PIONEER®

CORTEVA™ agriscience

2021 AGRONOMY RESEARCH SUMMARY

contents

Nutrient Management

Corn Planting Practices

Corn Growth and Development

Corn Management

Corn Fungicides

Corn Leaf Diseases

Corn Ear Rots

Corn Pest Management

Herbicides

Forages

Soybean Planting Practices

Soybean Management

Soybean Diseases

Soybean Pest Management

Wheat

Sorghum

* Research conducted as a part of the 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 Pioneer agronomists and customers, and Pioneer sales professionals.

intro

return to table of contents

2020 Growing Season in Review

The 2020 growing season was unusual right from the start with a global pandemic taking hold just as planting season got underway, causing significant disruptions to economic activity. This was an unprecedented situation for all of us but impacted some more directly than others; however, the ag industry persevered as it always does in the face of unforeseen challenges.

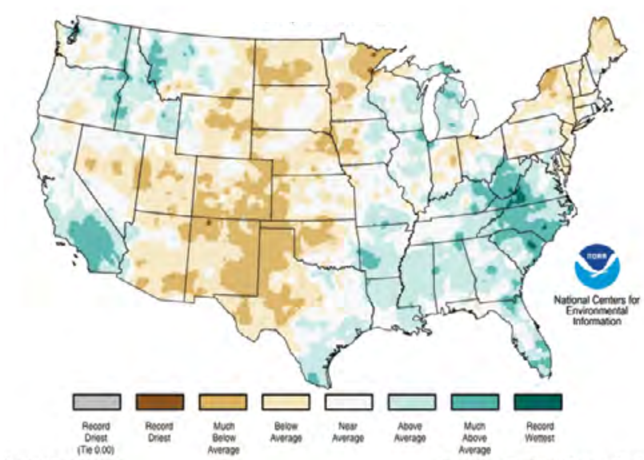


Figure 1. Total precipitation deviation from average for April to June 2020.

Planting Season

The 2020 season got off to a better start than 2019 in many areas, including most of the Central Corn Belt. Spring precipitation was closer to average (Figure 1), which allowed corn and soybean planting to proceed at a more normal rate compared to the widespread delays experienced in 2019 (Figure 2).

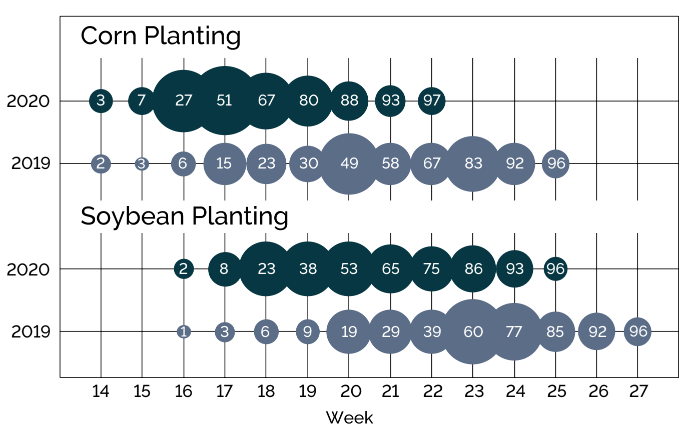


Figure 2. U.S. average corn and soybean planting progress by week in 2019 and 2020 (USDA-NASS).

It wasn't smooth sailing everywhere though. Prevent plant acres were down from the record 19.4 million in 2019 but still totaled nearly 9 million, which were concentrated in Arkansas and the Dakotas. Wet weather and unharvested acres from 2019 were major contributing factors.

While spring weather was more favorable overall for getting the crop planted, it wasn't necessarily the most conducive for getting it up and growing. Much of the eastern half of the U.S. experienced below-average temperatures in April and May (Figure 3), leading to variable corn emergence and early growth. June and July helped bring the crop along though, with generally favorable weather in many areas. The U.S. corn crop was rated 72% good to excellent at the close of July, right in line with the 5-year average.

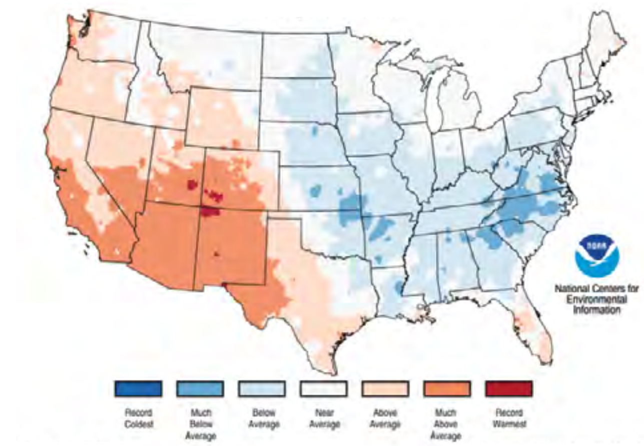


Figure 3. Average temperature percentiles for May 2020.

Severe Summer Weather

The prospect of a growing season relatively free of adverse weather impacts ended quickly and dramatically for many farmers during July and August when a number of severe weather events caused extensive damage to crops, including lodging and hail damage. The most destructive of these events occurred on August 10, when a severe derecho swept across multiple states, damaging buildings and bins and flattening crops. By the time the storm was over, it had carved a path of destruction that extended over 770 miles, resulting in an estimated $7.5 billion in damages, making it the costliest thunderstorm event in U.S. history.

Figure 4. A corn field flattened by the high winds of the August 2020 derecho near Adel, IA. *Photo: Lisa Schmitz - National Weather Service (Des Moines Office).*

What is a Derecho?

The term "derecho" is one that has only recently become familiar to many of us, despite the fact that it was first used over a century ago. A derecho differs from tornadoes and hurricanes in that it involves straight-line winds rather than rotating wind. Derechos lack the sheer destructive power of tornadoes but can cause damage over a much larger area. Derechos can also spawn tornadoes as was the case in 2020 with 21 confirmed tornadoes associated with the storm.

Figure 5. August 10, 2020, derecho: Lowest angle NWS radar reflectivity at one-hour time steps (NWS Chicago).

Derechos typically arise from a curved-shape band of thunderstorms called a "bow echo." A storm is classified as a derecho when it creates damaging winds in excess of 58 mph and extends over a path of at least 250 miles. A derecho can develop when certain atmospheric conditions are present that allow the storm to become self-sustaining and persist over a long time and distance. These conditions include unidirectional winds that increase in speed with altitude, air temperatures that sharply decrease with altitude, and abundant low-level moisture. The downdraft of cold air along the leading edge of the storm forces warm, moist air upward, creating new storm cells, this results in a feedback cycle that continues as long as there is warm, moist air to feed into the system.

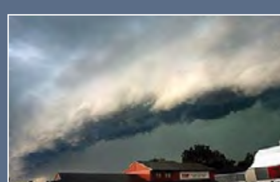


Photo: NOAA.

Severe weather effects weren't limited to the Corn Belt. In late August, the remnants of Hurricane Laura pushed inland into crop production areas of Louisiana and Arkansas, bringing heavy rainfall and damaging winds as harvest was getting underway.

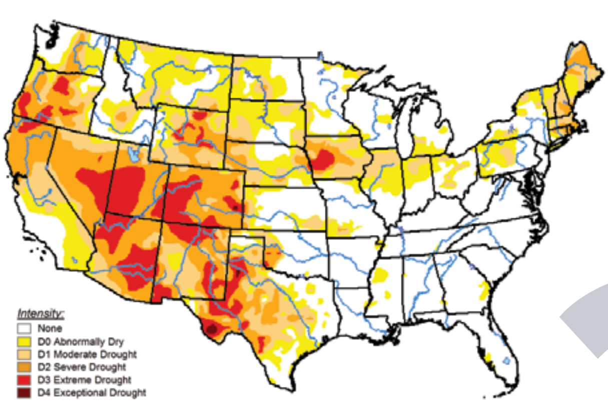


Figure 6. U.S. Drought Monitor map, September 1, 2020.

Late-Season Stresses Take Their Toll

Crop conditions declined in the latter half of the season as the accumulated stresses of 2020 began to take a toll on crop health in many areas. Drought was the primary driver of late-season crop stress as rainfall shut off in much of the Corn Belt in August. Western Iowa and Eastern Nebraska were particularly hard hit, but drought conditions affected portions of several states.

Drought stress was potentially compounded by a number of other factors. Lingering soil compaction effects from the 2019 season restricted root development in some fields, particularly in high-traffic areas along the field margins. Areas of poor root development were often revealed in the patterns of root lodging from summer storms. Cool early-season conditions likely reduced nitrogen mineralization in the soil, leading to a greater frequency of nitrogen stress later in the season. Corn rootworm pressure also increased substantially in much of the Corn Belt in 2020, which likely exacerbated drought and nitrogen stress and increased the susceptibility of corn to lodging. Higher corn rootworm populations will be a key management consideration for corn production in 2021.

Many agronomists noted a wide distribution of yield outcomes in 2020. Highly productive soils and rotated fields that managed to avoid the worst of the season's stresses performed well. Less-productive and more drought-prone soils often did not. Corn-on-corn acres, in particular, fell short of expectations as they proved more susceptible to the combination of yield-limiting stresses present in 2020.

The 2020 season dealt out its fair share of challenges but also demonstrated how far crop genetics and management have come over the years. Crops are often able to endure a range of yield-limiting stress conditions and still yield beyond what would have been achievable 20 or 30 years ago. Successful crop management under constantly evolving conditions requires smart and efficient use of resources, driven by sound agronomic knowledge. Pioneer agronomists work to help crop producers manage factors within their control and maximize productivity within the environmental constraints unique to a given growing season, be they favorable or not.

This Agronomy Research Summary is the latest edition of an annual compilation of Pioneer agronomy information and research results. This summary provides insights on numerous crop production topics; however, it represents just a small portion of the vast array of resources available in the Pioneer agronomy library at www.pioneer.com. We hope that resources available in this book and online will help you drive productivity, efficiency, and profitability in 2021.

Mark Jeschke, Ph.D.
Agronomy Manager

2021

return to table of contents

Forward—thinking Farming

a webinar series powered by Pioneer® Agronomy

return to table of contents

Forward-Thinking Farming Webinar

The *Forward-Thinking Farming* webinar series launched in early 2020, featuring the cutting-edge agronomic knowledge and expertise of the Pioneer® agronomy team. Each episode is led by a Pioneer Agronomy Manager as well as industry experts and is focused on the innovative tools, technology and agronomic practices of Pioneer to help farmers be successful and evolve into the future.

Listen in on the cutting-edge insights of the Pioneer Agronomy team!

Watch our recent *Forward-Thinking Farming* webinars at **pioneer.com/webinars**.

Pioneer Agronomy

Pioneer Agronomists and others take to the screen to share insights on topics important to you.

Scan the QR codes in text to watch videos from your Pioneer team.

2020 *Forward-Thinking Farming* Webinar Topics

Remote Sensing with Satellites and UAVs

Dr. Mary Gumz, Pioneer Agronomy Manager, T.C. Huffman, Area Digital Services Manager, and Eric Galdi, Pioneer Agronomy Systems Manager, discuss how characteristics of soil and crop surfaces measured using remote devices like satellites and drones can be an important source of data for making site-specific crop decisions.

Understanding the Needs of Contest Corn

Don Stall, high-yield farmer and Pioneer customer from Eaton County, MI, Karen Zuver, Pioneer Field Agronomist, and Dr. Brewer Blessitt, Pioneer Agronomy Manager, discuss how Pioneer agronomy is pushing the boundary to reach the 300 bu/acre mark.

Managing Your Farm Operation for Acre Level Profitability

Alex Petersen and Curt Hoffbeck, Pioneer Field Agronomists, and Kyle Kayser, Area Digital Services Lead at Granular, talk about budgets and why they matter, agronomic practices that have the highest ROIs, and profitability at the acre level.

Climate Change and Crop Management

Dr. Mark Jeschke and Dan Berning, Pioneer Agronomy Managers, discuss climate change implications for agriculture, including observed and projected changes in weather patterns, potential impacts on crop growth, and management ideas to consider.

Base Cation Saturation Ratio for Maximum Yield – Fact vs. Fiction

Dr. Matt Clover, Pioneer Agronomy Manager and Certified Professional Soil Scientist, digs into the concept of using base cation saturation ratio to interpret soil test data and whether it makes sense across diverse soil environments to meet crop nutrient needs.

Finding Success with Tissue Sampling

Dr. Brewer Blessitt, Pioneer Agronomy Manager and Certified Professional Agronomist, helps growers understand how to undertake effective tissue sampling as a tool to maximize yield.

Chasing 500: Using Foliar Fungicides to Maximize Corn Yield

Brian Bush, Pioneer Field Agronomist, Nate Wyss, Corteva Agriscience Market Development Specialist, and Dr. Mary Gumz, Pioneer Agronomy Manager, encourage you to think differently about the importance of foliar fungicides – not just for disease control and prevention – but as part of a strategic program to push the yield limits of your corn crop.

Plant Nutrient Management for 2020 and Beyond

Dr. Matt Clover, Pioneer Agronomy Manager and Certified Professional Soil Scientist, uses soil and plant data from the 2020 growing season to provide valuable insight on in-season action.

Center Pivot Irrigation for Today's Corn Hybrids

Russell French, Pioneer Strategic Account Manager and Certified Crop Advisor, shares best management practices for center pivot irrigation and corn nutrient management.

Reaching New Heights with Corn Yield

Dr. Matt Montgomery and Nate LeVan, Pioneer Field Agronomists, discuss genetic yield potential, foundational crop nutrition, and new novel management considerations to maximize the potential of your corn crop.

Late-Season Soybean Management

Don Kyle, Pioneer Soybean Breeder, and Dr. Ryan Van Roekel, Pioneer Field Agronomist, share their exclusive insights for increasing soybean yields.

Be among the first to hear new insights from Pioneer® Agronomy.

Sign up for *Forward-Thinking Farming* webinar invitations at **pioneer.com/us/sign-up**.

2021 *Forward-Thinking Farming* Webinar Topics

- Seed Quality Testing – Methods, Targets, and Results
- Nutrient Ratios
- The Science of Feeding the Crop
- Soil Chemistry and Nutrient Uptake
- Sulfur Fertility
- Corn Water Use – Irrigation Needs During Grain Fill
- Managing Nematodes in Crop Production
- Soil Health and Productivity

new nutrient sufficiency ranges for high-yield crops

Brewer Blessitt, Ph.D., *Agronomy Manager*

Summary

- Tissue sampling provides a measure of key nutrients critical to crop growth and development.
- Adoption of tissue sampling as a routine crop management practice has been limited for several reasons, one of which is the lack of clear guidelines on nutrient sufficiency levels for high-yielding crops.
- Pioneer agronomists conducted a multi-year study to characterize correlations between corn and soybean yield and nutrient levels at key growth stages and to create recommended nutrient sufficiency ranges.
- Results showed that nutrient levels differed significantly by yield level in both corn and soybean with higher yielding crops having higher total nutrient concentrations.
- Analysis of individual nutrients by yield level showed many significant correlations – some positive, some negative, and others that showed a peak or plateau in yield response.
- Continuing investigations into relationships or ratios of nutrients at key timings will help drive more efficient and environmentally friendly management practices.

Tissue Sampling in Crop Production

Plant tissue analysis, or tissue sampling, involves testing a sample of tissue from a growing plant to quantify nutrient levels in the tissue. In crop production, the goal of tissue sampling is to determine if nutrient levels are sufficient to maximize yield. Plant nutrient deficiency symptoms are an indication that the crop did not or is not receiving adequate nutrients. However, the crop has undergone stress by the time visual deficiencies appear, and application of nutrients following the appearance of deficiency symptoms may not fully recover yield. Tissue testing provides an alternative opportunity to measure nutrient levels before the crop shows visual symptoms of deficiency.

The National Corn Growers Association National Corn Yield Contest and other yield contests have shown the remarkable yields that can be achieved with modern hybrids and varieties when resources are non-limiting. As farmers participate in yield contests and work to incrementally boost yields, it becomes increasingly important to understand nutrient levels needed for maximizing crop yields and nutrient management programs necessary to achieve those levels. Tissue sampling for comparison across yield levels can provide insight into correlations that exist between tissue sample nutrient levels and yield. A defined set of tissue sample ranges for different yield levels could also potentially guide crop management for greater yields.

Forward-Thinking Farming Webinar

Maximizing Yield with Plant Tissue Sampling

Dr. Brewer Blessitt, Pioneer agronomy manager, shares on best practices for tissue sampling; key nutrient ranges and potential relationships; along with the top five management recommendations to date for macros and micros.

Watch at pioneer.com/webinars

Improving the Value of Tissue Sampling

Tissue sampling can be utilized in many ways, including problem diagnosis, nutrient program monitoring, or in-season nutrient management. However, adoption of tissue sampling as a routine crop management practice has been limited for several reasons, including cost and workload; variability of results; perceived lack of correlation between nutrient concentrations and crop performance; and the lack of clear guidelines on nutrient sufficiency levels for high-yielding crops and actions that can be taken to achieve those levels. Many published sufficiency ranges are based upon a frequency distribution, i.e., the optimal nutrient range corresponds to the most frequently observed levels. Other ranges are based on fertilizer amendment studies, growth reduction levels, or fewer still on antiquated, lower yield levels.

Pioneer Tissue Sampling Research

Pioneer agronomists conducted a multi-year study in which plant tissue samples were collected from select corn and soybean on-farm trials to explore the relationships between plant nutrient levels during the growing season and yield. The goals of this study were to characterize correlations between corn and soybean yield as well as plant nutrient levels at key growth stages and to use data from the highest-yielding locations to create recommended nutrient sufficiency ranges for maximum yield.

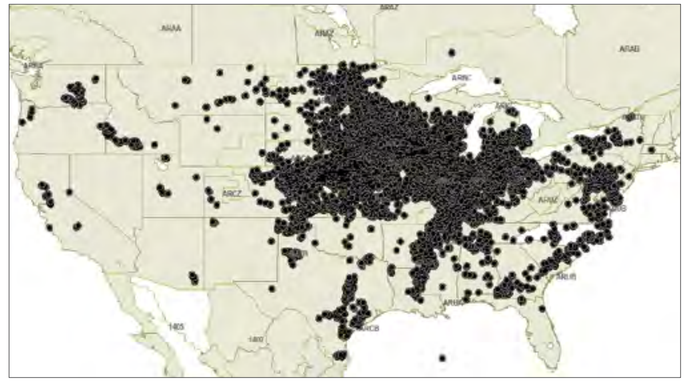


Figure 1. Pioneer on-farm trial locations in the U.S. and Canada, 2017-2019.

Tissue samples were collected from a select subset (550 corn, 467 soybean) of the nearly 12,000 on-farm trials that Pioneer agronomists conduct annually in the U.S. and Canada (Figure 1). Tissue samples were collected at three different timings in corn (V6, VT/R1, R3) and soybean (R1, R3, R5) during the growing season (Table 1 and 2). These growth stages relate to different physiological events and represent key periods in yield determination. Tissue samples were sent to Waypoint Analytical for nutrient quantification. Yields were recorded at harvest.

Table 1. Plant tissue sampling procedures for corn.

Timing	Plant Part	Number of Samples
V6-V8 (<12" tall)	Whole plant	15 - 20
V6-V8 (>12" tall)	Most recent mature leaf	15 - 20
VT-R1	Leaf opposite and below ear	15 - 20
R2-R5	Leaf opposite and below ear	15 - 20

Table 2. Plant tissue sampling procedures for soybeans.

Timing	Plant Part	Number of Samples
R1	Most recent mature leaf	20 - 30
R3	Most recent mature leaf	20 - 30
R5	Most recent mature leaf	20 - 30

Data Analysis

Tissue sample data were collected from Pioneer on-farm trials over multiple years. Soybean trials were sampled in 2017, 2018, 2019, and 2020 and corn trials in 2018, 2019, and 2020. Regression analyses were conducted to explore relationships between corn and soybean yield as well as nutrient levels at key growth stages during the season. Correlation coefficients for significant relationships were quantified and the simplest relationship with similar correlation coefficients was chosen. Correlation coefficients were then used to rank the effect of nutrients on yield.

return to table of contents

Sampling locations were assigned to one of four categories based on yield level:

1. Maximum yield (> 1 std. dev. above the mean)
2. High yield (< 1 std. dev. above the mean)
3. Below average (< 1 std. dev. below the mean)
4. Low yield (> 1 std. dev. below the mean)

Nutrient sufficiency ranges were created based on nutrient levels measured at locations in the maximum yield category for both corn and soybean. Maximum yield locations ranged from 270 to 474 bu/acre in corn and 86 to 123 bu/acre in soybeans. These ranges (and means) were compared to commonly published sufficiency ranges.

Results

Results showed that higher yielding crops generally had higher overall nutrient levels than lower yielding crops. Nutrient levels differed significantly among yield level categories for both corn and soybeans (Figure 2).

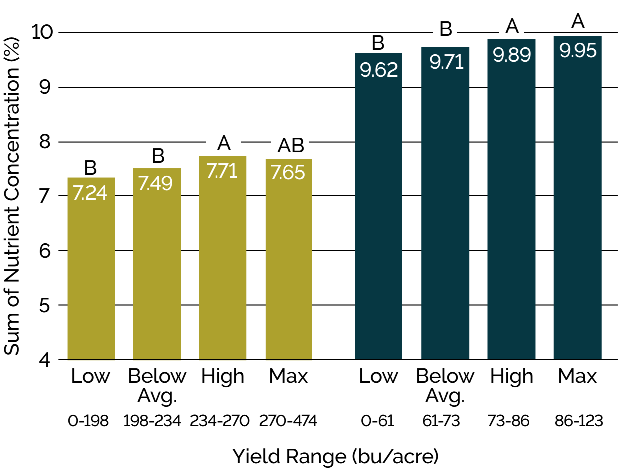


Figure 2. Mean comparison of sum total of measured nutrient tissue concentrations across 4 yield levels in corn and soybean. Sum of nutrient concentration is equal to % N+P+S+K+Mg+Ca+Na+*Fe+Mn+Zn+Cu+B+Mo+Al*.

Values with the same letter within a crop are not significantly different.

Analysis of yield correlation to individual nutrients showed many significant relationships. There were correlations between nutrient levels and yield for both corn and soybean (Table 3 and 4). Tissue concentration ranges for maximum yield as well as descriptions of the correlations (effect) are shown. The characteristics of correlations between yield and concentrations of individual nutrients suggested by the analysis varied:

- **Positive** – Yield increase with higher concentration
- **Inverse** – Yield decrease with higher concentration
- **Peak** – Yield is maximized at a specific level (shown in parentheses)
- **Trough** – Yield was greater at the top and bottom of the range

In general, more nutrients were critical in early stages of the corn crop, whereas in soybean, many nutrients were critical season-long. Overlap among key nutrients existed across the two crops. Some relationships were positive, some were inverse, and others indicated a peak or plateau in yield response to nutrient level.

Table 3. Nutrient tissue sample value statistics for relationship to yield in corn by growth stage. Nutrients are ranked by correlation coefficient (R^2). Only those nutrients with a Pr>F <0.10 were included.

Corn V6-V8 Growth Stage

Nutrient	R^2	Fn	Max Yield Range	Effect
K (%)	0.067	Linear	2.97-3.38	Positive
Fe (ppm)	0.040	Quad	168-207	Peak (250)
Al (ppm)	0.039	Quad	77-109	Peak (175)
Zn (ppm)	0.036	Linear	31.0-39.7	Peak (75)
N (%)	0.027	Linear	3.8-4.1	Positive
Cu (ppm)	0.022	Quad	11.0-13.5	Trough (15)
Mn (ppm)	0.021	Quad	66.8-94.9	Peak (225)
Na (%)	0.015	Linear	0.016-0.023	Positive
B (ppm)	0.015	Linear	10.2-14.3	Positive
S (%)	0.014	Linear	0.24-0.28	Positive
Cu (ppm)	0.011	Linear	12.0 - 16.0	Positive

Corn VT-R1 Growth Stage

Nutrient	R^2	Fn	Max Yield Range	Effect
Zn (ppm)	0.032	Cubic	26.5-38.6	Peak (90)
Al (ppm)	0.024	Quad	41-60	Peak (200)
Fe (ppm)	0.021	Quad	116-137	Peak (250)
Na (%)	0.019	Cubic	0.016-0.024	Peak (0.065)
B (ppm)	0.009	Linear	9.1-12.8	Positive
K (%)	0.009	Linear	2.18-2.46	Positive
Zn (ppm)	0.032	Cubic	26.5-38.6	Peak (90)
Al (ppm)	0.024	Quad	41-60	Peak (200)

Corn R2-R5 Growth Stage

Nutrient	R^2	Fn	Max Yield Range	Effect
Cu (ppm)	0.089	Cubic	10.5-13.3	Peak (12.5)
B (ppm)	0.046	Linear	10.7-17.7	Positive
Mg (%)	0.043	Linear	0.22-0.27	Inverse
K (%)	0.035	Linear	1.70-2.22	Inverse

Nutrient sufficiency ranges generated based on samples taken at maximum yield locations (>270 bu/acre in corn and >86 bu/acre in soybeans) were slightly or substantially higher than previously published ranges in many cases.

Table 4. Nutrient tissue sample value statistics for relationship to yield in soybean by growth stage. Nutrients are ranked by correlation coefficient (R^2). Only those nutrients with a Pr>F <0.10 were included.

Soybean R1 Growth Stage				
Nutrient	**R^2**	**Fn**	**Max Yield Range**	**Effect**
P (%)	0.049	Linear	0.48-0.54	Positive
Zn (ppm)	0.046	Linear	49-57	Positive
Cu (ppm)	0.046	Cubic	10.8-12.3	Peak (10)
K (%)	0.035	Linear	2.3-2.5	Positive
Mg (%)	0.033	Cubic	0.43-0.46	Positive
Na (%)	0.014	Quad	0.016-0.019	Inverse
Al (ppm)	0.012	Linear	47-73	Positive

Soybean R3 Growth Stage				
Nutrient	**R^2**	**Fn**	**Max Yield Range**	**Effect**
P (%)	0.148	Cubic	0.50-0.57	Positive (>0.5)
Mn (ppm)	0.086	Quad	86-102	Peak (150)
Zn (ppm)	0.066	Cubic	53-66	Peak (95)
Fe (ppm)	0.054	Quad	86-106	Keep <200
K (%)	0.037	Linear	2.06-2.22	Positive
Mg (%)	0.034	Linear	0.39-0.43	Positive
Cu (ppm)	0.016	Quad	10.8-11.7	Peak (11.5)
Ca (%)	0.015	Quad	1.07-1.20	Keep <1.5
B (ppm)	0.007	Linear	45-51	Linear

Soybean R5 Growth Stage				
Nutrient	**R^2**	**Fn**	**Max Yield Range**	**Effect**
Zn (ppm)	0.184	Linear	58-66	Positive
Mn (ppm)	0.14	Quad	132-161	Peak (200)
B (ppm)	0.105	Quad	49-57	Positive (>40)
Cu (ppm)	0.091	Quad	9.3-11.1	Trough (<15)
Mg (%)	0.091	Cubic	0.36-0.41	Peak (0.475)
S (%)	0.076	Cubic	0.29-0.32	Peak (0.33)
P (%)	0.053	Cubic	0.36-0.40	Peak (0.55)
Al (ppm)	0.046	Cubic	21-26	Peak (25)
Ca (%)	0.035	Cubic	1.59-1.83	Peak (2.5)
N (%)	0.037	Linear	5.25-5.48	Positive
Fe (ppm)	0.021	Linear	93-113	Inverse
Na (%)	0.014	Linear	0.018-0.022	Inverse

Sufficiency ranges for nitrogen (N) and potassium (K) during vegetative stages in corn were substantially higher than previously published ranges (Table 5). Numerous other nutrients had ranges that were slightly higher or narrower than published ranges at one or more growth stages. Sufficiency ranges for many nutrients were identified to be at the lower end of the published ranges. In six of the nutrient x growth stage combinations, luxury feeding is likely occurring. In four of the nutrient x growth stage combinations, the published range for the nutrient could be deleterious to yield.

Table 5. Nutrient tissue sufficiency ranges for maximum yield corn at critical growth stages. Colors indicate differences from previously published nutrient sufficiency ranges.

Nutrient	Corn Growth Stage		
	V6-V8	**VT-R1**	**R3-R5**
N (%)	3.8 - 4.1	3.2 - 3.4	2.6 - 3.0
P (%)	0.33 - 0.38	0.32 - 0.35	0.26 - 0.30
K (%)	2.97 - 3.38	2.17 - 2.45	1.7 - 2.22
S (%)	0.24 - 0.28	0.20 - 0.23	0.20 - 0.23
Mg (%)	0.20 - 0.26	0.20 - 0.26	0.22 - 0.27
Ca (%)	0.47 - 0.57	0.56 - 0.72	0.61 - 0.68
Na (%)	0.016 - 0.023	0.016 - 0.024ǂ	0.018 - 0.027
B (ppm)	10.2 - 14.3	9.2 - 13.0	10.7 - 17.7
Zn (ppm)	31.0 - 39.7*	26.5 - 38.7*	29.1 - 40.9
Mn (ppm)	66.8 - 94.9*	57.5 - 74.5	46.5 - 116.8
Fe (ppm)	168 - 207ǂ	116 - 137*	97 - 118
Cu (ppm)	11.0 - 13.5ǂ	10.6 - 12.0	10.5 - 13.3ǂ
Al (ppm)	77 - 109*	41 - 61*	34 - 52

Range extends beyond published nutrient sufficiency ranges
Range narrows in high end of published ranges
Range narrows in low end of published ranges

* Data indicate a peak in yield relative to nutrient level, suggestive of luxury feeding at high levels. If level is above this range, consult your Pioneer agronomist for specific recommendations.

ǂ Data indicate a decrease in yield relative to nutrient level beyond a certain point, suggestive of possible toxicity at high levels or antagonistic nutrient interaction. If level is above this range, consult your Pioneer agronomist for specific recommendations.

return to table of contents

In soybean, N sufficiency ranges were higher than published ranges at two of the three critical growth stages (Table 6). Ranges for phosphorus (P), K, boron (B), zinc (Zn), and manganese (Mn) were also greater than published ranges at one or more growth stages. Yet again, many nutrient sufficiency ranges were found to be at the lower end of published ranges. Fourteen combinations of nutrient x growth stage existed where yield would suffer from published ranges in this data set; three cases of luxury feeding existed.

Table 6. Nutrient tissue sufficiency ranges for maximum yield soybeans at critical growth stages. Colors indicate differences from previously published nutrient sufficiency ranges.

Nutrient	Soybean Growth Stage		
	R1-R2	R2-R3	R4-R5
N (%)	5.25 - 5.48	5.24 - 5.54	4.91 - 5.29
P (%)	0.48 - 0.54	0.50 - 0.57	0.36 - 0.40ǂ
K (%)	2.33 - 2.54	2.06 - 2.22	1.52 - 1.70
S (%)	0.28 - 0.30	0.28 - 0.30	0.29 - 0.31
Mg (%)	0.43 - 0.46ǂ	0.39 - 0.43	0.36 - 0.41*
Ca (%)	1.13 - 1.26	1.07 - 1.20ǂ	1.59 - 1.83ǂ
Na (%)	0.016 - 0.019ǂ	0.014 - 0.017	0.018 - 0.022ǂ
B (ppm)	42 - 47	45 - 51	49 - 57
Zn (ppm)	49 - 57	53 - 60*	58 - 66
Mn (ppm)	72 - 85	88 - 102ǂ	132 - 161*
Fe (ppm)	126 - 156ǂ	86 - 106ǂ	99 - 113ǂ
Cu (ppm)	10.8 - 12.3ǂ	10.8 - 11.7ǂ	9.3 - 11.1ǂ
Al (ppm)	47 - 73	21 - 28	21 - 26ǂ

Range extends beyond published nutrient sufficiency ranges
Range narrows in high end of published ranges
Range narrows in low end of published ranges

* Data indicate a peak in yield relative to nutrient level, suggestive of luxury feeding at high levels. If level is above this range, consult your Pioneer agronomist for specific recommendations.

ǂ Data indicate a decrease in yield relative to nutrient level beyond a certain point, suggestive of possible toxicity at high levels or antagonistic nutrient interaction. If level is above this range, consult your Pioneer agronomist for specific recommendations.

Next Steps

Pioneer research into nutrient management practices for maximizing corn and soybean yields is ongoing and includes further analysis into data collected from 2017 to 2020 as well as using insights from these analyses to inform further research projects. Specific areas of focus for next steps include:

1. Analysis to explore nutrient ratios at high yield levels
2. Development of nutrient application recommendations that account for both nutrient sufficiency levels and greater biomass accumulation at high yield levels
3. Application of tissue sampling and biomass measures to evaluate effects of nutrient management practices

Conclusions

Results from the multi-year tissue sampling study conducted by Pioneer agronomists showed that tissue nutrient concentrations are different at higher yield levels than lower yield levels and different in many cases from existing published values. Some nutrients are more critical to yield than others, and more is not always better. Crop producers should pay especially close attention to nutrients that showed a peak or plateau in yield response or that declined in concentration at higher yield levels.

Nutrient management programs for extremely high-yielding crops need to account for higher tissue sample nutrient values as well as the greater total biomass produced at higher yield levels. Improving nutrient availability in the soil and plant uptake by using practices like biologicals or fertilizer placement will be critical in continuing to drive yields upward. Ongoing research to elucidate relationships or ratios of nutrients at key timings will help drive more efficient and environmentally friendly management practices.

Yield is a complex equation with many parts. With clearly defined sufficiency values, growers and advisors can likely use tissue sampling to evaluate inputs based on the ability to reach these values, even in the absence of yield. The next steps in this research effort will focus on biomass accumulation and its relationship to yield level as well as genetic/hybrid interactions in nutrient management.

return to table of contents

corn planting depth: soil temperature and moisture flux in the furrow

Alex Lindsey, Ph.D., and **Peter Thomison, Ph.D.**, Department of Horticulture and Crop Science, Ohio State University

Shallow planting shortened the time to the start of corn emergence but lengthened the duration of emergence, resulting in a less uniform stand.

Soil moisture was lower and more variable closer to the soil surface, which likely contributed to the less-uniform emergence with shallower planting.

Planting depth affected yield in a higher organic matter field but had no effect in a lower organic matter field.

Objectives

- A three-year field study was conducted to assess effects of soil temperature and moisture flux on emergence of corn planted in fields with varying soil classifications and characteristics and to determine the impact of planting depth on emergence and yield.
- This research was conducted by Dr. Peter Thomison and Dr. Alex Lindsey, Ohio State University, as a part of the Pioneer Crop Management Research Awards (CMRA) Program.

Study Description

Years: 2017 to 2019

Locations: South Charleston, Ohio

- Field 1: Strawn-Crosby silt loam (2.0-3.1% organic matter)
- Field 2: Kokomo loam (3.8-4.6% organic matter)
    - » Research fields were within 0.5 miles of each other so were subject to similar weather conditions.

Planting Dates:

- May 16 (2017), May 11 (2018), June 4 (2019)

Previous Crops:

- Soybean (all years)

Nitrogen Fertility Program:

- 2017-2018: 180 lbs N/acre applied as anhydrous ammonia (82-0-0) prior to planting
- 2019: 180 lbs N/acre applied as UAN (28-0-0) at V6 (program changed due to excessive spring rain in 2019)

Seeding Rate: 35,300 seeds/acre

Experimental Design: Randomized complete block design with 4 replications of planting depth treatments; plots were 10 x 150 ft (four 30-inch rows)

Planting Depth (Targeted):

- 1 inch, 2 inches, 3 inches

Data Collection and Analysis

- A combination soil moisture and soil temperature sensor (CS655, Campbell Scientific) was installed at seeding depth in each plot. Once installed, the sensors were connected to a datalogger and continuously recorded average temperature as well as soil moisture every 20 minutes until the V3 growth stage.
- Soil moisture data was adjusted to plant available water content (AWC) for each field using field-specific calibrations (AWC of 100% = field capacity; AWC of 0% = permanent wilting point).
- Emergence curves were modeled using a sigmoid function:

$$Emerge_t = d + \frac{a}{1 + e^{(b - c*x)}}$$

where $Emerge_t$ (emergence at point t) is the dependent variable: x is days after planting (DAP) or soil accumulated growing degree days (GDDs, 50 °F base); and a, b, c, d were the model parameters used to best fit the equation.

Results

- Actual planting depths for the two and three inch treatments were slightly less than the targeted depths in both fields (Table 1).

Table 1. Actual depth to seed, time to 50% emergence (T_{50}), and the time from 10% emergence (T_{10}) to 90% emergence (T_{90}) as measured in calendar days and soil accumulated GDDs for each planting depth treatment and field.

Field	Target Depth	Actual Depth	T_{50}	T_{10}-T_{90}	T_{50}	T_{10}-T_{90}
	inches		*days*		*GDDs*	
Crosby (low OM)	1	1.1 c	5.0	2.2	131.2	37.8
	2	1.7 b	5.1	1.5	127.0	36.6
	3	2.5 a	5.8	1.5	132.8	35.1
Kokomo (high OM)	1	1.0 c	6.9	5.9	170.6	86.1
	2	1.8 b	6.3	4.0	162.0	57.9
	3	2.4 a	6.7	2.9	159.6	47.5

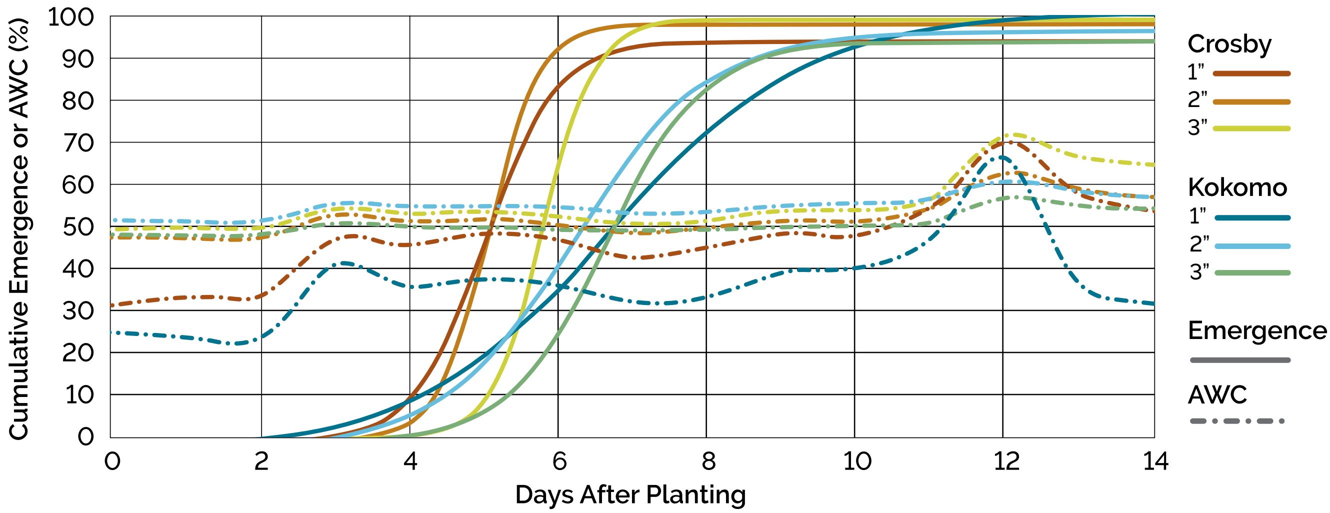


Figure 1. Cumulative daily emergence and available water content for the 1, 2, and 3-in planting depths in the Crosby (low organic matter) and Kokomo (high organic matter) fields. Models were built for data collected from 2017-2019.

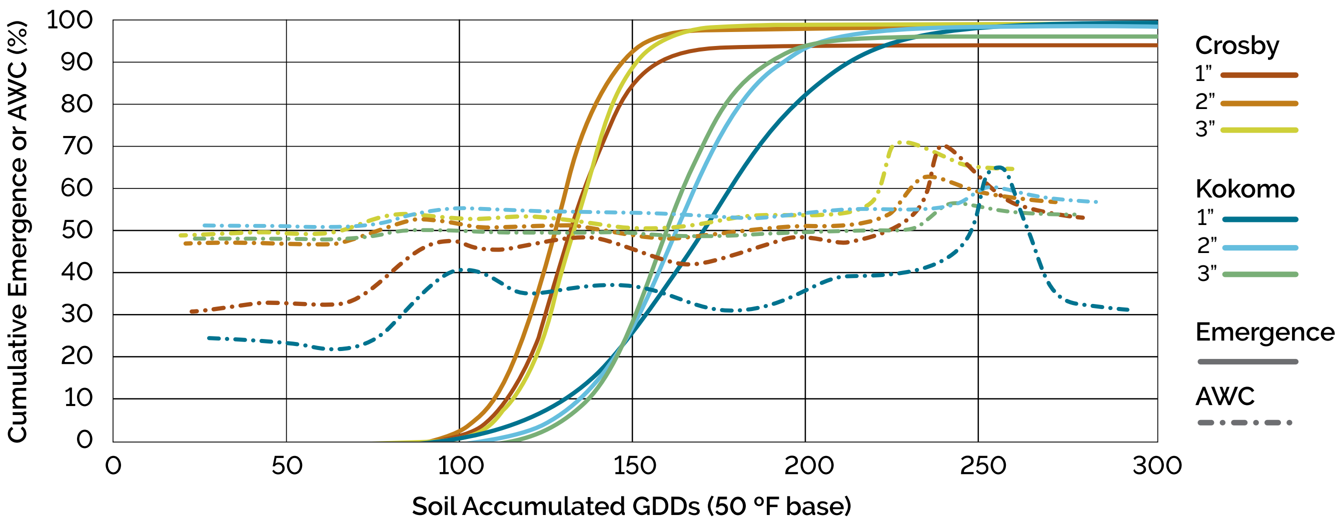


Figure 2. Cumulative emergence and available water content for the 1, 2, and 3-in planting depths in the Crosby (low organic matter) and Kokomo (high organic matter) fields as influenced by soil GDD accumulation. Models were built for data collected from 2017-2019.

- Emergence in the higher organic matter field was delayed slightly compared to the lower organic matter field.
- The time to 50% emerged for all depths was within 0.8 days and 5.8 GDDs for the low organic matter field and within 0.6 days and 11.0 GDDs for the high organic matter field.
- In both fields, the patterns of emergence differed with planting depth. Emergence commenced earliest with the shallowest planting depth but also had the longest emergence window (time from 10 - 90% emerged).
- The longer emergence window with shallow planting can be seen in the flatness of the sigmoidal curves in Figure 1 where model parameters b and c were significantly different ($P < 0.05$) between the 1-in and 3-in emergence curves in both fields.
- The longer emergence window with shallower planting may have been due to differences in available water content at planting, where AWC was 20-25% less at the shallowest depth.
- Soil water increased after approximately three days in the trials due to timely rainfall (Figure 1).
- Emergence began latest with 3-inch planting depth in both fields (Figure 1) but exhibited the shortest T_{10}-T_{90} interval (Table 2).
- When evaluating emergence as driven by soil accumulated GDDs, the patterns changed from calendar dates slightly (Figure 2).
- The difference between emergence curves for the 1-in and 3-in depths were no longer evident in the low organic matter field but were still evident in the high organic matter field.
- This was also reflected in the T_{10}-T_{90} values where the low organic matter field differed by 2.7 GDDs between depths, but the high organic matter field differed by 38.6 GDDs (Table 1).

return to table of contents

Figure 3. Installation of the soil moisture and temperature sensor in furrow in 2017.

- Planting depth did not affect plant biomass at the V3 growth stage, dominant ear leaf number, total leaf number, percent of runt plants, or stalk strength (data not shown).
- Planting depth did impact kernel per ear and had a marginal effect on total kernel dry weight per plant (Table 2) where the greatest values were observed at the 3-in depth.
- Basal emptiness was greatest with 1-in planting depth.
- The difference in total kernel number may have been driven by improved pollination or decreased kernel abortion leading to marginally greater kernel numbers per row (data not shown).
- Across years, there was a significant (P = 0.030) planting depth by field interaction for corn yield (Table 3).
  - » Yields were similar across planting depths in the low organic matter field (ranging from 213 - 217 bu/acre).
  - » In the high organic matter field, corn yield was significantly lower with the 1-in planting depth compared to the 2-in and 3-in depths.
  - » Lower yield with shallow planting may have been a result of the longer emergence window (T_{10}-T_{90}) as shown in Table 1.

Table 2. Ear yield components as impacted by planting depth across fields. There were no significant field or depth-by-field interactions for any yield component. Data were combined across 2017-2019 for analysis. Letters denote differences for the interaction of field by planting depth.

Target Depth	Kernels Per Ear	Basal Empty	100 Kernel Weight	Total Kernel Dry Weight Per Plant
inches	*——— count*	*———*	*——— g*	*———*
1	467 b	1.31 a	27.8	132.4
2	484 ab	1.21 ab	27.7	135.7
3	508 a	1.16 b	27.7	141.8
P-Value	0.009	0.021	0.958	0.112

Table 3. Grain yield as affected by planting depth across years. Letters denote differences for the interaction of field by planting depth.

Field	Target Depth	Actual Depth
	inches	*bu/acre*
Crosby (low organic matter)	1	217 ab
	2	216 ab
	3	213 ab
Kokomo (high organic matter)	1	211 b
	2	227 a
	3	232 a
P-Values	Field	0.690
	Depth	0.147
	Field x Depth	0.030

Conclusions

- Planting depth impacted emergence patterns in both a higher and lower organic matter field.
- In each field, the emergence was most uniform at the 2-in and 3-in planting depth settings, which resulted in actual depths of 1.7-2.1 and 2.5-2.7 in on average, respectively.
- Although first emergence was delayed in the 3-in depth treatment compared to the 1-in depth, the final emergence was reached more rapidly at the 3-in depth compared to the 1-in depth.
- Less uniform emergence with shallow planting was likely driven by lower and more variable soil moisture in combination with faster temperature accumulation.

Pioneer Agronomy

Planting Depth Effects on Corn Emergence

- Paul Yoder, Field Agronomist

return to table of contents

corn emergence and uniformity in high-residue fields

Ross Ennen, *Sr. Research Associate, and* **Mark Jeschke, Ph.D.,** *Agronomy Manager*

Summary

- Hybrid selection is crucial to establishing productive stands and achieving high yield potential. Corteva Agriscience conducts early planted trials in high-residue fields to evaluate hybrid performance under early season stress.
- Stress emergence and high-residue suitability ratings for Pioneer® brand corn products give guidance to growers for early planting and reduced-tillage systems.
- In stressful, high-residue environments, Pioneer brand corn products with higher stress emergence scores establish higher stands, on average, than ones with lower scores.
- Pioneer brand corn products with highly suitable (HS) and suitable (S) high-residue suitability ratings produced higher and more uniform stands in high-residue locations than hybrids with a poorly suited (X) rating.
- High-residue environments are more commonly associated with non-uniform emergence and "runt" plants due to uneven planting depth; temperature and moisture variability; and physical residue impediments.
- The use of row cleaners and other planter modifications can improve seed-to-soil contact, promote soil warming, and help reduce runt plants.
- Planting at soil temperatures above 50 °F (10 °C) or prior to a warming trend promotes rapid and uniform emergence in high-residue fields.

return to table of contents

Introduction

Trends toward early corn planting and conservation tillage systems increase the risk of reduced and uneven stands as well as subsequent yield loss. Soil temperatures at planting are typically well below the optimal temperature for corn emergence, which is around 85 °F (29 °C). Soils under heavy residue are typically wetter and cooler than bare soils in the early spring, adding extra cold stress and disease pressure. In addition to moisture and temperature disparities within the seedbed, uneven residue can also cause variations in planting depth, all contributing to uneven emergence and "runt" plants (plants at least one leaf stage behind most others). To improve stand establishment, it is critical to mitigate these risks with good management practices.

Hybrid Selection for High-Residue Fields

Every year, Corteva Agriscience conducts extensive corn emergence trials under a wide range of stressful environments and soil types, including early planted and reduced-tillage fields. Using data from stressful locations, as well as lab assays that mimic extreme cold stress, Pioneer brand corn products are assigned a stress emergence rating, which is based on the genetic potential for a hybrid to establish stand under stress conditions (e.g., cold, wet soils or environments with short periods of severe low temperatures). Stress emergence ratings range from 1 to 9. Ratings of 7 to 9 indicate very good potential to establish normal stands under such conditions; a rating of 5 or 6 indicates average potential to establish normal stands under moderate stress conditions; and ratings of 1 to 4 indicate the product has below-average potential to establish normal stands under stress and should not be used if severe cold conditions are expected immediately after planting. In emergence trials conducted in high-stress environments, hybrids with higher ratings typically have greater stand establishment than lower rated hybrids (Figure 1).

Pioneer Agronomy

Reviewing Stress Emergence in Corn

- Gary Brinkman, Field Agronomist

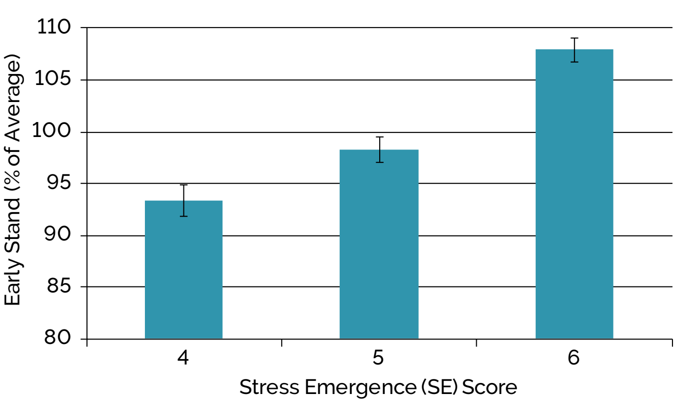


Figure 1. Relationship between early stand and stress emergence rating in stressful, high-residue Corteva Agriscience research locations in 2018.

Error bars represent +/- the standard error of the mean where n = the number of hybrids tested in each SE score category.

Pioneer brand corn products are also assigned high-residue suitability (HRS) ratings of highly suitable (HS), suitable (S), or poorly suited (X) for hybrid performance in reduced-tillage systems. Disease and stress emergence traits are key in high-residue fields. The HRS rating is calculated from the following five trait scores: stress emergence, northern corn leaf blight, anthracnose stalk rot, gray leaf spot, and Diplodia ear rot. The relative importance of each trait can vary by region. Therefore, the HRS rating is adjusted for each market region in North America.

In Corteva Agriscience high-residue emergence trials, Pioneer® brand corn products with an HRS rating of poorly suited (X) produced lower stands on average than ones with a rating of suitable (S) or highly suitable (HS), regardless of temperature stress level (Figure 2).

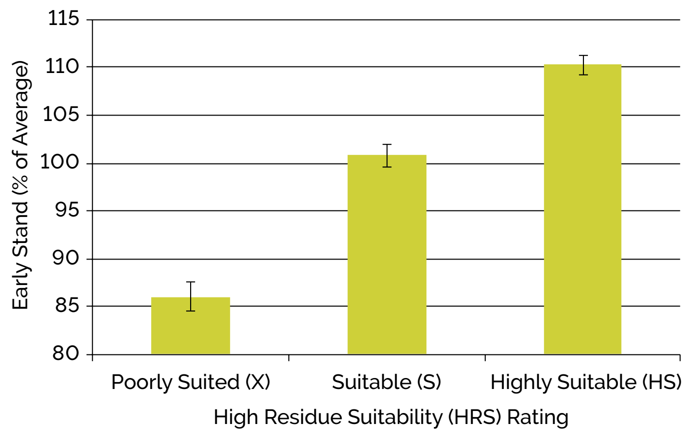


Figure 2. Relationship between early stand and high-residue suitability (HRS) rating in high-residue Corteva Agriscience research locations in 2018.

Error bars represent +/- the standard error of the mean where n = the number of hybrids tested in each HRS rating category.

Reduced-tillage systems can also lead to uneven stands and runts. In Corteva Agriscience trials, hybrids with a highly suitable (HS) rating tend to produce fewer runt plants than suitable (S) and poorly suited (X) hybrids (Figure 3).

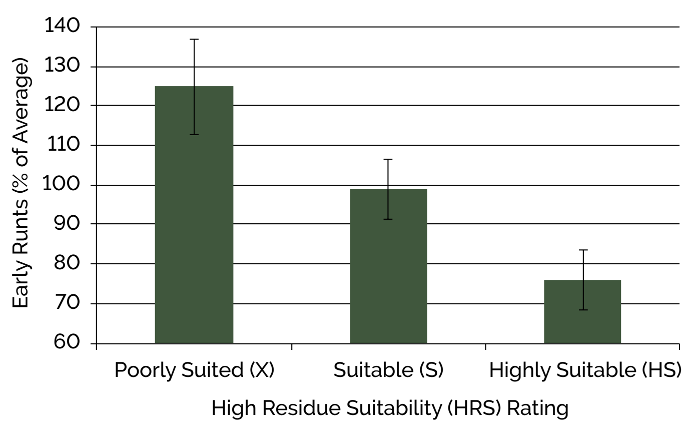


Figure 3. Relationship between early runts and high-residue suitability (HRS) rating in high-residue Corteva Agriscience research locations in 2018.

Error bars represent +/- the standard error of the mean where n = the number of hybrids tested in each HRS rating category.

return to table of contents

Stress Emergence

Genetic potential for a hybrid to establish stand under stress conditions (1-9 scale)

- 7-9 = Good emergence potential
- 5-6 = Average potential
- 1-4 = Below-average potential

High-Residue Suitability

Ratings of hybrid performance in reduced-tillage systems

- Highly Suitable (HS)
- Suitable (S)
- Poorly Suited (X)

Suitability rating based on field observations and a weighted calculation of ratings for:

- Gray leaf spot resistance
- Stress emergence
- Anthracnose stalk rot
- Northern corn leaf blight
- Diplodia ear rot

High-residue suitability ratings may vary by environment and geography.

Planting in High-Residue Fields

Reduced-tillage systems present challenges to growers. Heavy residue can hinder planting efforts (Figure 4). Planting problems, such as hairpinning, sidewall compaction, lack of consistent seeding depth, and failure of the furrow to close properly over the seed, reduce critical seed-to-soil contact.

To help improve stand establishment in high-residue systems, it is important to set up and operate the planter appropriately. Below are some general guidelines for planting in high-residue seedbeds. However, since planter operation may vary widely with soil type and conditions, it is helpful to consult with your agronomist or other no-tillers in your area to determine the best equipment and practices for your farm.

Figure 4. Heavy residue in corn-on-corn field provides physical barriers to seedling emergence in Corteva Agriscience corn-emergence trials.

Row Cleaners

The use of row cleaners ("residue managers") to clear the planting row of residue can aid the planting and emergence process by removing the physical barriers on the soil surface and speeding up soil warming after a cold spell (Figure 5). Spoked or spider row cleaners can be advantageous in heavy residue and wet soils. These row cleaners can be set to move residue without disturbing the soil, allowing warming and drying on the row. Floating row cleaners that better follow the contours of the soil surface are also available from some manufacturers.

Figure 5. Row cleaner failure (middle row) reduced stand and vigor compared to cleaned strip (right row) in corn-on-corn field near Schuyler, NE.

Planting Depth

Planting slightly deeper (at least two inches deep) can help overcome some of the moisture and temperature variability found near the soil surface in reduced-till soils. An aggressive setting for down pressure may be needed to keep gauge wheels in solid contact with the ground. Seed firmers can also help with seed placement in the planting slot.

Closing Wheels

Several variations of closing wheels are available to help close the planting furrow, depending on soil tilth and moisture. Spiked closing wheels tend to work better on heavy or wet soils, reducing sidewall compaction and closing the planting slot. Alternatively, growers can use one spiked wheel with one rubber wheel.

Planting Date

Because of its impact on stand establishment and yield, choosing a planting date is one of the most important crop management decisions for growers. Planting when the soil is too wet can interfere with row closure and cause sidewall compaction. Allocate extra time for the soil under heavy residue to dry before planting. Soil temperature data collected at Corteva Agriscience research plots show that planting at soil temperatures below 50 °F (10 °C) often leads to reduced stands. Also, it is important to monitor weather patterns. Snow, cold rain, or extended periods of cold weather after planting imposes significant stress on corn.

Good residue management practices are crucial to realize the benefits of reduced-tillage systems. Selecting the right hybrid, modifying the planter, and choosing a suitable planting date all help improve stand establishment in high-residue fields.

corn stand evaluation and replant considerations

Mark Jeschke, Ph.D., *Agronomy Manager*

Many different stress factors are capable of reducing corn stands, such as:

- Cold or Wet Soils
- Insect Feeding
- Unfavorable Weather Conditions

Stand Counts

- Take several sample counts to represent the field.
- Sample a length of row equal to 1/1,000th of an acre.
- Measure off the distance appropriate for your row width, count the number of live plants, and multiply by 1,000 to obtain an estimate of plants/acre.

Row Width	Length of Rows
38 in	13 ft 9 in
36 in	14 ft 6 in
30 in	17 ft 5 in
22 in	23 ft 9 in
20 in	26 ft 2 in
15 in	34 ft 10 in

- In situations like flooding damage, only a portion of the field may need to be considered for replant.
- Frost or hail can damage a wide area. In this case, plant density and health should be assessed across the entire field.
- When an injury event, such as frost or hail, occurs, it is best to wait a few days to perform a stand assessment as it will allow a better determination of whether or not plants will recover.

Figure 1. Growth of green tissue near the growing point indicates that this plant would have recovered.

Figure 2. Soft, translucent tissue near the growing point indicates that this plant will not recover.

Stand counts should be taken randomly across the entire area of a field being considered for replant; this may include the entire field or a limited area where damage occurred.

After a plant stand has been assessed, it is important to consider other factors, such as:

- Is the stand consistent; are gaps large gaps present?
- Will the stand have adequate crop canopy to assist with weed control and irrigation efficiencies?
- Will replanting provide an economic gain?
- Are remaining plants healthy and relatively equal in maturity?

Replant Yield Potential

- The expected yield from the current stand should be compared to expected replant yield.

Table 1. Yield potential for a range of planting dates and final plant populations (Nafziger, 2020).

Planting Date	Plant Population (1,000 plants/acre)						
	20	23	26	29	32	35	38
	% of maximum yield						
April 1-10	84	88	91	94	97	98	99
April 11-20	84	89	92	95	97	99	100
April 21-30	84	88	92	95	97	99	99
May 1-10	83	87	90	93	95	97	98
May 11-15	81	85	89	91	93	95	96
May 16-20	79	83	87	90	92	93	94
May 21-25	78	82	85	88	90	91	92
May 26-31	75	79	82	85	87	88	89
June 1-5	73	76	79	82	84	85	86

Other Factors to Evaluate

- **Stand Uniformity:** An uneven stand will yield less than a relatively even stand with the same number of plants.
- **Plant Health:** Plants that are severely injured or defoliated will have reduced photosynthetic capability and a lower yield potential.

Corn yield is influenced by stand density as well as stand uniformity:

- Variation in plant size can have a negative impact on yield.
- Plants with delayed emergence or development are at a competitive disadvantage with larger plants in the stand and will have reduced leaf area, biomass, and yield.

