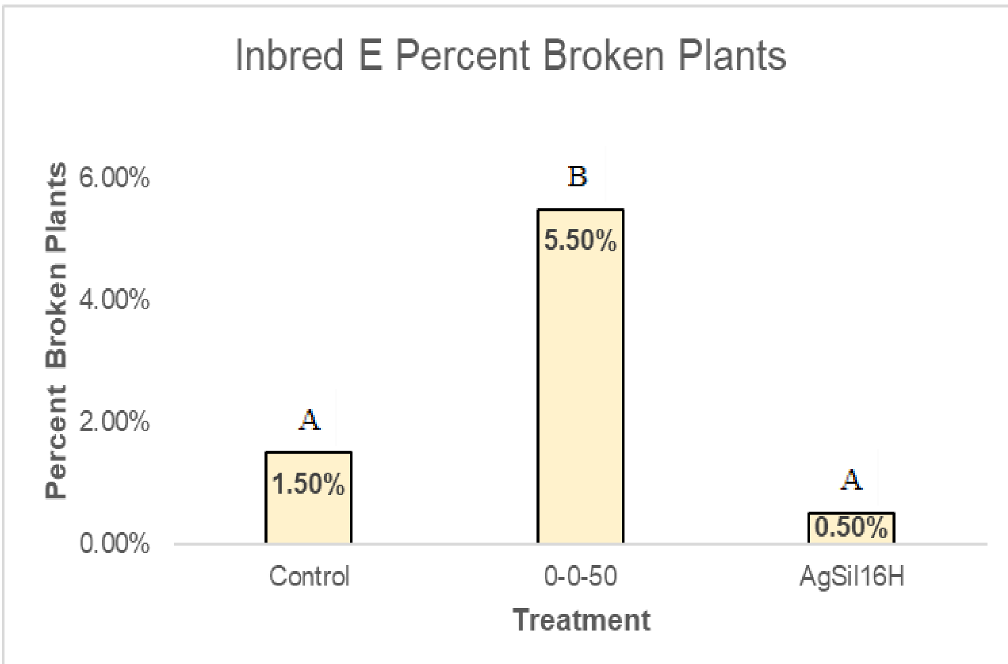
Graph 9. Inbred E graph showing the average breaking point between treatments. Data from stalk breakage measurements. Columns with a different letter indicate values significantly different at P=0.1

Inbred E Push Test - ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*Significance*[B]
Between Groups	9.33	2	4.67	4.62	0.03	Y*
Within Groups	15.17	15	1.01			
Total	24.5	17				

[B]Significance level set to 0.1; *data supports field observations

Figure 13. Push Test ANOVA table for inbred E, supporting field observations.



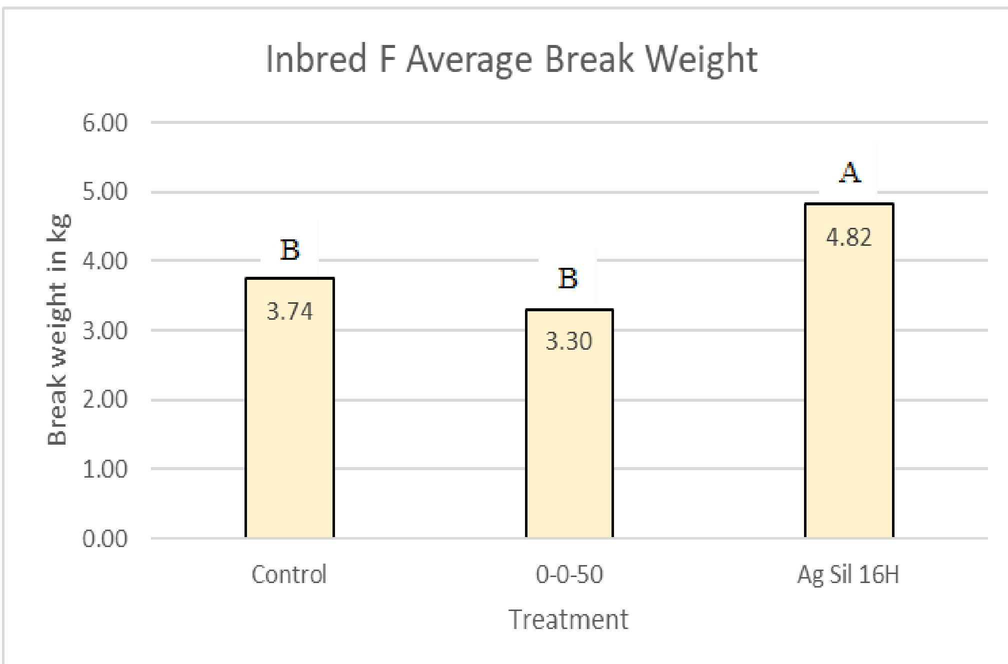
Graph 10. Inbred E graph showing the percent of broken plants measured during the push test. Columns with a different letter indicate values significantly different at P=0.1

