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AGRONOMY SCIENCES RESEARCH SUMMARY

2016 HEARTLAND EDITION

INTRODUCTION

The 2015 growing season was one of adjusting to a new normal for many in agriculture. Crop production and economic trends established in 2014 largely continued in 2015. Corn yields remained high with the projected 169.3 bu/acre U.S. average yield second only to the all-time high of 171 set in 2014. The 2015 soybean crop was the largest ever, slightly above 2014's record crop. Commodity prices were relatively stable in 2015 following the sharp drop off of recent highs that occurred over the previous two seasons. Although long-term prospects remain positive given demand growth associated with an expanding global population and growing middle class, tighter margins on the horizon for the near term have brought a renewed focus on efficient management that is driving changes on the farm and throughout the industry.

Successful crop management under current conditions requires smart and efficient use of resources driven by sound agronomic knowledge. Access to trusted advisors and research-based insights to provide a basis for sound decisions is more important than ever given the economic headwinds and continually evolving production challenges that growers face. At DuPont Pioneer, our commitment to improved crop management is the foundation of our GrowingPoint™ agronomy research structure – an industry-leading network of agronomists and researchers across North America. The mission of this team is to help maximize grower productivity by delivering useful insights built on rigorous, innovative research.

This Agronomy Sciences Research Summary provides insights on numerous crop production topics relevant to growers in the central Corn Belt; however, it represents just a small portion of the vast array of resources available in the Pioneer agronomy library. This wealth of information is more accessible than ever with the introduction of the Pioneer® GrowingPoint™ agronomy app in 2015. This free mobile app allows growers to quickly and easily view the hundreds of agronomy publications in the Pioneer agronomy library on a tablet or smartphone. We hope that resources available in this book and online will help you drive yield and profitability in 2016.

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TABLE OF CONTENTS

return to table of contents

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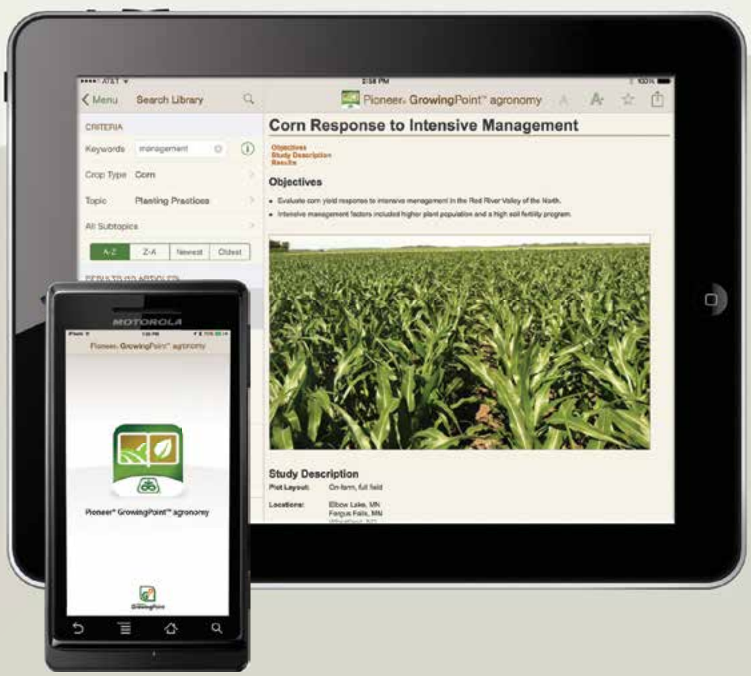

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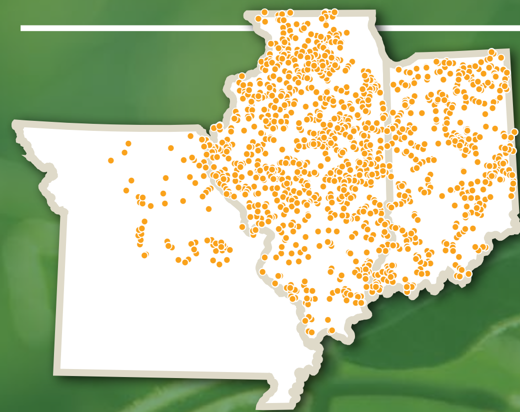

1,886 TOTAL TRIALS

1,418 CORN

468 SOYBEAN

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We're pursuing the same things.

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STRATEGIES AND CONSIDERATIONS FOR MULTI-HYBRID PLANTING

Farmers intending to replace old planters have a multitude of recent innovative features to consider, including planters with the ability to seed more than one hybrid or variety within a field. These new planters, often referred to as multi-hybrid or multi-cultivar planters, are configured with the equipment needed to automatically switch between two or more crop cultivars on-the-go. This technology allows growers to use prescription maps to match hybrids or varieties with specific field conditions and will likely be most beneficial in fields with variable landscapes. Initial implementation has largely focused on variable placement of corn hybrids, but the technology could potentially be used with any crop.

Precision farming pioneers have long envisioned that hybrid or cultivar would be an important input for variable management (Dudding et al., 1995). Extension agronomists consistently rate corn hybrid selection as one of the most important factors for maximizing yield (Coulter and Van Roekel, 2009; Elmore et al., 2006; and Thomson McClure, 2014). Variable cultivar planting takes this management decision to a higher level, allowing growers to choose the best-adapted cultivar for ***each part of the field.***

Commercial availability of multi-cultivar enabled planters makes it easier than ever to deploy a zone-based management strategy for crop cultivar selection. This article will discuss strategies to identify candidate fields and develop appropriate multi-cultivar prescriptions, as well as review some potential applications for multi-cultivar planting in corn and soybeans. Although many of the principles discussed can be applied to numerous crop species, the focus of this article will primarily be multi-hybrid strategies for corn.

DERIVING VALUE FROM MULTI-HYBRID PLANTING

Two conditions are necessary for a multi-hybrid planting strategy to provide a yield advantage. First, there must be significant within-field variation in yield due to environmental or management factors, including landscape topography and other soil variables (i.e., the more uniform a field, the less likely that multi-hybrid planting will increase yield). Secondly, there must be a difference between hybrids in yield response to the within-field environmental variation.

A statistical technique originally developed in the 1960s (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966) has commonly been used to describe yield stability of a corn hybrid across a range of environments. This method involves developing a linear regression of yield for a given hybrid versus the average yield of all hybrids tested across the same (multiple) environments. This provides a measure of relative yield stability for a given hybrid. A regression slope of 1 represents average yield stability with more stable hybrids (commonly referred to as "defensive" or "workhorse" hybrids) having a slope <1 and more responsive hybrids (commonly referred to as "offensive" or "racehorse" hybrids) having a slope >1 (Figure 1).

Planting a DuPont Pioneer multi-hybrid trial near Mexico, Missouri (April 22, 2015).

The average yield of all cultivars at a location is referred to as that location's environmental index. Although originally developed to characterize yield stability across multiple locations, this same model can be applied to assessing hybrid response to variability within a field and evaluating the potential value of variable hybrid planting.

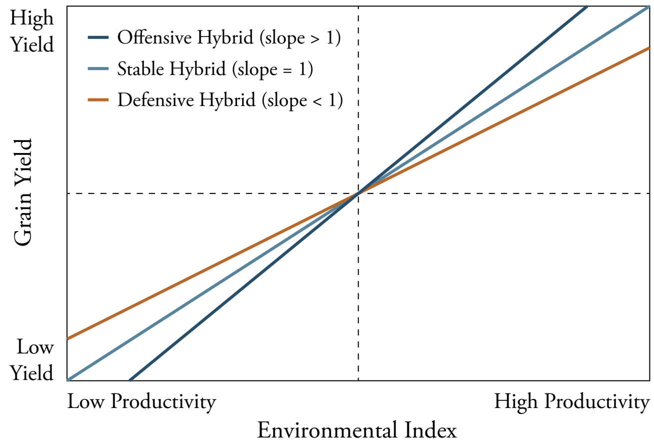


Figure 1. Corn hybrid yield stability model showing example linear regressions for offensive, stable, and defensive hybrids.

Figure 2 shows a hypothetical field in which yield performance is nearly (or "relatively") constant across the entire field. In this scenario, yield would be maximized by planting the highest-yielding cultivar across the entire field.

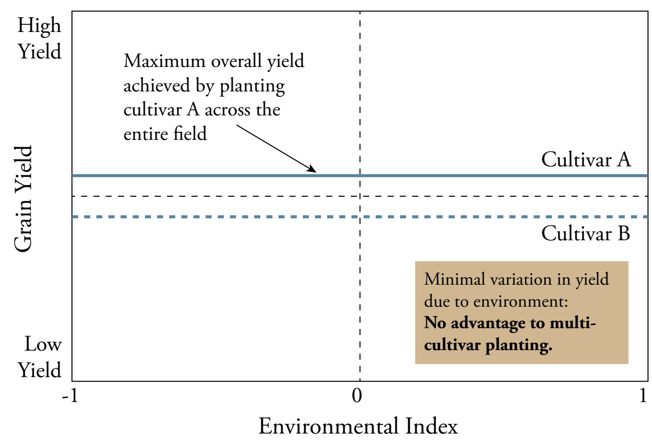


Figure 2. Grain yield of two cultivars in a hypothetical field in which there is no spatial variation in yield due to environmental conditions.

This example visualizes a scenario in which the environmental factors in question have little or no influence on yield of either cultivar. In reality, all fields have some degree of spatial variation in yield due to environmental or management factors; the greater this variation, the more potential there is for differential placement of cultivars within the field to increase yield.

Figure 3 shows a hypothetical field in which yield varies due to environmental factors, but the two cultivars respond similarly to the environmental variation. The environmental index in this example could be reflective of any environmental factor or combination of factors that contribute to spatial variation and impact grain yield, such as drainage, disease pressure, or soil properties, or management factors such as tillage or crop history. Although this field has substantial variation in yield across the landscape, cultivar A still out-yields cultivar B across all environments in the field; therefore, yield would be maximized by planting the entire field to cultivar A. It is important to remember that substantial variability in yield across a field does not automatically mean that variable placement of two cultivars will provide a yield advantage.

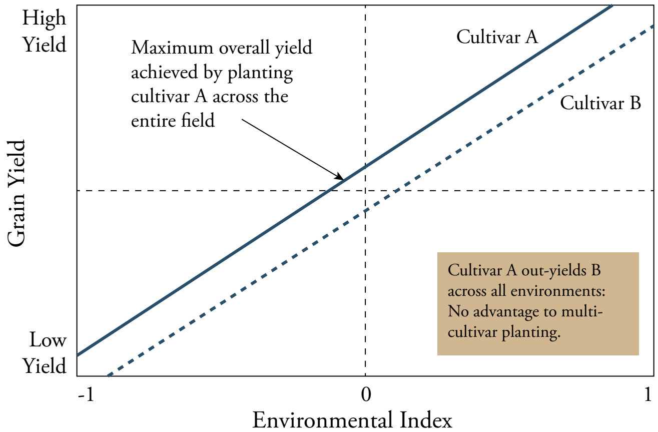


Figure 3. Grain yield of two cultivars in a hypothetical field in which both cultivars respond similarly to spatial variation in environmental conditions.

Figure 4 shows a scenario in which both conditions are met for multi-cultivar planting to be advantageous: variation in yield due to environmental or management factors and differential cultivar response to this variation.

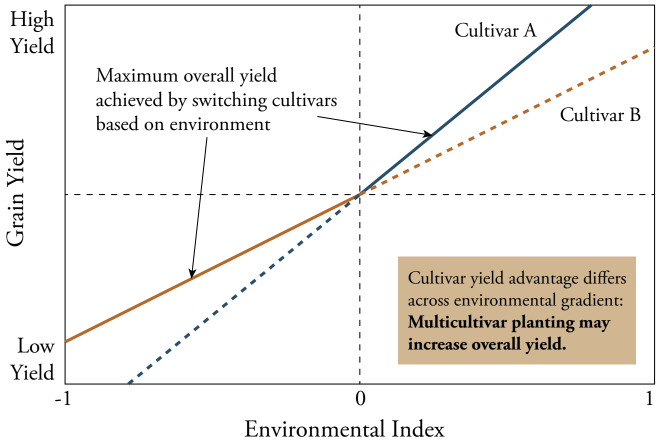


Figure 4. Grain yield of two cultivars in a hypothetical field in which the cultivars have a differential response to environmental or management variation.

In this field, yield would be maximized by planting cultivar A in the higher-yielding regions of the field and cultivar B in the lower-yielding areas, a scenario represented by the solid lines in the figure.

DuPont Pioneer split-planter trial near Harlan, Iowa, in 2001. Split-planter trials have been used extensively over the past 20 years to study the value of variable hybrid placement.

PREVIOUS RESEARCH

Even though commercial availability of multi-hybrid planting technology is relatively recent, the potential value of within-field variable hybrid placement has been studied extensively by DuPont Pioneer and university scientists for the past 20 years. Studies have typically involved using a conventional planter to plant two hybrids across a field using a split-planter arrangement. This method allows paired comparisons of two hybrids throughout an entire field to determine if they performed differently in different environments within the field. Numerous DuPont Pioneer on-farm split planter trials were conducted beginning in 1996 when the rapid adoption of yield monitors among growers made collection of spatial yield data across entire fields feasible for the first time (Doerge and Gardner, 1998; Figures 5 and 6).

Results of university split-planter studies generally have not supported widespread implementation of multi-hybrid planting. In the majority of studies, the hybrids responded similarly to within-field variation. A 3-year split-planter study conducted in 5 fields in New York found that spatial variability in yield differences between hybrids occurred in only 4 out of 15 site-years (Katsvairo et al., 2003). A study conducted from 1997 to 1999 in dryland production in eastern Colorado also found that the two hybrids tested responded similarly to in-field variation (Shanahan et al., 2004). Two studies conducted at multiple locations in eastern Illinois both found that there was no significant spatial variability in yield differences between hybrids in most fields tested (Miao et al., 2006a; 2006b).

A study was conducted by Pioneer and USDA researchers in the late 1990s using split-planter experiments to evaluate the potential yield benefits of variable hybrid planting in irrigated and dryland corn production in the far western Corn Belt (Doerge, 2000). Results showed that variation in grain yield across the landscapes in test locations was associated with site characteristics that do not change over time, such as elevation, pH, organic matter, soil color, and soil electrical conductivity; however, there was no evidence that hybrids responded differently to these site characteristics at either the dryland or irrigated locations in any year of the study.

These results are consistent with the scenario shown in Figure 3, in which environmental variation exists but hybrids responded similarly to it, making the best management strategy to plant the higher performing hybrid across the entire field.

One noteworthy aspect of all of these studies is that the hybrids used generally were not selected based on any specific agronomic characteristics. In the study conducted by Shanahan et al., an early-maturity and late-maturity hybrid were compared. The other studies simply compared hybrids that were commonly used within their respective regions at the time. Even though the results of these studies did not show that variable hybrid planting would have provided much value in most cases, they do not rule out the possibility that a multi-hybrid management strategy using hybrids selected based on specific agronomic characteristics appropriate for certain field areas could be beneficial. The accumulated body of research in this area suggests that the greatest likelihood of success with multi-hybrid planting would be to target implementation to select highly-variable environments, using hybrids carefully selected based on yield-limiting factors in the field.

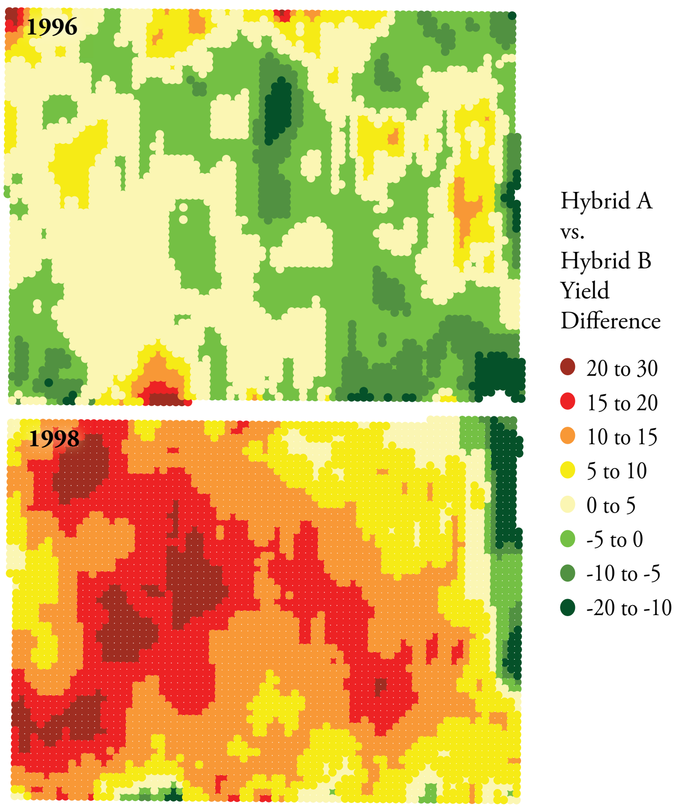


Figure 5. Yield difference maps from a DuPont Pioneer split-planter study conducted in northern Illinois in 1996 and 1998, using the same two hybrids both years. Results from individual years suggested potential value for variable hybrid placement. However, the vastly different spatial patterns between years indicated a high degree of temporal variability relative to spatial variability in this field, which would make effective hybrid placement a challenge.

CRITERIA FOR MULTI-HYBRID STRATEGIES

Initial attempts at developing multi-hybrid planting prescriptions have often followed in the footsteps of strategies developed for variable rate seeding. Variable rate seeding prescriptions typically

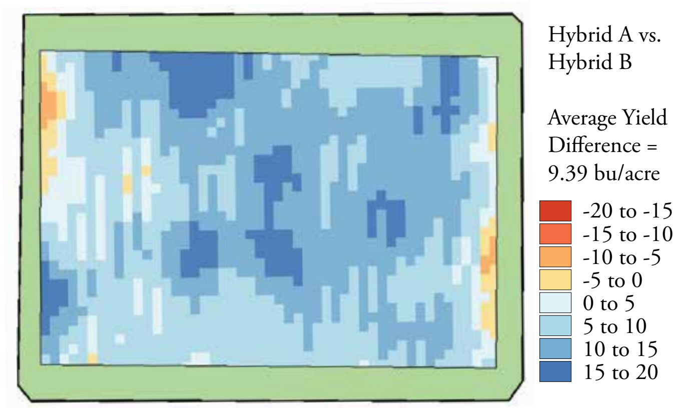


Figure 6. Yield difference map from a DuPont Pioneer split-planter study conducted in northern Illinois in 2002. In this study, hybrid A outyielded hybrid B across 96% of the field.

involve varying the seeding rate based on spatial variation in yield potential, where more productive areas usually receive a higher seeding rate (in the case of corn) and less productive areas a lower rate. Management zones are developed according to expected yield performance, often using past yield history as a basis or soil characteristics as a proxy for productivity (Butzen et al., 2009). Applications of this framework to multi-hybrid planting have typically involved splitting a field into higher-yielding and lower-yielding areas and then planting an "offensive" hybrid to the high yield areas and a "defensive" hybrid to the low yield areas.

This method of creating multi-cultivar prescriptions offers the advantages of being widely applicable and relatively straightforward to develop and execute. However, research suggests that it is unlikely to provide yield benefits in corn on a consistent basis for the simple reason that very few modern hybrids meet the criteria of being truly "offensive" or "defensive." A recent review of performance data on over 2,500 corn hybrids tested in 7 or more environments found that only 6% met the definition of offensive (slope >1) and 8% met the definition of defensive (slope <1), while the vast majority of hybrids (86%) were classified as "stable" (Lauer and Hicks, 2005). These findings are not surprising given that modern corn breeding programs have largely focused on developing hybrids that will provide consistent performance across a wide range of environmental conditions (Pierce and Nowak, 1999).

Consider Source of Yield Variation

To realize a benefit from multi-hybrid planting, it will most likely be necessary to go beyond simply characterizing spatial yield variation – understanding the factor or factors driving that yield variation and selecting hybrids accordingly will be required. By comparison, variable rate seeding per se is generally simpler because the only one management criterion is under consideration: seeding rate, which is adjusted either higher or lower based on productivity or other factors. Modern hybrids are typically characterized for numerous agronomic traits, such as drought tolerance, disease resistance, root strength, etc., which provide a wide range of potential criteria for creating multi-hybrid prescriptions. As illustrated in Figure 4, one of the two conditions necessary for multi-hybrid planting to be advantageous is a differential hybrid response to variation in productivity. Knowing both the field conditions and hybrid characteristics for success under those conditions is critical.

One of the environmental factors most likely to provide the basis for a successful multi-hybrid management strategy is soil moisture. This factor meets both the criteria for successful multi-hybrid planting: too much or too little soil moisture causes substantial variation in yields, and crop cultivars frequently differ in their response to insufficient or excessive moisture. Just as importantly, these differing responses are usually well-characterized. An example of recent research in this area is a collaborative study between DuPont Pioneer, Raven Industries, and South Dakota State University comparing conventional and variable planting at several locations in South Dakota. This study involved placing hybrids with greater tolerance to wet conditions in low landscape positions where there was likely to be excess moisture early in the season and more drought-tolerant hybrids at upper landscape positions likely to experience drought stress later in the season. Preliminary findings from the study have shown promise for this strategy, with yield benefits in the range of five to eight bu/acre at some of the study locations. (Sexton et al., 2013; 2014).

Overhead view of a DuPont Pioneer multi-hybrid trial in 2015 with differing canopy color of the two hybrids clearly visible.

POTENTIAL APPLICATIONS FOR MULTI-CULTIVAR PLANTING

There are many other possible applications and placement criteria for multi-cultivar planting. A multi-cultivar prescription could potentially involve multiple criteria, such as planting a drought tolerant hybrid on high ground prone to moisture stress and a disease tolerant hybrid on low ground prone to a foliar disease. In some cases, it may prove beneficial to select hybrids or varieties based on a predetermined multi-cultivar strategy, whereas in other cases the greatest benefit may be derived by first selecting the best available genetics and then using a multi-cultivar planter to optimize their placement.

Not all potential applications would necessarily require a multi-cultivar planter to execute but may be easier to implement with the ability to switch cultivars on the go. Some applications may have limited utility now but could become more valuable in the future with the development of new genetics and technologies. If multi-cultivar planting is widely adopted, it is possible that new technologies could be brought to market specifically to make use of this capability.

Soil Moisture: As previously discussed, soil moisture is probably the most obvious candidate to form the basis of a multi-cultivar strategy. Multi-cultivar planting could allow a more drought tolerant cultivar to be planted on hill slopes, sandy areas, or other areas prone to drought stress. Drought tolerant cultivars could also be planted in pivot corners in areas with central pivot irrigation. Conversely, a cultivar more tolerant to saturated soils or "wet feet" could be planted in low-lying or poorly-drained areas.

Disease Resistance: Hybrids or varieties with greater genetic resistance to disease could be placed on low-lying ground or other areas more prone to disease. Disease-resistant hybrids or varieties could also be placed in areas that are inaccessible for aerial applications of foliar fungicide, such as along treelines, near wind turbines or powerlines, or near populated areas.

Stress Emergence: Stress emergence ratings for Pioneer® brand corn products help categorize their genetic potential to emerge under stressful environmental conditions (including cold, wet soils or short periods of severe low temperatures) relative to other products. Multi-cultivar planting could be used to place a hybrid with a high stress emergence rating in areas of a field prone to poor emergence conditions, such as productive areas that may have high levels of residue, or low-lying areas that are slower to dry out and warm up in the spring.

Insect Resistance / Refuge Placement: Multi-cultivar planting would allow virtually limitless flexibility in placing structured insect refuges within a field. While this capability currently has limited utility in the Corn Belt due to the transition to blended refuge corn products, it could be useful in cotton-growing regions that require structured refuges, as a research tool, or possibly with a future insect protection technology in corn or other crops. Multi-cultivar planting would also allow selective placement of an insect-resistant hybrid or variety along fencerows or grass waterways to protect against insect pests that move in from field margins or in areas of a field at higher risk of insect damage due to prior cropping history or management practices.

Herbicide Resistance: With multi-cultivar planting, a hybrid or variety with additional herbicide resistant traits could be placed along field margins, field entrances, or grass waterways to allow spot-spraying for management of weed species moving in from seed brought in on machinery or from adjacent fields or fencerows. Planting a herbicide-resistant hybrid or variety along a field margin could also be used to protect against herbicide drift from an adjacent field.

Iron Deficiency Chlorosis Tolerance: Soils with pH above 8.0 can result in alkalinity-induced chlorosis and reduced yield in corn and soybeans. Corn hybrids and soybean varieties both vary in their tolerance to elevated soil pH. Multi-cultivar planting would allow planting a hybrid or variety tolerant to chlorotic conditions in some areas of a field and another hybrid or variety that is more productive on lower pH soils. A DuPont Pioneer / University of Nebraska study conducted during 1998 to 2001 explored the possible value of multi-hybrid planting for increasing corn yield on high pH soils in Nebraska, although weather conditions during the study were generally not conducive to inducing chlorosis symptoms, and results were ultimately mixed (Doerge, 2002).

Planting a DuPont Pioneer multi-hybrid trial in 2015.

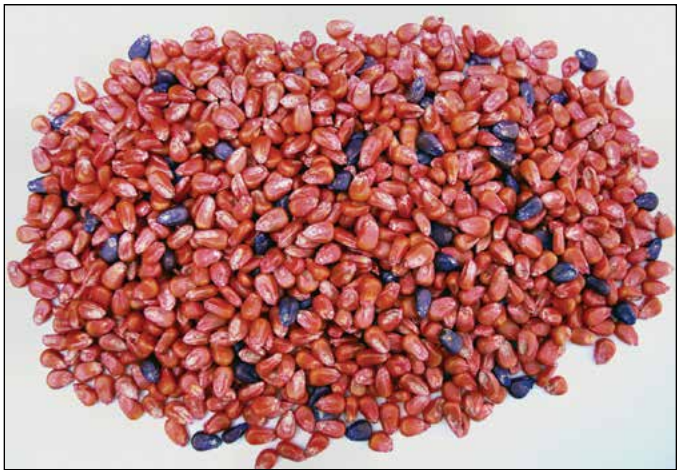
Standability: Multi-cultivar planting could potentially be used to help reduce the impact of lodging on yield. In the case of corn, this could involve planting a hybrid with stronger roots and/or stalks along field edges or other areas prone to wind lodging. For soybeans, a shorter stature variety could be placed on highly productive soils prone to lodging due to excessive plant height.

Maturity: Generally, planting of similar maturity hybrids or varieties would be an important component of a multi-cultivar strategy; however, in some cases, it could prove advantageous to selectively place products with differing maturities. A shorter maturity hybrid or variety could be placed in low lying areas or other parts of a field prone to slow maturity and drydown in the fall. A shorter maturity hybrid could also be placed in the end rows of a field to allow the field to be opened up earlier in the harvest season prior to harvesting the rest of the field.

Variable placement by hybrid or variety maturity could also be used to mitigate frost risk. Cold air accumulates in low-lying areas, putting them at a greater risk of frost damage. Placement of an earlier maturity hybrid or variety in these areas could reduce the risk of frost damage prior to physiological maturity, while allowing a fuller season hybrid or variety to be placed on higher ground less susceptible to early frost.

Seed-Applied Technology: Multi-cultivar planting could be used as a means to selectively place products based on seed-applied technology rather than genetics, or potentially based on both. As an example, this could involve placement of seed with a specific fungicide seed treatment in a part of a field prone to disease or an insecticide seed treatment in areas of a field at higher risk of insect damage due to prior cropping history or management practices. Populations of nematode species are known to vary by soil texture, with larger and more damaging species often more prevalent in sandy soils. Seed with a nematicide seed treatment could be placed in portions of a field at greater risk for nematode damage. With the rapid growth in seed treatment and seed-applied technologies, the potential applications for selective placement using a multi-cultivar planter will likely expand in the future.

Seed Production: Multi-cultivar planting technology could be useful in hybrid seed production, as it could allow greater flexibility and efficiency of planting male and female rows and border rows.



POTENTIAL DISADVANTAGES

Although it is hypothetically possible that a poorly designed multi-cultivar prescription could actually result in yield loss, this outcome is probably unlikely in most cases. The more realistic risk for most growers would be that multi-cultivar planting provides no yield advantage or a yield advantage that is insufficient to offset the additional cost and complexity associated with multi-cultivar planting. Multi-cultivar planting would substantially increase the complexity of planting operations due to the need to create prescriptions and handle a larger number of cultivars. Multi-cultivar planting would also likely increase the frequency of planter fills, particularly if a prescription is heavily weighted toward one product, which would increase the amount of time needed for planting.

IS THE FUTURE OF CORN PRODUCTION IN NARROW ROWS?

INTRODUCTION

The vast majority of corn acres in the U.S. and Canada are currently planted in 30-inch rows, with narrow rows generally defined as any row spacing or configuration less than 30-inches. Narrow rows have proven beneficial in some scenarios but generally have not shown a consistent yield advantage in the central Corn Belt region that makes up the bulk of North American corn production. Consequently, adoption of narrow rows has remained low.

Despite being used on less than 5% of corn areas, interest in narrow-row production has persisted. This is largely due to the perception that evolving corn production practices will eventually favor a transition to narrower rows, similar to the past shift away from 36- to 40-inch rows into the current 30-inch standard. The purpose of this summary is to examine research that addresses: 1) the question of whether changes in corn production will eventually favor narrow rows and 2) if a wide-scale shift into narrow rows will be necessary at some point to continue to drive gains in corn productivity. Two factors that relate to row spacing, plant population, and plant leaf architecture will be examined in detail.

PROVEN BENEFITS OF NARROW ROWS

To evaluate the potential benefit of narrow row corn in the future, it is worth examining scenarios where they have already proven beneficial. Research has shown a strong relationship between improved yields in narrow row corn and increased light interception (Andrade et al., 2002). To maximize yield, the crop canopy needs to capture 95% or more of photosynthetically active radiation (PAR) during the critical period immediately before and after silking (Figure 1). Corn at a given density can intercept a greater percentage of solar radiation when planted in narrow rows, which can increase yield in cases where corn in 30-inch rows does not meet this threshold (Andrade et al., 2002).

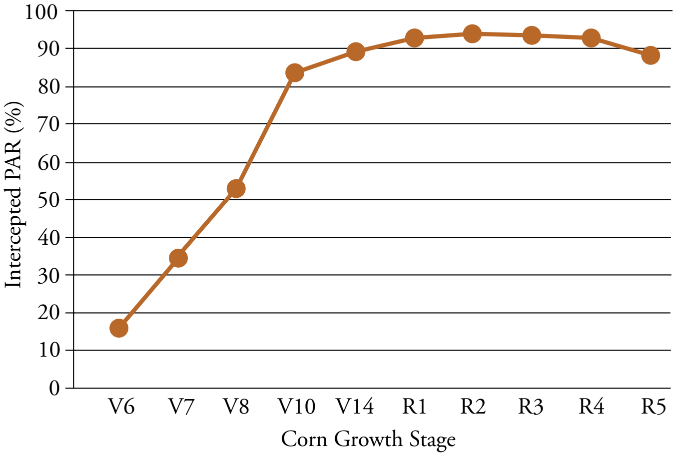


Figure 1. Percent of incident PAR intercepted by a corn canopy in central Iowa planted in 30-inch rows. *Adapted from Puntel, 2012.*

Figure 2. A corn canopy needs to intercept 95% or more of photosynthetically active radiation at silking to maximize yield.

Narrow rows can also improve nitrogen use efficiency of corn by increasing the ability of the crop to recover nitrogen from the soil (Barbieri et al., 2008). This can improve yield in nitrogen-deficient conditions; however, this advantage is reduced as nitrogen availability increases and may not result in increased yield when adequate nitrogen is available (Barbieri et al., 2000; Barbieri et al., 2008).

Yield benefits with narrow row corn have been observed more frequently in the northern portion of the Corn Belt in the area north of approximately 43°N latitude (a line running roughly through Mason City, IA; Madison, WI; and Grand Rapids, MI) (Lee, 2006). In a survey of several recent university studies comparing 15-, 20-, or 22-inch rows to 30-inch rows, an average yield advantage of 2.8% with narrow or twin rows was observed in northern studies, compared to no advantage on average (-0.2%) in the central Corn Belt (Jeschke, 2013). The lack of a consistent yield benefit in the central Corn Belt is likely because light interception and nitrogen uptake are generally not yield limiting in this area. Several studies have shown that corn in 30-inch rows can routinely capture over 95% of PAR in midwestern production (Figure 1) (Nafziger, 2006; Novacek et al., 2013; Robles et al., 2012; Sharratt and McWilliams, 2005; Tharp and Kells, 2001).

PLANT POPULATION

Long-Term Population Trends

It is generally assumed that optimum plant densities for corn will be significantly higher in the future than they are today. Examination of historical trends in plant population and corn yield show this assumption to be well-founded. Average corn yields have increased continually over the past 80 years as have average plant densities, increasing from around 12,000 plants/acre in the 1930s to over 30,000 plants/acre today (Duvick, 2005; DuPont Pioneer Brand Concentration Survey 2013). However, research has shown that yield potential per plant has not greatly increased over that time period. At low plant densities, current hybrids do not yield substantially more than hybrids of past decades (Duvick et al., 2004).

Examination of more recent data supports these findings. Average corn yield in the U.S. has increased from 118 bu/acre in 1985 to 158.8 bu/acre in 2013 (USDA NASS, 2014). Average corn seeding rates have increased linearly over this period, from approximately 23,300 seeds/acre in 1985 to over 30,000 seeds/acre in 2013. When corn yield and seeding rate data are used to calculate average grain yield/plant, the resulting trend line shows that average yield per plant has remained relatively constant at around 0.3 lbs/plant.

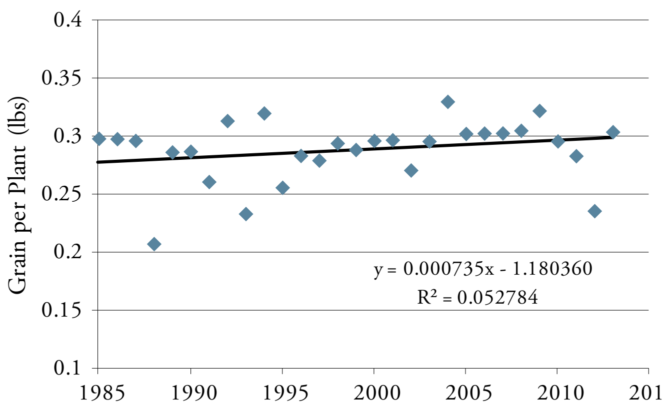


Figure 3. Average grain yield per plant in the U.S. from 1985 to 2013, based on average corn yields (USDA-NASS, 2014) and average corn seeding rates* (DuPont Pioneer Brand Concentration Survey 2013). **Assumes harvest stand = 95% of seeding rate.*

Higher plant density is not the only path to greater corn yields. In fact, growers who produced corn yields greater than 300 bu/acre in the 2013 NCGA National Corn Yield Contest did so over a wide range of plant populations. Harvest populations ranged from 29,000 plants/acre to 48,000 plants/acre, with the majority between 32,000 and 42,000 plants/acre (Jeschke, 2014).

Yield per plant varied widely as well, ranging from 0.36 lbs/plant to 0.64 lbs/plant. Grain yield per plant for these entries averaged around 0.5 lbs/plant, well above the current U.S. average. These data show that it is possible to increase corn yields per acre by increasing individual plant yield as opposed to plant density; however, this has not been achieved on a wide scale.

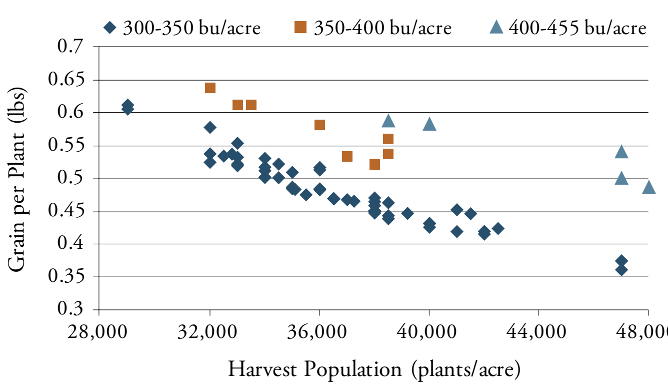


Figure 4. Harvest populations and grain yield per plant (lbs) of the 70 NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2013.

There is no guarantee that current trends will continue into the future; however, it seems likely that optimum plant densities will continue to increase beyond their current levels and will continue to be the main driver of increased corn productivity. A recent survey of plant density tolerance in U.S. corn germplasm indicated strong potential for further increases in optimum plant density (Mansfield and Mumm, 2014). At the current rate of growth, average corn seeding rates would increase from around 31,000 seeds/acre today to approximately 37,000 seeds/acre in 2035 and 42,000 seeds/acre in 2050 (Table 1). Assuming that 7,000 seeds/acre above the average is representative of a "high-end" seeding rate on the most productive ground, this would correspond to high-end seeding rate of 44,000 seeds/acre in 2035 and 49,000 seeds/acre in 2050.

Why Might Narrow Rows be Favorable at Higher Populations?

The primary rationale for narrow corn row spacings is that reducing the crowding of plants within a row, will reduce competition among individual plants and allow the crop to better utilize available light, water, and nutrients. As plant density increases, plants are closer together within a row and it seems reasonable to think that, at some point, this crowding could become yield-limiting.

Table 1. Current average and high-end seeding rates and projected rates for 2035 and 2050 based on current trends.

Seeding Rate	2013	2035 (projected)	2050 (projected)
		seeds/acre	
Average	31,000	37,000	42,000
High-End	38,000	44,000	49,000

The lack of a consistent yield benefit to narrow rows observed in most areas thus far suggests that this theoretical yield-limiting point has not been reached with current management practices. However, if such a point is reached in the future and higher corn yields continue to be driven by greater plant density, a wide-scale transition to narrower rows would then presumably be necessary to drive further gains. Several research studies may shed light on whether this theory is valid.