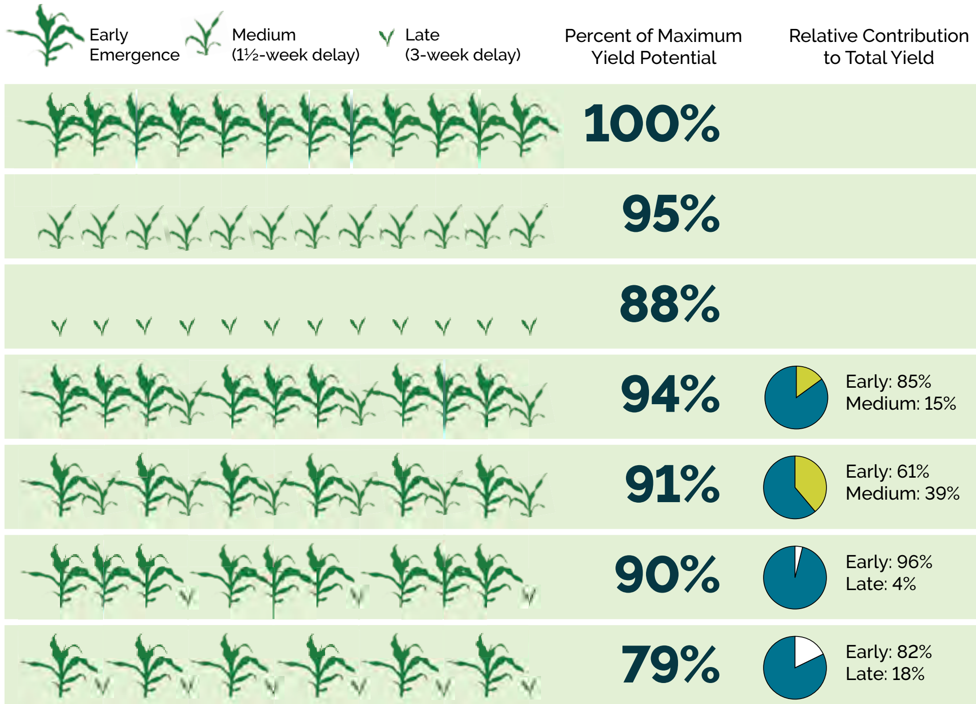


Figure 3. Yield potential of delayed and uneven corn stands (Carter et al., 1989).

Profitability of Replant

Even if replanting will increase yield, the yield increase must be sufficient to pay for all of the costs associated with replant, such as:

- Extra herbicide or tillage costs
- Planting costs
- Increased grain drying costs

Also consider these factors when making a replant decision:

- Probability of an autumn freeze prior to physiological maturity of replanted corn
- Increased susceptibility of late-planted corn to summer drought or disease and insect pests, such as gray leaf spot and European corn borer

Maturity Selection for Delayed Planting

- A frequent question pertaining to replanting corn is how full season of a hybrid can be planted and still reach normal physiological maturity.
- When considering which hybrid to replant, consider growing degree units (GDU) accumulation between the planting date and average first frost date as well as hybrid GDU requirements to reach physiological maturity.
- Research has shown that corn can adjust its growth and development, requiring fewer growing degree units (GDU's) to reach maturity, when planted late. Late-planted corn showed a reduction in GDU requirements of about six GDU's per day of planting delay.
- To help guide hybrid selection decisions for delayed planting and replant scenarios, Pioneer researchers conducted planting-date studies over 18 years that included hybrids with a range of different comparative relative maturities.
- Results indicate that farmers may consider switching from a full season to an early maturity hybrid if replanting after May 25 and from a mid-maturity to an early maturity hybrid if replanting after June 3 (Figure 4).

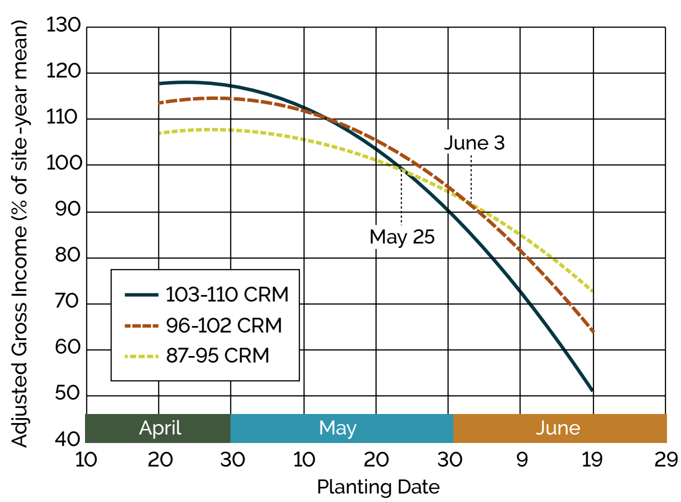


Figure 4. Relative profitability of full-season, mid-maturity, and early maturity hybrids in 29 North-Central Corn Belt environments over 17 years of Pioneer research. North-Central Corn Belt studies included 29 environments in South Dakota, Minnesota, Iowa, Michigan, and Ontario and a total of 96 different Pioneer® brand corn products ranging from 87 to 110 CRM.

Adjusted gross income/acre was calculated as gross income at a corn price of $3.50/bu minus drying costs and discounts for low test weights. Higher corn price would move switching date later.

Drying costs were calculated based on 4 cents/bu for each point of moisture above 15%. Higher drying costs would move switching date earlier.

diagnosing chilling and flooding injury to corn

***Ross Ennen**, Sr. Research Associate, and*
***Mark Jeschke, Ph.D.**, Agronomy Manager*

Summary

- Farmers often plant corn very early to increase yield potential and to avoid delays later in the planting season.
- Early planting offers potential advantages, but it also carries greater risk of cold injury and damage from pests.
- Ultra-early planted corn may require up to four weeks to emerge, depending on soil and weather conditions.
- During this time, the seed and emerging seedling are highly vulnerable to damage from insects, diseases, and herbicide exposure. The emerging seedling may also encounter adverse field conditions, such as crusting or ponding.
- In addition, chilling temperatures caused by rain, melting snow, or cold soils can damage the seed during imbibition or injure the delicate structures of the emerging seedling.
- These stresses are often compounded under no-till conditions due to lower soil temperatures and additional water in the crop residue.

Introduction

Choosing corn planting date is an important management practice for maximizing corn yield potential. Often that date is dictated by prevailing weather and soil conditions as well as the size of acreage to be planted. Historically, corn planting dates have moved earlier due to lengthening of the frost-free season, improved stress tolerance of newer corn hybrids, and the desire to avoid planting delays that could reduce yields. Early-planted corn is subject to greater risk of encountering cold temperatures and adverse weather systems often associated with those early spring dates.

Corn is a warm-season crop with tropical origins. It is not surprising then that corn is susceptible to stresses that result from early planting under cold soil conditions. When corn is planted extremely early and soil temperatures are below 50 °F (10 °C), it is possible for corn seeds to remain in the soil up to 3 to 4 weeks prior to emergence. The length of this period will depend on the soil temperature and its water-holding properties. During this time, corn may encounter a range of stresses, including injury from pre-emergence residual herbicides, insect damage, and disease pressure.

Snow covering a recently-planted corn field on May 1, 2013.

Even more problems may result from the physical properties of the seedbed, including crusting, ponding, or saturated soils. In addition, cold temperatures resulting from cold rain or even snow can severely impact the seed. This article will discuss effects of cold soils and water on germination and emergence of corn, including diagnosing plant injury symptoms caused by chilling and flooding.

Pioneer Agronomy

How Cold Weather Impacts Corn Seed Emergence

- Aaron Vammer, Field Agronomist

Effect of Cold Soils and Water

The early spring seedbed is a very unfavorable environment for corn seeds. Though dry seeds can be stored unharmed for many years at -20 °F (-29 °C) or below, corn planted very early is at risk to cold injury and even death once the seeds begin to imbibe water. Early planting often exposes seeds to hydration with cold water, which can cause direct physiological damage. In addition, prolonged exposure to low temperatures reduces seed and plant metabolism and vigor; increases sensitivity to herbicides and seedling blights; and causes oxidation damage due to the effects of free radicals in the cell. Free radicals are unstable molecules that damage cells and organs. This damage is similar to damage that occurs in mammalian cells during aging and sun exposure.

When the dry seed imbibes cold water as a result of a cold rain or melting snow, imbibitional chilling injury may result. The cell membranes of the seed lack fluidity at low temperatures, and under these conditions, the hydration process can result in rupture of the membranes. Cell contents then leak through this rupture and provide a food source for invading pathogens. Cold water can similarly affect seedling structures as they begin to emerge.

Corteva Agriscience routinely conducts research studies on corn germination and emergence in stressful environments in fields where soil temperatures are at or below the minimum recommended threshold for planting corn. Results of these studies have shown that temperatures at or below 50 °F (10 °C) are often detrimental to the germination and emergence process, especially if they persist long after planting (Table 1).

Table 1. Planting dates, average soil temperature the week after planting, cumulative precipitation the week after planting, days to emergence, and final stand in Corteva Agriscience research plots in 2018.

Location	Plant Date	Soil Temp	Precip.	Days to VE*	Stand*
		°F	inches		%
Riverdale, MI**	April 11	38	1.19	23	73
Janesville, WI**	April 11	39	1.29	21	79
Johnston, IA**	April 12	42	1.54	19	83
Eau Claire, WI	April 27	51	0.46	10	89
Moorhead, MN	April 30	50	0.82	12	91
Olivia, MN	May 5	57	0.19	12	94
Flandreau, SD	May 4	NA	0.82	13	95

* Values reflect averages of multiple hybrids planted at each location.

** Locations characterized as high-stress environments for germination and emergence.

In Corteva research studies conducted in 2018, days to emergence and percent final stand varied considerably depending on the average soil temperature and rainfall during the week following planting. Three research locations experienced average soil temperatures below 50 °F (10 °C) with greater than 1 inch (2.5 cm) of rainfall the week following planting. These locations had substantially longer time to emergence and lower stand establishment than locations with soil temperatures above 50 °F (10 °C) and less rainfall. These data show that cold, wet soils after planting can have serious consequences for stand establishment. However, the degree of damage will vary with soil type and is generally greater in heavier or poorly drained soils.

return to table of contents

Flooding Effects on Emergence

Flooding can have as equally devastating effect as cold soils on seedling emergence and survival. Most corn hybrids can only survive for 24 to 48 hours under water with smaller seedlings suffering the most damage. Flooding damages corn biochemically. By impairing mitochondria, it causes release of free radicals, which damage cell membranes. Flooding also causes oxygen starvation and shifts the plant's metabolic processes to anaerobic fermentation. Resulting acidosis (low pH) can kill the cells. At a minimum, flooding reduces the plant's metabolic rate, making seedlings more sensitive to disease, insects, and herbicides. In fact, many disease-causing fungi, such as *Pythium,* thrive in standing water. Seedlings that are weakened by flooding or cold damage usually succumb to disease if the pathogen is present in the soil.

Flooding damage does not only occur in obvious ponded areas of a field. If fields are completely saturated to the soil surface and remain that way due to continual rain or limited drainage, seeds and non-emerged seedlings are under water. Flooding damage may occur in these areas just as in ponded areas.

Field with saturated soil following spring rainfall.

Diagnosing Poor Stand Establishment

Careful examination of damaged seedlings can provide clues into the likely causes of stand establishment problems following early planting or abnormally cold weather conditions. Table 2 lists the main symptoms and likely causes of early season damage. Figures 1-5 show diagnostic images of chilling and flooding damage to corn seedlings during germination and emergence.

Corteva Agriscience Research

For decades, Pioneer plant breeders have selected within the natural variation expressed by corn genotypes to develop hybrids with strong emergence and vigor characteristics under cool soil conditions. In the late 2000s, Pioneer introduced a new rating for Pioneer® brand corn products called *stress emergence*. Stress emergence is a measure of the genetic ability or potential to emerge in the stressful environmental conditions of cold, wet soils or short periods of severe low temperatures relative to other Pioneer brand products. Ratings of 7 to 9 indicate very good potential to establish normal stands under such conditions; a rating of 5 or 6 indicates average potential to establish normal stands under moderate stress conditions; and ratings of 1 to 4 indicate the product has below-average potential to establish normal stands under stress and should not be used if severe cold conditions are expected immediately after planting. Stress emergence is not a rating for seedling disease susceptibility, early growth, or speed of emergence.

Corteva research scientists are continuing to work to improve early season corn performance through conventional and molecular breeding as well as through rigorous testing of research and commercial hybrids. By identifying molecular markers and pathways associated with superior cold germination, Corteva researchers are beginning to develop an understanding of the genetic basis of stress emergence. This knowledge should eventually lead to even stronger early season performance in elite Pioneer brand corn products.

return to table of contents

Table 2. Corn seedling symptoms and likely causes.

Symptom	Likely Cause	Result
Stubby coleoptiles Leaves emerging prematurely	Imbibitional chilling or cold damage	Death, unless unprotected leaf reaches the surface
Brown tissue behind root tip Adventitious roots	Chilling damage Flooding	Chance for survival unless shoot meristem is damaged
Leafing underground Leaves growing along soil crust	Mechanical damage Soil crusting	Usually death as seedlings lose ability to penetrate soil
Corkscrew mesocotyl or coleoptile	Temperature fluctuations Herbicide injury	Seedling death
Fused coleoptile or bursting on side	Cold damage Genetic tendency	Seedling death
Rotted seed or mesocotyl Spotty wilting	Seedling disease	Seedling death or stunting
Bleached leaves	Herbicide or cold injury	Seedlings can grow out of it unless impairment of photosynthesis is extensive
Pruned roots	Insect damage	Weak seedlings, wilting

Figure 1. Imbibitional chilling and cold injury. Note club-shaped coleoptile and leafing out underground.

Figure 4. Corn seedlings with necrotic tissue resulting from flooding.

Figure 2. Corkscrew mesocotyl growth. Can be caused by cold soils, extreme soil temperature fluctuations, or soil crusting.

Figure 3. Fused coleoptile /bursting on the side caused by cold injury.

Figure 5. Corn seedlings showing both brown root tissue and bursting on the side due to cold and flooded soil conditions.

[return to table of contents](#)

corn grain yield in relation to stress during ear development

Stephen D. Strachan, Ph.D., *Former Research Scientist*

Summary

- The size, placement, and amount of kernel set on the corn ear documents when this ear was subjected to environmental stress and the severity of this stress.
- Understanding how corn ears respond to stress can help determine what stress was present, when this stress occurred, and how to mitigate this stress in the future.
- In general, ear responses to environmental stress factors at specific times of the corn life cycle include:
  - A reduction in the number of kernel rows around the ear if substantial stress occurs at or just before ear initiation (approximately V7).
  - A reduction in the number of kernels along the length of the ear or a shorter ear if substantial environmental stress occurs from the late vegetative phase until just before pollination.
  - A portion of the cob that may be barren if substantial environmental stress occurs during pollination.
  - A portion of the cob that shows either very small kernels or kernel dieback if substantial environmental stress occurs during grain fill.

Introduction

Environmental stresses during any of four ear development stages significantly affect the number and weight of harvestable kernels and subsequent grain yield in corn. The four critical stages are: (1) when the corn ear is setting the maximum number of kernel rows around the ear (approximately V7), (2) when the ear is establishing the maximum number of ovules along the length of the ear (just before pollination), (3) when the maximum number of ovules are pollinated to form developing embryos (at pollination), and (4) when the ear sets maximum kernel size during the latter portion of grain fill (approximately R3 to R5). This article illustrates corn ear responses to some of the more common stresses that occur and explains why corn ears respond as they do. Corn developmental stages used in this article are based upon the Iowa State Publication "Corn Growth and Development" (Abendroth et al., 2011).

Environmental Stress During Kernel Row Establishment

Depending upon CRM, the corn plant determines the maximum number of rows around the ear at approximately the V5 to V8 stage in its life cycle. Figure 1 shows a picture of a developing corn ear at the V9 stage.

Figure 1. Development of the primary ear, node 14 (dome ~ 400µm).
Courtesy of Dr. Antonio Perdomo, Pioneer.

The meristematic dome is present at the tip of the ear, indicating the developing ear is still producing new rows of ovules along the length of the ear. The upper two-thirds of the ear shows a series of single rows of developing ovules. These ovules eventually divide to produce a pair of rows from each single row. This paired formation is visible near the base of the ear. The division explains why a corn ear always has an even number of kernel rows around the ear.

Placement of the primary ear varies with corn genetics. The corn pictured in Figure 1 is 103 CRM, and the primary ear (the ear to be harvested) is located on the V14 node. In general, corn lines varying from approximately 103 to 118 CRM produce the primary ear on the V13 or V14 node. Corn lines of earlier maturity will place the primary ear on a lower node, such as the V12 node, while corn lines of longer maturity may place the primary ear on a higher node.

The node of primary ear placement is an excellent reference point to determine when ear initiation starts. A general guideline is to determine the node containing the primary ear and then subtract seven. This V stage is approximately when the number of kernel rows around the ear is being established. For example, the corn line in Figure 1 positions the primary ear at the V14 node; thus, the number of kernel rows around the ear is being established at or very near the V7 stage.

Establishment of the number of kernel rows around the ear is a critical event in the life cycle of a corn plant. If a particular corn line normally has 16 or 18 kernel rows around the ear and the ear in question has less than the normal number, then some sort of stress was present at or just before this critical stage. From a diagnostic perspective, if an ear has 12 kernel rows around instead of the normal 16, then the stress factor that caused this event was present at approximately V7. This information helps to establish a "time window" in looking for the environmental event that caused ear response to occur.

The maximum number of ovules that the entire corn ear will produce is determined by the time the corn plant passes through approximately four more V stages.

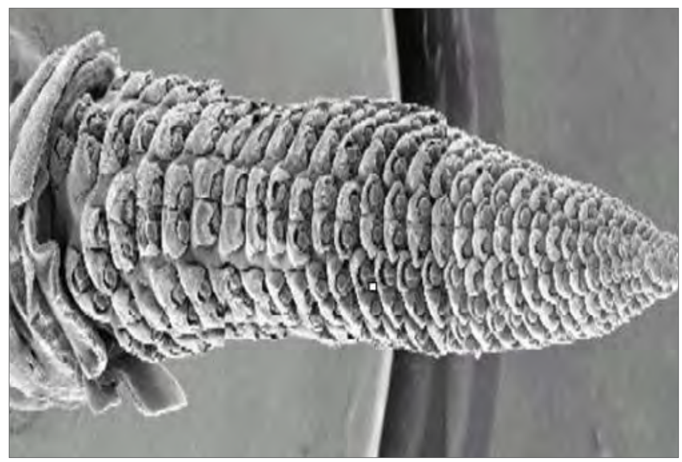


Figure 2. Development of the primary ear.
Courtesy of Dr. Antonio Perdomo, Pioneer.

Figure 2 illustrates an ear harvested at the V12 stage from the same corn line as that in Figure 1. The meristematic dome is no longer present, so maximum potential ovule formation is now established. Paired ovule formation is apparent along nearly the entire length of the ear. From a diagnostic perspective, if an ear has the proper number of kernel rows around the ear but the ear is shorter than normal, then sufficient stress of some sort while the corn plant was around the V12 developmental stage may have caused this event.

Cell division inhibitor herbicides, such as sulfonylurea herbicides, can substantially affect ear formation when misapplied during ovule formation. For most corn genetics, this is while the plant is between V7 and V10. Corn plants must metabolize these herbicides for crop safety. If metabolism is incomplete and sufficient active herbicidal ingredient is translocated to the developing ear, ovule formation may be inhibited. Such inhibition may stop ovules at the single-row developmental stage from doubling to form the paired row. When this occurs, the corn ear shows an abrupt change from a certain number of rows around the base of the ear to a lesser number of kernel rows around the ear at the tip. This is sometimes referred to as "pinched ears" (Figure 3).

Figure 3. Ear pinching due to sulfonylurea herbicide misapplied during ear formation.

Environmental Stress When the Corn Ear is Establishing Kernel Number Along its Length

Growth of the developing ovules between the stages of ear initiation until pollination can be thought of as a dynamic, two-step process. The first step is the initiation of the ovules as explained in the previous section. The second step is the cell differentiation and cell division that must occur to prepare these ovules for fertilization. At any moment in time between ear initiation and pollination, ovule formation differs along the length of the developing corn ear. Ovules near the base of the ear develop first, and newer ovules will continue to form as development progresses toward the tip of the ear. After the corn plant has established the maximum number of ovules, the nutrients, energy, and water to sustain these developing ovules must be supplied. If all resources are adequate, ovules along the entire ear will develop sufficiently to produce silks and be receptive to pollen.

If resources are limited, selected ovules will be sacrificed to allow the corn plant to adequately support the remaining viable ovules. Which ovules are sacrificed depends upon the amount, type, and duration of the stress. If the stress is a longer-term general stress, ovules near the tip of the ear are sacrificed, resulting in viable ovules only at the base of the developing ear. Ovules near the base of the ear are more likely to remain viable because these ovules are further developed and are closer to the source of nutrient supply. If the environmental stress is very short but very intense, the ovules that are sacrificed may be anywhere along the corn ear.

Figure 4. Cold chilling shock at different stages of development (date indicates planting date in Southern Hemisphere).

Figure 4 illustrates a corn hybrid grown in a semi-tropical climate. The same hybrid was planted every four days from December 20 to 28. During early ear formation, this corn was subjected to 2 single days of cold weather in which the temperature was less than 50 °F (10 °C). The corn from the earliest planting date was either past or nearly past a critical point in ovule formation. The corn planted at the middle date was midway through this critical phase, while the latest-planted corn was just entering the critical developmental period. Ovules formed after this environmental stress had passed developed normally.

A physiological response that produces very short ears, sometimes called "beer can ears," appears to be due to a combination of environmental stress–possibly cold stress or drought stress–during a critical stage in ovule formation, and genetics (Figure 5).

Figure 5. Very short ears, also called "beer can ears."

Figure 6. Arrested ear resulting from foliar application of an adjuvant at V14 growth stage.

Arrested ears are associated with application of fungicide or insecticide with NIS or COC in the two-week period preceding pollination (Figure 6). Arrested ears differ from "silkballing." Silkballing occurs when the silks lose orientation during the pollination process and begin to grow in many different directions inside the husk. We are not certain what causes silkballing. The event may be related to a combination of a brief interval of cold stress or drought stress sometime during the silk growth cycle and certain corn genetics.

The key to distinguishing between beer can ears and silkballing is to determine if silks are still present in the husk. The environmental stress that causes beer can ears produces either short ears or ears with long cobs and kernel set only near the base of the ears. Very few or no silks are present inside the husks of these ears. The environmental stress that causes silkballing may also produce long ears with kernel set only near the base of the ear. The difference is silkballed ears will very often contain a mass of silks inside the husks. Silks remain attached to developing ovules until these ovules are successfully fertilized. These ovules degrade if they are not fertilized. However, the silks can often remain in the husk until the ear is mature.

Figure 7. "Silkballing" (top) results in cobs with bare ends.

Environmental Stress During Pollination

Successful fertilization of mature ovules requires viable pollen to land on receptive silks. Insect pests, such as adult corn rootworms, may clip silks as they feed, resulting in poor pollination with subsequent poor kernel set. Management and diagnostics for adult rootworms are presented in a *Crop Focus* article (Rice, 2015).

There are two basic parts to the pollination process. First, viable pollen must land on receptive silks, and second, the silks must support the formation of pollen tubes to allow male gametes to fuse with female gametes inside the ovule. A large portion of mature pollen is usually released from corn anthers in mid-morning, depending upon environmental conditions. A minimum of 100 grains of pollen per square centimeter per day is needed to successfully pollinate a corn field. Pollen may lose viability within a few minutes if air temperatures are high (approximately 104 °F or 40 °C) and water deficit stress is present. Pollen grains contain about 80% water when first shed. These pollen grains die when the water content decreases to about 40%.

A lot of corn is successfully pollinated under higher temperature conditions. If soil moisture is adequate and the corn plant can transpire water rapidly enough to supply necessary water to the pollen, the pollen remains viable long enough to properly shed and complete the fertilization process. However, if the water supply is inadequate, pollen will die prematurely and not complete the fertilization process.

The second part of successful fertilization of ovules is the formation of the pollen tube and deposition of male gametes inside the ovule. This process relies heavily on the female portion of the plant because the silks supply all of the necessary nutrients and water for growth of pollen tubes. Based upon all of the pictures we have seen to date, viable pollen grains adhere to silk trichomes – not directly to the silks – to start the fertilization process.

Trichomes are hair-like projections that extend from the main stem of the silk, much like root hairs extend from a plant root. Within a few minutes after landing on the trichomes, the pollen grains start to initiate pollen tubes. These pollen tubes seem to always grow near the silk vascular bundle. This may occur because these vascular tissues contain a readily available source of water and nutrients essential for growth.

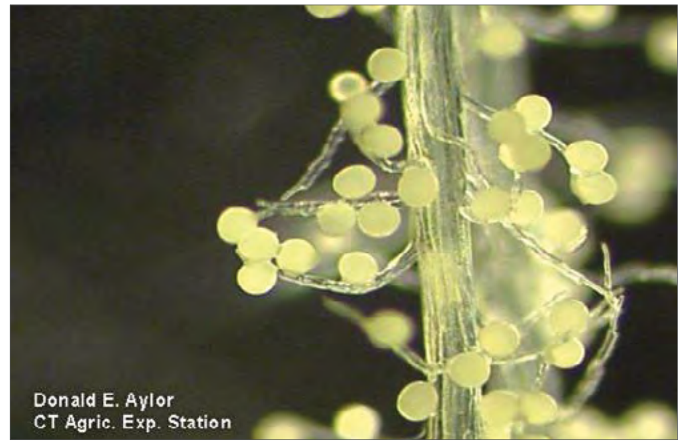


Figure 8. Pollen attached to silk trichomes.
Courtesy of Dr. Don Aylor, University of Connecticut.

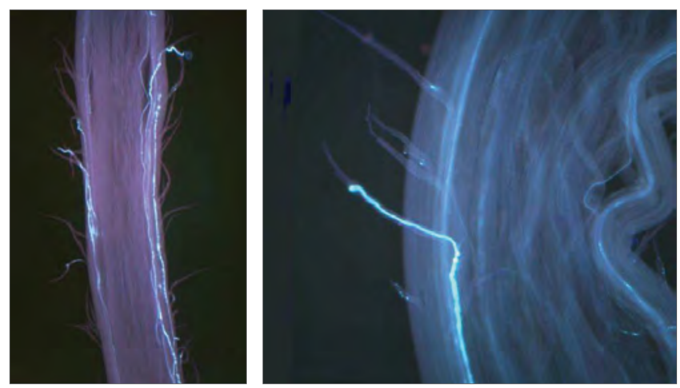


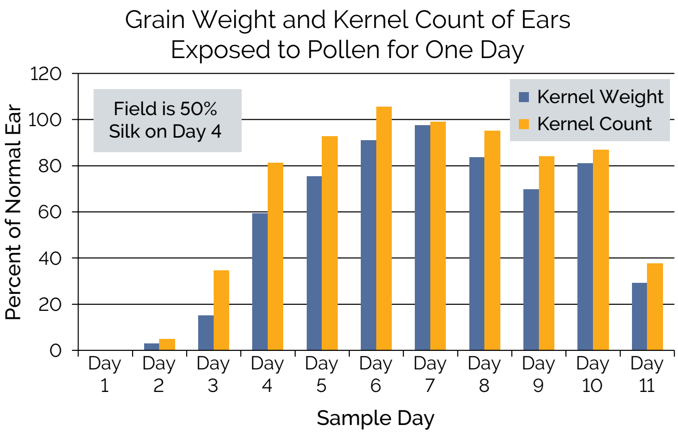
Figure 9. Pollen tubes growing along silk vascular tissue.
Courtesy of Dr. Antonio Perdomo, Pioneer.

Depending upon water availability and environmental conditions, it may take just a few hours to approximately one day for pollen tubes to grow all of the way to the ovules. When the corn plant is under greater drought stress, pollen tube growth is slower and the potential for successful fertilization decreases.

Environmental stress during pollination can have substantial effects on grain yield. For a specific hybrid, approximately 85% of grain yield is correlated with the number of kernels produced per acre with the remaining 15% being the weight of individual kernels at harvest (see Figure 10).

The amount of water available for silk growth substantially influences when silks emerge, their rate of growth, their length of receptivity, and their ability to supply water and nutrients to support pollen tube growth and fusion of gametes. Silk growth during pollination and grain production, as well as problems associated with improper or inadequate silk growth, are presented in a *Crop Insights* article (Strachan, 2016). From a diagnostic perspective, corn plants that are growing under stress during pollination produce ears with barren portions (examples shown in Figure 12). Portions of the cob are barren because mature ovules were not properly fertilized. These unfertilized ovules begin to disintegrate and disappear before the ear reaches physiological maturity.

*Silks exposed to pollen daily.



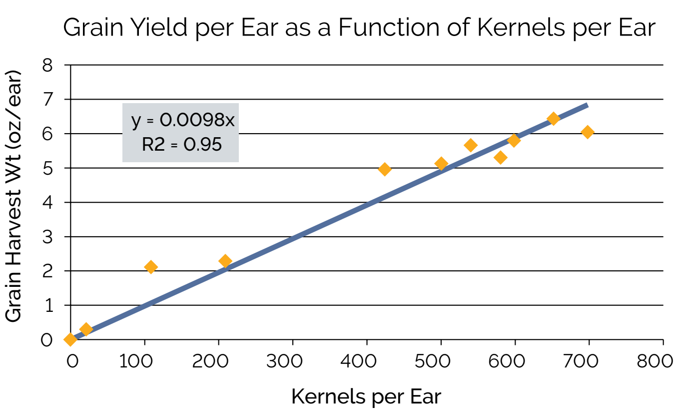


Figure 10. Relating kernel count to grain yield.

Environmental Stress During Grain Fill

A successfully fertilized kernel goes through two phases in the approximately eight weeks between pollination and physiological maturity.

For approximately the first three weeks after pollination, embryo cells are rapidly differentiating and dividing to produce the tissues necessary for the embryonic corn plant contained within the kernel. The remaining weeks of grain fill are devoted primarily to starch and storage tissue deposition to support new plant growth when this generation of seed is planted. All kernels are attached to the cob (Figure 11), and all kernels compete for available food and water.

Only those kernels that receive ample moisture and nutrients live. Typically, kernels near the butt of the ear develop a little earlier and are closer to the source of nutrients than kernels at the tip of the ear.

When stress is present, the ear will often sacrifice the tip kernels in favor of kernels at the butt of the ear. Depending upon the severity of the stress, tip kernel dieback will continue until the point at which the corn plant has the ability to supply adequate water and nutrients to support growth of the remaining kernels.

Figure 11. Kernel attachment to the cob.

Kernel formation or the lack thereof is an indicator of the time of stress occurrence – whether it occurred before or during pollination or during grain fill. If a portion of the cob is barren with no evidence of viable kernel formation, the stress occurred at or before pollination. If a portion of the cob shows either very small kernels or kernel dieback, the stress occurred sometime during the grain-filling process. If tip kernels did not abort but their test weight is decreased, the stress occurred during the very latter part of grain fill.

Conclusions

The size, placement, and amount of corn kernel set documents when the ear was subjected to environmental stresses and the severity of these stresses. Knowledge of ear development helps agronomists and corn producers determine when stresses occurred. It also provides a starting point for developing management practices to mitigate these stresses in the future. This could lead to more complete pollination and grain fill in addition to subsequent higher grain yields.

Figure 12. Stress during grain fill very often results in tip kernel die-back or some sort of kernel abortion.

return to table of contents

how kernel weight varies by hybrid

Ryan Van Roekel, Ph.D., Field Agronomist, **Dennis Holland,** Product Agronomist, **Alex Woodall,** Field Agronomist, and **Bill Long,** Field Agronomist

Kernel weight is a key component of grain yield that can vary among hybrid families and be affected by environmental conditions as well as management practices.

A 5-yr field study found that kernel weight can vary widely due to differences in growing conditions (from 52,000 to 137,000 kernels/bu) but that certain hybrid families tend to run consistently higher or lower than average.

These estimates for kernel weights by hybrid family can be useful for yield estimation, management decisions, and diagnosing yield results that differ from expectations.

The Challenge of Estimating Kernel Weight

- Corn grain yield can be estimated in-field based on estimates of yield components: ears per acre, kernels per ear, and kernel weight.
- The first 2 components are relatively straightforward to estimate – conducting several stand counts of 1/1000th of an acre can provide an estimate of ears per acre, and kernel counts can be used to estimate kernels per ear.
- Furthermore, new technology has greatly improved the speed and accuracy of estimating ears per acre and kernel per ear.
    - » UAV imagery powered by Corteva Flight can provide field-wide stand counts.
    - » The Yield Estimator tool in the Pioneer Seeds app can quickly count kernels per ear.
    - » The Vegetation Index from satellite imagery in Granular Insights can be used to guide sampling according to field variability to get a better estimate of whole-field yield.
- However, estimating the third yield component – kernel weight – remains challenging.
- A common practice is to assume 90,000 kernels/bushel, but this practice often underestimates yield and does not account for differences among hybrids or environments.
- While work is underway to develop a more reliable way to estimate kernel weights, Pioneer undertook research to characterize common hybrid families in local plots. The goal was to estimate how genetics influence kernels weights to provide more accurate yield estimates.
- Additionally, knowing a hybrid's expected kernel weight can help with understanding the yield impact of late-season management or environmental issues that may prevent a hybrid from reaching its normal kernel weight.

Our Research

- Kernel weight data was collected from hybrid plots across Iowa in 2016 to 2020.
- Kernel weights for each hybrid at a location were measured in one of two ways:
    - » A subsample of 100 random kernels, or more, was weighed and corrected to 15% moisture with the moisture data used to calculate the hybrid's grain yield.
    - » Multiple stand/ear and kernel counts were performed prior to harvest to provide a reasonably accurate estimate of ears per acre and kernels per ear. This data was divided by the hybrid's yield at 15% to determine kernels per bushel.
- Both methods have limitations, but hybrid trends were consistent; thus, datasets were combined to increase the number of locations.
- A location average kernel weight was calculated from the average of all hybrids in each plot location.
- To account for environmental differences across locations, kernel weight for each hybrid within a location was calculated as a percentage of the location average. Those percentages were then averaged by hybrid family over all plot locations as shown in Table 1.
- The standardized kernels per bushel in Table 1 were calculated as 80,000 kernels/bu divided by the average kernel weight percentage to provide a reasonable estimate for kernels/bu by hybrid family. This result is not the actual mean of the observed kernels/bu because the dataset is very unbalanced for locations between hybrids. As such, caution should be used with these results.

Figure 1. Representative kernels from the tip, middle, and butt of an ear from hybrid families with above-average (P1197) and below-average (P1082) kernel weight in 2019. *Photo courtesy of Bill Long.*

Table 1. Kernel weight as a percentage and standardized kernels/bu by hybrid family.

Hybrid Family	Kernel Weight (% of Loc. Mean)*	Standardized Kernels per Bushel**	# Loc.***
P9492	91.0%	88,000	4
P9772	99.5%	80,500	3
P0075	100.4%	79,500	27
P0157	99.8%	80,000	18
P0220	101.0%	79,000	26
P0306	106.0%	75,500	39
P0339	104.3%	76,500	32
P0421	103.8%	77,000	28
P0446	98.4%	81,500	17
P0574	111.3%	72,000	30
P0589	103.4%	77,500	43
P0595	102.9%	78,000	22
P0622	102.9%	77,500	32
P0688	95.0%	84,000	40
P0720	104.2%	77,000	9
P0963	111.9%	71,500	37
P0977	103.4%	77,500	27
P1082	97.7%	82,000	34
P1093	90.9%	88,000	45
P1108	101.7%	78,500	27
P1138	95.9%	83,500	14
P1185	96.4%	83,000	32
P1197	105.8%	75,500	56
P1213	104.5%	76,500	12
P1244	96.6%	83,000	20
P1353	96.7%	83,000	29
P1366	95.4%	84,000	63
P1380	100.7%	79,500	11
P1563	97.1%	82,500	15
P1587	106.3%	75,500	6
P1870	100.1%	80,000	4

* Calculated as hybrid kernels per bushel compared to the location average kernels per bushel, then averaged over all locations.

** Calculated as the kernel weight percentage applied to a "normal" value of 80,000 kernels/bu, rounded to the nearest 500.

*** Only hybrids with a minimum of 3 locations were included.

Results

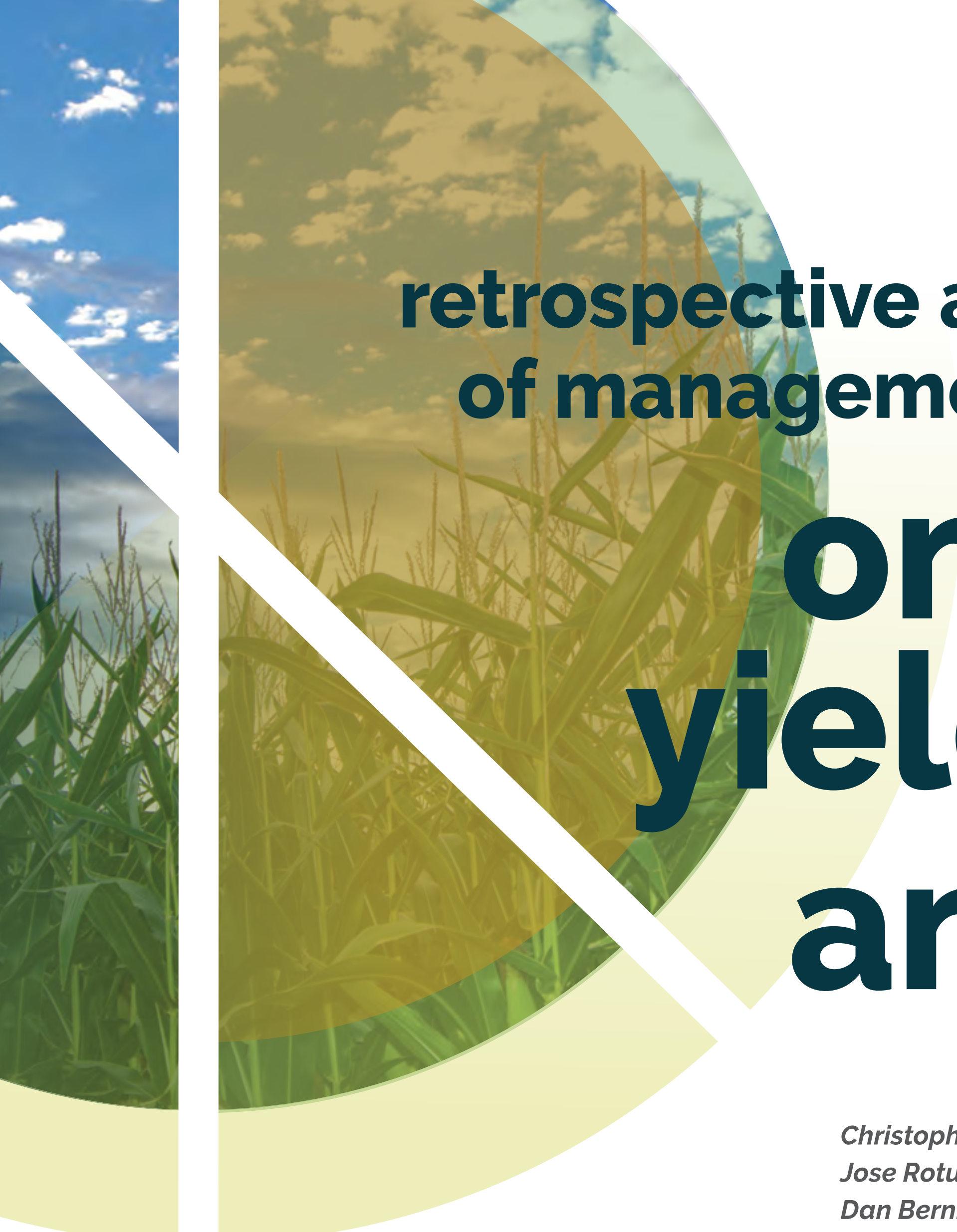
- Kernel weight (kernel/bu) was found to vary widely by hybrid and location.
- The grand mean of all kernel weight observations was 82,818 kernels/bu but ranged from 52,192 to 136,518 kernels/bu. Grain yield averaged 223.4 bu/ac with a range from 116.2 to 297.3 bu/acre.
- Individual hybrids also had a wide range in kernel weights between locations. For example, the Pioneer® P1197 family ranged from a high of 54,656 kernels/bu down to 115,749 kernels/bu. Across all locations, its kernel weight averaged 105.8% of the location average.

Key Points on Kernel Weight

- With the wide variation in observed kernels weights between hybrids and locations, exercise caution when using the standardized kernels/bu shown in Table 1.
  - » Environmental and management factors can and will greatly influence a hybrid's ability to maintain or extend its grain fill and express its full kernel weight potential.
  - » For example, the location average kernel weight in 2020 was 85,962 kernels/bu compared to 76,950 in 2019.
  - » Often, issues like disease pressure or nitrogen deficiencies can hinder late-season plant health and limit a hybrid's grain-fill period and resulting kernel weight.
- High kernel weights are not required for high yields.
  - » P1366 is an example of a hybrid family with average kernel weight that is capable of very high yields (up to 297 bu/acre in this study).
  - » P1366 tends to achieve high yields through kernel number (more rows around and/or ear length) vs. hybrid families like P1197, which tend to have more average kernel numbers but high kernel weights.
- Kernel weight is not correlated with test weight. Test weight is the weight of a volumetric bushel, while kernel weight is a measure of how many kernels are in a 56 lb bushel.
  - » An example of this distinction is the P1093 hybrid family, which has very high test weight with excellent grain quality but its high-density kernels tend to be smaller in physical size and thus, weigh less per kernel.
  - » Contrarily, the P1197 hybrid family tends to have less dense, lower test weight grain but very large kernels that result in high kernel weights.
  - » The P0963 hybrid family tends to have both high test weight and high kernel weight.
- When estimating yields, it is best to stick with an average kernel weight estimate of 80,000 kernels/bu for most hybrids.
  - » Consider using a lower kernels/bu (i.e., 70,000) for hybrid families like P0574 and P0963 and higher kernels/bu (i.e., 90,000) for hybrid families like P9492 and P1093.
  - » If late-season growing conditions are excellent, using a factor of 70,000 kernels/bu may be more appropriate.
  - » Conversely, if late-season conditions are poor, a factor of 90,000 kernels/bu might be more accurate.
  - » Be sure to get multiple, accurate estimates of kernels/ear and ears/acre to avoid overestimating yield.

Conclusions

- Kernel weight is a key component of corn grain yield that varies greatly by hybrid and environment.
- Having an idea of a hybrid's normal kernel weight can be useful for more accurate yield estimates.
- This knowledge also helps provide an understanding of how a hybrid makes its yield (kernel number vs. kernel weight), which can be useful when making management decisions or when diagnosing yield results that differ from expectations.



retrospective assessment of management decisions: on-farm yield gap analysis

Christopher Parry, Ph.D., Research Scientist,
Jose Rotundo, Ph.D., Research Scientist,
Dan Berning, Pioneer Agronomy Manager,
and Charlie Messina, Ph.D., Corteva Laureate

What is Yield Gap Analysis?

- Potential yield is determined by the duration of the growing season, the genotype, and the solar radiation and temperature environment.
- Water-limited yield potential is the attainable yield for any given amount of available water in the absence of nutrition limitations and pest and/or disease influence.
- Scientists at Corteva Agriscience have defined the water-limited yield potential of maize in the range 0 to 39 in of available water that was used by the crop.
- A gap analysis is the comparison between the observed farmer's yield versus the water-limited yield potential.
- Agronomic management strategies for corn production on individual fields need to be optimized in order to close the gap between observed and potential yields.
- A critical aspect of the gap analysis is the capability to determine crop water use in order to conduct a retrospective analysis to understand the gap between what was possible (potential) and what was achieved (observed).
- Opportunities for closing yield gaps may include:
    - » Adjusting seeding rates or plant populations to optimize the hybrid for the expected environment
    - » Refining nitrogen placement and timing
    - » Selecting the best adapted genotype for the expected environment
    - » Timing of irrigation
    - » Pest and disease management

Evapotranspiration Device And Method Overview

For yield gap analysis at the end of season, a crop evapotranspiration (ET) estimate is required to estimate a potential yield to which the actual yield can be compared and opportunities for closing the yield gap can be identified.

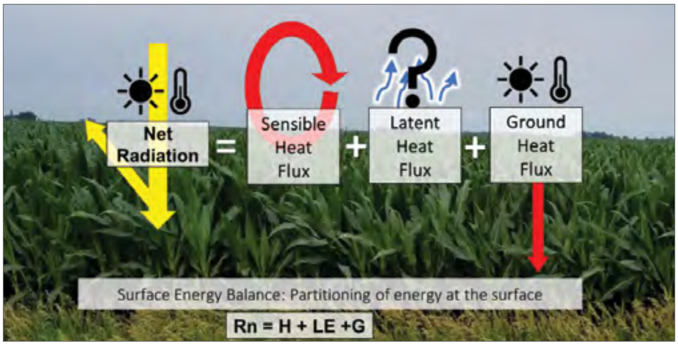


Figure 1. Surface energy budget over corn.

Evapotranspiration is calculated using the energy balance method (Figure 1). The surface energy balance equation used in this project for the crop-soil surface is written as

$$R_n = H + \lambda E + G$$

where R_n is net radiation, H is sensible heat flux, λE is latent heat flux, and G is the ground heat flux. R_n, the net radiation, is the absorbed solar and thermal energy from the atmosphere and is balanced by sensible (energy exchange from air movement), latent (energy exchange from transpiration/ evaporation), and ground (energy gained or lost during below-ground warming or cooling) heat fluxes.

The R_n and G components of the energy budget can be measured or modeled using meteorological variables measured by basic weather stations (windspeed, air temperature, relative humidity, and incoming solar radiation). The H term is calculated by characterizing the surface temperature fluctuations that are measured by an infrared thermometer (IRT), which is a non-contact thermometer; it is not in direct contact with a plant. The λE term is difficult to quantify using basic and inexpensive sensors and is, thus, calculated as the residual of the energy balance:

$$\lambda E = R_n - H - G$$

Evapotranspiration is then calculated by dividing λE by the latent heat of vaporization (λ) to convert the energy into a volume/depth of water loss.

In the 2019 and 2020 seasons, the measurement variables necessary for the energy budget were obtained from weather stations or IBM weather service and from Corteva Agriscience proprietary Internet of Things (IoT) devices equipped with an infrared thermometer. This IoT device (Figure 2) was designed and manufactured in-house by the Corteva Agriscience Predictive Ag and Engineering teams. The device measures the surface temperature, processes the data, and then sends 30-minute averaged values to a Corteva Agriscience-maintained cloud database using a cellular modem.

Figure 2. IoT device for measuring surface temperature (left) and the device deployed in a field (right).

Study Description

An on-farm experiment was conducted in 2019 and 2020 to evaluate the gap analyses framework by comparing observed yields for a given ET level that maximizes productivity. In 2019, farms were in Webster County, NE; Chase County, NE; and Thomas County, KS (Figure 3). Two hybrids were planted under the irrigation system in the fields with rainfed conditions in the corners of the fields with the center pivot. Each hybrid was planted at two different populations in the irrigated and rainfed areas of the field. Two replicates were planted at each location (Figure 4). Yield was estimated using the farmers' combine yield monitors, and ET was estimated from 16 ground-based IoT sensors deployed at each location using a modified surface renewal energy balance approach. Evapotranspiration was also measured at an additional location in Maynard, IA. With the help of 34 Pioneer field agronomists, who coordinated the efforts and deployed the IoT devices, the number of farmers' fields was extended to 94 in 2020 throughout the U.S. Corn Belt (Figure 3).

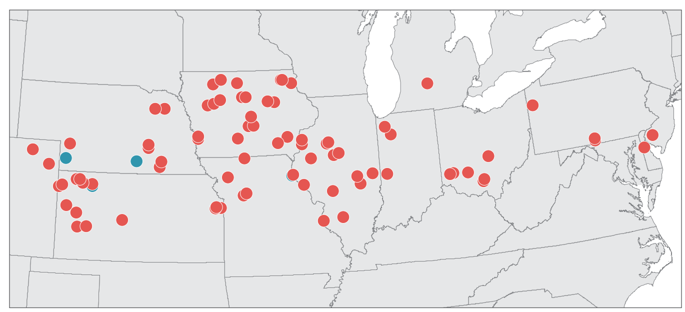


Figure 3. Gap analysis and ET measurement locations in North America, 2019 (blue) and 2020 (red).

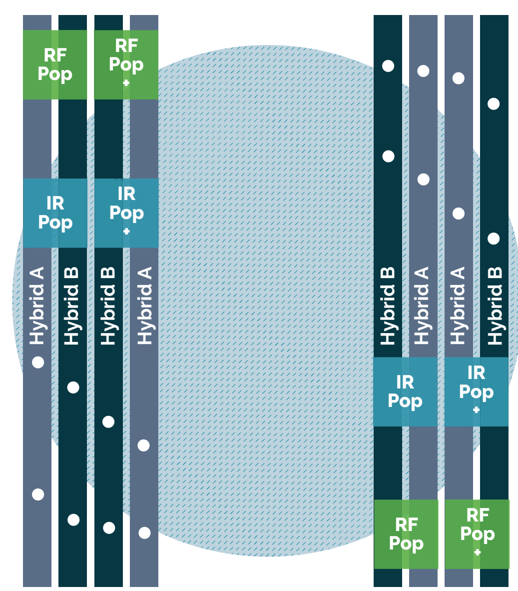


Figure 4. On-farm 2019 experiment design, rainfed (RF) and irrigated (IR) treatments with normal population (Pop) and increased population (Pop+) for two hybrids. Sixteen IoT sensors (•) were placed for ET measurements.

Observations

Figure 5 shows the observed yields for each location in the 2019 study and ET pairs by environment for each location.

The curved lines, designating the quantiles 80 and 99 percentiles, are shown to quantify yield gaps. The area defined by these curves represents the water-limited yield potential. Observed yields in that area indicate those fields had no yield gaps, and therefore, management was optimal. The maximum yield on the y-axis of the chart that can be obtained for the corresponding ET level on the x-axis of the chart should be between these 2 lines 80 to 99% of the time. The results demonstrate it is feasible to implement systems, using current technologies and hybrids, to improve and maximize water productivity. For example, the rainfed yield and ET level at the Blue Hill, NE, and Imperial, NE, locations were very similar. However, minor differences in timing of irrigation for very similar ET levels led to a large productivity gap at the irrigated Blue Hill location when compared to the irrigated Imperial location. Hybrid and population variables included at these two locations had much less impact on the yield level that was achieved when comparing these two locations. Figure 6 shows the observed yields and ET pairs for the 2020 locations that have been reported at the time of writing this article for 2020 along with the locations from the 2019 experiment.

Results show a high frequency of farms operating at or close to current water-limited potential yields. Also, there are many irrigated systems that can increase water productivity by reducing irrigation amounts without compromising productivity. Yield observations that fall below the 80% quantile suggest there are opportunities to improve product selection, nutrient management, and timing of irrigation. This tool can create awareness for both the overuse of a water resource, which could be allocated to grow another crop, or the existence of a gap that can increase the returns per acre by improving the agronomic management as well as the expression of the genetic potential for the product. The intent of this modeling tool is to empower agronomists and farmers to simultaneously increase productivity and sustainability.

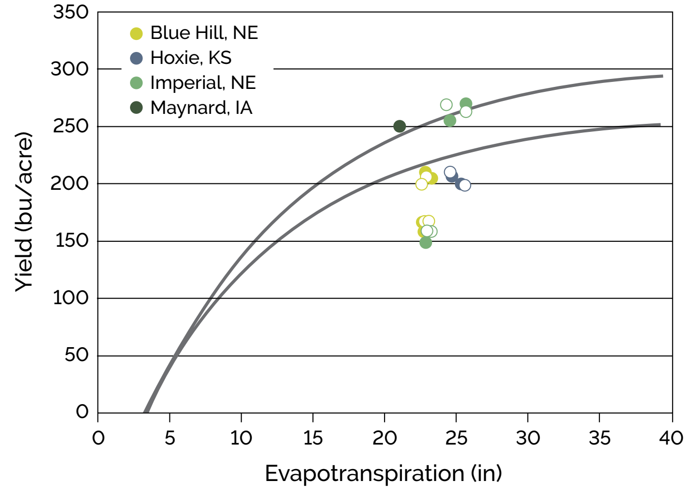


Figure 5. Theoretical maize yield response in 2019 to ET for quantiles 80 and 99 percentiles (lines) and yield observations for 4 locations in the Western U.S. Corn Belt for maize grown under rainfed and irrigated conditions as well as under normal (closed symbols) and increased plant population by 1 plant m^{-2} (open symbols).

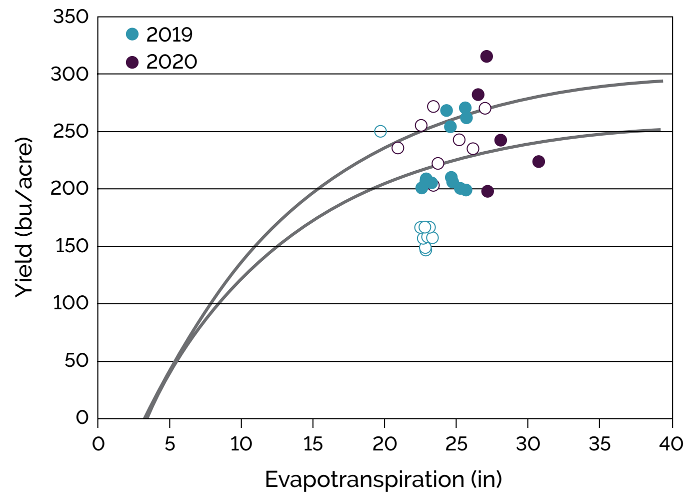


Figure 6 Theoretical maize yield response to ET for quantiles 80 and 99 percentiles (lines) and yield observations in the U.S. corn belt for maize grown under rainfed (open symbols) and irrigated (closed symbols) conditions in 2019 and 2020.

- This project will enhance our knowledge about the ET trends for the select locations and as aggregated for various yield levels as well as contribute to crop model refinement used by Pioneer and Corteva Agriscience teams.
- In addition to collecting ET data for end-of-year yield gap analysis, field agronomists were provided with ET reports to share with their cooperators (Figure 7).
- The identification of gaps or overuse of water resources can create awareness of business opportunities to increase the productivity and sustainability of the farm operations.

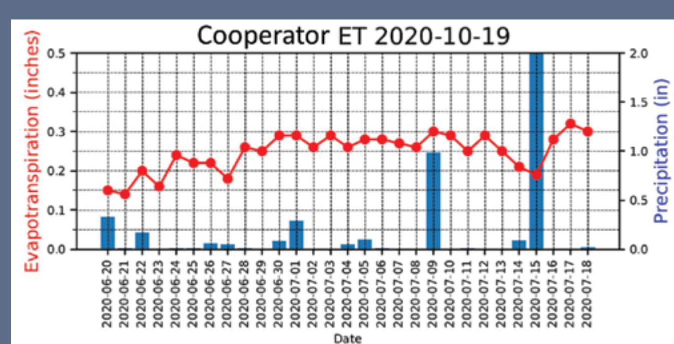


Figure 7. Example ET report with the ET (red) reported on the left and the recorded precipitation (blue) from IBM weather services reported on the right.

yield impact of premature plant death in corn

Study Description

Several conditions, including severe gray leaf spot infestations, hail, drought, spider mite damage, or an early killing frost, can cause premature plant death in corn. Pioneer agronomists have studied the impact on various hybrids of premature plant death (prior to black layer) on grain yield, moisture, and test weight in replicated plots. The objective of this three-year study was to learn more about corn response to death at various growth stages.

The corn plants in this study were prematurely killed by simulating complete defoliation. This was achieved by cutting the stalk off above the ear and removing all living leaves below the ear. The plants were defoliated at three stages of maturity (¼ milk line, ½ milk line, and ¾ milk line) and compared to plants that were allowed to reach physiological maturity, or black layer, in a normal manner. The plants in the black layer treatment were allowed to mature intact. Stage of maturity was determined by breaking three ears in half to reveal the position of the milk line. A summary of the yield data is presented in Figure 1.

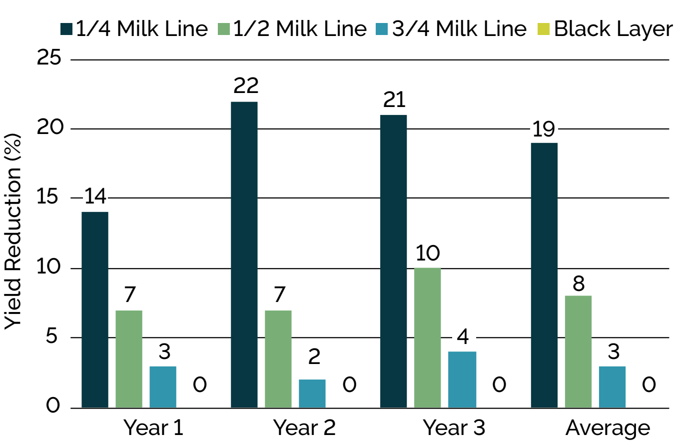


Figure 1. Yield reduction due to premature plant death.

Results and Analysis

When corn plants were defoliated before ¾ kernel milk line, grain yield was significantly reduced all three years. Averaged over years and hybrids, complete defoliation of plants at ¼ milk line reduced grain yield 19%. Defoliating plants at ½ and ¾ milk line reduced grain yield by 8% and 3% respectively.

On average, it took seven days to get from ¼ milk line to ½ milk line, six days from ½ milk line to ¾ milk line, and seven days from ¾ milk line to black layer (Figure 2).

Some variation in percent yield reduction and days between growth stages was observed among hybrids (Figure 3 and 4). These variations are small and not surprising, so they do not justify changes in hybrid management. The overall average numbers are the best guideline when evaluating early death due to frost, hail, drought, etc.

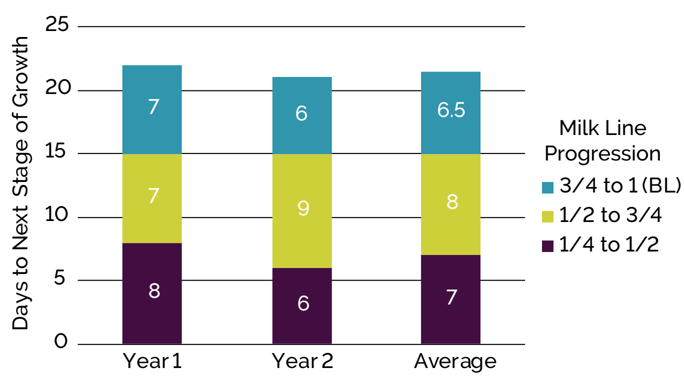


Figure 2. Days to maturity (multi-hybrid average).