Inbred F Stalk Breakage - ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*Significance*[B]
Between Groups	149.29	2	74.64	17.10	<.001	Y*
Within Groups	314.30	72	4.37			
Total	463.59	74				

[B]Significance level set to 0.1; *data supports field observations

<u>Figure 14. Stalk Breakage ANOVA table for inbred F, supporting field observations.</u>



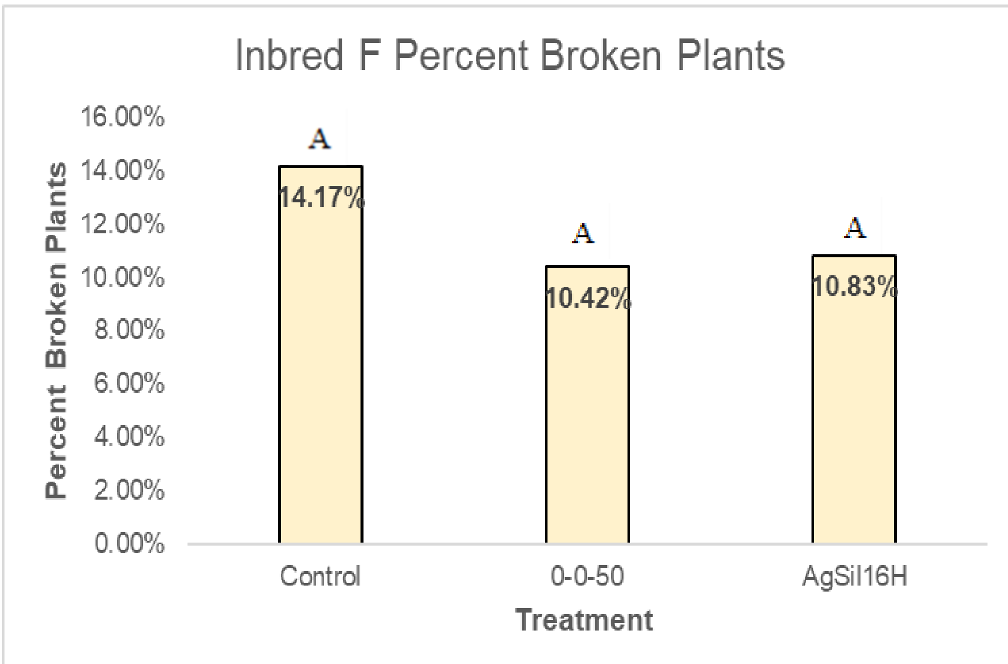
<u>Graph 11. Inbred F graph showing the average breaking point between treatments. Data from stalk breakage measurements Columns with a different letter indicate values significantly different at P=0.1</u>