Narrow Row, High Population Research

A number of corn row spacing studies published during the last 15 years have included plant populations well above the current average (Table 2). If plant crowding within the row is indeed yield-limiting at high plant populations, then narrow rows would be expected to have a yield advantage over 30-inch rows in these studies.

Studies 1 through 5 in Table 2 are university studies that included plant populations over 40,000 plants/acre. Four of these studies, conducted in Nebraska, Iowa, Minnesota, and Indiana, did not show any yield advantage to narrow or twin rows at high populations (Table 2). The one study that showed an advantage was conducted in northern Minnesota where yield advantages with narrow rows have tended to be more consistent.

Studies 6 and 7 were recently conducted in Illinois and Indiana comparing 30-inch and twin rows at extremely high plant

Table 2. Yield advantage (%) of 15-, 20-, or 22-inch and twin rows compared to 30-inch rows observed in recent corn row spacing research studies in the Midwestern U.S. that included high plant populations (indicated in bold).

Study	Location	Row Widths (inches)	Populations (1,000 plants/acre)	Row Width x Population Interaction?	Narrow Row Advantage at High Population
1	Minnesota	22 vs. 30	16.5, 22, 27.5, 33, 38.5, **44**	Yes	4%
2	Nebraska	twin vs. 30	28, 33, 38, **42**	No	—
3	Iowa	15 vs. 30	20, 28, 36, **44**	No	—
4	Minnesota	20 vs. 30	16.5, 22, 27.5, 33, 38.5, **44**	No	—
5	Indiana	twin vs. 30	28, 33, 38, **42**	No	—
6	Indiana	twin vs. 30	35, 40, 45, **50, 55, 65**	Yes	-8%
7	Illinois	twin vs. 30	25, 35, **45, 55**	Yes	-5%

1: Coulter and Shanahan, 2012; 2: Novacek et al., 2013; 3: Pecinovsky et al., 2002; 4: Van Roekel and Coulter, 2012; 5: Robles et al., 2012; 6,7: Haegele et al., 2014.

populations of up to 65,000 plants/acre. In both of these studies, corn yield was actually significantly reduced in twin rows at high populations (Table 2). In the Indiana study, at populations of 50,000, 55,000, and 65,000 plants/acre, yield in twin rows was 8% less than in 30-inch rows. In the Illinois study, at 45,000 and 55,000 plants/acre, twin rows had 5% lower yield but significantly greater yield at the lowest population tested (25,000 plants/acre). The researchers hypothesized that the yield reduction with twin rows at high populations may have been due to increased air and leaf temperatures in the middle stratum of the canopy, leading to accelerated leaf senescence.

Will Higher Populations Require Narrow Rows?

Because it is not supported by research, the theory that corn production at higher populations will need to transition to narrower rows for continued gains is called into question. Row spacing studies with high populations have not shown an advantage to narrow or twin rows outside of the northern Corn Belt, where narrower rows have historically had a more consistent yield advantage. Additionally, a new corn yield record of 454 bu/acre was set in 2013 at 47,000 plants/acre in 30-inch rows, clearly demonstrating the potential to achieve much greater yields at high populations without the need for narrower row spacing.

HYBRID CHANGES IN LEAF ARCHITECTURE

The development of hybrids especially suited to a narrow-row, high-population environment is often cited as potentially favoring narrower rows in the future. The idea of optimizing hybrids for narrow-row production has most commonly focused on leaf architecture, specifically, that plants with narrower and more upright leaves may be more suited to narrow rows. Like plant population, plant architecture is another factor in corn production that has greatly changed over the past several decades, so it is not unrealistic to suggest that the future could bring further changes.

Changes in Leaf Architecture in the Hybrid Era

Continual selection for greater yield during the hybrid era has resulted in significant changes to many plant characteristics. For example, modern hybrids tend to be slightly shorter with lower ear placement. Tassel size and number of branches has been significantly reduced compared to early hybrids. However, the difference in leaf architecture, specifically a trend toward upright leaves (Figure 5), is perhaps the most visually apparent contrast between early and modern hybrids (Duvick, 2005).

The shift toward more upright leaf architecture began with the introduction of Iowa State University's B73 inbred into breeding programs during the 1970s (Figure 6). Subsequent hybrids tended to have a more upright leaf angle and a greater length to the leaf flagging point compared to their predecessors (Duvick, 2005; Meghji et al., 1984; Lauer et al., 2012). Today, nearly all North American hybrids could be characterized as having upright leaves compared to those of the past.

Figure 5. Pioneer® hybrid 354 (introduced in 1953) and Pioneer P1365AMX™ (AMX, LL, RR2) brand corn (introduced in 2013) (Johnston, Iowa; July 16, 2013).

This industry-wide transition to more upright leaves is commonly considered to be an important factor that has enabled corn performance at higher plant densities. Upright leaves increase the distribution of light in the canopy; less light is captured by the uppermost leaves and more light penetrates further down where it is captured by lower leaves, thereby increasing photosynthetic efficiency. This improvement is greatest in corn canopies with a high leaf area index, generally associated with high populations. The canopy of a typical corn crop has greatly increased in leaf area index over the years, from approximately 2.4 m^2/m^2 in the 1930s to 4.8 m^2/m^2 or greater today (Lee and Tollenaar, 2007).

Figure 6. Iowa State University inbred B73 in a DuPont Pioneer demonstration plot (Johnston, Iowa; July 16, 2013).

The extent to which changes in leaf architecture have actually directly contributed to increased corn yield is unclear, however. Several experiments on corn leaf angle conducted during the 1960s and 1970s produced variable results; some showed an advantage with upright leaves at higher plant densities (Lambert and Johnson, 1978; Pendleton et al., 1968; Pepper et al., 1977), and some did not (Hicks and Stucker, 1972; Russell, 1972; Whigham and Woolley, 1974). It is possible that increased light penetration in the canopy associated with upright leaves may provide indirect benefits via increased carbohydrate partitioning to the ear and delayed leaf senescence (Hammer et al., 2009).

Research Comparing Hybrid Response to Narrow Rows

Most research studies conducted during the past 25 years have not found consistent differences in hybrid response to narrow rows. Out of 15 university row spacing studies published between 1997 and 2013 that included more than one hybrid, only one reported a significant hybrid by row spacing interaction (Farnham, 2001). Furthermore, none of these studies showed a significant difference in hybrid performance in narrow rows that was specifically associated with a difference in leaf architecture.

Research conducted in Michigan compared performance of six hybrids in narrow rows (Widdicombe and Thelen, 2002). Of these hybrids, two were characterized as having erect leaf orientation, three with semi-upright leaves, and one with wide leaves. Average corn yield was significantly higher in narrow rows, but performance did not differ among hybrids. A study in Minnesota comparing two hybrids of differing leaf architecture also found no difference in yield response to narrow rows (Sharratt and McWilliams, 2005).

A 3-year DuPont Pioneer/University of Missouri study compared 11 hybrids in 15- and 30-inch rows. This study found a significant hybrid by row spacing interaction; however, hybrids with more upright leaves did not perform any better than other hybrids in narrow rows.

Can Hybrids be Designed for Narrow Rows?

The fact that most recent research studies have not found a significant difference in hybrid response to row spacing indicates that there is likely little variation among modern hybrids in their suitability to narrow rows, although the few studies that have found such a difference show that some variation does exist. Whether or not this variation could be exploited to design future hybrids for narrow rows and whether or not this would significantly increase corn productivity is unclear. The transition to more upright leaves in modern hybrids has likely contributed to improvement in corn yield associated with higher plant densities to some extent; however, research suggests it is unlikely that further changes in leaf angle offer a meaningful opportunity for yield improvement in the future (Lee and Tollenaar, 2007).

Past research on hybrids with extremely upright leaves has shown that narrow rows may increase productivity for hybrids that are unable to capture 95% of PAR in 30-inch rows. Extremely upright leaves that remain close to the stalk can have the negative effect of allowing light in the interrow to penetrate to the soil surface, an effect that narrower rows would tend to help mitigate. A research study including a Chinese hybrid with extremely upright leaves noted this effect (Stewart et al., 2003). A canopy photosynthesis model predicted that changing from 30-inch to 15-inch rows would significantly increase photosynthetic production with this hybrid, whereas minimal benefit was predicted for a comparative hybrid at a similar leaf area index.

Research has examined the potential of developing semi-dwarf hybrids for corn production in the far northern Corn Belt, the primary advantage of which would be earlier maturity than conventional hybrids (Schaefer et al., 2011; Combs and Bernardo, 2013). Such hybrids would require narrow rows and extremely high plant populations, similar to small grain production, to maximize productivity. Semi-dwarf hybrids could also potentially be advantageous in arid climates or in double-crop rotations, although their overall value for improving corn productivity has yet to be determined.

IS THE FUTURE OF CORN PRODUCTION IN NARROW ROWS?

It is possible that changes in corn production practices may eventually favor a transition away from the current 30-inch row spacing standard to narrower rows; however, research provides little evidence to suggest such a transition will be necessary or justified in the near future. Future yield gains will likely continue to be driven by higher plant populations, but research that has compared row spacing at populations from 40,000 to 65,000 plants/acre has generally not shown a yield advantage to narrow rows outside of the northern Corn Belt.

Modern hybrids typically have not differed in their response to narrow rows. When yield differences have been observed, they have not been associated with any particular characteristic of leaf architecture. Research with extremely upright-leaf hybrids and semi-dwarf hybrids has shown that narrow rows can be beneficial when 30-inch rows do not allow complete capture of PAR at silking. These studies indicate that development of hybrids optimized for narrow rows is possible; however, it is not clear if such hybrids could lead to greater productivity on a wide scale.

SOURCES

Enter this link in your browser to view sources:

https://www.pioneer.com/home/site/us/agronomy/corn-production-narrow-rows/#sources

CORN PLANT POPULATION RESEARCH

DUPONT PIONEER RESEARCH

- DuPont Pioneer has been conducting plant population studies with corn hybrids for over three decades.
- These studies test for complex G x E x M (genetics x environment x management) interactions, which frequently play a key role in maximizing yield potential and reducing risk.
- Pioneer has conducted plant population research at over 260 locations throughout the U.S. and Canada in the last 5 years (Figure 1).

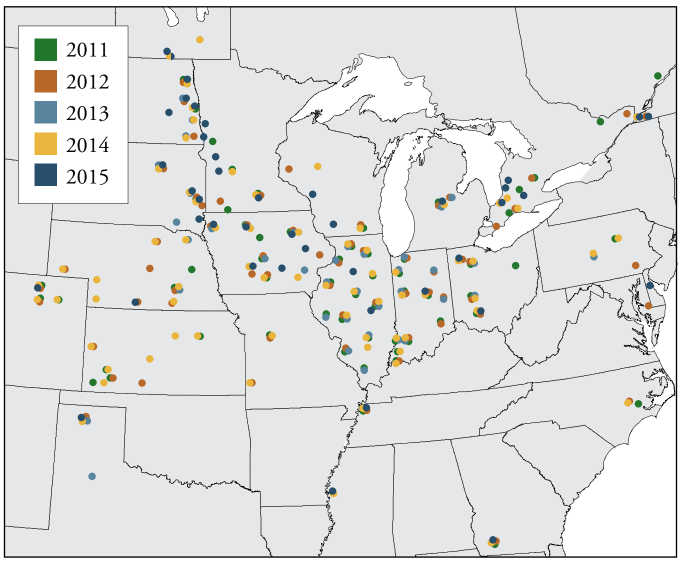


Figure 1. DuPont Pioneer plant population test locations in North America, 2011-2015.

- DuPont Pioneer researchers target representative environments based on maturity zone, expected yield (high or low), specific stresses (drought, pest pressure, high residue, early planting, etc.), and other unique location characteristics.
- Growers can use the multi-year and multi-location results to identify the best potential planting rates specific to their hybrid, location, and management practices.

Optimum Seeding Rate by Yield Level

- Like previous DuPont Pioneer studies, the 2009 to 2015 trials across the U.S. and Canada show that corn hybrid response to plant population varies by yield level (Figure 2).
- The seeding rate required to maximize yield increases as yield level increases.
- The economic optimum seeding rate varies from about 31,000 seeds/acre for locations yielding 150 bu/acre to over 39,000 seeds/acre for yields of 240 bu/acre.

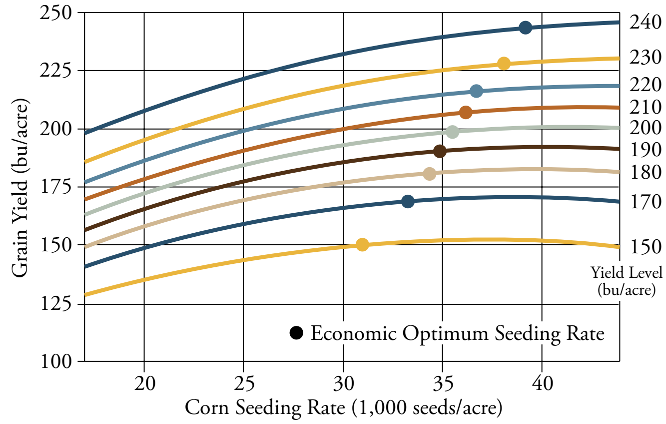


Figure 2. Corn yield response to population and optimum economic seeding rate by location yield level, 2009-2015.

Averaged across all hybrids tested. Economic optimums based on a corn grain price of $4.00/bu and a seed cost of $3.00 per 1,000 seeds; assumes 5% overplant to achieve target population.

- The economic optimum is the seeding rate that generates the most income when seed cost and grain price are factored in.

Optimum Seeding Rate by Hybrid Maturity

- Population response of five comparative relative maturity (CRM) groups is shown in Figure 3. These data show a fairly similar response of hybrid maturities to plant population.
- Previous research has shown that early maturity hybrids (<100 CRM) may require higher populations to maximize yield. Although this trend can still be detected when examining the response curves closely, it is a smaller difference than in the past. This change may be the result of different genetic backgrounds predominant in early maturities historically vs. currently, or other unknown factors.

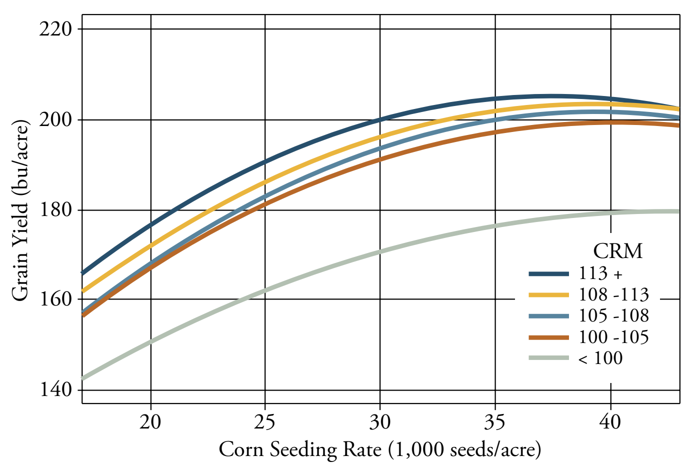


Figure 3. Yield response to plant population for corn hybrids from five maturity (CRM) ranges, 2009 to 2015.

Averaged across all hybrids tested.

PLANTING RATE ESTIMATOR

- The DuPont Pioneer Planting Rate Estimator, available on www.pioneer.com and as a free mobile app, allows users to generate estimated optimum seeding rates for Pioneer® brand corn products based on data from DuPont Pioneer research.

Enhanced Features for 2016

- The 2016 version of the Planting Rate Estimator has several improvements compared to previous versions.
- The most significant improvement is the ability to display population response curves for a greater range of yield levels, which provides greater utility for creating variable rate seeding prescriptions.
  - Previously, the Planting Rate Estimator displayed plant population responses for up to 3 yield levels: greater than 200 bu/acre, between 150 and 200 bu/acre, and less than 150 bu/acre.
  - Now it is possible to display plant population response curves at 10 bu/acre increments for all yield levels where there was a statistically significant response based on the available research data.
  - The yield levels available for display will vary among hybrids based on the available research data; hybrids tested at a greater number of locations with a wider range of yield levels will have more yield levels available in the dropdown selection.
- The 2016 Planting Rate Estimator also features greater flexibility in customizing the graph display.
  - Previously, users could select corn grain price and seed cost to determine economic optimum seeding rates at different yield levels for a given hybrid.
  - Users can now display up to three response curves based on any combination of hybrids, yield levels, grain prices, and seed costs.

				Plant Population at Harvest					Optimum Planting Rate*	
Hybrid	Yield Goal	Grain Price	Seed Cost	18,000	26,000	34,000	42,000	50,000	Seed Drop/A	Net Income/A
P1197AM	250	$4.00	$3.00	$790	$870	$890	$870	$790	33,900	$890
P1197AM	220	$4.00	$3.00	$710	$770	$780	$740	$650	31,400	$780
P1197AM	190	$4.00	$3.00	$630	$670	$660	$620	$540	29,000	$670
Years Tested : P1197AM : 2014, 2015							Locations : P1197AM : 42			

* Planting rate and seed cost were increased by 5% to account for early season stand loss.

Select and compare plant population responses based on hybrid, yield level, corn grain price, and seed cost.

Graph shows up to three plant population response curves with economic optimum seeding rates based on the criteria selected above. Results are displayed as net income/acre.

Tabular display of net income/acre at several seeding rates based on the criteria selected above and economic optimum seeding rates. Years of testing and number of testing locations for selected hybrid(s) shown below.

MANAGING SMALL SEED SIZES IN SEED CORN

- Seed corn size and shape can be affected by weather conditions during seed production.
- Production fields that experience very favorable growing conditions can have high kernel set, which results in smaller seed size.
- The following provides tips and guidance for managing seed with unusually small kernel sizes.

AGRONOMICS OF SMALL KERNEL SIZES

- DuPont Pioneer and university extension research have both shown that smaller sized seed will emerge and yield similarly to larger seed (Figures 1 and 2).
- See *www.agronext.iastate.edu/corn/production/management/planting/kernel.html* for more information.
- Bottom Line: Hybrid genetics are far more important to stand establishment and yield than kernel size.

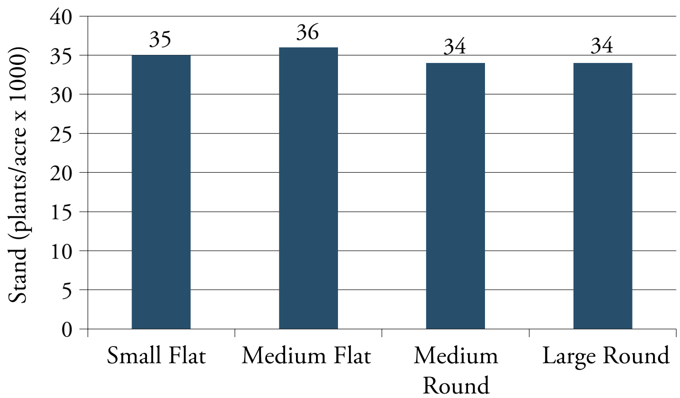


Figure 1. Kernel size effect on final stand in a 2-year DuPont Pioneer study. Means across 2 hybrids and 19 locations.

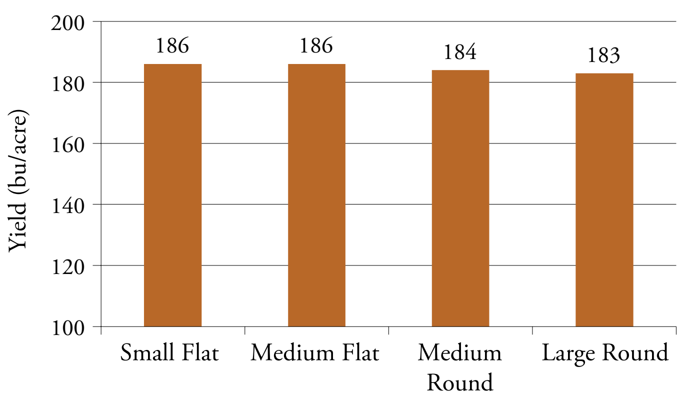


Figure 2. Kernel size effect on final yield in a 2-year DuPont Pioneer study. Means across 2 hybrids and 19 locations.

PLANTING CONSIDERATIONS

- The largest problem in planting small seed sizes is a greater frequency of doubles and triple seed drops.
- University research has shown that if the frequency of double seed drops remains below 10% of the stand, yield is not reduced (J. Prod. Ag. 9:238-240).
- For finger mechanisms, inspect and replace worn brushes that help eliminate doubles. Adjusting finger tension will also optimize singulation but is best performed by a planter service technician.
- For vacuum and air seeding meters, go to *www.pioneer.com/plantability* to select the optimum plate size and vacuum pressure for your seed.
- Manage planting speed to less than five mph to allow the meter mechanisms time to reduce doubles.
- If seed corn sizes are extremely small (greater than 3,000 seeds/lbs), consider popcorn or sunflower meter assemblies.
- Use normal planting depth of 1.5 to 2 inches. Even though the seed is smaller, it still has sufficient energy to emerge at a standard depth, and shallow planting will affect normal root development.

PLANTABILITY DATA

- Planter manufacturer recommended vacuum settings end between 2,500 to 2,800 seeds/lb.
- Table 1 shows plantability data for seed sizes greater than 2,500 seeds/lb or bag weights less than 32 lbs.
- Means across 106 seed lots did not indicate significant singulation problems.
- Please check the Pioneer® Field360™ Plantability app to get optimum settings for your seed.

Table 1. Plantability analysis for seed sizes greater than 2,500 seeds/lb (less than 32 lb bag weight).

Meter	Drop	Skips	Doubles
	-------------- % --------------		
Case IH ASM	100	0.4	0.8
Precision Planting eSet®	100	0.1	0.3
John Deere ProMAX 40	100	0.2	0.5
John Deere Reg	102	0.1	2.0
John Deere Small	101	0.5	1
Kinze Finger	102	0.6	2.4
Kinze Vacuum Meter	102	0.1	2.4

return to table of contents

MEETING CORN GRAIN PURITY STANDARDS FOR SPECIALTY MARKETS

Growing corn for "specialty" or "niche" markets provides an enhanced income opportunity for farmers. The higher price commanded by these markets is due to the additional management and risk associated with producing specialty grains. Additional management is required to meet the purity standards of these markets while incurring the risk that if purity standards are not achieved, the crop may have to be marketed in traditional commodity channels with no pricing premium. Specific contractual obligations may present another layer of risk. This article will discuss specialty corn markets (with particular focus on non-GMO markets), purity standards for these markets, and management practices to help achieve the purity requirements.

NON-GMO CORN PRODUCTION

A corn hybrid containing a "biotech" or "transgenic" trait is often referred to as a "Genetically Modified Organism," or "GMO." Following their introduction in the mid-1990s, GMO hybrids were adopted by farmers at an unprecedented pace. Today, approximately 95% of the U.S. No. 2 yellow corn crop is grown utilizing biotech or transgenic traits. The remaining 5% of the crop, generally referred to now as the "conventional" or "non-GMO" corn market segment, has essentially morphed into a new niche market for corn.

Though non-GMO production is one of the newest niche market opportunities, specialty corn production is not a new concept; many farmers have contracted to produce white, waxy, or other specialty types for decades. In general, the principles of achieving purity standards for one type of specialty production apply to other types as well; however, non-GMO production presents some unique challenges. This is primarily because countries have imposed their own purity standards for non-GMO grain, and these standards differ significantly from one another. In addition, non-GMO production for export to the European Union has much more stringent purity requirements than other markets. Thus, the non-GMO market can be best thought of as a series of niche markets, each with its own unique purity requirements.

Asian and European Non-GMO Markets

The primary driver for non-GMO corn has been and remains the Asian export market. Japan and Korea are the two major U.S. export customers for this grain. Both countries have GMO label laws in place that require notice on a product label of the presence of biotech traits. Many Japanese and Korean consumer product companies, particularly food companies, choose to source non-GMO corn in order to avoid putting such a notice on their products.

Japan defines non-GMO corn as having a minimum of 95% with no detectable traits. So Japan has set a 5% threshold of tolerance for unintended or "adventitious" presence (AP) of biotech traits in the corn grain they import. When non-GMO corn is originated in the United States, these tolerance thresholds are risk-managed and usually trade at 3% levels. South Korea, on the other hand, uses a minimum standard of 97%, thus a threshold

of tolerance for AP of 3%. These programs often trade at the point of origination at a 2% threshold of tolerance. Finally, Europe has the most restrictive standards for non-GMO corn, employing a 99.1% level of no detectable GMO traits, or a 0.9% threshold of tolerance for the adventitious presence of these traits.

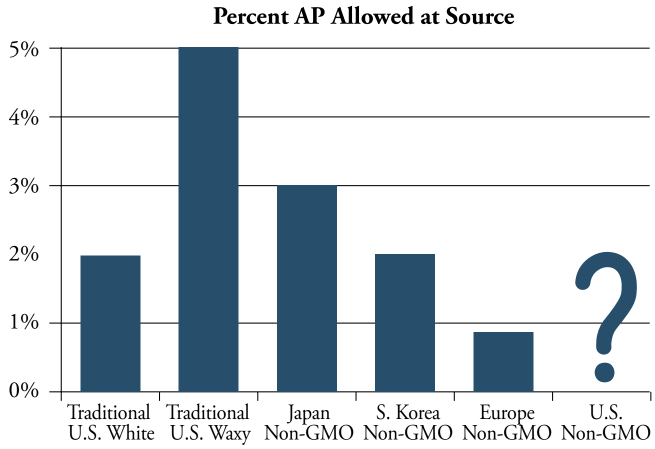


Figure 1. Percent adventitious, unintended, presence (AP) allowed in various specialty corn markets. (Examples of AP include yellow kernels in white corn production, normal starch in waxy production, and any GM trait in production for non-GMO markets.)

United States Non-GMO Markets

A non-GMO domestic market also exists in the United States, although it is relatively small. There are growers and consumers alike who demand choice and prefer to not utilize biotech traits. The primary challenge in this market is that there is currently no standard definition of "non-GMO;" rather, it is typically whatever the particular market wants it to be. This ambiguity presents an obvious challenge for growers; if they fail to clearly understand how their particular market defines "non-GMO," they could be disappointed when they deliver corn. This applies to all non-GMO production, not just production for U.S. markets. Growers must know for certain if the threshold of tolerance for GMO traits is defined in the contract as 3%, 2%, 0.9%, or some other standard. Clearly understanding these "rules of engagement" is necessary to make the best possible decision about participating in the non-GMO market opportunity.

ACHIEVING PURITY STANDARDS FOR SPECIALTY CORN

After carefully reviewing the purity standards mandated for the specialty crop being grown, producers must implement appropriate production practices to achieve those standards. This includes taking additional steps during planting, growing, and harvesting the crop and drying, storing, handling, and transporting the grain.

Planting the Crop

At planting, record-keeping, isolation, and equipment clean-out are the steps generally recommended to help ensure the grain ultimately meets required purity standards.

Record-keeping may be simple or sophisticated, depending on the technology available and grower expertise. As-planted (GPS-tagged) records that are transmitted in real time and backed up for safe-keeping are the most foolproof way to document planting. Electronic "notes" recorded on a smart phone or pad and also backed up in the cloud can be equally effective. Lastly, hand-written notes may still be adequate but lack the safety advantages inherent in backed-up electronic field records. Taking a picture of hand-written notes with a smart phone can lessen the risk of losing these records. Some contracts may require specific forms of documentation during the production of the specialty crop, including at planting. Be sure you are aware of any such contract requirements.

Isolation: Because corn is a cross-pollinated crop and its pollen is wind-dispersed, providing adequate isolation is at the very core of specialty corn production. In fact, the ability to sufficiently isolate the crop from other corn fields is often the deciding factor when considering specialty production. The degree of isolation required is, of course, closely tied to the level of purity targeted. For many end uses, the buyer will provide isolation guidelines to the grower. These guidelines will always take into account the distance and direction (upwind or downwind) of nearby corn fields and may also consider the type of corn (e.g., dent or sweet) in those fields. A commonly recommended isolation distance for some types of specialty corn production is 660 feet, but that distance could double when purity requirements are extremely high. Be sure to clearly understand the isolation distance needed to achieve your desired level of purity.

Inadequate isolation distance can often be overcome by using a number of rows of the specialty crop as a "buffer," segregating the buffer grain at harvest, and selling it as commodity grain if it does not meet the purity standards. "Time isolation" can effectively add to distance isolation. Time isolation involves staggering the planting dates of the specialty and nearby corn to create a pollination "differential." This practice may be risky if employed as the primary means of isolation, as crop pollination timing interacts with the growing environment and is not completely predictable.

Equipment Clean-out at Planting: A basic tenet of specialty corn production is cleaning equipment to remove kernels of contaminating (non-specialty) seeds and grain. Planters are reservoirs for contaminating seeds of previously planted hybrids. Each make of planter is different, but a thorough cleaning usually involves removing seeds from each individual seed metering unit in addition to the seed hopper(s). The planter owner's manual should provide tips on proper clean-out procedures, which may also be available online. Growers may also want to check for any videos demonstrating planter clean-out at www.youtube.com or other websites. Seed tenders, including the box and auger, must also be cleaned to prevent mixing or commingling of seeds.

Growing the Crop

In most cases, there are no visual differences between corn hybrid plants, whether they are GMO, non-GMO, or any number of other specialty grain types. That makes it difficult or impossible to identify and destroy unwanted plants prior to harvest. Thus, all possible steps should be taken to prevent possible inclusion of off-type seeds at or prior to planting.

Some unwanted plants in a specialty corn field are not sourced from the planting equipment; rather, they are volunteer corn plants from ears or grain left in the field from previous crops. When volunteer plants grow from a dropped ear of corn, they usually grow in a thick bunch that precludes the development of grain on any of the volunteer plants. However, tassels may be produced on some plants, leading to pollen mixing with the new crop. Just like pollen drifting in from a nearby field, this pollen mixing would reduce the purity of the specialty grain. Thus, all measures should be taken to prevent volunteer corn in a specialty crop, including timely harvest of preceding corn, rotation away from corn, and use of tillage or herbicides when appropriate.

Harvesting the Crop

Harvest presents an opportunity to increase the purity of the specialty crop, as well as a risk of decreasing it. Harvesting a number of "border" or "buffer" rows from the perimeter of the field and segregating that grain can increase the purity level in the remainder of the field. For example, harvesting 16 to 24 rows from the windward (usually south or west) side of a field may be recommended when there is a corn field nearby in that direction, especially if the isolation distance is at or below the suggested minimum.

The risk of decreasing crop purity comes from the chance that significant off-type grain is still present in the combine, grain cart or truck. Inspecting and cleaning the grain cart, or truck is a rather simple and basic process; doing the same for the combine is significantly more complex.

Combine Clean Out: If the combine has been thoroughly cleaned before storing the previous winter, harvesting the specialty field before any others can save a cleaning. Otherwise, additional steps are likely needed; studies have shown that as much as one to two bushels of grain may remain in the combine, even after running the unloading auger empty for a full minute.

The first step in combine clean-out is to determine what level of purity is needed. For some grain uses, simply "flushing" the existing grain will be adequate. This is accomplished by harvesting a load or partial load of the specialty hybrid and using that load for commodity grain. While negating any premium opportunities for those bushels, this method of clean-out may still be much more cost-effective than labor-intensive clean-out procedures.

Some types of specialty production (e.g., non-GMO production for European markets) may require a more thorough combine cleaning. Details for systematically cleaning the entire combine vary by brand and model. Consult your operator's manual for manufacturer instructions, or search for instructions or videos online. Then follow a systematic plan to clean specific areas in the machine, usually going from top to bottom and entry to exit. Be sure to conduct clean-out procedures with the utmost safety in mind, including blocking the head and removing the key when workers will be in harm's way. Clean-out may involve running the machine one or more times during the process; be sure all workers are clear of the machine.

Drying and Storing the Grain

Clean dryers and grain bins thoroughly of all residual grain. Growers generally do a good job of cleaning these areas between crops, such as corn and soybeans. Applying the same discipline to cleaning between commodity and specialty production may be needed to meet purity standards for some grain uses.

In addition to cleaning, labeling and record-keeping is important to maintain the identity of grain in storage. Clearly document the hybrid, cleaning procedures, and other information according to the intended end use or contract requirements.

Handling and Transporting the Grain

The existing commodity grain handling system is designed to store, transport, and distribute billions of bushels of crops. Growers, grain handlers, and processors did not have special segregation of crops in mind when they built bulk-handling systems. Consequently, there are numerous ways that adventitious presence may occur during grain handling and transport. Commonly referred to as "mechanical mixing" or commingling, these include mixing of grain during harvesting, handling (conveying systems), or hauling, or in processing equipment or storage facilities.

Conveying Systems: Auger and elevator contamination can be minimized by allowing conveying systems to run empty between loads of different grain types. Also, the auger sump, or pit, should be emptied of residual grain. If additional purity is needed, this can be followed by flushing the system with the new grain and placing the flushed grain in a mixed grain bin.

Grain Cart/Trucks: Clean all obvious surfaces where grain may reside, including horizontal ridges inside of the grain cart. The vertical auger sump in grain carts may have a clean-out shield at base.

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MAXIMIZING GENETIC PURITY OF SPECIALTY CORN

- If at all possible, discuss planting intentions with neighbors, and try to work together to maximize each other's grain marketing options.
- Thoroughly clean all other seed out of the planter before planting.
- Plant on land that did not have the specific hybrid type grown the previous year that you are trying to isolate against.
- Plant corn in blocks as large as possible, rather than in several smaller fields.
- Maximize isolation distances from all other corn. Acceptable distances may vary from 24 rows to as much as ¼ mile (1,320 ft.) or more separation, depending on target purity level, prevailing winds, planting date, hybrid characteristics, and general weather conditions.
- Exact isolation guidelines will depend on purity standards for acceptance of grain. However, the greater the isolation distance used, the greater the chance of maximizing purity.
- Even under the best conditions and practices, the biology and logistics of corn production and pollen movement make 100% purity nearly impossible to attain.
- To minimize prevailing wind effects on pollination, plant corn hybrids you are trying to isolate to the west or up wind from all other corn hybrids.
- Staggered planting can also be used to help minimize cross-pollination. The sequence and timing of planting will depend on a hybrid's flowering characteristics and maturity.
- Harvest outside rows of the field where you are trying to maximize purity and segregate this grain for other uses.
- Thoroughly clean combines, trucks, wagons, grain augers, dryers, and storage units when switching from one type of corn to another.
- Consider keeping samples of the seed, harvested grain, and delivered grain. Preserve the samples until the grain has met all identity and quality standards of the buyer.
- Remember that achieving 100% purity is virtually impossible in seed or grain production. These management practices are designed to help maximize production purity but do not guarantee absolute purity.

return to table of contents

MANAGING CORN FOR GREATER YIELD

Improvements in corn productivity that began with the introduction of hybrid corn nearly a century ago have continued through the present day. Over the last 20 years, U.S. corn yield has increased by an average of 1.8 bu/acre per year. These gains have resulted from breeding for increased yield potential, introducing transgenic traits to help protect yield, and agronomic management that has allowed yield potential to be more fully realized.

As growers strive for greater corn yields, the National Corn Growers Association (NCGA) National Corn Yield Contest provides a benchmark for yields that are attainable when environmental conditions and agronomic management are optimized. The average yields of NCGA winners are about double the average U.S. yields. This difference can be attributed to favorable environmental conditions, highly productive contest fields, and high-yield management practices used by contest winners.

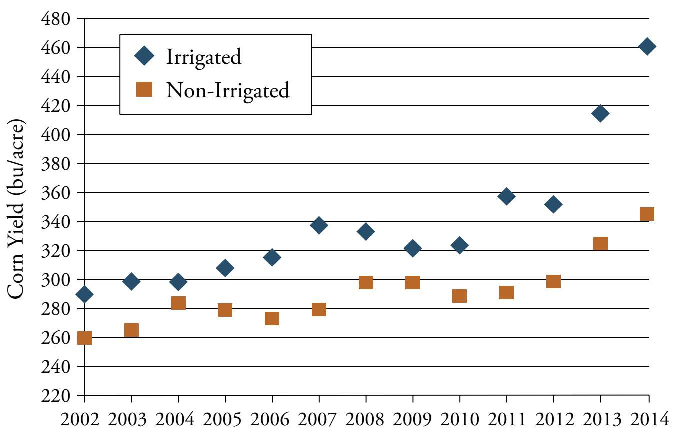

Figure 1. Average corn grain yield of NCGA National Corn Yield Contest national winners in irrigated and non-irrigated classes, 2002-2014.

NCGA NATIONAL CORN YIELD CONTEST

The NCGA National Corn Yield Contest achieved some notable milestones during the past two seasons. A new all-time corn yield record was set in 2013 and again in 2014. Five entries exceeded 400 bu/acre in the 2013 contest and seven in 2014.

The average yields of national winners also reached record highs in both the irrigated and non-irrigated classes. The average yield among irrigated winners topped 400 bu/acre for the first time, while the average yield among non-irrigated winners exceeded 300 bu/acre for the first time (Figure 1). In 2013, yields above 300 bu/acre were achieved in a total of 70 entries across all classes, which were located in 23 different states. In 2014, the number of 300 bu/acre entries nearly doubled to 136, located in 31 different states (Figure 2). This article summarizes basic management practices employed in 2013 and 2014 NCGA National Corn Yield Contest entries that exceeded 300 bu/acre and discusses how these practices can contribute to higher yields for all corn growers.