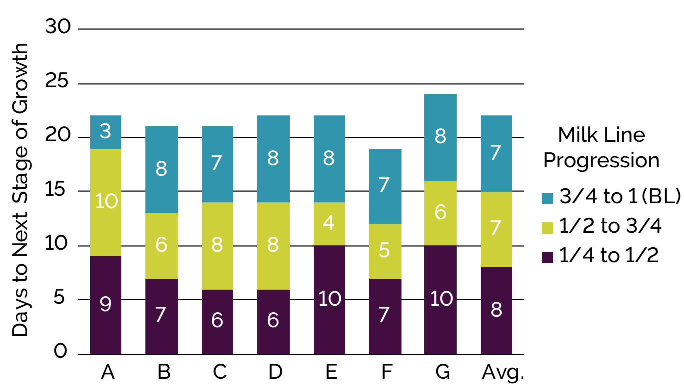


Figure 3. Days to maturity: hybrid variation (Year 1).

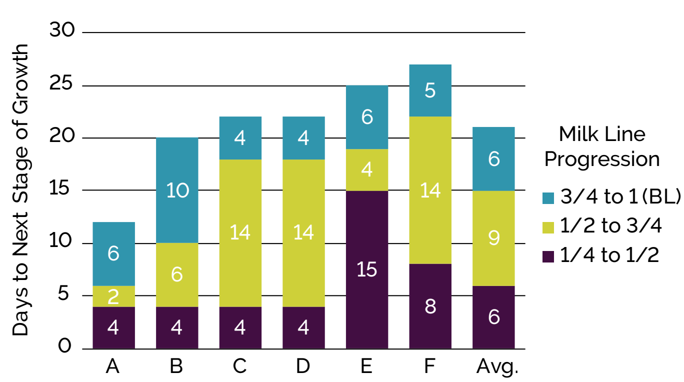


Figure 4. Days to maturity: hybrid variation (Year 2).

return to table of contents

managing corn for greater yield potential

Mark Jeschke, Ph.D., *Agronomy Manager*

Summary

- Improved hybrids and production practices are helping corn growers increase yields. Over the past 20 years, U.S. yields have increased by an average of 1.9 bu/acre/year.
- The NCGA National Corn Yield Contest provides a benchmark for yields that are attainable when conditions and management are optimized.
- The 2019 contest had 130 entries that exceeded 300 bu/acre, down from the record high of 224 entries in 2017.
- Selecting the right hybrid can affect yield by over 30 bu/acre, making this decision among the most critical of all controllable factors.
- Establishing sufficient population density is important to allow a hybrid to maximize its yield potential.
- High-yielding contest plots are usually planted as early as practical for their geography. Early planting lengthens the growing season and moves pollination earlier.
- Maintaining adequate nitrogen fertility levels throughout key corn development stages is critical in achieving highest yields. In-season applications can help supply nitrogen when plant uptake is high.

Introduction

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 1.9 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.

Forward-Thinking Farming Webinar

Understanding the Needs of Contest Corn

Pioneer field agronomist, Karen Zuver, hosts Don Stall, high-yield farmer and Pioneer customer, for a discussion on maximizing inputs. Dr. Brewer Blessitt, Pioneer agronomy manager, walks through soil test and tissue sampling.

Watch at pioneer.com/webinars

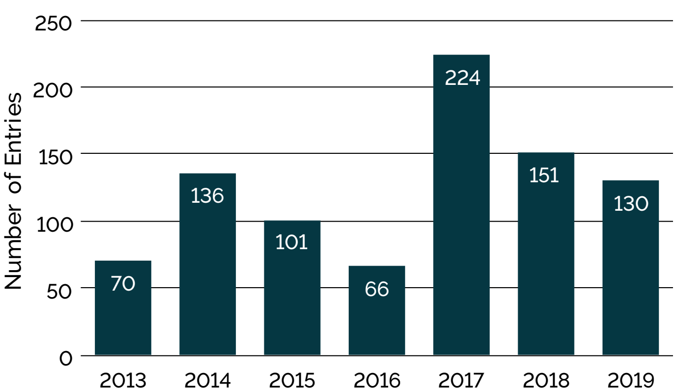


Figure 1. Total entries in the NCGA National Corn Yield Contest exceeding 300 bu/acre by year, 2013 - 2019.

2019 NCGA National Corn Yield Contest

The 2019 growing season was extremely challenging for corn production in many areas, a fact that was reflected to some extent in the results of the 2019 NCGA National Corn Yield Contest. The number of high-yield entries in the contest – defined for the purposes of this discussion as all entries yielding over 300 bu/acre – was down for the second year in a row from the all-time high set in 2017 (Figure 1). The biggest change was in the Central Corn Belt states of Nebraska, Iowa, Illinois, and Indiana, all of which saw a sharp drop in the number of high-yield entries compared to the past two years (Table 1). The geography that posted the best results relative to previous years was the Mid-Atlantic region with an uptick in high-yield entries in Pennsylvania, Delaware, New Jersey, and Virginia.

The top yield overall in the 2019 contest was 616.2 bu/acre achieved with Pioneer® hybrid P1197YHR (YGCB, HX1, LL, RR2). This marks the third time that the highest overall yield in the contest was produced with a product in the Pioneer® brand P1197 family of products.

Table 1. Number of NCGA National Corn Yield Contest entries over 300 bu/acre by state, 2015-2019.

State	2015	2016	2017	2018	2019
	number of entries				
AL	2	1	3	3	5
AR	1	1	2	1	0
CA	0	2	0	3	3
CO	3	2	4	1	0
DE	3	2	0	0	6
FL	3	0	0	0	0
GA	7	4	7	0	7
IA	5	7	16	8	3
ID	1	1	0	8	1
IL	9	5	25	18	6
IN	3	1	26	17	8
KS	4	1	2	3	2
KY	1	0	17	4	3
MA	2	1	1	2	4
MD	5	4	4	2	5
MI	4	1	7	1	4
MN	0	0	1	0	0
MO	2	1	12	4	3
NC	0	1	0	1	3
NE	7	1	41	39	7
NJ	7	0	1	1	9
NM	0	2	2	0	1
NY	1	0	4	0	0
OH	0	0	1	2	2
OK	2	3	2	2	0
OR	1	1	3	4	7
PA	3	0	0	0	15
SC	3	5	9	0	4
SD	0	0	2	0	0
TN	0	3	9	2	3
TX	6	4	3	7	1
UT	6	3	7	6	0
VA	4	3	5	2	9
WA	2	2	2	9	7
WI	1	1	6	1	1
WV	0	2	0	0	1
Total	**101**	**66**	**224**	**151**	**130**

return to table of contents

The average yields among national winners tend to be skewed by a small number of very high yields, particularly in the irrigated classes. Therefore, as a yield performance benchmark, it can be useful to look at a larger set of contest entries. Table 2 shows the median yield of the top 100 yielding entries in the irrigated and non-irrigated classes. Median yields of top entries in both the irrigated and non-irrigated classes exceeded 300 bu/acre for the third year in a row, which is about 75% greater than the current U.S. average. Median yields of the top 100 non-irrigated entries and irrigated entries in 2019 were both down from the highs achieved in 2017.

Table 2. Median yields of the top 100 irrigated and non-irrigated NCGA National Corn Yield Contest entries and the USDA average U.S. corn yields, 2013-2018.

Year	Non-Irrigated	Irrigated	U.S. Average
	bu/acre		
2013	293	299	158
2014	299	306	171
2015	292	288	168
2016	283	294	175
2017	312	317	177
2018	300	315	176
2019	302	311	167

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.

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 uniform stand establishment 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 as well as 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 as well as dropped ears.
- Good standability to minimize harvest losses.

Pioneer® brand products were used in 10 national-winning entries (Table 3) as well as 245 state-level winning entries – more than any other seed brand. State-level winners included a total of 79 different Pioneer brand products from 51 different hybrid families ranging from 82 to 120 CRM.

Table 3. 2019 NCGA National Corn Yield Contest national winning entries using Pioneer brand products.

Entrant Name Category	State	Hybrid/Brand[1]	Yield (bu/acre)
John F. Gause A: Conv. Non-Irrigated	SC	**P1847VYHR** (AVBL, YGCB, HX1, LL, RR2)	374.08
Don Stall A: Conv. Non-Irrigated	MI	**P0414AM™** (AM, LL, RR2)	356.29
Brigitte M. Young A: Conv. Non-Irrigated	IL	**P1366AM™** (AM, LL, RR2)	318.06
Chris Santini C: NT Non-Irrigated	NJ	**P1464AML™** (AML, LL, RR2)	344.52
Matthew K. Swanson D: NT Non-Irrigated	IL	**P1197**	330.43
Dominick Santini E: Strip-, Min-, Mulch-, Ridge-Till Non-Irrigated	NJ	**P1197**	339.10
Jerry Cox F: Strip-, Min-, Mulch-, Ridge-Till Non-Irrigated	MO	**P2089VYHR** (AVBL, YGCB, HX1, LL, RR2)	299.25
Carly Santini G: No-Till Irrigated	NJ	**P1197AMT™** (AMT, LL, RR2)	345.28
David K. Hula H: Strip-, Min-, Mulch-, Ridge-Till Irrigated	VA	**P1197YHR** (YGCB, HX1, LL, RR2)	616.20
Kevin Dowdy I: Conv. Irrigated	GA	**P1870YHR** (YGCB, HX1, LL, RR2)	478.02

The brands of seed corn used in the highest-yielding contest entries in 2015 through 2019 are shown in Figure 2. In all years, Pioneer brand products were used in more entries exceeding 300 bu/acre than any other individual seed brand.

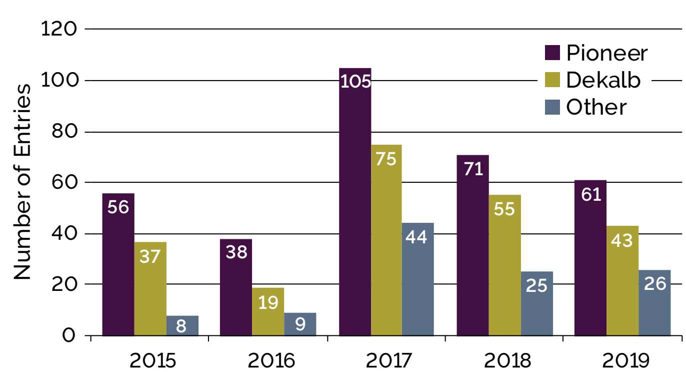


Figure 2. Seed brand planted in National Corn Yield Contest entries exceeding 300 bu/acre, 2015 - 2019.

Yields exceeding 300 bu/acre have been achieved using Pioneer brand products from 65 different hybrid families over the past 5 years, ranging from 91 to 121 CRM. The top-performing Pioneer hybrid families in the National Corn Yield contest are shown in Table 4. The Pioneer brand P1197 family of products has had the best performance in the contest by far, topping 300 bu/acre 78 times since its debut in the contest in 2014.

Table 4. Pioneer hybrid families with the most high-yield entries in the NCGA National Corn Yield Contest over the past 5 years.

Hybrid Family	2015	2016	2017	2018	2019	Total
	number of entries					
P1197	13	10	33	11	11	**78**
P2088	7	5	14	5	1	**32**
P1366			8	10	9	**27**
P0801	1	1	9	5	1	**17**
P1870			4	1	9	**14**
P1828				8	4	**12**
P1151	5	1	3	1	1	**11**
P0157	2	1	3	2	2	**10**
P1311	1	5	3			**9**
P0574			3	2	2	**7**
P1751	1	3	2	1		**7**
P1257	4		2			**6**
P1370			1	5		**6**
P9840		1	1	2	2	**6**
P9998				2	3	**5**

High-Yield Management Practices

Top performers in the NCGA yield contest not only have produced yields much higher than the current U.S. average, they have also achieved a higher rate of yield gain over time. Over the past 20 years, U.S. corn yields have increased at a rate of 1.9 bu/acre per year while winning yields in the non-irrigated yield contest classes have increased by 5.2 bu/acre per year. Contest fields are planted with the same corn hybrids available to everyone and are subject to the same growing conditions, which suggests that management practices are playing a key role in capturing more yield potential. The following sections will discuss management practices employed in contest entries yielding above 300 bu/acre.

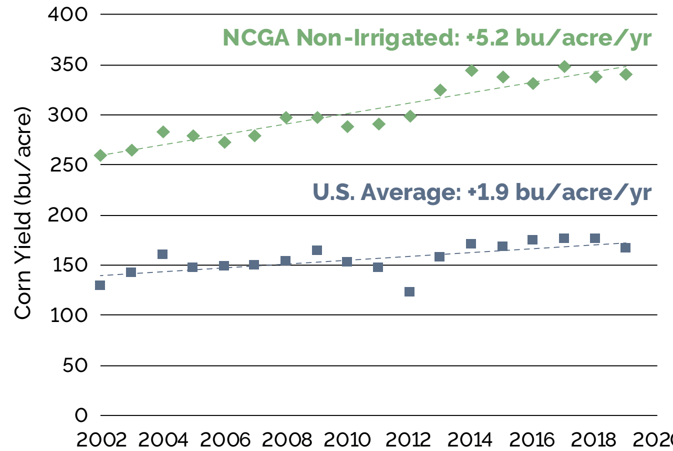


Figure 3. Average yields of NCGA National Corn Yield contest non-irrigated class national winners and U.S. average corn yields, 2002-2019.

Planting Practices

Plant Population

One of the most critical factors in achieving high corn yields is establishing a sufficient population density to allow a hybrid to maximize its yield potential. Historically, population density has been the main driver of yield gain in corn; improvement of corn hybrid genetics for superior stress tolerance has allowed hybrids to be planted at higher plant populations and produce greater yields.

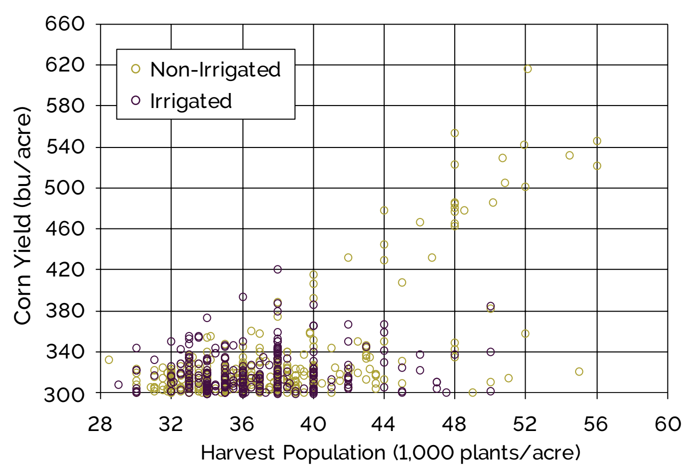


Figure 4. Harvest populations and corn yield of irrigated and non-irrigated NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2015-2019.

Harvest populations in irrigated and non-irrigated national corn yield contest entries over 300 bu/acre from 2015 through 2019 are shown in Figure 4. The average harvest population of irrigated entries (37,300 plants/acre) was slightly greater than that of non-irrigated entries (36,700 plants/acre) over five years. However, yields over 300 bu/acre were achieved over a wide range of populations, from 28,000 to 56,000 plants/acre, demonstrating that exceptionally high populations are not necessarily a prerequisite for high yields. Although population density is important in establishing the yield potential of a corn crop, it is just one of many factors that determine yield.

Planting Date

High-yielding 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.

Planting delays were a major challenge for corn production in many areas in 2019 and a lot of corn was planted in June. Planting dates for entries exceeding 300 bu/acre ranged from March 21 to June 4 in 2019. Mid-April to early-May planting dates have typically been the most common for high-yields in the Central Corn Belt. The 2019 contest had numerous high-yield entries planted in mid- to late-May (26 entries over 300 bu/acre were planted after May 15), demonstrating that high yields can still be achieved under favorable conditions if planting is not delayed for too long.

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 over the past five years have been planted in 30-inch rows (Figure 5). This proportion has increased slightly in recent years as wider row configurations (most commonly 36-inch or 38-inch) have declined and narrower row configurations (15-inch, 20-inch, 22-inch, or 30-inch twin) have largely remained steady.

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 generally not shown a consistent yield benefit to narrower rows outside of the Northern Corn Belt (Jeschke, 2018).

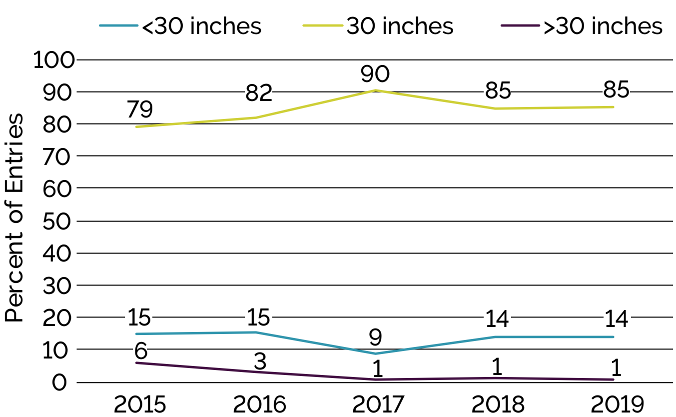


Figure 5. Row width used in NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2015-2019.

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 required in the following corn crop. A majority of the fields in the 300 bu/acre entries were planted to a crop other than corn the previous growing season (Figure 6).

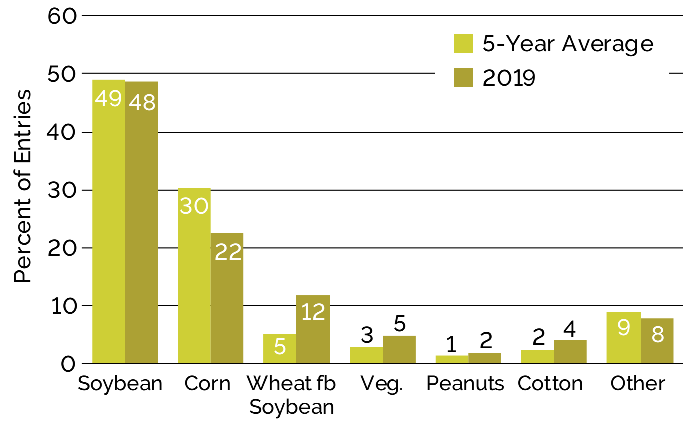


Figure 6. Previous crop in NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2019 and 5-year averages.

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.

Tillage

Over the past five years, close to half of the high-yield entries in the NCGA contest have used conventional tillage with the other half using no-tillage or some form of reduced tillage (Figure 7). The 2019 contest had a notable increase in the proportion of high-yield entries using no-till, offset by declines in conventional tillage and strip tillage. The proportion of high-yield entries using no-till (32%) was greater than the proportion of no-till entries in the contest overall (26%).

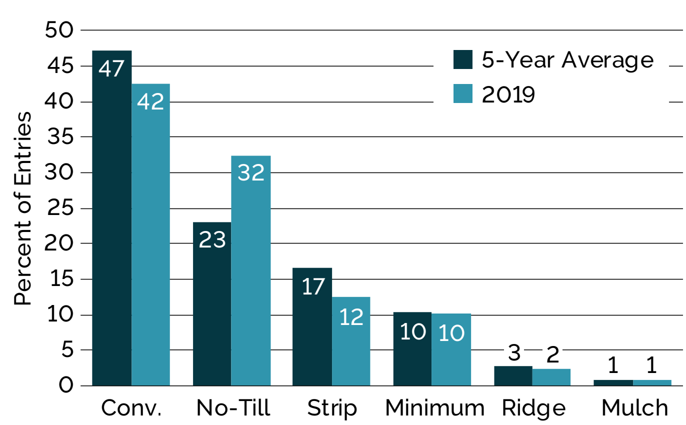


Figure 7. Tillage practices in NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2019 and 5-year averages.

Soil Fertility

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

Nitrogen

Corn grain removes approximately 0.67 lbs of N per bushel harvested, and stover production requires about 0.45 lbs of N for each bushel of grain produced (IPNI, 2014). This means that the total N needed for a 300 bu/acre corn crop is around 336 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 entries exceeding 300 bu/acre are shown in Figure 8.

Pioneer Agronomy

Corn Nitrogen Management Guide
- Troy Deutmeyer, Field Agronomist

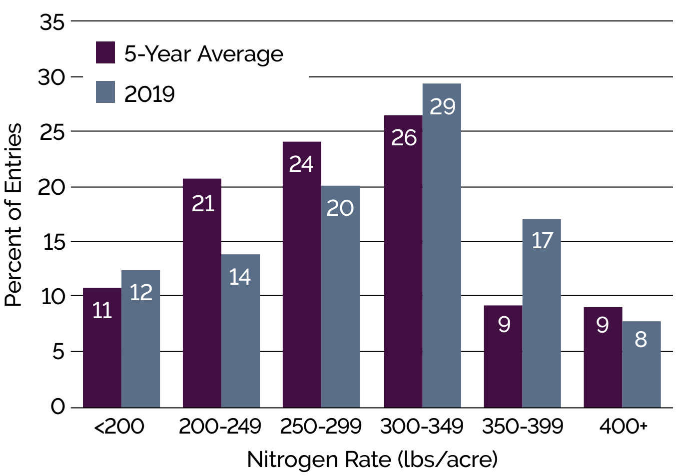


Figure 8. Nitrogen rates (total lbs/acre N applied) of NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2019 and 5-year averages.

The N application rates of 300 bu/acre entries varied greatly, but around half were in the range of 250 to 350 lbs/acre. 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 obtains from the soil through increased mineralization of organic N and improved root growth.

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. Around 90% of 300 bu/acre entries included some form of in-season N, either sidedressed or applied with irrigation. Multiple N applications were also used in around 90% of high-yield entries.

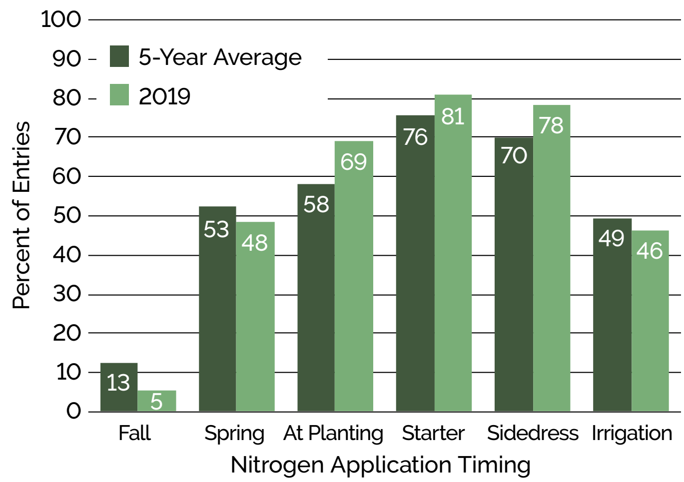


Figure 9. Nitrogen fertilizer application timing of NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2019 and 5-year averages.

Micronutrients

Micronutrients were applied on approximately 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 many 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 (Butzen, 2010). Additionally, as yields increase, micronutrient removal increases as well, potentially causing deficiencies.

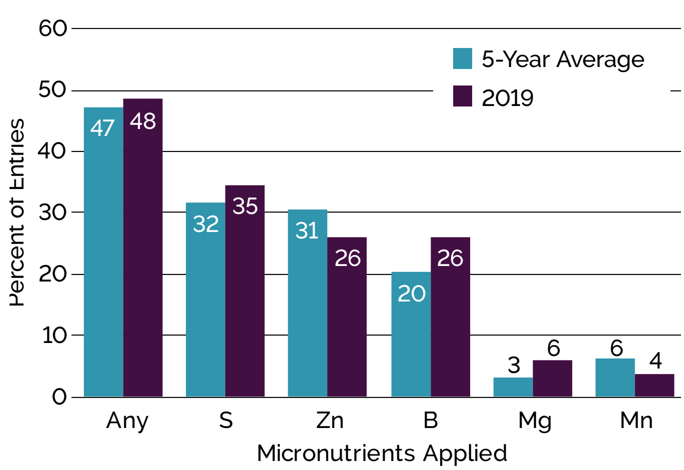


Figure 10. Micronutrients applied in NCGA National Corn Yield Contest entries exceeding 300 bu/acre in 2019 and 5-year averages.

return to table of contents

corn response to foliar inputs in narrow-row systems

Alex Lindsey, Ph.D., Peter Thomison, Ph.D., Allen Geyer, M.S., Matheus Ogando do Granja, Ashley Richie, and **Samuel Banks,** Department of Horticulture and Crop Sciences, Ohio State University, and **Kirk Reese, M.S.,** Former Agronomy Research Manager

+ **Foliar N increased yield in narrow rows but by just enough to pay for cost of application.**

− **Fungicide plus foliar N did not increase yield compared with fungicide alone in narrow rows.**

The value of foliar inputs in this study was likely limited due to crop rotations used at the research sites and low foliar disease pressure during the study.

Objectives

- A 3-year field study was conducted to determine if disease or nitrogen (N) demands increase in plants grown in narrow rows (15-inch spacing) compared with conventional row spacing (30 inches) and if intensive management involving application of foliar N with or without a fungicide can help increase grain yield in narrow-row systems.
- This research was conducted by Dr. Peter Thomison and Dr. Alex Lindsey, Ohio State University, as a part of the Pioneer Crop Management Research Awards (CMRA) Program.

Study Description

Years: 2016 to 2018

Locations:

- Western Agricultural Research Station (WARS); South Charleston, Ohio
- Northwest Agricultural Research Station (NWARS); Custar, Ohio

Planting Dates:

- May 24 (2016), June 2 (2017), May 9 (2018)

Previous Crops:

- WARS: Soybean (all years)
- NWARS: Soybean (2016), wheat (2017, 2018)

Base Nitrogen Program:

- WARS: 180 lbs N/acre applied as anhydrous ammonia (82-0-0) prior to planting
- NWARS: 200 lbs N/acre applied as UAN (28-0-0) prior to planting

Seeding Rate: 35,000 seeds/acre

Experimental Design: Split-plot randomized complete block design; whole plot factor: row spacing; split-plot factor: hybrid and foliar treatment combination

Hybrid/Brand[1]:

- P0843AM™ (AM, LL, RR2)
- P0825AM™ (AM, LL, RR2)

Row Spacings:

- 15 inches
- 30 inches

Foliar Treatments (Applied at R1 stage):

- Non-treated
- Foliar N (5.9 lbs N/acre, Coron® 28-0-0 Ag)
- Foliar fungicide (DuPont™ Aproach® Prima, 6.8 fl oz/acre)
- Foliar N + foliar fungicide

Disease severity at and below the ear leaf, ear leaf N content, and ear leaf chlorophyll content were measured at foliar application and 14 days after foliar application for all treatments.

Growing Conditions

- Weather conditions were generally favorable for corn production at both experimental sites over the three years of the study.
- Disease incidence was low (<6% leaf area coverage) across years, resulting in limited disease severity at the R1 stage and during early grain filling.
- Predominant foliar diseases by year:
  - 2016: Gray leaf spot, northern corn leaf blight
  - 2017: Common rust, gray leaf spot
  - 2018: Gray leaf spot

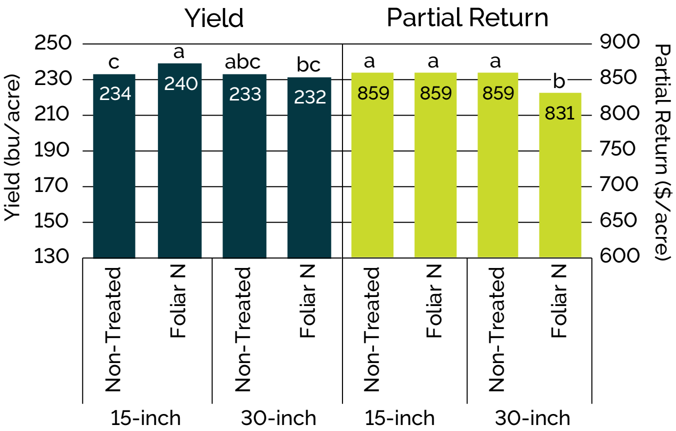


Figure 1. Treatment (non-treated vs. foliar N application) and row-spacing interaction effect on corn yield and partial return.

Different letters on the chart indicate that the means are different. Partial return calculation based on corn price of $3.80/bu and foliar N application cost of $20.11/acre.

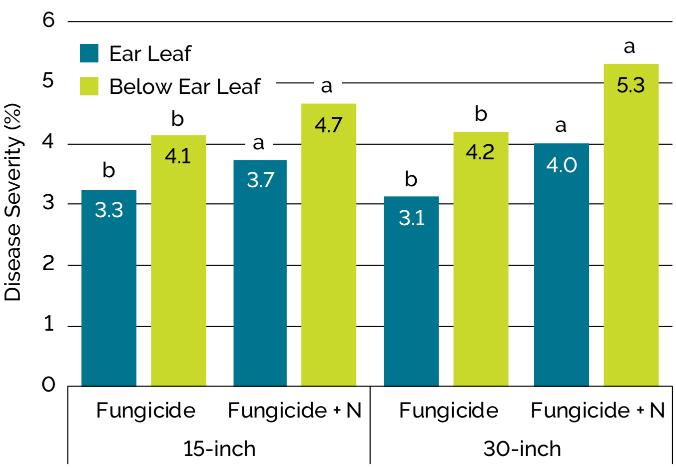


Figure 2. Effects of treatment (fungicide vs. fungicide + foliar N) on disease severity on the ear leaf and below the ear leaf across row spacings.

Different letters on the chart denote the means for the treatment effect are significantly different across row spacings.

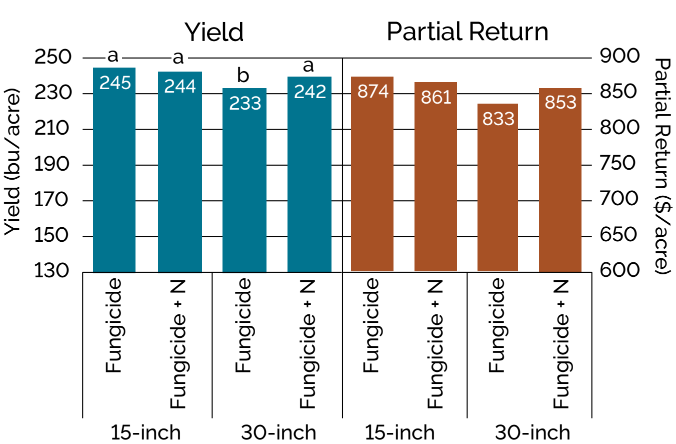


Figure 3. Effects of treatment (fungicide vs. fungicide + foliar N) and row spacing on yield and partial return.

Different letters on the chart denote the means are different for the interaction. The absence of letters denotes the Global F-test was not significant. Partial return calculation based on corn price of $3.80/bu, fungicide application cost of $23.10/acre, and fungicide + foliar N cost of $34.10/acre.

Results

Hybrid Differences

- Hybrid differences were evident for almost every parameter measured; however, the two hybrids responded similarly to management practices.
  - Pioneer® P0843AM™ brand corn exhibited less foliar disease than Pioneer® P0825AM™ brand corn and greater ear-leaf N concentrations and SPAD values than P0825AM™.
  - Although statistically different, ear-leaf N at the R1 stage was within the normal sufficiency range (2.90 to 3.50%) for each hybrid.
  - Despite having less disease and greater ear-leaf N content, P0843AM™ was lower yielding than P0825AM™

Foliar N vs. Non-Treated

- Foliar N increased yield in narrow-row corn by 5.8 bu/acre compared to the non-treated check. This yield gain was just enough to offset the cost of application (Figure 1).
- Foliar N did not increase yield in the 30-inch row corn, and the added cost of application resulted in significantly lower economic return.
- Disease severity 14 days after treatment was not affected by row spacing or by foliar N application.

Fungicide + Foliar N vs. Fungicide Alone

- The inclusion of foliar N with a fungicide treatment resulted in increased disease severity for both the ear-leaf as well as the leaf directly below the ear leaf; however, disease pressure overall was low and did not affect yield (Figure 2).
  - Previous research has shown that foliar N application can increase the severity of gray leaf spot, which is consistent with observations in this study.
- The addition of foliar N with the fungicide did not affect yield in narrow-row corn but increased yield by 8.9 bu/acre in 30-inch row corn (Figure 3).
- The average yield increase in 30-inch row corn with the addition of foliar N was more than enough to offset the added cost of the product, although differences in partial return were not statistically significant.

Conclusions

- Results of this study did not show a greater need for additional foliar inputs in narrow-row corn to maximize economic return.
- The value of foliar N and fungicide treatments in this study was likely limited by the low disease pressure and generally favorable growing environments.
- Foliar inputs may be more beneficial under conditions conducive to greater disease pressure and nitrogen deficiency stress. Future studies should examine reduced-tillage, continuous corn, and higher population density environments.

return to table of contents

timing corn harvest

Steve Butzen, M.S., *Agronomy Information Consultant*

Summary

- Proper timing of corn harvest has important implications for harvestable yield, grain drying costs, and profits.
- Monitoring maturity stages and then grain moisture as well as crop condition during the drydown period are useful tools in making the best possible harvest timing decisions.
- Deterioration of stalks and ear shanks leads to unharvested ears and is the most common cause of field losses.
- Wet fall conditions extend the drydown period and increase the rate of stalk and ear degradation.
- Most studies have refuted the notion that unknown causes of kernel dry matter loss occur during field drydown. Thus, base harvest timing decisions on known causes.
- Studies that measured kernel respiration discount the theory that respiration results in significant losses of dry matter.
- Comparing the additional cost of drying with the expected yield savings due to early harvest is a straightforward way to strike the right balance between the two.
- Pioneer studies in 18 locations showed a 1.5% advantage for early harvest – not enough to cover added drying costs.

return to table of contents

Introduction

Timing of corn harvest is a critical crop management decision for growers. Early harvest can reduce field losses but increases drying costs and may reduce grain quality and storability if kernels are damaged during combining and handling. Harvesting later reduces drying costs but may result in excess deterioration of the crop that may decrease harvestable yield and quality. Thus, there is a right time to harvest each field, but competing demands and weather play an important role in achieving the goal of harvest on a specific date. Nevertheless, growers taking a systematic approach to monitoring their fields during drydown and evaluating loss potential can make the best possible decision in prioritizing their fields for harvest.

Corn Development After Silking

A review of the corn development process during the grain fill period is a helpful tool in monitoring crop progress as maturity approaches. As kernels develop, they progressively gain in dry weight as starch accumulates and displaces moisture in the kernel. Beginning at the dent stage (R5), a line of demarcation is visible between the hard, structural starch deposited in the crown of the kernel and the milky content of the rest of the kernel (toward the tip). This border is known as the "milk line" (Figure 1 and Table 2).

Table 1. Approximate time after silking to beginning of each reproductive growth stage.

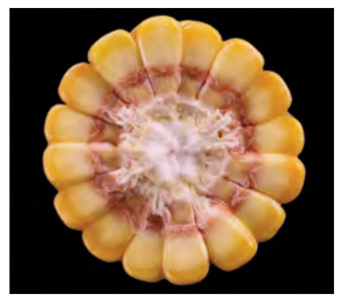
Reproductive Stage	Description of Stage	Weeks After Silking
R1	Silking	—
R2	Blister	2 weeks
R3	Milk	3 weeks
R4	Dough	4 weeks
R5	Dent	5 to 6 weeks
R6	Physiological maturity	8 to 9 weeks

Figure 1. Progression of milk line in corn kernels from R5, or early dent *(left)*, to R6, or physiological maturity *(right)*.

Figure 2. Progression of black layer development in kernels (at tip of kernels), indicating physiological maturity (R6).

Physiological maturity is defined as the point at which dry matter accumulation ceases in the grain. This point is visually indicated by the formation of a black abscission layer between the corn kernel and the cob (Figure 2). This abscission layer halts further nutrient transport from the plant into the grain and so represents the point of maximum dry matter accumulation (i.e., yield) in the grain.

Table 2. R5 to R6 kernel stages, grain moisture, and GDUs remaining to maturity.

	**Stage R5** Beginning dent Milk line starting to appear at top of kernel Grain moisture: ~50-55% ~400 GDUs remaining to maturity
	**Stage R5.25** ¼ milk line Grain moisture: ~45-50% ~300 GDUs remaining to maturity
	**Stage R5.5** ½ milk line Grain moisture: ~40-45% ~200 GDUs remaining to maturity
	**Stage R5.75** ¾ milk line Grain moisture: ~35-40% ~100 GDUs remaining to maturity
	**Stage R6** Black layer or "no milk line" Grain moisture: ~28-32% 0 GDUs remaining to maturity

Corn Kernel Drydown

The period from black layer to harvest is defined as the "drydown" period. Kernel moisture loss during the drydown period is entirely due to evaporative moisture loss affected by air temperature, relative humidity, and wind. When corn reaches maturity early in the season, field drydown is faster due to warmer air temperatures. For example, according to Ohio State University Extension, corn drying rates as high as 1% per day in September will usually drop to ½ to ¾% per day by early to mid-October, ¼ to ½% per day by late October to early November, and only ¼% per day or less by mid-November (Thomison, 2011).

Pioneer research indicates that it takes approximately 15 to 20 GDUs to lower grain moisture each point from 30% down to 25%, 20 to 25 GDUs per point of drydown from 25 to 22%, and 25 to 30 GDUs per point from 22 to 20%.

Grain moisture at harvest affects the time and cost required to dry the grain to acceptable storage moisture levels as well as grain quality. Wet grain can incur damage during combining, handling, and drying. If grain quality is significantly reduced during harvest and drying, allowable storage time is also reduced, dockage may result, and losses of fines as well as broken kernels can trim bushels of saleable grain. Consequently, choosing the optimum moisture for corn harvest is a critical management decision.

Can Field Drying Result in Corn Dry Matter Losses?

A rural legend has persisted in some circles over the decades that corn left to dry in the field after black layer is susceptible to so-called "mystery" or "phantom" yield loss. The reason for the "mystery" label is because the phenomenon is not ascribed to the most common yield-robbing culprits: dropped ears, lodged stalks, insect feeding, or ear rots. Rather, "kernel respiration" is hypothesized to be the primary cause for the supposed dry matter losses.

The narrative first gained credibility following testimonials in farm publications and a university study in the early 1990s (Nielsen et al., 1996). Following this, other researchers began to report data from previous studies that had measured grain weight as corn drying progressed. Additional studies were planned and conducted as well with the express objective of documenting kernel weight changes during field or lab drying. Results of these studies are summarized below.

- An Iowa State University study at 2 locations of 4 hybrids and 6 harvest dates documented no yield reductions as corn field-dried from 35 to 19% (Knittle and Burris, 1976).
- A University of Illinois study tested four hybrids and four harvest dates. No hybrid showed significant changes in dry weight as moistures decreased from 27 to 18% (Nafziger, 1984).
- Pioneer researchers measured kernel moistures and dry weights of eight hybrids at sequential harvest dates in 1983 and 1984 (Cerwick and Cavalieri, 1984). No hybrids showed yield reductions during drydown.
- Pioneer agronomists studied two hybrids at two locations (Reese and Jones, 1995). Dry weight did not decrease as drydown progressed from black layer to 15% grain moisture.
- In field and lab drydown studies conducted at the University of Nebraska from 1995 to 1997, a total of six hybrids and nine drying environment/harvest method combinations were examined (Elmore and Roeth, 1996). The study found no evidence of kernel dry matter loss following physiological maturity.
  - Importantly, the study included one of the same hybrids tested in the Purdue study but with conflicting results. The authors concluded that the different results were likely due to different methods in measuring grain moisture; the Nebraska study used oven-dry weights rather than an electronic moisture meter because meters may be inaccurate at moistures above 25%.
  - The authors concluded that their results showing stable grain dry matter following maturity do not support the need for early harvest and the associated energy expense for grain drying.
- In 2002 to 2004, field studies were conducted by Ohio State University researchers at three locations to determine effects of three harvest date periods and four plant densities on four corn hybrids differing in maturity and stalk strength (Thomison et al., 2011). They found no evidence of dry matter losses with harvest delays.
- In 2016 and 2017, Iowa State University conducted replicated studies at two locations to determine if corn dry matter loss occurred in the field after maturity (Licht et al., 2017). At each environment, three hybrids of differing maturity were planted at two planting dates and harvested on six (2016) or seven (2017) separate dates during the post-physiological maturity drydown period.
  - In this extensive study in which grain moistures ranged from over 30% down to 15% during drydown, kernel dry matter weight showed no change over progressive harvest dates (Figure 3).

Therefore, it appears that yield losses observed in on-farm studies with late compared to early harvest are due to other field loss factors. These factors may not be readily noticeable, but 1 bu/acre is lost with only 2 corn kernels per square foot,

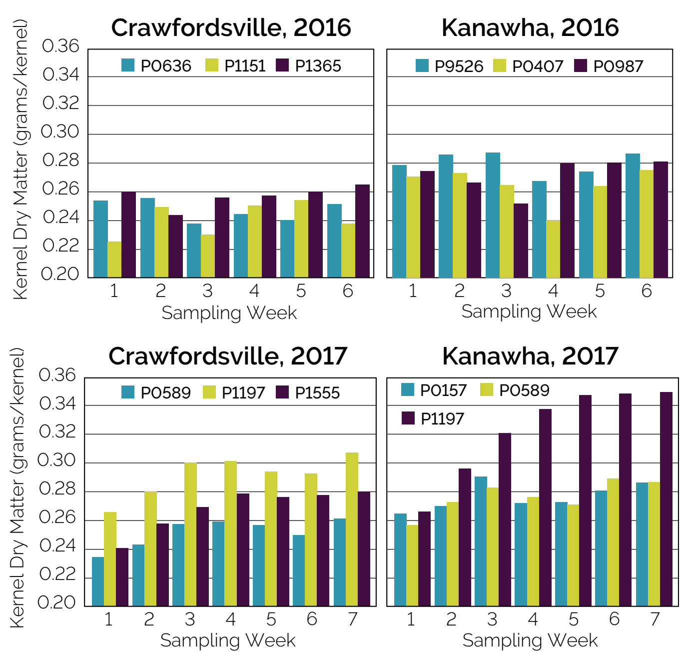


Figure 3. Corn kernel dry matter weights over the post physiological maturity dry down period (Sept. and Oct.) for 2 planting dates and 2 Iowa locations in 2016 and 2017.

and these losses can add-up quickly when corn is less than 20% grain moisture (Nafziger, 2018). Combine adjustments to minimize these losses are reviewed in the *Crop Insights* on "Measuring and Reducing Corn Field Losses" (Butzen, 2018).

Kernel Respiration Effect on Yield

Prior research studies were examined to determine if there was evidence of corn kernel respiration rates high enough to explain large yield losses in the field during drydown. A study conducted at Iowa State University showed that when kernel moisture dropped below 30%, the respiration rate slowed dramatically and was only a fraction of the rate measured at the dent stage (Knittle, and Burris, 1976).

In another study conducted by ag engineers at the USDA, shelled corn samples were evaluated for dry matter losses in storage at six temperatures (Saul and Steele, 1966). Samples were at 28% moisture at the beginning of the storage period. Researchers measured the amount of carbon dioxide given off by the samples over time, and converted this number to dry matter loss (DML). Results are shown in the following table:

Days Required for 1% Dry Matter Reduction in Stored Corn*

Temperature	35 °F	50 °F	65 °F	80 °F	95 °F	110 °F
Days	129	50	25	10	6	4

These results represent the undamaged control sample in the study.

Average temperatures in the Midwest U.S. are 55 to 65 °F in the last half of September and 50 to 60 °F in the first half of October. At these temperatures in the storage study, 1% dry matter loss would not occur for 25 to 50 days. This level of dry matter loss due to kernel respiration does not warrant early harvest and substantially higher drying costs for wet corn.

Stalk Quality Considerations on Corn Harvest Timing

Many different stresses to the corn plant can lower stalk quality with the result that stalk problems occur in some fields each year. Drought stress; reduced sunlight; insect and disease pressure; and hail damage are stresses that can result in poor stalk quality. Even high yields are a stress on the plant that may lead to stalk problems. Many additional factors, including cropping history, soil fertility issues, hybrid genetics, and microenvironment effects, can heighten the problem in particular fields.

Growers are encouraged to monitor their fields as harvest approaches to identify stalk quality problems and prepare to harvest before field losses occur. Scouting fields approximately two to three weeks prior to the expected harvest date can identify fields with weak stalks predisposed to lodging. Fields with high-lodging potential should be slated for early harvest. Weak stalks can be detected by pinching the stalk at the first or second elongated internode above the ground. If the stalk collapses, advanced stages of stalk rot are indicated. Another technique is to push the plant sideways about 8 to 12 in at ear level. If the stalk crimps near the base or fails to return to the vertical position, stalk rot is indicated. Check 20 plants in 5 areas of the field. If more than 10 to 15% of the stalks are rotted, that field should be considered for early harvest.

Grain Quality Considerations on Corn Harvest Timing

Maintaining grain quality through harvest and storage is a critical goal to optimize profitability. Harvest timing is the primary factor under control of the grower to optimize grain quality. Harvesting grain at too high of moisture content can result in severe kernel damage during threshing and drying. Conversely, allowing corn in the field too long can lead to reduced yield and quality if stalk or ear rot diseases or insect feeding damage are increasing.

Ear rots are a particular concern if weather conditions turn wet in the fall. If ears are in contact with the ground under these conditions, ear rots may develop quickly. Growers should scout fields regularly during the drydown period to inspect ears and for possible disease development. Strip back the husks on five plants in five areas of the field to check for insect feeding or ear rots. If these problems are severe, consider harvesting early and drying grain to below 18% moisture to stop progression of both insects and diseases as well as to maintain the best possible grain quality.

Most growers have experienced the need to harvest corn at high moistures when late planting or cool temperatures have delayed crop development and are well aware of the devastating effects on grain quality. For this reason, grain quality experts would like to see corn field dry below 20% moisture before harvesting. However, if grain quality is deteriorating, beginning harvest at about 25% moisture may be necessary, especially if there are many at-risk fields to follow. The key to which of these suggestions is appropriate for your fields is to closely monitor both moisture and crop condition, beginning at physiological maturity.

Cost of Extra Drying

Removing 1 point of moisture from a bushel of corn requires about 0.02 gal of propane. At the cost of $1.50/gal propane, the cost would be 3 cents/bushel. Thus, the additional drying cost incurred by harvesting at 25% moisture instead of field drying to 20% would be 15 cents per bushel. (This does not account for any costs attributable to the extra time involved in drying.) At $3.50/bu of corn, 4.3% of yield

Table 3. Bu/acre of corn required to offset additional drying costs when harvesting early.

Yield Level (bu/acre)	Extra Points of Moisture Due to Early Harvest					
	1	2	4	6	8	10
	Bu/acre Needed to Offset Extra Drying Costs					
100	0.9	1.7	3.4	5.1	6.9	8.6
125	1.1	2.1	4.3	6.4	8.6	10.7
150	1.3	2.6	5.1	7.7	10.3	12.9
175	1.5	3.0	6.0	9.0	12.0	15.0
200	1.7	3.4	6.9	10.3	13.7	17.1
225	1.9	3.9	7.7	11.6	15.4	19.3
250	2.1	4.3	8.6	12.9	17.1	21.4
275	2.4	4.7	9.4	14.1	18.9	23.6
300	2.6	5.1	10.3	15.4	20.6	25.7

Propane cost = $1.50/gal. Corn price = $3.50/Bu.

($0.15/$3.50) would have to be saved to pay for the cost of removing an additional 5 points of moisture in drying. Table 3 shows the bushel per acre of corn needed to pay for the additional drying costs of early harvesting at various yield levels.

Studies on Harvest Timing

For more than five decades, researchers have conducted studies that address the harvest timing decision. These studies have usually shown that yields are reduced with delayed harvest due to progressive deterioration of the crop caused by weather factors. As growers might expect, studies often showed differences between years, locations, and hybrids that were related to specific weather conditions occurring between the harvest dates.

Many previous studies indicated that stalk lodging was a major factor contributing to yield losses with delayed harvest. An Ohio State study (Thomison et al., 2011) tested four hybrids differing in maturity and stalk lodging ratings at four plant densities in three locations over three years. Predictably, the study showed that decreases in grain yield and increases in stalk rot and lodging associated with harvest delays were influenced by plant population and hybrid characteristics. Stalk rot as well as lodging increased at the higher plant populations, and this effect was magnified by late harvesting.

In 2013, Pioneer agronomists conducted studies in three states to help determine harvest timing effects on corn yield and moisture (Prestemon, 2013) (Figure 4).

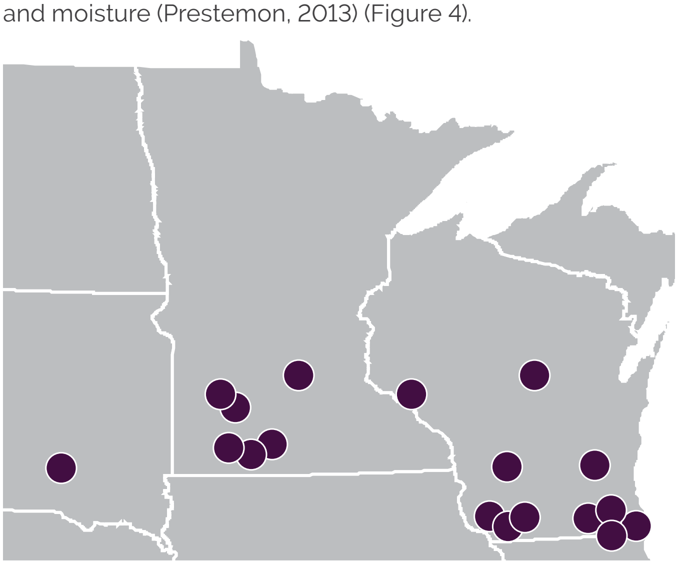


Figure 4. 18 locations evaluated in Wisconsin, Minnesota, and South Dakota for effect of harvest timing on corn yield and moisture, 2013.

A portion of each trial field was harvested “early” with a target moisture around 25%. The remaining portion of the field was harvested a week or more later with final harvest targeted moisture less than 20%. Yield was measured using a weigh wagon to eliminate possible variation due to yield monitor calibration or grain sensitivity. Results are shown in Figure 5.

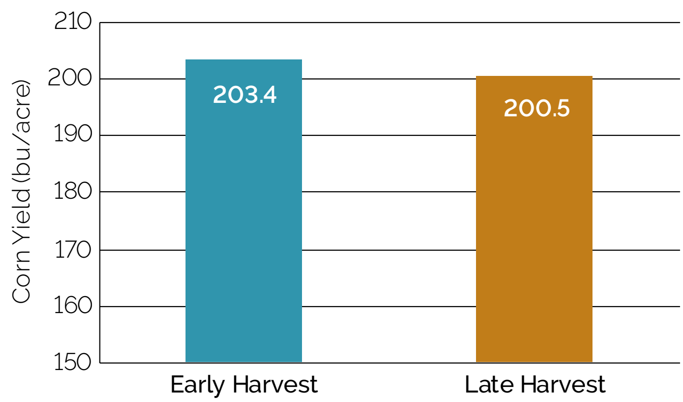


Figure 5. Average corn grain yield with early and late harvest timings across 18 locations, 2013.

As Figure 5 indicates, early harvest yields averaged 2.9 bu/acre higher than late harvest yields. No obvious agronomic issues were noted between early and late harvested areas. Moistures averaged 25.2% for the early harvest and 22.1% for the late harvest. At 3 cents per point of moisture removed per bushel, additional drying costs would be about $18/acre. At a grain price of $3.50/bu, 2.9 additional bushels per acre (~$10 in value) are not sufficient to pay the additional drying cost.

Conclusions

Timing corn harvest to maximize profitability usually means striking a balance between maximizing bushels harvested and minimizing drying costs. Close monitoring of crop condition during drydown is required to make the best possible harvest timing decision. Early harvest with the sole intention of avoiding so-called “dry matter losses” from unknown causes is not recommended.

Proper combine settings are also critical to reduce harvesting losses as well as increase harvested grain and profits. Combine settings must match crop conditions, which change from field to field and even from day to day. Continual monitoring of ears and kernels lost while harvesting is required to make necessary adjustments to the combine (Butzen, 2018).

maximizing the value of foliar fungicides in corn

Mark Jeschke, Ph.D., *Agronomy Manager*

Summary

- Pioneer has conducted extensive research to better understand the value of foliar fungicide treatments in corn production.
- Corn yield increased an average of 7.5 bu/acre in response to a foliar fungicide application across over 2,000 Pioneer on-farm trials conducted from 2007 to 2018.
- The most important factor determining the value of a foliar fungicide application is disease pressure. When weather conditions are conducive for foliar diseases, a fungicide application can be beneficial.
- Hybrids that have lower levels of genetic resistance to a given foliar disease are more likely to benefit from a fungicide application if that disease becomes prevalent.
- Continuous corn and minimum tillage fields can be at higher risk of foliar disease and more likely to benefit from a fungicide application due to greater amounts of surface residue harboring pathogens from the previous corn crop.
- Later-maturing fields can be at greater risk for yield loss due to foliar diseases and therefore, are more likely to benefit from a fungicide application.

Forward-Thinking Farming Webinar

Chasing 500: Using Foliar Fungicides to Maximize Corn Yield

Learn to think differently about foliar fungicides – not just for disease control and prevention – but as part of a strategic program to push the yield limits of corn.

Watch at pioneer.com/webinars

Introduction

Over the span of only a few years, foliar fungicide treatments went 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. Pioneer research conducted over the last several years has demonstrated that the value of fungicide applications can depend on disease pressure, hybrid susceptibility, and agronomic practices.

This article summarizes the key findings of several Pioneer research projects on foliar fungicide use in corn conducted between 2007 and 2018. 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) except where noted. Some of these studies provided the opportunity to assess the value of fungicide treatments against specific foliar diseases due to the presence of a single predominant disease at the trial locations.

On-Farm Fungicide Trial Survey

Between 2007 and 2018, Pioneer agronomists, sales professionals, and cooperators conducted over 2,000 on-farm fungicide trials comparing yield of corn treated with a foliar fungicide between tasseling and brown silk to non-treated corn. These trials encompassed a wide range of different hybrids, management practices, environmental conditions, and disease pressure.

The results of these trials provide an estimate of the average yield response that corn producers might expect from a foliar fungicide application. This average can serve as a starting point for foliar fungicide treatment decisions. Whether yield response in a given field is likely to be above or below this average will depend on the combination of disease pressure, hybrid genetic resistance, agronomic practices, and environmental conditions unique to that field.

Across the over 2,000 on-farm fungicide trials conducted from 2007 to 2018, the average yield response to fungicide application was an increase of 7.5 bu/acre (Figure 1). A positive yield response to fungicide application occurred in 79% of the trials. Yield response varied widely among the trials as would be expected given differences in weather conditions, disease pressure, and trial locations.

The economic viability of a fungicide application can vary according to the price of corn and cost of the fungicide as well as application. Higher corn prices and lower treatment costs reduce the break-even yield response, while lower corn prices and higher costs increase it (Table 1). At a break-even yield response of 5 bu/acre, 57% of the Pioneer on-farm trials would have seen an economic benefit from fungicide application (Figure 1). However, at a break-even point of 10 bu/acre, the success rate drops to only 36%.

Table 1. 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
	bu/acre			
$22	7.3	5.5	4.4	3.7
$24	8.0	6.0	4.8	4.0
$26	8.7	6.5	5.2	4.3
$28	9.3	7.0	5.6	4.7
$30	10.0	7.5	6.0	5.0
$32	10.7	8.0	6.4	5.3

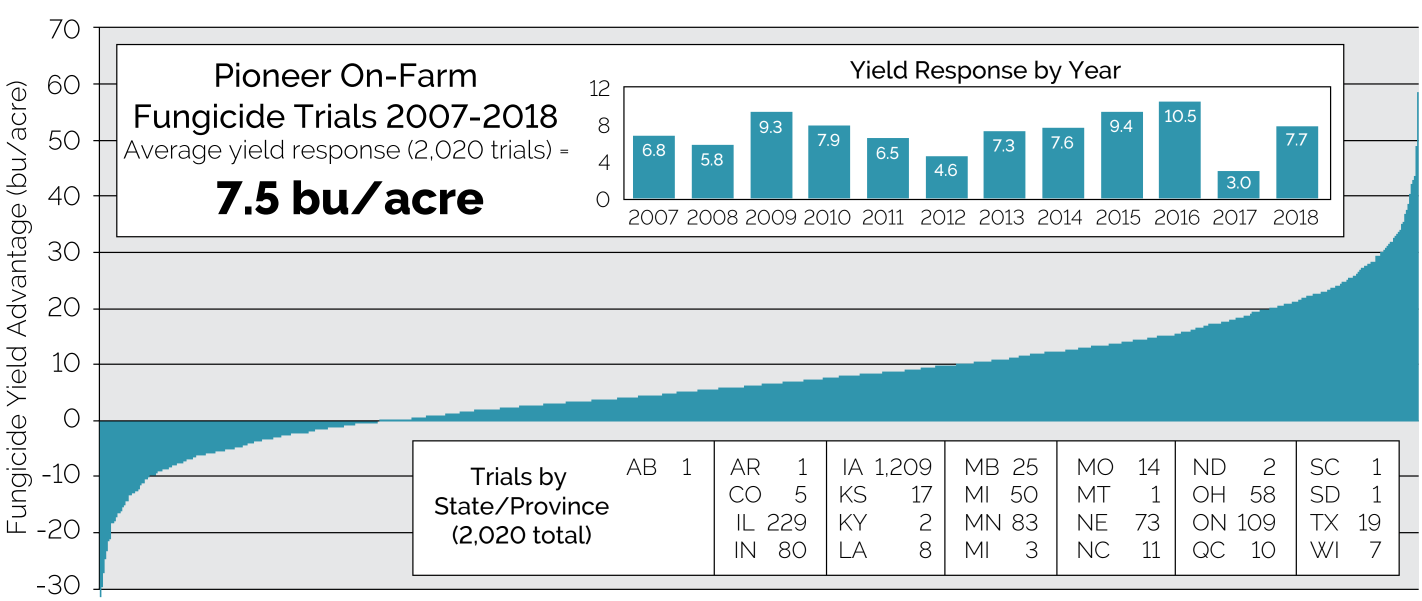


Figure 1. Corn yield response to foliar fungicide application in 2,020 Pioneer on-farm trials conducted from 2007 to 2018.

Yearly averages in fungicide yield response ranged from 3.0 to 10.5 bu/acre in the on-farm trial survey. The majority of trial locations were located in the Central Corn Belt; consequently, variation in yearly averages is largely reflective of differences in weather conditions and disease pressure in those states.

Factors Influencing Fungicide Response

Disease Pressure

The most important factor 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 may provide a substantial economic benefit.

There are two basic types of disease cycles among the fungal diseases that infect corn leaves. Many pathogens, such as northern corn leaf blight (NCLB), 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. 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.

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.

Previous Crop and Tillage

Continuous corn and minimum tillage fields can be at higher risk of foliar disease and more likely to benefit from a fungicide application due to greater amounts of surface residue harboring pathogens from the previous corn crop.

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 (GLS), NCLB, southern leaf blight, eyespot, tar spot, and northern leaf spot overwinter in corn residue, providing a source of inoculum to infect corn planted the following season.