Inbred F Push Test - ANOVA

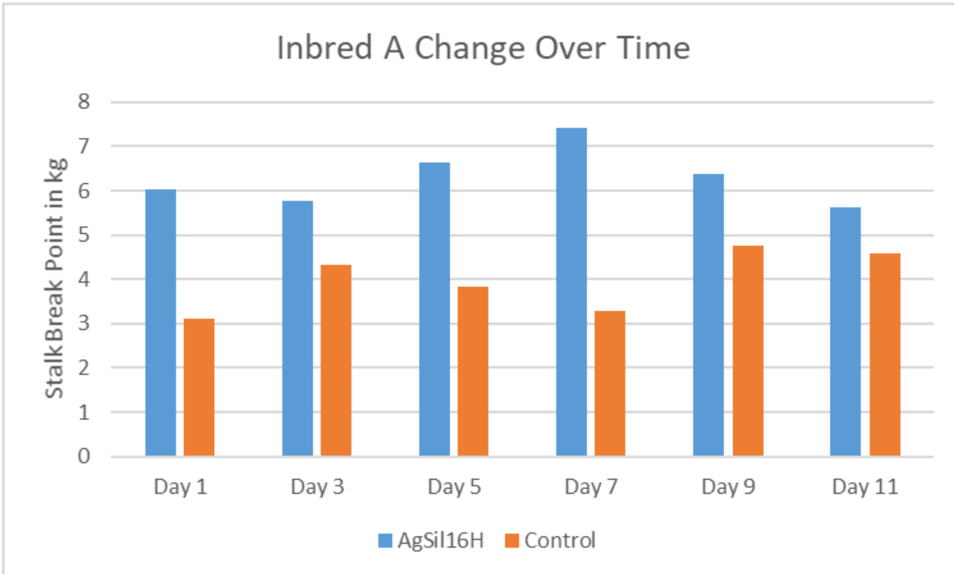
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*Significance* [B]
Between Groups	9.73	2	4.87	1.13	0.35	N*
Within Groups	51.60	12	4.30			
Total	61.33	14				

[B]Significance level set to 0.1; *data supports field observations

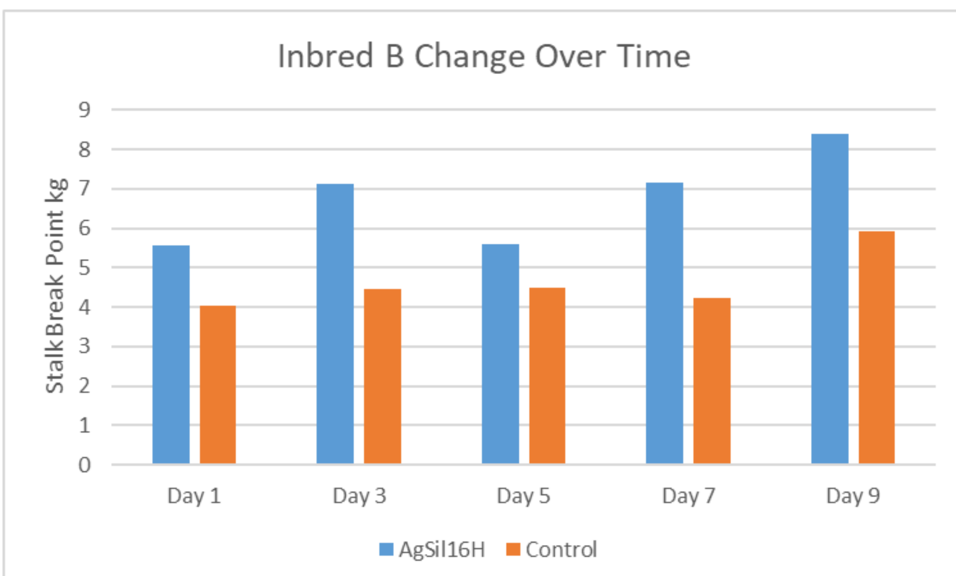
Figure 15. Push Test ANOVA table for inbred F, supporting field observations.