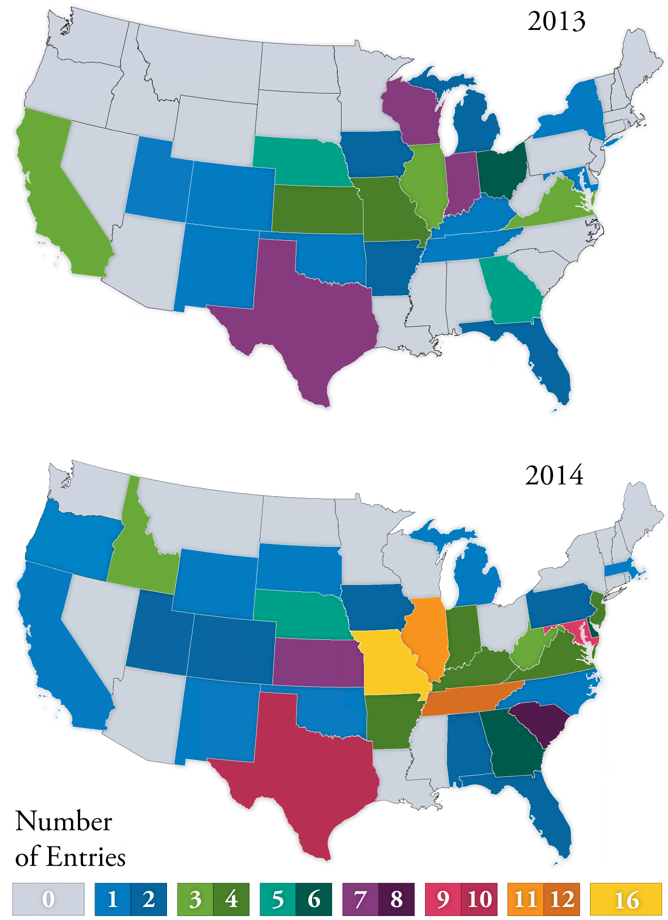

Figure 2. Locations of NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2013 and 2014.

HYBRID SELECTION

Hybrids tested against each other in a single environment (e.g., a university or seed company test plot) routinely vary in yield by at least 30 bu/acre. At contest yield levels, hybrid differences can be even higher. That is why selecting the right hybrid is likely the most important management decision of all those made by contest winners.

Table 1. 2014 NCGA National Corn Yield Contest winners with yields over 400 bu/acre using Pioneer® brand products.

Entrant Name	State	Hybrid/Brand	Yield (bu/acre)
David Hula	VA	**P1794VYHR** (AVBL, YGCB, HX1, LL, RR2)	**476.22**
Steven Albracht	TX	**P1883AM™** (AM, LL, RR2)	**459.45**
Dowdy Farms II	GA	**P1303HR** (HX1, LL, RR2)	**457.88**
Dowdy Farms VIII	GA	**P1739HR** (HX1, LL, RR2)	**444.15**

The yield potential of many hybrids now exceeds 300 bu/acre. Realizing this yield potential requires matching hybrid characteristics with field attributes, such as moisture supplying capacity; insect and disease spectrum and intensity; maturity zone, residue cover; and even seedbed temperature. To achieve highest possible yields, growers should select a hybrid with:

- Top-end yield potential. Examine yield data from multiple, diverse environments to identify hybrids with highest yield potential.
- Full maturity for the field. Using all of the available growing season is a good strategy for maximizing yield.
- Good emergence under stress. This helps ensure full stands and allows earlier planting, which moves pollination earlier to minimize stress during this critical period.
- Above-average drought tolerance. This will provide insurance against periods of drought that most non-irrigated fields experience.
- Resistance to local diseases. Leaf, stalk, and ear diseases disrupt normal plant function, divert plant energy, and reduce standability and yield.
- Traits that provide resistance to major insects, such as corn borer, corn rootworm, black cutworm, and western bean cutworm. Insect pests reduce yield by decreasing stands, disrupting plant functions, feeding on kernels, and increasing lodging and dropped ears.
- Good standability to minimize harvest losses.

The brands of seed corn used in the highest yielding contest entries in 2013 and 2014 are shown in Figure 3. Pioneer® brand products were used in the majority of entries exceeding 300 bu/acre.

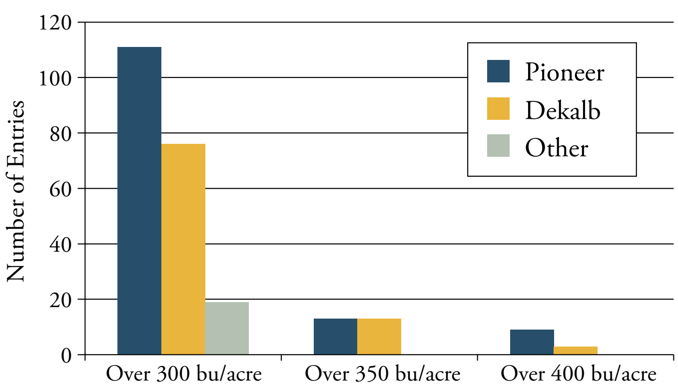

Figure 3. Seed brand planted in NCGA National Corn Yield Contest entries exceeding 300, 350, and 400 bu/acre in 2013 and 2014.

Nearly all entries above 300 bu/acre in 2013 and 2014 used a hybrid with transgenic herbicide resistance. Most included one or more Bt traits for resistance to above-ground insect pests and around half included at least one Bt trait for corn rootworm resistance (Table 2). Your Pioneer sales professional can help you select the top hybrids for your area with specific insect-resistant traits and other characteristics best suited for each individual field.

Table 2. Transgenic traits in hybrids used in 2013 and 2014 NCGA contest entries exceeding 300 bu/acre.

Traits	2013	2014
	-- % of Entries --	
Herbicide Resistance	100	99
Insect Resistance (above ground)	93	97
Insect Resistance (rootworm)	53	45

PLANTING PRACTICES

Plant Population

Improvement of corn hybrid genetics for superior stress tolerance has contributed to increased yields by allowing hybrids to be planted at higher plant populations. Harvest populations in irrigated and non-irrigated national corn yield contest entries over 300 bu/acre are shown in Figure 4. Harvest populations ranged from under 30,000 to over 50,000 plants/acre, but over 85% of plots were between 32,000 and 40,000 plants/acre. The average harvest population of irrigated entries was slightly greater than that of non-irrigated entries in both years.

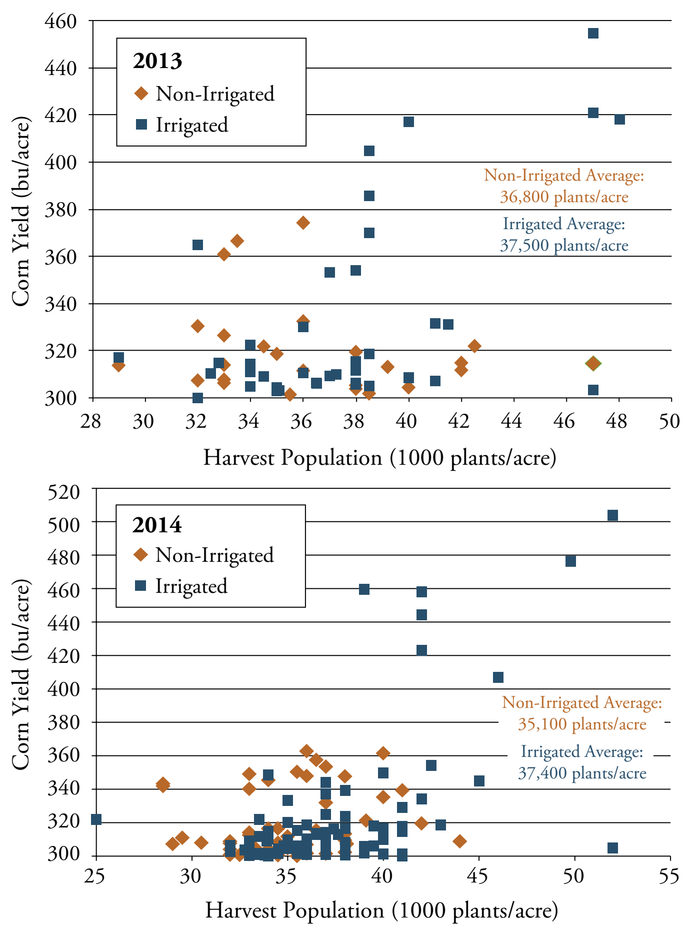

Figure 4. Harvest populations and corn yield of irrigated and non-irrigated NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2013 (top) and 2014 (above).

Row Width

The vast majority of corn acres in the U.S. are currently planted in 30-inch rows, accounting for over 85% of corn production. A majority of 300 bu/acre contest entries were planted in 30-inch rows (77%) (Figure 5). Narrower row configurations (15-inch, 20-inch, or 30-inch twin) were used in 14% of entries, and wider single or twin-row configurations were used in 9% of entries.

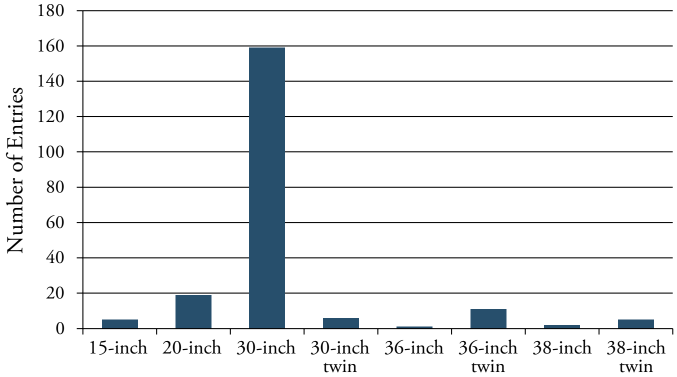

Figure 5. Row width used in NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2013 and 2014.

Row spacings narrower than the current standard of 30 inches have been a source of continuing interest as a way to achieve greater yields, particularly with continually increasing seeding rates. However, research has not shown a consistent yield benefit to narrower rows outside of the Northern Corn Belt (Jeschke, 2013). Results from the National Corn Yield Contest demonstrate that high yields can be attained in a variety of different row configurations.

Planting Date

Winning contest plots are usually planted as early as practical for their geography. Early planting lengthens the growing season and more importantly, moves pollination earlier. When silking, pollination and early ear fill are accomplished in June or early July; heat and moisture stress effects can be reduced.

When planting early, stand establishment is a primary concern. Seedling diseases have increased in recent years due to earlier planting and higher levels of corn residue left on the soil surface. For this reason, DuPont Pioneer provides a stress emergence score as well as a premium seed treatment on all Pioneer® brand hybrids. This seed treatment, called PPST 250, is an exclusive combination of biological, insect, and disease treatment technology and is the standard treatment program for all Pioneer® brand corn products. Available exclusively on select new Pioneer brand corn products in 2015 is PPST 250 plus DuPont™ Lumivia™ insecticide seed treatment, which includes a new mode of action featuring novel insecticide technology that provides rapid feeding cessation for immediate protection of seed. Growers also have the option on selected Pioneer brand corn products to choose Poncho® 1250 + VOTiVO® treatment where nematode or enhanced insect protection are needed.

CROP ROTATION

Rotating crops is one of the practices most often recommended to keep yields consistently high. Rotation can break damaging insect and disease cycles that lower crop yields. Including crops like soybean or alfalfa in the rotation can reduce the amount of nitrogen (N) required in the following corn crop. A majority of the fields in the 300 bu/acre entries in 2013 and 2014 (65%) were planted to a crop other than corn the previous growing season (Figure 6).

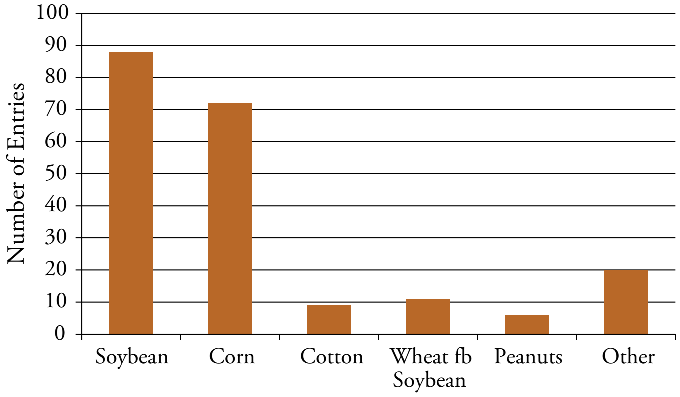

Figure 6. Previous crop in NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2013 and 2014.

The so-called "rotation effect" is a yield increase associated with crop rotation compared to continuous corn even when all limiting factors appear to have been controlled or adequately supplied in the continuous corn. This yield increase has averaged about 5 to 15% in research studies but has generally been less under high-yield conditions (Butzen, 2012). Rotated corn is generally better able to tolerate yield-limiting stresses than continuous corn; however, yield contest results clearly show that high yields can be achieved in continuous corn production.

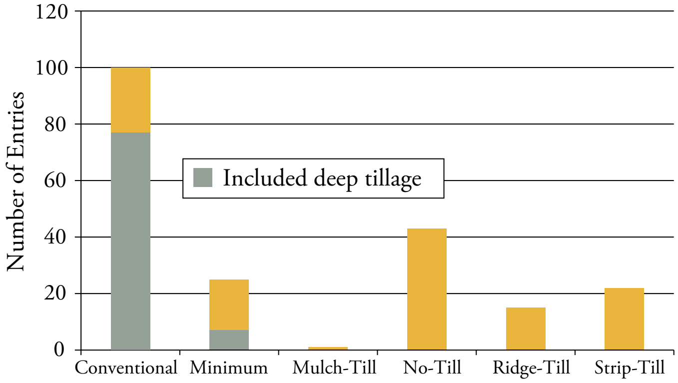

Figure 7. Tillage practices in NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2013 and 2014.

TILLAGE

Three of the six classes in the NCGA National Corn Yield Contest specify no-till or strip-till practices; however, over 60% of the contest entries over 300 bu/acre employed conventional, minimum, or mulch tillage (Figure 7). Of these entries, most included some form of deep tillage. Deep tillage implements included rippers, chisel plows, and sub-soilers. When fields are adequately dry, deep tillage can alleviate deep compaction and break up claypans and hardpans that restrict corn root growth. Deep roots are especially important as soil moisture is depleted during mid to late summer.

SOIL FERTILITY

Achieving highest corn yields requires an excellent soil fertility program, beginning with timely application of N and soil testing to determine existing levels of phosphorous (P), potassium (K), and soil pH.

Nitrogen

Corn grain removes approximately one pound of nitrogen per bushel harvested, and stover production requires a half-pound for each bushel of grain produced. This means that the total N needed for a 300 bu/acre corn crop is around 450 lbs/acre. Only a portion of this amount needs to be supplied by N fertilizer; N is also supplied by the soil through mineralization of soil organic matter. On highly productive soils, N mineralization will often supply the majority of N needed by the crop. Credits can be taken for previous legume crop, manure application, and N in irrigation water. Nitrogen application rates of contest winners are shown in Figure 8.

The N application rates of 300 bu/acre entries varied greatly, but a majority were in the range of 250 to 350 lbs/acre (Figure 8). Some entries with lower N rates were supplemented with N from manure application. As corn yield increases, more N is removed from the soil; however, N application rates do not necessarily need to increase to support high yields. Climatic conditions that favor high yield will also tend to increase the amount of N a corn crop is able to obtain from the soil through increased mineralization of organic N and improved corn root growth.

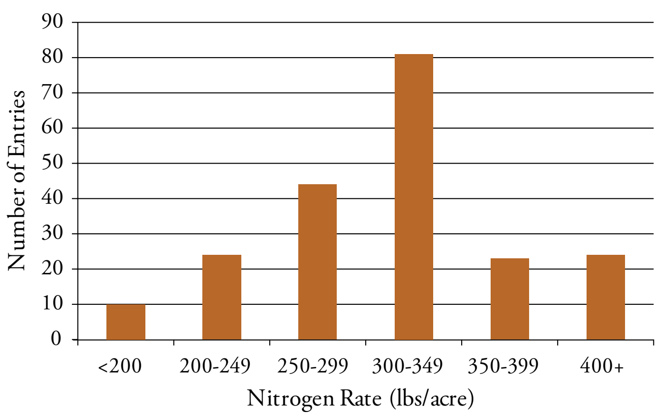

Figure 8. Nitrogen rates (total lbs/acre N applied) of NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2013 and 2014. *(Note that N rates above 300 lb/acre are usually appropriate only for contest plots and high-yielding irrigated fields.)*

Timing of N fertilizer applications can be just as important as application rate. The less time there is between N application and crop uptake, the less likely N loss from the soil will occur and limit crop yield. Nitrogen uptake by the corn plant peaks during the rapid growth phase of vegetative development between V12 and VT (tasseling). However, the N requirement is high beginning at V6 and extending to the R5 (early dent) stage of grain development.

Timing of N fertilizer applications in 300 bu/acre entries is shown in Figure 9. Very few included fall-applied N. Many applied N before or at planting. Over 80% of 300 bu/acre entries included some form of in-season nitrogen application, either sidedressed or applied with irrigation. Nearly all (96%) applied N at multiple timings.

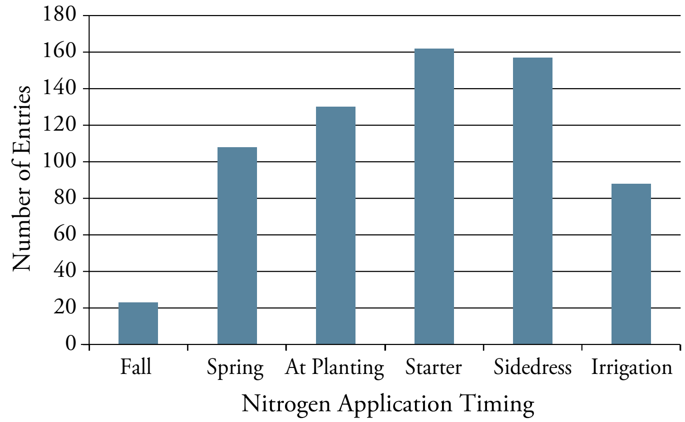

Figure 9. Nitrogen fertilizer application timing of NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2013 and 2014.

Phosphorus and Potassium

Assuming soils are maintained at adequate levels, growers should add at least the level of P and K that will be removed by the crop. In addition, these nutrients should be available in the root zone of the developing seedling. Corn grain removes about 0.43 lbs of P_2O_5 and 0.27 lbs of K_20 equivalents per bushel, according to the International Plant Nutrition Institute. That means that a 300 bu/acre corn crop will remove about 129 lbs of P_2O_5 and 81 lbs of K_20 per acre.

Micronutrients

Micronutrients were applied on nearly half of the 300 bu/acre entries (Figure 10). The nutrients most commonly applied were sulfur (S) and zinc (Zn), with some entries including boron (B), magnesium (Mg), manganese (Mn), or copper (Cu). Micronutrients are sufficient in most soils to meet crop needs. However, some sandy soils and other low organic matter soils are naturally deficient in micronutrients, and high pH soils may make some micronutrients less available and therefore, deficient (Butzen, 2010). Additionally, as yields increase, micronutrient removal increases as well, potentially causing deficiencies.

Sulfur is often ranked immediately behind N, P, and K in terms of importance to crop productivity. Mineralization is the primary source of plant-available S in non-fertilized soils. Soil organic matter content greatly affects the amount of S available to the crop. Sulfur fertility historically has not been a major concern on most soils; however, increased removal due to higher crop yields combined with reduced inputs from atmospheric deposition and other sources have increased the prevalence of S deficiencies.

Corn has high Zn requirements compared to other crops, so Zn is generally included in micronutrient formulations for corn. Zinc may be deficient in sandy soils; other low organic soils, such as those with topsoil removed; or soils with high pH. Seedlings may show deficiencies during cool, wet weather.

CROP PROTECTION

Insect Management

The most common insect management practice among 300 bu/acre entries was the use of hybrids with traits for insect resistance. Nearly all 300 bu/acre entries included one or more traits for resistance to above-ground insect pests and nearly half included

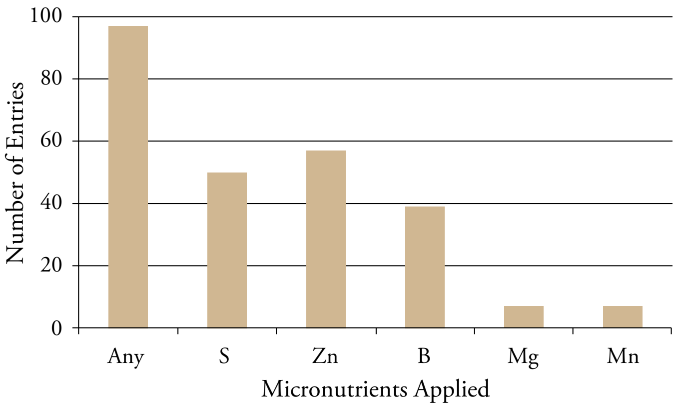

Figure 10. Micronutrients applied in NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2013 and 2014.

a trait for corn rootworm resistance (Table 2). Some entries also included a soil-applied insecticide or a foliar insecticide application.

Disease Management

Keeping corn free of stresses caused by leaf diseases and stalk rots is important to achieving maximum yield. Diseases like gray leaf spot, northern and southern leaf blight, and common and southern rust can quickly reduce a crop's green leaf area, photosynthetic capacity, and grain yield. In addition, reduced photosynthesis can cause depletion of stalk carbohydrates during ear fill, resulting in higher risk of stalk rots and lodging. Many of the 300 bu/acre entries reported using a foliar fungicide, some at more than one timing. Growers that applied more than one fungicide treatment frequently used multiple modes of action.

A 2012 DuPont Pioneer summary showed that in 475 DuPont Pioneer on-farm comparisons conducted from 2007 to 2011, a positive yield response to fungicide application occurred 80% of the time, with an average yield response of 7.0 bu/acre for applications between VT and R2 (Jeschke, 2012). Foliar fungicides tended to provide the greatest benefit on hybrids with less genetic disease resistance and when conditions were favorable for disease development.

Weed Management

In 2013 and 2014, nearly all 300 bu/acre entries used hybrids with the Roundup Ready® Corn 2 trait, and many also included the LibertyLink® trait. A glyphosate product was used on many of the entries; however, nearly all had more than one mode of action in their weed management program. Most included both pre- and postemergence treatments.

Regardless of the herbicide program used, excellent weed control beginning before weeds compete with the corn crop for water, light, and nutrients is essential for highest corn yields. Studies show that the "critical period" for preventing yield-reducing weed interference in corn is from the V2 to V3 growth stage until V12 (approximately three weeks through eight weeks after planting). A preemergence followed by postemergence herbicide program is likely to be the most reliable and effective under a wide range of growing environments.

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PREPLANT ANHYDROUS AMMONIA AND CORN SEEDLING INJURY

When spring field activities are delayed by unfavorable weather, growers may be forced to consider applying anhydrous ammonia and then planting within a few days, if not the same day. Planting shortly following anhydrous ammonia application can increase the risk of injury to developing seedlings in or near the NH_3 retention zone in the soil. This article explains why seedling damage may occur and reviews strategies that can help reduce that risk.

Figure 1. Tractor pulling a field cultivator and an anhydrous ammonia tank.

MECHANISM OF INJURY

When anhydrous ammonia is injected in the soil, it expands in all directions (2½ to 3 inches in most soils) creating a 5- to 6-inch cylindrical retention zone. Expansion can be even greater in dry or coarse soils. Free ammonia (NH_3) is highly toxic to developing seedlings. Once in the soil, the NH_3 molecules are converted to ammonium (NH_4^+) by associating with H^+ ions. Most of the H^+ ions come from the splitting of water molecules, leaving behind hydroxyl ions (OH^-) as a product of the reaction. The hydroxyl ions increase the pH of the soil at the injection site, slowing the conversion of NH_3 to NH_4^+. This allows some free ammonia to persist in the soil for a longer period of time, increasing the risk of injury and stunting to the roots of nearby corn seedlings (Figure 2). Several factors, including soil texture, temperature, and moisture, can influence the duration that NH_3 will persist in the soil.

PRACTICES TO REDUCE INJURY RISK

Reducing risk of injury involves separating the ammonia from the seed/seedling by either time or distance. Applying anhydrous ammonia well in advance of planting allows time for the NH_3 at the injection point to be converted to NH_4^+. Standard recommendations are generally five to seven days or longer between application and planting; however, free ammonia will persist longer in cooler and drier soils. Injury resulting from fall applications has even been observed in rare cases.

A more consistent solution is to create spatial separation between developing seedlings and the NH_3 retention zone by injecting anhydrous ammonia 7 to 10 inches deep in the soil.

Figure 2. Roots of corn seedlings showing injury due to spring application of anhydrous ammonia.

Consider a scenario in which anhydrous ammonia is applied at a depth of five inches. If the NH_3 expands three inches in all directions, it is now only two inches from the soil surface and will come in direct contact with the emerging root system. Injecting anhydrous ammonia deeper into the soil reduces the likelihood of injury (Figure 3).

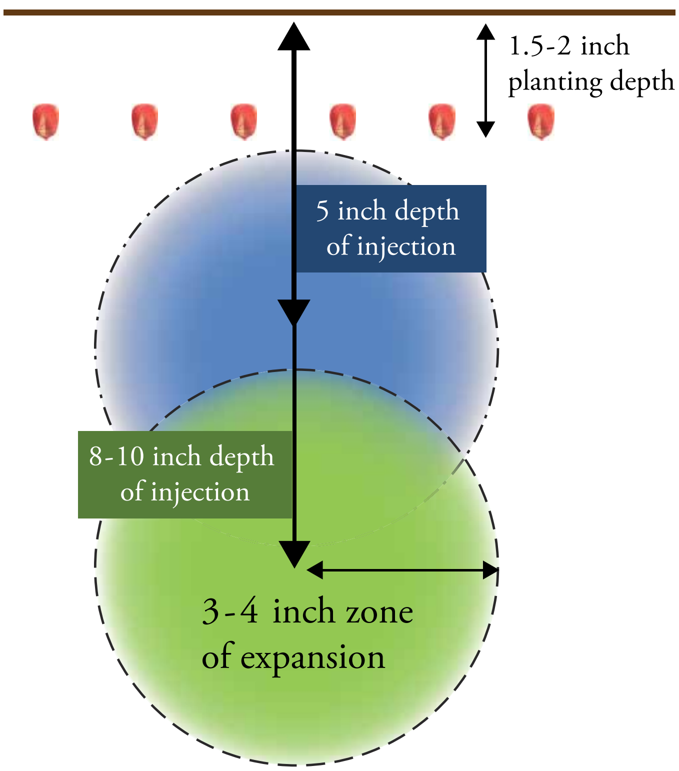

Figure 3. Applying anhydrous ammonia 8 to 10 inches deep can help prevent seedling injury by keeping the seed out of the NH_3 retention zone.

In a study conducted by the University of Illinois, anhydrous ammonia injected four inches deep caused severe injury at high rates. However, anhydrous ammonia injected 7 to 10 inches deep caused little injury to corn planted the same day (Colliver and Welch, 1970). In fact, applying anhydrous ammonia 10 inches deep reduced injury even more than waiting 10 days to plant.

Figure 4. Plants with anhydrous ammonia injury to the roots will appear wilted and spindly.

Another common practice to reduce injury risk is to apply anhydrous ammonia at an angle relative to the direction the corn will be planted so that entire rows are not at risk. Crop injury can still occur, but the injury will more likely affect individual plants rather than long lengths of row.

If anhydrous ammonia applications are made when the soil is wet, the knives can create sidewall compaction, forming a direct channel for the NH_3 to move up to the seed zone before it can be adsorbed to the soil. This can lessen the benefit of applying anhydrous ammonia deep in the soil.

Growers who are using high-speed, low-draft applicators do not have the option to place anhydrous ammonia 10 inches deep. Research has shown that applying high rates of nitrogen with these systems can result in significant seedling burn if planting directly over the injection zone (Fernández et al., 2011).

If a grower has RTK, it would be a good idea to run the application parallel to the corn row at least five inches to the side. This would be superior to the traditional practice of applying the anhydrous ammonia diagonally, which will result in seedling burn wherever the injection zone and seed row intersect.

SUMMARY

To prevent seedling injury, separate the seed and ammonia with time and/or distance.

- Although there is no magic number of days to delay planting after ammonia application, waiting at least five to seven days or longer is a good rule of thumb.
- If you cannot wait five to seven days after ammonia application to plant, apply the ammonia as deep as possible.
- Applying the ammonia at an angle or parallel with the corn row at least five inches to the side will minimize the potential for seedling injury.

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ANALYTICS OF THE ENCIRCA[SM] YIELD *NITROGEN MANAGEMENT SERVICE*

THE NITROGEN MANAGEMENT CHALLENGE

Nitrogen (N) management is among the most uncertain and costly aspects of modern corn production. Because soil nitrogen varies dynamically in response to the interaction between soils and weather, the optimal nitrogen application rate for any year or location varies widely (Figure 1; Scharf et al., 2005; Nafziger et al., 2008). As a result, nitrogen is often inadvertently over- and under-applied, reducing profitability (Lambert et al., 2006) and in some cases, leading to environmental contamination (Jaynes et al., 2001).

USING CROP MODELS TO GUIDE NITROGEN MANAGEMENT

Growers do not make corn nitrogen fertilizer rate decisions lightly, but yield goals (Hoeft et al., 2000) and generalized nitrogen response relationships (Sawyer et al., 2006) are often the best guidelines available to guide management. Neither of these approaches account for how variability in soils and weather affect crop growth and nitrogen availability at specific locations. Crop models offer one way to bring field and weather variability information into the nitrogen management decision-making process. While crop simulation models have historically been used for research purposes, advances in cloud computing and data management now make it possible to effectively extend crop models to commercial production systems. One of the major advantages of using crop models to guide nitrogen management decisions is that they can integrate the numerous, complex processes that affect soil nitrogen and provide actionable information that has meaning in a management context. Crop models can also incorporate weather information dynamically as it occurs so that nitrogen can be monitored and managed in real time.

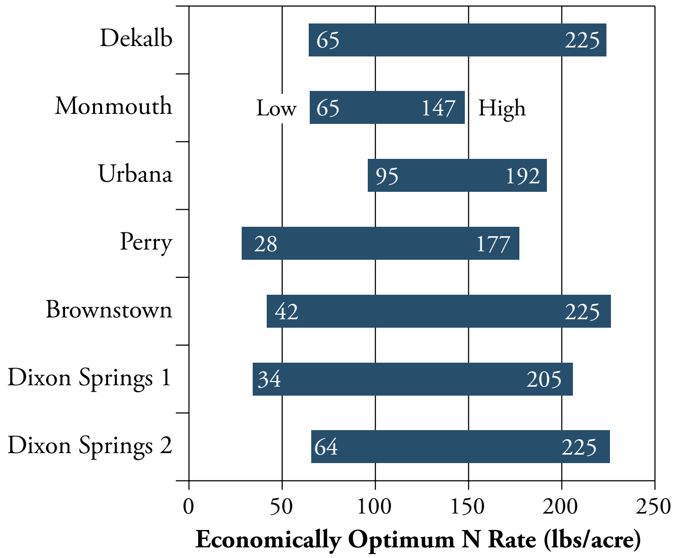

Figure 1. Variability in corn economic optimum nitrogen fertilization rate observed over six years at seven locations in Illinois (adapted from Nafziger et al., 2008).

ENCIRCA[SM] YIELD *NITROGEN MANAGEMENT SERVICE* MODEL

The Encirca[SM] Yield *Nitrogen Management Service* is based on a suite of crop and soil models developed by DuPont Pioneer scientists, using a combination of publicly available and proprietary data sources. Together, the components of the Encirca services nitrogen model estimate changes in soil nitrogen and crop nitrogen requirements that occur over time in response to weather, soil characteristics, crop growth, and management practices (Figure 2).

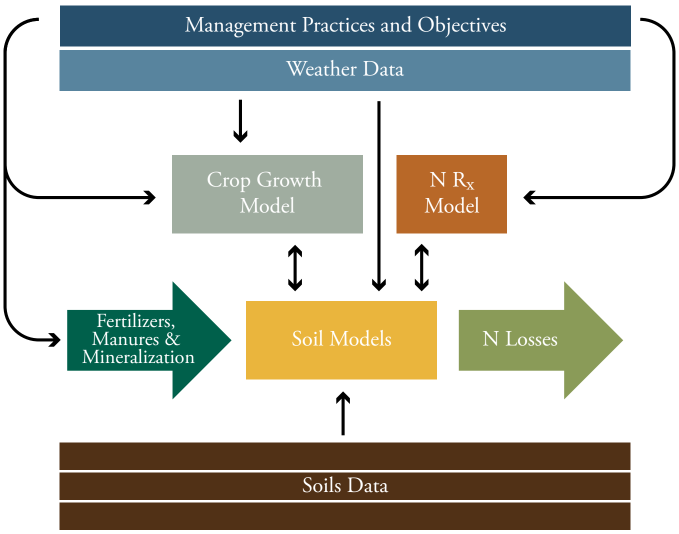

Figure 2. Schematic representation of the inputs and models comprising Encirca services nitrogen analytics.

ENCIRCA SERVICES NITROGEN MODEL INPUTS

Weather Data

The Encirca services nitrogen model is updated daily with high-resolution weather data from an industry-leading rural weather network powered by DTN/*The Progressive Farmer*, which links together thousands of on-farm weather stations. Growers that choose to enroll in Encirca View *Premium* have a weather station installed on their farm.

Soils Data

Pioneer scientists have collaborated with scientists at the University of Missouri and the USDA-Agricultural Research Service (ARS) to create improved soil maps called Environmental Response Units (ERUs). ERUs reclassify the spatial distribution of soil properties within fields based on high resolution digital elevation data and provide a more precise definition of the field-scale hydrological attributes that drive productivity and nitrogen availability.

Operational Data

Growers have the option to use their own historical yield data to help define productivity objectives for fields they enroll in the Encirca Yield *Nitrogen Management Service*.

Management Practices and Objectives

Growers work with their Encirca certified services agent or Pioneer sales professional to ensure that management practices and objectives in the model reflect reality.

ENCIRCA℠ YIELD *NITROGEN MANAGEMENT SERVICE* MODEL COMPONENTS

Crop Growth and Nitrogen Uptake

One of the core components of the Encirca services nitrogen analytics is a dynamic crop model that simulates corn growth, development, and nitrogen uptake (Figure 3). The crop model is driven by local weather and soils as well as management practices, including planting date and seeding rate, that are entered by the user. The rate of crop growth and development is also controlled by the relative maturity of the selected corn hybrid.

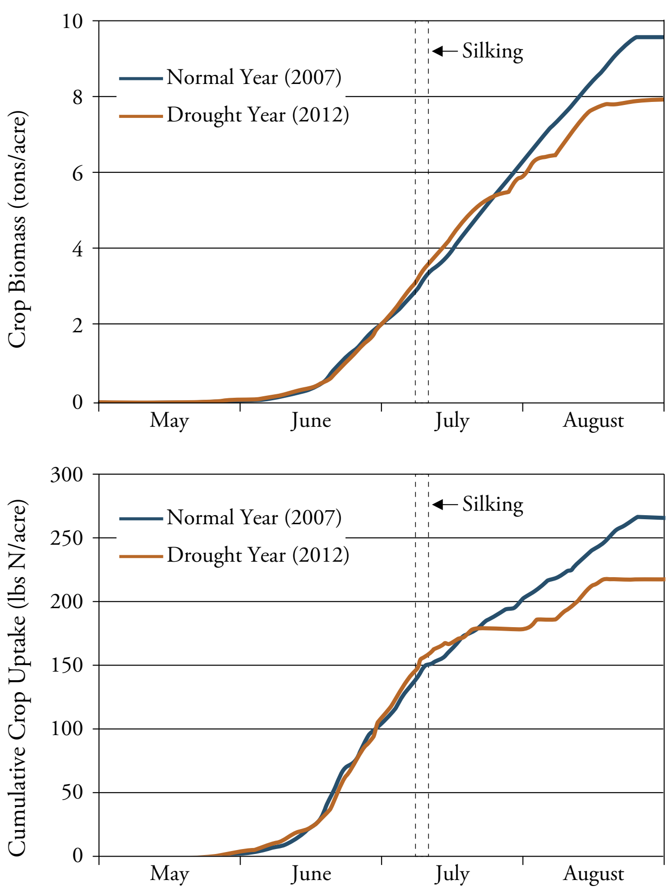

Figure 3. Model-estimated crop growth (upper panel) and nitrogen uptake (lower panel) for corn grown in Story Co., IA, in 2007 and 2012. See Table 1 for simulation details.

Nitrogen Mineralization

Mineralization describes the process by which soil microorganisms decompose organic matter (OM) and convert it into mineral components that are accessible to plants as nutrients. When mineralized, nitrogen in soil organic matter is first converted to ammonium (ammonification) and then to nitrate (nitrification). In the Encirca services nitrogen analytics, soil temperature, texture, drainage, organic matter, and previous crop are the primary factors that determine how much mineral nitrogen is released into the soil during the growing season and at what rate. Manure applications also affect N mineralization potential. All else equal, nitrogen mineralization will be greatest for warm, moist soils with high organic matter content (Figure 4).