Hybrid Maturity and Planting Date

Hybrid maturity and planting date have also been found to influence susceptibility to yield loss from foliar diseases. 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.

Pioneer Fungicide Research

Pioneer scientists, agronomists, and university collaborators have conducted several corn fungicide studies in which a single foliar disease was predominant at the research location or locations. In some cases, research locations were chosen specifically due to their history of a specific disease; in others, environmental conditions happened to be favorable for a given disease when the study was conducted.

Gray Leaf Spot

A research project was conducted over three years at the University of Tennessee Research and Education Center at Milan at a research site specifically chosen due to a history of high GLS pressure. The primary goal of this study was to determine the yield benefit associated with foliar fungicide management of GLS in hybrids with differing levels of genetic resistance. 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 GLS each year. Three Pioneer brand corn hybrids with differing levels of resistance to GLS were included in the study.

Results of the study demonstrated the potential for GLS 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 GLS; however, even with the most resistant hybrid, the yield benefit of the foliar fungicide application was great enough to potentially cover the cost of product and application (Figure 2). Under more moderate disease pressure, a fungicide application would likely not provide an economic benefit on a resistant hybrid.

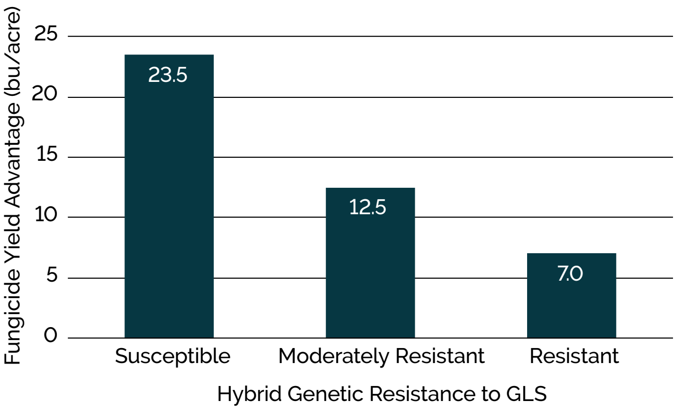


Figure 2. Average yield response of hybrids susceptible, moderately resistant, and resistant to GLS to foliar fungicide application in a 3-year Univ. of Tennessee/Pioneer research study.

Common Rust

Pioneer scientists conducted fungicide research trials at several Midwestern sites in 2009, a growing season that experienced unusually high common rust pressure in parts of the Midwest. Summer temperatures were cooler than normal in 2009, which favors development and spread of common rust. Studies were conducted at 10 different field locations across 5 states. Corn yield response to fungicide application varied widely among research locations, largely due to differences in common rust pressure. Common rust was prevalent at research locations in Iowa, Illinois, and Indiana.

Average yield response across locations in Iowa, Illinois, and Indiana was 11.4 bu/acre (Table 2). Conversely, average yield response across 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

Table 2. 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**

foliar fungicide application was greatest among hybrids with lower levels of genetic resistance to the disease (Figure 3).

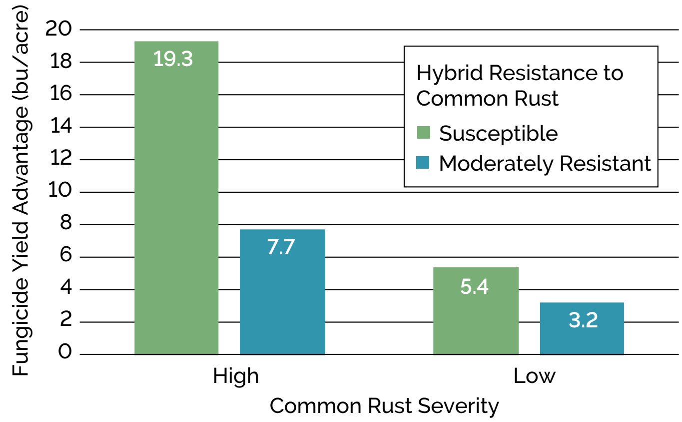


Figure 3. Average fungicide yield response of hybrids with low resistance (3 on a 1-9 scale) and moderate resistance (4-6) to common rust in Pioneer small-plot trials.

Common rust was prevalent in a trial at Macomb, IL, along with low to moderate levels of GSL and NCLB. Notable differences in disease symptoms and yield response to fungicide were observed (Figure 4).

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 4. Two hybrids treated (left) and non-treated (right) with fungicide at Macomb, IL. The fungicide helped to protect yield of a susceptible hybrid (top) but provided little benefit on a moderately resistant hybrid (bottom).

Northern Corn Leaf Blight

Pioneer on-farm trials were conducted at 40 locations in Iowa in 2015 to evaluate corn yield response to foliar fungicides applied at different timings. Northern corn leaf blight pressure was high in much of Iowa in 2015, and it was the predominant foliar disease at the trial locations. Trials compared yield of corn treated with DuPont™ Aproach® Prima fungicide at the VT, R1, or R2 growth stage to non-treated corn.

Results showed that yield response to fungicide application varied by hybrid genetic resistance to NCLB. A yield response of 13 bu/acre was observed with hybrids rated a 3 on a 1 to 9 scale for NCLB, while hybrids rated a 6 for NCLB had an average yield response of 9 bu/acre (Figure 5). Fungicide yield response was greatest at the VT application timing (Figure 6).

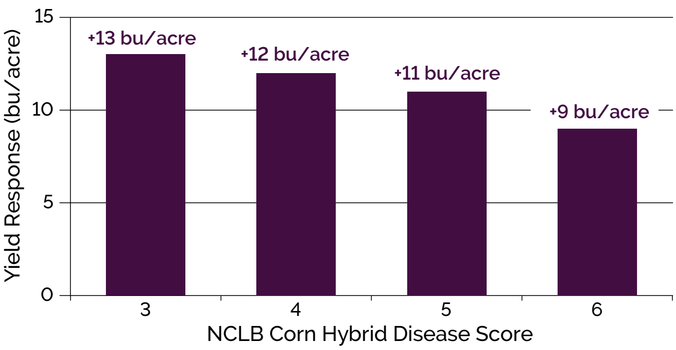


Figure 5. Average fungicide yield response of Pioneer® brand hybrids with different levels of genetic resistance to NCLB in 40 Pioneer agronomy trials in Iowa in 2015.

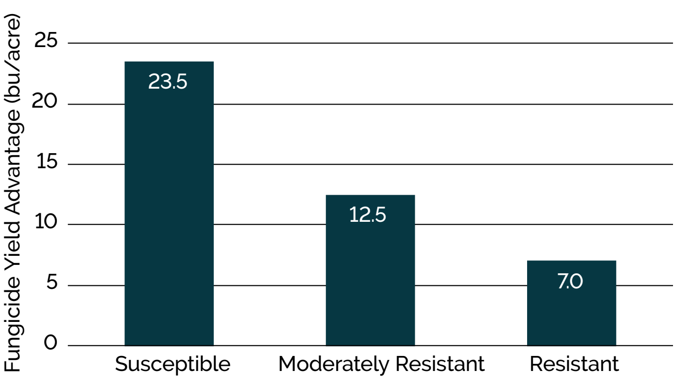


Figure 6. Average yield response to fungicide applications at the VT, R1, or R2 growth stages in 40 Pioneer agronomy trials in Iowa in 2015.

Southern Rust

Pioneer conducted fungicide research trials over two years in the Southeastern U.S. at locations where southern rust was the predominant foliar disease.

A replicated research study was conducted near Camilla, GA, in 2014 to assess southern rust infestation and corn yield response of six different Pioneer® hybrids with and without foliar fungicide treatment. This study included two different fungicide treatments: a single application at the V8-V10 growth stage, as well as a two-pass program with applications at both the V8-V10 stage and the VT-R1 stage. (The original protocol called for only the VT-R1 application, but treatment timings were altered when southern rust was detected earlier than expected at the research site.) Averaged over hybrids, there was no yield increase with early fungicide application alone, but yields were increased by an average of 20 bu/acre when the VT-R1 application was included (Figure 7).

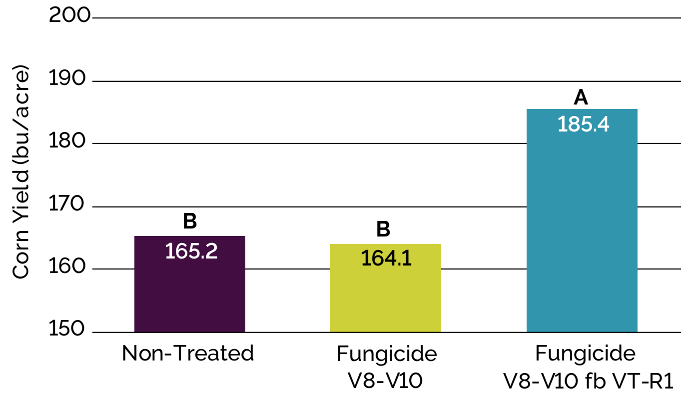


Figure 7. Corn yield as affected by fungicide treatments near Camilla, GA, in 2014.

Means with the same letter are not significantly different based on Tukey's HSD test conducted at the alpha=0.05 level. Means averaged over 2 planting dates and 6 hybrids.

A study was conducted the following year across seven locations in five southeastern states to evaluate corn yield response to a single-pass fungicide application at VT-R1 for control of southern rust. Averaged over 4 hybrids and 7 locations, corn treated with fungicide at the VT-R1 stage yielded 11 bu/acre more than non-treated corn (Figure 8).

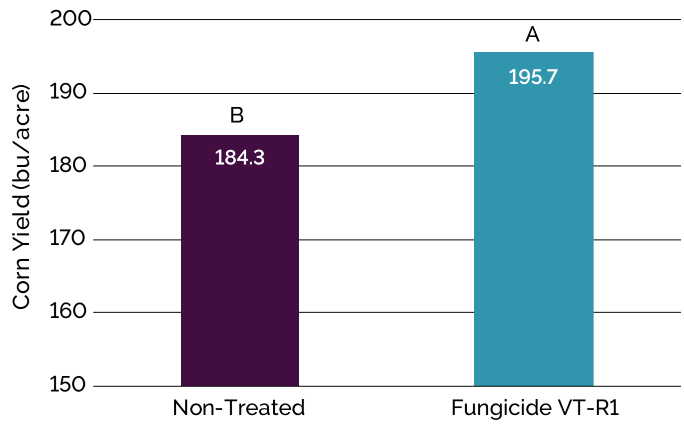


Figure 8. Average yield of corn treated with Aproach Prima fungicide at the VT-R1 corn growth stage and non-treated corn across 7 southern research locations in 2015.

Figure 9. Corn treated with fungicide at VT-R1 compared to non-treated corn at a research location near Winchester, AR, in 2015. Southern rust pressure was low at the time of application but increased in severity and ultimately caused premature death in the non-treated check before the end of the season.

return to table of contents

minimal corn yield response to fungicides under drought conditions

Dan Berning, Agronomy Manager

Dry conditions across the study area during the latter portion of the 2020 growing season resulted in low foliar disease pressure.

Foliar fungicide treatments had minimal effect on corn yield, averaging only 1.4 bu/acre more than the untreated check.

Similar results have been observed in previous growing seasons that experienced abnormally dry conditions.

Rationale and Objectives

- Foliar fungicides have proven their value as a disease management tool in corn; in over 2,000 Pioneer on-farm trials conducted from 2007 to 2018, a fungicide application increased corn yield by an average of 7.5 bu/acre (Jeschke, 2020).
- The most important factor determining the value of a foliar fungicide application is disease pressure. When weather conditions are conducive for foliar diseases, a fungicide application can be beneficial.
- Occasionally, conducive weather conditions can persist past the effective residual effect of the fungicide.
- Research was conducted in 2020 to evaluate the potential yield benefit of expanding the window of fungicide activity with a split foliar application at or near tasseling (VT/R1) and again at the milk stage of kernel development (R3).

Study Description

Experimental Design:

- 17 locations across the U.S. Corn Belt
- Strip plot design
- Two corn hybrids per location. Hybrid selection for each location varied.
- Fungicide treatments applied via ground application:
  - » Untreated check
  - » 6.8 oz/acre DuPont™ Aproach® Prima applied at VT/R1
  - » 3.4 oz/acre DuPont™ Aproach® Prima applied at VT/R1 followed by another 3.4 oz/acre at R3

Data Collected:

- Harvest yield
- Harvest moisture

Results

- Foliar fungicide treatments had little effect on corn yield in 2020. Across the 13 trial locations that were harvested for yield, the average yield with fungicide treatment was only 1.4 bu/acre greater than the untreated check (Figure 1).
  - » The 6.8 oz/acre treatment at VT/R1 averaged 0.5 bu/acre more than the untreated check. Grain moisture averaged 0.4 points wetter.
  - » The 3.4 oz/acre at VT/R1 followed by 3.4 oz/acre at R3 treatment averaged 2.3 bu/acre more than the untreated check. Grain moisture averaged 0.8 points wetter.

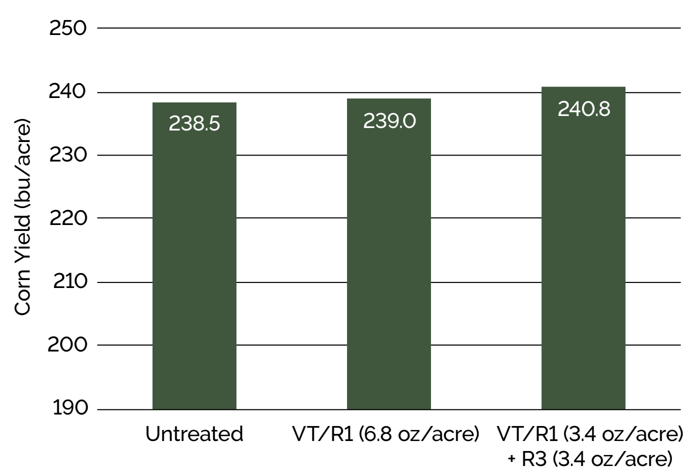


Figure 1. Average yield of foliar fungicide treatments across 13 on-farm trial locations in 2020.

Figure 2. Differences in green foliar tissue among treatments late in the season at an on-farm trial location in Missouri (September 3, 2020).

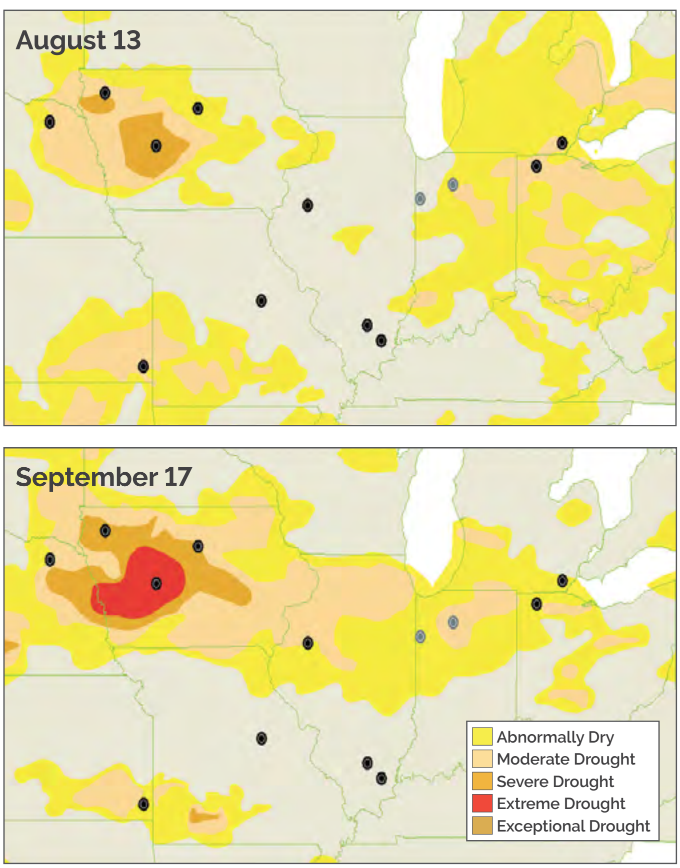


Figure 3. U.S. Drought Monitor maps showing the onset of drought conditions across much of the Corn Belt in the latter part of the 2020 growing season, affecting the majority of on-farm trial locations.

Results (continued)

- The most important factor determining the value of a foliar fungicide application is disease pressure.
- Due to the lack of disease pressure across on-farm trial locations in 2020, results of this study did not provide any insights into the potential value of split fungicide applications compared to a single application at VT/R1.
- When weather conditions are conducive for foliar diseases, a fungicide application can be beneficial; however, in 2020, the very dry weather conditions that occurred at most of the trial locations in August and September were not conducive for late-season foliar disease progression.
- Results similar to those of this study have been observed in previous growing seasons that experienced drought conditions during the latter portion of the growing season.
    - In 2011 and 2012, which were both abnormally dry years in Iowa, the average yield response to foliar fungicide treatments in Pioneer on-farm trials in Iowa was 2.5 bu/acre (Jeschke, 2017).
    - In 2013 and 2014, which had normal to above-average precipitation, the average yield response to fungicide treatment was 7.5 bu/acre.

common and southern rust

***Mark Jeschke, Ph.D.**, Agronomy Manager, **Bill Dolezal, Ph.D.**, Former Research Fellow, **Adda Sayers**, Former Research Scientist, and **Steve Butzen, M.S.**, Agronomy Information Consultant*

Summary

- Persistent moist weather conditions encourage the development and spread of rust in corn fields.
- Unlike other major foliar diseases of corn in North America, the rusts do not overwinter in the Corn Belt. Infections in this region result from spores carried northward with prevailing weather systems from the Southern U.S.
- Distinguishing common rust from southern rust is important. Common rust rarely causes significant yield losses in corn, but severe southern rust can decrease yields.
- Common rust is favored by cool, humid conditions; found on upper and lower leaf surfaces; and distinguished by elongated red to cinnamon-brown pustules.
- Southern rust is favored by high temperature and humidity; found on the upper leaf surface only; and more orange or reddish-orange in appearance. Pustules are small and circular with a pinhead appearance.
- In recent growing seasons, southern rust has occurred further north in the Midwestern U.S. earlier in the season than is typical for this disease.
- Several fungicide choices are available to help protect corn from leaf damage due to common and southern rust.
- Corn stalk quality is closely tied to leaf function. Where leaf diseases have occurred, growers are encouraged to monitor stalk quality as corn maturity progresses.

Introduction

Pioneer Agronomy

Common and Southern Rust

- Tony Zerrusen, Field Agronomist

Rusts are fungal leaf diseases that can spread rapidly in corn fields when wet weather patterns persist over a large geography for an extended period of time. Rust outbreaks generally occur during the ear-fill period of corn growth. Unlike other major foliar diseases of corn in North America, such as gray leaf spot (*Cercospora zeae-maydis*) and northern corn leaf blight (*Exserohilum turcicum*), the rusts do not overwinter in the Corn Belt. Rusts develop first in southern corn fields, and then may spread into primary corn-growing states. Movement is by windblown spores that travel northward with prevailing weather systems.

Two kinds of rust can affect corn in North America – common rust *(Puccinia sorghi)* and southern rust *(Puccinia polysora).* Although these rusts have similar life cycles on corn, their impact on the crop can be very different. Consequently, it is important for growers to recognize which rust disease is occurring. This article will explain the life cycles of common and southern rust; explore the weather conditions that promote rust development; and describe the symptoms of each disease, including the characteristics that distinguish them from each other.

Figure 1. Southern rust symptoms visible in the upper canopy of corn in Johnston, Iowa (Sept. 11, 2017).

Common Rust

Life Cycle

Common rust can be found in corn worldwide in environments with ample moisture, mild temperatures, and high humidity, which favor disease development. The pathogen that causes common rust has a complex life cycle and requires two host species to complete its life cycle. The sexual stage of the life cycle occurs primarily in subtropical regions where *Oxalis* species (wood sorrel) serve as the host. The asexual stages of the life cycle occur on corn. Teliospores (thick-walled resting spores) overwinter in tropical and subtropical regions and provide the primary source of inoculum in subsequent seasons.

Urediospores can be spread over large distances by wind and disseminate into temperate regions during the spring and summer where they infect corn. In North America, rust spores already present in southern corn fields historically move northward with southerly weather patterns, which move moisture from the Gulf of Mexico to the Midwest. These weather systems provide most of the moisture needed throughout the growing season for millions of corn acres in the U.S.

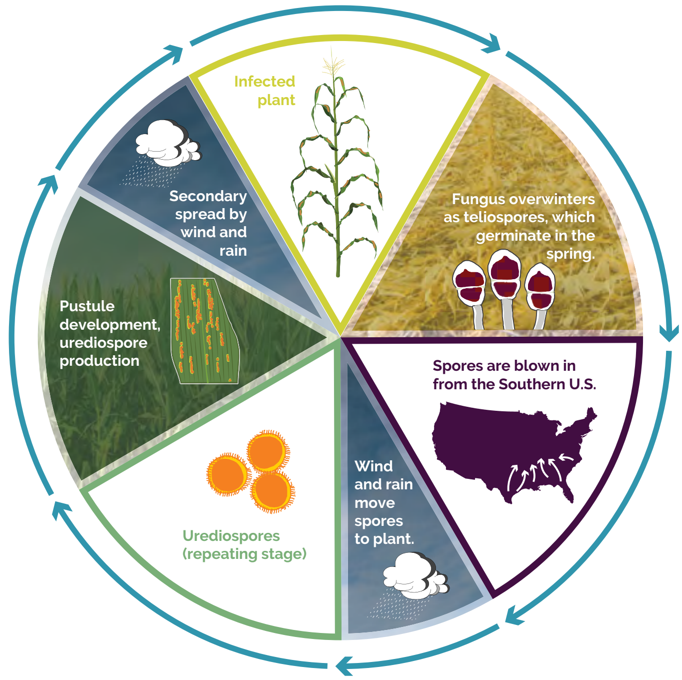


Figure 2. Common rust disease cycle *(Puccinia sorghi).*

Common rust development is favored by relatively cool temperatures (60 to 77 °F) and humid conditions. Hot, dry conditions typically slow down or stop the development of the pathogen. Common rust can be found throughout corn-producing regions in the U.S. and southern Canada where it most commonly occurs at low levels.

Symptoms

Common rust starts out as small flecks on the leaves, which develop into small tan spots, then brick-red to cinnamon-brown colored pustules. These pustules blister on both the upper and lower leaf surface and turn dark brown to black late in the season. Pustules have an elongated, jagged appearance (Figure 3).

Figure 3. Common rust pustules on a corn leaf.

Southern Rust

Life Cycle

Southern rust (also known as Polysora rust) is favored by high relative humidity and high temperatures and therefore, tends to be confined to tropical and subtropical regions more than common rust. In seasons with higher than average temperatures, southern rust can spread into temperate regions where it can impact corn yield. In North America, southern rust usually occurs later in the growing season and is more prevalent in the southern states. Southern rust does not occur as often from year to year as common rust, but it is usually more severe when it does occur. The disease can develop very rapidly during warm, humid conditions, and its effects can be devastating.

Unlike common rust, the pathogen that causes southern rust is not known to have an alternate host. Urediospores are the sole source of inoculum for both primary and secondary infection. Although teliospores are produced, they have not been shown to germinate and consequently, do not play a role in the disease cycle. At the start of the growing season, urediospores from infected corn residue are spread by wind and rain on to growing corn plants. Infection of these plants produces spores that serve as secondary inoculum and can be disseminated over hundreds of miles by wind.

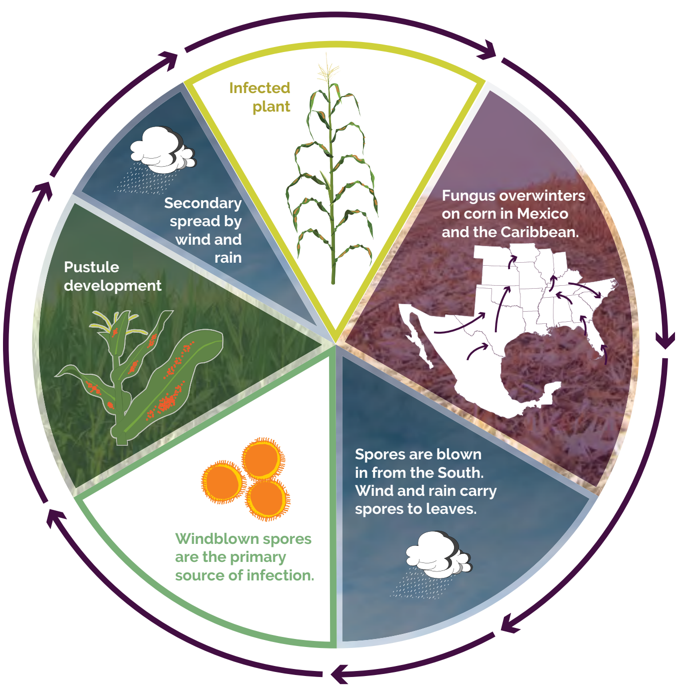


Figure 4. Southern rust disease cycle *(Puccinia polysora)*.

Symptoms

Southern rust looks very similar to common rust, but several characteristics distinguish the two. Southern rust pustules are usually confined to the upper leaf surface, while common rust is found on both upper and lower surfaces. Southern rust is more orange or reddish-orange in appearance, while common rust is red or cinnamon-brown. Southern rust pustules have a circular appearance (Figure 5), while those of common rust have an elongated, jagged appearance.

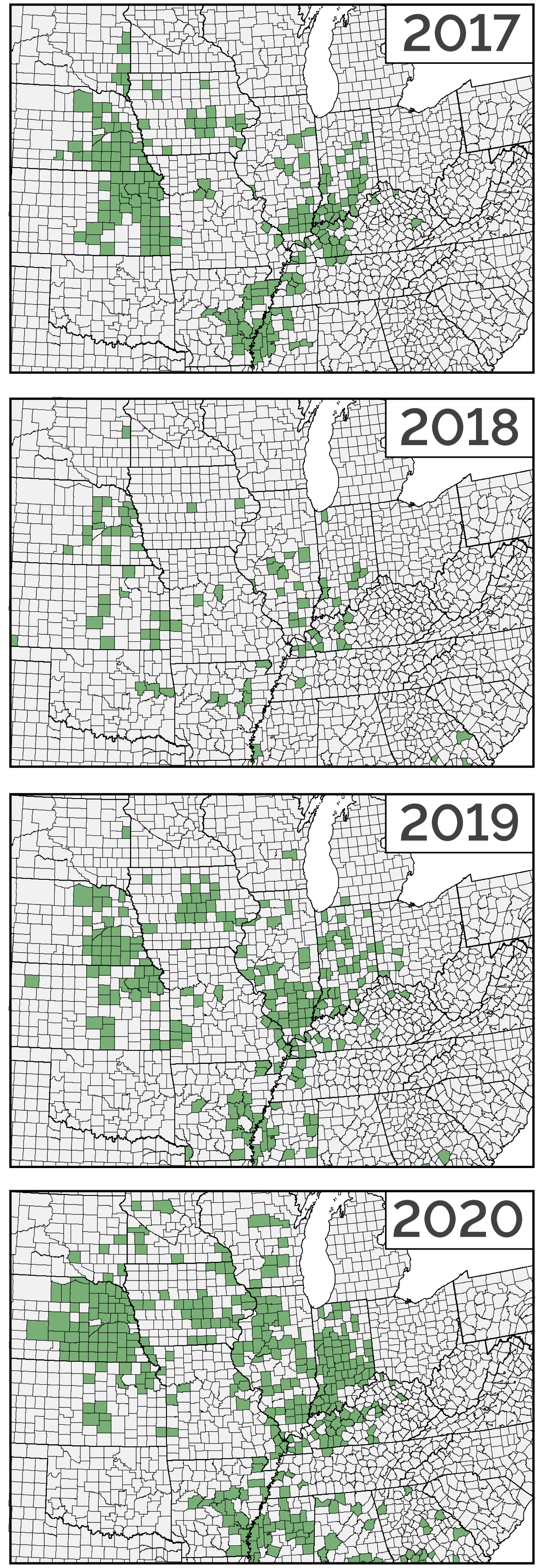


Figure 5. Confirmed detections of southern rust in corn through the first week of September during the 2017 to 2020 growing seasons. *Source: http://www.ipipe.org.*

return to table of contents

Figure 6. Southern rust pustules on a corn leaf. *Photo courtesy of Eric Alinger, Pioneer Field Agronomist*

Expanded Range of Southern Rust in Recent Years

Historically, southern rust has not been a frequent disease of corn in the Corn Belt. In recent growing seasons, however, it has appeared further north earlier in the season than is typical, with confirmed detections in several counties in Indiana, Illinois, Iowa, Nebraska, and Kansas and even some cases in South Dakota and Wisconsin (Figure 5). Southern rust was prevalent at the Corteva Agriscience research station in Johnston, Iowa, in 2017. The increased prevalence of southern rust in the Corn Belt makes it important for growers to be able to distinguish it from common rust.

Table 1. Distinguishing characteristics of common vs. southern rust.

	Common Rust	Southern Rust
Pathogen	*Puccinia sorghi*	*Puccinia polysora*
Ideal Environment	Cool – warm Moist 60-77 °F	Warm – hot Moist 77+ °F
Appearance of Pustules	Large, circular to elongated	Small circular, pinhead appearance
Color of Pustules	Brown to cinnamon-brown	Reddish orange
Location of Pustules	Both upper and lower leaf surfaces Infects leaves only	Upper leaf surface May also infect husks

Yield Loss From Rust

Both rust diseases of corn can cause substantial yield losses under severe disease pressure; however, southern rust generally poses a greater risk to corn yield than common rust. Yield loss due to rust depends on timing of infection, amount of leaf area damaged, and location of damaged leaves on the plant. If significant damage to upper leaves occurs early in the life of the hybrid, yield losses will be higher. If damage is confined to lower leaves of the corn plant or occurs in the later reproductive stages of development, little economic loss would be expected. Consequently, the latest-planted corn in an area is at higher risk for yield loss due to leaf diseases.

Common rust usually does not reach levels in the Corn Belt that would justify a fungicide application; however, severe infections can occur under conditions favorable for disease development. Such conditions were experienced in several Midwestern states in 2009, a growing season that was characterized by lower than normal temperatures throughout much of July and August (Lutt et al., 2016). Pioneer fungicide research trial locations in Illinois and Indiana experienced intense common rust pressure in 2009. At one research location in Indiana, the average yield response to fungicide treatment was over 22 bu/acre (Jeschke, 2017). Yield response to fungicide treatment varied greatly with common rust pressure at the research locations and hybrid genetic resistance to common rust (Figure 7 and 8).

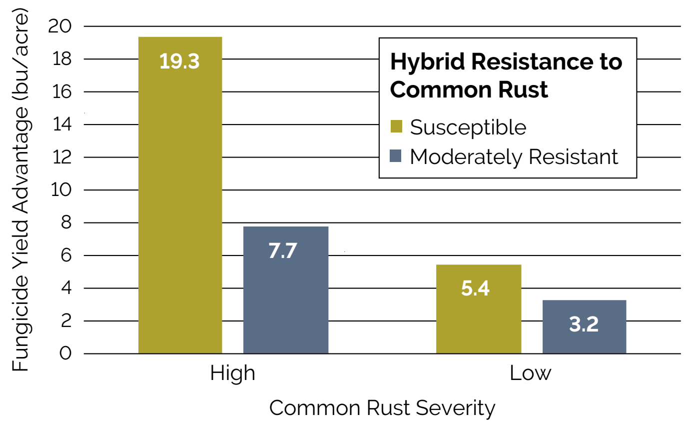


Figure 7. Average fungicide yield response of hybrids with low resistance (3 on a 1-9 scale) and moderate resistance (4-6) to common rust in Pioneer research trials in 2009.

Southern rust is generally more damaging to corn than common rust due to its ability to rapidly develop and spread under favorable conditions. In a Pioneer research study conducted near Camilla, Georgia, in 2014, treatment with DuPont™ Aproach® Prima fungicide significantly reduced southern rust symptoms and increased corn yield by an average of 20 bu/acre (Poston, 2014a). Fungicide yield response of individual hybrids ranged from 10 to 38 bu/acre. Yield losses in excess of 80 bu/acre due to southern rust have been reported from university research trials in Alabama (Hagan, 2017). Southern rust has increased in importance in the Southern U.S. and has appeared more frequently in Midwestern states in recent years, making careful monitoring and correct identification of the disease critical for making management decisions.

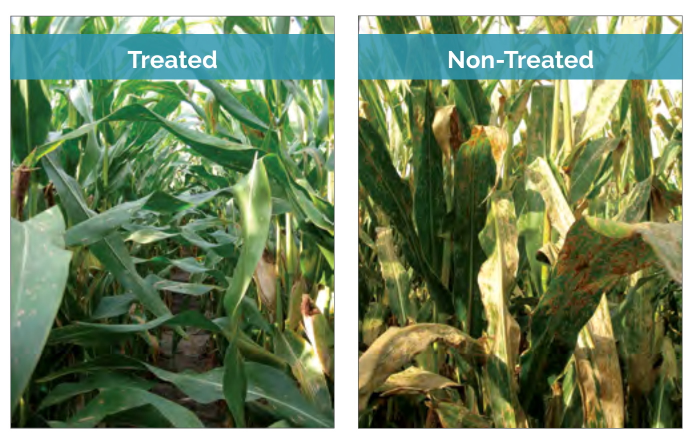


Figure 8. A hybrid susceptible to common rust (3 on a 1-9 scale) treated with a fungicide (left) compared to the same hybrid, non-treated, showing severe common rust (right) at a Pioneer research location in Illinois in 2009.

Figure 9. Southern rust in a plot treated with DuPont Aproach Prima fungicide (left) vs. a non-treated plot (right) near Camilla, GA, in 2014 (Poston, 2014b).

Severe localized epidemics of common and southern rust in past years have generated interest in the usefulness of treating with fungicides to prevent further disease development. The chances for a profitable return from spraying are greater when rust outbreaks are severe and corn prices are high. To be profitable, fungicide applications must be made in a timely manner before rust has spread throughout the canopy and before corn plants are near physiological maturity.

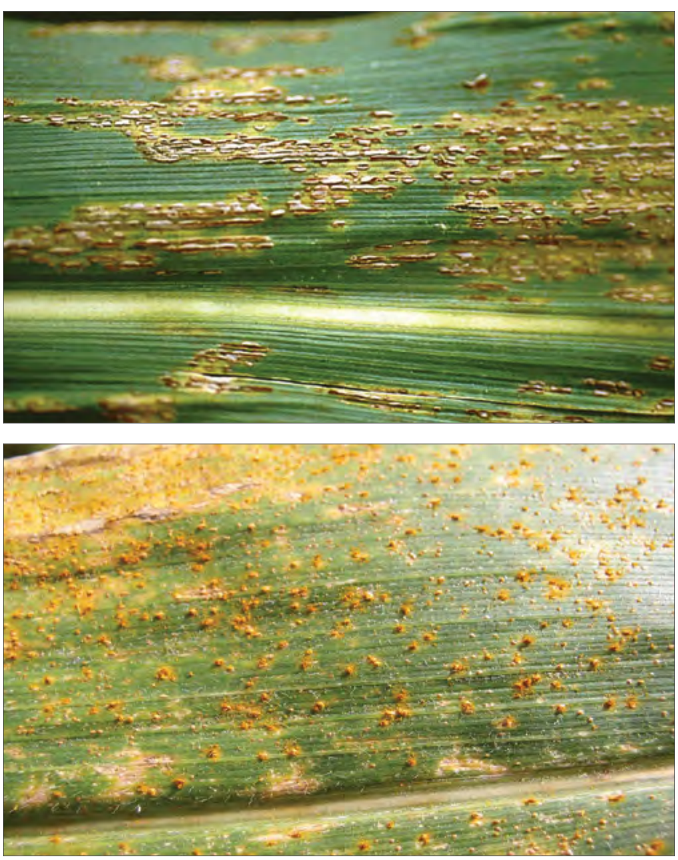


Figure 10. Typical symptoms of common rust (top) and southern rust (bottom) on corn leaf.

Scouting and Treatment Guidelines

If applied properly and in a timely manner, fungicide treatments can be effective in protecting corn leaves from foliar diseases. Whether the treatment will provide an economic return is often difficult to predict. To help with this decision, the University of Illinois gives the following fungicide treatment guidelines for rust and other foliar diseases (Bissonnette, 2000):

- Scout for fungal leaf diseases two weeks before tasseling to two weeks after tasseling.
- At that point, at least a 15% whole-plant infection is needed to justify a fungicide treatment.
- Also consider these factors to make a reasonable decision:
  - » First, consider the weather. Fungi, in general, and rusts, in particular, need free water (on the leaves) and continued wet weather to continue to flourish.
  - » Next, consider the probability of other fungal leaf blights developing in the field and in your particular hybrid. Cropping history and corn residue levels can affect development of diseases, such as gray leaf spot.
  - » Consider the **price** of corn and **cost** per application.

Fungicide Application

Timely foliar fungicide applications can help reduce leaf damage due to common or southern rust.

Table 2. Foliar fungicide efficacy on common and southern rust in corn (Wise, 2019).

Fungicide	Active Ingredient(s)	Common Rust	Southern Rust
DuPont™ Aproach®	picoxystrobin	VG-E	G
DuPont™ Aproach® Prima	picoxystrobin + cyproconazole	U	G
Affiance® SC	tetraconazole + azoxystrobin	G-VG	G
Fortix® SC	flutriafol + fluoxastrobin	U	VG
Preemptor® SC	flutriafol + fluoxastrobin	U	VG
Headline® SC	pyraclostrobin	E	VG
Headline AMP®	pyraclostrobin + metconazole	E	G
Priaxor®	pyraclostrobin + fluxapyroxad	VG	VG
Quilt Xcel®	azoxystrobin + propiconazole	VG-E	VG
Stratego® YLD	trifloxystrobin + prothioconzole	E	G
Trivapro®	benzovindiflupyr + azoxystrobin + propiconazole	U	E

G = good, VG = very good, E = excellent, U = unknown or insufficient data to rank product.

Getting the application on early enough and achieving good coverage of the upper leaf canopy are essential for control of rust with fungicides. For aerial applications, a minimum of five gal/acre of water should be used. For ground application, use a minimum of 20 gal/acre of water and hollow cone nozzles with spray pressure of at least 30 to 40 psi. However, spray pressures greater than 40 to 50 psi are not recommended because they create small droplets that do not penetrate to the ear zone.

For ground applications on corn greater than five feet in height, the following spray strategy is recommended:

- One nozzle spraying over the top of the whorl or plant, and
- A drop nozzle on either side of the row to spray the ear leaf zone.

Always read and follow product label recommendations when using any fungicide.

Stalk Rots Often Follow Leaf Diseases

Stalk quality is closely tied to leaf function. Loss of leaf area by disease lesions reduces the amount of photosynthate produced by the leaves. When the demand for sugars from developing kernels exceeds that produced by the leaves, the plant takes structural carbohydrates from the stalk to meet the need. The stalk is weakened, fungi invade, and stalk rots develop (Figure 11). If lodging occurs, harvest loss may result.

Where leaf diseases have occurred, growers are encouraged to monitor stalk quality as corn maturity progresses. To detect stalk rot occurrence, pinch stalks at two internodes near the base of the plant in several areas of the field. If the stalk collapses, advanced stages of stalk rot are indicated. Another test is to push plants sideways 6 to 12 inches at ear level. Stalk rot is indicated if plants break rather than returning to vertical. Agronomists suggest that fields be scheduled for early harvest if 10 to 15% of the stalks are rotted.

Figure 11. Corn stalk showing substantial pith degradation in the lower internodes. Weather conditions and foliar diseases at this site favored carbohydrate remobilization from the stalk, which allowed stalk rot pathogens to invade.

Silage From Rust-Infected Corn

The Integrated Crop Management Newsletter (Iowa State University) provided the following information about harvesting rust-infected corn for silage (Munkvold and Farnham, 1999):

"Producers who intend to chop and feed rust-infested corn silage may wonder about the forage quality and potential animal health risks. Forage quality may be lowered primarily because of the early death of the plant. Producers should monitor the crop to ensure that it is harvested at the optimum moisture content for ensiling (60 to 70 percent).

There are no known toxic effects from feeding rust-infected corn silage. If the forage is ensiled, the ensiling process generally creates enough heat and acids to kill the fungus and detoxify the forage. In addition, the sugars and other by-products that are produced during the ensiling process should overwhelm any unpalatable tastes that the rust may impart.

If working in the open in rust-infested fields, it would be advisable to wear a respirator to avoid the inhalation of the rust spores. Initial exposure to the rust spores may result in a hypersensitivity to the spores upon subsequent exposures. Severe respiratory ailments have been known to develop causing pneumonia and other similar human health problems."

managing northern corn leaf blight

***Leroy Svec,** Former Research Scientist, **Bill Dolezal,** Former Research Fellow,*
***Madeline Henrickson,** Agronomy Sciences Intern, and **Mark Jeschke, Ph.D.,** Agronomy Manager*

Summary

- Northern corn leaf blight (NCLB) is found in humid climates wherever corn is grown. It has spread in recent years due to major weather events, especially hurricanes, which carry the organism from southern climates to North America.
- NCLB is caused by the fungus *Exserohilum turcicum*. Multiple "races" have been identified in the U.S.
- Yield losses are most severe when NCLB infects corn plants early and reaches the upper leaves by the beginning of ear fill. Slowing disease progression relative to crop development reduces the impact of the disease.
- Genetic resistance to the NCLB races is available in corn. Due to race shifts and the presence of multiple races in certain locations, Corteva Agriscience corn breeders are incorporating multiple resistance genes into hybrids.
- Corteva Agriscience rigorously evaluates and characterizes hybrids for resistance to NCLB, so growers have critical information to aid in hybrid selection.
- Selecting resistant hybrids; reducing corn residue by crop rotation, tillage, or stover harvest; and applying foliar fungicides are the primary means of controlling NCLB.
- Fungicide application may reduce yield losses, but economic return depends on hybrid resistance level, cropping history, tillage practices, location, corn price, yield potential, and weather.

[return to table of contents](#)

Disease Development and Symptoms

Northern corn leaf blight (NCLB) is caused by the fungus *Exserohilum turcicum*, also known as *Setosphaeria turcica* and previously known as *Helminthosporium turcicum*. The disease organism overwinters as mycelia and conidia in diseased corn leaves, husks, and other plant parts. 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 (18 to 27 °C).

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 NCLB 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 NCLB organism into additional northern regions.

Pioneer Agronomy

Northern Corn Leaf Blight Management
- Adam Owens, Product Agronomist

Northern Corn Leaf Blight Disease Cycle
(Setosphaeria turcica)

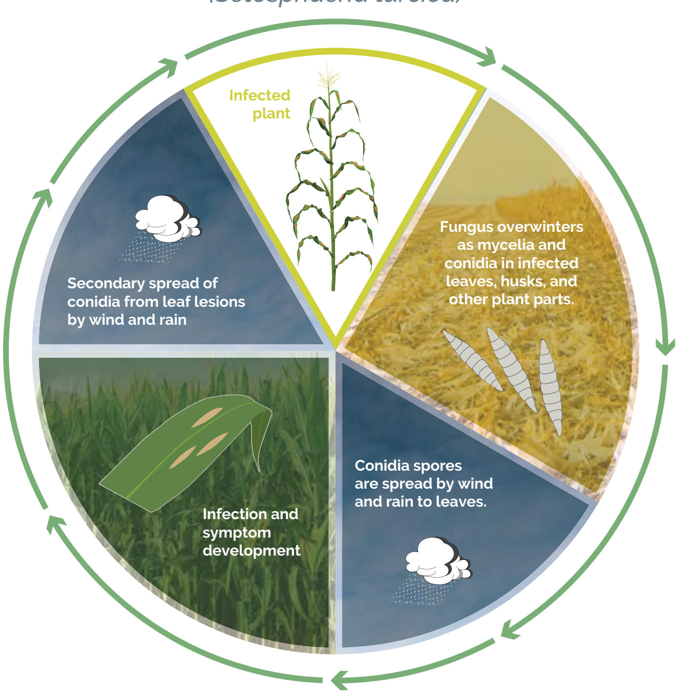


Figure 1. NCLB disease cycle.

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

Races of Northern Corn Leaf Blight

There are multiple races of *Setosphaeria turcica* documented in North America. These races can be region specific and are able to undergo race shifts. This requires corn breeders to be mindful of the different races and tailor their breeding programs accordingly. The resistance genes available to corn breeders are named "Ht" based on the previous NCLB fungal name *(H)elminthosporium (t)urcicum.* The common sources of resistant Ht genes are dominant genes and provide resistance to key races of *Setosphaeria turcica* (St) as shown in Table 1.

Table 1. Common sources of resistance Ht genes.

Pathogen	Host (Ht) Reaction to Each Race			
St 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

Pioneer Breeders Target Multiple NCLB Races

To provide disease resistance to NCLB when multiple races might be present, two or more Ht genes may be needed. Because of these multiple races of NCLB, Pioneer breeders are incorporating additional Ht genes in their hybrid development programs (i.e., a "multigenic" approach). Resistant phenotype and inheritance of NCLB resistance genes are shown below (Table 2).

Table 2. "Ht" resistance genes.

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

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

return to table of contents

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 2a). These NCLB 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 can maintain its health longer even with the disease organism present (Figure 2b).

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 3-5.

Figure 2a. Ht1 "chlorotic" reaction – slower to develop and fewer spores produced per lesion.

Figure 2b. HtN type reaction – fewer, smaller lesions develop and fewer spores produced per lesion.

Figure 3. Susceptible response, early lesions. Plant has no resistance, but lesions have not had time to fully develop.

Figure 4. Susceptible response, later lesions. Lesions have expanded to form large areas of necrotic tissue. Entire leaves may eventually become necrotic.

Figure 5. Resistant response. Note chlorotic halo surrounding lesions and restricted development of lesions, indicative of resistant response.

Evaluation and Characterization of Corn Hybrids for NCLB Reaction

Corteva evaluates corn hybrids in multiple environments to observe their reaction to NCLB 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 NCLB incidence, helps ensure that some environments will provide severe NCLB pressure to challenge even the best hybrids. It also helps provide exposure of hybrids to as many race variants of NCLB as possible. The critical time for evaluating disease damage begins in the early reproductive stages of development.

The Pioneer 1 to 9 NCLB 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. In determining overall hybrid ratings, experimental hybrids are compared to hybrids of "known" response to NCLB. 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.

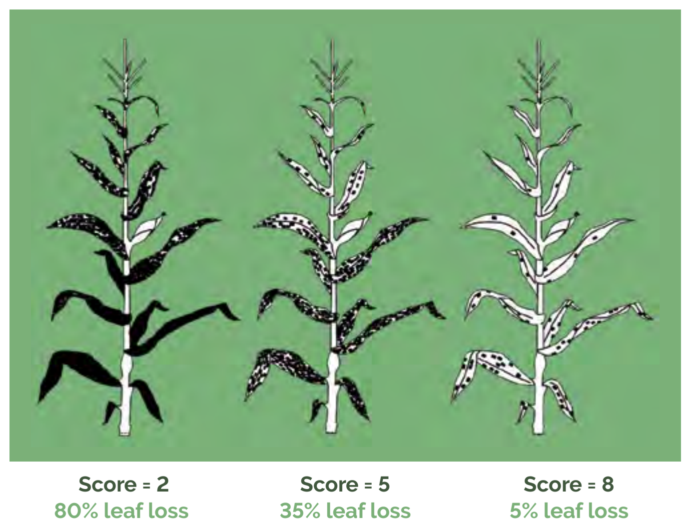


Figure 6. Illustration of Pioneer scoring system for NCLB.

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 NCLB in Corn Production

Effective management practices that reduce the impact of NCLB 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 NCLB rating reflects the hybrids' expected performance against the major NCLB races predominant in your area. As race shifts inevitably occur, continued testing by Corteva Agriscience researchers may result in a rating adjustment for some hybrids. Use of multigenic resistance by breeders increases hybrid stability as NCLB races shift over time.

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

Reducing Previous Corn Residue

Reducing corn residue decreases the amount of NCLB 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 NCLB 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 NCLB development (Table 3).

Table 3. Common corn foliar fungicides and efficacy against NCLB[3,4] (Wise, 2019).

Fungicide/ Company	Active Ingredients	NCLB Efficacy
Aproach®	picoxystrobin	very good
Aproach Prima	picoxystrobin + cyproconazole	very good
Domark	tetraconazole	very good
Headline® AMP	pyraclostrobin + metconazole	very good
Headline® EC Headline® SC	pyraclostrobin	very good
Quadris®	azoxystrobin	good
Quilt® Xcel	propiconazole + azoxystrobin	very good
Stratego® YLD	prothioconazole + trifloxystrobin	very good
Tilt®	propiconazole	good
Piraxor®	pyraclostrobin + fluxapyroxad	very good – excellent
Miravis	pyraclostrobin + fluxapyroxad	very good – excellent

Though fungicides are routinely used by growers to protect against several common leaf diseases, NCLB may not always be controlled as completely as some other diseases. This is due to the more rapid life cycle of NCLB, which may be as short as one week under favorable conditions. Because NCLB sporulates so rapidly, it is more difficult to time a single fungicide application. Consequently, selecting resistant hybrids is a crucial first step in managing NCLB 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. 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.

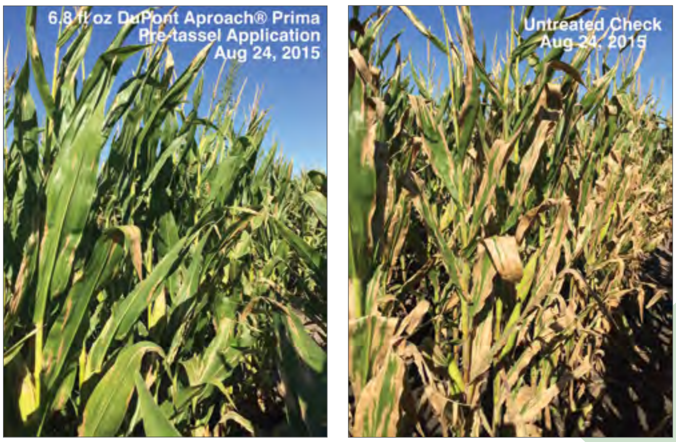


Figure 7. Field trial comparing fungicide treated (leaf) and non-treated corn (right) at a location with high NCLB pressure in 2015.

Fungicide Research Results

Pioneer on-farm trials were conducted at 40 locations in Iowa in 2015 to evaluate corn yield response to foliar fungicides applied at different timings. Northern corn leaf blight pressure was high in much of Iowa in 2015, and it was the predominant foliar disease at the trial locations (Figure 8). Trials compared yield of corn treated with DuPont™ Aproach® Prima fungicide at the VT, R1, or R2 stage to non-treated corn.

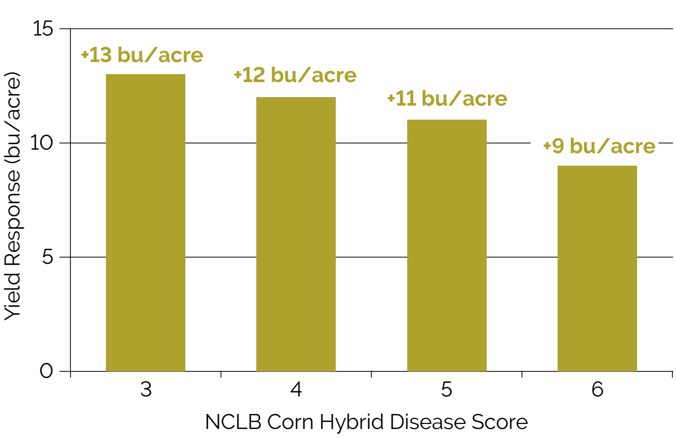


Figure 8. Average fungicide yield response of Pioneer® brand hybrids with different levels of genetic resistance to NCLB in 40 Pioneer agronomy trials in Iowa in 2015.

Results showed that yield response to fungicide application varied by hybrid genetic resistance to NCLB. A yield response of 13 bu/acre was observed with hybrids rated a 3 on a 1-9 scale for NCLB, while hybrids rated a 6 for northern corn leaf blight had an average yield response of 9 bu/acre (Figure 8). Fungicide yield response was greatest at the VT application timing (Figure 9).

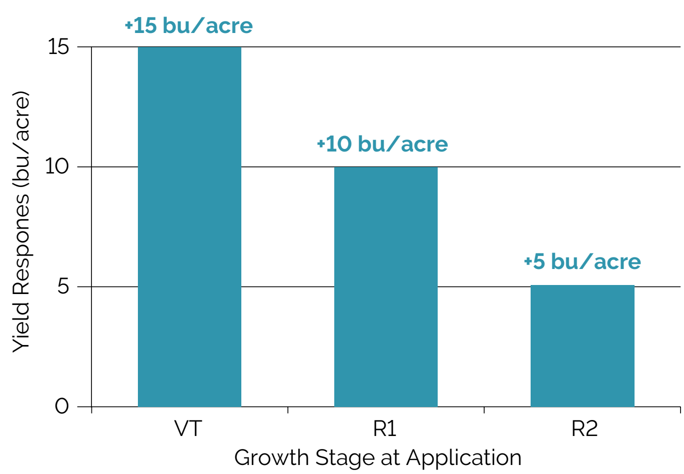


Figure 9. Average yield response to fungicide applications at the VT, R1, or R2 growth stages in 40 Pioneer agronomy trials in Iowa in 2015.

anthracnose leaf blight

***Madeline Henrickson,** Agronomy Sciences Intern*

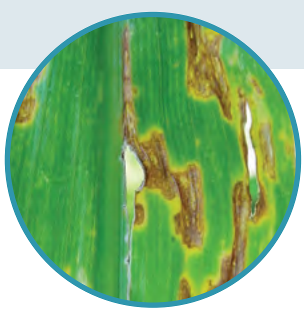
Pathogen Facts

- Anthracnose leaf blight in corn is caused by the fungal pathogen *Colletotrichum graminicola.*
- The leaf blight phase of the disease typically shows up early in the season.
- Anthracnose leaf blight does not generally have an impact on corn yield as it usually only affects the lower leaves and corn quickly grows out of the disease.
- Although they are caused by the same pathogen, the presence of anthracnose leaf blight has not been shown to correlate to anthracnose stalk rot later in the season.

Corn plants showing symptoms of anthracnose leaf blight on lower leaves (Kansas, June 2020).

Symptoms

- Early symptoms appear on lower leaves prior to spreading up the plant.
- Lesions are tannish-brown with darker edges and are generally spindly or oval-shaped.
- On severely infected leaves, lesions may coalesce into large dead patches, causing the leaf to turn yellow and wither.
- Necrotic tissues will have small, spiky, black, fruiting bodies.



Life Cycle

- The fungus overwinters as mycelium or sclerotia in corn residue.
- Spores are spread primarily by splashing water during the spring.
- Disease development is favored by wet weather during early crop growth with moderately warm temperatures.
- Disease develops soon after planting and continues to develop until canopy closure.

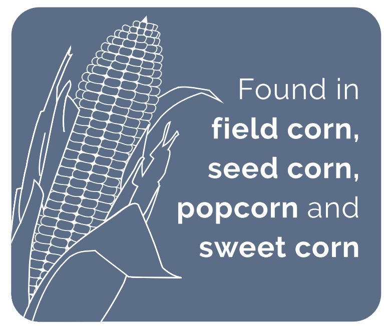
Management Considerations

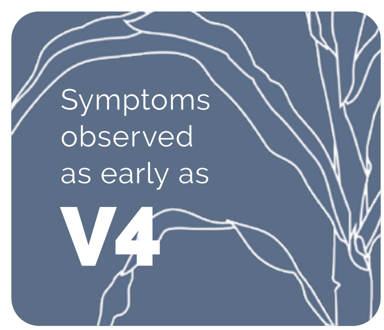
- Anthracnose leaf blight rarely affects corn yield.
- More prevalent in fields planted to continuous corn
- Infection is typically limited to lower leaves, *which do not contribute to yield.*
- Fungicides are unlikely to provide an economic benefit.

return to table of contents

bacterial leaf streak

Samantha Teten, *Agronomy Sciences Intern*





Disease Facts

- Caused by the bacterium *Xanthomonas vasicola* pv. *vasculorum*
- First detected in North America in 2014 in a Nebraska corn field
- Currently confirmed in 11 states: Nebraska, Colorado, Illinois, Iowa, Kansas, Minnesota, Missouri, South Dakota, Oklahoma, Texas, and Wisconsin
- Can be found in field corn, seed corn, popcorn, and sweet corn
- Plant does not have to be injured for disease to enter the plant. Bacterium can enter plant through stomatal openings.
- Bacterial inoculum overwinters on plant residue and causes symptoms on several host plants.
- Many diseases look similar to bacterial leaf streak, so it is recommended to confirm disease through a diagnostic laboratory.
- A different but closely related pathogen affects sorghum; *Xanthomonas vasicola* pv. *holcicola.*

Global Distribution and Spread

- Bacterial leaf streak of corn was first detected in 1948 in South Africa.
- The first confirmed case in the United States was in Nebraska in 2014; although, there is evidence it may have been present as early as 2010.
- Bacterial leaf streak has also been confirmed in Argentina (2017) and Brazil (2018).
- It is not known how the pathogen was spread to North and South America.

Disease Cycle

- *X. vasicola* pv. *vasculorum* appears to overwinter in infected crop residue from the previous growing season.
- Bacteria move from residue onto living plant tissue via rain splash. Bacteria can enter the plant through stomata or wounds.
- Symptoms often appear on the bottom leaves of a plant and spread upwards.
- Spread of secondary infection upwards through the canopy, from plant to plant, and into adjacent fields is facilitated by overhead irrigation or wind-driven rain.

Symptoms and Impact on Crop

Symptoms

- Bacterial leaf streak produces narrow tan, yellow, brown, or orange lesions that have a bright-yellow halo when backlit.
- Lesions can extend to several inches long and stay in between leaf veins (interveinal).
- Edges of the lesions are wavy and have a jagged appearance, which is a key distinguishing feature.
- Lesions can also appear greasy or water-soaked.
- Symptoms have been observed as early as the V4 growth stage in the field.

Impact on Corn Yield

- Preliminary observations suggest that severe infestations can impact corn yield. The extent of yield reduction in these cases and the frequency with which severe infestations capable of reducing yield occur are not well-understood at this point.

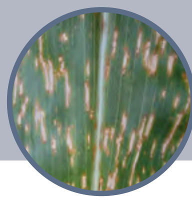
Impact on Corn Yield (continued)

- Generally, yield losses appear to be minimal as long as extensive symptoms are not present before or during grain fill.
- The presence of other foliar diseases, such as gray leaf spot, in combination with bacterial leaf streak can result in more yield loss due to greater leaf area loss. Fungicides do not control bacterial leaf steak, but can help protect yield by managing accompanying fungal diseases.