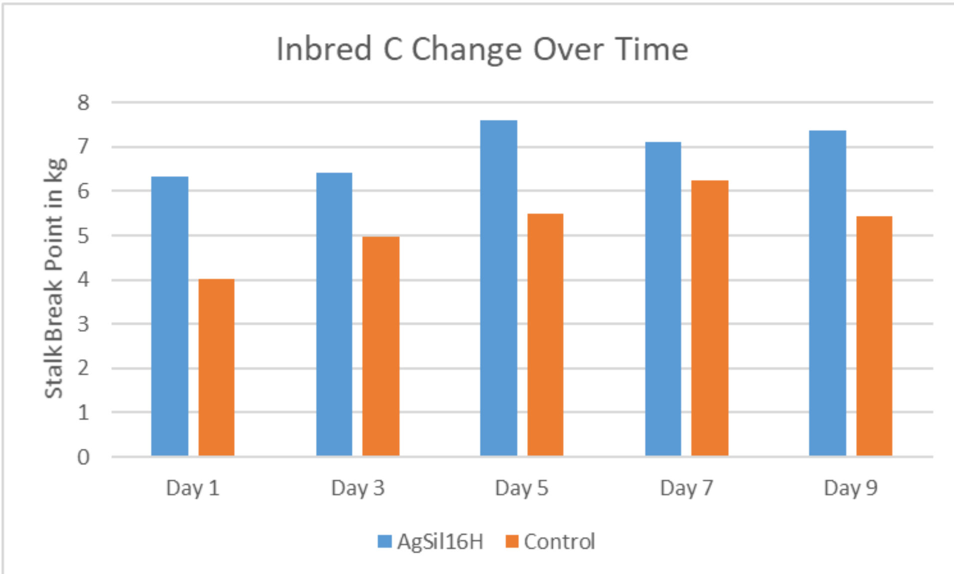
Graph 12. Inbred F graph showing the percent of broken plants measured during the push test. Columns with a different letter indicate values significantly different at P=0.1



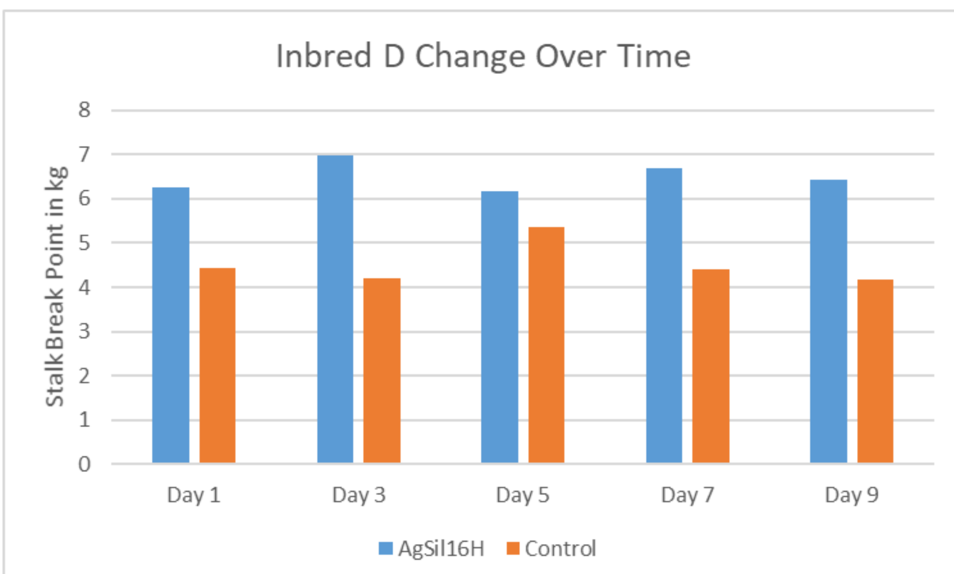
Graph 13. Inbred A stalk break point through time, AgSil16H and control treatments