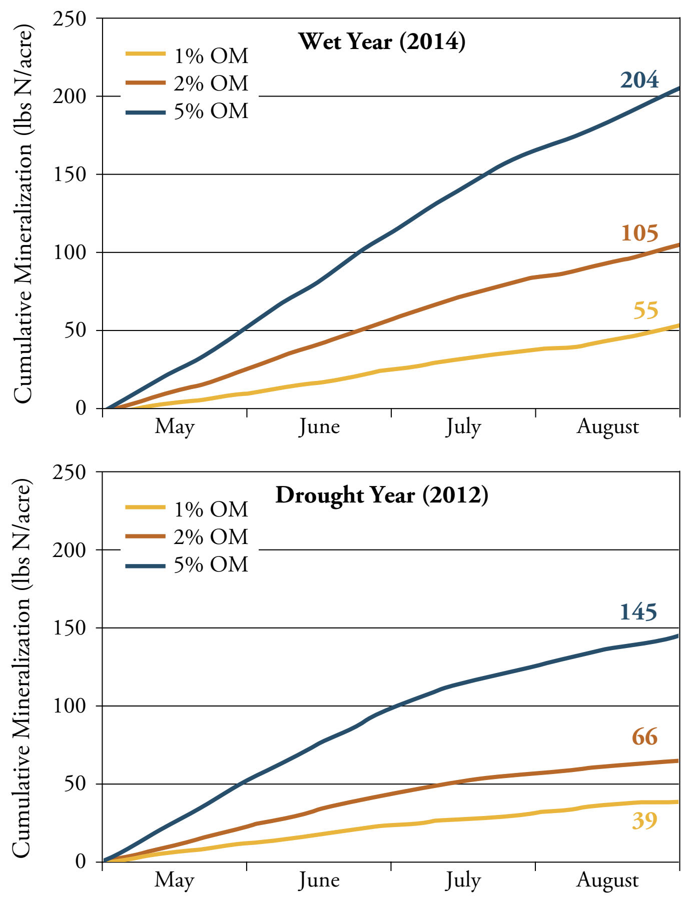

Figure 4. Model-estimated, cumulative soil nitrogen mineralization in Clay Co., NE, in 2014 (upper panel) and 2012 (lower panel). See Table 1 for simulation details.

Nitrate Leaching

Soil texture, soil temperature, drainage, precipitation, and crop growth all interact in the Encirca services nitrogen analytics to determine how much nitrate-nitrogen may be lost from the soil as a result of leaching. Well-drained soils and heavy precipitation may lead to excessive leaching, while little or no leaching may occur in the absence of precipitation or on poorly-drained soils (Figure 5). In most situations, leaching losses are confined to the first 30 to 60 days after planting. Soil temperatures prior to planting are generally too low for much of the nitrogen in the soil to be converted to nitrate. By 60 days after planting, crop nitrogen uptake is so rapid that little nitrate is typically available in the soil to be lost.

Denitrification

Denitrification represents the loss of nitrate-nitrogen that is converted to a gaseous form in the absence of oxygen. Denitrification most commonly occurs on low-lying field areas that pond after heavy precipitation. In the Encirca services nitrogen analytics, denitrification is driven by many of the same factors that cause leaching, but the effect of soil texture and drainage is reversed. Poorly-drained soils typically experience moderate to high levels of denitrification when saturated for an extended period of time, while little or no denitrification occurs on well-drained soils, even with heavy precipitation (Figure 5).

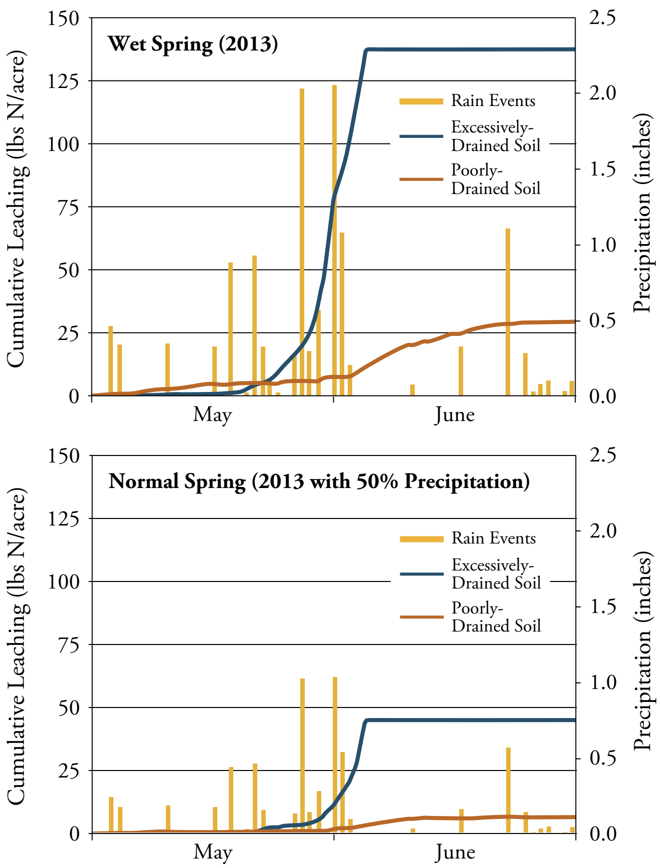

Figure 5. Model-estimated cumulative nitrogen leaching in Woodford Co., IL, in 2013 (upper panel) and a hypothetical year with half as much May-June precipitation as 2013 (lower panel). See Table 1 for simulation details.

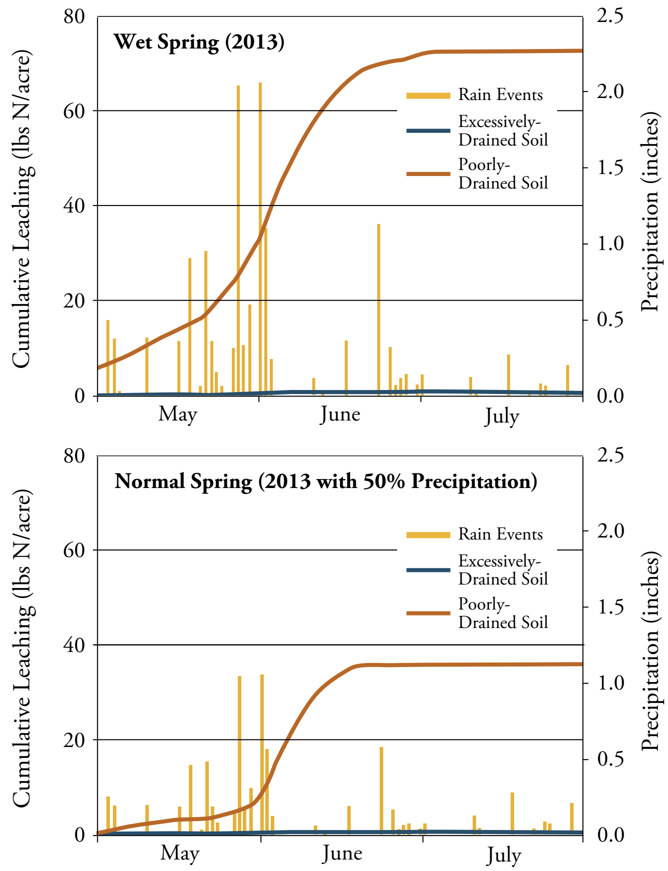

Figure 6. Model-estimated cumulative denitrification in Woodford Co., IL, in 2013 (upper panel) and a hypothetical year with half as much May-June precipitation as 2013 (lower panel). See Table 1 for simulation details.

Ammonia Volatilization

Fertilizers containing urea are subject to a third form of loss called volatilization. Once applied, urea breaks down to ammonia and carbon dioxide in the presence of the ubiquitous urease enzyme. If ammonia is on the soil surface, it can be lost as a gas. In the Encirca services nitrogen model, the amount of ammonia volatilization depends on application method, soil temperature, pH, and soil water content. Volatilization losses are greatest when surface applied urea comes into contact with warm, dry soils (Figure 7). In contrast, cool, wet soils and/or urea incorporation greatly reduce the potential for volatilization. High pH soils can also have greater volatilization losses.

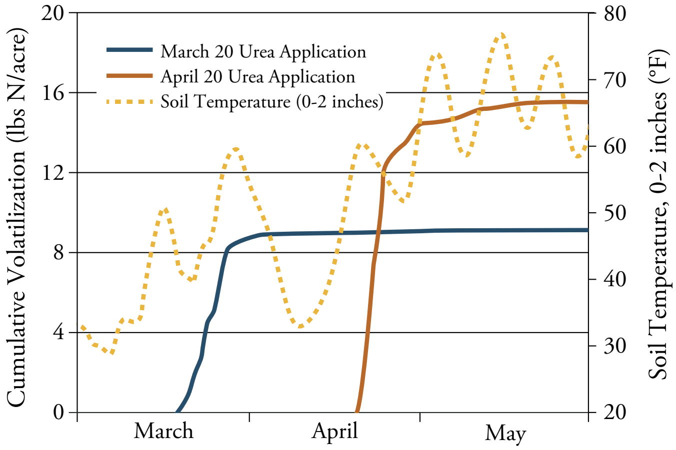

Figure 7. Model-estimated cumulative nitrogen volatilization for two surface-applied urea applications in Putman Co., OH, in 2007. See Table 1 for simulation details.

FRAMEWORK FOR RISK-BASED DECISION MAKING

The outcomes of nitrogen management decisions are inherently uncertain due to imperfect knowledge of future weather events that strongly influence crop growth and soil nitrogen levels. To account for uncertainty in nitrogen management, the Encirca services nitrogen analytics simulate historical and forecasted weather in conjunction with grower yield goals to provide estimates of the risk associated with planned management actions. The level of risk for a given management plan or set of plans is displayed in the Encirca Yield *Nitrogen Management Service* user interface using an intuitive color-coded system (Figure 8).

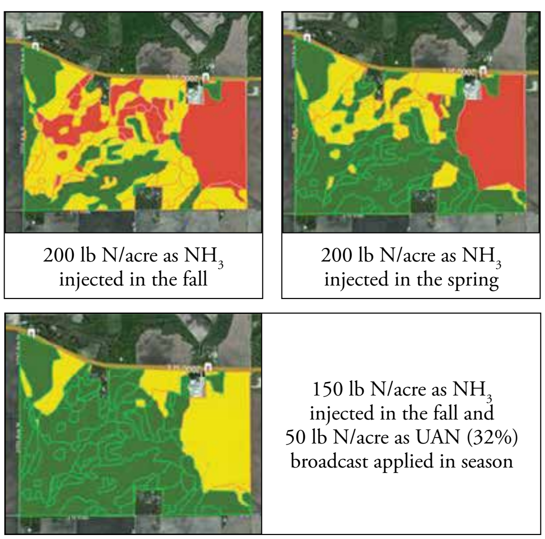

Figure 8. Risk associated with three hypothetical nitrogen management plans for 2015 based on simulations conducted on November 15, 2014. Green field areas represent low risk potential, while yellow and red field areas represent moderate and high risk potential, respectively.

VARIABLE RATE NITROGEN RECOMMENDATION MODEL

The Encirca services nitrogen analytics can be used to generate and export variable rate nitrogen recommendations for any desired application date, method, and product. The variable rate recommendation component of the model shares a common structure with the method described above for estimating nitrogen decision risk. The difference between the risk assessment framework and the variable rate recommendation logic is that the former shows the risk associated with currently planned applications, while the latter computes the rate of nitrogen required to minimize economic and other potential risk given all prior applications entered into the user interface as well as historical and forecast weather (Figure 9).

Figure 9. The Encirca services nitrogen model uses soil and weather information in conjunction with yield goals to generate variable rate nitrogen recommendations that minimize risk of yield loss from insufficient nitrogen.

Table 1. Details for model scenarios presented in Figures 3-7. All simulations were based on a 109 CRM corn hybrid planted at 34,000 seeds per acre on May 1. Soybean was the previous crop in all simulations.

Scenario/ Related Figure	State, County	Weather Year(s)	Soils	N Fertilization
Corn Growth/ N Uptake 3	IA, Story	2007; 2012	Webster clay loam	April 20: 150 lb N/acre[1] May 1: 30 lb N/acre[2]
Mineral-ization 4	NE, Clay	2012; 2014	Thurman loamy sand; Hastings silt loam	April 20: 150 lb N/acre[1] May 1: 30 lb N/acre[2] *(32%)*
Leaching 5	IL, Wood-ford	2013. 2013^	Plainfield sand; Sawmill silty clay	April 20: 150 lb N/acre[1] May 1: 30 lb N/acre[2]
Denitrifi-cation 6	IL, Wood-ford	2013; 2013^	Plainfield sand; Sawmill silty clay	April 20: 150 lb N/acre[1] May 1: 30 lb N/acre[2]
Volatiliza-tion 7	OH, Putman	2007	Toledo clay	March 20: 150 lb N/acre[3] April 20: 150 lb N/acre[3]

^Modeled as 2013 with each precipitation event reduced in magnitude by 50%.
[1]Injected NH_3, [2]Broadcast UAN, [3]Broadcast urea.

SOURCES

Enter this link in your browser to view sources:

https://www.pioneer.com/home/site/us/agronomy/encirca-yield-n-mgmt-service/

return to table of contents

SOLAR RADIATION IN CORN PRODUCTION

SOLAR RADIATION AND CROP NEEDS

- Along with water and nutrients, solar radiation (sunlight) is an essential input for plant growth.
- Plant leaves absorb sunlight and use it as an energy source in the process of photosynthesis.
- A crop's ability to collect sunlight is proportional to its leaf surface area per unit of land area occupied, or its "leaf area index" (LAI).
  - » At "full canopy" development, a crop's LAI and ability to collect available sunlight are maximized.
- From full canopy through the reproductive period, any shortage of sunlight is potentially limiting to corn yield.
  - » When stresses, such as low light, limit photosynthesis during ear fill, corn plants remobilize stalk carbohydrates to the ear. This may result in stalk quality issues and lodging at harvest.
- The most sensitive periods of crop growth (e.g., flowering and early grain fill) are often the most susceptible to stresses, such as insufficient light, water, or nutrients.

CLOUD EFFECTS ON SOLAR RADIATION

- Plants are able to use only a portion of the solar radiation spectrum. This portion is known as "photosynthetically active radiation" (PAR) and is estimated to be about 43% to 50% of total radiation.
- Amount of PAR available to a crop is reduced proportionately to cloud cover (Figure 1).

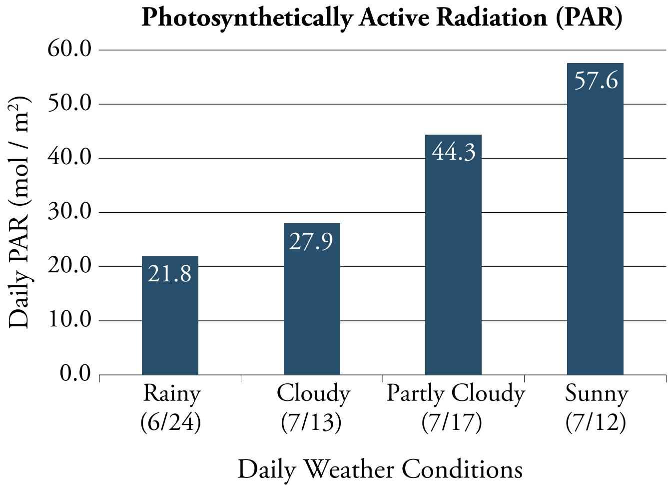

Figure 1. Daily PAR received in Johnston, IA, under rainy, cloudy, and sunny conditions on four different days in summer.

- As Figure 1 shows, PAR was reduced by 25% to 50% on partly cloudy to cloudy days and by over 60% on rainy days.
- It is not surprising, then, that cloudy, rainy periods during susceptible stages of crop development can have significant effects on yield.

EFFECT OF SHADE ON CORN YIELD

- A study using "shade cloth" reduced solar radiation by 55% during various crop stages (Liu and Tollenaar, 2009).
- Yield was significantly reduced by shading at the silking and post-silking stages (Table 1).

Table 1. Effect of shade treatments on yield (Tollenaar, 2009).

Shade Period[1]	Yield Reduction (%)
4 weeks pre-silking[a]	3.2% NS
3 weeks at silking[b]	12.6% **
3 weeks post-silking[c]	21.4% **

[1] Weeks relative to silking: [a] -5 to -1, [b] -1 to +2, [c] +2 to +5.
NS=not significant, **= highly significant (Prob>F=0.05).

- In another study, solar radiation was reduced by 50% using shade cloth (Reed et al., 1988).
- Yield was significantly reduced by shading at the flowering and post-flowering stages.
- Shading during flowering reduced yield primarily through decreasing the number of kernels per row.
- Shading during grain fill reduced yield primarily through decreasing kernel weight.

Table 2. Effect of shade treatments on yield (Reed et al., 1988).

Shade Period	Yield Reduction (%)	Change in Kernels/ Rows	Change in Kernel Wt.
Vegetative	12%	-5%	+1%
Flowering	20%	-21%	+9%
Grain Fill	19%	-5%	-13%
LSD (.05)	7%	4.5%	6%

return to table of contents

AVERAGE U.S. SOLAR RADIATION

- Daily light integral (DLI) is the total amount of solar radiation received at a location each day.
- The southern versus northern U.S. has higher DLIs in the fall and winter due to longer days and higher angle of the sun (Figure 2).
- From May through August, the primary DLI differences occur between the eastern and western U.S. (Figure 2).
  - » Northern areas have longer days but a lower solar elevation angle, so DLI is about the same as in southern areas during most of the corn growing season.
- Elevation and regional weather patterns (primarily cloud cover and humidity) also contribute to regional differences.

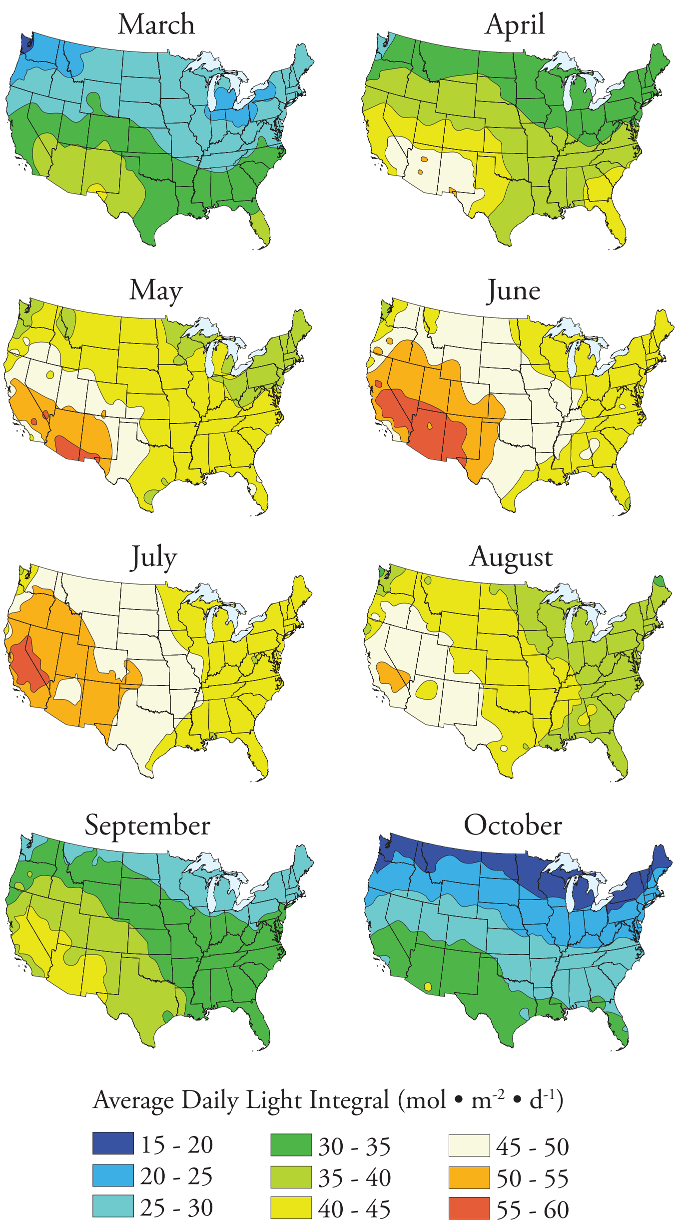

Figure 2. Average U.S. daily light integral (DLI) by month (Korczynski, et al., 2002).

2015 GROWING SEASON AND SOLAR RADIATION

- Cloud cover and rainfall during vegetative, flowering, and early kernel development reduced solar radiation during these stages in 2015 (Figure 3).
- Flowering generally occurred from 7/10 to 7/25 in the central Corn Belt and from 7/20 to 7/31 in northern states and Ontario.
  - » This period (R1) and the very early kernel development stage that follows (R2 or "blister") are especially sensitive to environmental conditions.

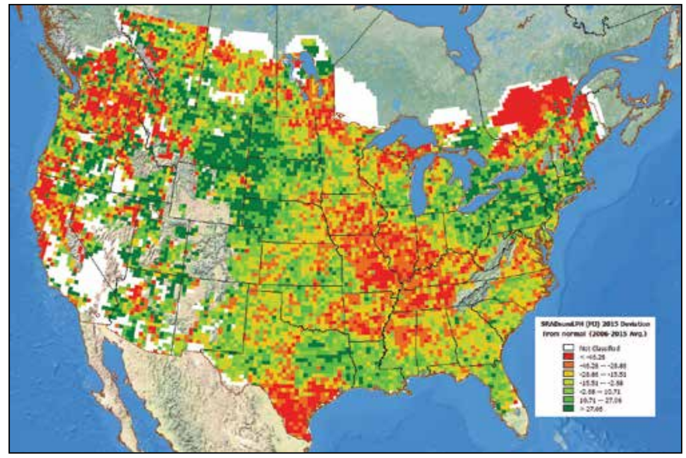

Figure 3. 2015 deviation from normal (2006-2015 avg.) solar radiation during the "lag phase" of development.

"Lag phase" is the time from pollination to the beginning of the linear phase of rapid dry matter accumulation in the kernel and corresponds with the R1 (silking) through R2 (blister) stages of development.

- Solar radiation during early kernel development in 2015 was well below the 10-year normal in many locations.
- Research (see Tables 1 and 2) indicates that inadequate sunlight during this stage can result in decreased yield, primarily due to less kernels produced per ear ("nosing back").
- In addition to aborted ear tip kernels, lower sunlight during grain fill often results in lower kernel weights, poor stalk quality, and premature plant death.
  - » Growers should monitor stalk quality and schedule harvest based on lodging potential, rather than just grain moisture.

REFERENCES

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Korczynski, P., J. Logan and J. Faust, 2002. Mapping monthly distribution of daily light integrals across the contiguous United States. Hort. Tech. 12:12-16.

Reed, A., G. Singletary, J. Schussler, D. Williamson and A. Christy, 1988. Shading effects on dry matter and nitrogen partitioning, kernel number, and yield of maize. Crop Sci. 28: 819–825.

return to table of contents

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AGRONOMY RESEARCH UPDATE

DUPONT PIONEER.

Corn Leaf Angle Response to Plant Density

2015

Background and Objectives

- Previous research has shown that corn plants can alter their leaf angle in response to their environment.
- At greater densities, plant leaf angle tends to be more upright in order to optimize capture of sunlight.
- Plasticity of leaf angle in response to plant density have been shown to differ among hybrids.
- A research study was conducted in 2015 to evaluate leaf angle response to plant density with two Pioneer® brand corn products.

Study Description

Location: Johnston, IA
Replicates: 4
Plot Layout: Small plots (10 x 17.4 ft.), RCBD
Row Width: 30 inches
Planting Date: May 19, 2015
Factors:

- **Pioneer® brand corn products**
  Hybrid/Brand[1]: P1151AM™ (AM, LL, RR2)
  P1311AMXT™ (AMXT, LL, RR2)
- **Population**: 30,000, 40,000, and 50,000 plants/acre

- Hybrids were selected to represent contrasting leaf types: Pioneer® P1151AM™ brand corn had more upright leaves than Pioneer® P1311AMXT™ brand corn in 2014 research.

Leaf Angle Measurements

- Leaf angle measurements were taken on the 10th and 14th leaf of ten plants in each plot (Figure 1).
- Angle of the leaf relative to the stalk (smaller number = more upright leaf angle)
- Measured at the base of the leaf using a clinometer smartphone app (Figure 2).

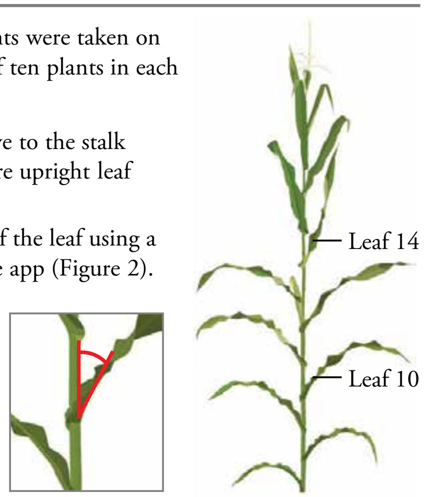

Figure 1. Leaf angle measurements on leaf 10 and leaf 14.

Figure 2. Leaf angle measurements were taken using a clinometer smartphone app.

Results

- Upper leaves tended to be substantially more upright for both corn products across all population densities (Figure 3).

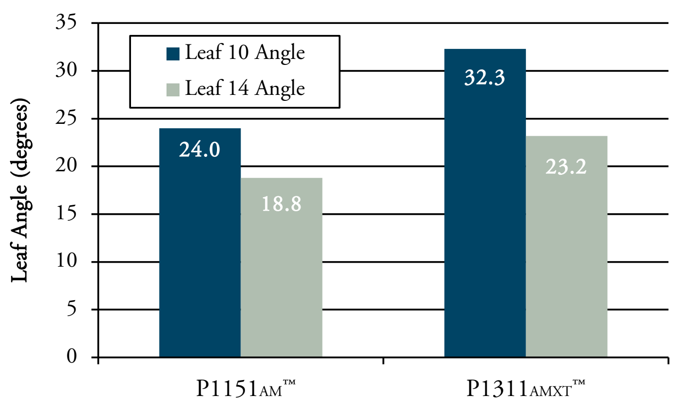

Figure 3. Average angle of leaf 10 and leaf 14 for Pioneer® P1151AM™ brand corn and Pioneer® P1311AMXT™ brand corn.

- Angle of leaf 10 was significantly influenced by both plant density and corn product.
  - Average leaf angle was significantly more upright with greater population density (Figure 4).
  - The average angle of leaf 10 was significantly more upright for P1151AM™ than P1311AMXT™ (Figure 5).

[1]All Pioneer products are hybrids unless designated with AM1, AM, AMRW, AMX, AMT and AMXT, in which case they are brands. 2015 data are based on average of all comparisons made in one location through August 17, 2015. Multi-year and multi-location is a better predictor of future performance. Do not use these or any other data from a limited number of trials as a significant factor in product selection. Product responses are variable and subject to a variety of environmental, disease, and pest pressures. Individual results may vary. PIONEER® brand products are provided subject to the terms and conditions of purchase which are part of the labeling and purchase documents.

Results (continued)

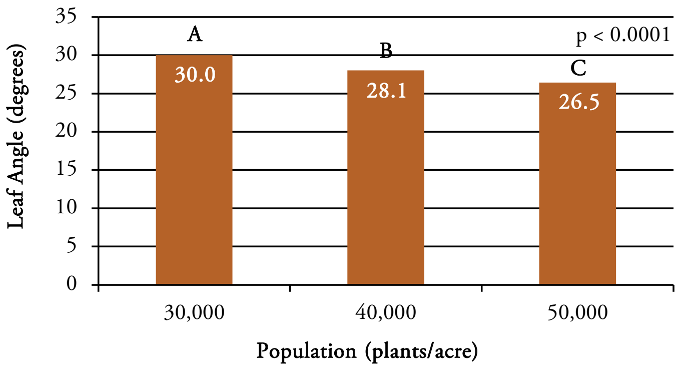

Figure 4. Average angle of the 10th leaf (degrees from vertical) as affected by plant density.

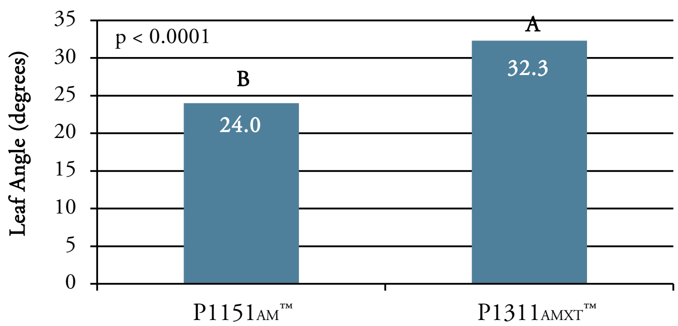

Figure 5. Average angle of the 10th leaf (degrees from vertical) by corn product.

- There was a significant interaction between corn product and population density in their effects on angle of leaf 14.
- P1311AMXT™ had a greater response to density than P1151AM™.

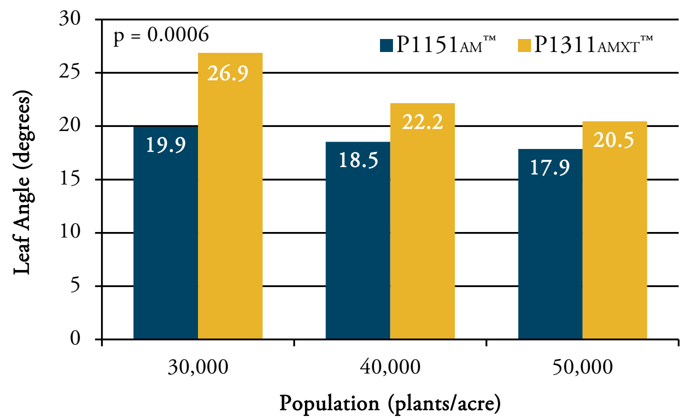

Figure 6. Average angle of the 14th leaf (degrees from vertical) by corn product and plant density.

Conclusions

- The results of this study demonstrate the ability of corn plants to adjust their leaf angle in response to their environment.
- Future efforts to optimize the crop canopy for maximum light utilization and yield need to take this effect into account.
- Results suggest that attempts to optimize crop canopy through management may have limited benefit due to the inherent ability for plants to adjust themselves in response to their environment.

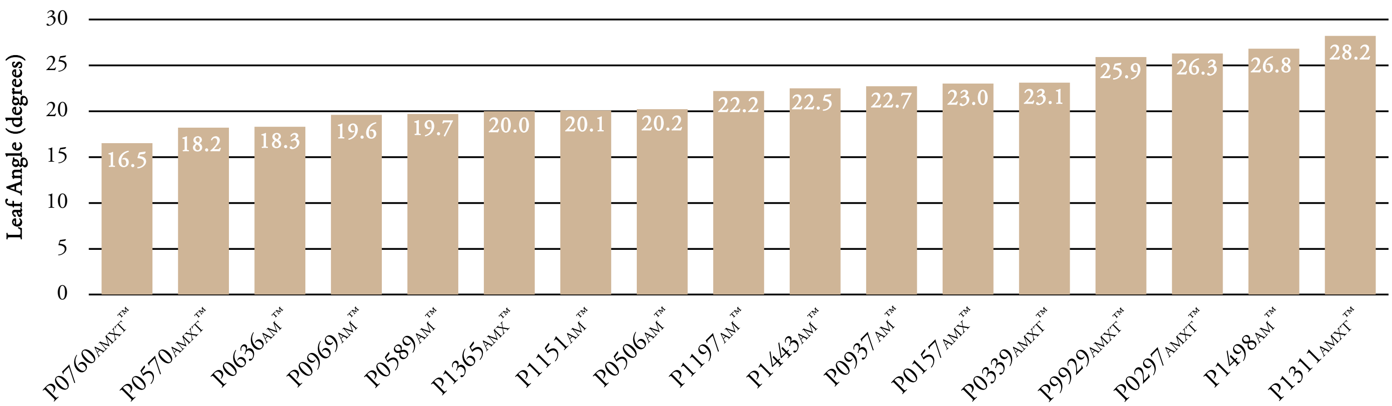

Figure 7. Average angle of the 12th leaf of several Pioneer® brand corn products at 35,000 plants/acre in Johnston, IA plots in 2015.

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AGRONOMY RESEARCHUPDATE

DUPONT® PIONEER®

Corn Leaf Orientation Response to Plant Density

2015

Background and Objectives

- Previous research has shown that corn plants can alter their leaf orientation in response to their environment (Girardin, 1992; Maddonni et al., 2001; Maddonni et al., 2002).
- Leaves may preferentially orient toward the inter-row in order to optimize capture of sunlight.
- A research study was conducted in 2015 to evaluate leaf orientation response to plant density with two Pioneer® brand corn products.

Study Description

Location: Johnston, IA
Replicates: 4
Plot Layout: Small plots (10 x 17.4 ft), RCBD
Row Width: 30 inches
Row Direction: North-south
Planting Date: May 19, 2015
Factors:

- **Pioneer® brand corn products**
  Hybrid/Brand[1]: P1151AM™ (AM, LL, RR2)
  P1311AMXT™ (AMXT, LL, RR2)
- **Population**: 30,000, 40,000, and 50,000 plants/acre

- Hybrids were selected to represent contrasting leaf types: Pioneer® P1151AM™ brand corn had more upright leaves than Pioneer® P1311AMXT™ brand corn in 2014 research.

Leaf Measurements

- Leaf orientation measurements were taken on the 2nd, 6th, 10th, and 14th leaf of ten plants in each plot.
- Leaf orientation was measured using a compass smartphone app.
  - 0° and 180° = parallel to the row
  - 90° and 270° = perpendicular to the row

Results

- Leaf orientation distribution did not significantly differ between corn products or among population densities.
- Leaves tended to orient more toward the inter-row with successive growth stages (Figure 1).
  - Preferential orientation toward the inter-row was apparent at leaf 6, indicating that plants were responding to neighboring plants at relatively early stages of vegetative growth.
  - These results are consistent with previous research that has also detected nonisotropic structure in corn plants as early as the 6th leaf (Girardin, 1992).

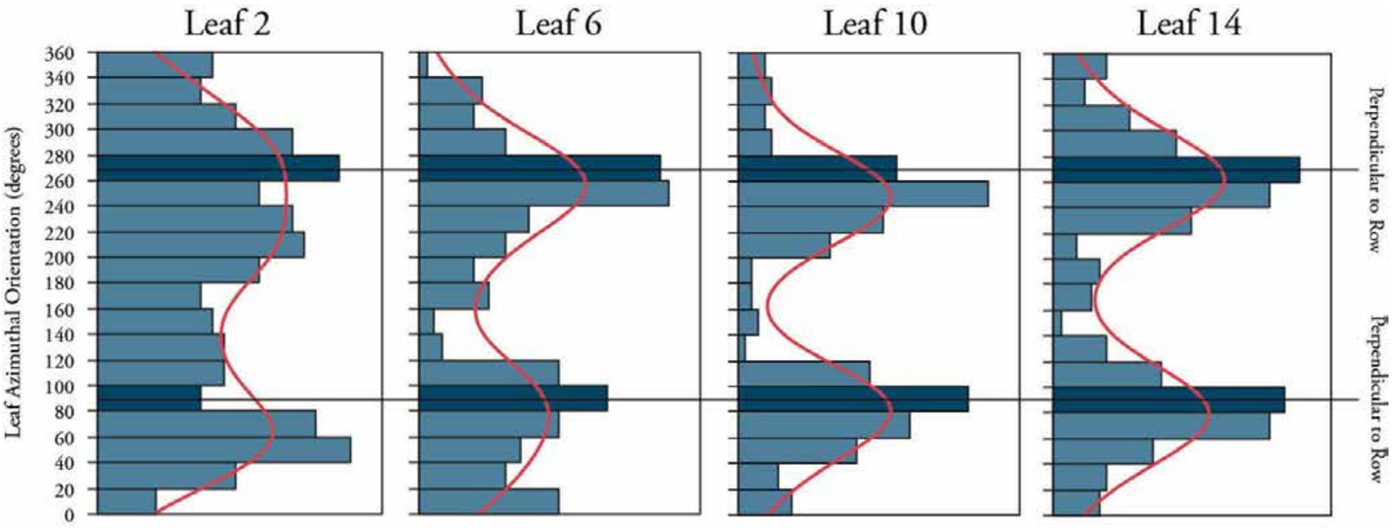

Figure 1. Distribution of azimuthal orientation for leaf 2, leaf 6, leaf 10, and leaf 14 averaged across corn products and population densities.

[1]All Pioneer products are hybrids unless designated with AM1, AM, AMRW, AMX, AMT and AMXT, in which case they are brands. 2015 data are based on average of all comparisons made in one location through August 17, 2015. Multi-year and multi-location is a better predictor of future performance. Do not use these or any other data from a limited number of trials as a significant factor in product selection. Product responses are variable and subject to a variety of environmental, disease, and pest pressures. Individual results may vary. PIONEER® brand products are provided subject to the terms and conditions of purchase which are part of the labeling and purchase documents.

return to table of contents

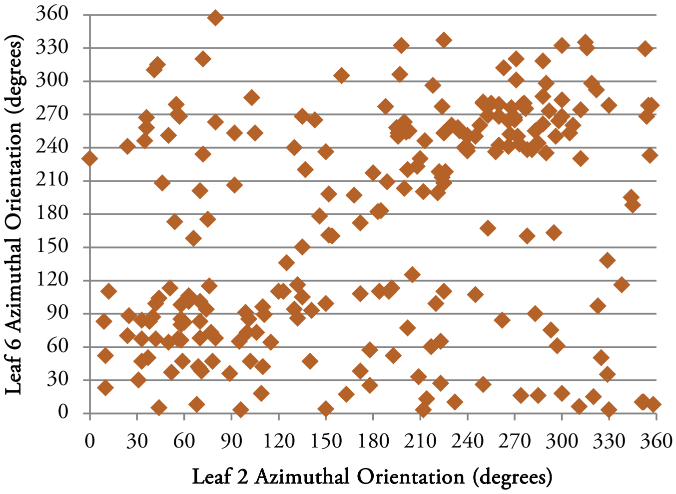

Figure 2. Azimuthal orientation of leaf 6 compared to leaf 2 for all plants sampled.