Symptoms of bacterial leaf streak compared to other foliar diseases

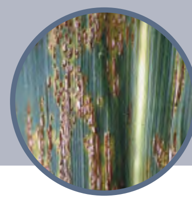
Bacterial Leaf Streak

- Bacterial
- Long lesions with a wavy edge
- When backlit, has a translucent appearance with a yellow halo
- Will exhibit bacterial streaming under a microscope



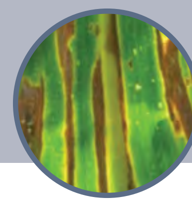
Gray Leaf Spot

- Fungal
- Rectangular lesions that have very straight sides
- Light does not shine through easily (more opaque)
- Can have dark, fungal structures, which produce clear spores characteristic of gray leaf spot



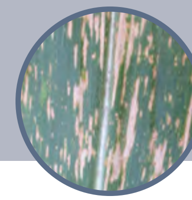
Common Rust

- Fungal
- Lesions often more oval or circular in shape
- Appear dark when leaf is backlit
- Pustules are raised above the leaf surface and are orange to reddish-orange from rust spore production



Diplodia Leaf Streak

- Fungal
- Lesions are mostly oval to elongated.
- Lesions may have yellow edges, especially when backlit.
- Often contain black pycnidia (fungal fruiting structures) embedded in leaf tissue



Southern Corn Leaf Blight

- Fungal
- Lesions are rectangular to oblong in shape.
- Appears tan in color
- Lack of uniformity makes it difficult to identify. Laboratory testing can help differentiate

Factors Favoring Bacterial Leaf Streak

Weather

- Warm conditions with a high relative humidity
- Can withstand cooler temperatures (different from gray leaf spot) and can be found as early as V4 in corn
- Thought to be spread by wind-driven rain and irrigation

Management Systems

- More common in continuous corn fields but has been found in other rotation systems, particularly those that include another host crop
- Favored by minimum-tillage systems where inoculum can remain on residue

Disease Management

- Proper identification of the disease is crucial since it cannot be treated by chemical controls unlike many similar-appearing diseases.
- Minimize continuous exposure to the crops and weeds that have been identified as susceptible hosts.
  - » Control volunteer corn, which can serve as a host.
  - » Proper weed management and pasture grass control
- Harvest infected fields last to reduce the spread of inoculum.
- Tillage and residue management are possible considerations.
- There appears to be some variability among corn hybrids in susceptibility to bacterial leaf streak.

Plant species that display symptoms and are potential disease hosts for bacterial leaf streak

Crops

Corn, oats, rice

Weeds

Johnsongrass, yellow nutsedge

Prairie Grasses

Orchard grass, Indiangrass, big bluestem, little bluestem, green foxtail, bristly foxtail

tar spot of corn

Madeline Henrickson, *Agronomy Sciences Intern, and*
Mark Jeschke, Ph.D., *Agronomy Manager*

Pathogen Facts

- Tar spot, caused by the fungal pathogen *Phyllachora maydis*, is a relatively new foliar disease of corn in the United States, first appearing in Illinois and Indiana in 2015.
- Look for tar spot to develop during cool temperatures (60-70 °F, 16-20 °C), high relative humidity (>75%), frequent cloudy days, and 7+ hours of dew at night.
- Tar spot reduces yield by reducing the photosynthetic capacity of leaves and causing rapid premature leaf senescence.

Identification and Symptoms of Tar Spot

- Tar spot is the physical manifestation of circular-sharped, tar-colored, fungal fruiting bodies, called "ascomata," developing on corn leaves.
- Initial symptoms are small brown lesions that darken with age.
- The texture of the leaf becomes bumpy and uneven when the fruiting bodies are present.
- Tar spot lesions cannot be rubbed away completely or dissolved in water.

Figure 1. Corn leaves infected with tar spot in a field in Illinois in 2018.

- Under favorable conditions, tar spot spreads from the lowest leaves to the upper leaves, leaf sheathes, and eventually the husks of the developing ears.
- Severe infection can cause leaf necrosis.
- Affected ears can have reduced weight and loose kernels; additionally, kernels at the ear tip may germinate prematurely.

Figure 2. Corn leaf under magnification showing dense coverage with tar spot ascomata.

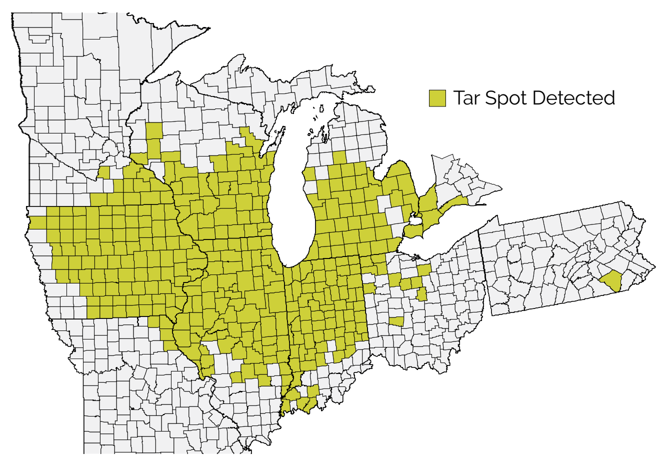


Figure 3. Counties with confirmed incidence of tar spot, 2015-2020 (as of 10-12-20). Source: Corn ipmPIPE, 2020.

Tar Spot Occurrence in the U.S.

- Tar spot in corn was first observed over a century ago in high valleys in Mexico.
- The first confirmations of tar spot in the U.S. were in Illinois and Indiana in 2015 (Bissonnette, 2015; Ruhl et al., 2016).
- It has subsequently spread to Michigan, Wisconsin, Iowa, Ohio, Missouri, Minnesota, Pennsylvania, and southern Ontario (Figure 3).
- Tar spot has also been found in four counties in southern Florida.
- In 2018, tar spot established itself as an economic concern for corn production in the Midwest with severe outbreaks reported in several states.

return to table of contents

Tar Spot Epidemiology

- *P. maydis* is an obligate pathogen, which means it needs a living host to grow and reproduce. It is capable of overwintering in the Midwestern U.S. in infected crop residue on the soil surface.
- Tar spot is more likely to develop during cool temperatures (60-70 °F, 16-20 °C), high relative humidity (>75%), frequent cloudy days, and 7+ hours of dew at night.
- Tar spot is polycyclic and can continue to produce spores as well as spread to new plants as long as environ-mental conditions are favorable.
- *P. maydis* produces windborne spores that have been shown to disperse up to 800 ft. Spores are released during periods of high humidity.

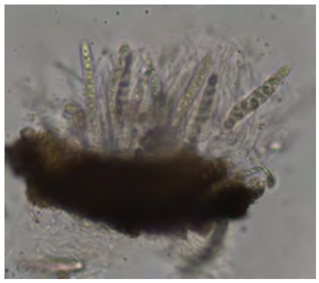


Figure 4. Microscopic view of fungal spores of *P. maydis*.

Figure 5. Corn field showing symptoms of tar spot infection.

Management Considerations

Yield Impact of Tar Spot

- 2018 was the first time that corn yield reductions associated with tar spot were documented in the U.S.
- University corn hybrid trials conducted in 2018 suggested potential yield losses of up to 39 bu/acre under heavy infestations (Telenko et al., 2019).
- Severe tar spot infestations have been associated with reduced stalk quality. If foliar symptoms are present, monitor stalk quality carefully to determine harvest timing.
- There is no evidence that tar spot causes ear rot or produces harmful mycotoxins (Kleczewski, 2018).

Differences in Hybrid Response

- Observations in hybrid trials indicate that hybrids differ in susceptibility to tar spot (Kleczewski and Smith, 2018).

Table 1. Efficacy of fungicides labeled for tar spot in corn (Wise, 2020).

Fungicide	Tar Spot Efficacy
Affiance® 1.5SC	good
DuPont™ Aproach® Prima 2.34SC	good - very good
Delaro® 325SC	good - very good
Headline® AMP 1.68SC	good - very good
Lucento®	good - very good
Miravis® Neo 2.5SE	good - very good
Priaxor® 4.17SC	unknown
Quilt Xcel® 2.2SE	good - very good
Revytek™	good - very good
Topguard® EQ	good - very good
Trivapro® 2.21SE	good - very good
Veltyma™	good - very good

Fungicide application timing is extremely important and needs to be made near the onset of the tar spot symptoms. Efficacy ratings based on limited site locations from 2018 and 2019. A 2(ee) label is available for several fungicides for control of tar spot, however, efficacy data are limited. Check 2(ee) labels carefully, as not all products have 2(ee) labels in all states.

- Longer maturity hybrids for a given location have been shown to have a greater risk of yield loss from tar spot than shorter maturity hybrids (Telenko et al., 2019).
- Genetic resistance to tar spot should be the number one consideration when seeking to manage this disease as it appears to have a greater impact on symptoms and yield loss than either cultural or chemical management practices.

Foliar Fungicides

- Several foliar fungicides are labeled for control of tar spot in corn (Table 1).
- Field research on tar spot has been limited so far but has shown that fungicides can reduce tar spot symptoms and help protect yield.
- Specific management recommendations for fungicides in the Midwestern U.S. are still being developed.
- Research suggests that tar spot may be challenging to control with a single fungicide application due to its rapid reinfection cycle, particularly in irrigated corn.

Agronomic Practices to Manage Tar Spot

- The pathogen that causes tar spot overwinters in corn residue. How the amount of residue on a field's soil surface affects disease severity the following year is unknown.
- Observations, so far, suggest that rotation and tillage probably have little effect on tar spot severity.
- Duration of leaf surface wetness appears to be a key factor in the development and spread of tar spot. Farmers with irrigated corn in areas affected by tar spot have experimented with irrigating at night to reduce the duration of leaf wetness.

return to table of contents

physoderma brown spot

Madeline Henrickson, *Agronomy Sciences Intern*

Pathogen Facts

- Physoderma brown spot is caused by the fungal pathogen *Physoderma maydis*.
- Infection is most common during the V5 to V9 stages when water is in the whorls of plants due to wet weather or irrigation.
- This disease is generally of minor economic importance.
- Localized outbreaks may occur in years when weather favors disease development.

Figure 1. The diurnal cycle of infection often results in the banded pattern of lesions seen on leaves.

Disease Symptoms

- Leaf symptoms of Physoderma brown spot are distinctive.
- Infected leaves will have numerous small, yellowish or brown spots.
- Lesions often occur in bands across the leaf, a result of infection happening while leaves are in the whorl.
- Lesions also occur on the leaf midrib – a key identifying characteristic. Midrib lesions are typically purplish or black.
- As disease progresses, small lesions may coalesce to form larger affected areas.
- Lesions occur on the mid-canopy, mainly on leaves, but may also occur on leaf sheath, stalks, outer ear husks, and tassels.

Figure 2. Dark spots on the midribs are a key distinguishing characteristic.

Disease Cycle

- Overwintering fungal structures, sporangia, survive in infected corn tissue or soil.
- Sporangia germinate to produce infective zoospores under conditions of moisture and light.
- With favorable water, light, and temperature conditions, infections often occur on a diurnal cycle when leaves are in the whorl, resulting in a banded pattern.
- *P. maydis* is also the casual pathogen of Physoderma stalk rot.
- Leaf symptoms are not necessarily predictive of stalk rot later in the season. It is not uncommon for Physoderma stalk rot to occur in fields with little to no foliar disease.

Figure 3. *Physoderma maydis* can also produce lesions on the stalks.

Conditions Favoring Disease

- Wet growing seasons are more favorable for disease development. Infection occurs when water has been in the whorl for extended periods of time.
- Warm temperatures (75 to 85 °F) and sunlight are also necessary for infection to take place.

Management Considerations

- Inoculum levels can be reduced via crop rotation or tillage to promote the decomposition of old, infected tissues.
- Specific management for this disease is not typically required as the occurrence is sporadic and effect on yield is minimal.
- Some fungicides are labeled for control of *P. maydis*, but there is limited data on efficacy and optimum application timing.

return to table of contents

diplodia ear rot

Mark Jeschke, Ph.D., *Agronomy Manager*

Disease Facts

- Caused by the fungus *Stenocarpella maydis*, previously known as *Diplodia maydis*
- Wet weather during grain fill and upright ears with tight husks promote Diplodia.
- Pathogen can cause ear rot, stalk rot, and seedling blight.
- Corn is the only known host.
- Wet weather plus moderate temperatures allow infection to occur if spores are present from early silking until two to three weeks after silking.
- Diplodia is highly dependent on quantity of infected, unburied corn residue (stalks, cobs, and kernels).

Figure 1. Diplodia infection usually begins at the base of the ear.

Disease Symptoms

- Early infected plants have tan spots on husks or bleached husks that are obvious from a distance.
    - » Husks on severely infected plants dry down well before the rest of the plant.
- White mycelial infection progresses from base of ear to tip.
- Extensive mycelial growth causes ears to remain erect and husks to bind tightly to ear.
- Rotted seed may germinate prematurely (vivipary).
- Later-infected plants are less damaged and may show no obvious symptoms on husks.

Figure 2. Corn cob showing Diplodia ear mold symptoms.

Impact on Crop

- Infection can reduce grain quality as well as yield due to lower kernel size and test weight.
- If infection occurs early, some ears may not produce harvestable grain. Less damage results if the ear is more developed when infection occurs.
- Fungal growth is most common during milk, dough, and dent stages.
- Mycotoxins are not associated with this disease, but some animals may reject infected feed.

Figure 3. Ear of corn showing severe diplodia ear mold symptoms (left) and corn husk showing black fungal fruiting structures (right).

Management

- Hybrids differ in their susceptibility to Diplodia ear rots, but all will show some damage under severe conditions
- Harvest seriously infected fields early, and dry grain to below 15% moisture (below 13% for storage through the following summer).
- Cool infected grain below 50 °F (10 °C) as quickly after harvest as possible and store at 30 °F (-1 °C).
- Clean grain after drying and before storing to remove lighter, damaged kernels, cobs, and fines.
- Diplodia development on ears in field can worsen in the bin if grain is not dried properly.
- Screen grain, and store the most infected grain separately to help avoid putting the whole bin at risk.

return to table of contents

aspergillus ear rot

Mark Jeschke, Ph.D., *Agronomy Manager*

Disease Facts

- Aspergillus ear rot is a fungal disease most commonly caused by *Aspergillus flavus,* although it can be associated with other Aspergillus species.
- Aspergillus ear rot is most common under drought conditions, high temperatures (80 to 100 °F, 27 to 37 °C), and high relative humidity (85%) during pollination and grain fill.
- Disease and associated aflatoxins are a common problem in the Southeastern United States and Texas but less common and detrimental in the Corn Belt.
- Corn ears damaged by insects or weather, such as hail, high winds, or early frost, that cracks the kernels may predispose grain to infection (Figure 1).
- Aspergillus fungal spores are produced on crop residue in fields as well as on discarded kernels and fines around grain bins.
- Infection most commonly occurs via kernel wounds or insect damage, but fungal spores can also infect kernels by growing down the silk channel when silks are yellow-brown and still moist.
- Aspergillus can occur on many types of organic material, including forages; cereal grains; food and feed products; and decaying vegetation.

Figure 1. Aspergillus infection following hail injury.

Symptoms

- Gray-green, olive, yellow-green, or yellow-brown powdery mold growth on and between kernels (Figure 2)
- Infection often occurs at the tips of ears but can develop anywhere on the ear, particularly if the ear has experienced physical injury or insect damage.
- Fungal spores are powdery and may disperse when the husk is pulled back from the ear.

Mycotoxins

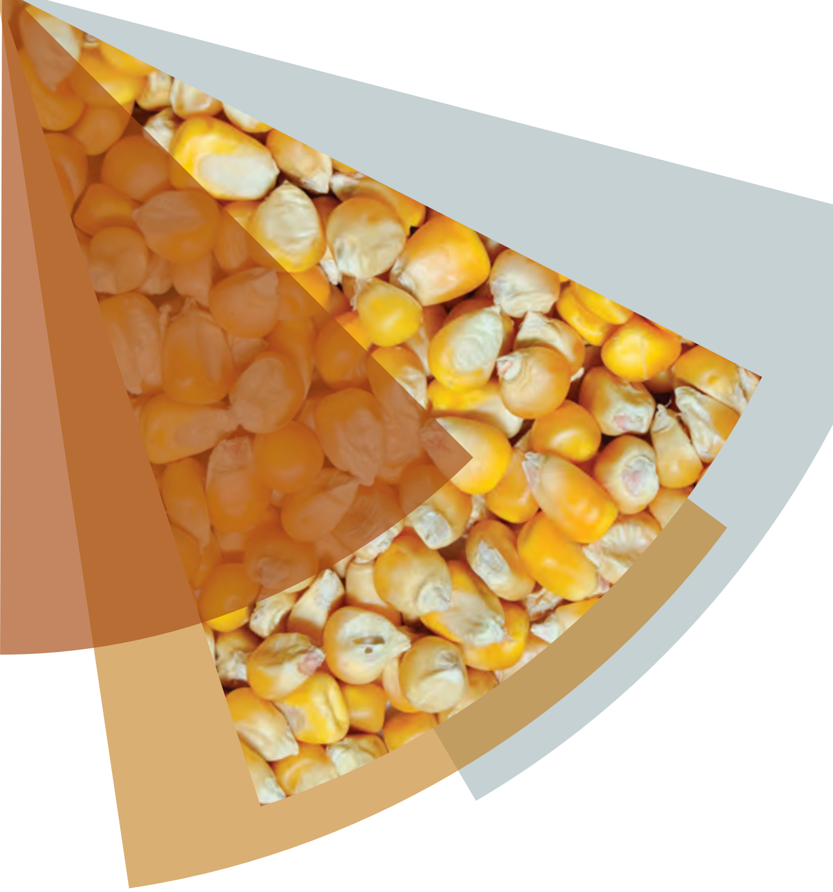
- Aflatoxins, produced by *A. flavus* and *A. parasiticus*, are the only mycotoxins for which the U.S. FDA has established formal action levels (Table 1).
- Corn grain with aflatoxins above 20 parts per billion (ppb) may not be sold for transport across state lines.
- Mycotoxin levels can vary among infected ears and do not necessarily correlate to the severity of visible infection.
- If Aspergillus ear rot is present in a field, the harvested grain should be tested for aflatoxin.

Figure 2. Corn ear with aspergillus ear mold. A laboratory test for aflatoxin is recommended where Aspergillus ear rot is suspected.

Management

- When Aspergillus occurs, crop yield has likely already been reduced by drought stress. Fungal infection may further reduce weight of infected kernels.
- Production of aflatoxin by fungus is variable, but more likely under heat and drought stress.
- If Aspergillus is confirmed, the corn must be tested to determine if aflatoxin is present and to determine the proper marketing channel.
- Blending corn lots to reduce the level of aflatoxins is prohibited for interstate trade.

return to table of contents



- There is no method to "detoxify" infected corn.
- Aflatoxins are not destroyed by fermentation and will be concentrated in dry distillers grain.
- Since the disease enters the ear primarily through injury and insect feeding, hybrids with one or more aboveground insect-protection traits can have a lower risk of Aspergillus ear rot.
- Little native hybrid resistance exists, and seed companies do not rate hybrids for Aspergillus.
- Hybrids that perform well in drought conditions can have lower risk for Aspergillus infection than less drought-tolerant hybrids.

Figure 3. Corn ear with aspergillus ear mold.

Table 1. U.S. FDA action levels for aflatoxin contaminated corn (FDA, 2000).

Grain Intended Use	Action Level (ppb)
Finishing beef cattle	300
Finishing swine (100 lbs or greater)	200
Breeding beef cattle, swine, mature poultry	100
Immature animals	20
Dairy animals	20
Human consumption	20

Figure 4. Corn ear with aspergillus ear mold.

Harvest and Storage

- Clean bins, areas around bins, and all grain-handling equipment before putting grain in storage.
- Infected fields or areas should be harvested as early as possible since the fungus will continue to develop and produce aflatoxin as the corn dries down. Begin harvest when grain is at 25% moisture and dry to 15% or lower within 24 to 48 hours.
- Corn going into long-term storage should be dried to below 13% moisture and cooled to 30 °F (-1 °C).
- Adjust combine to minimize trash and broken kernels.
- Harvest and store grain from Aspergillus-contaminated fields separately.
- Clean grain going into storage by screening or gravity separator to remove lightweight and broken kernels, foreign material, and fines.
- High concentrations of aflatoxin may be found in corn screenings, so they should be disposed of properly.

fusarium ear rot

Mark Jeschke, Ph.D., *Agronomy Manager*

Disease Facts

- Fusarium rot is the most common fungal disease on corn ears.
- Caused by *Fusarium verticillioides* (previously known as *Fusarium moniliforme*) and several other Fusarium species
- The causal organism survives on residue of corn and other plants, especially grasses.
- Infection can occur under a wide range of environmental conditions but is more severe when weather is warm and dry.
- Disease enters ear primarily through wounds from hail or insect feeding.
- Airborne spores can germinate and grow down the silk channel to infect kernels.

Disease Symptoms

- Scattered or groups of kernels are typically affected.
- Mold may be white, pink, or salmon-colored.
- Infected kernels may turn tan or brown.
- "Starburst" pattern often associated with the disease (light-colored streaks radiating from top of kernels where silks were attached)
- In severe infections, ears may be completely consumed by the fungus, leaving lightweight husks cemented to the kernels by mycelia.

Figure 1. Kernels showing "starburst" pattern typical of Fusarium infection.

Impact on Crop

- Infection can reduce grain quality as well as yield due to lower kernel size and test weight.
- If infection occurs early, some ears may not produce harvestable grain. Less damage results if ear is more developed when infection occurs.
- Fungal growth is most common during milk, dough, and dent stages.
- Mycotoxins are not associated with this disease, but some animals may reject infected feed.

Figure 2.
Left: Bt ears – no insect feeding or disease symptoms.

Right: Non-Bt ears – insect feeding allowed entry of Fusarium fungus with resulting symptoms.

Management

- Since the disease enters the ear primarily through injury and insect feeding, hybrids with one or more aboveground insect-protection traits can have a lower risk of Fusarium ear rot.
- Hybrids differ in their susceptibility to fusarium ear rot. If Fusarium ear rot has caused significant damage in the past, growers should consider planting only hybrids with a Fusarium ear rot rating of 5 or higher.

Harvest and Storage

- Clean bins before storage.
- Harvest at 25% moisture, and dry to 15% moisture or lower if storing grain into the following summer.
- Cool infected grain below 50 °F (10 °C) as quickly after harvest as possible, and store at 30 °F (-1 °C).
- Clean grain before storing to remove infected kernels, cobs, and fines.
- Store infected grain separately, if possible.

return to table of contents

gibberella ear rot

***Mark Jeschke, Ph.D.**, Agronomy Manager*

Disease Facts

- Caused by the fungus *Gibberella zeae*
- Overwinters in infected crop residue
- Spores are spread from residue to corn ears by wind and rain.
- Infection of corn ears occurs through young silks.
- Infection favored by cool, wet weather during and after pollination (optimum temperature 65-70 °F, 18-20 °C)
- Often a problem in the Northern and Eastern Corn Belt (both U.S. and Canada)
- Most common in continuous corn or corn following wheat that was infected with Fusarium head blight

Figure 1. Gibberella ear rot on tip of corn ear.

Disease Symptoms

- Most readily identified by the red or pink color of the mold starting at ear tip
- Mold may be very pale in some cases, causing it to be confused with other ear rots.
  - » Gibberella almost always begins at the ear tip and progresses from there.
  - » Fusarium is usually scattered throughout the ear or localized on injured kernels.
  - » Diplodia usually starts at the base of the ear, mold is gray rather than pink, and husks may be "bleached."
- Early, severely infected ears may rot completely with husks adhering tightly to the ear and the mold growing between the husks and ear.
- Perithecia, or black fungal fruiting structures, may be lightly attached to kernel surface.

Mycotoxins

- *Gibberella zeae* can produce two mycotoxins in the infected kernels: deoxynivalenol and zearalenone.
- These mycotoxins can be harmful to many monogastric animals, especially swine.
- Mycotoxin contamination of grain may or may not accompany ear-mold symptoms.

Figure 2. Ear of corn showing gibberella infection.

Management

- Scout fields before harvest in order to make informed decisions about harvest timing, post harvest grain handling, storage, and utilization.
- Fields with significant infestations of Gibberella ear rot should be harvested as early as possible and handled separately.
- Set combine to reduce kernel damage and remove fines as well as shriveled or broken kernels.
- Dry infected grain at high temperature to a moisture of 15% or less, and monitor grain in storage to maintain its condition.
- Test grain for presence of mycotoxins, and manage accordingly.

return to table of contents

corn rootworm population levels in illinois and indiana in 2020

***Crystal Dau,** Field Agronomist, and **Mary Gumz, Ph.D.**, Agronomy Manager*

Objectives

- In 2020, Pioneer undertook research to:
  - » Quantify corn rootworm (CRW) beetle populations across Illinois and Indiana with Pherocon® AM/NB sticky traps
  - » Understand how management practices influence CRW population levels
  - » Identify best management practices for growers to make informed decisions for the following growing seasons
- This project built on a CRW trapping project conducted in northern Illinois in 2019.
- The study revealed areas with potentially heavy CRW infestations and identified best management practices for farmers to make informed decisions for the following growing seasons.

Study Description

Locations: 522 field locations in Illinois and Indiana

Sampling Methods:

- Six sticky traps placed per field starting at blister stage (R2)
- Northern and western corn rootworm beetles were counted every seven days.
- Trapping continued for five consecutive weeks by Pioneer sales professionals and Pioneer agronomists.
- Trapping was conducted in fields managed in the following rotations:
  - » Continuous corn fields
  - » Corn following soybean fields
  - » Soybean following corn fields

Figure 1. A new Pherocon® AM/NB sticky trap set in a corn field near Mount Morris, Illinois. Trapping extended for 5 consecutive weeks with traps replaced and beetles counted every week.

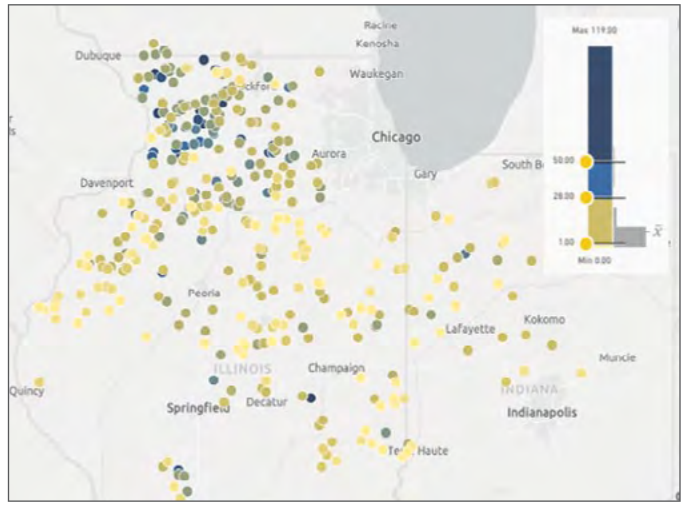


Figure 2. Peak population levels observed at CRW beetle trapping locations in 2020.

- CRW populations were characterized at four different levels for each sampling location. The percentage of locations at each level is summarized in Table 1.
  - » Zero = no beetles collected
  - » Low = <21 beetles/week
  - » Moderate = traps averaged 21-50 beetles/week
  - » High = traps averaged >50 beetles/week

Table 1. Corn rootworm population levels by year.

CRW Level	2019	2020
Zero	7%	17%
Low	80%	66%
Moderate	10%	9%
High	3%	8%

- The incidence of high CRW populations more than doubled in 2020 compared to 2019 as did the occurrence of zero pressure locations.
- This seems contradictory; however, the 2020 study area as well as sample size were much larger than in 2019 and expanded south and east into areas where CRW pressure has historically been lower. As a result, there was an increased number of locations that had zero beetles trapped as well as locations with high CRW populations.

return to table of contents

- Corn rootworm species compositions varied among locations depending on population levels (Figure 3).
  - High CRW pressure locations largely consisted of western corn rootworms (82%).
  - Moderate pressure locations had a more even mix of species with a 70:30 ratio of western to northern CRW.
- In Indiana and eastern Illinois, only western CRW was found.

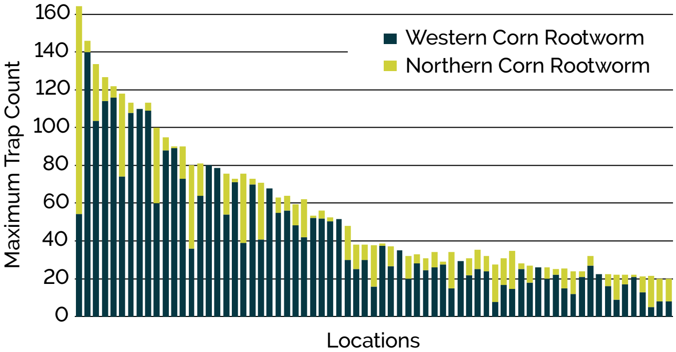


Figure 3. Species compositions for high and moderate population locations across northern Illinois in 2020.

- Planting date had less influence on the timing of peak trap counts in 2020 than it did in 2019 when planting dates were spread out over a much longer window (Table 2).
- Most locations had peak CRW counts during the third week of counting (usually around August 3).
- Plots with extremely high counts (100+ beetles) early returned to more moderate counts later in the study. There were no sites with very early low counts that spiked to higher counts later.

Table 2. Corn rootworm population levels by year.

Planting Date Month	Number of Locations	Average Peak Count Date	Average Peak Count
April	82	8/3/2020	**28**
May	252	8/3/2020	**13**

- Crop rotation affected CRW pressure levels (Table 3).
  - Fields of continuous corn or with two years back-to-back corn in past three years were more likely to have high or moderate trap counts.
  - Fields with at least one year of soybeans in between corn crops in the past three years had lower trap counts than the back-to-back corn sites but had more sites with low pressure compared to 2019 when most rotated sites had no CRW pressure.

Table 3. Distribution of pressure levels based on crop rotation.

Crop Rotation	High	Moderate	Low	None
Continuous corn	24	27	49	3
Two years back-to-back corn in past three years	6	5	14	2
At least one year soybeans between corn crops	5	2	150	39

Comparison to 2019 Results

- Overall results show increased total CRW populations and increased pressure in the southern and eastern portions of the study area.
- Ratios of western and northern CRW beetles were similar to 2019 in northern Illinois. In eastern Illinois and Indiana, populations were comprised almost entirely of western CRW.
- Fields with a soybean rotation in the past three years were more likely to show some CRW infestation in 2020 compared to 2019.

Action Thresholds and Control Options

If traps average <21 beetles per week:

- **Low** rootworm populations are anticipated next year
  - Rotate acres to another crop.
  - Plant a corn rootworm Bt corn product.
  - Plant a non-Bt rootworm product with Poncho® 1250/VOTiVO® insecticide treatment OR a soil insecticide for larvae.

If traps average 21-50 beetles per week:

- **Moderate** rootworm populations are anticipated next year
  - Rotate acres to another crop.
  - Plant a corn rootworm Bt corn product.
  - Apply a soil insecticide at planting for larvae.

If traps average >50 beetles per week:

- **High** rootworm populations are anticipated next year
  - Rotate acres to another crop.
  - Apply foliar insecticide in the current year to control adult beetles prior to egg-laying, and use a corn rootworm Bt corn product or soil-applied insecticide the following year.

Management Considerations

- These results show an increased risk of CRW infestation across northern Illinois and Indiana. Fields rotated to corn for two or more consecutive years need to have a plan to manage CRW.
- Pioneer and university research suggests that continuous, uninterrupted use of the same CRW Bt technology can lead to reduced product efficacy against these insects.
- To maintain efficacy of Bt corn rootworm products, it is essential to develop a rootworm management plan that:
  - Breaks the cycle
  - Manages populations
  - Protects the Bt trait

Please contact your Pioneer sales professional for more information.

novel corn rootworm beetle control options

Hannah Weber, *Agronomy Intern,*
Jake Bates, Alex Woodall, *and* ***Nate LeVan,*** *NC Iowa Field Agronomists*

How effective is Steward® EC insecticide in reducing corn rootworm (CRW) populations?
Pioneer conducted trials in several long-term continuous corn fields in north central Iowa.

Steward EC is a group 22 insecticide with up to 14 days of residual control, which could provide greater flexibility when treating for CRW adults to suppress populations in corn-on-corn fields.

Steward EC insecticide provided control of CRW adults for at least 14 days after treatment at all locations and for 21 days or more at most locations.

Importance of Integrated Pest Management

- The best way to manage corn rootworm (CRW) is with an integrated pest management (IPM) system that includes multiple effective control tactics, such as:
  - Rotation to a non-host crop
  - Planting hybrids with multiple Bt traits for CRW control
  - Applying in-furrow or lay-by insecticides
  - Scouting for and managing CRW adults
- Management for extended corn-on-corn systems (3+ years corn) requires using multiple strategies every season for long-term success and profitability.
- CRW have shown to be highly adaptive with rotation-resistant northern CRW (extended diapause variant) and western CRW (adults that lay eggs in soybean fields) as well as some populations that are resistant to Bt traits or insecticides.
- Single-strategy tactics, such as ephemeral use of only soil-applied insecticides or only CRW Bt corn, may decrease the length of time that tactic is effective and reduce available options for CRW management.

Adult Corn Rootworm Control

- Foliar insecticide treatment to control adult CRW, a practice commonly referred to as "beetle bombing," involves applying an insecticide as CRW beetles begin to emerge in a field.
  - This tactic is used to suppress CRW populations by reducing egg laying as well as reduce silk feeding by CRW beetles, which can have serious effects on pollination.
  - Timing of foliar treatments has historically been based on GDU accumulation or corn growth stage typically around VT/R1.
- A properly timed insecticide application can be very effective in reducing adult CRW populations (Figure 1).

Figure 1. Well-timed insecticide applications for control of CRW beetles can reduce silk feeding in the current crop and eggs laid for the following year's CRW population.

- A challenge with using foliar insecticides to reduce egg laying and future CRW root feeding pressure has been timing the application to coincide with the peak emergence of female CRW beetles, which generally emerge later than males.
- Sticky traps are a useful tool for monitoring adult emergence. Use these in conjunction with corn growth stage and GDU accumulation to determine the best time for treatment (Figure 2).

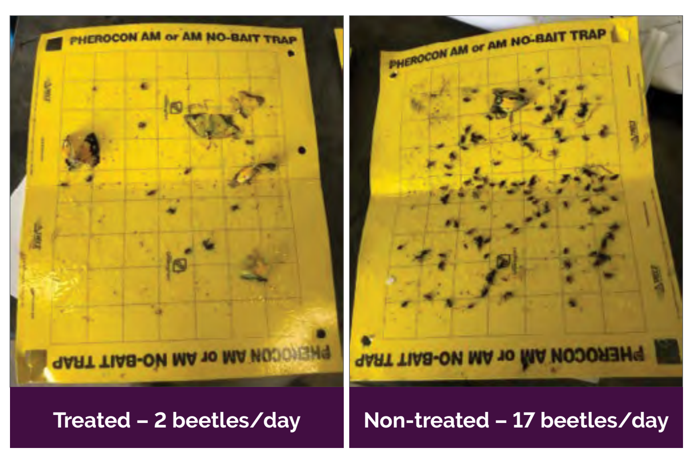


Figure 2. Corn rootworm sticky trap one week following an insecticide application (left) compared to a trap from a non-treated check (right).

return to table of contents

Dealing With Extended CRW Beetle Emergence

- Recently, the duration of CRW beetle emergence has extended over a wider window than historically "normal" in north-central Iowa with emergence continuing later into the growing season.
- Extended duration of CRW beetle emergence can reduce the effectiveness of a foliar insecticide application, even when properly timed.
- Many insecticides are available that provide excellent knock-down of high populations of CRW beetles; however, a new product, Steward® EC, offers extended residual control of adult CRW beetles.
  - » Steward EC is a group 22 insecticide with up to 14 days of residual control according to the manufacturer.
  - » The active ingredient, indoxacarb, works through both contact and ingestion.
- An insecticide with a longer window of residual control could provide flexibility when treating for CRW adults to suppress populations in corn-on-corn fields.

2020 Pioneer Research Trials

- In 2020, foliar insecticide trials were conducted in several long-term continuous corn fields in north central Iowa likely to have high CRW beetle emergence (>7.0 beetles/trap/day) to evaluate effectiveness in reducing CRW populations.
- All trial fields included an area treated with 8 oz/acre of Steward EC insecticide; some also included a non-treated check.
- The study included both ground and aerial applications.
- Fields were monitored for CRW adult pressure once every week for up to two weeks prior and six weeks after insecticide application.
- Trial locations included populations of both northern and western CRW, which were composited in beetle counts.

Results

- At six trial locations where CRW beetle populations were moderate to high prior to treatment, Steward EC insecticide reduced populations to low levels (avg. three or fewer beetles/trap/day) (Figure 3).

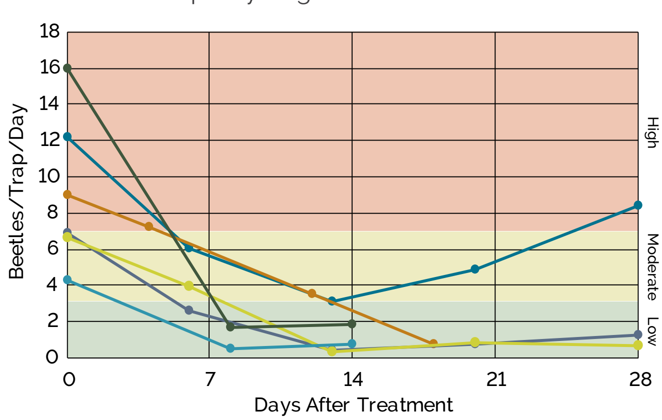


Figure 3. Corn rootworm beetle populations (beetles/trap/day) at 6 moderate to high pressure locations following treatment with Steward EC insecticide. (Beetle counts at T_0 reflect samples taken within 8 days prior to insecticide application.)

- Among 3 locations where beetle populations were measured through 28 days after treatment, populations remained low at 2 locations but rebounded after 14 days at 1 location.
- Four trial locations included a nontreated check in the field and were sampled 35 days or more after treatment, providing an extended look at CRW population levels following treatment compared to no treatment.
  - » At one location, beetle counts were very low throughout the sampling period (data not shown).
  - » Two locations had high CRW pressure, and one had low to moderate pressure (Figure 4).
- Insecticide treatment reduced beetle populations relative to the nontreated check throughout the sampling period at all three locations with CRW pressure.
  - » Beetle populations remained low for more than 21 days after treatment.
  - » Beetle populations rebounded somewhat beyond 28 days after treatment at the 2 higher-pressure locations but were still lower than the nontreated checks.
  - » Minimal rainfall during late July and August of 2020 at many of the trial locations may have helped extend the duration of insecticide residual activity.

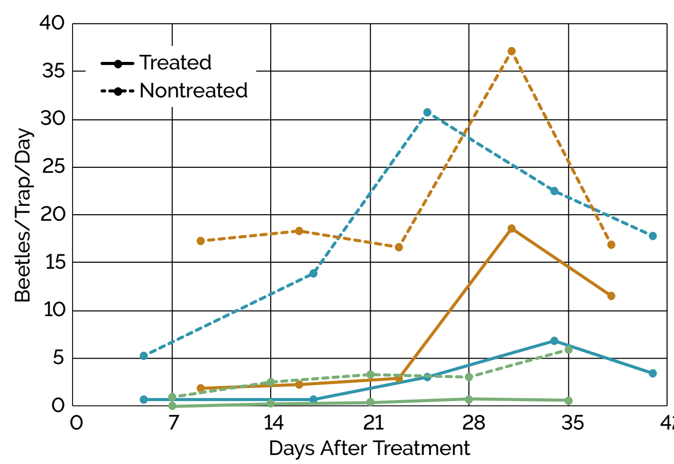


Figure 4. Corn rootworm beetle populations (beetles/trap/day) with and without insecticide treatment at 3 moderate to high-pressure locations that included both a treated and nontreated area.

Conclusions

- Steward EC insecticide provided control of CRW adults for at least 14 days after treatment at all locations and for 21 days or more at most locations.
- Results demonstrate that a properly-timed foliar insecticide application can be very effective at reducing adult CRW populations, making it a valuable option to consider as part of an integrated CRW management plan.

Always read and follow product label directions.

Please reach out to your local Pioneer sales representative for more agronomic insights.

corn rootworm scouting and management strategies

Dan Berning, Ph.D., *Agronomy Manager, and* **Chris Zwiener, M.S.,** *Product Life Cycle Manager*

Corn rootworms can evolve and overcome management tactics.

Controlling this pest is difficult.

An integrated approach is key to an effective corn rootworm management program.

Develop a scouting program that monitors larvae and adult numbers, which predicts potential egg laying and future problems.

In areas with high numbers of adult corn rootworms, consider incorporating a beetle suppression program that utilizes foliar-applied insecticides.

Corn Rootworm: A Challenging Pest of Corn

Corn rootworm (CRW) larvae and adults cause economic loss every year. The impact of CRW larvae on yield varies greatly depending on:

1. The timing of rootworm feeding
2. Available moisture
3. The hybrid's ability to regenerate damaged roots

Plants with damaged root systems are more susceptible to drought stress and lodging. Adult CRW feeding on corn silks during pollination can cause poor seed set and subsequent yield loss.

This pest's ability to evolve has made crop rotation ineffective in many areas. The soybean variant of western corn rootworm has evolved to lay eggs in non-corn fields. The northern corn rootworm has shown extended diapause in which eggs remain viable in the soil for several years before hatching. Additionally, resistant populations have now been documented for all four commercially available Bt proteins for CRW control.

Figure 1. Corn rootworm larvae.

How to Scout for Corn Rootworm Larvae

- Begin in early to mid-June or when the corn is in the V6 to V12 growth stage.
- Dig up 2 plants at each of 5 locations with the soil from 6-8 in around the plant. Sift soil over a sheet of black plastic looking for $\frac{1}{32}$ - ½ in long larvae.
- There is no economic threshold for larvae per plant. Some consultants determine emergency controls are needed when they find an average of 2 to 3 larvae per plant using a visual search, or 8 or more larvae using soil washing.
- If average length of larvae is >½ in or if pupae are found, a rescue treatment may be too late.

Figure 2. Severe corn rootworm feeding damage.

return to table of contents

How to Scout for Adult Corn Rootworm

- The western corn rootworm (WCRW) and northern corn rootworm (NCRW) are the most destructive species found throughout the Midwestern U.S. and Canada.
- Adults begin emerging in early to mid-July with male beetles emerging before females.
- Evaluate fields for silk clipping. If pollination is in progress and the beetles have chewed back the silks so that less than ½ in of silks is exposed beyond the husks, beetles should be controlled.

Pioneer Agronomy

Scouting for Adult Corn Rootworm

- Josh Shofner, Field Agronomist

Figure 3. Northern *(left)* and western *(right)* corn rootworm beetles.

- To control adults before egg laying, examine 2 plants in 25 locations in the field. Consider an insecticide treatment if the number of beetles averages 0.75 or more per plant and 10% of females are gravid with eggs (abdomen visibly distended with eggs).
  - » The first beetles to emerge are mostly male, and females require at least 10-14 days of feeding before they can lay eggs.
  - » Treatments applied too early may be ineffective if large numbers of females emerge after the residual effectiveness of the treatment has dissipated.

Figure 4. Gravid female western corn rootworm beetle *(left)*. Western corn rootworm eggs squeezed from the abdomen of a female beetle *(right)*.

- If more than 10% of the adult females within a field are gravid, significant egg laying probably has already occurred, so suppression of adult rootworms will likely not be as effective in reducing larval damage the next year.
- Fields may become re-infested 2-3 weeks after an insecticide application, so some fields may require 2 applications of insecticide to significantly reduce egg laying.

Corn Rootworm Management

A yearly scouting program is the first step to effective management because corn rootworms can rebuild their populations rapidly. Monitor larvae and adult beetle numbers to predict potential egg laying and future problems. The level of rootworm feeding and beetle activity will determine the best management options. Incorporate several of these options to effectively control CRW with an integrated approach.

Crop Rotation

- Can reduce corn rootworm pressure
- Ineffective in areas with soybean variant WCRW that lay eggs in non-corn fields or variant NCRW whose eggs may remain in the soil for several years before hatching (extended diapause)

Suppress Larval Development

- Use a granular or seed-applied insecticide at planting.
- Plant a product with multiple modes of action of control against CRW, such as Optimum® AcreMax® Xtreme or Qrome® products.
- Consider using a CRW Bt-traited product with Poncho® 1250 + VOTiVO® insecticide seed treatment for additional protection.
- Applying a soil-applied insecticide in addition to using a CRW Bt-traited product is not recommended except in limited circumstances. Consult with your Pioneer sales professional, university extension, or other local experts for further guidance.

Control CRW Beetles With Insecticides

- A well-timed foliar insecticide application can effectively reduce gravid egg-laying beetles.

Be sure to alternate modes of action when using insecticides. When using corn hybrids that contain Bt traits for corn rootworm control, it is essential that refuge acre requirements are followed. Failure to comply with refuge requirements and lack of control of adult beetles within the refuge acres will only accelerate the pest's ability to develop resistance.

Areas with high numbers of adult corn rootworms should consider incorporating a beetle suppression program that utilizes foliar-applied insecticides. This should help reduce the amount of egg laying and potential problems in the future.

return to table of contents

Table 1. Insecticide treatments for adult corn rootworms. Always read and follow product label directions.

Mode of Action	Product Name	Common Name	Rate (Formulation per Acre)	Restrictions / Comments
3A R	Ambush® 2EC	permethrin	6.4-12.8 fl oz	REI 12 hrs. PHI 30 days for grain or fodder.
3A R	Asana® XL 0.66	esfenvalerate	5.8-9.6 fl oz	Field corn. May be chemigated.
3A R	Baythroid® XL	beta-cyfluthrin	1.6-2.8 fl oz	PHI 21 days for grain or fodder. REI 12 hrs.
3A R	Bifenture® 2E, Brigade® 2EC, Discipline® 2E, Sniper® 2E, Tundra® 2EC	bifenthrin*	2.1-6.4 fl oz	
3A	Delta Gold®	deltamethrin	1.5-1.9 fl oz	REI 12 hrs. PHI 21 days for grain or fodder, 12 days for cutting or grazing for forage.
1B	Dimethoate 4EC, Dimate 4E	dimethoate	1.0 pt	REI 48 hrs. PHI for harvest, feeding, or grazing 14 days. Do not apply to corn during pollen-shed if bees are present.
3A R	Hero®	zeta-cycpermethrin + bifenthrin	4.0-10.3 fl oz	REI 12 hrs. PHI 30 days for grain and stover, 60 days for forage, 30 days for grazing. Use of ultra-low volume on corn is prohibited. Do not make aerial or ground applications to corn if heavy rainfall is imminent.
1A R	Lannate® LV	methomyl	1-1.5 pt/acre	REI 48 hrs; PHI 21 days for field corn, 0 days for sweet corn.
1B R	Lorsban® 4E	chlorpyrifos	1-2 pts	Field corn, seed corn. May be chemigated.
3A R	Mustang® Max EC, Respect®	zeta-cypermethrin	2.72-4.0 oz	Apply in a minimum of 2 gal/acre by air and 10 gal/acre by ground.
3A R	Proaxis™	gamma-cyhalothrin	2.56-3.84 fl oz	REI 24 hrs. PHI 21 days, grazing 1 day, feeding corn forage/fodder/silage 21 days.
1A	Sevin XLR	carbaryl	1-2 qts	Field corn and popcorn. See bee caution on label. May be chemigated.
1B, 3A R	Stallion®	chlorpyrifos + zeta-cypermethrin	3.5-4.7 fl oz	PHI 30 days for grain and 60 days for forage.
22A	Steward® EC	indoxacarb	6.0-11.3 fl oz	REI 12 hrs. PHI 14 days for grain and stover.
3A, 4A	Swagger™	bifenthrin + imidacloprid	8.45-25.6 fl oz	PHI 30 days. Apply in a minimum of 2-5 gal/acre by air or 10 gal/acre by ground.
3A R	Warrior II w/Zeon Technology®	lambda-cyhalothrin	1.28-1.92 fl oz	

IRAC Mode of Action Classification:
Group 1 = Acetylcholine esterase inhibitors: 1A = Carbamates, 1B = Organophosphates
Group 3 = Sodium channel modulators: 3A = Pyrethroids, Pyrethrins
Group 4 = Nicotinic acetylcholine receptor (nAChR) competitive modulators: 4A = Neonicotinoids
Group 22 = Voltage-dependent sodium channel blockers: 22A = Oxadiazines
R = Restricted-use product
* Resistance to the pyrethroid insecticide bifenthrin has been documented in corn rootworm in southwest Nebraska.

spider mite management in corn

Grant Groene, M.S., *Global Seed Agronomy Lead*

The Banks grass mite (BGM) and the two-spotted spider mite (TSM) are problematic pests for corn producers in the High Plains and Western United States, often causing significant economic injury.

The amount of economic loss that spider mites cause varies from year to year based on several biotic and abiotic factors and has been documented as high as 47% in corn grain.

Spider mites damage corn by rupturing leaf cells and drinking the contents out; most damage is done when feeding is on leaves at or above ear level.

Managing for resistance is a key issue that growers should be aware of when controlling spider mites.

This article discusses spider mite life cycle, plant damage, identification, and management options.

What are Spider Mites?

Spider mites (family: *Tetranycidae*, order: *Acari*) are not insects but are tiny arachnids closely related to ticks and spiders. They can be problematic pests for corn producers, primarily in the High Plains and extending through the Western U.S. While high spider mite numbers frequently cause significant damage to corn (grain, silage, and sweet), the level of economic loss is different from season to season. Temperature, humidity, rainfall, soil type, pesticide applications, host proximity, and natural enemies affect population dynamics from year to year. High temperatures and drought stress generally accompany high populations of mites. Higher populations of spider mites are often found in sandy soil types as these soils typically incur drought stress in western states even under irrigation.

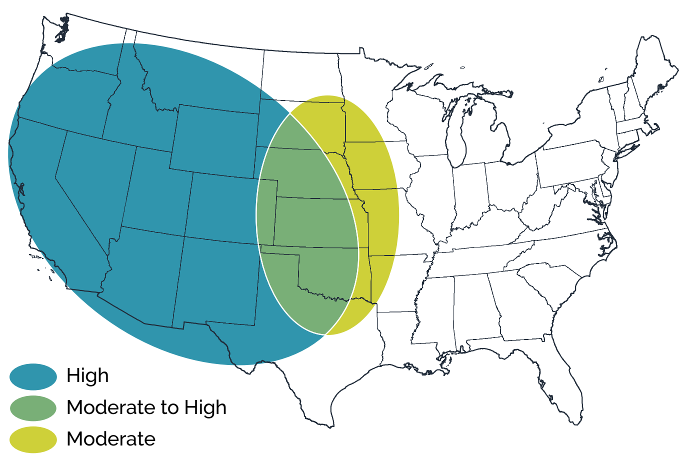
Two Common Mite Species in Corn

The two most common and widespread mite species causing concern for corn producers across the Western U.S. (Bynum et al., 1997) are:

1. The Banks grass mite [*Oligonychus pratensis* (Banks)] (BGM) – predominant earlier in the growing season
2. The two-spotted spider mite [*Tetranychus urticae* Koch] (TSM) – extends later into the growing season

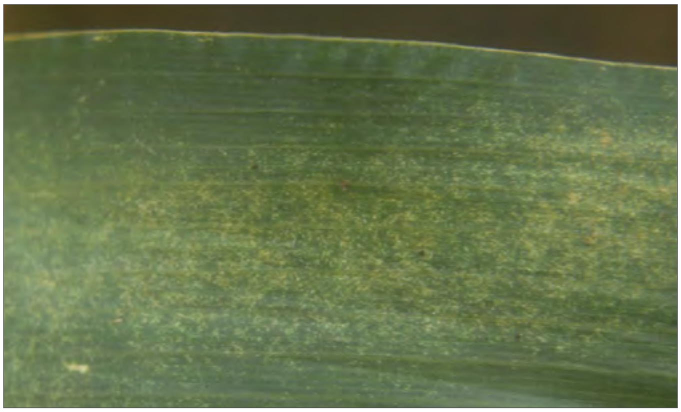
Spider mites can damage corn from the seedling stage all the way to maturity. Both the BGM and TSM feed primarily on grass species. They can differ in their susceptibility and resistance to insecticides, making them difficult to manage.

Risk of Spider Mite Infestation in Corn in the Western U.S.



Spider Mite Damage to Corn

The BGM and TSM damage plants by using needle-like stylets to rupture leaf cells, pushing their mouth into the torn tissue and drinking the leaf contents. This results in clusters of dead cells, leaving a stippled or speckled appearance on the upper leaf surface. Concentrated chlorotic areas begin along the midrib and folded areas of the leaf, spreading to the basal half of the leaf. In instances of severe feeding, leaves will become gray, yellow, bronzed, dry, or bleached. High populations of untreated mites will cause loss of vigor and eventual death.



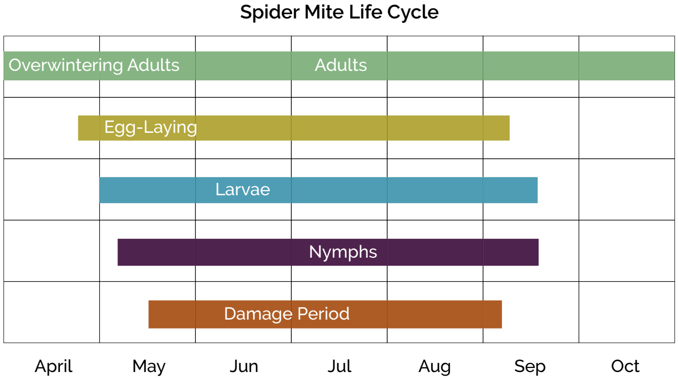
Mottled, discolored corn leaf from spider mite feeding.

Mite activity increases under hot and dry conditions. Crop damage is most severe when feeding occurs on the leaves at or above the ear level between tasseling and hard dough. Yield loss attributed to spider mite feeding may be as high as **40%** (on a dry matter basis) in corn silage, and grain losses may be as high as **47%** (Archer and Bynum, 1993). A long-term university study observed yield losses ranging from **6 to 48%** with an 18-year average of **21%**.

Biology and Life Cycle

Spider mites have four life stages: egg, larva, nymph, and adult. Mites may occasionally overwinter in crop residue, but primarily the BGM will overwinter in crowns of winter wheat and native grasses. The TSM primarily overwinters in alfalfa and other broadleaf species bordering fields. Beyond that, the life cycles of the two mite species are quite similar. When conditions are favorable, overwintering adult females will begin to move into the corn crop by crawling short distances or being carried by the wind.

Spider Mite Life Cycle

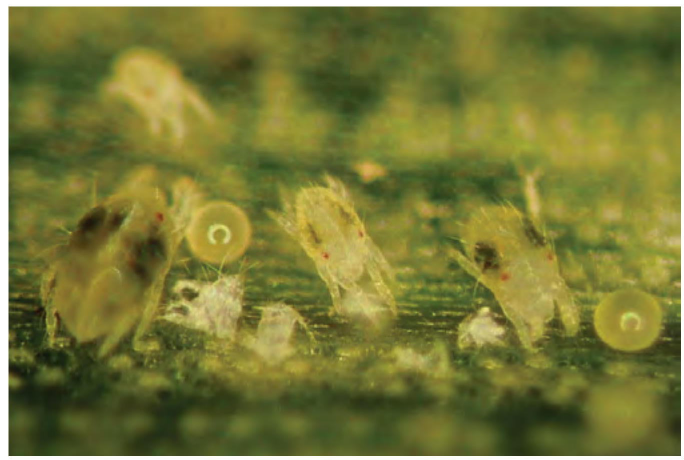


Adapted from Purdue University.[5]

Spherical, pearly white eggs are laid and fastened to the underside of the leaf by webbing produced by the adult females. Eggs are minute, will hatch in a range of 3 (75 °F) to 19 (50 °F) days depending on temperature, and will change in color from pearly white to a yellowish-green just prior to hatching. The larvae have six legs, are colorless, and resemble the nymph and adult. Little leaf nutrients are consumed in this stage. The nymph has eight legs, looks like the adult, but is smaller and sexually immature. The nymphs will undergo both a protonymph and deutonypmh instar stage. Adults are eight-legged and range in color from bright green to red. Females are 1/60 in long and are slightly larger and more robust than males, which are only 1/80 in long.

Spider mites are an arrenotochous species, meaning a female will lay both fertilized and unfertilized eggs. The fertilized eggs will turn into diploid females, and the unfertilized eggs will turn into haploid males. The ratio of males to females can vary considerably from one population to the next but is normally female-biased.

A generation usually proceeds from start to finish in as little as 5 to 20 days, depending on temperature. Hot and dry conditions will increase the rate of development. Optimum temperatures differ slightly for the BGM and TSM. BGM are more fecund in climates with lower humidity and 97 to 98 °F temperatures. However, the TSM thrives in climates with a higher percent humidity and 86 to 90 °F temperatures. BGM populations have been shown to increase 70-fold in 1 generation. It is typical for both mite species, and all mite stages, to be present with 7 to 10 generations per season overlapping one another.



Two-spotted spider mite eggs, larvae, nymphs, and adult.

Table 1. Developmental time for spider mites on corn.

Stage	77 °F	97 °F
	number of days	
Egg	4.3	2.1
Larva	1.7	0.8
Protonymph	1.3	0.8
Deutonymph	1.9	1.4
Adult	19.1	5.8
Generation	9.9	5.5

Adapted from Perring et. al., 1983.[6]

Spider Mite Scouting and Identification Tips

- **When:** Scouting for spider mites should begin as soon as wheat, alfalfa, native grasses, and broadleaf weeds bordering fields begin to dry down and continue until corn reaches dent.
- **Where:** Early in the season, scouting plants next to grass waterways, field edges, or stressed areas will give the best indication of whether spider mites are feeding on corn.

return to table of contents

- **How:** Spider mites will produce fine webbing to protect themselves and their eggs. Check the underside of discolored leaves for both the webbing and mites. Mites are small and sometimes hard to see. Taking a white piece of paper and shaking the leaf over it can help to visually identify mite presence.

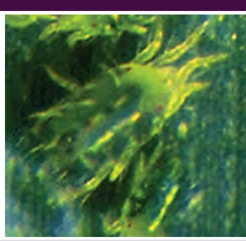
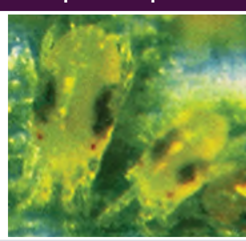
When scouting, identify which mite species is present. Even though the BGM and TSM are similar in appearance and can appear simultaneously, they have several different biological characteristics and differ in their susceptibility to pesticides (Table 2). The **BGM** will appear earlier in the season from mid-whorl through the early grain-filling stages and feed mostly on the lower leaves before moving to the upper leaves of the plant. The **TSM** will appear mid to late season, usually after flowering, and feed over the entire plant. To identify the type of mite present, use a 10X hand lens, and observe 20 adult females. It is best to do this procedure in 5 to 10 randomly selected areas in the field. Females will be the largest individuals present and have rounded bodies, while males have a more slender, tapered body.