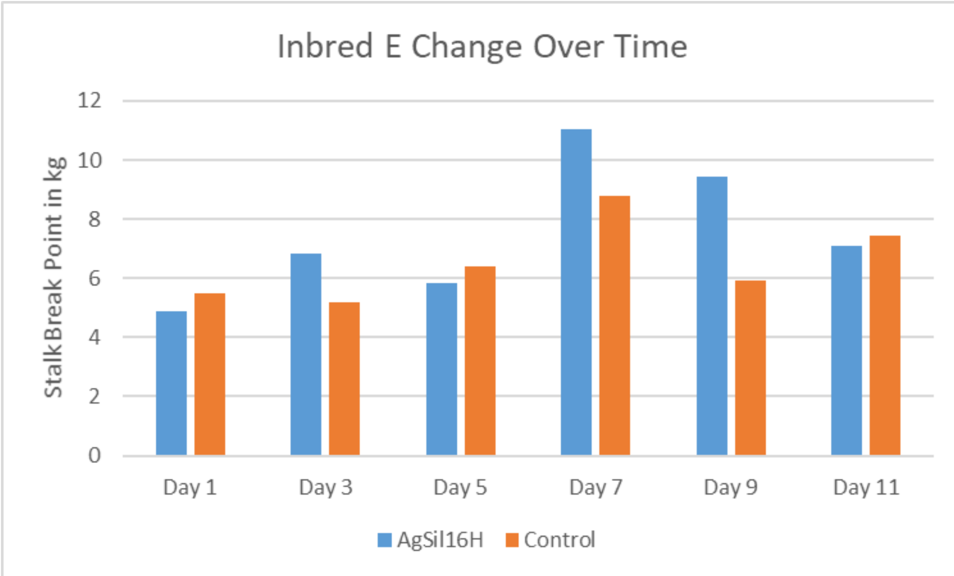
Graph 14. Inbred B stalk break point through time, AgSil16H and control treatments



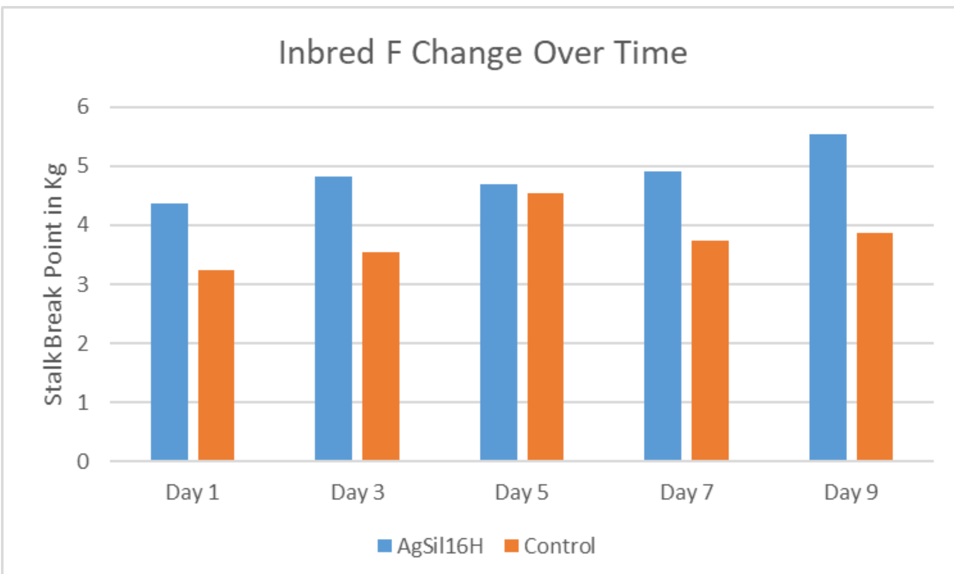
Graph 15. Inbred C stalk break point through time, AgSil16H and control treatments



Graph 16. Inbred D stalk break point through time, AgSil16H and control treatments