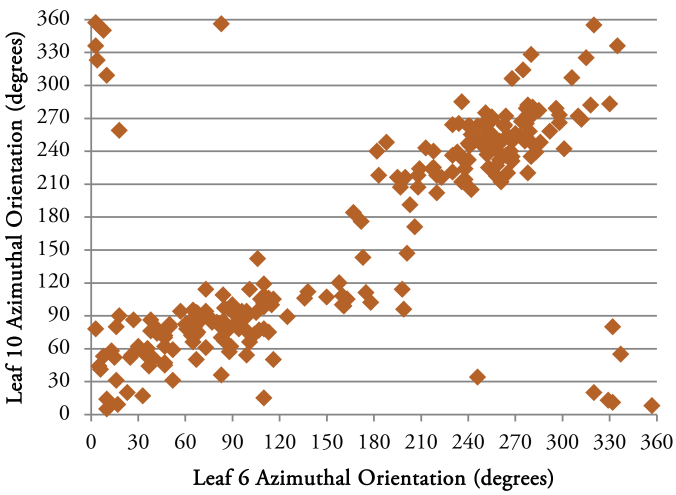

Figure 3. Azimuthal orientation of leaf 10 compared to leaf 6 for all plants sampled.

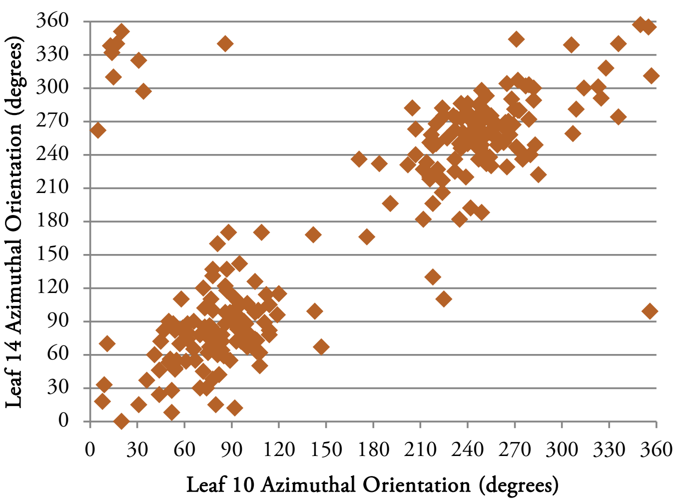

Figure 4. Azimuthal orientation of leaf 14 compared to leaf 10 for all plants sampled.

Results (continued)

- Azimuthal orientation of leaf 6 showed little correlation to the orientation of leaf 2 (Figure 2).
- Orientation of leaf 10 showed a much stronger relationship to the orientation of leaf 6 (Figure 3), as did leaf 14 to leaf 10 (Figure 4).
- These results suggest that leaf orientation response of corn plants to neighboring plants occurred largely during early vegetative growth between V2 and V6, after which leaf orientation was relatively static.

Conclusions

- The results of this study demonstrate the ability of corn plants to adjust their leaves in response to their environment.
- Future efforts to optimize the crop canopy for maximum light utilization and yield need to take this effect into account.
- Results suggest that attempts to optimize corn leaf orientation through seed positioning at planting may have limited benefit due to the inherent ability for plants to adjust themselves in response to their environment.

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Authors: Mark Jeschke and Adelyn Uppena

return to table of contents

Chilling Injury Effect on Corn Emergence and Yield in Eastern Missouri

2014

Background and Objective

- Previous research has shown that the effect of cold stress following planting on corn germination and emergence can differ based on the timing of stress conditions and the stress tolerance of the corn hybrid.
- A field demonstration was established in 2014 using ice applied to corn rows following planting to show the effect of cold stress timing on emergence and productivity of two Pioneer® brand corn products.

Study Description

Location: Shelbyville, MO

Plot Layout: 10-ft long single rows

Row Width: 30 inches

Pioneer® brand products

Hybrid/Brand[1]:

P1151AM™ (AM, LL, RR2) - Stress emergence rating = 4
P0993HR (HX1, LL, RR2) - Stress emergence rating = 5

Planting Date: April 19th, 2014

Treatments: Ice application timing (hours after planting):

- 0, 24, 48, 72, and check (no ice)

Data Collected:

- Time-lapse cameras used to capture differences in emergence timing
- Ears collected from 10-ft strips to weigh and estimate yield

10-ft forms were built from 2” x 4” lumber to hold ice over the row (left). TimelapseCam 8.0 and TimelapseCam editing software were used to monitor emergence (right).

Results and Conclusions

- Time to complete emerge was three days longer for Pioneer® hybrid P0993HR than Pioneer® P1151AM™ brand corn with chilling stress initiated immediately after planting (Figure 1).
- Chilling stress did not cause a delay in time to complete emergence for either corn product at any of the other timings.

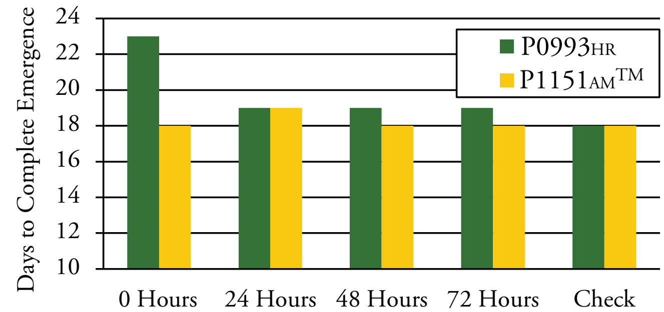


Figure 1. Effect of chilling timing on days to complete emergence.

- Estimates of final yield based on hand-harvested ears indicated the potential for substantial yield penalties associated with chilling injury after planting (Table 1).
- Estimated yield reduction was similar for the two corn products when chilling stress was applied immediately after planting.
- For all subsequent chilling application timings, estimated yield reduction was greater for P1151AM™ (which has a lower stress emergence rating) than P0993HR.

Table 1. Estimated yield reduction relative to the check based on timing of chilling (hours after planting).

Hybrid/Brand[1]	0 hours	24 hours	48 hours	72 hours
P0993HR	28%	6%	8%	0%
P1151AM™	26%	25%	13%	14%

Ears from P0993HR (left) and P1151AM™ (right) hand-harvested from the untreated check and each of the chilling stress application timings.

- This demonstration proved very useful while training sales teams on early season diagnostics as well as late season visuals on the risks of planting ahead of a cold front.
- The demonstration showed that even though a stand can be established in adverse conditions, the effect on harvestable plants and yield is something that should be considered as well.

return to table of contents

Glyphosate-Resistant Waterhemp in Illinois

2015

Background

- Glyphosate-resistant waterhemp was first identified in Missouri in 2005 and subsequently has been identified in Illinois and several other states.
- Given the heavy reliance on glyphosate for weed management in both corn and soybean, glyphosate-resistant waterhemp is driving changes in the approach to weed management in Illinois.
- Further exacerbating this problem is the increasing prevalence of resistance to PPO-inhibiting herbicides (e.g., the diphenylethers) in waterhemp, sometimes "stacked" with glyphosate resistance.

Objectives

- A survey was conducted of grower-submitted waterhemp samples from across Illinois to evaluate the prevalence of glyphosate- and PPO-resistant populations.
- Objectives of this study were to:
  - Increase awareness among farmers that glyphosate-resistant waterhemp is becoming prevalent in Illinois
  - Confirm the existence of glyphosate-resistant waterhemp in grower fields and the need for alternative waterhemp management strategies

Study Description

- Samples of waterhemp suspected to be resistant to glyphosate were solicited from Illinois growers.
- Over 1200 plant samples were received from 252 Illinois fields from 2010-2014.
- DNA was extracted from each sample and used in molecular assays to test for resistance to glyphosate and PPO-inhibiting herbicides.
  - For glyphosate resistance, the molecular assay detects amplification of the EPSPS gene, which encodes the glyphosate target site.
  - For resistance to PPO inhibitors, the molecular assay is based on a specific mutation that has been found in the PPX gene, which encodes the target site of these herbicides.

Results

- This study determined that waterhemp populations that are resistant to PPO inhibitors and to glyphosate are common across the state of Illinois.
- Samples from 94 fields evaluated in 2014 showed that nearly half of the fields had both glyphosate and PPO-inhibitor resistance present in the waterhemp population (Figure 1).
- Glyphosate-resistant waterhemp increased in prevalence across the state during the study period (Figure 2).

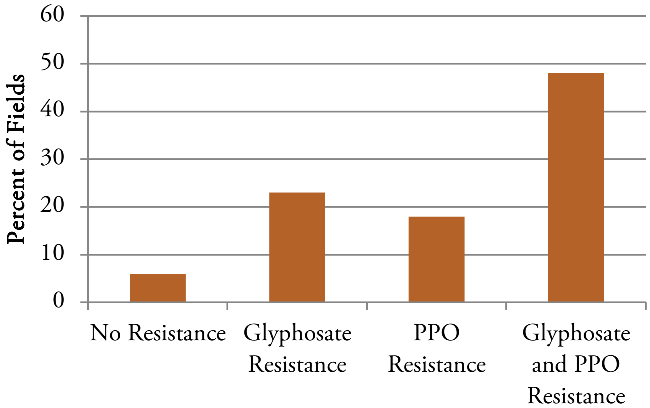


Figure 1. Percentage of fields with no resistance, resistance to glyphosate, resistance to PPO-inhibiting herbicides, or resistance to both herbicides.

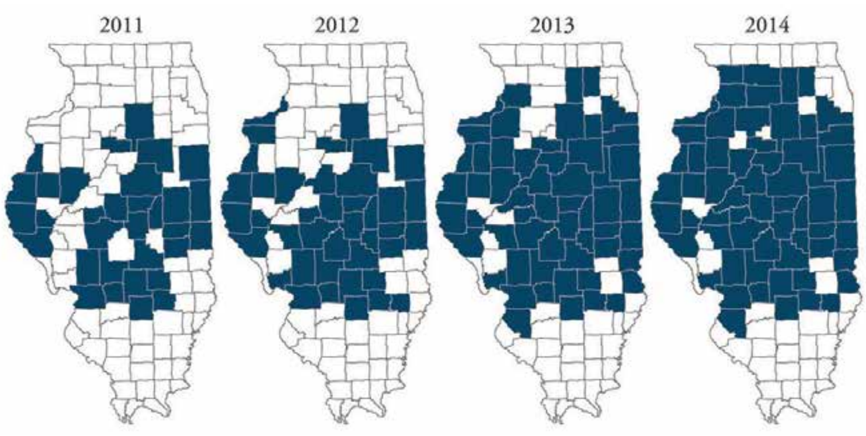


Figure 2. Counties in which glyphosate-resistant waterhemp has been identified based on grower-submitted samples 2011-2014.

Research conducted by Dr. Pat Tranel, University of Illinois, as a part of the DuPont Pioneer Crop Management Research Awards (CMRA) Program. This program provides funds for agronomic and precision farming studies by university and USDA cooperators throughout North America. The awards extend for up to four years and address crop management information needs of DuPont Pioneer agronomists, Pioneer sales professionals and customers. The foregoing is provided for informational use only. Please contact your Pioneer sales professional for information and suggestions specific to your operation.

return to table of contents

ALS INHIBITOR HERBICIDES

The ALS inhibiting herbicides were introduced in the early 1980s by DuPont with the registration of the first sulfonylureas. Since then, these herbicides have become among the most widely used in the world. The general mode-of-action of ALS herbicides is to inhibit the ALS enzyme, blocking the biosynthesis of valine, leucine, and isoleucine as well as depriving the plant of these essential amino acids.

The Herbicide Resistance Action Committee and the Weed Science Society of America classify five herbicide families in the "ALS inhibitors" group. These families are the imidazolinones, the pyrimidinylthiobenzoates, the sulfonylaminocarbonyltriazolinones, the sulfonylureas, and the triazolopyrimidines.

ALS herbicides have been labeled for annual and perennial grass, broadleaf, and brush control for many uses including small grains, rice, corn, canola, alfalfa, grain sorghum, soybeans, sunflower, peanuts, cotton, sugarbeet, turf, pasture grasses, forestry, and non-crop industrial and rights-of-way among others. These herbicides are active at very low use rates and have very favorable environmental and toxicology profiles.

MODE OF ACTION

ALS herbicides inhibit the enzyme acetolactate synthase (ALS), also called acetohydroxyacid synthase (AHAS). This enzyme catalyzes the first step in branched-chain (essential) amino acid biosynthesis. This pathway leads to the synthesis of valine, leucine, and isoleucine and is unique in plants. Blocking this pathway interferes with DNA synthesis and cell growth.

ALS herbicides are absorbed by roots, shoots; and foliage and are translocated throughout the plant in the xylem and phloem. ALS herbicides accumulate in meristematic growing points of the plant, such as apical buds at the tips of roots, shoots, leaf axils, and reproductive structures. Translocation and symptom development tend to be slow with these herbicides. It can take 7 to 14 days or longer for these herbicides to completely kill a plant.

Many annual and perennial grass and broadleaf weed species are susceptible to different members of the ALS herbicide families. Some ALS herbicides have a narrow range of species activity while others are broad spectrum. Plant tolerance to the ALS herbicides is primarily through degradation to nontoxic metabolites. Susceptible species are unable to detoxify the herbicide before plant death occurs.

Several weed species have developed resistance to ALS herbicides. Weed resistance to these herbicides is generally associated with a genetically altered form of the ALS enzyme that is less sensitive to these herbicides. Several different altered enzyme sites have been isolated in resistant weeds. Some of these altered enzymes are resistant only to one family of the ALS inhibitors while others are cross-resistant to two or more families. Rapid metabolic break-down of these herbicides within some formerly susceptible weed populations has also been recently discovered. A wide range of tolerance to these herbicides has also been reported within biotypes or varieties of a single plant species, such as corn and shattercane or grain sorghum.

PHYSICAL AND CHEMICAL PROPERTIES

There is a wide range of chemical behavior and properties among the herbicides in the four families of ALS inhibitors. All of these herbicides are active on plants at very low use rates. They have low mammalian toxicity and favorable environmental impact profiles, which has usually led to "reduced-risk" registration status with the United States Environmental Protection Agency (EPA).

Imidazolinones

The imidazolinone herbicides were introduced in the mid-1980s and are used preemergence and postemergence for control of annual and perennial weeds. Most of these herbicides have medium to long soil persistence. Residual weed control with the imidazolinones varies from a week up to two years or more depending on the specific herbicide and application rate. Degradation in the soil is primarily through microbial action. Dry weather and cool temperatures are primarily responsible for longer persistence in the soil due to low microbial activity under these conditions. High organic matter and low pH may also contribute to persistence and carryover to rotational crops.

Pyrimidinylthiobenzoates

The pyrimidinylthiobenzoates are active primarily on broadleaf weeds. Pyrithiobac (DuPont™ Staple® herbicide) is the only herbicide in this family currently registered in the United States. It is used as a postemergence broadleaf herbicide in cotton. Photolysis and microbial breakdown are thought to be the primary mechanisms of degradation.

Sulfonylaminocarbonyltriazolinones

The sulfonylaminocarbonyltriazolinones are a newer group of ALS inhibiting herbicides that are active on grass and broadleaf weeds. They are especially good on grass weeds for selective use in corn and wheat. Microbial breakdown is thought to be the primary mechanism of herbicide degradation.

Sulfonylureas

The sulfonylureas were introduced in the early 1980s and are also active preemergence and postemergence on annual and perennial weeds. These herbicides have medium to long soil persistence that can last from several weeks to several years depending on the herbicide and application rate. Soil degradation is by microbial action and chemical hydrolysis. Hydrolysis is significantly faster at low soil pH than at high pH. Soil degradation of sulfonylurea herbicides is faster at low soil pH where microbial action and hydrolysis are both contributing to breakdown. At high soil pH; only microbial degradation significantly contributes to herbicide break-down. Because of this, carryover to rotational crops is often more of a problem for sulfonylureas at high soil pH.

Triazolopyrimidines

The triazolopyrimidines (also called the sulfonanilides) were introduced in the early 1990s and are used preemergence and/or postemergence to control annual broadleaves and some perennial broadleaves. These herbicides have medium to long soil persistence with half-lives from several weeks to several months. The main pathway of degradation is microbial. These herbicides are more tightly adsorbed to soil colloids (clay and organic matter) at low soil pH resulting in slower degradation at low soil pH.

SYMPTOMS

Plant response symptoms appear slowly with the ALS herbicides. Inhibition of plant growth will occur rapidly, but visible symptoms of plant response may not show up for one to three weeks depending on the herbicide and environmental conditions.

Typical symptoms of ALS herbicides on plants include stunting, interveinal yellowing (chlorosis) and purpling, inhibition of root growth (pruning of lateral roots often called "bottlebrush"), death of the terminal growing point, and inhibition of grass leaf unfurling.

Soybean response is typically interveinal yellowing, and leaf veins that may be red to purple in color. Corn response may be improper unfurling of the whorl leaves, yellow to translucent leaves, stunting, reduction in kernel rows on the cob (called "pinched ears"), or even a "bear claw" ear due to loss of apical dominance in the ear. Severe injury to corn from late applications of ALS herbicides can lead to sterile ears.

Sometimes there are no visible injury symptoms, but crop yield may be reduced. This can occur when the herbicide is translocated to flower primordia and concentrated in the cells just as they are developing in the plant. This can usually be avoided by following the application timing guidelines on the label regarding rates, application timings, and adjuvants.

The degree of plant response will vary with application rate, stage of plant growth, plant species, plant (or crop) variety, and environmental conditions. Each herbicide within this class also has different levels of activity on different species. There is a wide variation in the crop selectivity among these herbicides that has allowed the ALS inhibitors to be a very versatile and widely used group of herbicides.

INSECTICIDE / ALS HERBICIDE INTERACTIONS

During the development of the sulfonylurea herbicides nicosulfuron and primisulfuron for postemergence grass control in corn, researchers discovered an interaction with certain organophosphate (OP) insecticides. A postemergence application of these herbicides following a planting time soil application of several different OP insecticides was observed to cause foliar and root injury to corn that did not occur in the absence of insecticide application. Since this discovery, most ALS herbicides labeled for corn specify management restrictions on the use of certain OP insecticides. These labels should be consulted before using an OP insecticide with an ALS herbicide in corn.

Differential Response in Corn Inbreds and Hybrids

Numerous research studies have been conducted on the differences in corn genotypic response to ALS herbicides. Most of this research has been conducted with the sulfonylurea family of herbicides. Researchers at DuPont reported a 40,000-fold difference in sensitivity between the most sensitive and most tolerant corn inbreds they have tested. Research determined that tolerant inbreds were able to metabolize the sulfonylurea herbicides much quicker than susceptible inbreds. Field experience indicates the short-season, flint-type corn germplasm has a greater number of lines with reduced tolerance to ALS herbicides than longer-season dent-type corn hybrids. Hybrid tolerance to sulfonlyureas can be enhanced by using at least one tolerant inbred parent,

Figure 1. Yellowing of leaf margins and veins on soybeans due to chlorimuron-ethyl.

Figure 2. Stunting of soybean (on right) due to application of imazaquin at a 3x rate.

Figure 3. Pruned lateral roots of corn treated with imazaquin (right).

Figure 4. Yellowing due to chlorimuron-ethyl applied preemergence to corn.

backcrossing a tolerant inbred with a sensitive, or using an ALS modified gene. DuPont Pioneer currently tests its hybrids for sensitivity to ALS herbicides.

ALS Resistant Crops

ALS herbicide resistant crop lines have been created by using ALS modified genes. These ALS resistant crops incorporate a resistance gene obtained through mutagenesis, selection of naturally occurring genes, or transgenic modification. The use of these resistance genes significantly reduces the risk of crop response from ALS herbicides and has allowed the registration and use of ALS herbicides on some of these crops that could not have been used without the genes.

Guidelines for Using ALS Herbicides in Corn and Soybean Production

Several ALS herbicides are registered for use in conventional and ALS resistant corn and soybeans. Each has unique weed species activity, application timing, and rate guidelines. Several herbicides in the ALS families are labeled for preemergence and postemergence applications. Early application of postemergence ALS herbicides is encouraged by herbicide manufacturers and university specialists to minimize the risk of crop response and maximize weed control. As a general rule, the risk of crop response increases as plants get larger and especially when they start flower formation.

The ear primordia growing points of corn plants begin to develop after the V6 to V7 stage and can be adversely affected by ALS herbicides. This may result in production of fewer kernels per ear, malformed ears, or sterile ears. Good growing conditions and healthy corn plants are important for enhancing rapid ALS herbicide degradation and minimizing the risk of crop response.

ALS herbicides registered for use in soybeans include preemergence and postemergence herbicides with short to long residual activity. These herbicides primarily provide annual broadleaf weed control. Again, the postemergence herbicides are most effective when applied to small weed seedlings.

There has not been any definitive research to indicate significant differences in soybean varietal tolerance to ALS herbicides. Healthy plants and favorable growing conditions maximize the ability of soybeans to quickly metabolize the ALS herbicides and prevent significant crop response. Some ALS herbicides for corn now include safeners that significantly reduce the probability of seeing a negative crop response. DuPont has also developed soybeans with enhanced sulfonylurea herbicide resistance.

Herbicides in the ALS families are also labeled for use in many other crops, including alfalfa, canola, grain sorghum, rice, sunflower, and wheat. There is too much diversity among these products and uses to cover in this article. The general rule applies that healthy crop plants enhance rapid degradation of these herbicides, which reduces the risk of crop response.

To view authors, references, and a list of ALS herbicide families and active ingredients, follow this link:

https://www.pioneer.com/home/site/us/agronomy/library/als-inhibitor-herbicides

PPO INHIBITOR HERBICIDES

There are several herbicide families classified as PPO inhibitors. Inhibition of the PPO enzyme ultimately leads to accumulation of peroxidative agents that cause the breakdown of cell membranes. For this reason, the PPO inhibitors are also called cell membrane disruptors. The Herbicide Resistance Action Committee and the Weed Science Society of America classify seven herbicide families in this group. These families are the diphenylethers, N-phenylphthalimides, oxadiazoles, phenylpyrazoles, thiadiazoles, triazolinones, and triazolopyridinones.

The first PPO inhibitor herbicides were introduced in the 1970s and early 1980s. The diphenylethers were the first widely used family of PPO inhibitor herbicides. These herbicides have been labeled primarily for preemergence and postemergence annual broadleaf weed control. However, some of these herbicides also have limited preemergence grass activity. They are widely registered for many agronomic and horticultural crops.

Figure 1. Soybean seedling showing sulfentrazone splash injury, resulting in burning of the hypocotyl and cotyledon tissue.

MODE OF ACTION

The primary mechanism of action of the PPO inhibitor herbicides is inhibition of the protoporphyrinogen oxidase enzyme (also called Protox). The Protox enzyme controls the conversion of protoporphyrinogen IX to protoporphyrin IX. The result of inhibiting the Protox enzyme is accumulation of singlet oxygen in the presence of light. This leads to a light-induced breakdown of cell components. Cell membranes are destroyed by this light peroxidation reaction, which results in cell leakage, inhibited photosynthesis, and finally bleaching of chloroplast pigments. The primary site of action is cellular membranes where Protox is mainly located.

The PPO inhibitor herbicides are absorbed mostly by leaves, with some limited root absorption. These are mainly contact-type herbicides that are translocated primarily in the xylem, although movement within the plant from leaf absorption is very limited. Herbicide degradation in the plant is through conjugation with glutathione and/or glucose. The mechanism of selectivity in tolerant plants appears to be breakdown of the herbicide to inactive metabolites. Metabolic breakdown is much slower in

Figure 2. Carfentrazone herbicide symptomology on corn.

susceptible weed species than in tolerant plant species. A resistance gene has also been discovered in resistant weeds that involves a unique codon deletion in the PPX2 gene. It is suspected that metabolic degradation may also play a role in weed resistance to PPO herbicides.

PHYSICAL AND CHEMICAL PROPERTIES

Many of the PPO inhibitors are foliar-applied, contact-type herbicides. Plant absorption is increased with high relative humidity. Most of these herbicides require spray additives to improve foliar coverage and leaf absorption. Spray additive recommendations should be followed closely because using the wrong additive can lead to greater crop response. The PPO-inhibiting herbicides have low volatility, low toxicity to mammals, and very favorable environmental impact profiles. Most of the herbicides in these families are fairly immobile in soil through strong adsorption to soil organic matter and clay. These herbicides are primarily degraded by sunlight (photodegradation) and microbial action. The soil-active members of these herbicide families have somewhat short half-lives with short to moderate residual activity in the four to six week range.

SYMPTOMS

The PPO inhibitor herbicides are primarily foliar-applied and have limited soil activity. They are contact-type herbicides that primarily affect only the sprayed plant tissues. The leaves of susceptible plants will quickly become chlorotic (yellow), then desiccated and necrotic (brown) within one to three days. The youngest leaves of tolerant plants may show yellow or reddish spotting (called "bronzing"), and plants can be temporarily stunted. Soil-applied PPO inhibitors cause rapid yellowing, necrosis, stunting, and death of germinating susceptible plants.

The degree of plant response will vary with application rate, stage of plant growth, plant species, plant (or crop) variety, and environmental conditions. Plant response tends to be more severe and common with high humidity and extremely cool or hot temperatures.

Plant response to the soil-applied PPO inhibitors tends to be greater with saturated soils or following high intensity rainfall that splashes treated soil onto young seedlings. These herbicides can cause yellowing, burning, girdling, stunting, and stand loss of plant seedlings under severe environmental conditions.

DIFFERENTIAL RESPONSE IN SOYBEAN VARIETIES

University of Arkansas and Auburn University researchers discovered differences in susceptibility among soybean varieties to sulfentrazone. Their research indicated susceptible varieties lacked a gene for tolerance to PPO-inhibiting herbicides. Additional research conducted by DuPont Pioneer and the University of Arkansas confirmed that the gene for resistance was a single dominant trait. Pioneer has published charts that identify Pioneer® brand soybean varieties as having reduced tolerance to PPO herbicides with more potential for exhibiting crop injury. Screening for PPO tolerance is an on-going program at Pioneer.

Figure 3. Soybean leaf bronzing due to acifluorfen.

GUIDELINES FOR USING PPO INHIBITING HERBICIDES IN SOYBEAN AND CORN PRODUCTION

The PPO-inhibiting herbicides are valuable broadleaf weed control tools in soybean and corn production systems. Important herbicides in this group can provide quick control of many difficult-to-control broadleaf weed species, including morningglory, Palmer amaranth, waterhemp, and velvetleaf. The contact-type herbicides require good foliar coverage. The soil-applied herbicides require rainfall for good "activation." Herbicide performance is enhanced by using higher spray volumes to maximize coverage. Weed control is also improved under good growing conditions and higher relative humidity.

The level of crop tolerance to PPO-inhibiting herbicides varies with the specific herbicide, crop genetics, and environmental conditions. Most crop responses to these herbicides occur during extended periods of high humidity, very low or high temperatures, and/or wet soils. Crop response is mostly cosmetic and short-lived since there is very little translocation within the plant. Applying these herbicides at the correct growth stage, using only recommended spray additives, and avoiding conditions of crop growth stress will minimize crop response and provide the greatest level of weed control.

To view authors, references, and a list of PPO herbicide families and active ingredients, follow this link:

https://www.pioneer.com/home/site/us/agronomy/library/ppo-inhibitor-herbicides/#references

return to table of contents

Corn Rootworm Monitoring: 2014 & 2015

2015

Objectives

- Evaluate and monitor corn rootworm protection of Pioneer® brand corn products with the Herculex® RW (HXRW) trait in the central and northern Corn Belt, specifically targeting fields where HXRW has been used in two or more consecutive growing seasons.
- Estimate corn rootworm population levels in fields in the central and northern Corn Belt using Pherocon® AM/NB sticky traps.

Study Descriptions

Study 1: Evaluate and monitor corn rootworm protection

- **Years:** 2014 and 2015
- **Locations:** 136 fields in IA, IL, IN, MN, NE, SD, and WI
- **Sampling Methods:**
  - Targeted fields for sampling with a history of continuous corn and continuous use of HXRW trait (Table 1)
  - All fields were planted with a Pioneer brand corn product with Optimum® AcreMax® 1, Optimum® AcreMax® Xtra, or Optimum® AcreMax® XTreme insect protection in the year that sampling took place.
  - Sampled 10 roots per location (five 2-plant clusters)
  - Roots were washed and corn rootworm injury rated using 0-3 Node Injury Scale (NIS)

Table 1. Locations by state and history of fields sampled for evaluation of corn rootworm protection efficacy in 2014 and 2015.

Field History	IL	IN	IA	MN	NE	SD	WI	Total
Not Reported	4		2	4				**10**
2 Years HXRW	9		1	1	2		3	**16**
3 Years HXRW	9		7	5			3	**24**
4 Years HXRW	14	3	2	14		1	9	**43**
5 Years HXRW	2		2				2	**6**
≥6 Years HXRW	4		5	11			7	**27**
Competitive Trait Problem Field	4			1				**5**
HXRW/Soy Rotation	2			3				**5**
Total	**48**	**3**	**20**	**39**	**2**	**1**	**24**	**136**

Study 2: Estimate corn rootworm population levels

- **Year:** 2015
- **Locations:** 638 fields in IA, IL, MN, SD, and WI
- **Sampling Methods:**
  - Sticky traps placed in field beginning at blister stage (R2)
  - Sticky traps placed per field: 1 or 6
  - Beetles counted on each trap at 7-day intervals
  - If weekly count averaged more than 50 beetles/trap, trapping was discontinued
  - If the beetle count was below 50 beetles/trap average, new traps were placed in the field and for another 7 days
  - Trapping continued for 4 consecutive weeks, or until traps averaged >50 beetles per trap, whichever came first

western corn rootworm

northern corn rootworm

Results

Study 1: Evaluate and monitor corn rootworm protection

- Corn rootworm injury was low at all locations in the study; average node injury score less than 1.0 (one node removed).
- Corn rootworm injury did not differ based on HXRW trait history (Table 2).

Table 2. Average node injury score (NIS) by field history.

Field History	NIS	Locs
Not Reported	0.03	10
2 years HXRW	0.08	16
3 years HXRW	0.05	24
4 years HXRW	0.09	43
5 year HXRW	0.02	6
6 years HXRW or more	0.06	27
Competitive trait problem field	0.04	5
HXRW/soybean rotation	0.05	5

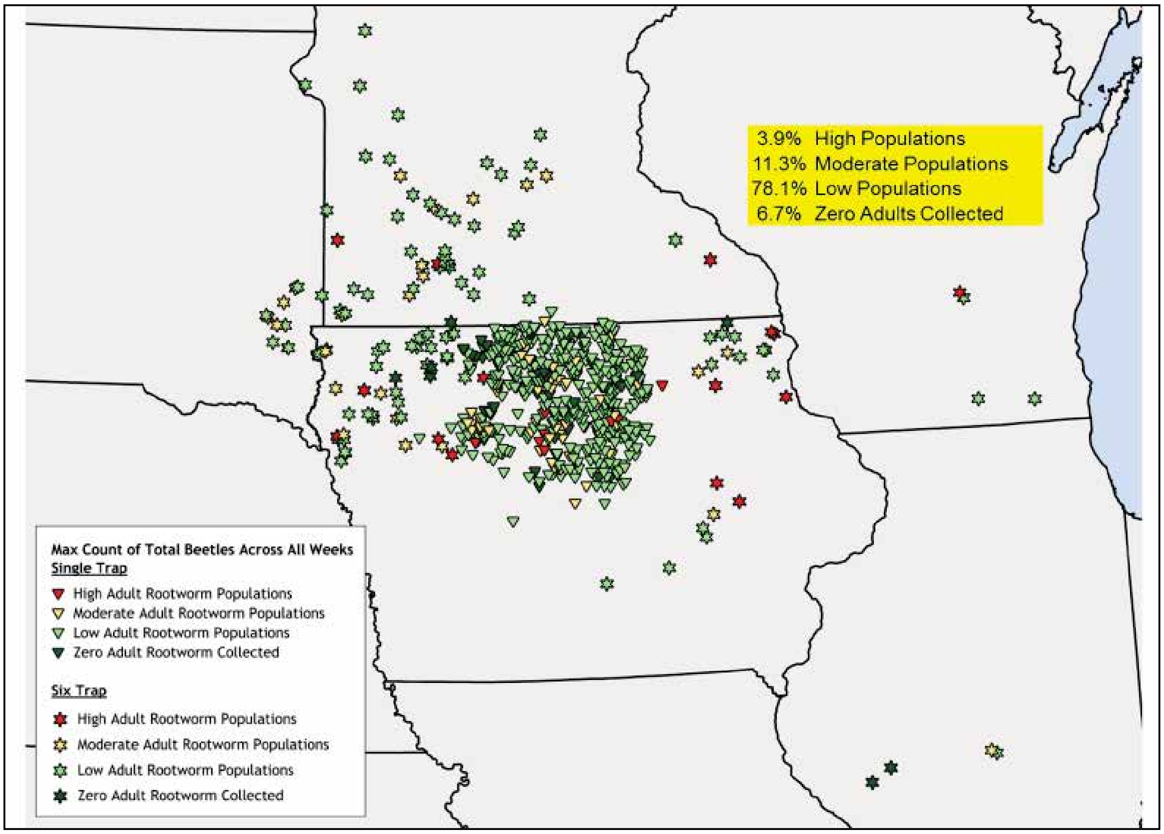


Figure 1. Population levels observed at corn rootworm beetle trapping locations in 2015.

Study 2: Estimate corn rootworm population levels

- Corn rootworm population levels were categorized at zero, low, moderate, or high for each sampling location in 2015
  - Zero = no beetles collected
  - Low = traps average <21 beetles/week
  - Moderate = traps average 21-50 beetles in a single week
  - High = traps average >50 beetles in a single week
- Corn rootworm beetle population levels observed (Figure 1):
  - 3.9% of locations had high populations
  - 11.3% of locations had moderate populations
  - 78.1% of locations had low populations
  - 6.7% of locations had zero adults collected

Management Considerations

- Corn rootworm protection of Pioneer® brand corn products with the Herculex® RW trait was extremely consistent across all sampling locations in 2014 and 2015 and was not influenced by HXRW trait use history.
- **Although this study has shown that the HXRW trait remains an effective tool for corn rootworm management, DuPont Pioneer and university research suggests that continuous, uninterrupted use of the same corn rootworm Bt technology can lead to decreased corn rootworm susceptibility to that technology, and may result in reduced product efficacy against these insects.**
- To help maintain the efficacy of Bt corn rootworm products, it is essential to develop a multi-faceted rootworm control management plan.
- Your DuPont Pioneer Sales Professional or your local Extension professionals can assist you in developing best management practices for your farming operation.
- Please contact your authorized Pioneer Representative or consult with your local University Extension for more information regarding insect resistance management guidelines, best management practices and to understand whether there has been insect resistance documented in your area.

Authors: Jeff Mathesius, Marlin Rice, Ryan French, Brad Van Kooten, Mark Jeschke, and DuPont Pioneer Field Agronomists

return to table of contents

AGRONOMY RESEARCHUPDATE

Insect Protection Technologies for Corn Rootworm Management

2015

Objective

- Research trials were conducted in 2013, 2014, and 2015 to evaluate corn rootworm (CRW) protection efficacy of insect protection technologies available in Pioneer® brand corn products under various levels of CRW feeding pressure.

Study Description

Years: 2013, 2014, 2015

Locations: 9 in 2013, 11 in 2014, 15 in 2015; research locations in IA, IL, IN, MN, NE, SD, and WI

Plot Layout: Small research plots, 4 rows each

Replications: 3 per location

Hybrid Platforms: 4 or 5 per location

Insect Protection Technologies – Pioneer brand products:

Qrome™ products

Optimum® AcreMax® XTreme (AMXT)

Optimum® AcreMax® Xtra (AMX)

Optimum® AcreMax® TRIsect® (AMT) with Poncho® 1250 + VOTiVO® insecticide

CRW non-protected check (HX1, LL, RR2)

- Evaluated CRW feeding damage on 5 plants per plot
- Samples did not exclude refuge plants
- CRW feeding damage rated using the Iowa State 0-3 node injury score (Oleson et al., 2005)
- Research locations were selected and managed specifically to create high CRW pressure environments, with some sites utilizing trap crops and/or manual CRW infestations

Site Characterization

- Research locations were categorized as having low, moderate or high CRW feeding pressure based on the average CRW node injury in the CRW non-protected check:

Low: 0 - 0.75 Moderate: 0.75 - 1.75 High: 1.75 - 3.00

Results

- Across all three years of the study, a total of 14 locations had moderate to high CRW pressure (0.75 - 3.00) The average CRW node injury score of the CRW non-protected check was 1.77 across these 14 locations (Figure 1).
- All CRW protection technologies had excellent CRW protection efficacy, with average CRW node injury scores significantly lower than the non-protected check, ranging from 0.22 to 0.38.

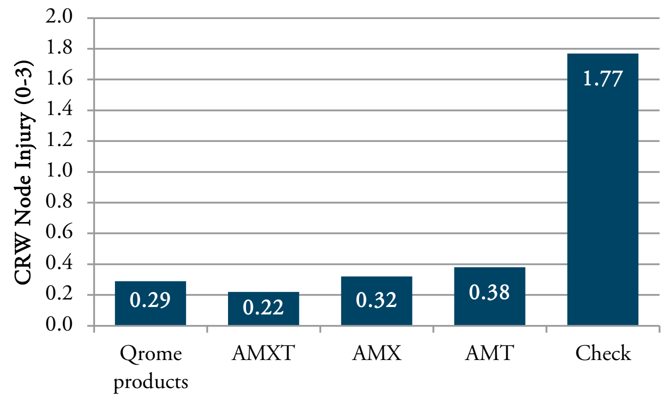


Figure 1. Average CRW node injury by insect protection technology at moderate and high CRW pressure locations, 2013-2015. N = 14 locations with ~1000 observations/treatment.

See your local Pioneer sales representative to better understand which products make sense on your farm.