Pioneer Agronomy

Early Season Spider Mite Scouting in the High Plains

- Russell French, Strategic Account Manager

Table 2. Biological comparison of Banks grass mite and two-spotted spider mite.[7,8]

Banks Grass Mite	Two-Spotted Spider Mite
	
Produce less webbing	Produce more webbing
Generally less robust, smaller	Generally more robust, larger
Pointed rear	Rounded rear
More susceptible to miticides	Less susceptible to miticides
Burn leaves of plant from bottom up	May occur in high numbers without burning leaves
Generalized gut pigmentation*	Concentrated gut pigmentation*

**Visible green markings on spider mites are a result of ingested plant material and differences in gut structure.*

How to Control Spider Mites in Corn

The economic damage spider mites can cause varies from year to year and depends on several biotic and abiotic factors. When deciding how best to manage spider mite infestations in a corn crop, consider biological, cultural, and chemical control methods, individually or in combination.

Biological and Cultural Control

In some years, fields may not have to be treated as beneficial predatory insects keep the mite populations below economic injury levels. Beneficial predatory insects include the *Stethorus* lady beetles, minute pirate bugs, lacewing larvae, and thrips. In addition to predatory insects, *Neozygites floridana*, a naturally occurring fungus, is a common pathogen that attacks spider mites and can be beneficial in controlling population numbers. Daily temperatures below 85 °F with high relative humidity create favorable conditions for fungal growth on the spider mites.

Hot and dry climates tend to have higher levels of spider mite infestations as natural enemies cannot keep up with increasing spider mite numbers, and the fungal pathogen *Neozygites floridana* is not as active. Avoiding drought stress with properly applied irrigations is a key cultural control component. However, once spider mite populations are established, irrigation will not decrease the density of the population. Other cultural components to consider are later plantings or planting a fuller-season hybrid if these options are feasible.

Chemical Control With Miticides

Biological and cultural control practices can be beneficial but often unreliable. Many growers rely heavily on chemical control. While chemical control can be effective, this method does not come without problems or concerns. The TSM is more tolerant to miticides and is harder to control than the BGM. Additionally, spider mites colonize on the bottom side of the leaves, leading to difficulties in application coverage. It is recommended to use three or more gallons of water per acre to increase effectiveness. Aerial applications are most effective. More scouting and secondary treatments can usually be expected as it is difficult to kill eggs with a miticide application. Re-infestation will likely occur within 7 to 10 days after initial application.

Early season preventative treatments can provide some economic benefit. Growers should carefully consider:

- The amount of plants infested with small colonies of mites
- Temperature and humidity patterns
- Any drought stress the crop may be under
- Predatory insect populations
- Field history of mite infestations

Again, this places a high emphasis on properly scouting for the pest.

A simple guideline in determining treatment thresholds is to treat when damage is visible in the lower third of the plant, colonies are present in the middle third of the plant, and the corn has not yet reached hard dough stage. Once the corn crop has reached the hard dough to dent stage, no economic benefit will be gained from a miticide treatment.

Another more sophisticated guideline takes into account the cost of treatment and expected crop value based on the percent of infested leaves and the amount of leaf area damaged (Table 3). To use this table, the control cost (miticide + application cost) and the expected crop value (grain bu/acre x market price) must be determined. Then a two-step sampling method is used. First, select an individual plant, and check green leaves for presence or absence of mites to calculate the percentage of infested green leaves (first value listed in table). This should be done 10 times in different portions of the field. If percent of green leaves infested exceeds that of the control cost and crop value, then the percent of leaf area damaged will need to be determined.

Example: If the estimated control cost is $20/acre, the crop is valued at $300/acre and the percent of green leaves infested exceeds 39, then the percent leaf area damaged needs to be estimated. If the percent leaf area damaged exceeds 21, then it will likely pay to apply a miticide treatment.

Table 3. Economic injury threshold for BGM and TSM in corn.

Cost per Acre	Crop Value per Acre						
	$250	$300	$350	$400	$450	$500	$550
	— % infested leaves per plant / % leaf area damaged —						
$ 5	12/6	10/5	8/5	7/4	7/3	6/3	5/6
$ 10	24/13	20/10	17/9	15/18	13/7	12/6	11/6
$ 15	35/19	29/16	25/13	22/12	20/10	18/9	16/9
$ 20	47/25	39/21	34/18	29/16	26/14	24/13	21/11
$ 25	59/31	49/26	42/22	37/20	33/17	29/16	27/14

Developed by Archer and Bynum, 1993.[9]

Leaves showing progression of no damage (top) to intense damage (bottom) due to spider mite feeding.

Resistance Management

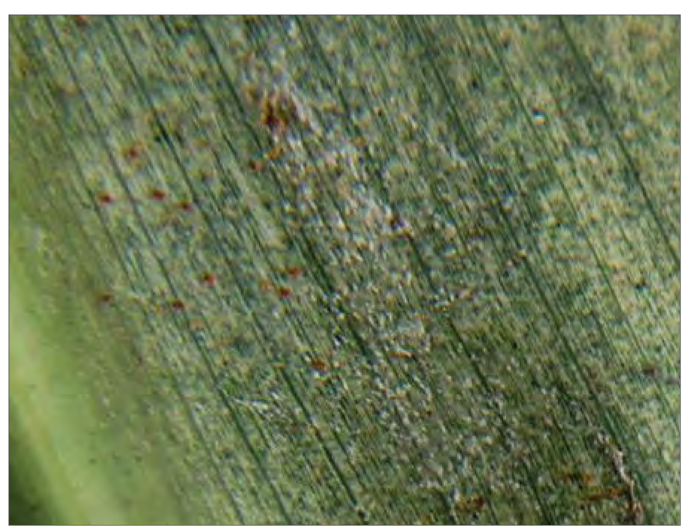
Because spider mites can develop resistance to miticides, resistance management is a key concern for growers. Continued use of any one miticide will naturally select against susceptible mites and increase the number of tolerant mites in each subsequent generation. In areas where spider mites are a consistent problem, the following resistance management strategies can be extremely helpful.

- If able, keep corn well-watered and avoid drought stress.
- Avoid planting corn next to winter wheat and alfalfa fields, particularly if mite infestations are known.
- Use insecticides only when faced with serious yield loss.
- Beneficial insects that are predatory on spider mites are better able to thrive when insecticides are not used on corn. Planting Pioneer® brand hybrids with aboveground insect protection technologies can help preserve yield potential while reducing or eliminating the need for insecticides.
- Only apply miticides when yield is threatened based on treatment thresholds and application guidelines.
- When miticide applications are necessary, be sure to maximize miticidal activity by applying with the proper carrier volumes and appropriate adjuvants (Table 4).
- Do not consistently use the same miticide year after year.

Table 4. Spider mite management options.[10]

Insecticide**	Trade Name	Rate
Bifenthrin	numerous products	0.08 to 0.10 lb. a.i./acre (5.1 to 6.4 fl. oz.)
Etoxazole	Zeal®	4 to 6 oz./acre
Fenpyroximate	Portal®	2 pt./acre
Hexythiazox	Onager®	0.073 to 0.176 lb. a.i./acre (10 to 24 fl. oz.)
Propargite	Comite® II	2.25 pt./acre
Spiromesifen	Oberon® 4 SC	0.09 to 0.25 lb. a.i./acre (2.85 to 8.0 fl. oz.)
Zeta-cypermethrin + Bifenthrin	Hero®	10.3 fl. oz. of product/acre
Dimethoate	Dimethoate, Dimate®	0.33 to 0.5 lb. a.i./acre

***Always read and follow manufacturers label, directions, and recommendations.*



Corn leaf infested by spider mites, showing webbing and damage on underside of leaf.

corn nematode populations in the corn belt and southeastern U.S.

Mary Gumz, Ph.D., *Agronomy Manager*

This study found over 50% of corn fields sampled throughout the Corn Belt and Southeast had medium to high levels of nematode pressure.

Nematodes were widely distributed through all sample areas and not confined only to sandy soils.

The most prevalent species of nematodes varied by region and included lance nematode in the Eastern Corn Belt; stubby root and dagger in the Western Corn Belt; dagger and root-knot in Wisconsin; and root-knot and stubby root in the Southeast.

Stunted growth of the corn plant on the left due to corn nematode pressure. Above-ground symptoms of nematodes are often non-descript and resemble low fertility, weather stress, or insect and disease pressure.

Rationale and Objectives

- Corn nematodes can cause significant yield loss by damaging corn roots, which impairs water and nutrient uptake as well as creates entry points for pathogens.
- In 2019 and 2020, Pioneer agronomists sampled corn fields in several regions to assess nematode population levels and the range of species present:
  - » Eastern Corn Belt: Illinois and Western Kentucky
  - » Western Corn Belt: Iowa, Nebraska, Kansas, Colorado, Missouri, and Texas
  - » Wisconsin
  - » Southeast: Alabama, Florida, and Georgia

Study Description

- A total of 748 corn fields were sampled for nematode populations in 2019 and 2020.
- Soil samples were taken at approximately the V6 growth stage.
- Soil samples were taken from both within and between the row and contained corn root tissue.
- Samples were submitted to a nematode testing service and analyzed using a sugar-floatation method plus a 500 mesh sieve.

Nematode Pressure Levels

- Scientists at Corteva Agriscience have developed high population indicators for major corn nematode species as a relative measure for population levels (Table 1).
- Nematode pressure in a field was classified based on the high population indicator level for each species.
  - » High: Above indicator level for one or more species
  - » Medium: Above 50% indicator level for one or more species
  - » Low: Less than 50% indicator level for all species

Table 1. Corteva Agriscience high population indicators for major corn nematode species.

Species	Nematodes/ 100cc Soil	Species	Nematodes/ 100cc soil
Sting	1	Dagger	100
Needle	1	Lesion	150
Lance	50	Stunt	300
Stubby-Root	50	Ring	200
Root Knot	50	Spiral	500

Results

- Nearly all fields sampled (93%) had corn nematode species present at some level (Figure 1).
- Medium and high population levels were prevalent across all regions in the study.

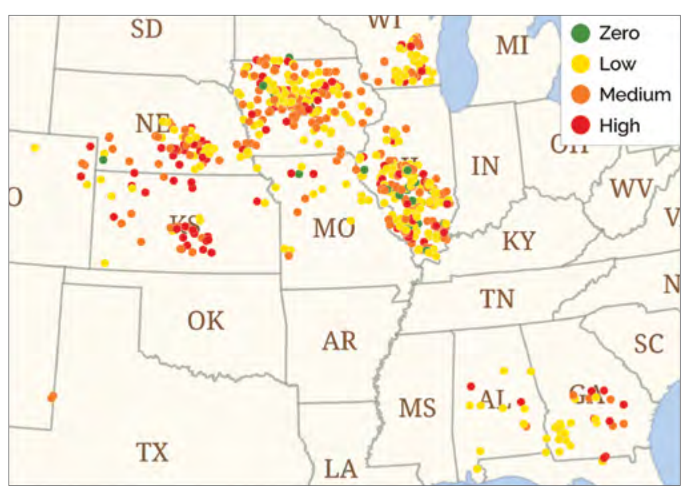


Figure 1. Corn nematode pressure at sites sampled in 2019 and 2020.

return to table of contents

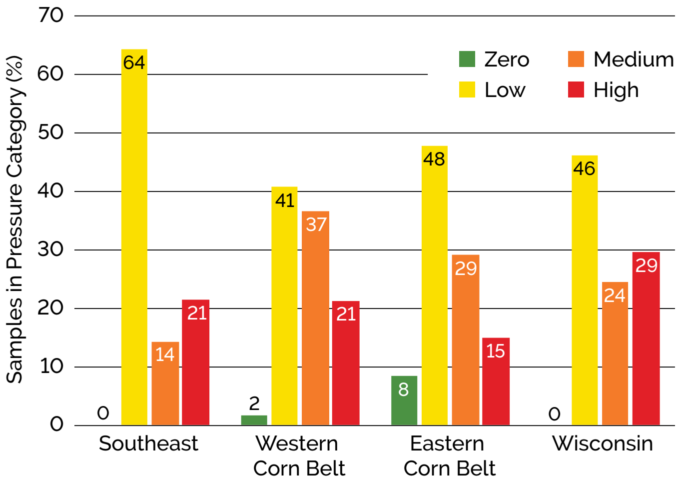


Figure 2. Corn nematode pressure level of fields sampled in 2019-2020.

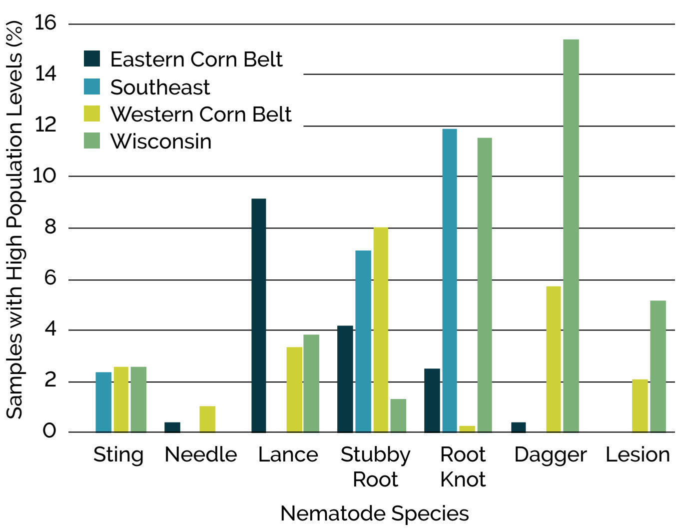


Figure 3. Corn field sampled in 2019-2020 with high population levels of major corn nematode species by region.

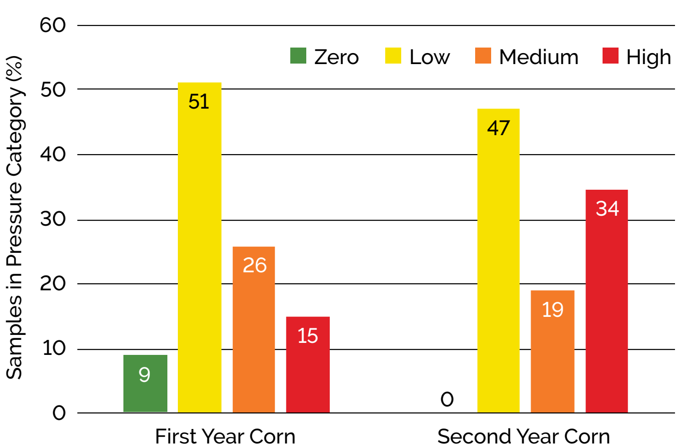


Figure 4. Corn nematode pressure level of fields planted to first-year corn compared to fields in second-year corn.

- The Western Corn Belt and Wisconsin had the highest percentage of fields with medium and high corn nematode pressure; however, potentially damaging levels of corn nematodes were widespread in all regions (Figure 2).
- Lance, stubby root, and spiral nematodes were the species most commonly found at levels above the high population indicator (Figure 3).
- Over 10% of fields had more than 2 species of nematodes above the high population indicator level.
- Sting and needle nematodes, which are potentially damaging at any population level, were found in all regions but less commonly in the Eastern Corn Belt (Figure 3).
- Root knot nematode, which can also affect soybean production, was found most often in the Southeast and Western Corn Belt (Figure 3).
- Average corn nematode pressure tended to be higher in corn following corn. 41% of first-year corn fields had moderate to high levels of nematodes compared to 53% of second-year corn fields (Figure 4).

Management Considerations

- Results of this study showed that potentially damaging levels of corn nematode populations are prevalent throughout corn production areas in the U.S.
- If damaging levels of corn nematodes are found, implementing control measures, such as rotation, sanitation, or use of nematicide seed treatments, should be considered.
- Nematode species vary in their host range, so rotation can be effective for reducing populations of some, but not all, corn nematode species.
- Pioneer® brand corn products are available with two seed treatment options for nematode control:
  - » **Lumialza™ nematicide seed treatment** is a biological product that contains the active ingredient *Bacillus amyloliquefaciens* – Strain PTA-4838 and has activity against all primary corn nematode species.
  - » National trials have shown yield improvements of 3.7 bu/acre under low pressure and up to 9 bu/acre in high-pressure fields.
  - » Research has shown that nematode protection lasts for more than 80 days in the upper, middle, and lower root zones.
  - » **Poncho® 1250 + VOTiVO® insecticide** provides a biological mode of action to protect corn seedlings and roots against nematodes.
  - » Poncho 1250 + VOTiVO insecticide contains a unique strain of bacteria that lives and grows with young corn roots, creating a living barrier that helps protect corn seedlings and roots against nematodes.

n to table of contents

cell division inhibitor herbicides

Michael DeFelice, Ph.D., *Former Senior Manager: Herbicide, Ag Traits, & Seed Treatments*

Summary

- The cell division inhibitor herbicides include several families, most notably the preemergence acid amide grass herbicides.
- The general mode of action of these herbicides is interference with cell division and cell enlargement. The primary mechanism of action of the acid amide herbicides is still unknown.
- These herbicides are absorbed by roots as well as shoots and are translocated throughout the plant, primarily in the xylem. Research suggests the grasses absorb these herbicides through emerging shoots (coleoptiles) while broadleaf plants absorb them primarily through emerging roots.
- The most common visual symptoms of acid amide herbicides on emerging seedlings include shoot inhibition; grasses that leaf-out below the soil surface or fail to unfurl causing a "buggy whip" appearance; and broadleaves with crinkled leaves and/or a shortened mid-vein, which produces a "drawstring" appearance on the leaf tip.
- The mechanism of selectivity in tolerant plants is rapid breakdown of the herbicide to non-toxic metabolites. Plant response tends to be more severe and common with cool, saturated soils at the time of crop emergence.

History of Cell Division Inhibitor Herbicides

There are several herbicide families classified as inhibitors of cell division in plants. The most widely known and used herbicides with this general mode-of-action are the "acid amide" families of preemergence grass herbicides. The primary mode of action for these herbicides is still largely unknown.

The Herbicide Resistance Action Committee and the Weed Science Society of America classify five herbicide families and a few unclassified herbicides in the "cell division inhibitors" group. These families are the acetamides, the benzamides, the chloroacetamides, the oxyacetamides, the tetrazolinones and "others." This article will focus on the chloroacetamides and oxyacetamides since these families contain the most widely used herbicides in this class for corn and soybean production.

Figure 1. Corn seedling not unfurling due to interference with cell division and enlargement (acid amide herbicide).

The first herbicide in this general group was discovered in the 1940s with the introduction of diphenamid (Enide). In the 1970s and early 1980s, alachlor, a chloroacetamide, was one of the most widely used herbicides in the world.

The amide herbicides are classified into three groups: 1) the soil-applied chloroacetamides and oxyacetamides (the focus of this article), 2) other soil-applied amides (diphenamid, napropamide, and others), and 3) foliar applied amides (propanil). These herbicides have been labeled primarily for preemergence annual grass and nutsedge control with additional control of small-seeded broadleaf weeds. They are widely registered for many agronomic and horticultural crops.

Mode of Action

The primary mechanism of action of the acid amide herbicides is still unknown. However, they are known to inhibit several metabolic functions in plants including lipid biosynthesis (not ACCase) and the synthesis of proteins, gibberellins, anthocyanin, and lignin. It may be that these herbicides are acting on several sites of action at the same time. The general mode of action is interference with cell division and cell enlargement.

The acid amide herbicides are absorbed by roots as well as shoots and are then translocated throughout the plant, primarily in the xylem. Current research suggests the grasses absorb these herbicides through emerging shoots (coleoptiles) while broadleaf plants absorb them primarily through emerging roots. These herbicides do not inhibit seed germination, but rapid uptake by the emerging shoot and roots usually kills susceptible weeds before they emerge from the soil. Degradation in the plant is through conjugation with glutathione and/or glucose. The mechanism of selectivity in tolerant plants appears to be rapid detoxification by conjugation of the herbicide with glutathione.

Physical and Chemical Properties

There is a wide range of chemical behavior and properties among the herbicides in the five families of cell division inhibitors. This discussion will focus on the acid amide chloroacetamide and oxyacetamide family herbicides that are of primary interest for corn, soybean, and grain sorghum production.

The acid amide herbicides are soil applied and must be moved down into the weed seed germination zone by tillage or "activation" (leaching from rainfall or irrigation). The acid amide herbicides are adsorbed to soil clay as well as organic matter and tend to leach only one to two inches deep in the soil. Soil persistence of the acid amides is relatively short at one to three months, so these herbicides have short crop rotation restrictions. Degradation in the soil is primarily through microbial action. The rate of degradation is greater at higher soil moisture levels.

Figure 2. Corn leafing out underground from application of acid amide in cool, wet spring.

Herbicide "Antidotes" or "Safeners"

The acid amide herbicides have broad-spectrum grass activity. This has made it difficult to find herbicides in this group that have natural selectivity to monocot crops, such as corn and grain sorghum. Herbicide "antidotes" or "safeners" have been discovered that provide additional tolerance to these herbicides on treated plants.

Several safeners have been registered for use on crops, such as corn and grain sorghum. Grain sorghum can be protected from the herbicide by treating the seed with one of these safeners. The emerging roots and shoots adsorb the antidote before the herbicide can cause significant damage to the plant. Other acid amide herbicides contain the antidote mixed in the formulation itself, such as Dual II (metolachlor plus antidote) and Harness/Surpass (acetochlor plus antidote). These antidotes have structures and activity very similar to the acid amide herbicides themselves. They provide a "safening" effect by stimulating glutathione S-transferase metabolic activity in the crop, which causes more rapid conjugation with glutathione and detoxification of the herbicide.

Symptoms

The acid amide herbicides are primarily soil applied and have very little foliar activity. Typical symptoms of acid amide herbicides on emerging seedlings include inhibition of shoots resulting in plants that do not emerge from the soil. Grasses may leaf-out below the soil surface or fail to unfurl, causing a "buggy whip" appearance. Broadleaves may have crinkled leaves and/or a shortened mid-vein, which produces a "drawstring" appearance on the leaf tip.

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 cool, wet soils at the time of crop emergence.

Weed resistance to acid amide herbicides has been relatively uncommon despite their widespread use around the world. The first reported acid amide resistant weed was rigid ryegrass (*Lolium rigidum*) in Australia in 1982. There are currently seven weed species populations that have evolved resistance to acid amide herbicides reported from nine countries (Table 1). No resistant weeds had been reported in the corn and soybean production areas of the United States until 2016 when resistant populations of both waterhemp (*Amaranthus tuberculatus*) and Palmer amaranth (*A. palmeri*) were confirmed in Illinois and Arkansas, respectively.

Table 1. Weed species with populations resistant to cell division inhibitor herbicides (Heap, 2020).

Weed Species	Country and Year
Blackgrass *Alopecurus myosuroides*	Germany – 2007
Palmer Amaranth *Amaranthus palmeri*	U.S. (Arkansas) – 2016 U.S. (Arkansas) – 2017
Tall Waterhemp *Amaranthus tuberculatus*	U.S. (Illinois) – 2016
Wild Oat *Avena fatua*	Canada (Manitoba) – 2015
Barnyardgrass *Echinochloa crus-galli*	China – 1993 Thailand – 1998 Philippines – 2005
Italian Ryegrass *Lolium perenne ssp. multiflorum*	U.S. (Idaho) – 2005 France – 2018 United Kingdom – 2018 U.S. (Oregon) – 2018 U.S. (Washington) – 2018
Rigid Ryegrass *Lolium rigidum*	Australia – 1982 Australia – 1984

Differential Response in Corn Inbreds and Hybrids

Several seed company and university research studies have shown that corn inbreds and hybrids have different levels of tolerance to the acid amide herbicides. These differences in tolerance to acid amide herbicides are most likely related to differential metabolism among the inbred and hybrid lines. The acid amide herbicides have been widely used in corn production for almost 50 years, so inbred selection in the presence of these herbicides in the field has probably eliminated most of the more susceptible lines.

Figure 3. Classic "drawstring" appearance of soybean leaf from acid amide herbicide.

Figure 4. Corn not unfurling from acid amide application. Corteva Agriscience tests both inbreds and hybrids for plant response to acid amide herbicides.

Guidelines for Using Acid Amide Herbicides in Corn, Grain Sorghum, and Soybean Production

The acid amide herbicides are widely used on corn, grain sorghum, and soybeans, among other crops. They are popular and effective preemergence grass herbicides that are used on a large percentage of the world's corn and grain sorghum crops. Their preemergence grass activity makes the acid amide herbicides the perfect companion to atrazine, which provides broadleaf weed control in corn and grain sorghum. The acid amide herbicides are also used for preemergence grass control in conservation and no-till soybeans because they do not require mechanical incorporation into the soil.

The level of crop tolerance to acid amides varies with the specific herbicide, crop genetics, and addition of herbicide antidotes or safeners. Most crop responses to these herbicides occur during extended periods of cool temperatures and/or wet soils. Note that corn or sorghum leafing out below the soil surface can also be increased or caused by soil crusting. Rotary hoeing can sometimes alleviate this effect. Crop response from these herbicides can be minimized by planting crop seed at the proper depth below the treated soil, ensuring seed furrow closure, and by keeping soils well drained.

return to table of contents

corn ear injury risk with off-label glyphosate applications

Mark Jeschke, Ph.D., *Agronomy Manager*

Injury Risk With Late Applications

- Applying glyphosate in glyphosate-resistant corn later than recommended according to product label guidelines can result in damaged ears and reduced yield.
- Injury symptoms associated with late, off-label glyphosate applications are commonly referred to as "bubble kernel" or "jumbled kernel syndrome."
  - » Affected ears have some kernels that fail to develop properly.
  - » Healthy kernels expand to fill the gaps left by the injured kernels, resulting in the ear having a jumbled appearance.
- Injury symptoms may also occur along field edges due to glyphosate treatment in adjacent soybean fields or spot treatment of weeds in fence rows.

Figure 1. Erratic kernel set of ear (left) caused by late application of glyphosate, compared to normal ear (right). *Photo courtesy of Clyde Tiffany, Pioneer Field Agronomist.*

Injury Mechanism

- Damage can occur when glyphosate is present in the developing ear at a time when it is susceptible to damage.
- Glyphosate is phloem-mobile in the plant and therefore, tends to translocate to and accumulate in sink tissues, such as developing shoots and roots (Hetherington et al., 1999).
- There is little to no metabolism of glyphosate molecules in the plant, meaning that the herbicide remains in its active form and can damage developing tissues that have inadequate expression of the resistant form of the target site (Feng et al., 2010).

Application Timing

- Roundup WeatherMax® can be applied over the top to corn with Roundup Ready® 2 Technology up to the V8 stage or until the corn reaches 30 in tall, whichever comes first, according to label guidelines.
- For corn 30 to 48 in tall, treatments can only be made using a ground applicator equipped with drop nozzles.
- **Always read and follow label guidelines.**

Figure 2. A dissected corn plant at the V9 growth stage showing developing ear shoots present at several nodes.

Photo courtesy of Iowa State University Extension.

Only Some Kernels Are Affected

- Many glyphosate-resistant hybrids are not homozygous for the trait; one parent (typically the female parent) is resistant and the other is not.
- The resulting F1 hybrid plants are all heterozygous for the trait with one resistant and one susceptible allele. The resistant allele is dominant, so the hybrid plants are all glyphosate-resistant.
- The fertilized kernels on the plant represent the F2 generation. Since the F2 embryos are all the product of 2 heterozygous F1 parents, they will segregate out into 25% homozygous resistant, 50% heterozygous resistant, and 25% homozygous susceptible.
- This means that approximately 25% of the developing kernels on an ear are susceptible to damage if exposed to glyphosate.

Parent 2 \ Parent 1	R	r
R	RR	Rr
r	Rr	rr

F2	
RR	25%
Rr	50%
rr	25%

Figure 3. Left: Ear showing translucent "bubble" kernels as a result of injury from a late glyphosate application. Right: An injured ear later in development where the affected kernels have shrunk and collapsed. *Photos by Dan Emmert and Curt Hoffbeck, Pioneer field agronomists, 2010 (L) and 2014 (R).*

- In affected kernels, the germ will die while the seed coat and endosperm remain alive.
    - » Initially, this results in the characteristic translucent "bubble" appearance.
    - » As ear development progresses, the damaged kernels will appear hollow and eventually collapse.
    - » The adjacent kernels expand to fill the gaps left by the injured kernels, resulting in the ear having a jumbled appearance.

Figure 4. Corn ears on the right showing the effects of late (off-label) application of glyphosate on corn. Two corn ears on the left are from an area in the same field that was not sprayed with a late application of glyphosate. *Photo by Curt Hoffbeck, Pioneer field agronomist, 2014.*

Factors That Influence Injury Risk

- The primary risk factor for corn ear injury with glyphosate is late, off-label applications.
- Injury risk also increases with glyphosate rate, meaning that sprayer overlap areas or plants along field edges exposed to high-rate spot treatments in fencerows can be affected.
- Injury symptoms can vary due to environmental conditions. A 3-year study of off-label late and high-rate applications in Michigan and Ontario found injury resulting in yield loss at only about half of the locations (Mahoney et al., 2014).

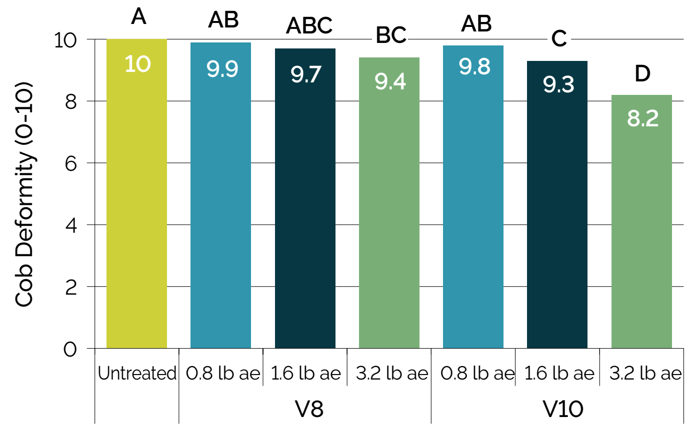


Figure 5. Cob deformity associated with glyphosate treatment at 2 timings and 3 rates at 5 Ontario and Michigan locations in 2009-2011. Cob deformity visually rated on a 0-10 scale; 10 = no injury, 0 = completely deformed.

Means noted with the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

0.8 lb ae/acre rate of glyphosate equivalent to 22 oz/acre of Roundup WeatherMax®.

Yield Impact

- Since in most cases 25% of kernels on an ear would be susceptible to glyphosate injury, theoretical yield loss could be up to 25%.
- Actual yield loss is likely to be less than this, although could still be significant.
- Kernels adjacent to those affected will expand into the gaps on the ear, partially compensating for the missing kernels.
- The greatest yield loss observed in a 3-year field study was 10% on average across 5 locations with an above-labeled rate of glyphosate applied at the V10 stage.

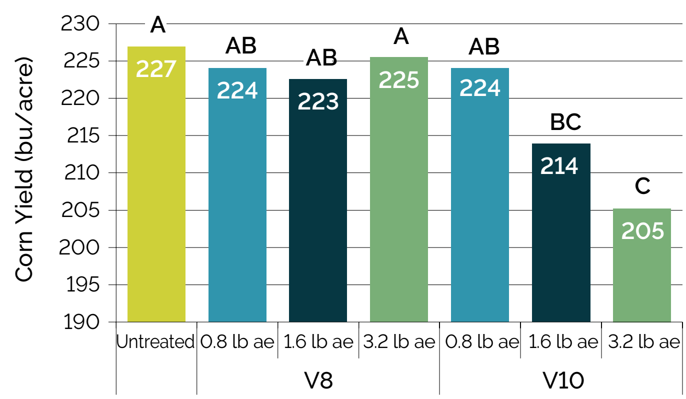


Figure 6. Corn yield associated with glyphosate treatment at 2 timings and 3 rates at 5 Ontario and Michigan locations in 2009-2011.

Means noted with the same letter are not significantly different according to Fisher's Protected LSD ($P < 0.05$).

Management Recommendations

- Always read and follow product label guidelines for timing and rate of glyphosate applications.
- Do not apply later than recommended, and use drop nozzles when treating in larger corn.

why dry conditions increase risk of herbicide carryover

***Stephen Strachan, Ph.D.**, Former Research Scientist, and **Kevin Hahn, Ph.D.**, Field Development Senior Consultant*

1 Herbicides break down through microbial and/or chemical degradation in the presence of soil moisture.

2 When soils are very dry, herbicide breakdown via microbiological activity is diminished.

3 Chemical degradation continues to occur in dry soils and may increase due to higher soil temperatures.

4 If there is a concern about planting a sensitive crop into soil that was treated with a herbicide that degrades via only microbial activity, carefully check the rotational crop portion of the label, and plant the crop according to these guidelines.

Watch Out for Herbicide Carryover

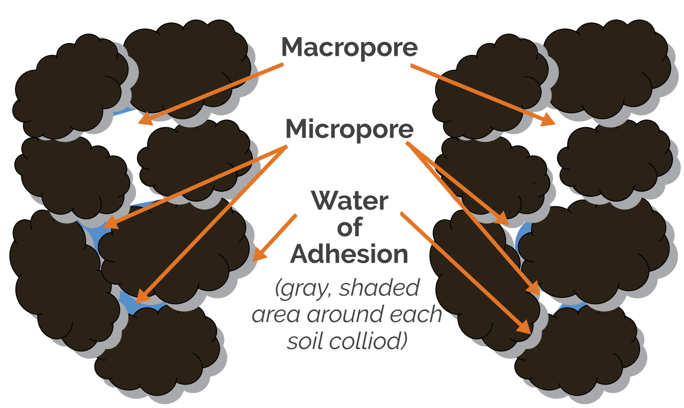
In the growing season following a drought, growers should be wary of potential herbicide carryover. Herbicides break down through microbial and/or chemical degradation in the presence of soil moisture. When soils are very dry, herbicide breakdown via microbiological activity is diminished. Growers who suspect and need to diagnose herbicide carryover issues arising from severe drought conditions can use this information to identify how the applied herbicide degrades and how its degradation rate may be affected.

Herbicide Degradation in Dry Soils

To understand herbicide degradation in dry soils, it is important to understand how drought affects soil water; microbiological activity; herbicide degradation pathways; and the interaction between microorganisms and herbicides.

Characteristics of Water in Soil

A saturated soil contains about 50% solids, 25% plant- available water in the micropores, and 25% air space in the macropores. As the soil dries, plant-available water from the micropores is consumed. There is also a third type of water in soil called "adhesion water." This is the water that surrounds the soil colloids and is held in the soil by strong chemical and hydrogen bonds. This water is not plant available. In addition, this adhesion water does not evaporate under dry conditions and comprises about 2 to 5% of the weight (~20 to 50 tons) of an acre furrow slice of air-dry soil. One acre furrow slice comprises 1 acre of soil to a depth of approximately 6 inches and weighs approximately 1,000 tons (Foth and Turk, 1972).



Saturated Soil

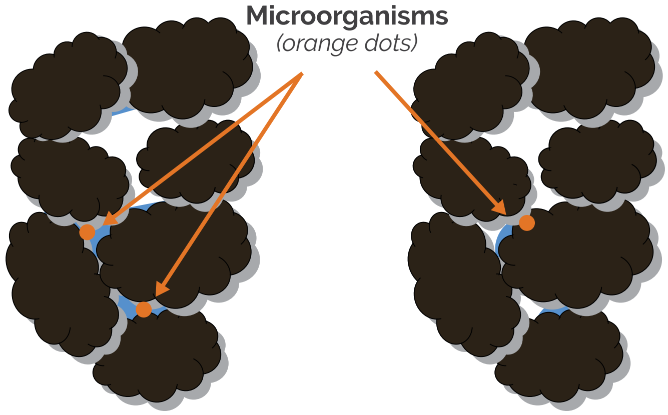
- Macropores filled with air
- Micropores filled with water
- Thin film of water (water of adhesion) surrounds each soil colloid

Soil Under Drought Conditions

- Water still present only in the smallest micropores and as a film around the soil colloids

How Microorganisms Function in Soil

Microorganisms (bacteria, fungi, etc.) require water for life and must live in a "sea of water" for survival. As the soil dries, the seas in the micropores diminish, thus reducing microbiological populations. As soils become very dry, fewer microorganisms are present for herbicide degradation, so the rate of microbial herbicide degradation decreases.

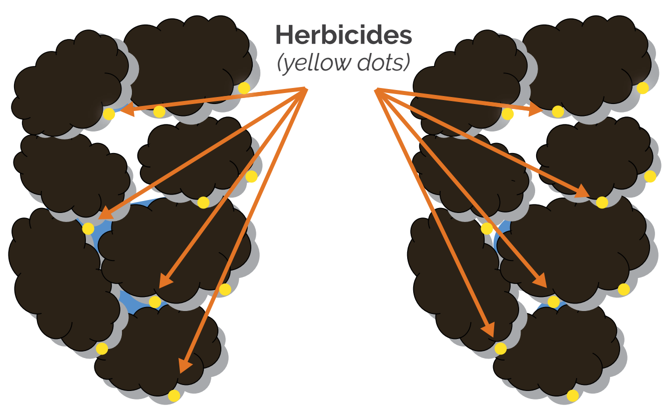


Saturated Soil **Soil Under Drought Conditions**

- Require water to survive
- Reduce populations as soil water content decreases
- Are relatively large (a few microns in length) and require small pools of water for maximum activity

Herbicides in Soil

Herbicides tend to exist as single molecules in the soil profile. These molecules tend to bind or associate with soil colloids, soil clay, or soil organic matter. A large portion of the herbicide molecules is, therefore, associated with the adhesion water. Another portion of herbicides is dissolved in the water contained in the soil micropores. Herbicide molecules associated with the soil adhesion water and with the micropore water eventually reach equilibrium concentrations and move between the two types of water. As the soil dries, the relative amount of herbicide molecules associated with the adhesion water increases.

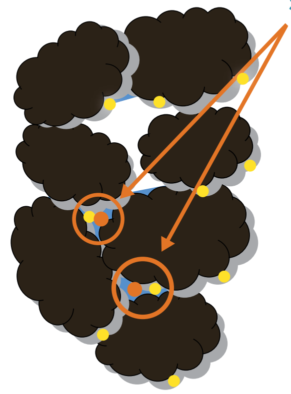


Saturated Soil **Soil Under Drought Conditions**

- Exist as single molecules (a few angstroms in length)
- Tend to accumulate in the film of soil water next to the soil colloids
- Some percent of molecules remain in the water held in micropores
- Herbicide molecules move between the two water phases

How Microorganisms Degrade Herbicides in Moist Soil

Microorganisms must either ingest or be very closely associated with herbicide molecules in order to degrade these molecules. Most microbiological degradation, therefore, occurs in soil micropores. When a microorganism degrades a herbicide molecule in the micropore, a new equilibrium is established between the herbicide in the micropore water solution and herbicide associated with the adhesion water.



Saturated Soil

- Microbes must either ingest or be closely associated with herbicide molecules for herbicide degradation to occur
- Microbes are relatively large and require ample water and space to live
- Micropores filled with water best support microbial growth
- Herbicide molecules move from the water film on the soil colloid into the micropores as microbes degrade molecules in the micropores

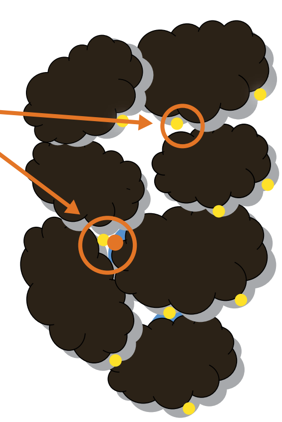
As the herbicide molecules are removed from the micropore water by microbiological degradation, the amount of herbicide molecules associated with the adhesion water subsequently decreases until, eventually, all herbicide molecules are consumed.

Drier Soil Slows Microbial Degradation

The rate of microbiological degradation of herbicides decreases as soils become drier for two reasons. First, microorganisms require water to live. If there is less available water, there are fewer microorganisms. If there are fewer microorganisms, there are fewer "factories" to degrade the herbicide molecules. Second, the very small size of the herbicide molecule allows these molecules to penetrate very tiny pore openings. Herbicide molecules are a few angstroms in size (1 angstrom = 10^{-10} m), while microorganisms are a few microns in size (1 micron = 10^{-6} m). Microorganisms are about 10,000 times larger than herbicide molecules. These small molecules remain "hidden" or "protected" from microbiological attack because the relatively larger microorganisms cannot penetrate these openings.

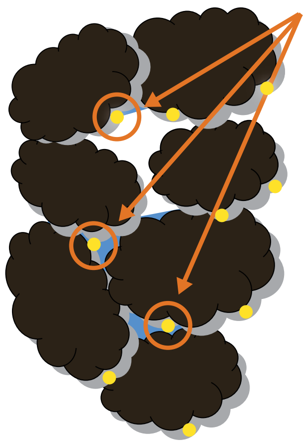
Soil Under Drough Conditions

- Less available water to support microbial populations (fewer microorganisms present to degrade herbicide molecules)
- Microorganisms are about 10,000 times larger than herbicide molecules and cannot enter all locations in the film of water where the herbicide molecules are located (limited access to the herbicide molecules)



Chemical Degradation of Herbicides in Soil

Chemical degradation occurs wherever water is present. This includes water associated with soil micropores and water closely associated with the soil colloids (adhesion water).



Saturated Soil

- Chemical degradation can occur wherever water is present in the soil
- Herbicide molecules associated with the thin film of water near the soil colloids and in water contained in soil micropores are susceptible to chemical degradation

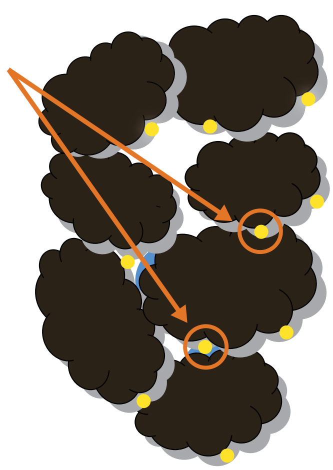
Even the driest soil in its natural state contains about 2 to 5% of water by weight. As long as water is present, chemical degradation can occur.

Chemical Degradation of Herbicides Continues in Drier Soils

Soil temperature also plays a critical role in herbicide degradation. Chemical reactions typically occur faster as temperatures increase. Under drought conditions, soils are drier, and soil temperatures also tend to be hotter. Therefore, chemical degradation of herbicides tends to increase. It is not known how much the rate of chemical degradation increases relative to the rate of decrease in microbiological degradation as soils become drier under drought.

Soil Under Drought Conditions

- Even very dry soils contain a thin film of water surrounding the soil colloids
- Herbicide molecules are either attached to soil colloids or located in the thin film of water surrounding the soil colloids and are susceptible to chemical attack
- As long as water is present, chemical degradation continues to occur
- Rate of chemical degradation may increase because drier soils tend to have higher temperatures (rates of chemical reactions increase as the temperature increases)



How Common Herbicides Degrade

The following table contains a few examples of how some of the more common herbicides degrade in soil. Note that the chemical class is more important than the mode of action in determining primary pathways for herbicide degradation. As an example, imidazolinone and sulfonylurea herbicides both affect the ALS binding site. However, imidazolinone herbicides degrade primarily via microbiological degradation, whereas sulfonylurea herbicides (e.g., chlorimuron ethyl, rimsulfuron, and tribenuron) degrade via both microbiological and chemical pathways.

Pioneer Agronomy

Symptomology of ALS Herbicide Carryover in Corn
- Ron Gehl, Field Agronomist

Table 1. Degradation pathways of herbicides (typically based on chemical class, not mode of action).[a]

Primarily Microbial Activity	Atrazine[b]
	Flumetsulam
	Flumioxazin (not persistent)
	Fomesafen
	Imidazolinones
	Mesotrione
	Metolachlor (safe to most crops)
	Metribuzin
	Sulfentrazone
Combination of Chemical and Microbial Activity	Chlorimuron ethyl
	Isoxaflutole
	Pyroxasulfone
	Rimsulfuron
	Saflufenacil
	Simazine[c]
	Thiencarbazone
	Tribenuron

[a] References: Senseman, 2007; EPA-published documents.

[b] Greater rotational crop concern if followed by metribuzin ahead of soybeans.

[c] High pH: microbial only. Low pH: chemical and microbial.

Herbicide Degradation During a Drought Year – Follow the Label

Many of the active ingredients listed in Table 1 have been used for many years. These herbicides have been applied during drought years (e.g., 1988) and in very wet years (e.g., 1993). Product labels commonly have a "safety buffer" built into the label guidelines. If there is a concern about planting a sensitive crop into soil that was treated with a herbicide that degrades via only microbial activity, carefully check the "following crop" or "rotational crop" portion of the label, and plant the crop according to these guidelines.

return to table of contents

how to mitigate herbicide carryover injury following drought

Dave Johnson, Ph.D., *Research Scientist, and* **Stephen Strachan, Ph.D.,** *Former Research Scientist*

Extended dry conditions can increase potential for carryover of herbicides to crops planted the following season.

Herbicide concentrations remaining in the soil depend on characteristics of the chemical, the site, and the weather.

Carryover injury depends on the herbicide concentration in the soil and the susceptibility of the intended rotational crop to that herbicide.

Most herbicides primarily degrade by soil microbial processes, which are reduced by dry conditions.

While growers cannot do much to change the concentration of herbicides present in the soil, they can do several things to reduce the risk of carryover injury.

The first step in evaluating carryover potential is to examine spray records and product labels.

Compare time intervals between herbicide application and the projected planting date of the rotational crop to time intervals listed on the rotational crop portion of the product label.

Herbicide Carryover Risk After Drought

Growing seasons with extended periods of drought conditions can increase potential for carryover injury from herbicides applied during the drought season to crops planted the following season.

The potential for herbicide carryover injury is driven by two main factors:

1. Concentration of available herbicide remaining in the soil at the time of rotational crop planting
   - » Depends on herbicide chemical properties, soil characteristics, and weather
2. Susceptibility of the rotational crop to the herbicide
   - » Rotational crops differ in their susceptibility to herbicides with some crops not injured by relatively high concentrations and other crops highly injured by low concentrations.
   - » The stresses that the newly planted crop faces during establishment can also affect response. Emerging plants are more likely to show injury to residual levels of herbicide if other stresses, such as compaction or cold, wet soils, are also present.

Herbicide labels have requirements on how much time should elapse between herbicide application and planting of specific crops (rotational cropping restrictions). Some label requirements are also conditional and may depend on the rate applied, the geographical region where applied, and the weather conditions experienced since application. Different herbicides have different characteristics and interact with soils as well as weather in different ways, so broad, sweeping recommendations are not possible.

Understanding how the chemical properties, soil characteristics, weather, and crop susceptibility interact is critical to evaluating the risk of carryover injury. If the risk appears high, the important question is: what can be done now to mitigate carryover injury?

How Herbicides Degrade in Soil

Degradation is the transformation of active herbicide molecules to products that no longer have herbicidal activity. Degradation rate is often described by half-life, which is the time required for half of the herbicide molecules to degrade from the soil. Herbicides with longer half-lives tend to be more persistent and have higher potential for carryover.

Damage to a soybean plant from atrazine carryover. Dry conditions the previous year can lead to these symptoms if there is insufficient moisture for breakdown of the atrazine.

The primary mode of degradation for many herbicides is by soil microbes, which can use herbicide molecules as an energy and/or nutrient (i.e., nitrogen) source. Non-microbial chemical degradation can also be important for some herbicide classes. This can occur in soil water (hydrolysis) or by direct exposure to sunlight on soil surfaces (photo-decomposition).

Four Factors Affecting Herbicide Carryover

1. Characteristics of the Herbicide

The chemical structure of a herbicide affects its water solubility, vapor pressure, soil binding, and susceptibility to microbial and chemical degradation. These characteristics, as well as how they interact with soil and weather (described below), determine how much herbicide is left at the time of rotational crop planting the following season. For example, herbicides that are highly bound to soil particles are often less likely to be available for microbial degradation.

2. Soil Characteristics

Soil characteristics have a large influence on herbicide persistence. Soils that are higher in clay and organic matter tend to bind more herbicide molecules to their surfaces (adsorption). This may reduce their availability for microbial degradation. Soil pH also has an effect since it can influence herbicide solubility and also microbial activity. Soil microbes (bacteria, fungi, etc.) tend to be most active near neutral soil pH.

Soil pH levels significantly lower or higher than about 6.5 to 7.0 may alter the relative populations of species of microbes growing in the soil and therefore, reduce degradation, leading to higher persistence. Soil pH can also affect chemical degradation. Some herbicides, such as sulfonylureas, are more readily degraded by chemical processes at lower soil pH and therefore, may be less likely to cause carryover damage at pH levels below 7. In contrast, imidazolinone herbicides, which are primarily microbially degraded, are more tightly bound to soil colloids in lower pH soils and are more likely to cause carryover injury at lower soil pH due to reduced susceptibility to microbial degradation.

3. Weather Conditions

Temperature and rainfall have a large effect on herbicide persistence and the potential for carryover injury. Weather patterns that favor microbial activity (warm, moist conditions) increase degradation and lessen carryover potential (Figure 1). Temperature can also influence chemical processes with warmer conditions favoring degradation.

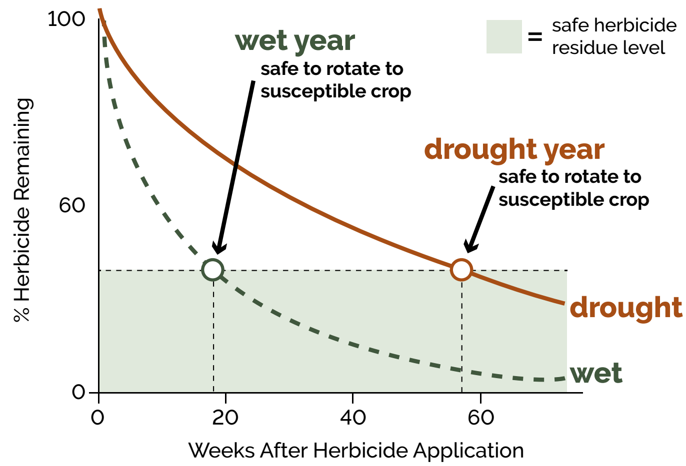


Figure 1. Illustration* of soil moisture effect on herbicide persistence – herbicides can persist much longer in dry vs. wet soils. Adapted from Colquhoun, 2006. *Does not pertain to any actual herbicide; check labels for rotational restrictions.

4. Susceptibility of the Rotational Crop

Crop species differ in susceptibility to different herbicides. That is why most herbicides are registered for some crops and not others. Therefore, choice of crop to plant following a specific herbicide application the previous year can greatly influence injury potential. For example, corn is highly tolerant to atrazine, but soybeans are relatively susceptible. If atrazine carryover is likely in a field, it may be best to plant corn (or sorghum) that year to avoid potential problems.

All of the factors described above – herbicide characteristics, soil characteristics, weather conditions, and rotational crop planted – interact with each other to cause or avoid carryover injury. These factors also vary from field to field and area to area within individual fields, often leading to uneven carryover response across a field. Figures 2 and 3 show how carryover injury can vary just within a few feet in a field.

Figure 2. Uneven response of corn to soil residues of imazaquin applied to soybeans the previous year.

Figure 3. Uneven response of soybeans to soil residues of atrazine applied to corn the previous year.

Fomesafen: A Broadly Used Herbicide With Rotational Restrictions on Label

Pioneer Agronomy

Fomesafen Carry-Over Into Corn
- Curt Hoffbeck, Field Agronomist

The development of glyphosate-resistant weeds, especially amaranth species like waterhemp and Palmer amaranth, has led to increased use of several older herbicide products. One active ingredient that has seen high use recently is fomesafen, the active ingredient in herbicides like Reflex®, Flexstar®, and Prefix®. Fomesafen is in the PPO class, which includes herbicides like flumioxazin (Valor® and others), sulfentrazone (Authority® and Spartan® products), and saflufenacil (Sharpen® and others). The average field half-life of fomesafen is reported as about 100 days, meaning it can be fairly persistent. It primarily degrades by soil microorganisms, so factors that reduce microbial activity, such as dry soils, may increase the half-life and therefore, persistence as well as carryover potential.

Figure 4. Buggy-whipping symptom from carryover of PPO herbicides to corn.

Many growers are using fomesafen-containing products in soybeans to control pigweeds and other species, sometimes in combination with other herbicides in the PPO class. Fomesafen product labels specify a 10-month interval between application to soybeans and planting corn. This means that if fomesafen was applied to soybeans in late June, the minimum time until corn can be planted is late April the following year. Planting corn prior to the 10-month interval increases the chance for carryover injury. Dry conditions may increase this potential even more.

Figure 5. Leaf chlorosis and mid-vein breakage symptom from fomesafen carryover to corn.

Symptoms of PPO herbicide carryover injury to corn include buggy whipping (Figure 4); leaf chlorosis and mid-vein breakage (Figure 5); and necrotic leaf tissue (Figure 6). Corn often rapidly outgrows this injury, but if the injury response remains for an extended time, yield potential may be compromised.

Figure 6. Leaf necrosis symptom from fomesafen carryover to corn.

Reducing the Risk of Crop Injury From Herbicide Carryover

The vast majority of herbicide degradation resulting from microbial activity occurs during the summer and early fall after the herbicide is applied. The microbes responsible for herbicide degradation are most active in warm (not hot), moist soils. Soil conditions most conducive for excellent plant growth are the same conditions for maximum microbiological activity.

Microbial activity is reduced in hot and dry soils, thus increasing the risk for herbicide carryover potential for those herbicides that degrade mainly by microbial activity. Even where dry conditions have been relieved, some carryover potential may still remain, especially if moisture came primarily in the winter months. Cold soil temperatures decrease microbial activity, and moisture during winter may not substantially increase microbial populations to enhance the rate of herbicide degradation. As soils warm during the spring, microbes will become more active, but the relatively short time until planting will limit the amount of degradation that occurs. At this point, there is not much growers can do to affect the amount of residual herbicide present in their fields. However, there are a few things that can be done to reduce the risk of crop injury:

1. Review spray records for each field, and review product labels to see what restrictions are indicated.

Many labels specify the time required between herbicide application and planting of a rotational crop (see Table 1). Planting sooner than the specified time increases the risk of injury. In addition to a time interval, labels may also list conditions under which a particular crop may or may not be planted, so scrutinizing the "fine print" is key. After a drought year, it is probably best to err on the conservative side regarding plant-back times.

2. Ensure seedling stresses are minimized to give the young crop plants their best chance of surviving herbicide residues with little damage.

This can include making sure soil pH and fertility levels are optimum for the crop, reducing compaction, and avoiding planting into cold, wet soils. Other stresses that the seedling experiences can exacerbate response to herbicide residues (and to the herbicide applied in the current year).

3. Change planned crop.

In some cases, it may be best to plant the same crop as the previous year or at least a crop for which last year's herbicides are also labeled. This significant step has the most potential to reduce the risk of crop injury and is worthy of consideration in high-risk fields.

4. Delay planting.

In drought years, herbicide degradation rates are typically slower than normal, so more time than normal may be required for sufficient degradation. With spring moisture and warming soil temperatures, the microbes will start to act again to degrade herbicide residues. However, it is unlikely that this will have a significant impact in early spring, and the yield potential gained with earlier planting could be lost to herbicide injury.

Growers could plan to plant suspect fields last to give more time for degradation to occur. Seedlings in later-planted fields often experience lower stresses and faster development than those in early planted fields, which could help the crop outgrow putative carryover injury more quickly.

5. Consider tillage?

The jury is out on whether tillage impacts carryover potential. Tillage may dilute the herbicide in the soil profile and provide aeration as well as faster soil warming to stimulate microbes, but results are mixed on whether this will provide a significant benefit. Growers in long-term no-till who try to reduce carryover potential by tilling will sacrifice many of the soil quality benefits accrued from no-till over the years, possibly without a major impact on crop response this year.

6. Conduct a bioassay or chemical analysis.

Some growers plan to sample fields and plant their intended crop in greenhouse pots to see if any symptoms appear (Figure 7). However, to be valuable, this must be done with care, and interpretation of the results can be difficult or misleading. Laboratory analyses, while fairly accurate, are costly and only tell you the concentration of herbicide present. As discussed previously, carryover injury is impacted by many factors besides just how much herbicide is present. Differences in the inherent susceptibility of different crops to each herbicide affect how concentration results should be used.

Figure 7. Bioassay showing response of alfalfa (left and middle) to fomesafen applied to soybeans the previous season. The pot on the right shows alfalfa growth in soil from an untreated part of the field.

Conclusion

In growing seasons following drought, there is potential for a higher than normal carryover response to herbicides applied the prior season. Although there is not much a grower can do to change the amount of herbicide present at planting, several options are available to reduce risk, including:

- Understanding which herbicides were applied the previous year and what the label requires for rotational crop-planting intervals
- Working to reduce the other stresses the seedling crop faces as it germinates, emerges, and grows
- Rethinking the intended crop to plant
- Delaying planting to extend the time for herbicide degradation and reduce cold stress that exacerbates crop injury from carryover

return to table of contents

Table 1. Carryover risk to corn, soybeans, cotton, and sugarbeets for several commonly used herbicides. Risk may be higher in drought conditions.

MOA/Family	Active Ingredient	Primary Dissipation Mode	Risk for Carryover Injury the Year After Application to[a]:			
			Corn	Soybean	Cotton	Sugarbeets
EPSPS	glyphosate	adsorption, microbial	very low	very low	very low	very low
GS	glufosinate	microbial	very low	very low	very low	very low
ALS/ IMI	imazaquin	microbial	high[b,c]	very low	high[d]	high[d]
ALS/ IMI	imazethapyr	microbial	moderate	very low	high[d]	high[d]
ALS/SU	chlorimuron	chemical, microbial	low to moderate[e]	very low	low	high[d]
PSII	atrazine	microbial	very low	high[f]	low	high[d]
PSII	metribuzin	microbial	low	low	high[†]	high[d]
PPO	fomesafen	microbial	moderate	very low	very low	high[d]
PPO	flumioxazin	microbial	low	very low	low	moderate[g]
PPO	saflufenacil	microbial	very low	low	low	low
PPO	sulfentrazone	microbial	low	very low	moderate[h]	high[d]
HPPD	mesotrione	microbial	very low	moderate[i]	low	high[d]
HPPD	topramezone	microbial	very low	low	low	high[d]
HPPD	tembotrione	microbial	very low	low	low	high[b,c]
HPPD	isoxaflutole	microbial	very low	low	high[d]	high[b,c]
Auxin	2,4-D	microbial	very low	very low	very low	very low
Auxin	dicamba	microbial	very low	very low	very low	very low
Auxin	clopyralid	microbial	very low	moderate[b]	high[d]	very low

[a] See product labels for details.

[b] Label states planting interval depends on amount of rainfall received after application and/or soil organic matter content.

[c] Label requirements differ for regions.

[d] Label prohibits planting the year following use.

[e] Low at pH < 7-7.5, moderate at pH >7-7.5. See label for details.

[f] Varies with region, use rate, and soil characteristics. See label for details.

[g] Depends on use rate.

[h] Label requires 12-month planting interval.

[i] Label restrictions in place if mesotrione applied twice to corn the previous year.

Read and follow all herbicide label instructions.

alternate forage options for high rootworm pressure fields

Brent Wilson, M.S., *Product Line and Agronomy Leader, and* ***Adam Krull, DVM,*** *Senior Nutritionist*

Corn is increasingly the preferred forage crop for dairy production because of its high yield and energy content.