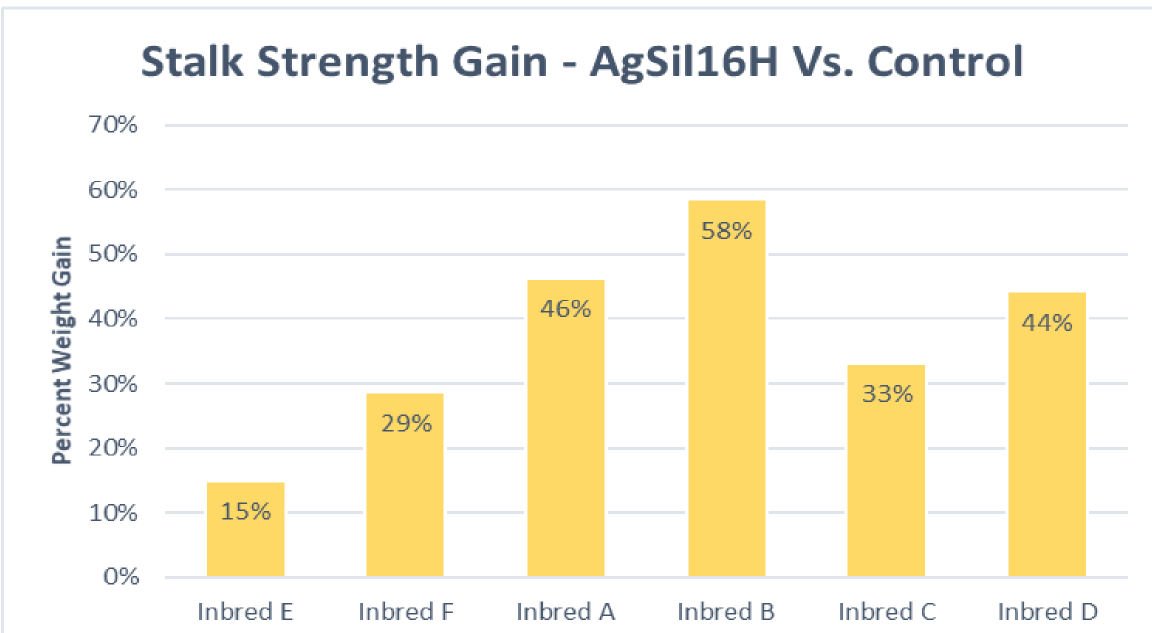
<u>Graph 17. Inbred E stalk break point through time, AgSil16H and control treatments</u>



<u>Graph 18. Inbred F stalk break point through time, AgSil16H and control treatments</u>

	2017		2018			
Inbred	**E**	**F**	**A**	**B**	**C**	**D**
Inbred Stalk Rating	2*	3*	5*	4*	4*	4*
Tech Sheet Comments	Strong stalk.	Some green snap potential	Brittle stalk	Moderate green snap potential	May green snap	May green snap
	1=Strong Stalk 5=Brittle Stalk *Ratings from Neal Campbell, Senior Production Angronomist, Beck's Hybrids					

Table 1. Inbred stalk ratings and comments. Provided by Neal Campbell, Senior Production Agronomist at Beck's Hybrids.



Graph 19. Percent gain in the force required to break the plant-stalk from the stalk breakage measurements. This graph represents the gain measured in the AgSIl16H treatment versus the control treatment.

Within each female inbred line, a positive effect of the silicon treatment on stalk strength was measured (Graph 19). These results were measured by the Stalk Breakage test and represent the gain in force required to break the plant-stalk measured in the AgSil16H treatment when compared to the control treatment. The inbred stalk rating chart (Table 1) and the stalk strength gain graph (Graph 19) show a generally positive response to a silicate application. These measured responses are in general agreement with our field observations of the increased stalk strength in response to silicon applications.

The positive response to the silicate application occurred quickly after application and the gain was maintained throughout the data collection period on all inbreds during both production seasons. Graphs 13-18 show how each inbred responded to the application. Silicate had a positive impact on all inbreds, some more than others, for example inbred E shows little response while inbreds A and B show a much greater response. The most noted responses were observed and measured in inbred lines that are known per experience and per supplier technical sheets to be poorer in stalk strength and integrity, i.e. inbred lines A and B (Table 1)

Return on Investment

Calculating a return on investment (ROI) for the use of the potassium silicate product proved challenging. The basis of this research was to investigate a product that was intended to reduce the chance of a stalk breakage event occurring just prior to or during the detasseling season. Due to these reasons, the following ROI is developed based on the following set of assumptions.

- A plant is counted as broken if it breaks at the primary ear node preventing it from producing an ear
- A broken plant equals a lost ear.
- The female inbred is planted at a 79,040 seeds/ha
- Only 78% of the crop zone is female plants (4:1 row pattern)
- 78% of 79,040 seeds/ha is 61,651 seeds/ha
- The female population is 61,651 plants/ha
- A harvested ear 14 rows around and 20 kernels long (280 seeds).
- Yield per hectare 172.9 sellable units
- A unit is 80,000 seeds.
- A unit of hybrid seed has an end user value of $300.
- AgSil16H cost $9.88/ha
- No assumed application costs; product is applied with an existing spray pass across the field.
- The costs to walk a field for green snap are:
    - 2-10% green snap - $86.45/ha
    - 10-20% green snap - $148.2/ha
    - 20-30% green snap - $247/ha

- Calculations are based on the performed push test results.