A decrease of susceptibility to certain technology traits in corn has been observed in some CRW populations, which may result in lower efficacy than depicted in this chart. Please contact your authorized Pioneer sales representative or consult with your local University Extension for more information regarding insect resistance management guidelines, best management practices, and to understand whether there has been insect resistance documented in your area.

Oleson, J.D., Y. Park, T.M. Nowatzki, and J.J. Tollefson. 2005. Node-injury scale to evaluate root injury by corn rootworms (Coleoptera: Chrysomelidae) *J. Econ Entomol.* 98(1): 1-8).

Authors: Murt McLeod, Steven Paszkiewicz, and Mark Jeschke

return to table of contents

Performance of PPST 250 plus DuPont™ Lumivia™ Insecticide Seed Treatment in Corn — 2014

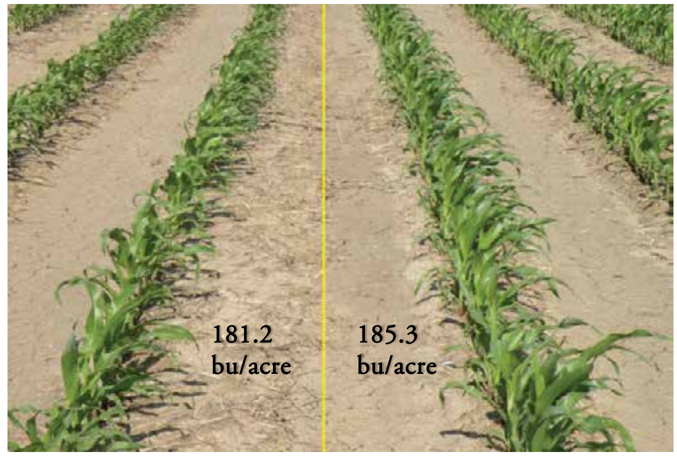
Objective

- Evaluate performance of PPST 250 plus DuPont™ Lumivia™ insecticide seed treatment in corn

Study Description

- **PPST 250 plus Lumivia insecticide** is a combination of the standard PPST 250 corn seed treatment (4 fungicides & Cruiser® 250 insecticide) with the addition of the new insecticide seed treatment DuPont Lumivia (0.25 mg ai/seed), which contains the active ingredient chloranthraniliprole.
- **PPST 250 plus Lumivia insecticide** provides enhanced activity against a broad spectrum of early-season insect pests in corn including wireworm, black cutworm, fall armyworm, white grub and seedcorn maggot.

Treatments:	PPST 250 PPST 250 plus Lumivia insecticide
Years:	2013 & 2014
Locations:	160 agronomy research and on-farm trials
Plots:	Agronomy research: 8 rows by 40 ft On-farm: 3+ acres/treatment
Hybrids:	1 hybrid per location (2 to 3 adapted hybrids per region across trials)



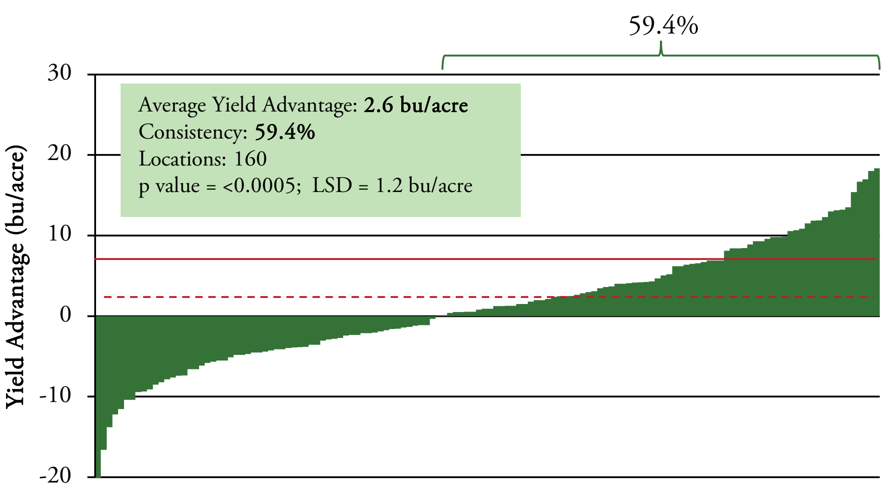
Side by side comparison of PPST 250 (left) vs. PPST 250 plus Lumivia insecticide (right) in a 2014 Pioneer® GrowingPoint® agronomy research trial (Leland, MS; 4.1 bu/acre advantage).

- **PPST 250 plus Lumivia insecticide performance in 2013 & 2014 trials:**

  At some locations PPST 250 plus Lumivia insecticide provided enhanced early growth compared to PPST 250, however plant stands and early-growth were generally similar when averaged across all locations.

Results

Yield Advantage of PPST 250 plus Lumivia insecticide over PPST 250 in 2013 & 2014 Pioneer Research & On-Farm Trials



- **2013 & 2014 agronomy research and on-farm locations (160 Locations):**
  - Across all locations, PPST 250 plus Lumivia insecticide showed an average yield advantage of 2.6 bu/acre (yield increase at 59.4% of locations) over PPST 250 alone.
  - In responsive locations (95/160 locations) PPST 250 plus Lumivia insecticide showed an average yield advantage of 8.1 bu/acre.

2013-2014 data are based on average of all comparisons made in 160 locations through Nov. 30, 2014. Multi-year and multi-location is a better predictor of future performance. Do not use these or any other data from a limited number of trials as a significant factor in product selection. The foregoing is provided for informational use only. Please contact your Pioneer sales professional for information and suggestions specific to your operation. Product performance is variable and depends on many factors such as moisture and heat stress, soil type, management practices and environmental stress as well as disease and pest pressures. Individual results may vary.

NORTHERN LEAF BLIGHT RACE SHIFTS

DISEASE DEVELOPMENT AND SYMPTOMS

Northern corn leaf blight (NLB) is caused by the fungus *Exserohilum turcicum*, also known as *Setosphaeria turcica* and previously known as *Helminthosporium turcicum* (Figure 1). The disease organism overwinters as mycelia and conidia in diseased corn leaves, husks, and other plant parts (Figure 2). Spores are produced on this crop residue when environmental conditions become favorable in spring and early summer. These spores are spread by rain splash and air currents to the leaves of new crop plants, where primary infections are produced. Infection occurs when free water is present on the leaf surface for 6 to 18 hours and temperatures are 65 to 80° F.

Figure 1. NLB symptoms on leaf of susceptible corn hybrid.

Secondary spread occurs from plant to plant and field to field as spores are carried long distances by the wind. Infections generally begin on lower leaves and then progress up the plant. However, in severe NLB outbreak years (that have high spore levels), infections may begin in the upper plant canopy. This can occur when weather systems deposit spores from southern growing areas, such as Mexico and the Caribbean. In recent years, weather patterns with large storms moving from south to north over the North American continent have spread the NLB organism into additional northern regions.

Heavy dews, frequent light showers, high humidity, and moderate temperatures favor the spread of NLB. Development of disease lesions on the ear leaf or above and significant loss of green leaf area can result in yield loss.

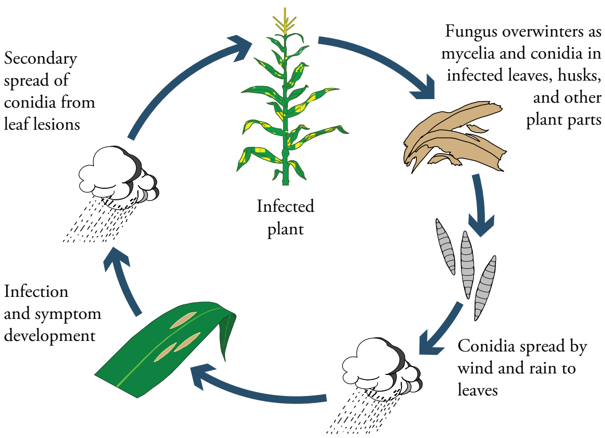


Figure 2. NLB disease cycle.

RACES OF NLB

There are multiple races of *Setosphaeria turcica* documented in North America; Race 0, Race 1, and Race 23N are the most prevalent. Ferguson and Carson (2007) reported a survey of NLB races that indicated that frequency of Race 0 isolates decreased from 83% in 1974 to 50% in the 1990s. During this same period, Race 1 isolate frequency increased. Low levels of Race 23 and 23N were present throughout the 20-plus years. The authors attribute the decrease in Race 0 frequency to the widespread use of the Ht1 gene, which has provided control of Race 0 but not of Race 1, by the sweet corn and hybrid corn industries.

The resistance genes available to corn breeders are named "Ht" based on the previous NLB fungal name *(H)elminthosporium (t) urcicum*. The common sources of resistant Ht genes are dominant genes and provide resistance to the various key races of *Exserohilum turcicum (Et)* as shown in Table 1.

Table 1. Common sources of resistance Ht genes.

Pathogen	Host (Ht) Reaction to Each Race			
Et Race Designation	Ht1 Gene	Ht2 Gene	Ht3 Gene	HtN Gene
0	R	R	R	R
1	S	R	R	R
2	R	S	R	R
12	S	S	R	R
23	R	S	S	R
23N	R	S	S	S
123N	S	S	S	S

DuPont Pioneer Breeders Target Multiple NLB Races

To provide disease resistance to NLB when multiple races might be present, two or more Ht genes may be needed. For example, a combination of Ht1 and Ht2 genes would provide resistance to Races 0, 1, and 23N, the predominant races of NLB in the U.S. and Canada. Because of these multiple races of NLB, DuPont Pioneer breeders are incorporating additional Ht genes in their hybrid development programs (i.e., a "multigenic" approach). Resistant phenotype and inheritance of NLB resistance genes are shown below (Table 2).

Table 2. "Ht" resistance genes (Welz and Geirger, 2000).

Gene	Resistant Phenotype	Inheritance
Ht1	Chlorosis	Dominant
Ht2	Chlorosis	Dominant, suppressed by sht1 gene[1]
Ht3	Chlorosis	Dominant
Ht4	Chlorosis halo	Recessive
Htn1	Latent period prolonged	Dominant
Htm1	Complete resistance	Dominant
NN	Complete resistance	Dominant

[1]sht1 is a dominant inhibitor of Ht2, Ht3, and Htn1 (but not of Ht1) in some parent lines.

The resistant phenotype, which appears with Ht1, Ht2, and Ht3 genes, is tissue chlorosis, where normal green color begins to change to a yellow hue in leaf lesions (Figure 3, left). These NLB lesions are slower to develop, and there are fewer spores produced per lesion.

With the Ht4 gene, a chlorotic "halo" appears around the lesions, which are somewhat smaller in size and fewer in frequency.

The Htn1 gene prolongs the latent period before lesions occur; fewer and smaller lesions develop with fewer spores produced per lesion. The plant is able to maintain its health longer even with the disease organism present (Figure 3, right).

The Htm1 and NN genes provide complete resistance, and minimal lesions are noted in plants with these genes present.

Susceptible and resistant reactions are shown in Figures 4-6.

Figure 3. *Left:* Ht1 "chlorotic" reaction – slower to develop and fewer spores produced per lesion. *Right:* HtN type reaction – fewer, smaller lesions develop and fewer spores produced per lesion.

Figure 4. Susceptible response, early lesions. Plant has no resistance, but lesions have not had time to fully develop.

Figure 5. Susceptible response, later lesions. With time, lesions have expanded to form large areas of necrotic tissue. Entire leaves may eventually become necrotic.

Figure 6. Resistant response. Note chlorotic halo surrounding lesions and restricted development of lesions, indicative of resistant response.

EVALUATION AND CHARACTERIZATION OF CORN HYBRIDS FOR NLB REACTION

DuPont Pioneer evaluates corn hybrids in multiple environments to observe their reaction to NLB infection. Inoculated plots as well as "natural infection" sites are used to establish disease pressure. Both basic research trials (small-plots) and advanced testing trials (larger IMPACT™ plots) are used for this hybrid characterization process. Use of numerous widespread locations, including those with a history of extreme NLB incidence, helps ensure that some environments will provide severe NLB pressure to challenge even the best hybrids. It also helps provide exposure of hybrids to as many race variants of NLB as possible. The critical time for evaluating disease damage begins in the early reproductive stages of development.

The DuPont Pioneer 1 to 9 NLB scoring system is based on "leaf loss" from the disease. A score of "9" indicates no leaf loss, and a score of "1" denotes 95% leaf loss in the presence of the disease (Figure 7). In determining overall hybrid ratings, experimental hybrids are compared to hybrids of "known" response to NLB. This provides a "relative" rating system in which new hybrids are characterized as accurately as possible relative to established hybrids that are more familiar in the marketplace.

Score = 2 80% leaf loss	Score = 5 35% leaf loss	Score = 8 5% leaf loss

Figure 7. Illustration of DuPont Pioneer scoring system for NLB.

When photosynthesis is limited by loss of green leaf area due to disease lesions, corn plants remobilize stalk carbohydrates to developing ears. When this occurs, stalk quality is reduced, often resulting in harvest losses. Hybrids with higher leaf disease scores tend to maintain leaf health and overall plant health longer into the grain filling period. This maintenance of plant health results in higher yields, better stalk standability, and increased grain harvestability.

MANAGING NLB IN CORN PRODUCTION

Effective management practices that reduce the impact of NLB include selecting resistant hybrids, reducing corn residue, timely planting, and applying foliar fungicides.

Resistant Hybrids

Selection of resistant hybrids based on disease reaction characterization scores is an important first step in managing this disease. The Pioneer NLB rating reflects the hybrids' expected performance against the major NLB races predominant in your area. As race shifts inevitably occur, continued testing by DuPont Pioneer researchers may result in a rating adjustment for some hybrids. Use of multigenic resistance by breeders increases hybrid stability as NLB races shift over time.

Hybrids should be selected based on all important traits needed for a field. In addition to NLB resistance, select hybrids with high yield potential, appropriate insect resistance traits, suitable (usually full-season) maturity for the area, and consistent performance demonstrated through data from multiple locations and years. Strong emergence, stalk strength, and drought tolerance are other agronomic characteristics to consider to help optimize stands and harvestable grain yields.

Reducing Previous Corn Residue

Reducing corn residue decreases the amount of NLB inoculum available to infect the subsequent crop. Crop rotation is one effective method of reducing residue. In addition, any form of tillage that places soil in contact with corn residue promotes decomposition and decreases the amount of residue that survives to the subsequent cropping season. Stover harvest for cellulosic ethanol production or animal feed is another means to reduce corn residue and disease inoculum. However, reducing corn residue does not protect against spore showers carried into a field on wind currents.

Timely Planting

Timely planting can often help hybrids escape the most severe damage from NLB if crop development outpaces normal disease progression. The latest-planted corn in an area may be infected when plants are smaller, resulting in the disease progressing more rapidly relative to the crop. However, in cases of high disease incidence, both early- and late-planted corn may be severely damaged.

Fungicide Application

Various foliar fungicides are available to help control or suppress NLB development (Table 3). Though fungicides are routinely used by growers to protect against several common leaf diseases, NLB may not always be controlled as completely as some other diseases. This is due to the more rapid life cycle of NLB, which may be as short as one week under favorable conditions. Because NLB sporulates so rapidly, it is more difficult to time a single fungicide application. Consequently, selecting resistant hybrids is a crucial first step in managing NLB where incidence is historically high.

Decisions to use a fungicide must be based on the disease risk factors of the field, including hybrid susceptibility, cropping sequence, tillage system, location, disease history, yield potential, the price of corn, and expected weather during reproductive development. In fact, weather conditions anticipated during ear fill are a primary factor for disease development and often have the most impact (along with hybrid disease rating) on the profitability of fungicide applications.

Survey results from 374 on-farm trials where previous crop and tillage practices were reported showed an inverse relationship between tillage intensity and yield response to foliar fungicide application in both corn following corn and corn following soybean (Figure 8). These results indicate that rotation and tillage have a positive impact on reducing disease pressure.

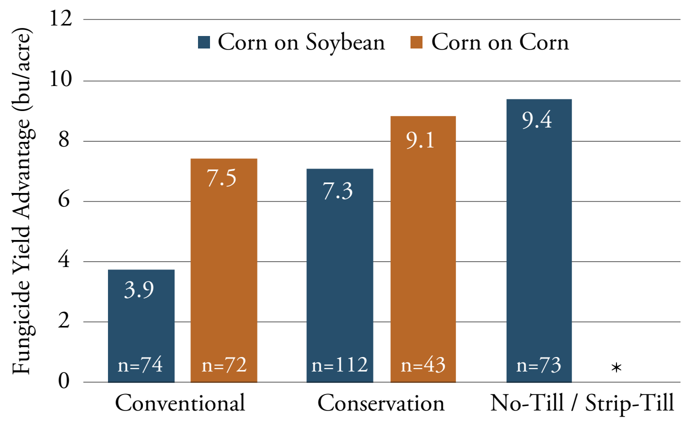


Figure 8. Average yield response to foliar fungicide application as influenced by tillage and previous crop in 374 on-farm trials from 2007-2014 (Jeschke, 2015).[a] n = number of locations, * = insufficient data.

Other studies (results not shown) show a similar relationship between hybrid disease rating and yield response to fungicides; the more resistant the hybrid, the less advantage achieved by fungicide application. Hybrids with a score of "6" or greater often show little or no economic benefit from a fungicide application under moderate infestation levels. Fungicides for NLB management are shown in Table 3.

Table 3. Corn foliar fungicides and efficacy against NLB. [a, b] Adapted from Wise (2015).

Fungicide[c] / Company	Active Ingredients	Chemical Group	NLB Efficacy
Aproach® *DuPont*	picoxystrobin	methoxy-acrylates	very good
Aproach Prima *DuPont*	picoxystrobin + cyproconazole	methoxy-acrylates & triazoles	very good
Domark® *Valent*	tetraconazole	triazoles	no data
Headline® AMP *BASF*	pyraclostrobin + metconazole	methoxy-carbamates & triazoles	very good
Headline® EC Headline® SC *BASF*	pyraclostrobin	methoxy-carbamates	very good
Quadris® *Syngenta*	azoxystrobin	methoxy-acrylates	good
Quilt® Quilt® Xcel *Syngenta*	propiconazole & azoxystrobin	triazoles & methoxy-acrylates	very good
Stratego® YLD *Bayer*	prothioconazole &trifloxystrobin	triazoles & oximino-acetates	very good
Tilt® *Syngenta*	propiconazole	triazoles	good

[a] Fungicide performance is variable and subject to a variety of environmental and disease pressures. Individual results may vary.

[b] Always read and follow all label directions and precautions for use when applying fungicides. Labels contain important precautions, directions for use and product warranty and liability limitations that must be read before using the product.

[c] Mention of a product does not imply a recommendation.

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return to table of contents

MAXIMIZING THE VALUE OF FOLIAR FUNGICIDES IN CORN

Over the span of only a few years, foliar fungicide treatments have progressed from a mostly new and untested practice to a trusted component of many growers' management systems. This has occurred as research results and grower experience have demonstrated that fungicides can be very effective tools for managing foliar diseases and protecting yield in corn. However, studies have also shown that fungicide applications do not always result in an economic benefit for growers. Extensive DuPont Pioneer research conducted over the last eight years has demonstrated that the value of fungicide applications depends on disease pressure, hybrid susceptibility, previous crop, and tillage.

This article summarizes the key findings of three major foliar fungicide research projects conducted between 2007 and 2014. These studies involved several different foliar fungicide products and included both aerial and ground applications, but all were focused on application timings between tasseling and brown silk (VT – R2).

- On-farm fungicide trial survey: Survey of on-farm foliar fungicide side-by-side trials conducted between 2007 and 2014.
- Pioneer small-plot research: 2009 study conducted to identify factors influencing yield response of multiple hybrids to foliar fungicide application across several Midwestern sites.
- University of Tennessee/Pioneer small-plot research: 2006 to 2008 study comparing foliar fungicide response among hybrids with differing levels of genetic resistance to gray leaf spot at a site chosen specifically due to its history of high GLS pressure.

YIELD RESPONSE TO FUNGICIDE TREATMENT

Between 2007 and 2014, DuPont Pioneer researchers conducted a total of 780 on-farm fungicide trials comparing yield and moisture of non-treated corn to corn treated with a foliar fungicide between tasseling and brown silk. Across these trials, the average yield response to fungicide application was an increase of 6.9 bu/acre (Figure 1).

A positive yield response to fungicide application occurred in 80% of the trials. Yield response varied widely among many of the trials, as was expected given differences in weather conditions, disease pressure, and trial locations.

Pioneer small-plot research found similar results, with an average yield response to fungicide treatment of 8.9 bu/acre across 10 research locations in 2009 (Table 1). Average yield response varied among locations, ranging from 0.6 to 22.6 bu/acre, largely due to differences in disease pressure.

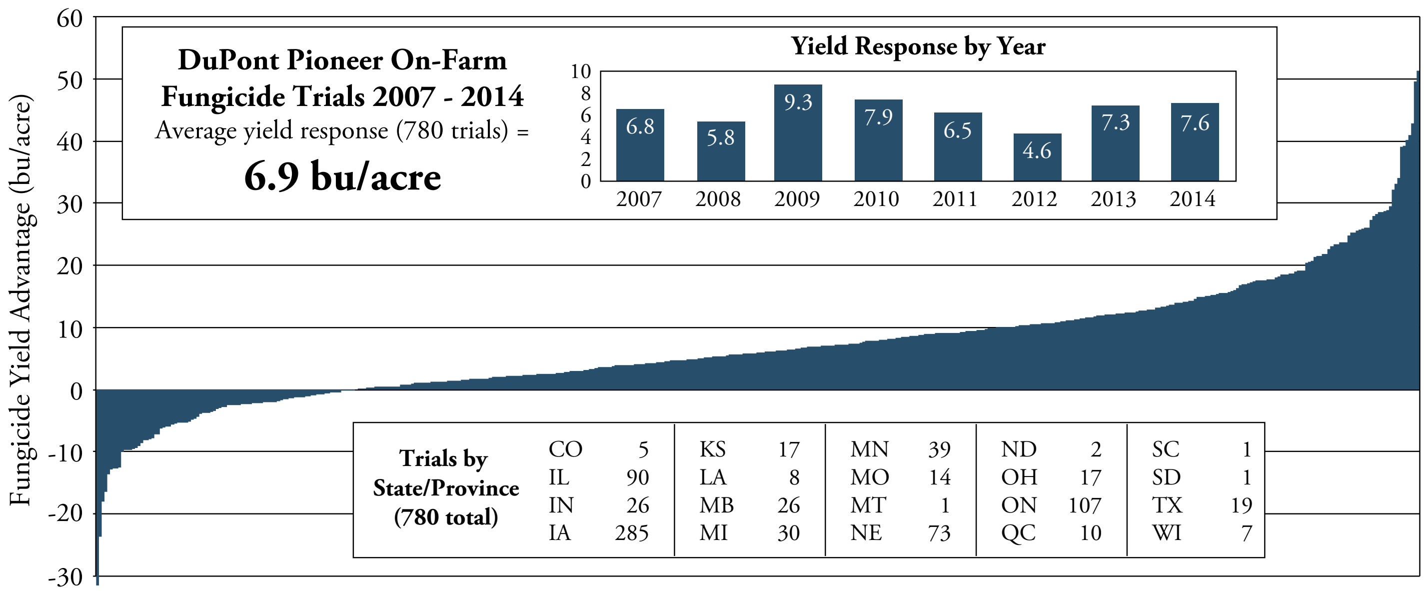


Figure 1. Corn yield response to foliar fungicide application in 780 DuPont Pioneer on-farm trials conducted from 2007 - 2014.

Table 1. Average corn yield response to foliar fungicide treatment at Pioneer small-plot research locations.

Location	Previous Crop	Tillage	Yield Response
			bu/acre
Mankato, MN	Soybean	Conv.	6.4
Waltham, MN	Soybean	Conv.	4.6
Janesville, WI	Soybean	Conv.	0.6
Minburn, IA	Corn	Strip	10.6
Breda, IA	Corn	Conv.	11.5
Alleman, IA	Soybean	Strip	8.0
Seymour, IL	Soybean	Conv.	11.8
Macomb, IL	Soybean	Conv.	7.1
Windfall, IN	Corn	Conv.	5.8
Gwynneville, IN	Soybean	No-Till	22.6
Average			**8.9**

The economic viability of a fungicide application can vary greatly according to the price of corn and cost of the fungicide and application. Higher corn prices and lower treatment costs reduce the break-even yield response, while lower corn prices and higher costs increase it (Table 2).

Table 2. Yield response necessary to cover the cost of fungicide and application over a range of costs and corn prices.

Fungicide + Application Cost/Acre	Corn Price/Bu					
	$3	$4	$5	$6	$7	$8
	----------------- bu/acre -----------------					
$22	7.3	5.5	4.4	3.7	3.1	2.8
$24	8.0	6.0	4.8	4.0	3.4	3.0
$26	8.7	6.5	5.2	4.3	3.7	3.3
$28	9.3	7.0	5.6	4.7	4.0	3.5
$30	10.0	7.5	6.0	5.0	4.3	3.8
$32	10.7	8.0	6.4	5.3	4.6	4.0

At a break-even yield response of 4 bu/acre, 60% of the DuPont Pioneer on-farm trials conducted over 8 years would have seen an economic benefit from fungicide application (Figure 1). However, at a break-even point of 7 bu/acre, the success rate drops to only 45%.

FACTORS INFLUENCING YIELD RESPONSE

Disease Pressure

Pioneer research has shown that one of the most important factors determining the value of a foliar fungicide application is disease pressure. Foliar diseases can occur anywhere corn is grown in North America but are more common in the warmer, more humid growing areas of the South and East. Most widely grown hybrids have at least moderate resistance to the major leaf diseases, which may be sufficient protection against low to moderate disease pressure. However, in years when weather conditions are very conducive for disease, a fungicide application can provide a substantial economic benefit.

There are two basic types of disease cycles among the fungal diseases that infect corn leaves. Most of the pathogens, such as northern leaf blight, overwinter in diseased corn leaves, husks, and other plant parts. Spores are produced on this crop residue when environmental conditions become favorable in the spring and early summer. These spores are spread by rain splash and air currents to the leaves of new crop plants, where primary infections are produced. Secondary spread then occurs from plant to plant and even from field to field as spores are carried long distances by the wind. As the plants die, the fungi remain in the dead plant tissue.

The rust diseases have a different cycle because they do not overwinter in crop residue and cannot survive the winters throughout much of the Corn Belt. Instead, disease starts in corn fields in the Southern United States, and spores are windblown long distances into the Corn Belt. Disease onset depends on weather systems that carry the spores northward combined with favorable conditions for infection. Secondary spread occurs similarly to the other leaf diseases.

Foliar infections can occur at any growth stage, and the earlier lesions develop, the more leaf area is reduced and the more damage results. However, plants are generally more susceptible to infection after silking. Damage may include yield losses due to decreased photosynthesis and harvest losses if secondary stalk rot infection and stalk lodging accompany loss of leaf area.

Figure 2. A hybrid susceptible to common rust (3 on a 1-9 scale) treated with a fungicide (left) compared to the same hybrid, non-treated, showing severe common rust symptoms (right). As expected, yield was greatly improved by the fungicide application due to high disease pressure at this DuPont Pioneer research study near Seymour, IL.

DuPont Pioneer small-plot research trials conducted in 2009 demonstrated the degree to which yield response to foliar fungicides can vary due to differences in disease pressure. The wide variation in yield response to fungicide application among locations was largely attributable to differences in common rust pressure. Common rust was prevalent at several Iowa, Illinois, and Indiana locations in 2009. Average yield response across locations in these states was 11.4 bu/acre (Table 1). Conversely, average yield response at Minnesota and Wisconsin locations where common rust was less prevalent was only 3.9 bu/acre. At sites with high common rust pressure, yield response to foliar fungicide application was greatest among hybrids with a low level of genetic resistance to the disease (Figure 2).

Pioneer on-farm research trials conducted in Iowa from 2007 to 2014 demonstrated the extent to which corn yield response to foliar fungicides can vary year to year due to weather conditions. Disease pressure is generally lower under drought conditions, as development and spread of several common foliar diseases is favored by moisture and humidity. 2011 and 2012 were both abnormally dry years in Iowa, whereas 2007 to 2010, 2013, and 2014 all experienced normal to above-normal precipitation in most parts of the state. The average yield response to foliar fungicides in on-farm trials conducted during the two drought years of 2011 and 2012 was well below the average response observed in years with greater precipitation (Figure 3).

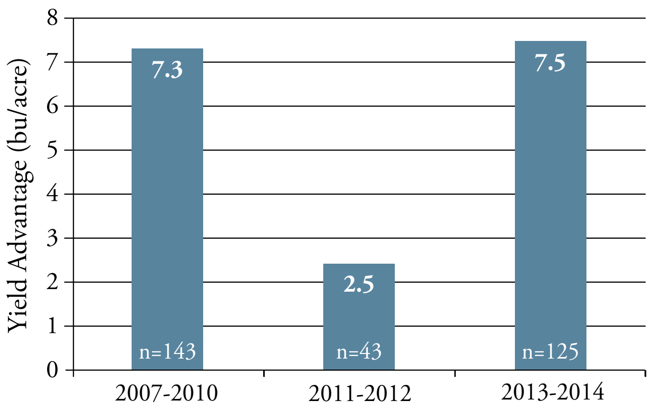


Figure 3. Average corn yield response to foliar fungicides in Iowa on-farm trials in drought years (2011-2012) compared to years with normal or above-normal precipitation (2007-2010 and 2013-2014).

Hybrid Disease Susceptibility

In Pioneer and university studies with multiple hybrids of varying disease resistance, the probability of using a fungicide profitably has often been directly related to the susceptibility of a hybrid to the predominant leaf diseases. Pioneer® brand hybrids are rated on a scale of 1 to 9 for their level of genetic resistance to major foliar diseases, with 1 to 3 indicating a susceptible hybrid, 4 to 5 moderately resistant, 6 to 7 resistant, and 8 to 9 highly resistant. In cases where a foliar disease is not severe, a foliar fungicide application may not provide an economic benefit with a resistant or highly resistant hybrid. Hybrids that are susceptible to a common foliar disease are more likely to benefit from a fungicide application and should be monitored for disease symptoms, particularly when weather conditions are favorable for disease development.

Corn leaf showing symptoms of gray leaf spot.

A research project was conducted over three years at the University of Tennessee Research and Education Center at Milan. The primary goal of this study was to determine the yield benefit associated with foliar fungicide management of gray leaf spot in hybrids with differing levels of genetic resistance. The research site was specifically chosen due to a history of high gray leaf spot pressure. The plot area was in irrigated no-till corn production for four years prior to the start of the study, with a high level of gray leaf spot each year. Three Pioneer brand corn hybrids with differing levels of resistance to gray leaf spot were included in the study (Table 3).

Table 3. Gray leaf spot resistance ratings of Pioneer® brand hybrids used in a 3-year foliar fungicide study at the University of Tennessee.

Hybrid	Hybrid GLS Resistance	GLS Rating*
1	Susceptible	3
2	Moderately Resistant	5
3	Resistant	7

** See GLS CI (2009).*

Results of the study demonstrated the potential for gray leaf spot to cause substantial reductions in yield when disease pressure is very high. Hybrid resistance was effective in mitigating a large portion of yield loss due to gray leaf spot; however, even with the most resistant hybrid, the yield benefit of the foliar fungicide application was great enough to likely cover the cost of product and application (Figure 4). Under more moderate disease pressure, a fungicide application would likely not provide an economic benefit on a resistant hybrid.

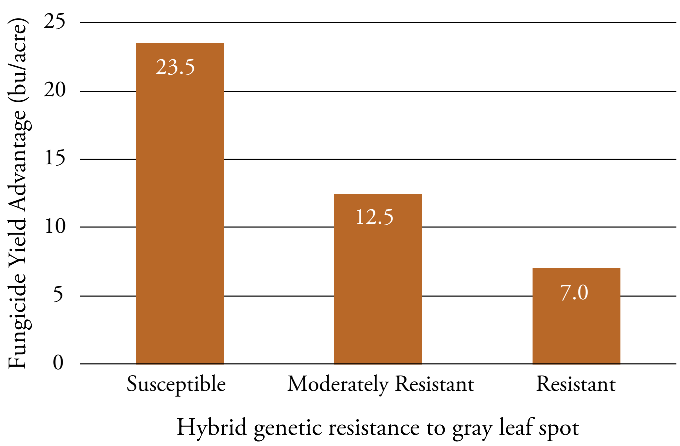


Figure 4. Average yield increase of hybrids susceptible, moderately resistant, and resistant to gray leaf spot due to foliar fungicide application in a 3-year University of Tennessee/DuPont Pioneer research study.

Another example is the small-plot study described previously where common rust was prevalent at some of the locations. Yield response to foliar fungicide application in this study was greatly influenced by genetic resistance of hybrids to this disease. Among locations with high common rust severity in Illinois and Indiana, yield response to fungicide application was much greater for susceptible hybrids compared to hybrids with a moderate level of resistance (Figure 5). At Minnesota and Wisconsin sites with low common rust severity, a fungicide application could still have been profit-able on susceptible hybrids (depending on prices) but most likely would not have been profitable on moderately resistant hybrids.

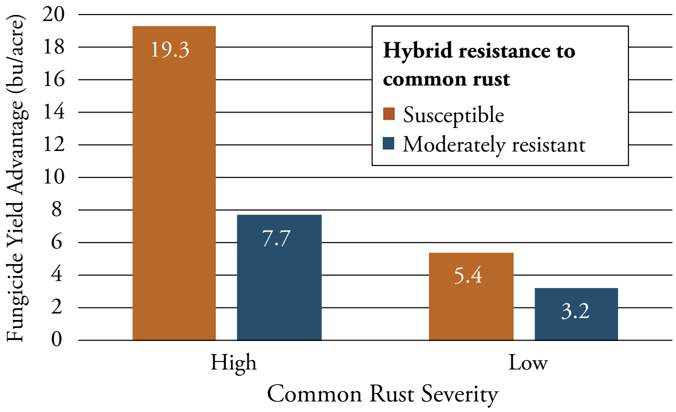
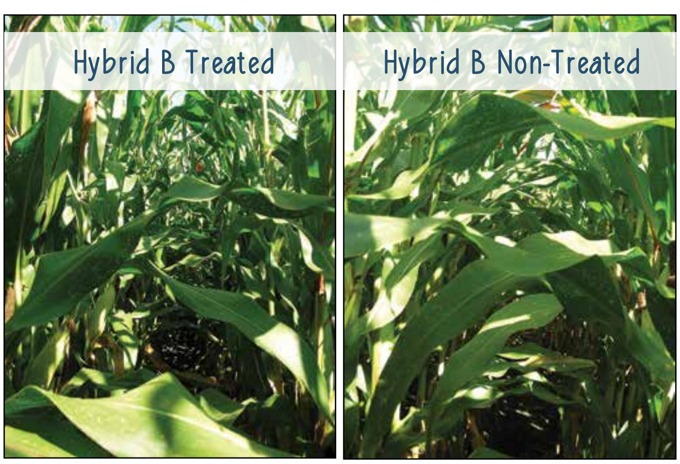


Figure 5. Average fungicide yield response of hybrids with low resistance (3 on a 1-9 scale) and moderate resistance (4-6) to common rust in DuPont Pioneer small-plot trials.

Common rust was prevalent at a trial at Macomb, IL, along with low to moderate levels of gray leaf spot and northern leaf blight. Notable differences in disease symptoms and yield response to fungicide were observed at this location (Figure 6). These research results from 2009 demonstrate the value of foliar fungicides in protecting yield when disease outbreaks occur; however, genetic resistance of hybrids may also provide adequate protection and should be considered in fungicide treatment decisions.

Figure 6. Two hybrids treated (left) and non-treated (right) with fungicide at Macomb, IL. The fungicide helped to protect yield in hybrid A (above) but provided little benefit on hybrid B (below), which had minimal disease.



Previous Crop and Tillage

Research results have clearly shown that corn-following-corn fields are at a higher risk and more likely to benefit from a fungicide application than corn-following-soybean fields. Survival of diseases in corn residue can lead to earlier infection and higher disease incidence and severity in the subsequent corn crop. Many common diseases, including gray leaf spot, northern leaf blight, southern leaf blight, eyespot, and northern leaf spot, overwinter in corn residue, providing a source of inoculum to infect corn planted the following season.

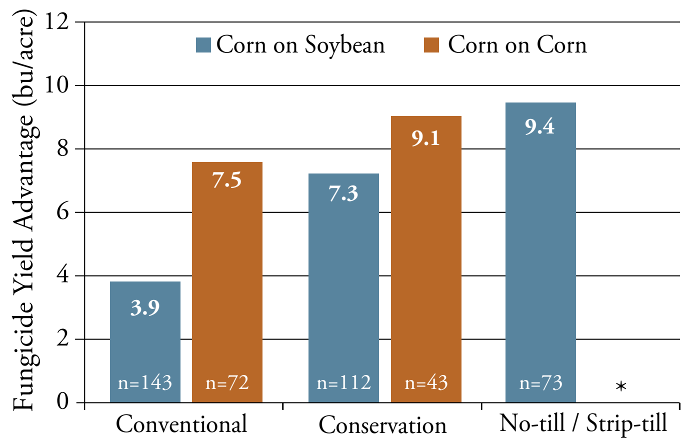


Figure 7. Average yield response to foliar fungicide application as influenced by tillage and previous crop in on-farm trials (374 trials, 2007 - 2014). n = number of locations, * = insufficient data.

Research studies have confirmed that tillage can influence disease pressure and potential benefits of fungicide application in much the same way as cropping sequence. By leaving more crop residue on the soil surface, conservation tillage and no-till can greatly increase the disease inoculum load.