Continuous production of corn for grain or silage in the same field can lead to corn rootworm problems.

Forage programs that combine a winter cover crop followed by an alternative spring-seeded forage crop can come close to replacing the value of a corn crop, particularly if corn rootworm damage is limiting corn yields.

Use this article as a starting point for introducing rotation into a feed production operation using some of the easier-to-manage forage alternatives to corn.

Corn Rootworm Problems in Continuous Corn

Corn is king in much of dairy country and is displacing alfalfa acres in the rotation because it supplies high forage quantity and quality. However, planting corn in the same fields year after year may lead to challenges in managing corn rootworm. Continuous corn fields can favor higher corn rootworm populations, even when using Bt corn products (Pilcher et al., 2018). Relying on a single corn rootworm management tactic can result in reduced efficacy over time.

Rotating fields with historically high levels of corn rootworm pressure out of corn can greatly aid in reducing corn rootworm populations and maintaining the efficacy of corn rootworm control options. There is no single crop that can completely replace the tonnage and feed value of corn silage.

However, by leveraging multiple crops in the growing season, a producer can come close to replacing the value of a corn crop. This is particularly true if corn rootworm damage is limiting corn yields. Table 1 summarizes the comparative values for various forage crops. Combining a winter cereal with a summer forage crop results in similar feed value to corn silage when corn yields are challenged.

Figure 1. Corn rootworm larvae feeding on corn roots (left) and lodging caused by root damage (right).

Identify an Alternative Forage System

Developing an alternative forage cropping plan that uses multiple crop species can help meet the feed needs of a dairy or livestock operation while also effectively managing corn rootworm. An effective plan involves two key steps:

Step 1 – Start with a small grain cover crop planted shortly after corn silage harvest.

Step 2 – In the spring, follow the small grain cover crop with an alternate forage crop. Common spring-planted options discussed in this article include:

- Forage sorghum
- Sorghum-sudangrass
- Clear-seeded alfalfa

return to table of contents

Table 1. Relative yield and feeding value of forage crops.

Crop	Yield	DM	Starch	Protein	NDFd 30[a]	uNDF 240[b]	Starch Value	Protein Value	pdNDF Value[c]	NDFd Milk Adj[d]	Total Value[e]
	tons/acre	*%*					*$/acre*				
Corn silage	26	35	34.70	8.04	58.91	10.02	296.82	542.15	290.25	176.94	**1,306**
CRW-damaged corn silage (20% yield loss)	20	35	27.76	8.04	58.91	10.02	182.66	417.03	223.27	136.11	**959**
BMR sorghum silage	18	35	16.00	10.30	54.80	15.40	94.75	480.83	307.77	19.96	**903**
Grain sorghum silage	12	35	26.00	8.93	48.36	19.24	102.65	277.92	175.39	(93.80)	**462**
Sorghum-sudan silage	14	35	2.95	9.79	55.00	14.10	13.59	355.47	246.89	19.40	**635**
Alfalfa silage	6	40	0.00	20.64	47.89	17.01	-	367.06	58.00	(58.07)	**367**
Soybean silage	7	35	0.10	19.62	46.43	17.30	0.23	356.19	63.95	(73.44)	**347**
Small grain silage	8	35	0.01	12.30	54.95	16.41	0.03	255.20	116.53	10.53	**382**
Small grain + BMR sorghum silage											**1,286**
Small grain + grain sorghum silage											**844**
Small grain + sorghum-sudan silage											**1,018**
Small grain + alfalfa silage											**749**
Small grain + soybean silage											**729**

[a] NDFd30 = NDF digestibility measured at 30 hours. [b] uNDF240 = undigestible NDF measured at 240 hours. [c] pdNDF = potentially digestible NDF (NDF-uNDF240). [d] NDFd Milk Adj = 0.55# milk per NDFd point (Jung MN Nut Conf 2004) - $18 milk, 18# DM inclusion rate in TMR. [e] Total Value = Sum of Starch, Protein, pdNDF +/- NDFd milk adjustment.

Nutritional values from Dairyland Summaries. The starch levels for BMR sorghum were changed to more closely reflect current varieties. Corn cost $3.50/bu. Protein calculated from $350/ton SBM. pdNDF from $150 soy hulls.


Photo courtesy of Deere and Co.

Start With a Cover Crop

Many fall cover crop options are available, but winter rye or winter triticale are currently the most common. They are widely available; are adaptable to establish stands and over-winter in cold conditions; and have relatively low seed cost. Small grain forages are widely used by many dairy operations and growers who have integrated cover crops into their management systems.

How to Manage Small Grain Cover Crops

- **Planting**
  - » Plant winter rye (or winter triticale) in the fall after corn silage harvest.
  - » Target a seeding rate of around 100 lbs/acre. Seeding rate should be higher under challenging seeding conditions or when broadcasting and can be lower (75 to 80 lbs/acre) when planting conditions are favorable.
  - » Planting is best accomplished using a drill with a seeding depth of ¾ to 1 in.
  - » Plant as soon as possible after corn silage harvest. If applying manure prior to planting, a tillage pass may be necessary to incorporate the manure and prepare the field for planting.
  - » Consider broadcast seeding in late August (corn dent stage) if harvest will occur after early October.
- **Management**
  - » Weed control is not typically needed for a fall-seeded crop with adequate stands, but watch for winter annuals, such as chickweed and henbit. Yield can be reduced if weeds are not adequately controlled.
  - » Apply 50 to 75 lbs/acre of nitrogen at green-up in the spring to encourage tillering and increase forage yields. Higher rates of nitrogen can improve crude protein levels in the harvested forage, and a summer annual crop can use any remaining nitrogen.
- **Harvest**
  - » Harvest small grain crops in the late-boot to early heading stage to optimize forage quality and energy content.
  - » Apply Pioneer® inoculant 11G22 when harvesting for silage to reduce DM losses during fermentation and feed out.

Figure 2. Newly emerged fall-seeded cereal rye cover crop.

Choose a Follow Crop

Option 1: Forage Sorghum

Hybrid forage sorghum types grow 8 to 10 ft tall and have thick stems. Like corn grown for silage, they are designed to be harvested a single time during the grain maturation stage for forage.

- **Hybrid Selection**
  - » Pioneer® hybrid 845F is a 68 RM forage sorghum widely adapted across the U.S.
  - » Pioneer hybrid 849F is a slightly fuller season choice with increased plant height.
- **Planting**
  - » Plant at a rate of 7 to 8 lbs/acre (90,000 to 100,000 seeds/acre) in 30-inch rows to optimize forage harvest for silage. If planting with a drill or broadcasting, increase seeding rate to 10 to 15 lbs/acre.
  - » Forage sorghum should be planted after the overwintering cover crop is harvested and when soil temperature has reached 65 °F.
  - » Sorghum is sensitive to cool soils; adequate soil temperatures at planting are necessary to ensure rapid emergence.
- **Management**
  - » Forage sorghum requirements for nitrogen, phosphorus, and potassium are like those of corn silage. Use a yield target of 80 to 90% of a typical corn silage crop for the area.
  - » When applying manure, incorporate it prior to planting, and credit the available manure nutrients when calculating fertility needs.
  - » Metolachlor or s-metolachlor products (contained in the herbicide brands Bicep® and Dual®) can be used for grass weed control when safened seed is used. Pioneer forage sorghum hybrids are available with Concep® III seed safener to help protect against phytotoxic effects of s-metolachlor herbicides.
  - » Atrazine, dicamba, and 2,4-D can be used for broadleaf weed control in sorghum crops.
  - » Check state labels for herbicide products, and consult local advisors for all potential herbicide options, including pre-harvest intervals for use as forage.
- **Harvest**
  - » Harvest at mid-dough to mature-grain color stage to optimize tonnage and quality.
  - » Maturity can change quickly, so close monitoring of grain maturity and whole plant forage moisture is necessary for proper fermentation and to optimize feed quality. Starting early is preferable to delayed harvest for best quality and can help avoid lodging.
  - » Using a BMR forage sorghum hybrid improves fiber digestibility of the forage, though there may be reduced dry matter yields and agronomic concerns like standability.
  - » Apply Pioneer® inoculant 11G22 when harvesting as silage to reduce fermentation and feed-out losses.

Figure 3. Field of sorghum-sudangrass

Option 2: Sorghum-Sudangrass

Sorghum-sudangrass hybrids have high yield potential provided adequate rainfall or irrigation. They are designed for multiple harvests and can be stored as silage or hay when properly wilted or dried down.

- **Hybrid Selection**
  - » Pioneer® hybrid 877F sorghum-sudangrass is widely adapted and suitable for planting across the U.S.
- **Planting**
  - » Plant at a rate of 8 to 12 lbs/acre (100,000 seeds/acre) in rows or at 15 to 20 lbs/acre when seeding with a drill or broadcasting.
  - » Sorghum-sudangrass should be planted after the overwintering small-grain crop is harvested and when soil temperature has reached 60 °F (16 °C).
  - » Sorghum-sudangrass is sensitive to cool soils; adequate soil temperatures at planting are necessary to ensure rapid emergence.

return to table of contents

- **Management**
  - » Forage sorghum requirements for nitrogen, phosphorus, and potassium are similar to those of a corn silage crop.
  - » Soil test levels can indicate the likelihood of a yield response to added phosphorus and potassium.
  - » Nitrogen response is similar to that of corn. Yield target with sorghum-sudangrass should be 60 to 70% of a good corn silage crop.
  - » Metolachlor and alachlor products (contained in the herbicide brands Dual® and Lasso®) can be used for grass weed control when safened seed is used. Pioneer sorghum-sudangrass hybrids are available with Concep® III seed safener to help protect against phytotoxic effects of s-metolachlor herbicides.
  - » Atrazine, dicamba, and 2,4-D can be used for broadleaf weed control in sorghum crops.
  - » Check state labels for herbicide products, and consult local advisors for all potential herbicide options.
- **Harvest**
  - » Two cuttings are often achievable in a 75- to 90-day growth period. Take the first cutting at boot stage to optimize tonnage and quality. Leave 4 to 7 in of stubble when harvesting to encourage rapid regrowth.
  - » A second cut is typically ready 30 to 35 days after the first cut. Ensure that the crop is at least 26 in tall before cutting.
  - » Apply Pioneer® inoculant 11G22 when harvesting as silage to reduce fermentation and feed out losses.

Figure 4. Field of alfalfa.

Option 3: Summer-Seeded Alfalfa

Alfalfa is a highly digestible, high-protein forage source for all livestock classes. It is a perennial crop that is harvested frequently to maximize tonnage and quality.

- **Variety Selection**
  - » Pioneer offers a range of alfalfa varieties adapted to your local growing conditions. Consult with your local Pioneer sales professional for both conventional and Roundup® Ready choices.
  - » If planning on a short alfalfa rotation (<2 years), an economical variety, such as Pioneer® brand 54B66™, minimizes seed cost.
- **Planting**
  - » Plant alfalfa after harvest of the small-grain cover crop at a rate of 15 to 18 lbs/acre (60 to 80 seeds/ft^2).
  - » Prepare a firm seedbed to ensure good seed-to-soil contact for rapid germination and seedling growth.
  - » Maintaining soil moisture is key for late spring plantings. Consider no-till seeding in areas with low rainfall or irrigation potential to prevent surface soil from rapidly drying with tillage.
- **Management**
  - » Ensure soils have a pH of 6.5 to 6.8 or greater, and apply lime during the preceding season if necessary. Apply phosphorus and potassium based on recent soil tests.
  - » Weed competition is typically higher with later seeding dates and warmer soils.
  - » Consider herbicide options that control weeds, and allow the alfalfa to establish stands. Alfalfa with Roundup® Ready technology can help establish weed-free stands with high forage yield and quality potential.
  - » If no pre-emergent herbicide is planned, consider increasing seeding rates by up to 10 lbs/acre, and take an earlier cutting to reduce early weed competition.
- **Harvest**
  - » Harvest from bud to early bloom stage.
  - » Use Pioneer® inoculant 11H50 when harvesting and storing as silage (haylage) to reduce DM losses and retain high nutrient content.

harvesting lodged, immature corn for silage

Bill Mahanna, Ph.D., *Global Nutritional Sciences Manager, and*
Adam Krull, DVM, Ph.D., *Senior Nutritionist*

Energy Value of Immature Corn

Was your corn field severely damaged by summer storms? Harvesting lodged, immature corn for silage may be a favorable option. Immature corn silage is a unique feed; while yield is certainly compromised because grain accounts for upwards of 50% of silage dry matter, the overall energy content may not be as poor as expected. The relatively high energy value is due to:

1. Sugars retained in the stover portion that were not translocated into kernel starch
2. High stover fiber digestibility (NDF) in the immature plant

It is very important to have immature corn silage analyzed for fiber digestibility (NDFD), sugar content, and starch level.

Feeding Silage From Immature Corn

Two characteristics of immature corn silage can predispose cows to subclinical rumen acidosis (digestive upset) issues:

1. Kernels will likely be more easily broken by chopper processors, allowing for easier rumen microbial access.
2. Kernels contain a starch/protein matrix that will undergo a faster rumen degradation.

Nutritionists must deal with two important issues:

1. How the nutrients are partitioned (stover sugars and more digestible fiber vs. reduced but more ruminally available kernel starch)
2. What feed sources nutritionists use to compliment this unique mix of sugars/starch/fiber in the ration

Starch deposition is the primary driver of corn silage drying down as it matures in the field. Most of the moisture will be contained in the stalk, and without advancing starch deposition, moistures at harvest will likely be in the 70%+ range. This lack of kernel starch in immature corn silage is what results in high moisture levels, which may require management of effluent (runoff) to prevent environmental contamination. Silage effluent has very high "biological oxygen demand," which can cause significant fish kills in contaminated streams. To prevent excess effluent, do not chop finer than 19mm, and do not over-process the crop as the immature kernels will not need aggressive processing.

Nitrates should not be a concern for several reasons. Plants are presumably healthy; therefore, metabolizing prior to lodging and the fermentation process degrades nitrates by 50%, making any nitrates left in the silage within acceptable limits to ruminants. The only time nitrates could be an issue is if beef cattle are allowed to graze the unfermented crop.

Fermentation (lowering pH) also should not be an issue because the plants are very high in sugar content. However, stressed plants are typically high in yeast counts, and soil contamination in downed plants may also expose the plant material to spoilage organisms. If corn is left in the field long enough for fungal growth, there is potential for mycotoxin production.

The **high sugar content**, even after fermentation is complete, coupled with high yeast can initiate the cascade of events leading to silage heating. This can cause unstable silage in the storage structure and feed bunk. It is recommended that silage fed out in the warmer times of the year be inoculated with Pioneer® brand 11C33 to conserve dry matter (given already compromised yields) and reduce heating/palatability issues. For silage fed out in the colder winter months, Pioneer brand 1174 would be the inoculant of choice.

Harvesting Lodged Corn

Harvesting downed corn is always a challenge. In general, farmers should be prepared to slow down and be patient when harvesting. Slowing down the head so it does not turn as fast may be necessary to allow the head time to cut the corn and not pull it out of the ground. The best equipment and practices for harvest can depend on the direction of the lodging:

- If the corn is lying parallel with the rows, then a row head will likely be the best option for chopping.
- If the corn is lying against the rows, then a large-drum Kemper head is the best option.
- Harvesting in a single direction often helps the corn feed into the head better. This may be parallel, across, or diagonal to the rows depending on the direction of the lodging.

Farmers with crop insurance should contact their agents to be informed of any issues with taking the crop as silage.

return to table of contents

effects of cold temperatures following soybean planting

Mark Jeschke, Ph.D.*, Pioneer Agronomy Manager,* ***Adam Gaspar, Ph.D.****, Global Biology Leader Seed Applied Technologies, and* ***Ryan Van Roekel, Ph.D.****, Field Agronomist*

Imbibitional chilling injury can occur when cold water is imbibed by the seed within 24 hours of planting.

Emerged soybeans are more susceptible to damage from freezing temperatures than corn because their growing points are above the soil surface.

The use of a fungicide seed treatment is important in early planted soybean when development can be delayed by poor conditions.

Benefits and Risks of Early Planting

- Trends toward larger farms and planting equipment size along with the availability of effective seed treatments and proven yield benefits have prompted a shift toward earlier planting of soybeans.
- Several Pioneer agronomy research studies have shown the benefits of early planting with a full-season soybean variety for maximizing soybean yield.
- Early planted soybeans generally reach canopy closure sooner, intercept more sunlight, and spend a longer duration in reproductive growth.
- However, it is possible to plant too early every year, and several management factors as well as risks associated with early planting must be considered.
- Cold and wet conditions at and after planting can injure developing seedlings; delay germination and emergence; and reduce stand establishment.

Figure 1. Pioneer® brand soybean varieties are rated for field emergence, which is based on speed and strength of emergence in suboptimal temperatures.

Soil Temperature

- Like corn, soybeans are typically planted into soils well below their optimum temperature for germination, making early growth conditions inherently stressful. The optimum temperature for soybean germination is around 70 °F (21 °C).
- A minimum soil temperature of 50 °F (10 °C) during the 24 hours following planting is recommended. At soil temperatures below 50 °F (10 °C), the risk of slow germination, infection of seedling diseases, and reduced stand establishment increases.
- Soybeans typically require between 90 and 130 GDUs to emerge, depending upon soil type.
- The GDU requirement of soybean is similar to corn with a base temperature of 50 °F (10 °C). Thus, planting ahead of a cold spell often does not result in accumulation of additional GDUs or gain any early growth.

Imbibitional Chilling Injury

- The initial uptake of water into the seed following planting is referred to as the imbibitional phase. A soybean seed imbibes approximately 50% of its weight in water during germination.
- The imbibitional phase occurs very rapidly after planting, typically not lasting more than 24 hours.
- Imbibitional chilling injury and stand loss can occur when very cold soil water (<40 °F, 4 °C) is imbibed by the seed during this time. A damaged seed coat can increase the likelihood of imbibitional chilling injury. Care should be taken when handling/treating seed.
- Once the imbibitional phase is completed, the risk of chilling injury associated with cold soil temperature or rain declines.

Risk of Freezing Injury

- Emerged soybeans are more susceptible to damage from freezing temperatures than corn because their growing points are above the soil surface as soon as the plants emerge.
- Temperatures below 32 °F (0 °C) can cause frost damage to emerged soybean plants, while temperatures below 28 °F (-2 °C) for an extended period of time (>4 hrs) can be lethal, especially on lighter-textured soils.

Figure 2. Just-emerged soybean plants damaged by frost. The cotyledons are still green and look healthy, but the region of the hypocotyl just below the cotyledonary node is turning brown and is becoming soft and shrunken.

- Heavier-textured soil can better store and release previously accumulated heat near the soil surface when air temperatures drop, helping to protect recently emerged soybean plants.
- High levels of residue on the soil surface can increase the risk of freezing injury by reducing the transfer of heat from the soil to the plants.
- A soybean plant at the cotyledon stage has three growing points – the main shoot and two axillary buds at the base of the cotyledons. Recovery from freezing injury is possible as long as at least one of these buds survives.
- Soybean seedlings that have just cracked the soil surface will be more tolerant to freezing temperatures than plants at the cotyledon or unifoliate stages.
- The cotyledons are full of solutes, which makes them good buffers to protect the three potential growing points between them, and causes them to be more resistant to injury.
- Freezing damage that extends below the cotyledons will result in the death of the plant.

Disease Risk

- Cold, wet soils following planting increase the risk of seed rots and seedling blights in soybeans.
- The use of a fungicide seed treatment is important in early planted soybean when development can be delayed by poor conditions.
- Pythium is favored by cold and wet soils. In fields where the disease is present, infection is likely when soils are cold and heavy rains occur soon after planting.
- Cold, wet conditions early in the growing season can also result in higher incidence of sudden death syndrome (SDS).
- SDS is caused by a virulent strain of the common soil-inhabiting fungus *Fusarium virguliforme*, which infects soybean plants very early in the growing season, often as early as germination to just after crop emergence.
- The use of resistant soybean varieties and ILeVO® fungicide seed treatment (active ingredient: fluopyram) provides protection of seedlings against *Fusarium virguliforme* infection and can reduce the incidence of SDS in early planted soybean.

Figure 3. Soybean seedlings with damping-off symptoms due to Pythium seedling blight, a soil-borne fungal pathogen that is favored by wet soil conditions and cool temperatures just after planting. Damping-off occurs when germinating seedlings are infected prior to or just after emergence. Diseased seedlings collapse when the infection girdles the hypocotyl.

Management Considerations

- Early soybean planting is a consistently proven management practice for high-yield soybean production.
- Imbibitional chilling injury can occur when very cold soil water is imbibed by the seed within 24 hrs after planting. However, if the soil is fit, soil temperatures are near 50 °F (10 °C), and the weather forecast for the next 24 to 48 hours is favorable, soybean planting should begin.
- Predicting a frost event 10 or more days after planting when soybeans are beginning to emerge is a difficult task. Many factors affect the potential for freezing injury to emerged soybean plants – growth stage; air temperature and duration; soil temperature; soil texture; residue; and field topography.
- If temperatures drop below freezing after soybeans have emerged, allow approximately five days before assessing any potential stand loss and replant considerations.
- Planting soybean seed treated with a fungicide seed treatment can help protect against elevated disease risks associated with early planting, particularly when development is delayed by poor conditions.

return to table of contents

impact of late planting on soybean yield in southern illinois

Eric Alinger, *Field Agronomist, and* ***Dr. Emerson Nafziger,*** *University of Illinois*

Background and Objectives

- Many growers are sometimes faced with the decision to plant soybeans at very late dates during the growing season.
- Yield of late-planted soybeans can be impacted by the shortened growing season, dry soil conditions, or freeze injury.
- Delays in planting caused by unfavorable weather in 2015 and 2019 in southern Illinois provided the opportunity to observe the effect of late planting on soybean yield.

Figure 1. Late-planted soybean showing fall freeze symptoms.

Study Description

- Surveys were conducted of late-planted soybean locations in southern Illinois in 2015 and 2019.
    - » 2015: 158 fields planted between July 15 and August 17
    - » 2019: 237 fields planted between July 1 and July 20
- Grower location, soybean maturity, planting date, planting rate, and grain yield data were collected.

Results

2015

- Yield declined with increasingly late planting dates and dropped off sharply when planting was delayed into August (Figure 2).
- Yield declined an average of 1.3 bu/acre per day when planted after July 15 (Figure 3).

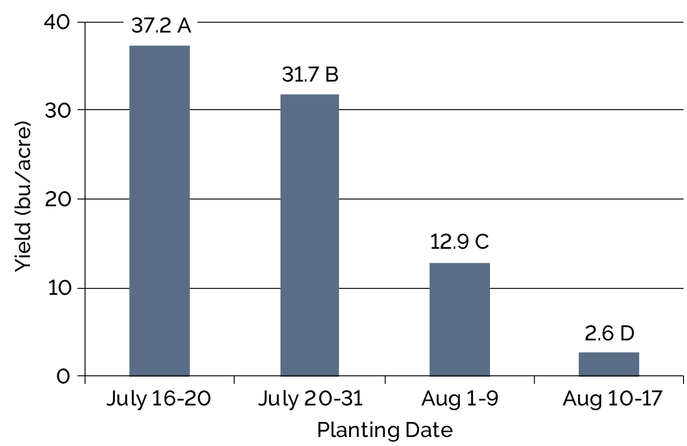


Figure 2. Soybean yield grouped by planting date range. Means with different letters were significantly different at P <0.001.

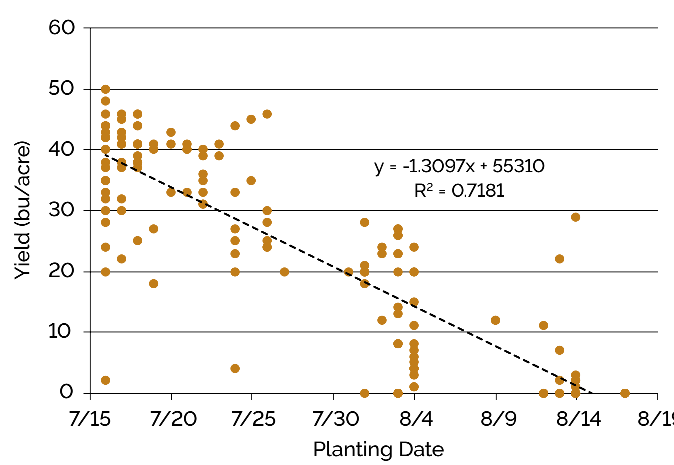


Figure 3. Soybean yield response to late planting among 158 grower fields in southern Illinois in 2015.

Results (continued)

2019

- Late-planted soybean locations spanned a smaller range of planting dates in 2019 than 2015, from July 1 to July 20.
- Soybean yield declined by an average of 0.3 bu/acre per day of delayed planting over this time period (Figure 4).
- Within the planting date range that 2015 and 2019 locations overlapped (July 16 to July 20) yields were similar, averaging 37.2 bu/acre in 2015 and 39.6 bu/acre in 2019.
- Locations planted with maturity group 4.0 and shorter soybean varieties yielded less than longer-season varieties with both early July and mid-July planting (Figure 5).

Photo courtesy of Deere and Co.

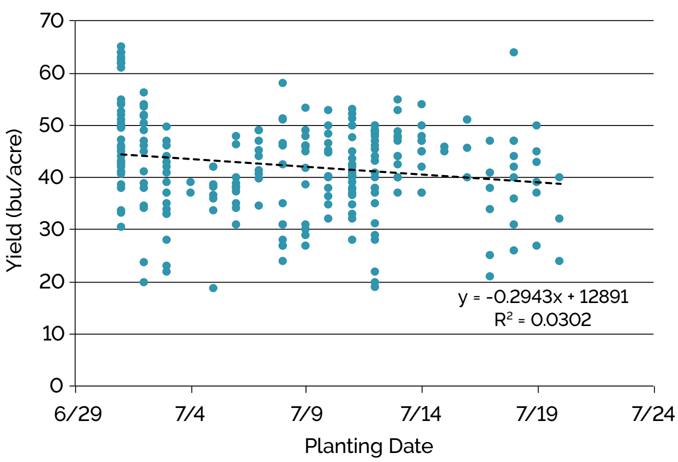


Figure 4. Soybean yield response to late planting among 237 grower fields in southern Illinois in 2019.

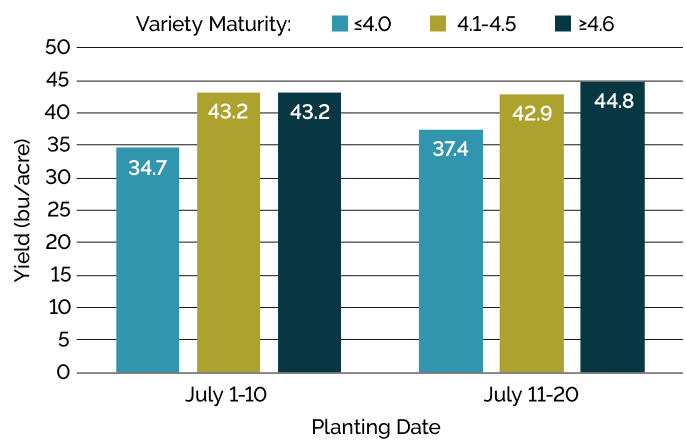


Figure 5. Soybean yield response to late planting by variety maturity group among 237 grower fields in southern Illinois in 2019.

iron deficiency chlorosis in soybeans

***Matt Essick, M.S.**, Agronomy Manager, and*
***Landon Ries, Ph.D.**, Research Scientist*

Summary

- Iron deficiency chlorosis (IDC) is a challenge for soybean farmers in several regions of North America, particularly in poorly drained calcareous soils in Minnesota, the Dakotas, Nebraska, and Iowa.
- Several soil properties can influence the severity of IDC in a field, including carbonate levels, salts, and drainage.
- Environmental conditions, such as soil moisture, temperature, and compaction, can also influence IDC, resulting in variability of symptoms from year to year.
- Selection of soybean varieties with good iron chlorosis tolerance is the most important management strategy.
- Corteva Agriscience soybean breeders are continually implementing new methods for understanding and evaluating soybean response to IDC.

Iron Deficiency Chlorosis in Soybeans

Soybean iron deficiency chlorosis (IDC) is a nutrient deficiency with general symptoms of chlorosis (yellowing) of the soybean foliage and stunting of the plant. IDC is most commonly associated with high pH soils and soils containing soluble salts where chemical conditions reduce the availability of iron. This condition is yield-limiting in many soybean fields in the Northern and Western Corn Belt including western Minnesota, the Dakotas, Nebraska, Iowa, and other states.

Iron Deficiency Symptoms

The primary symptomology of soybeans affected by IDC is interveinal chlorosis, where the leaves turns yellow but the veins of the leaves stay green. Iron is an important constituent of enzymes essential for producing chlorophyll, so a deficiency of iron will limit chlorophyll production, resulting in yellowing of plant tissue. If conditions are severe, the entire leaf may turn yellow and the leaf margins may turn brown, a condition known as "necrosis."

Pioneer Agronomy

Iron Deficiency Chlorosis in Soybeans

- Matt Wilson, Territory Manager

Symptomology does not occur until soybeans begin to develop trifoliate leaves. Cotyledons and unifoliate leaves do not exhibit IDC symptomology. Symptoms may increase or decrease in intensity during the season depending on growing conditions. Iron is not mobile within the plant, so symptoms will appear on the youngest leaves first. Iron chlorosis in a soybean field typically appears in spots, often with no apparent pattern, due to differences in chemical and physical properties of the soil.

Factors Contributing to IDC

Soils typically have abundant levels of iron, so IDC is not caused by a lack of iron but rather by conditions that limit the availability of iron for plant uptake. The factors that may cause chlorosis are complex and interact with each other to intensify the level of chlorosis. The most dominant factors related to IDC occurrence are carbonate levels, salts, and depressional field areas with poor drainage. IDC severity can vary from year to year within the same field depending on the environmental conditions of the growing season.

Soil Properties

Soybean IDC frequently occurs in calcareous (lime-containing) soils. These soils are often referred to as "alkaline soils" and have high pH values (>7.5). At high soil pH, iron is less soluble, making it less available for uptake by plant roots. However, chlorosis of soybeans does not occur on all high-pH soils. The pH of surface soils in areas where IDC symptoms occur and areas where they do not are often the same, but there can be differences in both chemical and physical properties of subsoil. The subsoil in a chlorotic soybean area is generally poorly drained; is higher in pH; contains soluble salts and excess lime (carbonates); and may have a higher concentration of sodium.

Weather Conditions

The interaction of weather conditions with soil properties causes differences in IDC severity from year to year and field to field. Growing seasons with excess rainfall and cool soils typically result in higher incidence of IDC. Soils with high calcium carbonate levels near the soil surface can often have significant symptomology of IDC. Biological activity in the soil converts calcium carbonate into carbon dioxide and bicarbonate (HCO_3^-). Wet conditions limit air exchange between the soil and the atmosphere, causing bicarbonate ions to accumulate in the water in the topsoil. Bicarbonate interferes with both uptake and mobility of iron within the plant.

Continual rainfall and saturated soils also reduce oxygen in the root zone. Oxygen is needed for plant uptake of iron. Soil compaction along with excess rainfall can be contributing factors in the reduction of iron uptake. Cool springs with lower soil temperatures reduce microbial activity within the soil. The reduction of microbial activity leads to less iron uptake and increased severity of IDC.

Figure 1. Interveinal chlorosis pattern characteristic of iron chlorosis of soybeans.

Nitrate Levels

Researchers at the University of Minnesota have shown through both field and greenhouse studies that higher nitrate levels in the soil are also a contributing factor to IDC (Kaiser et al., 2011). Differences in IDC driven by soil nitrate levels are commonly seen when wheel tracks through a chlorotic area of the field remain green (Figure 2). The soil under the wheels is slightly more compacted, creating a lower oxygen environment that increases denitrification. The compacted soils under the wheels are not excessively compacted, just enough to account for differences in nitrate in the soil. The fact that lower oxygen levels in the soil can both reduce IDC severity due to a reduction in nitrates in the soil and increase IDC severity in saturated soils by limiting iron uptake exemplifies the complexity of factors and interactions that contribute to IDC occurrence.

Figure 2. A field with reduced IDC symptoms in areas where soil was compacted by wheel traffic.

Assessing Soil Properties for IDC Risk

The table below was developed by AGVISE Laboratories, a soil testing firm with labs in Minnesota and North Dakota where IDC is often a perennial issue (Table 1). The index is a tool to help producers differentially target certain fields or parts of fields for IDC management strategies. Fields can be soil sampled for carbonates and soluble salts to help make these decisions.

- Fields with a low level of carbonate and low level of salts have a low risk of developing IDC symptoms.
- Fields that test high in carbonates (CCE, calcium carbonate equivalent) and soluble salts have a higher risk of developing IDC symptoms and may be severe.
- All soils that have a pH greater than 7.3 should be tested for CCE and salts to determine the actual level in the soil. Two different soils with the same pH of 7.5 may have different CCE values and, therefore, different risk of IDC.

Table 1. Soybean IDC severity risk (AGVISE Laboratories).

Calcium Carbonate Equivalent	Soluble Salts Electrical Conductivity (EC) mmhos/cm (1:1)			
	< 0.25	0.26 - 0.5	0.51 - 1	> 1
< 2.5%	Low	Low	Moderate	Very High
2.6 - 5%	Low	Moderate	High	Very High
> 5%	Moderate	High	Very High	Extreme

Risk	Management Considerations
Low	IDC not likely to be in this portion of field based on low EC and salt levels.
Moderate	IDC may develop in some areas of this field in wet, cool conditions based on EC and salt levels. Plant an IDC-tolerant variety.
High	IDC is likely to develop in some areas of the field under wet, cool conditions based on EC and salt levels. Plant an IDC-tolerant variety.
Very High	IDC may be severe in this field under wet, cool conditions based on EC and salt levels. Planting an IDC tolerant variety is strongly advised.
Extreme	IDC may be severe in this field under wet, cool conditions based on EC and salt levels. Potential for substantial reductions in yield. Soybeans are not recommended for this field.

Management Options for Growing Soybeans in Areas With Iron Chlorosis

There are several management practices that can be used to help reduce the impact of IDC on soybean yields. A survey of soybean producers in areas affected by soybean IDC found that selection of IDC-tolerant soybean varieties was the most common management tactic (employed by 70% of respondents), followed by planting practices (42%), field drainage (33%), tillage (16%), fertility practices (11%), and herbicide selection (6%) (Hansen et al., 2003).

Variety Selection

Soybean varieties vary widely in their tolerance to IDC, making variety selection the most important step in managing this problem. Corteva Agriscience has a significant research effort to characterize soybean germplasm for IDC tolerance and select for tolerant varieties. The use of genetic prediction models and multi-year field testing allows for a high degree of confidence in the IDC ratings assigned to Pioneer® brand soybean varieties. Varieties are rated on a 1 to 9 scale where 1 indicates poor tolerance and 9 indicates excellent tolerance. If growers are planting into an area with a history of IDC, they should select varieties with an IDC score of 6, 7, or 8.

Additionally, Pioneer agronomists routinely establish observation plots of soybean varieties in soils prone to IDC. Symptoms are assessed throughout the growing season to help further understand variety tolerance to IDC and optimize IDC management at the local level.

Figure 3. Pioneer soybean variety trial showing differences in IDC symptoms between a more susceptible variety (left) and a more tolerant variety (right).

Seeding Density

University and Pioneer research studies have shown that higher seeding rates can reduce iron chlorosis symptoms and increase yield in areas of fields with a history of iron chlorosis (Goos and Johnson, 2001; Naeve, 2006). Soybean roots excrete acids as they are growing that increase the availability of iron. Higher plant density increases the amount of this acid in the root zone.

In a Pioneer study in Minnesota in a field with high soluble salt levels, chlorosis effects were more severe when plant density was low (seeding rate < 140,000 seeds/acre). Soybeans yielded from 10 to 15 bu/acre more at 200,000 versus 100,000 seeds/acre. Growers should seed soybeans at densities of 200,000 seeds/acre or above for maximum protection against iron chlorosis.

Variable rate seeding allows farmers to increase seeding density in areas of the field with a history of iron chlorosis and reduce in areas that are not prone to iron chlorosis. Reducing seeding rate in areas of the field that do not exhibit iron chlorosis can help reduce pressure from white mold.

Improving Soil Drainage

Soils with poor drainage often have higher accumulations of soluble salts and carbonates that reduce the solubility of iron in the soil. Wet soils also lead to lower oxygen levels in the soil as well as reduced root growth and health. The reduction in root health and the lower solubility of iron in wet soils are major contributors to IDC symptoms. Practices that improve soil structure and water infiltration can reduce issues with IDC. Field tile drainage is also important to consider, where applicable, to help with soil moisture levels.

Figure 4. Soybeans showing differences in IDC symptoms at different plant densities. Soybeans on the left were planted at 200,000 seeds/acre, and those on the right were planted at 140,000 seeds/acre.

Herbicide Selection

Foliar- and soil-applied herbicides may increase plant stress, which can accentuate symptomology of IDC. Research has shown increased potential for greater yield loss when applying some post-emergence herbicides to soybeans under chlorotic stress. Reduce stress from herbicides by following manufacturer recommendations for weather and application conditions.

Use of a Companion Crop

In fields with high levels of nitrates, a companion crop of oats may reduce iron chlorosis symptomology. This companion crop needs to be terminated by the time it is 10 to 12 in tall.

Iron Chelate

Pioneer Agronomists have studied the use of an iron chelate (Fe-EDDHA chelate) fertilizer to help reduce IDC symptoms and increase yields. Iron chelate products have been evaluated as seed treatments, foliar treatments, and in-furrow treatments. Benefits of seed-applied and foliar-applied treatments have been inconsistent. Research by both university and Pioneer agronomists has shown a more consistent yield response to in-furrow applications of iron chelate.

Soygreen® is a commonly used in-furrow iron chelate fertilizer that entered the market in 2006. New formulations have been added since then, including a liquid formulation that is less likely to be leached out of the root zone following rainfall.

A Pioneer agronomy study conducted in 2012 across 11 locations in Nebraska and Kansas with a history of IDC found an average yield response of 2.3 bu/acre with a 3 lbs/acre in-furrow application of Soygreen (Mueller, 2012) (Figure 5). Yield differences were minimal at some locations; however, visual differences were noted as the varieties treated with an in-furrow application of Soygreen were greener and more robust. A similar study conducted in 2008 to 2009 found an average yield advantage of 3.9 bu/acre with Soygreen.

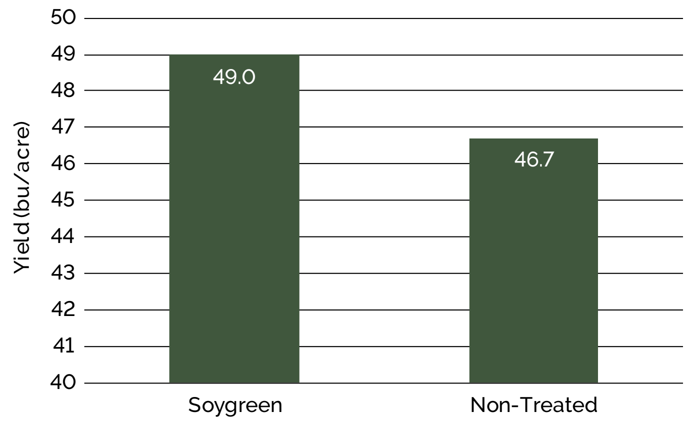


Figure 5. Average soybean yield with and without Soygreen® in-furrow treatment across 11 locations with a history of IDC.

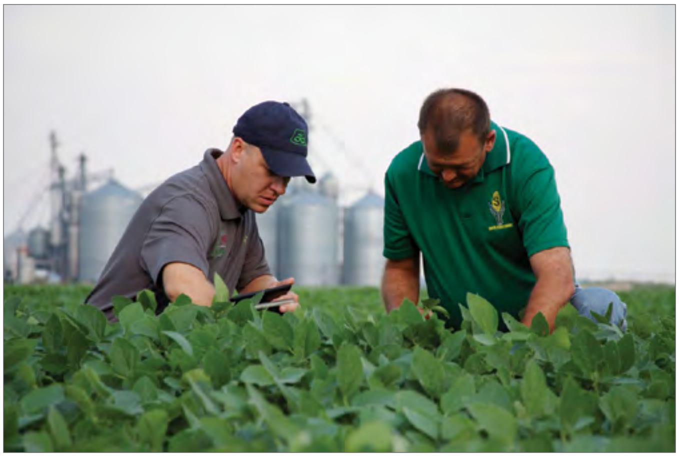
Corteva Agriscience IDC Characterization Strategy

Soybean breeders at Corteva Agriscience characterize genetic tolerance of soybean varieties to IDC in multiple ways through the course of the product development pipeline.

Genetic Prediction Models

Genetic prediction models give soybean breeders the ability to predict the probable IDC tolerance of a soybean line and leverage that information in variety selection prior to any in-field testing. Observations captured from multiple soybean lines over multiple years and locations, coupled with molecular marker and genotypic data, are used to create these models. Soybean lines predicted to have high levels of IDC tolerance can be selected and advanced into field-screening trials for further characterization.

Figure 6. Corteva Agriscience single-row observation plots showing varietal differences in tolerance to IDC.



Field Screening

Field assessment of soybean varieties for IDC tolerance is crucial for refining tolerance ratings for soybean lines as well as improving genetic prediction models. IDC tolerance is assessed in field screening nurseries beginning at the R2 pipeline stage, approximately three years before commercial release. Characterization continues through R3 and R4 precommercial stages, providing three years of IDC tolerance data across multiple environments for a soybean variety, when the decision is made whether to commercialize it. The combination of genetic prediction models with multi-year, multi-location field screening provides a high level of confidence in the IDC trait scores assigned to Pioneer® soybean varieties.

Field trials for tolerance are conducted at managed screening nurseries located from the Red River Valley of northwest Minnesota through central Minnesota and north central Iowa to eastern Nebraska. Multiple replications of each genotype are planted in fields identified as having uniform characteristics conducive for IDC manifestation and a history of IDC sensitive observations. Each plot is scored on a scale of 1 through 9 with 1 being the most sensitive to IDC and 9 being the most tolerant. Field-screening nurseries often include thousands of plots (Figure 7).

Figure 7. Aerial view of a Corteva Agriscience soybean IDC field-screening nursery.

Advancements in Phenotyping and Characterization

Historically, IDC tolerance scores have been determined based on a researcher's visual assessment of a plot at approximately the V3 to V5 growth stage. While this has been a successful approach for characterizing and driving IDC improvement for decades, there are inherent limitations and inefficiencies associated with visual phenotyping. Over the last few years, scientists at Corteva Agriscience have deployed new methods using unmanned aerial systems (UAS) to capture IDC data from screening nurseries. This technological advancement has enabled improvements in the quality and consistency of data captured from field screening nurseries and has greatly increased the efficiency and scale of data collection (Figure 8).

Corteva Agriscience researchers continue to explore further enhancements to IDC characterization efforts. An emerging advancement enabled by UAS technology is the capturing of time-series data from field-screening nurseries. Assessing IDC symptoms at multiple timings allows soybean breeders to observe how different lines respond for several weeks beyond the initial appearance of IDC symptoms. Two lines with the same traditional IDC tolerance value may respond and recover differently over time; understanding these differences provides an opportunity for additional differentiation in IDC tolerance.

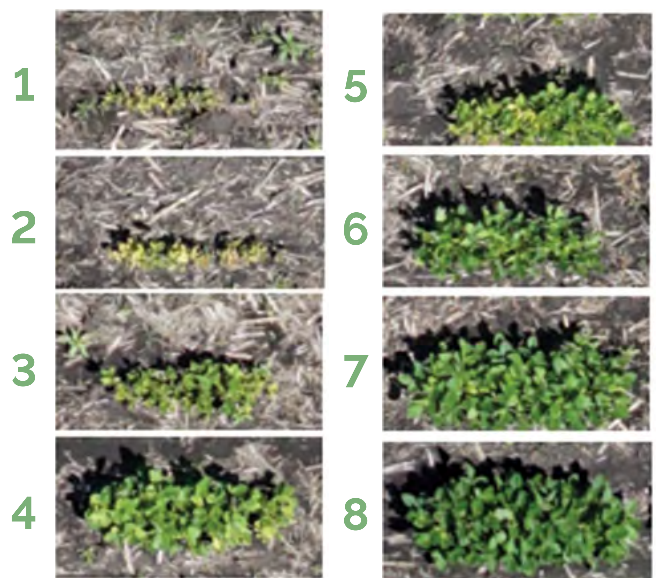


Figure 8. UAS imagery showing differences in IDC tolerance among soybean varieties in a Corteva Agriscience field-screening nursery.

Summary

Iron deficiency chlorosis is caused by complex interactions of soil properties and the environment. Understanding the history of fields with iron chlorosis and applying management techniques, including variety selection, higher seeding densities, and incorporating the use of in-furrow chelated iron, can help reduce the impact from IDC. Corteva Agriscience will continue to lead the way in development and characterization of varieties with greater tolerance to iron chlorosis and other traits.

return to table of contents

tips for a successful soybean double-crop

Kevin Fry, *Field Agronomist*

1. Optimize Wheat Harvest for Double-Crop Planting

- Consider harvesting wheat at 18 to 20% moisture and artificially drying the grain to allow for earlier double-crop planting. This should help maximize your wheat and double-crop soybean yields while maintaining grain quality.
- Make combine adjustments to maintain soil moisture for double-crop beans and decrease residue that can harm seed/soil contact during bean planting.
  - » Try harvesting in different directions to find the angle at which the header best picks up the wheat.
  - » Adjust the reel slightly ahead of the cutter bar and far enough down to lay the head on the platform.
  - » The reel should turn slightly faster than ground speed.

2. Prepare for Weeds by Selecting the Right Variety

- Weed pressure can be significant in double-crop soybeans. Select seeds that will allow for effective herbicide treatments, such as the Enlist E3® soybean trait with tolerance to 2,4-D choline, glyphosate, and glufosinate.

3. Follow Some of Your Full-Season Planting Practices

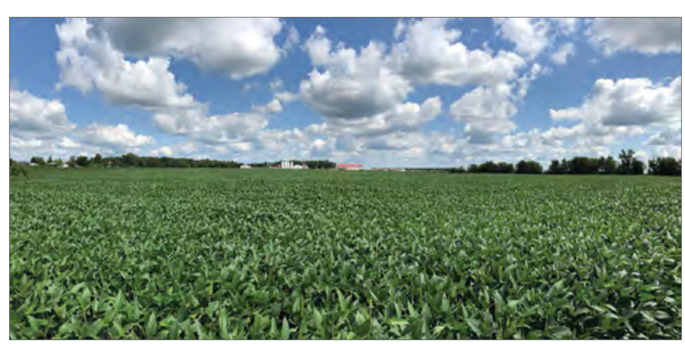
- Use the same practices that you would for full-season beans when it comes to soil moisture and soil conditions to achieve timely germination.
- Plant at 1 to 1.5 in depth for ideal emergence time.

4. Increase Your Seeding Rate

- Double-crop soybeans require higher seeding rates because they are destined to be shorter and produce fewer pods per plant. Higher seeding rates enhance plant and pod height to compensate, and they counteract the effects of any high wheat residue in your field.
- Higher rates also enable quicker canopy closure, which can be a benefit in drought- and/or heat-prone environments, and can slow down or inhibit weed emergence as well as early growth.

5. Consider Decreasing Row Spacing

- Narrower row spacing is likely to provide a greater yield benefit in double-crop beans when soybeans have limited time for vegetative growth before flowering. Consider planting 15-inch rows, which some research suggests produces a 4 bu/acre yield advantage over 30-inch rows.
- Watch out for moisture stress, brown stem rot, white mold, nitrogen stress, and soybean cyst nematode. These threats are more common in narrow row spacing and can reduce or erase yield advantage.



return to table of contents

6. Evaluate Stand Establishment Promptly

- Heavy residue in a double-crop field can cause hairpinning and poor emergence of soybeans. Evaluate stand count upon emergence to determine whether you will have a good crop.
- Count the stands inside a 30-inch hoop, and multiply the number by 8,878 to determine field population. Take stand counts in multiple spots throughout the field.

7. Scout Early and Often for Pests and Diseases

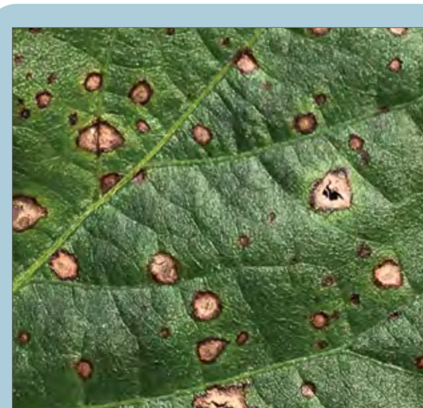
- Smaller crops are more vulnerable to pests, making scouting very important in double-crops. Pests to watch for in late-planted beans include:
  - » Defoliating insects like bean leaf beetles, Japanese beetles, Mexican bean beetles, and a variety of caterpillars
  - » Soybean aphids
  - » Stink bugs
  - » Soybean podworm (corn earworm)
- Keep an eye out for these common diseases in double-crop beans:
  - » *Rhizoctonia solani*
  - » Phytophthora root and stem rot
  - » Cercospora leaf blight and seed stain
  - » Frogeye leaf spot
  - » Viruses

Soybean aphids on the underside of a soybean leaf.

The soybean podworm is the same insect that also feeds on corn ears, in which case it is called the corn earworm. *Helicoverpa zea*

Soybeans infected with Rhizoctonia root rot. *Rhizoctonia solani* can cause seed rot, root rot, and reddish-brown lesions on hypocotyls at the soil line.

Soybean plants wilting due to Phytophthora rot. Infection occurs early, but plant death may occur at any time during the growing season.



Frogeye leafspot on soybean. This disease is most serious in warm regions or during periods of warm, humid weather.

return to table of contents

genetic yield gain and nitrogen fixation in soybean

Santiago Tamagno and **Dr. Ignacio A. Ciampitti,**
Department of Agronomy, Kansas State University

This study showed a genetic gain of 0.57 bu/acre/year for soybean varieties released between 1980 and 2013.

High-rate N fertilizer increased yield by an average of 7.9 bu/acre, primarily due to increased seed weight.

The primary driver of genetic yield gain was increased seed set per unit area.

Soybean yield response to added nitrogen fertilizer did not differ by year of variety commercial release.

Rationale and Objectives

- A 2-year field study was conducted to quantify yield improvement for soybean using a set of 7 Pioneer® brand soybean varieties commercially released over a 33-year period (1980-2013).
- Soybean varieties were grown with no nitrogen (N) fertilization and with high N fertilization (500 lbs/acre) to compare effects on yield components, particularly seed weight.
- This research was conducted by Santiago Tamagno and Dr. Ignacio A. Ciampitti at Kansas State University as a part of the Pioneer Crop Management Research Awards (CMRA) Program.

Study Description

Years: 2016, 2017

Locations: Kansas River Valley Research Station, Rossville, KS, Soil test: 21 ppm P (Mehlich, 6-in depth), 158 ppm K (6-in depth), 3 ppm N (24-in depth)

Planting Dates: May 12 (2016), May 18 (2017)

Plot Size: 10 x 50 ft

Row Spacing: 30 inches

Experimental Design: Split-plot

Nitrogen Fertility Program:

- 0 lbs N/acre (zero N)
- 500 lbs N/acre (high N) – applied as UAN (28-0-0), ⅓ at planting, ⅓ at R1, ⅓ at R3

Variety/Brand[2] (Sub-Plot Factor) and Year of Release:

- P3981 1980
- 9391 1987
- 9392 1991
- 93B82 1997
- 93B67 (R) 2001
- 93M90 (R) 2003
- P35T58R (R) 2013

Data Collection and Analysis:

- The two center rows in each plot were harvested with a plot combine for yield.
- Seed weight was measured from a 1,000 seed subsample.

- Seeds were sampled in all plots at R5 weekly until harvest maturity in order to characterize the seed-filling curve and estimate final seed weight.
- At each sampling time, plants were removed to use the stem fraction to measure ureide and nitrate concentration using the hot water extraction method, following Hungria and Araujo (1994).
- Both concentrations were used to calculate the relative abundance of ureides as a parameter to estimate biological N fixation throughout the seed-filling period.
- The percentage of biological N fixation was quantified using established calibrations from Unkovich et al. (2008). A quadratic function was fitted to characterize the dynamics during the seed-filling period.

Results

- Soybean yield (bu/acre) was significantly influenced by soybean variety and N treatment (Table 1).
- Seed number (seeds/m²) significantly differed among varieties.
- Nitrogen fertilization increased soybean yield by an average of 7.9 bu/acre. The yield effect of N fertilization did not differ among soybean varieties.

Table 1. Soybean variety and N treatment effects on soybean yield and seed number.

	Yield	Seed Number
	bu/acre	seeds/m²
P3981 (1980)	41.6 c	1621 c
9391 (1987)	49.0 bc	2015 bc
9392 (1991)	47.0 bc	1939 bc
93B67 (2001)	48.9 bc	1964 bc
93B82 (1997)	53.5 b	2173 ab
93M90 (2003)	52.5 b	2121 b
P35T58R (2013)	64.0 a	2589 a
Zero N	47.0 b	1936
High N	54.9 a	2184
Variety	***	***
Treatment	**	ns
Variety x Treatment	ns	ns

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability level respectively. ns = not significant. Means followed by the same letter are not significantly different based on Tukey ($P < 0.05$).

- Soybean yield increased with year of variety commercial release by an average of 0.57 bu/acre/year (Figure 1).
- Average seed number increased with year of variety commercial release as well, indicating that genetic yield gain was driven in large part by a greater number of seeds per unit area.

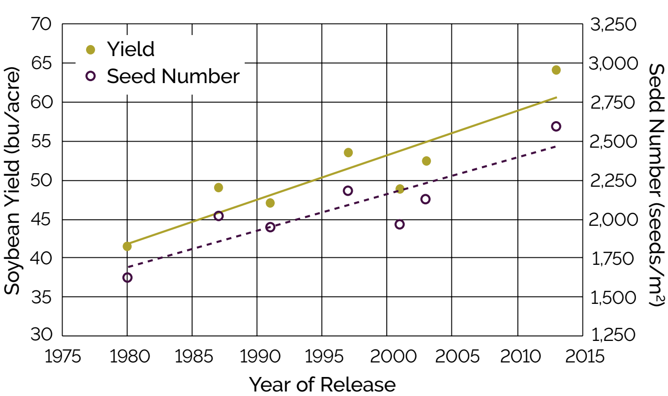


Figure 1. Yield and seed number of soybean varieties by year of commercial release.

- Seed weight significantly differed among soybean varieties and N treatments (Figure 2).
- The high N fertilizer treatment significantly increased average seed weight for all soybean varieties compared to no N treatment.
- Seed weight did not show any relationship with the year of variety commercial release; hence, for the varieties used in this study, genetic yield gain can be fully attributed to increases in seed set per area.
- Results did not indicate a tradeoff between seed number and seed weight associated with genetic gain; newer varieties were able to set more seed per acre while maintaining seed weight.
- While seed weight showed differences among varieties and treatment, its contribution to the overall yield was lower compared with the seed number.

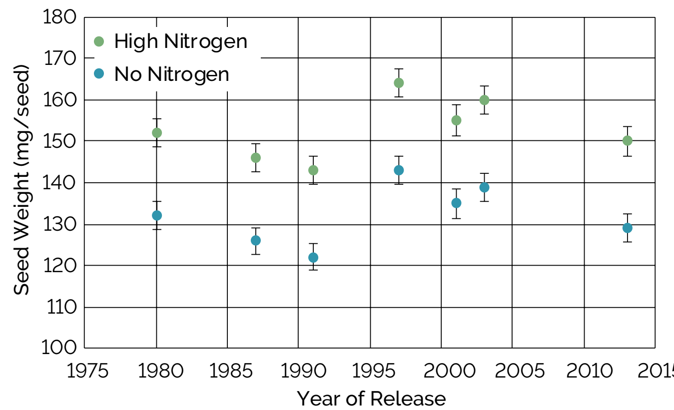


Figure 2. Final seed weight and standard errors for soybean varieties by year of commercial release with and without added N fertilizer.

- There were no interactions or differences between soybean varieties for biological N fixation dynamics, meaning that genetic gain did not introduce differences in this process (data not shown).
- The percentage of biological N fixation at the beginning of the seed-filling period was significantly higher in the control compared with the high N treatment (Figure 3).
- The magnitude of this response can be attributed to the effect of the nitrates in the soil originated from fertilizer applications, which inhibited the activity in the nodules.
- Even though biological N fixation is typically the main source of N during the seed-filling period, the N supplied by the fertilizer application was enough to maintain photosynthesis levels to supply photoassimilates to the seeds and increase seed weights.

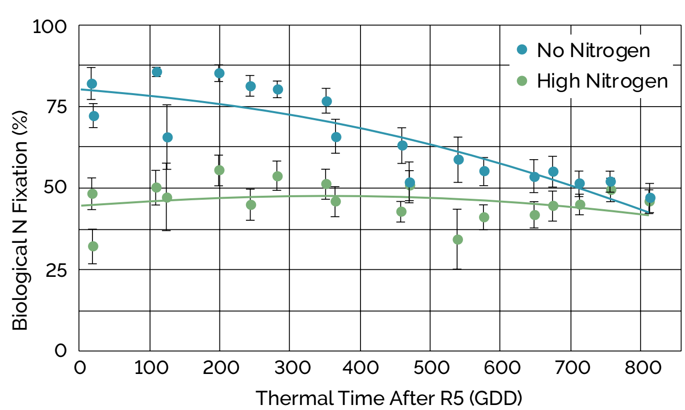


Figure 3. Changes in proportion of biological N fixation during the seed-filling period with and without added N fertilizer. Each data point is the average for each year.

return to table of contents

cercospora leaf blight and purple seed stain

***Mark Jeschke, Ph.D.**, Agronomy Manager*

Disease Facts

- Caused by a fungal pathogen, *Cercospora kikuchii*
- Infection is favored by humid conditions and temperatures of 75 to 80 °F (24 to 27 °C) or higher.
- Can be found throughout the U.S. and Canada. Disease is becoming more common in the Midwestern U.S.
- Generally occurs during pod-filling stages (August), affecting both leaves and seeds of soybeans

Disease Development

- Disease organism survives as mycelia on soybean residue and on the seed coat of infected seed.
- Sporulation occurs under conditions of high humidity and temperatures of 75 °F (24 °C) or higher. Sporulation increases as temperatures rise above 80 °F (27 °C).
- Spores carried by wind and water infect leaves and stems. Infection may remain latent until favorable conditions develop during soybean pod-fill stages.
- Lesions develop on leaves during hot, humid conditions. Sporulation from lesions results in secondary infections.
- Seeds become infected when the fungus invades the pod and grows through the upper vein. The hilum and eventually the seed coat become infected.
- Infected plants and seeds provide inoculum for the next soybean crop.