2017

Treatment	Percent Plants Broken	Value Lost/Ha	Potential Value Minus Loss	Value after Walks/Sprays	Return on Investment
Control	8.41%	$ 5,443.52	$ 46,426.48	$ 46,340.03	
AgSil16H	6.14%	$ 3,972.30	$ 47,897.70	$ 46,823.25	**$ 483.22**

Table 2. 2017 Return on investment calculations.

2018

Treatment	Percent Plants Broken	Value Lost/Ha	Potential Value Minus Loss	Value after Walks/Sprays	Return on Investment/Ha
Control	13.93%	$ 9,016.49	$ 42,853.51	$ 42,705.31	
AgSil16H	5.00%	$ 3,236.69	$ 48,633.31	$ 47,558.86	**$ 4,853.55**

Table 3. 2018 Return on investment calculations.

ROI is crucial when making farm management plans. A producer's bottom line is directly impacted by these decisions. In 2017, a positive ROI was observed. Note that application of AgSil16H in 2017 to inbreds that are known to have less potential for stalk breakage still gave an ROI of $483.22 per hectare (Table 2).

The weather in 2018 allowed the target inbreds to be used and gave a much more favorable and consistent ROI. Field observations and data support a greater impact of AgSil16H application on the inbreds in 2018. The response to AgSil16H application provided a ROI of $4853.55 per hectare (Table 3).

Conclusions

Applying a potassium silicate product (AgSil16H) at a V10 application window had a positive impact on the observed and measured stalk strength on the six female inbreds tested. Each female inbred responded differently to the application of the silicate product. The tables on pages 13 and 33 give an idea as to which inbreds could be more responsive to a silicate application. These stalk ratings had a field by field correlation to the response observed and measured. Inbred E, expected to be the strongest stalk, had the lowest response rate, while Inbreds A and B were expected to be the weakest stalks, these had the greatest response to the silicate application. This type of response, pending further research, can be used to make a prediction prior to a production season about which inbreds could benefit from a silicate application. More years of data collection and model building are needed to develop more robust recommendations.

The positive results observed and measured in this research provide strong justification for additional work to be done on a greater number of inbred lines. This work will shed new light on the impact that silicate treatments can have on hybrid seed production. It might allow inbred seed lines previously discarded due to poor stalk strength characteristics to be utilized in full scale production. Silicon is known to reduce the impact of environmental stresses, thus improving maize plants ability to grow and reproduce successfully. Such a favorable response could impact other areas of grain production as well. Improved plant standability and nutrient status could promote grain yield in organic production systems, for example, where options for weed control and fertilizer are more limited.

There are several unknowns with regards to silicon and its roles and uses in the seed production industry. More work with a wider array of inbreds is needed to verify the positive responses seen here. Additionally, more research is needed to discover what silicate can do for the agriculture industry in the future. A few of the questions follow.

- Is V10 the best application time?
- Would multiple applications improve response?
- How is the small amount of silicon (compared to the total plant uptake) applied impacting the plant?
- What is the role of silicon in a maize plants leaf physiology?
- Is 3180 mg/kg of SiO2 an optimum application concentration?
- How much silicate does maize acquire from the soil?
- Are the same positive effects observed in commercial production?

The application of potassium silicate has the potential to be a game changing tool for managing stalk quality in both the hybrid maize seed production industry and the commercial production of maize and silage. Stalk integrity is an important factor for success in both industries. In addition to improved stalk integrity, greater WUE has the potential to have even more impact on the maize seed industry. As maize growing regions experience more variable weather, water stress prior to seed set becomes increasingly likely, leading to loss of stalk integrity. An additional management tool such as silicon and potassium silicate application to protect crop yield will become increasingly valuable to seed producers. The future is exciting for silicon research.

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