Survey results from 374 on-farm trials where previous crop and tillage practices were reported showed an inverse relationship between tillage intensity and yield response to foliar fungicide application in both corn following corn and corn following soybean (Figure 7). Rotation away from corn to a different crop, such as soybean, is often recommended as a way to manage corn diseases by reducing inoculum levels. These results support that recommendation and indicate that rotation with soybean does have a positive impact on reducing disease pressure; however, residue levels still appear to have an impact on disease pressure in corn following soybean.

The 2009 DuPont Pioneer small-plot trials also included different cropping sequences and tillage practices among locations (Table 1). Average yield response to fungicide application tended to be higher among locations planted to corn the previous year and locations using no-till or strip-till practices; however, high yield response at some locations was driven primarily by common rust pressure. Common rust does not overwinter in crop residue so would not be affected by crop rotation or tillage practices.

OTHER CONSIDERATIONS

Grain Moisture

One concern with fungicide treatments in corn is the potential for increased grain moisture at harvest, resulting in higher drying costs. Observations have varied among university trials with some showing a small increase in moisture in treated versus non-treated corn and some showing no difference. Among Pioneer on-farm trials, grain moisture of fungicide-treated corn was only slightly higher (+0.3 points) than non-treated corn. This difference was not greatly affected by overall moisture level at harvest. In trials where harvest moisture of the non-treated corn was greater than 25%, treated corn averaged 0.36 points wetter.

One possible reason a fungicide application could increase grain moisture at harvest is that disease pressure in the non-treated corn was severe enough to cause premature death of the plant. In such a case, the increase in moisture would probably be accompanied by an increase in yield, which may more than offset any additional drying costs.

There is some evidence of this trend among the Pioneer on-farm trials. Among those trials in which the harvest moisture of the treated corn and non-treated corn was similar (treated corn 0 to 0.3 points wetter), the average yield response to fungicide application was 5.9 bu/acre. In trials where the treated corn was more than 2.0 points wetter, the fungicide yield advantage was 8.8 bu/acre. Finally, in the small number of trials where the treated corn was more than 2.5 points wetter, the average yield response was 14.3 bu/acre.

Hybrid Maturity and Planting Date

Hybrid maturity and planting date have also been found to influence susceptibility to yield loss from foliar diseases (data not shown). These factors are important relative to the timing of disease development. Later planted fields and/or later maturing hybrids can be more vulnerable to yield loss because they are still filling grain while disease development is peaking in late summer. Therefore, these later fields are often more likely to benefit from a fungicide application.

NEMATODE MANAGEMENT IN SOYBEANS AND CORN

Nematode activity in row crops varies throughout the northern Corn Belt. Nematode species can often affect multiple crop species with the exception of soybean cyst nematodes, which are restricted to feeding on soybeans, and needle nematodes, which affect corn. Several species, such as dagger, lesion, stunt, lance, stubby root, and root-knot nematodes, can damage both corn and soybeans. This article will discuss effects of nematodes in row crops, focusing on soybean cyst nematodes, as well as management options currently available.

INFECTION AND SYMPTOMS

Nematode species differ in how they infect the host plant. Certain species will invade the root tissue (endoparasites), whereas other species only feed on the external root tissue (ectoparasites). Both types of nematodes can damage crop plants by:

- taking nutrients
- interrupting root function (reducing moisture and nutrient uptake)
- providing an area for pathogen entry (e.g., sudden death syndrome) and increase in severity
- in soybeans, reducing the number and functionality of nodules
- diminishing growth

Though nematodes are relatively host specific, they can sustain on secondary hosts. Needle-nematodes generally use corn as the host; soybean cyst nematodes rely on soybeans (as well as other legumes like dry beans) as the host crop. However, populations can often maintain or increase slightly even when crop rotation is part of the management system. In addition to the various species of nematodes, there are often different biotypes within species.

It is important to sample for nematodes. Fred Warner, Michigan State University Nematologist, recommends sampling on a regular basis, similar to soil sampling. This will help to identify the issue before it becomes a significant factor to soybean yields.

SOYBEAN CYST NEMATODES

Soybean cyst nematodes (SCN) are a major soybean pest in the northern Corn Belt. Although common throughout the Corn Belt, SCN survive winters more readily than other nematode species that are common further south. SCN move through the roots to the vascular tissue where they start to feed on nutrients. The secretions that they inject as they feed modify the root cells, converting them to feeding sites. As they feed on the root, their body swells; females swell beyond the root tissue, making the cyst exposed on the surface of the root.

SCN Management

Nematologist Fred Warner states that the most serious error a soybean grower can make is planting an SCN-susceptible soybean variety in a field where a resistant variety should have been sown. That mistake can result in a 50% or greater yield loss. What complicates variety selection even further is that SCN exists as different "types" (formerly known as races). These different types

Figure 1. Soybean stunting and yellowing due to soybean cyst nematode feeding on the root tissue.

of SCN endure differently based on the type of soybean they use as a host.

SCN-resistant varieties are available for management of soybean cyst nematodes. There are two main sources of resistance available in the northern region, PI88788 and PI548402 (Peking). Other sources are available, though limited in top-yielding varieties. A test (HG-type-test) identifies how the type of SCN affects the different resistant varieties. In this test, the varieties are grown in the infected soil. The variety that has a 10% or more ***increase*** in population of SCN is then associated with the type (Table 1). For instance, if there is a 10% increase on just the variety with PI88788 resistance, the soil sample is given a "2" for type. This means that the population of soybean cyst nematode in the soil is something ***other than*** races 3 or 14 and will damage soybeans with PI88788 source of resistance. Therefore, the PI88788 ***should not*** be grown.

Table 1. Types of soybean cyst nematode resistance and associated types with variety recommendations.

Type of Resistance	SCN Races Managed	Use This Source For HG-type:	Brand/Varieties* to Use
PI88788	3, 14	0,1,3,4,5,6,7	P20T79R2, P15T46R2, P10T91R, P25T51R, P10T02R, P22T73R, P19T60R, P18T26R2
PI548502 (Peking)	1, 3, 5	0,2,3,4,5,6,7	P22T41R2, P22T69R

**All Pioneer products are varieties unless designated with LL, in which case some are brands.*

SCN Sampling

Sampling is the key to knowing the kind and race of nematodes that are present in production fields. According to nematologist Fred Warner, sampling is best done when soil temperatures are below 75° F. The sample should consist of soil cores taken throughout a field. Adequate soil is needed to identify and possibly type-test for the pest. A sample of two gallons of soil is needed to type-test for soybean cyst nematodes. Including an intact root for assessment of nematodes may be necessary depending on nematode populations. For the type-test, the process involves growing out soybean plants that are type-resistant varieties. The nematodes are allowed to feed and develop on these plants for 35 days. The roots are then scrubbed, releasing the females so they can be counted. Based on the results, recommendations regarding variety selection will be provided.

Though results may seem low, populations can maintain and increase on alternate hosts. Weeds can also host nematodes, allowing populations to increase. Sampling fields after harvest, especially those that have winter annual weeds (brought on by good growing conditions in the fall), can give a good indication of populations for the next season. This allows time for proper crop management.

NEMATODE MANAGEMENT

Management of nematodes is necessary for increasing grain production. There are additional options available today, including resistant soybean varieties and seed treatments for corn and soybeans. Sampling to know the presence and type of nematode is necessary for proper management. Rotation does help manage populations by not providing the pest with an optimum host, therefore limiting the population. In addition to rotation, understanding the type of nematodes that are present will help in selecting the best management practice. In the case of SCN, varietal selection is key to keeping all biotypes managed. Seed treatments, such as Poncho® 1250 + VOTiVO® for corn and Poncho®/VOTiVO® for soybeans, can allow for additional protection. VOTiVO employs a biological mode of action with a unique bacteria strain that lives and grows with young roots, creating a living barrier that prevents nematodes from causing damage. Using technologies and best management practices, such as sampling and rotation, will help keep nematode populations in check. Understanding the scope of nematode populations in a farm operation will provide another tool in protecting maximum yield potential.

Figure 2. Roots of a corn plant affected by corn nematodes. Symptoms of corn nematodes include root pruning, proliferation of fibrous roots, thickening or swelling of the smaller roots, and mild to severe discoloration.

Special acknowledgement to Dr. Fred Warner, Nematologist, Michigan State University.

Pioneer GrowingPoint
AGRONOMY RESEARCH UPDATE
DuPont Pioneer

Performance of Pioneer® Brand Soybeans with ILeVO® Fungicide Seed Treatment Against SDS

2015

Background and Objective

- **ILeVO® fungicide** (active ingredient: fluopyram) is a seed treatment that provides protection of soybean seedlings from *Fusarium virguliforme* infection, the causal agent of Sudden Death Syndrome (SDS).
- DuPont Pioneer soybean research trials were conducted in 2012, 2013, and 2014 to evaluate ILeVO fungicide seed treatment performance in soybeans across a broad range of environments (SDS and non-SDS locations).

May 2014, SDS location in Johnston, IA. Soybean seedlings commonly respond to ILeVO fungicide seed treatment by exhibiting discoloration or chlorosis along cotyledon margins. This discoloration is less-frequently seen past the cotyledon growth stage. The cotyledon discoloration is caused by the systemic movement of ILeVO fungicide seed treatment into the cotyledons.

Study Description

Years: 2012, 2013, & 2014

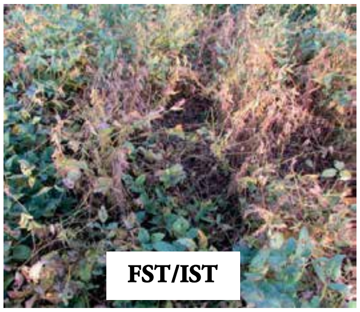
Locations: 80 (total)

Plot Design: Replicated small-plot research trials

Seed Treatment:

1. FST/IST (fungicide seed treatment/insecticide seed treatment)
2. FST/IST + ILeVO 600 FS @ 1.18 fl oz/140k unit

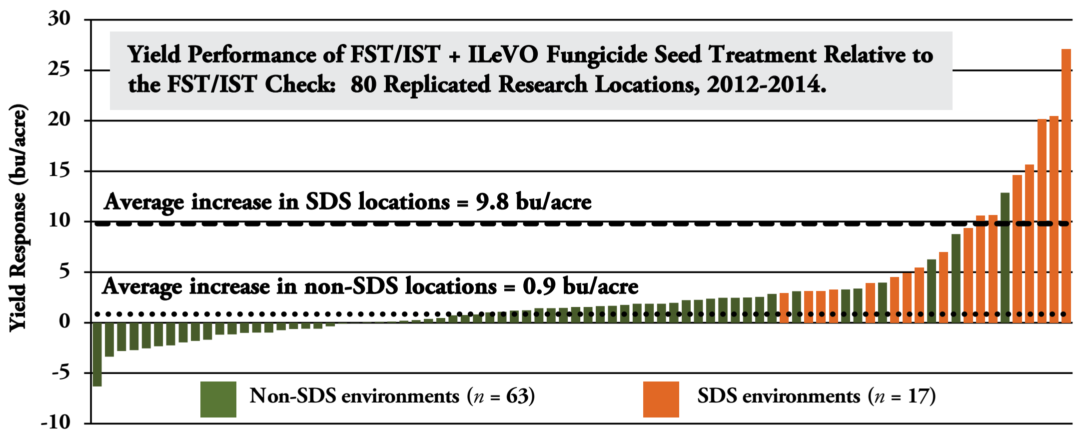
SDS: If late-season SDS symptomology was present then locations were characterized as SDS locations; if no SDS symptomology was present then locations were characterized as non-SDS locations.



August 2014, SDS location in Lawrence, KS. ILeVO fungicide activity against SDS in soybeans.

Results

- Over 3 years & 80 locations, the addition of ILeVO fungicide to the FST/IST check increased soybean grain yield 2.8 bu/acre (positive response at 73% of locations).
- The addition of ILeVO fungicide to the FST/IST check increased soybean yield by 0.9 bu/acre across non-SDS locations (n=63) and 9.8 bu/acre across the 17 SDS locations.



2012-2014 data are based on average of all comparisons made in 80 locations through Nov 1, 2014. Do not use these or any other data from a limited number of trials as a significant factor in product selection. The foregoing is provided for informational use only. Please contact your Pioneer sales professional for information and suggestions specific to your operation. Product performance is variable and depends on many factors such as moisture and heat stress, soil type, management practices and environmental stress as well as disease and pest pressures. Individual results may vary. Pioneer® brand products are provided subject to the terms and conditions of purchase which are part of the labeling and purchase documents.

SUDDEN DEATH SYNDROME OF SOYBEANS

Sudden death syndrome (SDS) of soybeans was first reported in Arkansas almost 40 years ago. Since then, it has spread from the mid-South Mississippi River basin to infect soybean fields in almost all soybean-growing U.S. states and Ontario, Canada. SDS favors poorly drained and/or compacted field areas that remain wet and seasons with high rainfall. SDS continues to spread to new fields and progressively larger areas of infected fields each year. In fact, plant pathologists in many states now rank this disease as second only to soybean cyst nematode (SCN) in economic losses caused to soybeans.

SDS is caused by a virulent strain of the common soil-inhabiting fungus *Fusarium virguliforme*. This root-rotting organism infects soybean plants very early in the growing season, often as early as germination to just after crop emergence. However, above-ground symptoms occur much later when the fungus produces a toxin that damages the leaves. This article will discuss the environmental conditions leading to SDS development, the symptoms it causes in soybeans, and the management strategies growers can use to limit its damage to the crop.

CONDITIONS FAVORING SDS DEVELOPMENT

Like other soil-borne root rots, SDS often appears first in certain spots in the field, such as low, poorly-drained or compacted areas. In some cases, severe SDS outbreaks can also occur on highly productive soils with high moisture-holding capacity. Because disease severity is highly dependent on environmental conditions, time of infection, and other stresses on the soybean crop, severity varies from year to year and within field areas. Higher incidence of SDS often occurs when soybeans have been exposed to cool, moist soil conditions early in the growing season. Early planting is, therefore, much more likely to predispose the crop to SDS.

Though SDS infects soybean plants just after germination and emergence, symptoms usually do not appear until the reproductive stages of crop development (typically mid-summer or later in the Midwest U.S.). The appearance of symptoms is often associated with weather patterns that bring cooler temperatures and significant rainfall to an area during flowering or pod-fill. First symptoms are often noticed about 10 to 14 days after heavy rains that saturate soils. Wet soils allow toxins to be produced by the fungus in the roots of the plant, which are then translocated to the leaves. These toxins are responsible for the striking foliar symptoms of SDS, even though the fungus itself remains in the roots and base of the stem and does not invade the leaves, flowers, pods, or seeds of the plant.

SDS symptoms are usually more severe if SCN is also problematic in the field. SCN increases the stress on the soybean plant and also provides wounds through which the SDS pathogen can enter the roots.

SDS LIFE CYCLE AND SYMPTOMS

The *Fusarium virguliforme* fungus that causes SDS survives in crop debris and as mycelia in the soil. The organism enters soybean roots early in the growing season. Root infection is facilitated by wounds from SCN, insect feeding, and mechanical injury. The fungus colonizes the soybean root system and has been isolated from both the taproots and lateral roots but is not found above the crown of the plant. A toxin produced by the fungus and translocated throughout the plant is responsible for above-ground symptoms.

Root and Stem Symptoms

SDS begins as a root disease that limits root development and deteriorates roots and nodules, resulting in reduced water and nutrient uptake by the plant. On severely infected plants, a blue coloration may be found on the outer surface of tap roots due to the large number of spores produced. However, these fungal colonies may not appear if the soil is too dry or too wet. Splitting the root reveals that the cortical cells have turned a milky gray-brown color while the inner core, or pith, remains white. The general discoloration of the outer cortex can extend several nodes into the stem, but its pith also remains white.

Figure 1. SDS-infected stem and root. Note blue mold at soil line.

Figure 2. Split soybean stem on top shows stem symptoms of SDS infection. Split stem on bottom is healthy.

Leaf Symptoms

Leaf symptoms of SDS first appear as yellow spots, usually on the upper leaves, in a mosaic pattern. The yellow spots coalesce to form chlorotic blotches between the leaf veins. As these chlorotic areas begin to die, the leaf symptoms become very distinct, with yellow and brown areas contrasted against a green midvein and green lateral veins. Rapid drying of necrotic areas can cause curling of affected leaves. Leaves drop from the plant prematurely, but leaf petioles remain firmly attached to the stem.

Whole-Plant Symptoms

As plants lose leaf area and roots deteriorate, yield components are affected. Flower and pod abortion are common, resulting in fewer pods and seeds produced. Seeds that do develop are usually smaller. Later-developing pods may not fill, or seeds may not mature. Because plants and pods dry down faster, harvest losses may also increase in SDS-infected plants. Severity of yield reduction is highly dependent on the growth stage of the soybean plant when infection and symptoms occurred.

In some cases, premature death of the entire plant can occur without the typical defoliation symptoms, as affected plants yellow and die gradually.

Distinguishing SDS from Other Diseases

Leaf symptoms of SDS are similar to both brown stem rot (BSR) and stem canker. However, there are several characteristics that readily differentiate these diseases. To distinguish SDS from the other two diseases, first examine the outside of the stem. If the outside of the stem has large brown-black sunken lesions, then it is likely stem canker. If no lesions are present, split the bottom eight inches of the soybean stalk. If SDS is the problem, the pith of the stem will be white, and the surrounding cortex will appear grayish-brown. In contrast, BSR will cause the pith to be dark brown while the cortex remains green.

MANAGEMENT OF SDS

Sudden death syndrome varies in severity from area to area and from field to field. Therefore, growers must clearly understand the extent of SDS infection in each of their fields to effectively manage the disease. This requires scouting fields when disease symptoms are present, ideally using GPS tools to map SDS-prone areas. Such maps could be overlaid with yield maps to reveal the extent of yield losses from SDS.

Once the scope of the problem is documented, a combination of crop management practices can help minimize the damage from SDS. These include selecting SDS-tolerant varieties, controlling SDS and SCN using effective seed treatments, planting the most problematic fields last, managing SCN, improving field drainage, reducing compaction, evaluating tillage systems, and reducing other stresses on the crop.

Foliar Fungicides Not Effective

Although foliar symptoms and defoliation are trademarks of SDS, the fungus itself does not spread to the leaves. Rather, the fungus produces toxins that are transported to the leaves, while the fungus only colonizes the roots and base of the stem. For this reason, foliar fungicides are not effective in reducing damage to soybeans from SDS.

Scouting Fields

Scouting for SDS involves identifying suspect plants based on leaf and whole plant symptoms and then looking closer at the stem and roots to distinguish SDS from other soybean diseases (see previous section on symptoms). SDS is evident from a considerable distance when full-blown above-ground symptoms develop. This usually occurs in August in the Midwest U.S.

Tolerant Soybean Varieties

Soybean varieties can show dramatic differences in tolerance to SDS infection with tolerance exhibited primarily as a reduction in symptom severity. For that reason, variety selection is a key management practice to reduce plant damage and yield loss due to SDS. To assist growers in choosing resistant varieties, DuPont Pioneer researchers rate products in multiple test sites with known historical SDS occurrence. These sites, located in three states where SDS is problematic, are irrigated and/or planted early to encourage SDS development. Tolerance data are collected and analyzed across years to determine the appropriate SDS tolerance score. Due to continued improvements in breeding for this trait, Pioneer now has varieties that score as high as "8" for SDS tolerance on a 1 to 9 scale (9 = most tolerant).

DuPont Pioneer research efforts are providing higher levels of tolerance to SDS in high-yielding, elite soybean varieties. Pioneer is leading the industry in developing proprietary marker-assisted selection processes to protect soybean yield from harmful pests. Providing multiple resistance traits in the same variety is especially important to manage SDS because both SDS tolerance and SCN resistance are frequently needed in the same product. See your DuPont Pioneer representative for information on tolerant varieties with top yield potential, SCN resistance, and other important traits for your area.

ILeVO® Fungicide Seed Treatment

ILeVO® fungicide (active ingredient: fluopyram) is a seed treatment that provides protection of soybean seedlings from *Fusarium virguliforme* infection, the causal agent of SDS. DuPont Pioneer soybean research trials were conducted in 2012, 2013, and 2014 to evaluate ILeVO fungicide seed treatment performance in soybeans across a broad range of environments. A total of 80 small-plot replicated research trials were conducted over 3 years comparing soybean yield performance with a standard fungicide and insecticide seed treatment (FST/IST) to FST/IST + ILeVO 600 FS (1.18 fl oz/140k unit). If late-season SDS symptomology was present, then locations were characterized as SDS locations; if no SDS symptomology was present, then locations were characterized as non-SDS locations.

Over 3 years and 80 locations, the addition of ILeVO fungicide to the FST/IST check increased soybean grain yield an average of 2.8 bu/acre. The addition of ILeVO fungicide to the FST/IST check increased soybean yield by 0.9 bu/acre across non-SDS locations (n=63) and 9.8 bu/acre across 17 SDS locations (Figure 3). ILeVO seed treatment also has activity against SCN in soybeans (data not shown).

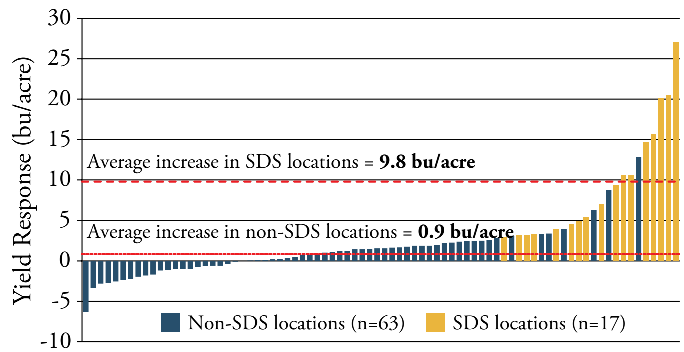


Figure 3. Yield performance of FST/IST + ILeVO® fungicide seed treatment relative to the FST/IST check (80 replicated research locations, 2012-2014).

Planting Sequence

Although many growers today are reluctant to delay planting when fields are ready, research has demonstrated later planting to be effective in reducing SDS occurrence. For this reason, growers should at least consider planting high-risk fields last in their planting sequence. If this delays planting for one or two weeks, the impact on SDS occurrence could be significant. In order to schedule planting in order of lowest to highest SDS risk, growers should have scouted and documented the extent of SDS infection in each of their fields.

Figure 4. Soybeans treated with FST/IST (left) and FST/IST + ILeVO® fungicide (right) at a research location with SDS near Lawrence, KS, in August 2014.

Managing Soybean Cyst Nematode (SCN)

SCN is a problem requiring management in many soybean fields that are also at risk to SDS. SCN increases the stress on the soybean plant and also provides wounds through which the SDS pathogen can enter the roots. Scientists have also discovered the SDS pathogen can be carried in SCN bodies. This means that managing SCN and limiting its stress on the soybean plant is critical to also limiting damage due to SDS.

Like SDS, SCN cannot be eradicated from an infested field. However, planting SCN-resistant varieties, use of seed treatments effective against SCN, rotating crops, and rotating sources of SCN resistance can reduce SCN populations in the field. Keeping SCN numbers below levels that will cause significant yield loss is the primary goal of SCN management. In addition, any practice that promotes good soybean health and growth will also help against SCN.

Improving Field Drainage and Reducing Compaction

Improving field drainage and reducing compaction go hand-in-hand as wet areas are easily compacted, and compacted areas stay wetter due to restricted soil drainage. Wet, compacted field areas fare badly in the presence of the SDS fungus. SDS infection is aided by high soil moisture conditions, and soybean roots already inhibited by compacted and saturated soils are further diminished by the disease.

When stress conditions develop on these fields, yields are often severely reduced due to a limited root system as well as the devastating effects of the SDS toxin on the plant. Growers should strive to improve field drainage and remediate compacted areas as a high priority to reduce the effects of SDS.

Evaluating Tillage Systems

A study conducted at the University of Missouri showed that no-till systems resulted in much higher percentages of SDS-infected leaves than disking or ridge-till with both May and June planting dates. High crop residue levels are known to result in colder, wetter seedbeds in the spring. In fields with high levels of SDS infection, growers may want to reevaluate the tillage system they are using.

Reducing Other Stresses

Other plant stresses can render soybeans more vulnerable to SDS attack. These include herbicide stress, nutrient deficiencies, high pH, and pest pressure. Maintaining adequate soil fertility; reducing compaction; and controlling weeds, diseases; and insects all improve soybean growth and plant health and enable the plants to better withstand the effects of SDS.

ANTHRACNOSE OF SOYBEAN

DISEASE FACTS

- Anthracnose is a fungal disease of soybean that occurs worldwide wherever soybean is grown.
- Anthracnose in soybean is primarily caused by the fungal species *Colletotrichum truncatum* in the Midwestern U.S. but may also be caused by several related species.
- *Colletotrichum* species that infect soybeans have a wide host range, including alfalfa, velvetleaf, and ragweed; however, anthracnose of corn is caused by a different pathogen.
- Anthracnose can infect stems, leaves, and pods of soybean and is generally present in soybean fields to some degree every season.
- Significant yield reductions are rare in the Midwestern U.S., but they are more common in the South.

DISEASE SYMPTOMS

- Soybeans are susceptible to infection at all stages of development. Plants and seed may be infected.
- If infected seed is planted, early disease development may result in damping off (seed or seedling rot causing plant death). Dark brown lesions develop on cotyledons, stem may collapse, and seedling may die under severe infection.
- Most commonly, however, plants become infected during bloom and podfill (reproductive stages) due to spores spread from infected plant residue.
  - » Symptoms appear on stems, pods, and leaf petioles as irregularly-shaped brown blotches.
  - » Severe symptoms may include leaf rolling, premature defoliation, and stunted plants. Pods may be shriveled and contain less seed, moldy seed, or no seed.
- In some cases, pods can be diseased, and the seed may be infected but without symptoms in the seed.

DISEASE LIFE CYCLE

- *Colletotrichum* species overwinter as mycelia on crop residue or infected seed.
- Infected seed can result in pre- and postemergence damping off.
- Spores from infected plant residue are distributed by wind and rain. Spores can infect soybean plants at any stage.
- Wet, warm weather favors the disease. Infection may occur when leaf wetness, rain, or dew periods exceed 12 hours/day.
- Leaf, stem, and pod infections generally develop later in the season.
- Black fungal fruiting bodies develop on infected tissue, generally when the soybean plants are near maturity.
- The disease survives on residue of plants and seeds to infect future crops.

return to table of contents

Figure 1. Anthracnose-infected soybean stem. Irregular, randomly distributed lesions are covered by small black dots, which are the fruiting bodies (acervuli) of the fungus. Tiny black spines (setae) may be evident when viewed with 10X magnification.

Photo by Jim Boersma, DuPont Pioneer Field Agronomist, 2012.

YIELD IMPACTS

- Under typical growing conditions, anthracnose is unlikely to cause significant yield reductions in the Midwestern U.S.
  - Yield impacts in the Southern U.S. are more common; anthracnose was determined to be 1 of the 10 most damaging diseases averaged over 15 southern states (Wrather and Koenning, 2006).
  - Anthracnose is favored by warm, humid, and wet environments and can cause severe yield reductions under these conditions.
- Infected pods generally contribute more to yield loss than infected stems or petioles. Infected pods may produce small seed or no seed at all.
- In addition to direct yield loss from infected pods and seeds, harvest losses can occur if plants lodge.

Figure 2. Soybean plants lodging due to anthracnose infection. Photo by Donald Specker, DuPont Pioneer Product Agronomist, 2004.

DISEASE MANAGEMENT

- Rotation to non-host crops is a proven strategy to reduce anthracnose inoculum in a field. As soybean residue breaks down over time, it deprives the pathogen of its survival host.
- Tillage that buries or shreds crop residue, enhancing its breakdown in the soil, is beneficial in reducing anthracnose inoculum in prior fields of soybeans or other host crops.

Figure 3. Soybean plant showing anthracnose stalk rot.

- Foliar fungicides applied between the R3 and R5 soybean growth stages can help suppress anthracnose and reduce seed infection.
- DuPont Pioneer offers producers high quality, disease-free seed, which enhances seed vigor and stand establishment.
  - This seed comes with several choices of Pioneer Premium Seed Treatment, including EverGol® Energy fungicide seed treatment.
  - EverGol® Energy fungicide seed treatment is a next-generation technology with multiple modes of action that provides enhanced protection against a broad spectrum of seed borne and soil borne diseases.
- A recent research study investigated soybean varieties' resistance to anthracnose (Yang and Hartman, 2015).
  - Results showed no significant differences among commercial varieties in resistance to this disease.
  - However, at least one source of soybean germplasm showed significantly better resistance; thus, genetic solutions may have potential in the future.

Figure 4. Soybean plant showing moderate symptoms of anthracnose on the stem. This level of infection would likely result in little or no yield loss due to the disease. Photo by Travis Kriegshauser, DuPont Pioneer Sr. Manager, Encirca Services, 2014.

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return to table of contents

SOYBEAN FUNGICIDE DECISION GUIDE

Scout for foliar diseases in soybeans just prior to R3, and answer the following questions when considering an application of foliar fungicide:

What Has The Weather Been Like?

- Rainy and/or humid weather is most favorable to foliar diseases.

How Susceptible is the Variety?

- The greater the disease resistance rating for a variety, the less likely a fungicide application will result in economic benefit.

Frogeye Leaf Spot

- Symptoms appear as light-gray centers surrounded by dark borders.
- Yield losses can reach 30% with a severe infection.
- Infection occurs when spores from infected residue are splashed onto the leaves.

Frogeye leaf spot

Septoria Brown Spot

- Disease starts in the lower canopy.
- Spots are small, dark brown and irregularly shaped.
- Warm, wet weather favors the development of the disease.

Septoria brown spot

Asian Soybean Rust

- Disease does not overwinter in the Midwest.
- Spores are carried by southern storms.
- Extended periods of cool, wet weather or high humidity favor the disease.

Asian soybean rust

Does the Field Have a History of Disease?

- Some field locations may have a history of greater foliar disease severity.
- River bottoms, low areas, or fields surrounded by trees may be more prone to foliar diseases.

What was the Previous Crop?

- Foliar pathogens survive on soybean stubble.
- Risk of foliar diseases increases when a field is planted with soybeans consecutive years.

- For best results, make a fungicide application to soybeans at growth stage R3 (pods are 3/16 inch long at one of the 4 uppermost nodes).
- A spray volume of at least 15 gallons/acre (for ground applications) will provide the best coverage.
- For aerial applications, use a volume of five gallons/acre.

Table 1. Average yield response to fungicide treatments evaluated in 2004 to 2008 DuPont Pioneer small-plot studies.

Fungicide Treatment/ Growth Stage	Years Tested	N	Yield Response (bu/acre)
Headline® *R1*	2007	40	2.3
Headline *R3*	2004-08	100	3.7
Quadris® *R3*	2004-08	100	2.9
Folicur® *R3*	2004-06	48	1.5
Headline *R5*	2004-06	48	2.7
Quadris *R5*	2004-06	48	1.6
Headline *R3 + R5*	2004-06	48	4.6

Table 2. Average yield response to fungicide treatments evaluated in 2007 to 2014 DuPont Pioneer on-farm trials.

Fungicide Treatment	Years Tested	N	Yield Response (bu/acre)
Headline	2007-11	109	2.6
DuPont™ Aproach®	2012-14	123	2.7

return to table of contents

AGRONOMY RESEARCH UPDATE

Soybean Yield Response to Nitrogen

2015

Rationale and Objective

- As higher soybean yields become more common due to improvements in genetics and management practices, nitrogen additions may be needed to maximize potential yields.
- A nitrogen "budget" developed from numerous research studies shows that soil and fixed nitrogen are generally sufficient to supply nitrogen needs at yields up to 60 bu/acre. As yields increase to 80 bu/acre and higher, a nitrogen deficit may result.
- An experiment was conducted in Johnston, IA in 2015 to evaluate yield response of two Pioneer® brand soybean varieties to nitrogen fertilizer applied at the R2 growth stage.

Soybean nitrogen fertility experiment at Johnston, IA prior to harvest (October 8, 2015).

Study Description

Location: Johnston, IA
Replicates: 5
Plot Layout: Small plots (10 x 17.4 ft.), RCBD
Row Width: 30 inches
Planting Date: June 1, 2015
Factors:

Pioneer® brand soybean varieties
Variety/Brand[1]: 93M11 (R), P25T51R

Nitrogen Rate: 0, 25, and 50 lbs/acre

- Nitrogen was hand-applied as ammonium nitrate at the R2 growth stage (full flowering).

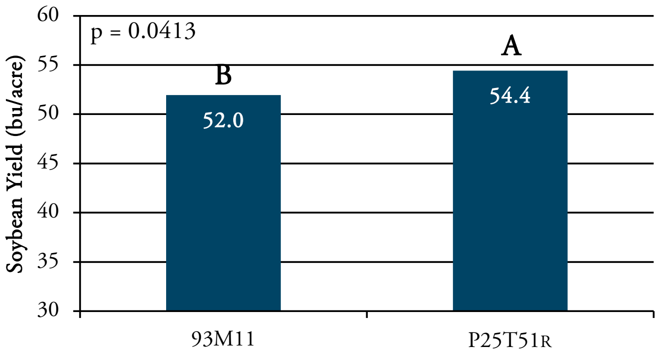


Figure 1. Average yield of Pioneer® variety 93M11 (R) and Pioneer® variety P25T51R.

Results

- The average yield of P25T51R was significantly greater (+2.4 bu/acre) than that of 93M11 (R) at α=0.05 (Figure 1).
- Application of 50 lbs/acre of nitrogen significantly increased average soybean yield relative to the non-treated check (+4.8 bu/acre) (Figure 2).
- No significant effect on soybean yield relative to the non-treated check was observed with the 25 lbs/acre nitrogen application.
- The yield effect of nitrogen treatment did not significantly differ between soybean varieties.
- It is notable that yield levels in this study were below the range where a nitrogen deficit might be expected based on previous research, but a significant yield increase with nitrogen application was still observed.

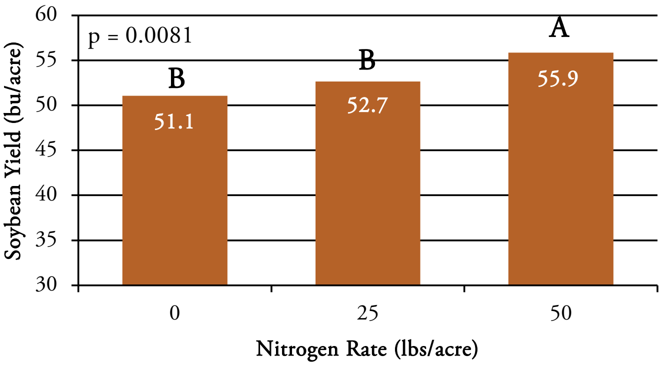


Figure 2. Average soybean yield by nitrogen rate. Means designated with the same letter are not significantly different at α=0.05.

Author: Mark Jeschke

Glyphosate Tolerant

[1]All Pioneer products are varieties unless designated with LL, in which case some are brands. R - Contains the Glyphosate Tolerant trait. Always follow grain marketing, stewardship practices and pesticide label directions. Varieties with the glyphosate tolerant trait (including those designated by the letter "R" in the product number) contain genes that confer tolerance to glyphosate herbicides. Glyphosate herbicides will kill crops that are not tolerant to glyphosate. Pioneer® brand products are provided subject to the terms and conditions of purchase which are part of the labeling and purchase documents. 2015 data are based on average of all comparisons made in one location through October 8, 2015. Multi-year and multi-location is a better predictor of future performance. Do not use these or any other data from a limited number of trials as a significant factor in product selection. The foregoing is provided for informational use only. Please contact your Pioneer sales professional for information and suggestions specific to your operation. Product performance is variable and depends on many factors such as moisture and heat stress, soil type, management practices and environmental stress as well as disease and pest pressures. Individual results may vary.

SOYBEAN STAND ESTABLISHMENT AND SEEDING RATE CONSIDERATIONS

- Establishing healthy, uniform stands is important to maximize soybean profitability, even though soybeans respond to reduced stands better than many other crops.
  - » Increased lateral branching can compensate for lower stands that are still relatively uniform (such as stand shown at right) but only partially for gaps.

- Because there are many factors that affect soybean stand establishment, optimum seeding rates vary considerably by region, cropping practice, and field.
  - » Listing factors known to influence stands in each field and adjusting seeding rates to account for potential stand losses is a practical way to make the best seeding rate decisions.
- Use of seed treatments improves stand establishment and uniformity by protecting seeds and emerging seedlings from biotic causes of stand loss, including disease infection and insect feeding.
- Stand issues due to abiotic causes (crusting, residue interference, other seed-soil contact issues, cold water imbibition, hail, etc.) are not remediated by seed treatments.
- This article will discuss factors affecting soybean stand establishment and how to adjust seeding rates to compensate for common losses of stand.

Stands that emerge uniformly with no large gaps or skips have highest yield potential.

SEEDING RATE DISTRIBUTION

- Each year, DuPont Pioneer conducts a grower survey that documents soybean seeding rates used by customers on their soybean acres. 2014 results are shown below:

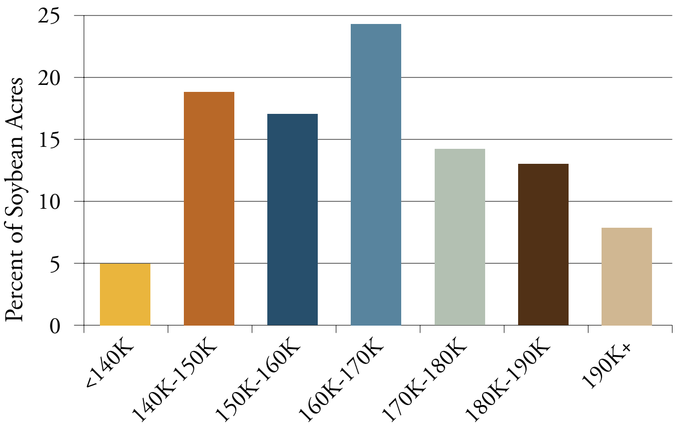


Figure 1. Seeding rate distribution by percent of soybean acres planted in IL, IN, and E. MO. Source: 2014 DuPont Pioneer brand concentration survey.

- Figure 1 shows that seeding rates are variable in this region, with almost 75% of acres seeded at 140,000 to 180,000 seeds/acre. Differences in row width (planter versus drill), planting date, soybean variety and maturity group, seedbed condition (tillage, residue cover and soil type), seedling disease risk, seed treatment combination, and grower preferences lead to this diversity of rates within states or regions.

FACTORS AFFECTING SOYBEAN SEEDING RATE

The primary factors affecting soybean seeding rate in IL, IN, and E. MO are listed below. Agronomists suggest increasing seeding rates by 5 to 10% for factors that reduce stand.

- Planter or Drill: Planters have traditionally done a better job of seed singulation and placement, increasing plant counts and stand uniformity. Growers using drills may need higher seeding rates to establish equally productive stands.
- Planting Date: Early planting usually means colder, wetter soils, slower emergence, and reduced stands. Soybeans planted very late, including double-crop beans, require higher rates because they are destined to be shorter and produce fewer pods per plant.
- Soybean Variety / Maturity Group: Some varieties respond more to higher soybean rates than others. In addition, studies have shown that early soybean varieties require higher populations for top yields.
- Tillage / Residue Cover / Seedbed Condition: No-till systems provide a less hospitable environment for soybean emergence due to colder soils, more residue, and possible seed placement/soil contact challenges. Cloddy soils may also reduce seed-soil contact.


Soybean stand reduced by a soil crust at emergence.

- **Seedling Disease Risk:** Some regions have higher seedling disease risk due to soil types, weather patterns, and pathogen race shifts. Higher seeding rates are needed to establish target stands in areas or fields with a history of higher disease risk.
- **Seed Treatment Combination:** Research shows that some seed treatments improve soybean stands by using additional active ingredients that combat seedling diseases. Your Pioneer sales professional can help you select the best seed treatments for your field.
- **Soil Type:** Soils with high clay content are much more likely to crust and restrict soybean emergence and also promote seedling diseases in wet springs.

CALCULATING SEEDING RATE

- After deciding on a final stand target, the grower must account for non-germinating and non-emerging seeds to calculate his seeding rate, according to the following equation:

$$\text{Seeding rate} = \frac{\text{Targeted final stand}}{(\%\ \text{germination} \times \%\ \text{emergence})}$$

Example 1

- In order to reduce gaps, maximize profitability, and minimize replant risk, a grower planting a maturity group 2.5 soybean variety in 15-inch rows in a well-tilled seedbed in mid-May targets a final stand of 140,000 plants/acre.
  - The seed tag indicates that germination is 90%, and because he is planting under relatively good conditions, he estimates emergence at 95%. His seeding rate is calculated as:

140,000 / (.90 x .95) = 140,000 / 0.855 = **164,000 seeds/acre**

Example 2

- A grower drilling a maturity group 3.0 soybean variety in 7.5-inch rows in a no-till field in late April targets a final stand of 142,000 plants/acre.
  - The seed tag shows that germination is 90%. Because he is planting early in a no-till system, he anticipates cool soils and potential seedling disease challenges. Consequently, he estimates % emergence at 80%. Thus, his seeding rate calculation is:

142,000 / (.90 x .80) = 142,000 / 0.72 = **197,000 seeds/acre**

AGRONOMIC ADVANTAGES OF MAINTAINING MODERATE TO HIGH SEEDING RATES

- Thicker seeding rates can enhance plant and pod height, which is especially important on sandy soils or with late-planted soybeans that tend to have shorter plants.
- Higher seeding rates can provide a buffer against the need to replant due to light to moderate stand reduction events, such as hail.
- Higher seeding rates enable quicker canopy closure, which can be a benefit in drought and/or heat prone environments. High levels of heat reflected from the soil surface can reduce early vegetative growth.
- Quicker canopy closure due to higher seeding rates can also benefit in weed control strategies by providing shade to slow down or inhibit weed emergence and early growth.


Good seedbed conditions resulting in a uniformly emerging soybean crop positioned for highest yields.

return to table of contents

WHAT DATA LAYERS ARE IMPORTANT FOR VARIABLE RATE SOYBEAN SEEDING PRESCRIPTIONS?

Growers are collecting many forms of spatial data for their fields, including yield, elevation, and soils data. Highly accurate GPS systems along with advances in variable rate technology (VRT) are allowing growers to create and use variable rate planting prescriptions to optimize soybean yields and seed placement (Hoeft et al., 2000). As soybean seed prices continue to rise (USDA-ERS, 2014), growers are looking for ways to optimize seeding rates across their fields (Hoeft et al., 2000). However, growers and researchers alike feel there is an abundance of raw data but a shortage of methods and knowledge on how to use the data for advancements in precision agriculture (Bullock et al., 2007). To address these issues, a research study was initiated.

STUDY OBJECTIVES

The objectives of this research were to:

- find the key measurable predictors determining soybean yield in Wisconsin and
- use those predictors to create accurate, data-based VRT prescriptions.

RESEARCH PROCEDURES

This study was conducted on a total of 22 sites between 2013 and 2014 as shown in Figure 1. Seeding rate prescriptions containing three unique rates were created prior to planting for each site as shown in Figure 2. The middle seeding rate was equivalent to the single rate each individual grower would have used in their respective field without VRT capabilities and the high and low rates were targeted at ±30% from the medium rate. After planting, soil samples were taken at geo-referenced points and submitted for pH, organic matter, phosphorus, and potassium levels. Soil survey and satellite imagery data were also obtained during the growing season to determine any possible relationships with soybean yield.

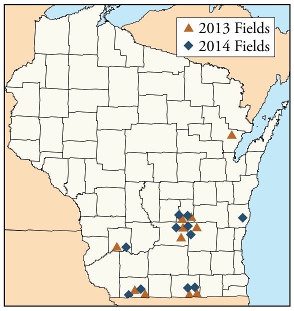


Figure 1. Research locations.

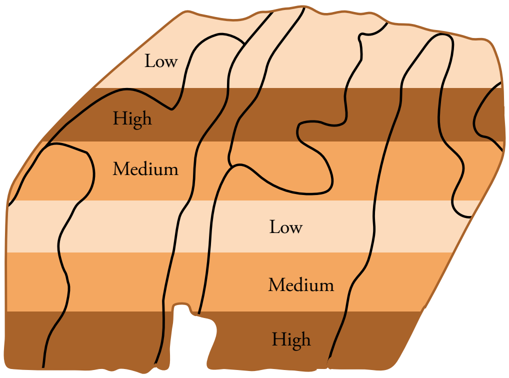


Figure 2. Example of seeding rate and soil type map.

Climate and Planting Factors

Soybean plant counts were taken at the same geo-referenced points used for soil sampling to verify the prescriptions were applied correctly. Relative emergence compared to the planted rate is shown for each field in Figure 3, and the 80% emergence level is highlighted by a dashed line. The 2013 growing season was more stressful, both early and late in the season, compared to 2014 (National Climate Data Center, 2015). As a result, some sites had noticeably low emergence. Discussions with the growers at these locations revealed that field conditions (soil moisture, temperature, etc.) and equipment (coulters, age of disc openers, etc.) were most likely to blame.

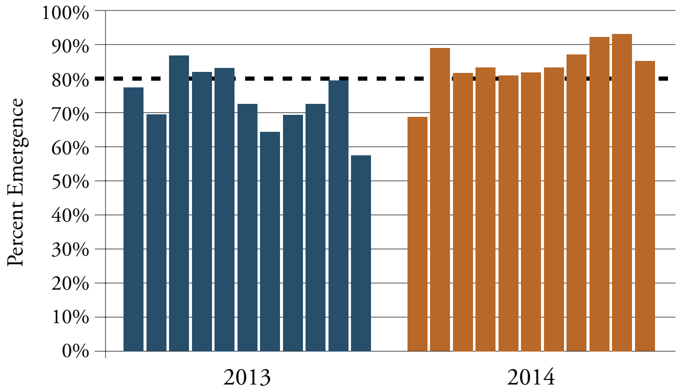


Figure 3. Average soybean emergence levels at each site based on initial seeding rates.

POOLED RESULTS

The average soybean yield for the 2013 sites was 52 bu/acre with individual field averages ranging from 37 to 68 bu/acre, and the pooled average for the 2014 sites was 55 bu/acre with individual fields yielding from 30 to 69 bu/acre on average. The "random forest method" (Breiman, 2001), a statistical algorithm, determined predictor importance in each data set, and the ranked results are found in Table 1. Soil symbol[a] was ranked as the most important factor regardless of year.

Table 1. Random forest results[b] from 2013 and 2014 pooled data.

2013 Most Important Predictors (Pooled)	2014 Most Important Predictors (Pooled)
Soil Symbol [a]	Soil Symbol [a]
Soil Phosphorus	Soil Phosphorus
Soil Organic Matter	Elevation
Available Water Supply from 0 to 39 Inches	Soil Potassium
Soil Potassium	Soil Organic Matter
Elevation	
Soil pH	

[a] A soil symbol (or "map unit symbol") is a descriptive label on a soil map. It gives information about soil type (or "series") and other soil features, such as slope, erosion, etc.

[b] Results of a statistical algorithm used to rank items in order of their importance to soybean yield.

return to table of contents

INDIVIDUAL FIELD RESULTS

The results from similar analyses for individual fields were, in general, quite different compared to the pooled dataset from the same growing season. The predictor rankings were averaged (value in parentheses), and elevation was the top predictor for soybean yield across both years (Table 2).

Table 2. Average random forest results[b] from 2013 and 2014 individual field analyses.

2013 Individual Field Predictor Rankings	2014 Individual Field Predictor Rankings
Elevation (1.55)	Elevation (2.00)
Soil Organic Matter (3.18)	Soil pH (3.09)
Soil Potassium (3.36)	Soil Potassium (3.27)
Soil Phosphorus (4.09)	Soil Organic Matter (3.45)
Soil pH (4.09)	Soil Phosphorus (3.82)

[b] Results of a statistical algorithm used to rank items in order of their importance to soybean yield.

The commonly used soil sampling variables of organic matter, potassium, phosphorus, and pH made up the rest of the top five predictors in both years. Soil symbol fell to sixth most important on average when looking at individual fields. The National Commodity Crop Productivity Index (NCCPI) was not determined to be an important predictor at any site.

Figure 4. Elevation and the soil sampling factors of soil phosphorus, potassium, organic matter, and pH were the most important predictors when looking at fields on an individual basis.

SATELLITE IMAGERY AND QUANTILE REGRESSION RESULTS

Satellite images were gathered from June to September for 2 sites in 2013, and for 3 sites in 2014. Early season (June) images showed no correlation to final soybean yield in either year. At both sites in 2013 the late-season (early September) NDVI values showed high correlation to yield (r values of 0.762 and 0.857). The 2014 sites showed less correlation overall, with the highest correlation appearing in the mid-season (July/Aug) images at 2 sites (r values of 0.425 and 0.77) and the remaining site showing the highest correlation in September (0.486). Quantile regression was used to see if the seeding rate impacted yield across the yield ranges in each field. Only 4 of the 22 sites (18%) had a majority of the data points fall outside the linear regression, meaning the remaining sites had a consistent relationship between seeding rate and yield throughout the field. However, over 36% of the fields had a negative linear regression slope, which means that yield decreased as seeding rate increased.

CONCLUSIONS

Soil symbol was by far the most important variable for predicting soybean yield in both the 2013 and 2014 statewide pooled data sets. This could be useful for wide-ranging recommendations and statewide research. However, elevation and the soil sampling factors of phosphorus, potassium, organic matter, and pH were the most important predictors when looking at fields on an individual basis. Since this type of analysis is possible for many growers and agronomists, these factors should be more useful for specific fields if the data are available.

NDVI and other aerial imagery data were unable to accurately predict soybean yield until mid- to late-summer and were more accurate during the 2013 growing season when many fields were exhibiting late season stress. It also appears that scale is an important factor when determining the predictors best for characterizing soybean yield due to the differences between the pooled and individual data sets.

The pooled results can be used for general recommendations; however, if accurate data are available for specific fields, more accurate results would be likely and should be addressed in order of importance. In short, VRT soybean prescriptions are useful in certain cases, but other factors are better predictors of soybean yield and should be analyzed and addressed first. A "one size fits all" approach for creating the prescriptions is not recommended due to the numerous possible differences between fields.

ACKNOWLEDGEMENTS

Research conducted as a part of the DuPont Pioneer Crop Management Research Awards (CMRA) Program. This program provides funds for agronomic and precision farming studies by university and USDA cooperators throughout North America. The awards extend for up to four years and address crop management information needs of DuPont Pioneer agronomists, Pioneer sales professionals, and customers. This article was adapted from the final report entitled “What data layers are important for variable rate soybean seeding prescriptions?” by Ethan Smidt, John Gaska, and Shawn Conley, Department of Agronomy; and Jun Zhu, Department of Statistics and Department of Entomology; University of Wisconsin-Madison. This project was sponsored by DuPont Pioneer Agronomy Sciences and coordinated by Barry Anderson and Paul Carter with local support from DuPont Pioneer Field Agronomists Arnie Imholte, Bob Berkevich, and Aaron Prestemon.

To view authors and references follow this link:

https://www.pioneer.com/home/site/us/agronomy/data-layers-variable-rate-soybean-seeding/#data-based-vrt-references

return to table of contents

Soybean Planting Date and Varietal Maturity Interact to Determine Yield

2015

Background

- Over the last decade, researchers in the U.S. Corn Belt states have updated soybean planting date guidelines based on research showing maximum yields with late April to early May planting dates.
- Researchers have designed experiments to test if management strategies such as row spacing, seeding rate, and the decision to use seed treatments should change with these new planting date guidelines.
- However, few research efforts have been established to test if varietal maturity selection should change with the earlier planting date recommendations.

Objective

- A three-year field research study was conducted as part of the DuPont Pioneer Crop Management Research Awards (CMRA) Program with Dr. Emerson Nafziger at the University of Illinois.
- The objective of this study was to test whether or not there is a need to change varietal maturity recommendations based on when soybeans are planted.

Study Description

- Replicated small-plot research trials were conducted from 2012 through 2014 at several DuPont Pioneer and University of Illinois research farms.
- In total there were 12 site-years (research locations) & 26 different Pioneer® brand soybean varieties used in these trials.
    - 6 site-years in northern IL and 2 in central IA
    - 4 site-years in central IL
- There were two planting dates used at each site, an "early" (targeting late April) and a "normal" (targeting late May) planting date
- For the purposes of data analysis, the 8 northern IL/IA and 4 central IL site-years were grouped separately.
    - At the northern locations the varieties ranged in maturity from MG 1.9 to 3.8, with a "baseline" of 2.9
    - At the central locations the varieties ranged in maturity from MG 2.5 to 4.5, with a baseline of 3.5

A MG 4.5 variety reaching harvest maturity later than earlier-maturing varieties at a research farm near Urbana, IL. Photo taken on Sept. 19, 2014.

Results

- Averaged across all varieties, planting in late April or early May compared to late May/early June increased yields by 4.7 and 7.9 bu/acre in the northern and central regions, respectively (Table 1).

Table 1. Average grain yield, and the average early and normal planting dates for the 8 and 4 site-years in the northern and central regions.

Region	# Site-Years	Planting Date (Average)		Yield	
		Early	Normal	Early	Normal
				(bu/acre)	
Northern	8	April 28	June 1	70.8	66.1
Central	4	May 5	June 3	69.9	62.0
Average				70.4	64.1

- In both the northern and central regions, there were highly significant interactions ($P<0.001$) between planting date and varietal maturity.
- So we know that varietal maturity affected soybean yield, but we also can see that the effect of varietal maturity on grain yields was different for the early compared to the normal planting date.

Northern Region

- In the northern region, maximum yields were produced by varieties 0.4 and 0.2 maturity units later than the mid-maturity (MG 2.9) baseline varieties at the early and normal planting dates, respectively (Figure 1).
- The interaction between varietal maturity and planting date in the northern region was the result of:
    - Higher yields with early planting for the mid- and full-season varieties, but no such increase in yields for short-season varieties planted early.
    - Those varieties that were 0.5 maturity units shorter to 1.0 unit longer than the mid-maturity baseline (2.9) varieties had higher yields when planted early, while those that were 0.5 to 1.0 units shorter than the mid-maturity varieties did not have higher yields with early compared to normal planting.

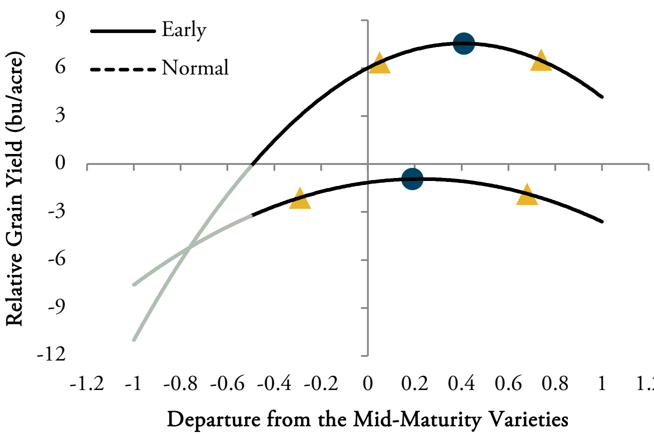


Figure 1. Interaction between varietal maturity across 8 site-years in the northern region. The blue dots indicate the maturity with maxi-mum yields for each planting time and the yellow triangles represent the ends of ranges over which yields are within 1 bu/acre of the maximum yield. Gray lines show where differences were not significant at P=0.10.

Central Region

- In the central region, maximum yields were produced by varieties 0.1 maturity units longer and 0.3 maturity units shorter than the mid-maturity baseline (MG 3.5) varieties at the early and normal planting dates, respectively (Figure 2).
- The interaction between varietal maturity and planting date in the central region was a result of:
    - Mid and full-season varieties produced higher yields from early planting, but short-season varieties did not.
    - The fullest-season varieties lost more yield when planting was delayed than did the short-season varieties.
    - Those varieties that did not have higher yields with early planting were 0.3 maturity units shorter to 1.0 unit shorter than the mid-maturity baseline (3.5) varieties.

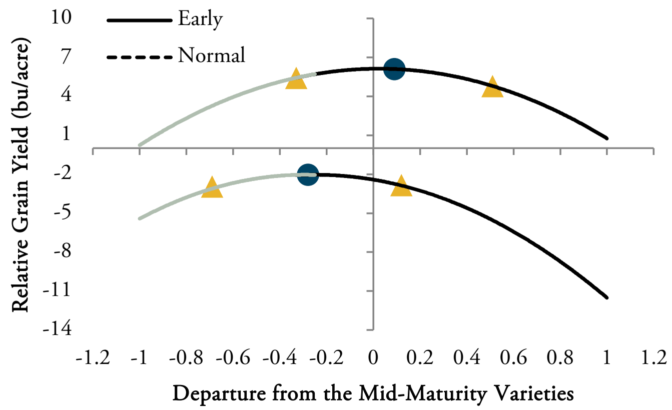


Figure 2. Interaction between varietal maturity across 4 site-years in the central region. The blue dots indicate the point of maximum yield and the yellow triangles represent the ends of ranges over which yields are within 1 bu/acre of the maximum yield. Gray lines show where differences were not significant at *P*=0.10.

Conclusions

- On average, yields within 1 bu/acre of the maximum were produced by varieties over a range of about 0.9 maturity units.
- Among individual site-years in the northern region, maximum yields were produced by varieties from as early as a 1.9 to as late as 3.8 relative maturity.
    - Taken together, these two observations reconfirm that the focus should remain on selecting top-yielding genetics, and that these top-yielding varieties can be found over a modest range of maturities relative to the latitude of production.
- These findings suggest that growers who are often able to plant starting in late April or early May should consider making a small shift toward varieties later than MG 2.9 in the northern region, with less response expected from doing this (relative to the baseline of MG 3.5) in the central region.
    - Any such shift should be small, perhaps only 0.2 or 0.3 units longer (e.g. from 2.9 to 3.1 or 3.2), and the emphasis should remain on choosing top-yielding varieties, not only on changing to longer maturity.
- Shorter-season varieties showed little yield increase from early planting in the central region, similar to what we found in the northern region. Though the interaction between planting date and maturity was less striking in this region compared to the northern region, fuller-season varieties lost a little more yield when planting was delayed than did earlier-maturing varieties.
    - Data from more site-years in the central region would help strengthen these findings.

Research conducted by Dr. Emerson Nafziger and Jake Vossenkemper, University of Illinois, as a part of the DuPont Pioneer Crop Management Research Awards (CMRA) Program. This program provides funds for agronomic and precision farming studies by university and USDA cooperators throughout North America. The awards extend for up to four years and address crop management information needs of DuPont Pioneer agronomists, Pioneer sales professionals and customers.

SPRING WHEAT MANAGEMENT

NEED ADEQUATE STANDS FOR TOP PRODUCTION

- Stand establishment of 27 to 35 plants/ft^2 with 3 to 5 tillers/plant is optimal. Data suggest that to maximize potential yield, you must have at least 40 heads/ft^2, with the optimum numbers between 60 and 80 heads/ft^2.
- Stands of 15 to 18 plants/ft^2 or less are candidates for replanting to corn or soybeans.
- Old Rule of Thumb:1.3 to 1.6 bu/acre for each head/ft^2.

WHEAT NITROGEN MANAGEMENT

- Wheat uses 1.1 lbs of nitrogen for each bushel of expected yield and utilizes 70 to 75% of its total nitrogen requirements between Feekes growth stage 6 and 10. The greatest amount of nitrogen should be available at that time.
- At 70+ tillers/ft^2, apply nitrogen at Feekes growth stage 4 to 5 (prior to jointing).
- 100 to 140 lbs/acre of nitrogen spring-applied is recommended.
- A high rate of nitrogen may cause lodging in certain varieties. Avoid overlaps in application.
- If a high rate of nitrogen is planned, consider a split application of 40 lbs/acre before greenup and another 60 lbs/acre at Feekes growth stage 4-5 (prior to jointing).
- Do not delay nitrogen application on a marginal stand of wheat. If stands are thin and tiller counts are low, an early application of nitrogen can help induce tillering and consequently increase heads/ft^2. In this situation, a split application may help. Apply 60 lbs/acre of nitrogen for a first application (before greenup) and another 40 lbs/acre at Feekes growth stage 4 to 5.
- For light or sandy soils, a split application of nitrogen is suggested.
- Nitrogen application rates can be reduced if fields have a history of manure application.
- If a stand is destroyed, credit 50 to 75% of applied nitrogen to a subsequent corn crop (depending on growth stage).
- What form of nitrogen should be used? The form of nitrogen is not as important as how accurately it is applied. Apply a uniform rate across the entire application width, and avoid application methods that may burn the leaves, which could reduce yield (such as 28% solution applied with herbicides). Common forms of nitrogen used include: ammonium sulfate, urea, and 28% solution.

Table 1. Recommended topdress nitrogen fertilizer rates for wheat at various yield levels and soil textures.

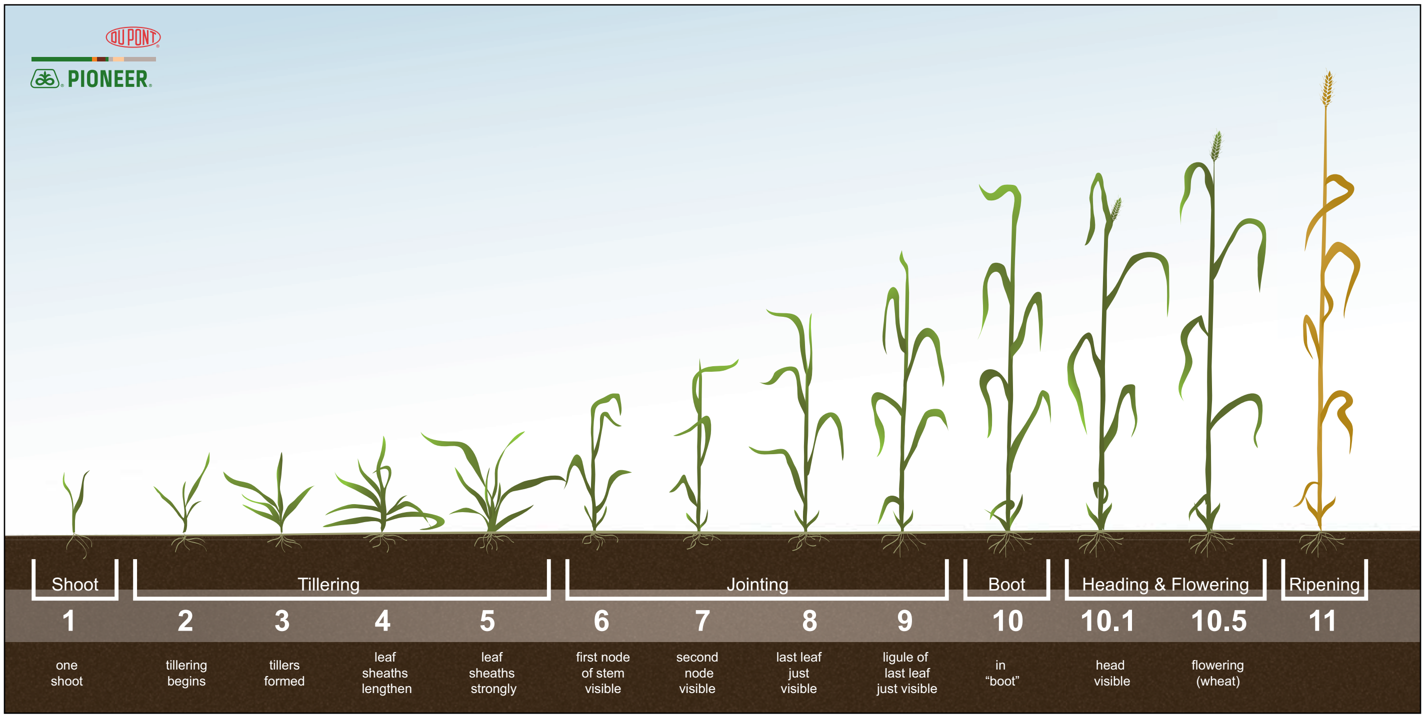
Cation Exchange Capacity	Nitrogen Rate When Yield Goal (bu/acre) is:					
	30-44	45-54	55-64	65-74	75-85	>85
meg/100g	------ lbs/acre ------					
<6	50	60	70	80	90	100
6-10	40	50	60	70	80	100
11-30	30	40	50	60	70	90
>30	20	30	40	50	60	60

Source: Purdue University

PEST MANAGEMENT

- Insects: Scouting is critical. If aphid populations exceed thresholds (10 per foot of row with early greenup and good conditions), a treatment should be applied to protect from barley yellow dwarf virus (BYDV).
- Diseases: A good crop with high yield potential and high wheat prices will increase the probability of an economic benefit to fungicide application. 100+ bu/acre wheat is thick and does not get a lot of air movement within the canopy – a perfect environment for disease if the weather also remains wet and provides a favorable environment for disease.
- Apply DuPont™ Aproach® fungicide at 3 to 4 fl oz/acre between tillering and jointing for early-season disease control/suppression.
- For optimizing yield and flag-leaf disease control, apply DuPont™ Aproach® Prima fungicide at 6.8 fl oz/acre at Feekes 9.
- Weeds: Keep fields clean early, and do not let weeds get too big. Recommendation: DuPont™ Harmony® Extra SG herbicide with TotalSol® soluble granules 0.75 oz/acre + 2,4-D LVE 8 oz/acre (as needed) + NIS 1 qt/100 gal.
- Spring herbicide applications should be made to actively growing weeds prior to flag leaf. Do not apply 2,4-D LVE to wheat before tillering or after the joint stage.
- Do not apply a total of more than 1.5 oz/acre of Harmony Extra SG herbicide per season. Consider the fall weed management program before proceeding with spring treatments.

This reference guide is not intended as a substitute for the product label for the products referenced herein. Product labels for the above products contain important precautions, directions for use and product warranty and liability limitations that must be read before using the product. Applicators must be in possession of the product label(s) at the time of application. Always read and follow all label directions and precautions for use when using any pesticide alone or in tank mix combinations.



Boot Stage

Feekes 10.0

- **10.1** Awns visible; heads emerging through slit of flag leaf sheath
- **10.2** Heading ¼ complete
- **10.3** Heading ½ complete
- **10.4** Heading ¾ complete
- **10.5** Heading complete
  - **10.5.1** Beginning flowering
  - **10.5.2** Flowering complete to top of spike
  - **10.5.3** Flowering complete to base of spike
  - **10.5.4** Kernels watery ripe.

Source: Purdue Extension

Source: Jonah Johnson, DuPont Pioneer

Ripening Stage

Feekes 11.0

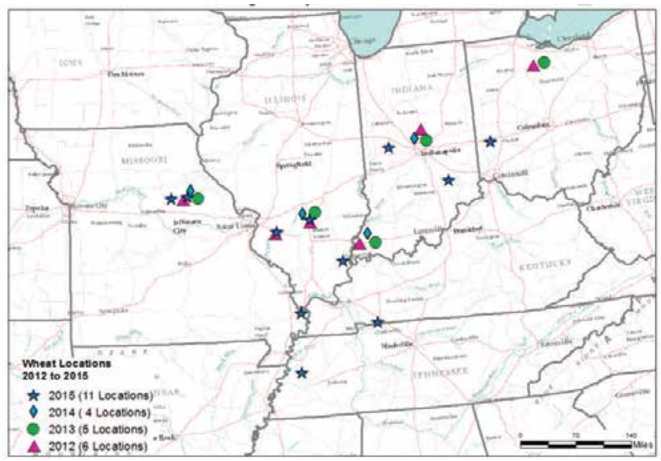
- **11.1** Milky ripe
- **11.2** Mealy ripe
- **11.3** Kernel hard
- **11.4** Harvest ready

AGRONOMY RESEARCH UPDATE

Pioneer Premium Seed Treatment Offering for Soft Red Winter Wheat | 2015

Introduction & Objective

- Pioneer Premium Seed Treatment (PPST) offering for wheat includes the fungicide seed treatments (FST) Dividend Extreme® (mefenoxam and difenconazole) and Vibrance® (sedaxane) plus the insecticide seed treatment (IST) Gaucho® (imidacloprid).
- Dividend Extreme/Vibrance wheat FST provides protection against numerous seed borne, soil borne, and foliar diseases, including *Pythium*, *Rhizoctonia* and dwarf bunt. The addition of sedaxane FST provides enhanced activity against *Rhizoctonia* and *Fusarium*.
- Gaucho IST provides early-season control of aphids, which can vector the barley yellow dwarf virus, Hessian fly, and suppression of wireworm.
- **Research trials were conducted in 2012, 2013, 2014, and 2015 to evaluate performance of Dividend Extreme/Vibrance FST + Gaucho IST for wheat.**



DuPont Pioneer wheat seed treatment research locations in 2012, 2013, 2014, and 2015.

Study Description

Years: 2012, 2013, 2014, and 2015
Treatments:

1. Untreated
2. Dividend Extreme/Vibrance FST (2.8 fl oz/cwt) + Gaucho IST (0.8 fl oz/cwt)

Locations: 26 DuPont Pioneer research locations
Plots: 18 ft long; 6- to 7-inch row spacing
Varieties: 2 adapted varieties per location
Replications: 6 replications per treatment per location

Results

- Results of a four-year wheat seed treatment trial showed Pioneer Premium Seed Treatment offering for wheat (Dividend Extreme/Vibrance FST + Gaucho IST) provided an average yield increase of 2.3 bu/acre over the untreated control across 26 research locations in 2012-2015 (P-value <0.01).
- A positive yield response was observed at 17 of the 26 research locations (65.3% of site-years).

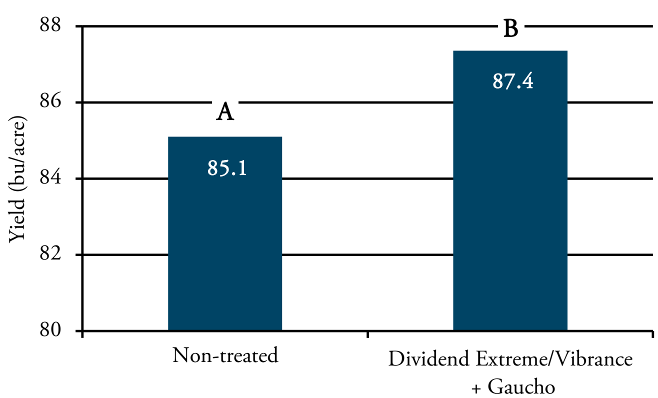


Figure 1. Seed treatment effect on soft red winter wheat yield across 26 locations from 2012-2015.

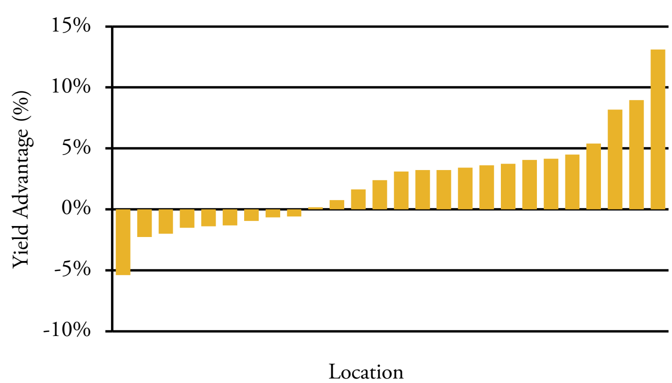


Figure 2. Seed treatment effect on soft red winter wheat yield over no treatment (by location 2012-2015).

AM - Optimum® AcreMax® Insect Protection system with YGCB, HX1, LL, RR2. Contains a single-bag integrated refuge solution for above-ground insects. In EPA-designated cotton growing counties, a 20% separate refuge must be planted with Optimum AcreMax products.

AMX - Optimum® AcreMax® Xtra Insect Protection system with YGCB, HXX, LL, RR2. Contains a single-bag integrated refuge solution for above- and below-ground insects. In EPA-designated cotton growing counties, a 20% separate refuge must be planted with Optimum AcreMax Xtra products.

Product performance in water-limited environments is variable and depends on many factors such as the severity and timing of moisture deficiency, heat stress, soil type, management practices, and environmental stress as well as disease and pest pressures. All hybrids may exhibit reduced yield under water and heat stress. Individual results may vary.

AVBL, YGCB, HX1, LL, RR2 - Optimum® Leptra™^ contains the Agrisure Viptera® trait, the YieldGard Corn Borer gene, the Herculex® I gene, the LibertyLink® gene, and the Roundup Ready® Corn 2 trait.

^ EXPORT APPROVAL NOTICE: This product is fully approved in the United States and Canada. Traits included in these products may or may not be approved in key global markets; therefore, the combination of these traits and the grain and certain by-products from THESE PRODUCTS MAY NOT BE APPROVED for all markets. For questions about specific countries please contact your Sales Representative or refer to www.pioneer.com/stewardship. Customers are advised to discuss trait acceptance policies with their local grain handler prior to delivering grain containing biotech traits.

Agrisure Viptera® is a registered trademark of, and used under license from, a Syngenta Group Company. Agrisure® technology incorporated into these seeds is commercialized under a license from Syngenta Crop Protection AG.

LL - Contains the LibertyLink® gene for resistance to Liberty® herbicide.

Liberty®, LibertyLink®, the Water Droplet Design, ILeVO®, Poncho® and VOTiVO®, and EverGol® are registered trademarks of Bayer.

RR2 - Contains the Roundup Ready® Corn 2 gene that provides crop safety for over-the-top applications of labeled glyphosate herbicides when applied according to label directions.

YGCB - The YieldGard® Corn Borer gene offers a high level of resistance to European corn borer, southwestern corn borer and southern cornstalk borer; moderate resistance to corn earworm and common stalk borer; and above average resistance to fall armyworm. Contains the YieldGard® Corn Borer gene.

YieldGard®, and the YieldGard Corn Borer design are registered trademarks used under license from Monsanto Company.

HX1 - Contains the Herculex® I Insect Protection gene which provides protection against European corn borer, southwestern corn borer, black cutworm, fall armyworm, western bean cutworm, lesser corn stalk borer, southern corn stalk borer, and sugarcane borer; and suppresses corn earworm.

HXX - Herculex® XTRA contains the Herculex I and Herculex RW genes.

Herculex® Insect Protection technology by Dow AgroSciences and Pioneer Hi-Bred. Herculex® and the HX logo are registered trademarks of Dow AgroSciences LLC.

Components under the Pioneer Premium Seed Treatment offering for soybeans are applied at a DuPont Pioneer production facility or by an independent sales representative of Pioneer. Not all sales representatives offer treatment services, and costs and other charges may vary. See your Pioneer sales representative for details. Seed treatment offering exclusive to DuPont Pioneer and its affiliates.

Fungicide performance is variable and subject to a variety of environmental and disease pressures. Individual results may vary. Always read and follow all label directions and precautions for use when applying fungicides. Labels contain important precautions, directions for use and product warranty and liability limitations that must be read before using the product. Mention of a product does not imply a recommendation. The foregoing is provided for informational use only. Please contact your Pioneer sales professional for information and suggestions specific to your operation. Product performance is variable and depends on many factors such as moisture and heat stress, soil type, management practices and environmental stress as well as disease and pest pressures. Individual results may vary.

R - Contains the Glyphosate Tolerant trait. Always follow grain marketing, stewardship practices and pesticide label directions. Varieties with the glyphosate tolerant trait (including those designated by the letter "R" in the product number) contain genes that confer tolerance to glyphosate herbicides. Glyphosate herbicides will kill crops that are not tolerant to glyphosate.

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