Figure 1. Leaf symptoms of *Cercospora kikuchii,* which causes purple seed stain of soybean seeds. Leaf symptoms begin as a light purple color that extends over the leaf and develops a leathery appearance.

Disease Symptoms – Leaf Blight

- The Cercospora leaf blight phase generally begins in August at the start of pod fill on late-planted soybeans.
- Sun-exposed leaves on the upper part of the plant develop a reddish-purple to bronze discoloration (Figure 1).
- Discoloration results from numerous irregular-shaped lesions that range from small specks to half-inch spots and may extend to the upper stems, petioles, and pods.
- Lesions form large, necrotic blotches as the disease progresses and lesions merge.
- As plants mature, infected leaves develop a leathery appearance.
- Severely affected upper leaves may drop, but the petioles remain on the plant; lower leaves of the plant remain green and attached (Figure 2).
- Infection sites on petioles and stems are sunken red lesions that can be up to ¼ inch in length.

Figure 2. Field infected with Cercospora leaf blight of soybeans. The pathogen overwinters on infested debris or seed.

Impact on Crop

- Plants infected early from diseased seed may lose their cotyledons, become stunted, or die.
- Loss of leaf tissue or entire leaves may occur. Extensive blighting of fields is common with severe infections.
- Defoliation may reduce yield if disease occurs early relative to pod fill. Significant yield loss is more common in southern states than in northern and central states.
- Purple seed stain may reduce quality and marketability of soybeans. Severely stained seed may be docked at the elevator, depending on percent of seed affected.

return to table of contents

Symptoms – Purple Seed Stain

- Lesions and a purplish discoloration are symptoms of infected pods. Seeds are infected through their attachment to the pod, the hilum (Figure 3).
- Infected seeds may show a pink or pale to dark-purple discoloration, which varies in size from specks to blotches that cover the entire seed coat.
- Seed discoloration extends from the seed hilum in all cases. However, seed is sometimes infected without showing obvious symptoms.

Figure 3. Close-up of soybean seeds with purple seed stain, caused by a fungal disease, *Cercospora kikuchii*. Infected seeds have a pink-to-purple discoloration on their seed coats.

Management

Rotation and Tillage

- A one- to two-year rotation to corn or small grains will reduce inoculum levels. Other legumes should not be included in the rotation.
- Tillage, where practical, can be used to incorporate and hasten the decomposition of crop residue on which Cercospora pathogens survive.

Genetic Resistance

- Soybean varieties vary in their response to Cercospora, but a high level of resistance is not currently available. Nevertheless, many commercial varieties demonstrate at least some degree of tolerance.
- Resistance to the leaf blight and seed infection stages are thought to be under different genetic control.

Seed Treatments

- The fungicide component of seed treatments can help protect against early infection of seedlings that may result in cotyledons shriveling, turning dark purple, and dropping early or plants dying or becoming stunted.

Fungicides

- Many commonly used foliar fungicides are labeled for Cercospora leaf blight on soybeans; however, research has shown efficacy to often be variable (Table 1).
- Single applications at R2 to R4 (full-flower to full-pod stages) tend to perform better in reducing the leaf blight phase of this disease than applications made at the R5 (beginning-seed) stage.
- Single applications at R4 to R5 (full-pod to beginning-seed stages) can reduce the incidence of purple seed stain but may or may not improve soybean yield.
- The cost-effectiveness of multiple applications has not been proven.

Table 1. Efficacy of select foliar fungicides for control of Cercospora leaf blight (Smith, 2020).

Fungicide	Active Ingredient(s)	Efficacy*
DuPont Aproach® Prima 2.34SC®	cyproconazole, picoxystrobin	P-G
Domark® 230ME	tetraconazole	P-G
Headline® 2.09EC/SC	pyraclostrobin	P
Miravis® Top 1.67SC	pydiflumetofen, difenoconazole	P-G
Priaxor® 4.17SC	pyraclostrobin, fluxapyroxad	P-G
Quadris® 2.08SC	azoxystrobin	P
Quadris Top® 2.72SC	azoxystrobin, difenoconazole	P-G
Quilt Xcel® 2.2SE	azoxystrobin, propiconazole	F
Stratego® YLD 4.18SC	trifloxystrobin, prothioconazole	F
Topguard® 1.04SC	flutriafol	P-G
Trivapro®	benzovindiflupyr 2.9% azoxystrobin 10.5% propiconazole	P-G
Topguard® 1.04SC	flutriafol	P-G

* E=Excellent; VG=Very Good; G=Good; F=Fair; P=Poor.

diaporthe/ phomopsis fungi complex in soybeans

Samantha Reicks, *Agronomy Sciences Intern*

Fungi Facts

- *Phomopsis (P. longicolla)* and *Diaporthe (D. phaseolorum var. sojae)* are fungi that function as a complex and infect soybeans.
- The fungi cause diseases to form in the plant, which can reduce yield. Some of these diseases include:
  - Pod and stem blight
  - Phomopsis seed decay
  - Stem canker
- Mature plants that are split longitudinally may show signs of zone lines on lower stems as seen in Figure 1. This was previously often mistaken for symptoms of charcoal rot.
- *Diaporthe/Phomopsis* can infect the plant at any time in the growing season but may not be visible until later in the growing season.
- This fungus complex and diseases associated with it can be found throughout most soybean-producing areas in North America.

Figure 1. Dark zone lines in the longitudinal section of the lower stem are an indicator of *Diaporthe* fungal infection.

Conditions Favoring Infection

Hosts of the Fungus

- *Diaporthe/Phompsis* fungi complex overwinters in soybean residue for several years after an infected crop was present. Repeatedly planting soybeans will increase the risk of a field being infected.
- Early season rainfall can splash spores onto the growing plant.
- Plants with infected pods will produce infected seeds. Chances for severe pod infection increase when the pod begins maturing, especially around R5 and R6. When the pods are infected, seeds are susceptible to seed decay.
- Several weeds, such as velvetleaf, morning glories, and pigweed, can host the *Diaporthe/Phomopsis* fungi complex and will not show symptoms.

Life Cycle

- The plants can be infected at any time in the growing season but are most often infected early in the season. When the leaves are wet for extended periods early in the growing season, the diseases are more likely to occur in the field.
- There is an increased chance of infection when the weather is warm and humid close to maturity.
- Wet weather that delays harvest will increase the chance and severity of seeds being infected. Rainfall during pod fill can also splash fungi spores from residue onto pods.
- High winds, hail, and other events that rip the plant tissue give the pathogen an entryway into the plant.
- Chance for infection decreases at R7 and when the seed moisture is below 19%.

Potential Diseases

Pod and Stem Blight

- Leaves may have water-soaked margins that are grey in color and/or small black specks called "pycnidia." The black dots may be more prevalent on leaves and petioles that have fallen on the ground. It is also possible that no symptoms are visible.
- Stems have parallel rows of pycnidia on mature plants (Figure 2). These black dots are often mistaken for anthracnose stem blight and charcoal rot, which have unorganized black specks on the stems (Figure 3 and 4).

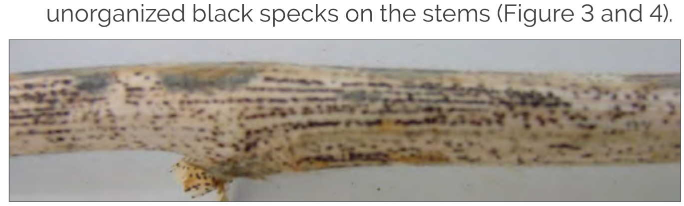


Figure 2. Soybean infected with pod and stem blight disease have black specks that are in linear rows.

Figure 3. Anthracnose infected soybean stem with black lesions in an unorganized pattern.

Figure 4. Black, dusty microsclerotia in an unorganized pattern on the outer stem are a characteristic symptom of charcoal rot.

Figure 5. Dark zone lines on the lower stem are an indicator of *Diaporthe* fungal infection.

- Pycnidia on pods will not be in organized rows and will begin to occur near the end of the reproductive stages, around R6 and R8.
- If the plant is infected, there is a possibility that all of the seeds that are produced are also infected. The seeds will produce seedlings with orange lesions on the cotyledon and red/brown mark on the hypocotyl. This looks similar to *Phomopsis* seed decay.

Phomopsis Seed Decay

- Seeds appear shriveled, cracked, and elongated; they may be covered with a thin, white layer of mold. Seeds with a critical amount of infection may not germinate.
- Infections are not always visible and may be on the inside of the seed coat.
- Infected seeds have symptoms that look similar to the symptoms of white mold and downy mildew.
- Pods are more likely to be infected if they are near the bottom of the plant.
- Seedlings develop orange and red-brown lesions on the cotyledons as well as streaks on the lower part of the stem near the soil.
- Small black specks of pycnidia may occur on the seeds.

Stem Canker

- Infection most often occurs during the early season, but cankers do not begin forming until after flowering.
- Nodes near the bottom of the plant will have gray/brown lesions with red/brown margins and sunken cankers around R1. These lesions can wrap the stem or grow up the stem several nodes (Figure 6).
- Leaves may begin to wilt, and interveinal chlorosis as well as necrosis are present. Leaves do not drop but stay attached after the plant dies. Plants often die when they are infected with this disease.
- Stem canker may be present in small areas throughout a field, or an entire field can be infected.
- Stem canker is often confused with phytophthora, anthracnose, brown stem rot, charcoal rot, and sudden death syndrome, as well as herbicide, frost, and lightning damage.
- If the taproot of the plant is split and the inside of the root displays a color that is not normal, the plant most likely has brown stem rot or sudden death syndrome, not stem canker.
- Stem canker is more likely to infect fields with high fertility and organic matter.

Figure 6. Stem canker in soybeans caused by the fungus *Diaporthe*.

Management Practices

Before Planting

- Rotate from soybeans to corn or a non-legume that is not a host for the fungi complex. Alfalfa is a potential host for stem canker.
- Fertilize to maintain sufficient levels of potassium. Seed infection increases when potassium is deficient.
- Tillage will reduce the amount of residue on the surface and lower the chances of spores splashing on to future crops.
- *Diaporthe/Phomopsis* fungi complex is more likely to occur in soybeans that mature early. Planting soybeans with a late relative maturity will decrease the chance of humid conditions in the late stages of reproduction.

During the Growing Season

- Strive to achieve a full, even stand. Extensive branching due to gaps in the stand can result in lodged plants with broken branches. Broken branches give the fungi a means of entry into the plant.
- Fungicides can be used in fields that have low to moderate disease pressure and in areas that favor severe disease pressure.
    - » To mitigate pod and stem blight, apply fungicides between R3 and R5.
    - » The amount of disease may diminish in the field, but this does not necessarily mean that the yield will improve.
- Do not delay in harvesting the crop. The longer soybean seeds remain in the field after maturity, the greater the chances of the seeds being infected.

sudden death syndrome of soybeans

***Steve Butzen, M.S.**, Agronomy Information Consultant*

Summary

- Sudden death syndrome (SDS) has spread to most soybean-growing states and Ontario, Canada. Many states now rank SDS second only to soybean cyst nematode (SCN) in economic losses caused to soybeans.
- Early planting and cool, moist conditions early in the growing season often result in higher incidence of SDS. The disease is usually more severe if SCN is also a problem in the field.
- SDS often appears first in low, poorly drained or compacted field areas. Though infection occurs early in the season, symptoms usually do not appear until mid-summer.
- As plants lose leaf area and roots deteriorate due to SDS, yield components are affected. Flower and pod abortion are common, resulting in fewer pods and seeds. Seeds may be smaller, and late-forming pods may not fill or mature.
- SDS varies in severity from area to area and from field to field. Growers must understand the extent of infection in each of their fields to effectively manage SDS.
- Management practices for SDS include selecting tolerant varieties; control of SDS and SCN using effective seed treatments; planting problematic fields last; managing SCN; improving field drainage; reducing compaction; evaluating tillage systems; and reducing other stresses on the crop.

Introduction

Sudden death syndrome (SDS) of soybeans was first reported in Arkansas almost 50 years ago. Since then, it has spread from the mid-South Mississippi River basin to infect soybean fields in almost all soybean-growing 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.

Soybean leaf showing classic symptoms of sudden death syndrome infection with yellow and brown areas contrasted against a green midvein and green lateral veins.

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 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 Sudden Death Syndrome 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, it 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-infected stem and root. Note blue mold at soil line.

SDS begins as a root disease that limits root development and deteriorates roots as well as 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.

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.

Split soybean stem on top shows stem symptoms of sudden death syndrome infection. Split stem on bottom is healthy.

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, Corteva Agriscience 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).

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 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. Pioneer soybean research trials were conducted over three years 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 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.

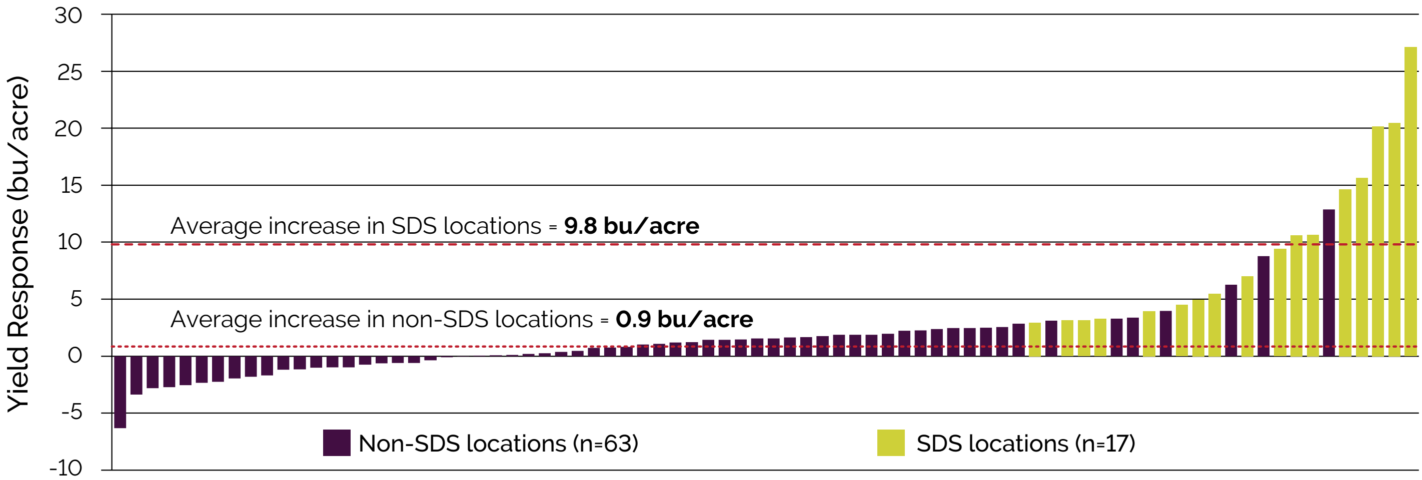


Figure 1. Yield performance of FST/IST + ILeVO fungicide seed treatment relative to the FST/IST check (80 replicated research locations, 2012-2014).

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 1). ILeVO seed treatment also has activity against SCN in soybeans (data not shown).

Figure 2. Soybeans treated with FST/IST (left) and FST/IST + ILeVO fungicide (right) at a research location with SDS near Lawrence, KS, in August 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.

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 re-evaluate 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 as well as plant health and enable the plants to better withstand the effects of SDS.

return to table of contents

integrated management of white mold

Jeff Wessel, Ph.D., *Former Agronomy Trials Manager,* **Steve Butzen, M.S.,** *Agronomy Information Consultant, and* **Mark Jeschke, Ph.D.,** *Agronomy Manager*

Summary

- Risk factors for white mold development in soybeans include geographic location, seasonal climate conditions, and field history of disease.
- Integrating several cultural practices is the most effective means of managing white mold. Cultural practices include variety selection, crop rotation, weed management, zero tillage, and if necessary, limiting dense canopy formation.
- When white mold risk factors are high, it may be beneficial to also use chemical or biological products to reduce disease severity and yield loss. These products have shown efficacy in some studies, but control has been variable.
- DuPont™ Aproach® fungicide, Domark® fungicide, Endura® fungicide, Topsin® fungicide, and lactofen (Cobra® herbicide and Phoenix® herbicide) are chemical products labeled for control or suppression of white mold. Contans® fungicide is a biological agent that acts against the disease's overwintering structures.
- Foliar chemical applications should be targeted at early flowering (R1); penetration of spray to the lower soybean canopy is necessary for effective control.
- Improved soybean varieties with native and transgenic sources of tolerance are expected to enhance future white mold management.

return to table of contents

Introduction

White mold, also known as sclerotinia stem rot, has spread in recent years, partly due to cultural practices that accelerate soybean canopy development. These practices, including early planting and narrow rows, are also proven to increase soybean yields. This presents a dilemma for growers: should they manage their crop with the goal of maximizing yield or minimizing white mold incidence? To answer the question, growers must understand the factors that affect white mold development and potential severity, including geography, climate, and field history. If these factors suggest a high risk of white mold damage, growers should consider management practices that may minimize disease severity. These include soybean variety selection, crop rotation, weed control, chemical application, and possibly cultural practices that reduce early, dense canopy development. This article will discuss white mold risk factors, disease development, and management practices to help reduce white mold challenges to soybean yields.

White Mold Risk Factors

Geography: White mold is a perennial problem in northern states of the U.S. and in Canada. This is because cool, moist conditions in July that coincide with soybean flowering are ideal for disease development, and these conditions are most likely to occur in northern areas. In addition to the northern-most states, white mold may also be prevalent in bordering states, such as Iowa, Illinois, Indiana, and Ohio, particularly in the northern regions of those states. Other states are not immune from the disease, but its occurrence is less likely and impact is usually limited.

Figure 1. White mold on soybean stems, which often results in reduced yield and standability.

Climate: Cool and moist conditions at flowering favor white mold development. These conditions may occur even outside the obvious geographies where white mold is most problematic. Such conditions were widespread in the Midwestern U.S. in 2009 and so was white mold incidence. More important than general climatic conditions is the microclimate beneath the soybean canopy. For this reason, dense soybean canopies can be more disease-prone than more open canopies.

Field History: Once white mold has occurred in a field, it is nearly impossible to eradicate it. White mold has at least 400 alternate plant hosts, including many common weeds and crops. In addition, long-term survival structures of this organism (sclerotia) ensure that inoculum is always available to attack the next soybean crop should conditions allow. For that reason, soybean growers in risk areas with previously infected fields must treat white mold as a perennial threat to top yields and profits.

Disease Description and Life Cycle

White mold persists in soybean fields over time by survival structures called "sclerotia" (Figure 2). These dark, irregularly shaped bodies about ¼ to ½ inch long are formed within the white, cottony growth both inside and outside the stem.

Figure 2. White mold sclerotia on soybean stem.

Sclerotia contain food reserves and function much like seeds, surviving for years in the soil and eventually germinating, producing millions of spores beneath the plant canopy. White mold spores are not able to invade plants directly but must colonize dead plant tissue before moving into the plant. Senescing flowers provide a ready source of dead tissue for preliminary colonization. From these senescing flowers in the branch axils or stuck to developing pods, the fungus spreads to healthy tissue. Stem lesions develop and may eventually be overgrown with white mold. The disease can then spread directly from plant to plant by contact with this moldy tissue.

Wet, cool conditions are required throughout the white mold disease cycle, including germination of the sclerotia in the soil, spore release, infection of soybean flowers by spores, and spread of white mold from plant to plant (Figure 3).

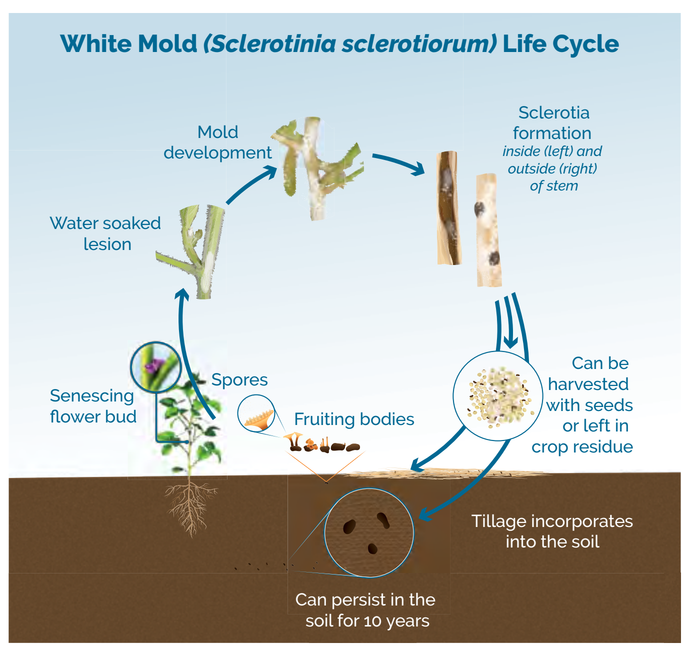


Figure 3. White mold life cycle in soybeans.

return to table of contents

Cultural Practices for White Mold Management

No single management practice is likely to control white mold when the growing environment favors the disease. Rather, the most effective approach is one that integrates both cultural and chemical control tactics (Bradley, 2009a). Fields with a history of white mold should first be managed culturally to limit disease. Such cultural practices include varietal selection, crop rotation, weed management, zero-tillage, and management to limit dense canopy development.

Soybean Variety Selection: There is no absolute resistance available to white mold (all varieties can get the disease under severe pressure), but differences in tolerance exist between varieties. Pioneer® variety ratings range from 2 to 7 on a scale of 1 to 9 (9 = resistant). Ratings reflect varietal differences in the rate at which infection develops as well as the extent of damage it causes and are based on data from multiple locations and years. Choosing varieties that rate high for tolerance is an important management practice in areas that commonly encounter white mold. Your local Pioneer sales professional can suggest white mold tolerant varieties with a complete package of traits needed for top soybean production in your area.

Crop Rotation: Rotation with a non-host crop is an effective means of reducing disease pressure in a field. Non-host crops include corn, sorghum, and small grains. Susceptible crops to avoid in a rotation include alfalfa, clover, sunflower, canola, edible beans, potato, and others. Depending on soybean tolerance, field history, and other factors, more than one year away from soybeans may be required to reduce white mold problems. Because sclerotia survive for up to 10 years in the soil, rotation is only a partial solution.

Weed Management: White mold's 400+ plant hosts include many broadleaf weeds. Host weeds that are also common weed species throughout soybean growing areas are lambsquarters, ragweed, pigweed, and velvetleaf. In addition to acting as host to the disease, weeds can also increase canopy density, which favors disease development.

Zero Tillage May Minimize Disease: Sclerotia germinate from the top two inches of soil. Below that depth, they can remain dormant for up to 10 years. Because of this longevity in the soil, it is difficult to devise a strategy to control white mold with tillage. Deep tillage buries sclerotia from the soil surface but may also bring prior sclerotia into their zone of germination. If the disease is new to a field and a severe outbreak has occurred, a deep tillage followed by zero tillage or shallow tillage for many years may help. Research studies have shown that zero tillage is generally superior to other tillage systems in limiting white mold.

Figure 4. White mold infection.

Limiting Dense Canopy Formation: In areas of high risk, cultural practices that encourage early, dense canopy development may need to be avoided. This includes early planting, narrow rows, and excessive plant populations. However, efforts to limit vegetative growth of soybeans seem counter-intuitive as virtually all management practices associated with high soybean yields are geared to promote vegetative biomass. Increasing leaf area and thus, light interception during reproductive growth typically increases seed yield (Ma et al., 2002). Soybeans can, however, produce a leaf area index of six to seven—well in excess of what is necessary for maximum light interception (Nafziger, 2009). To limit overly dense soybean canopies and maintain maximum yield, avoid rows spaced less than 15 in apart and seeding rates greater than 150,000 seeds/acre. Especially early planting dates, such as mid-April, are probably not necessary for maximum yield in many years and should also be avoided in fields with a history of white mold.

Foliar Applications for White Mold Management

Despite the best use of cultural practices to limit the incidence of white mold, weather and other conditions conducive to disease development may still cause heavy infestations. In cases of high disease risk, a foliar application of a chemical product or a soil application of a biological product may help reduce disease severity and protect soybean yield. Conditions that favor disease development include:

- Weather – predicted to be cool (< 85 °F or 29 °C) and wet with high relative humidity
- Field – a moist soil surface
- Crop – a relatively large or dense crop canopy

Products labeled for white mold control or suppression include synthetic fungicides (DuPont™ Aproach® fungicide, Quadris® fungicide, Topguard® fungicide, Proline® fungicide, Domark® fungicide, Topsin® fungicide, and Endura® fugnicide, (Table 1)), a biological fungicide (Contans® fungicide), and the herbicide lactofen (Cobra® herbicide and Phoenix® herbicide).

Application Timing

Optimum application time of fungicides and lactofen for white mold control in soybeans is approximately the R1 growth stage, also known as the beginning bloom or first flower stage (Mueller et al., 2004; University of Wisconsin – Madison, 2008). For much of the U.S. Corn Belt, the R1 stage coincides with the first two weeks of July when the vegetative growth stage is typically about V7 to V10 (Pedersen, 2009).

Table 1. Fungicides labeled for control of white mold in soybeans (Wise, 2017).

Fungicide Trade Name	Active Ingredient	Use Rate	White Mold Efficacy
		fl. oz./acre	
DuPont™ Aproach®	picoxystrobin	6.0-12.0	good-very good
Quadris®	azoxystrobin	6.0-15.5	poor
Topguard®	flutriafol	7.0-14.0	fair
Proline®	prothioconazole	2.5-5.0	fair
Domark®	tetraconazole	4.0-5.0	fair
Topsin-M®	thiophanate-methyl	10.0-20.0	fair
Endura®	boscalid	3.5-11.0	very good

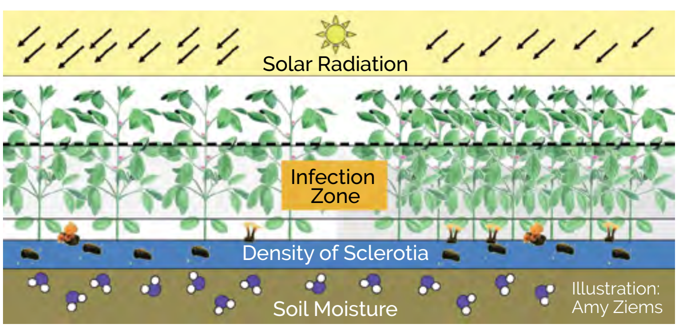
return to table of contents

Synthetic fungicides and lactofen have little activity on established disease and must be applied prior to white mold invasion of senescing flowers. Applications made just prior to pathogen invasion have helped reduce disease severity in some studies. Because soybeans normally flower for 30 days or more (R1 to R5) and fungicides for white mold control have maximum residual activity of about 2 weeks, a second application may become necessary if conducive environmental conditions persist into mid-summer.

One drawback to subsequent or late (R3) fungicide application is the potential for reduced canopy penetration. Though soy-beans grown in 30-inch rows at moderate seeding rates may allow for good penetration of the lower canopy at R1, spray coverage of the lower nodes becomes increasingly difficult with continued vegetative growth. As depicted in Figure 5, the lower canopy can remain relatively wet or humid, providing the appropriate environment for pathogenicity.

Thus, it is essential for spray droplets to reach the lower ⅔ of the soybean canopy in order to obtain satisfactory disease control. To enhance coverage of the lower canopy, use the highest carrier rate that is practical – about 20 to 30 gal/acre for ground application.

Factors That Influence White Mold Development



Dense canopy favors white mold pathogen.

Figure 5. Depiction of environmental conditions and canopy zone conducive to white mold infection. Illustration by Amy Ziems.

Research Results on White Mold Control Products

DuPont™ Aproach® fungicide: In research trials conducted by Ohio State University, Michigan State University, and the University of Illinois in 2009 to 2011, Aproach® fungicide reduced white mold severity and increased yield by 7.2 bu/acre (Table 2).

A University of Wisconsin research trial conducted near Hancock, WI, in 2016 found significant increases in soybean yield associated with DuPont™ Aproach® fungicide treatment under high levels of white mold pressure (Figure 6). A single treatment at the R3 growth stage increased yield by 11.5 bu/acre, and sequential applications at the R1 and R3 stages increased yield 16 bu/acre compared to the non-treated check.

DuPont on-farm research trials were conducted in 2017 at locations near Orchard, NE, and Edgar, WI, that experienced high white mold pressure. Both trials compared sequential applications at the R1 and R3 growth stages and single-pass treatments at both R1 and R3 to a non-treated check. The Wisconsin trial was non-replicated, and the Nebraska trial included two replications. The two-pass fungicide program increased yield by an average of 13.3 bu/acre in these trials (Table 3). The R3 and R1 treatments increased yield by an average of 8.7 and 6.7 bu/acre.

Table 2. Performance[a, b] of DuPont™ Aproach® fungicide vs. untreated check in 6 comparisons (Ohio, Michigan, and Illinois; 2009-2011).

Treatment	% Reduction in Severity of White Mold[a]	Yield Advantage (bu/acre)[b]
DuPont™ Aproach® Fungicide vs. Non-treated	27.6 %	*7.2 bu/acre*

[a] % severity rating is a DSI index rating based on 0-100, where 100 means all 30 plants rated in a plot had severe infection on the main stem resulting in plant death and poor pod fill, and 0 means no white mold. The DSI index is a measure of area diseased, hence, severity — so is reported as % severity.

[b] **Reported yield advantage is a summary of checks from:**

2009 Tests: Dorrance, Ohio State (MWH-09-679, Williams var.) treatments applied once; Bradley, Univ. Illinois (MWE-09-679) treatments applied twice.

2010 Tests: Kirk, Mich. State Univ. (MWH-10-779, S20-P5 var.) treatments applied twice; Bradley, Univ. Illinois (MWE-10-779, A2902 var.) treatments applied twice.

2011 Tests: Kirk, Mich. State Univ. (MWH-11-679, 92Y51RR var.) treatments applied twice; Bradley, Univ. Illinois (MWE-11-679, P92M54 var.) treatments applied twice; Dorrance, Ohio State (MWH-11-579, P93B36 var.) treatments applied twice, run in grower field.

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

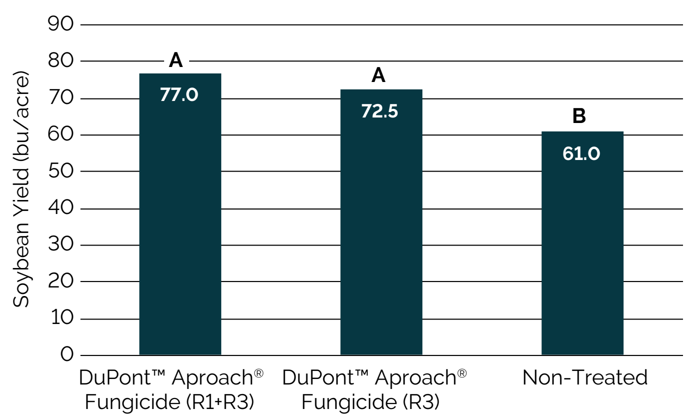


Figure 6. Yield of soybeans treated with DuPont™ Aproach® fungicide at the R3 growth stage and the R1 and R3 stages compared to non-treated soybeans in a Univ. of Wisconsin trial at Hancock, WI, in 2016 (Smith et al., 2016).

Means labeled with the same letter are not significantly different based on Fisher's least significant difference (LSD; α=0.05).

Table 3. Soybean yield associated with DuPont™ Aproach® fungicide treatments in on-farm trials with heavy white mold pressure in Wisconsin and Nebraska in 2017.

Fungicide Treatment	Edgar, WI	Orchard, NE	Average	Yield Advantage
	bu/acre			
DuPont™ Aproach® Fungicide (R1+R3)	66.6	55.9	61.3	**+13.3**
DuPont™ Aproach® Fungicide (R3)	57.7	55.6	56.7	**+8.7**
DuPont™ Aproach® Fungicide (R1)	61.9	47.4	54.7	**+6.7**
Non-Treated	54.8	41.2	48.0	

The DuPont™ Aproach® fungicide label* specifies to make an initial preventative application at 100% bloom (1 flower blooming on all plants) and follow with a second application 7 to 10 days later at full bloom. A second application is most important if cool, wet, environmental conditions conducive to disease development persist throughout flowering.

Apply DuPont™ Aproach® fungicide in a minimum volume of 10 gal/acre. Penetration of spray droplets into the lower canopy is critical to achieve optimum efficacy. Ensure spray volume and spray pressure are optimized to achieve thorough coverage.

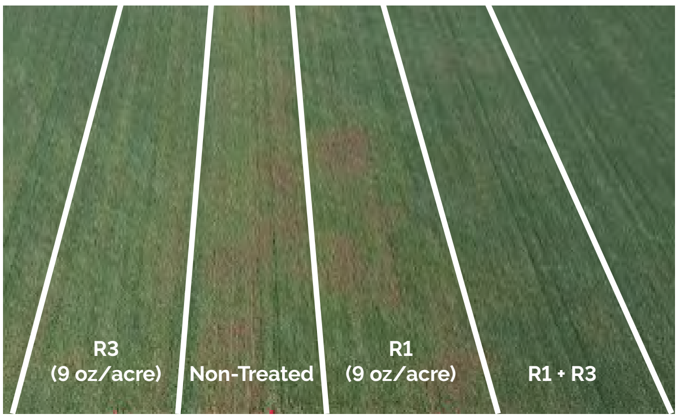


Figure 7. DuPont on-farm fungicide research trial near Edgar, WI, comparing DuPont™ Aproach® fungicide applied at R1, R3, and R1+R3 growth stages to a non-treated check under heavy white mold pressure (September 11, 2017).

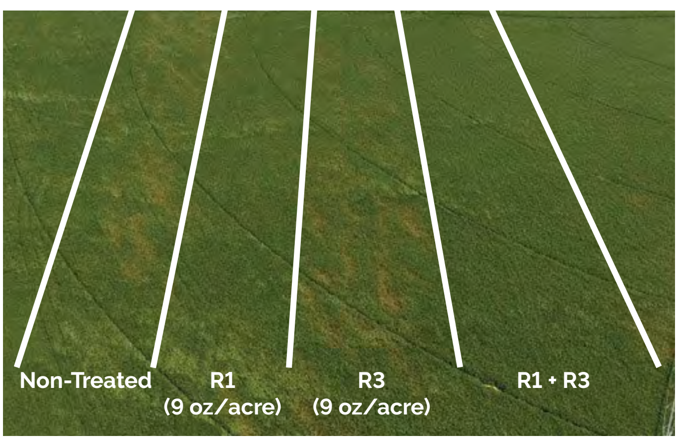


Figure 8. DuPont on-farm fungicide research trial near Orchard, NE, comparing DuPont™ Aproach® fungicide applied at R1, R3, and R1+R3 growth stages to a non-treated check under heavy white mold pressure (August 23, 2017).

Topsin® Fungicide: Topsin fungicide has been evaluated for a number of years for its efficacy on white mold (Mueller et al., 2001; Mueller et al., 2004). Both studies reported by Mueller demonstrated that soybean yield can be protected with Topsin fungicide; however, if disease incidence was near 50% or greater and canopy penetration was poor, yield was not protected in the studies. Applications after R1 also failed to protect yield, and in some instances, two applications were required.

Endura® Fungicide and Cobra® Herbicide: Endura fungicide has been shown to increase soybean yield under severe white mold infestation, but two applications were necessary (Bradley, 2009). In the same trial, a single Cobra herbicide application also increased yields.

Cobra Herbicide: Lactofen, the active ingredient in Cobra herbicide and Phoenix® herbicide, is for post-emergence weed control in soybeans. In addition, it is a potent elicitor of the phytoalexin glyceolin (Nelson et al., 2001). Phytoalexins are toxic (antimicrobial) substances produced by plants in response to invasion by certain pathogens or by chemical or mechanical injury (Agrios, 1988).

Studies have shown that the optimum application time for Cobra herbicide is at R1 (University of Wisconsin – Madison, 2008), which is identical to timing recommendations for foliar fungicides. Although small yield improvements were observed with V4 to V5 Cobra herbicide treatments, yield increases were larger and more consistent with applications at R1 (Figure 6). Despite heavy disease pressure (48% incidence), Cobra herbicide has been shown to reduce disease incidence and increase yield of susceptible soybean varieties (Oplinger et al., 1999). However, a moderately resistant variety showed no response to Cobra herbicide and produced a higher yield than a treated susceptible variety. Due in part to unpredictable disease levels and variations in varietal tolerance to white mold, yield increases with Cobra herbicide have tended to be highly variable (Nelson et al., 2002).

Herbicides with PPO inhibiting sites of action, such as Cobra herbicide, usually cause moderate levels of leaf necrosis. Although the reduction in leaf area from this necrosis is likely a contributing factor in white mold control with Cobra herbicide, yield loss may result in the absence of disease (Dann et al., 1999; Kyle, 2014). Producers should use caution when considering the widespread use of Cobra herbicide, especially on moderately resistant varieties when environmental conditions do not favor disease.

Contans® WG Fungicide: Contans fungicide is a biological control agent of white mold. The product contains the soil fungus *Coniothyrium minitans*, which acts as a parasite attacking the overwintering survival structures (sclerotia) of white mold. Contans fungicide is applied to the soil, its spores germinate with sufficient moisture, and the fungus can destroy sclerotia if given adequate time. According to the manufacturer, Contans fungicide should be applied at least three months prior to white mold infection, and soil-incorporated immediately following application to a depth of at least 4 inches. Contans fungicide has been evaluated in both greenhouse and field studies (Hao et al., 2010). In both cases, efficacy has been good as reduced apothecia number and improved soybean yield have been observed. Although Contans fungicide may be fall- or spring-applied, fall applications have performed better than those done in spring.

Future Tools to Help Manage White Mold

Variety Improvement: Corteva Agriscience researchers have targeted improvement of varieties for white mold tolerance as a key research objective. To accomplish this goal, soybean breeders use new lab and field techniques as well as conventional selection in white mold environments. Corteva Agriscience scientists also continue to screen novel, exotic, and alternative germplasm sources with native tolerance to white mold. Future possibilities include transgenic approaches – transferring resistance genes from other crops or organisms into soybeans.

bean leaf beetle management in soybeans

Marlin E. Rice, Ph.D., *R&D Academic Engagement Leader*

Summary

- Bean leaf beetle is a pest of soybean in most soybean growing regions of the United States. There may be three generations in the Southern U.S., two generations in the Central Corn Belt (Nebraska, Iowa, and Illinois), and only one generation in the Northern Corn Belt.
- Adults feed on cotyledons, leaves, and the external surface of pods. Larvae feed underground on nodules and roots.
- Adult bean leaf beetles also can transmit a soybean pathogen—bean pod mottle virus—which causes "stay green" and delays soybean maturity.
- Following mild winters, which contribute to higher-than-average survival, bean leaf beetle populations can reduce plant populations by feeding on newly emerging soybeans, especially in early planted fields.
- During vegetative growth from the V2 stage to flowering, soybeans can tolerate from 40 to 60% defoliation without yield loss. Bean leaf beetles rarely, if ever, cause this degree of defoliation.
- Second-generation beetles usually peak during soybean pod-fill stages, resulting in injured pods. Yield loss can occur at this time (usually during August in Midwestern states).
- Scouting regularly for bean leaf beetle and spraying, if necessary, is recommended to address this problem insect. A new strategy to treat second-generation beetles based on first-generation beetle numbers has been proposed.

Identification and Life Cycle

Adult bean leaf beetles are approximately ¼ inch in length and vary in color (dull yellow, orange, tan, or red) and markings. Usually the wing covers have four "large" black spots and distinct black margins, but these are absent in some beetles. However, all bean leaf beetles have a black triangle just behind the head (Figure 1). Larvae resemble corn rootworm larvae: slender, cream colored, and dark headed but with a dark-brown shield at the tip of the abdomen.

Bean leaf beetles hibernate (i.e., overwinter) as adults beneath plant debris in woods, grassy areas, and cropland. When spring temperatures reach 50 to 55 °F (10 to 13 °C), adults become active and seek host plants, such as alfalfa, clover, and certain weeds. When soybeans emerge, these overwintered beetles may move to soybean fields to feed and lay eggs. Females lay 130 to 200 eggs, and these will hatch in about 1 week at a soil temperature of 82 °F (28 °C).

Figure 1. Bean leaf beetles vary in color, but adults always have a black triangle at the base of the wing covers. Usually there are 4 large spots (left), but these may be absent (right). *Photos courtesy of Marlin Rice, Corteva.*

Larvae remain in the soil, feeding on soybean root hairs and nodules. The effect of this feeding is largely unknown but is generally considered not to cause yield loss. Time of development from egg to adult depends on soil temperature; 674 to 740 degree days are required at a base threshold of 46 °F (8 °C).

Pupation occurs in earthen cells below the soil surface. Adults, comprising the first generation, emerge about a week later, usually in July in Midwestern states. This cycle is repeated, and a second generation of beetles will emerge in late August or September. As soybeans reach maturity, this second generation exits the fields to alternate hosts and eventually enters hibernation (i.e., overwintering) sites.

Bean leaf beetles overwinter in woodland leaf litter, in grassy fencerows, and under heavy soybean debris, and their survival is highly dependent on winter temperatures. Researchers at Iowa State University determined that winter survival can be predicted by a model that uses accumulated daily average subfreezing temperatures from Oct. 1 to April 15 (Lam and Pedigo, 2001). This model shows that beetle survival averages about 30% in Iowa over the long term but can be greater, such as in the winter of 2001 to 2002 that averaged 52% (Rice and Pope, 2002). Survival of the overwintered beetles strongly influences subsequent problems throughout the growing season.

Feeding on Soybeans

Bean leaf beetles possess chewing mouth parts and feed on soybean plants at all stages of crop development. When overwintering populations are high, newly-emerged soybean stands can be reduced by beetles feeding on cotyledons and the growing point (Figure 2). The first-generation beetles feed primarily on soybean leaves while the second-generation beetles feed on leaves and pods.

Leaf feeding by the bean leaf beetle can be identified by small round holes between the veins. Although leaf feeding injures the plants, soybeans can withstand a surprising amount of defoliation without incurring economic losses. In the vegetative stages, soybeans can usually sustain 50% leaf area loss without economic yield reductions.

Bean leaf beetles do not feed directly on soybean seeds, but they reduce soybean seed yield and quality by feeding on the pods. Occasionally, entire pods may be clipped when feeding occurs at the base of the pod. During a drought year, beetles were observed to clip pods at a rate of 0.125 pods per beetle per day (Smelser and Pedigo, 1992). Beetles frequently consume the outside layer of pod tissue, leaving a thin layer still covering the seed. Moisture and diseases can enter the pod through this lesion. Secondary infection by fungal pathogens, such as *Alternaria*, results in shrunken, discolored, and moldy seeds.

Figure 2. Bean leaf beetle feeding injury to soybean hypocotyl (left) and cotyledons (right). *Photos courtesy of Kirby Wuethrich, Corteva.*

The Virus Connection

The bean leaf beetle is also a vector of several soybean viruses, including yellow cowpea mosaic, cowpea chlorotic mottle, southern bean mosaic, and bean pod mottle virus. Bean pod mottle has been identified at increasingly high levels in Illinois, Iowa, and other major soybean-producing states. This virus can reduce yields 10 to 15% and by much more in combination with other viruses.

Bean pod mottle virus causes mottling and distortion of the upper soybean leaves. The crinkled leaves and stunted plants can resemble injury from herbicide drift or soybean

return to table of contents

Table 1. Economic thresholds for bean leaf beetles in early stage soybeans (Hunt et al., 1995; Rice et al., 2005).

Soybean Market Price	Soybean Growth Stage / Cost of Treatment ($/acre)											
	VC				V1				V2			
	$6	$10	$14	$18	$6	$10	$14	$18	$6	$10	$14	$18
$/bu	beetles/plant				beetles/plant				beetles/plant			
5.00	2.5	4.1	5.8	7.4	3.8	6.3	8.9	11.4	6.0	9.9	13.9	17.9
10.00	1.2	2.1	2.9	3.7	1.9	3.2	4.4	5.7	3.0	5.0	7.0	9.0
15.00	0.8	1.4	1.9	2.5	1.3	2.1	3.0	3.8	2.0	3.3	4.6	6.0

mosaic virus. Death of new terminal leaf growth may also occur. The virus also gives rise to "green stem" symptoms in some soybean plants. Affected plants do not mature normally, and stems remain green throughout the harvest period. (However, factors other than viruses are implicated in green stem syndrome as well.)

Bean pod mottle virus may also affect the seed, causing a light purplish discoloration of the seed coat. Seed mottling may also occur, resulting from pigments diffusing from the hilum of the seed. Yield reductions of 3 to 52% may occur depending on the soybean variety and the time of infection (see Hadi et al., 2012 for a detailed discussion).

Scouting and Management for Feeding Injury

Bean leaf beetles are present throughout the soybean growing season, so all crop stages–from emergence to R7–are exposed to feeding. Additionally, the beetles also transmit several viruses. This management section will focus on feeding injury only, and virus control will be addressed at the end.

Emerging Soybeans Through V2 Stage

Just-emerged soybeans are at risk for significant feeding injury when beetle populations are high, especially when planted early and emerging first in an area. The period from emergence through establishment of the first trifoliolate leaf is one of the most critical for soybean damage. If the cotyledons (seed leaves) are destroyed before the unifoliolate leaves fully emerge or if the growing point is severely damaged, stands and yields may be reduced.

Scouting of bean leaf beetles on just-emerged soybeans is done by direct observation as beetles are easy to see and count at this stage. Each state has developed its own treatment thresholds for bean leaf beetle feeding at various stages of crop development. Recommendations from Iowa and Nebraska are shown in Table 1.

Once the trifoliolate leaves have unrolled, soybeans can tolerate from 40 to 60% defoliation without yield loss. Scouting may be done by direct observation at V2 or V3, but this method will become impractical as canopy development progresses. At this point, use of a drop cloth or sweep net is necessary. Scouting procedures and treatment thresholds vary by state; check your state's publications, website, or extension entomologist's recommendations.

Soybeans in Reproductive Stages

Both the first and second generations may feed on soybeans during reproductive development. The first generation populations usually peak in the late vegetative and early reproductive soybean stages. Feeding at this time seldom causes economic losses.

The second generation usually peaks during pod-fill stages, resulting in injured pods. It is essential to scout fields regularly for bean leaf beetles at this time. Management decisions are based on beetle densities, which can change rapidly. During times of bean leaf beetle activity, fields should be scouted every five to seven days. Counts can be stopped when any of the following conditions apply:

1. Beetle populations start to decline.
2. Soybean pods begin to turn yellow (R7 stage).
3. The field is sprayed.

Figure 3. Bean leaf beetles and feeding injury to young soybeans. *Photo courtesy of Marlin Rice, Corteva.*

For scouting at this time, entomologists recommend using a drop cloth between soybean rows, shaking the soybeans vigorously, and counting the beetles as they hit the cloth. A sweep net can also be used and is recommended by some entomologists for narrow-row soybeans. When using the sweep net, sweeping technique is important for accurate sampling and use of economic thresholds. The table on the following page shows economic thresholds from Iowa State University (Table 2; Rice, 2000).

New Control Strategy Proposed

Second generation bean leaf beetles may feed on pods for several weeks before population densities reach the economic threshold. In such situations, some loss of yield and

return to table of contents

Table 2. Bean leaf beetle economic thresholds in reproductive stage soybeans.*

Soybean Price ($/bu)	Treatment Cost per Acre (Insecticide + Application)								
	$7	$8	$9	$10	$11	$12	$13	$14	$15
	beetles per foot of row								
$5.00	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.0	11.8
$6.00	4.6	5.2	5.9	6.5	7.2	7.8	8.5	9.2	9.9
$7.00	3.9	4.4	5.0	5.6	6.1	6.7	7.3	7.8	8.4
$8.00	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5
	beetles per sweep								
$5.00	3.5	4.0	4.5	5.0	6.5	7.2	7.7	8.3	8.7
$6.00	2.9	3.3	3.7	4.1	5.4	6.0	6.4	6.9	7.3
$7.00	2.4	2.8	3.1	3.5	3.8	4.2	4.5	4.9	5.2
$8.00	2.2	2.5	2.8	3.2	4.1	4.5	4.8	5.2	5.5

**Economic thresholds are based on a row spacing of 30 inches and a plant population of 8 plants per ft. of row. For narrow-row soybeans (8-inch rows) and a plant population of 3 plants per ft. of row, multiply the above economic thresholds by 0.7.*

quality is inevitable prior to insecticide application. A new approach that would attempt to prevent such damage before it occurs has been proposed by Iowa State University (Hadi et al., 2012). This system is radically different from other management approaches that use economic thresholds. The new concept is to sample first-generation beetle density and use this information to make management decisions regarding the more damaging second generation. This strategy requires the use of degree days from planting as well as weekly sampling to time a possible insecticide application. (Details of this dynamic strategy may be found in the link in the references.)

Managing Bean Pod Mottle Virus

Growers who have had bean pod mottle virus symptoms in their fields in recent seasons (particularly green stem syndrome) may be concerned about controlling this soybean virus. However, much about the relationship between the beetle, the virus, and soybeans remains unknown. It is commonly known that the earlier soybeans are infected, the greater the potential reduction in yield.

Delayed soybean planting date has been suggested as a bean pod mottle virus management tactic (Giesler et al., 2002), but a three-year field study in Iowa showed that delayed planting did not consistently result in lower bean pod mottle virus infection (Krell et al., 2005).

Soybean seed treatment for overwintered bean leaf beetle or foliar pyrethroid insecticides between emergence and first trifoliolate reduces total bean pod mottle virus incidence likely by protecting soybean seedlings from early beetle populations (Krell et al., 2004; Bradshaw et al., 2008). Additional applications of foliar insecticides by using foliar pyrethroid insecticides midseason (around blooming) aimed at controlling the first generation of bean leaf beetle may further suppress virus incidence (Krell et al., 2004; Bradshaw et al., 2008).

Insecticides for Bean Leaf Beetles

A variety of insecticides are registered for bean leaf beetle in soybeans (Table 3). Effective insecticides should have good initial knockdown as well as residual control; consult your state university extension entomologist for details. Growers should also consider the pre-harvest interval when selecting an insecticide. Some insecticides have intervals of 21 days or less, but others have 45 day pre-harvest intervals.

Table 3. Common insecticides labeled for bean leaf beetle in soybean (Mississippi State University, 2015).**

Trade Name	Chemical Name	Product Rate per Acre	Pounds A.I. per Acre	Pre-Harvest Interval
Asana® XL 0.66EC	esfenvalerate	5.8 – 9.6 oz.	0.03 – 0.05	21 days
Baythroid® XL 1EC	beta-cyfluthrin	1.6 – 2.8 oz.	0.0125 – 0.022	45 days
Brigade® 2EC	bifentrhin	2.1 – 6.4 oz.	0.033 – 0.10	18 days
Karate® Z 2.08CS	lambda-cyhalotrhin	0.96 – 1.6 oz.	0.015 – 0.025	45 days
Larvin® 3.2F	thiodicarb	18 – 30 oz.	0.45 – 0.75	28 days
Mustang® Maxx 0.8EC	zeta-cypermethrin	2.8 – 4 oz.	0.0175 – 0.025	21 days
Orthene® 90S	acephate	0.83 – 1.1 lb.	0.75 – 1.0	14 days
Prolex™ 1.25EC	gamma-cyhalothrin	0.77 – 1.28 oz.	0.0075 – 0.0125	45 days
Sevin® XLR 4L	carbaryl	1 – 2 pt.	0.5 – 1.0	21 days

***Some insecticides are restricted use. Read and follow all label directions.*

return to table of contents

integrating genetic resistance and seed treatments for SCN management

***Julie Abendroth, Ph.D.**, Project Leader, **Don Kyle,** Soybean Breeder*
***Justin Gray,** Senior Research Associate, and **Li Feng, Ph.D.,** Research Scientist*

Rationale and Objectives

- Soybean cyst nematode (SCN) is found in all soybean production areas in North America. Industry reliance on one source of genetic resistance (PI88788) for SCN management has resulted in selection for SCN populations capable of parasitizing and reproducing on soybean varieties with PI88788 resistance. The PI88788 source of resistance no longer adequately controls SCN in many fields today, and the use of other sources of genetic resistance as well as nematicide seed treatments are needed.
- In fields with SCN populations capable of reproducing on varieties with PI88788 resistance, research was conducted in 2017 and 2018 across a wide swath of the soybean growing region of the U.S. to:
    1. Evaluate the integration of native resistance with a nematicide seed treatment for SCN management
    2. Determine whether the addition of a nematicide seed treatment to varieties with PI88788 resistance can protect yield and allow them to perform at parity with varieties containing the Peking source of SCN resistance

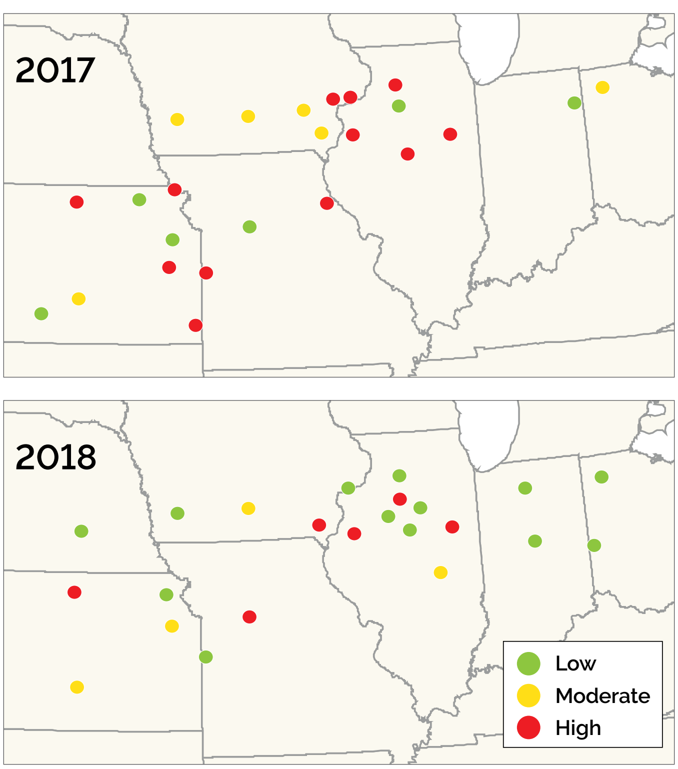


Figure 1. SCN management field trial locations in 2017 and 2018.

Study Description

- Research locations were randomly selected for testing across the maturity group 3 soybean growing region, an area where SCN has been common for more than 20 years (Figure 1).
- Yield data were collected from 47 trial locations.
- SCN egg count samples were collected at the beginning of the season to identify locations with medium or high SCN numbers.
    - » 19 locations had low SCN pressure (<100 eggs/100 cc soil).
    - » 10 locations had moderate SCN pressure (100-1,000 eggs).
    - » 18 locations had high SCN pressure (>1,000 eggs).
- For locations with moderate or high SCN pressure, all plots were then sampled at the end of the season to quantify SCN level for each SCN genetic resistance and seed treatment combination.
- A pair of 3.4 RM highly isogenic soybean lines were developed with either the PI88788 or Peking genes that provide resistance. These isolines were >99% identical genetically - only different at the genomic locations for the genes for SCN resistance.
- The two varieties were compared in each trial in combination with four different seed treatments:
    1. Base fungicide/insecticide seed treatment (FST/IST)
    2. Base + ILEVO® nematicide: SCN rate (0.60 fl oz/140k unit)
    3. Base + ILEVO nematicide: SDS rate (1.18 fl oz/140k unit)
    4. Non-treated
- Trials were arranged in a randomized complete block design with six replications at each trial location.

Results

- Approximately 38% of the randomly selected fields were found to have high SCN pressure. In these fields, the PI88788 source of resistance was being overcome by SCN.
- Across the 19 locations with low SCN populations (<100 eggs), the Peking and PI88788 isolines yielded within an average of 0.1 bu/acre of one another (statistically not different).
- The Peking isoline out-yielded the PI88788 isoline by 1.1 bu/acre and 3.5 bu/acre under moderate and high SCN pressure, respectively.

return to table of contents

Results (continued)

- In moderate SCN environments, the addition of ILEVO nematicide seed treatment to the PI88788 isoline resulted in significant yield recovery, performing near parity with the Peking isoline (Figure 2). ILEVO seed treatment on the PI88788 isoline provided a 2.4 to 4.0 bu/acre yield increase above the base FST/IST treatment.
- In high SCN environments, egg counts were 4-fold lower by utilizing Peking rather than PI88788 (Figure 3). On the PI88788 isoline, ILEVO nematicide seed treatment reduced egg counts by 15% and recovered 1.6 bu/acre above the base FST/IST treatment. While pairing ILEVO with PI88788 isoline increased yield in the high SCN environments, it did not bring it to parity with the Peking + ILEVO seed treatments.

Moderate Pressure Locations

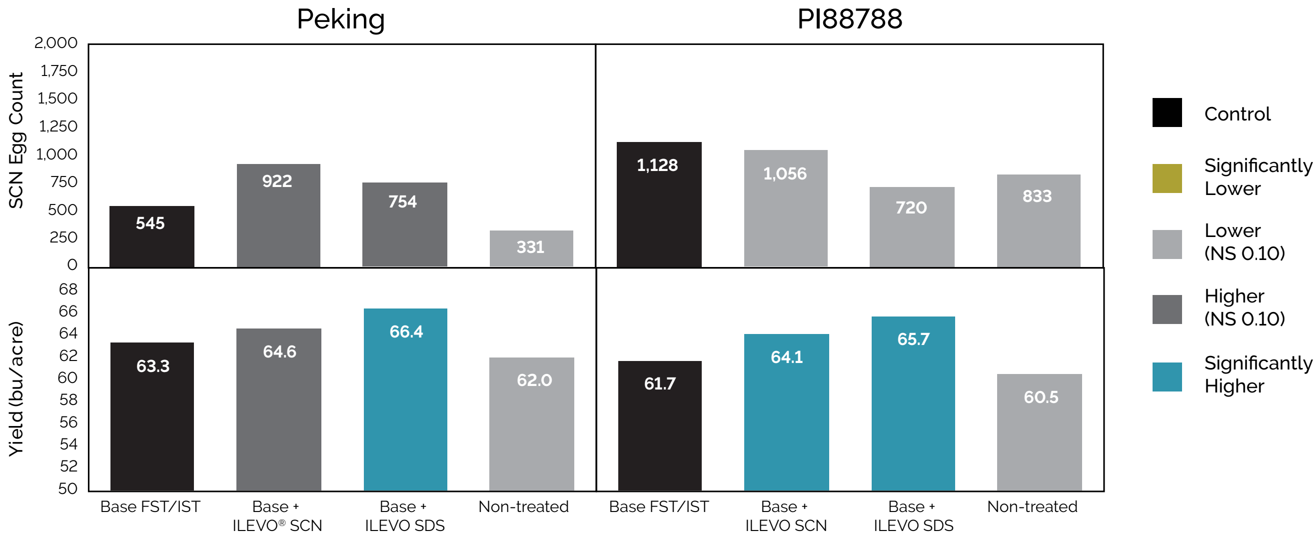


Figure 2. Average SCN egg counts and yield in locations with moderate SCN pressure.

High Pressure Locations

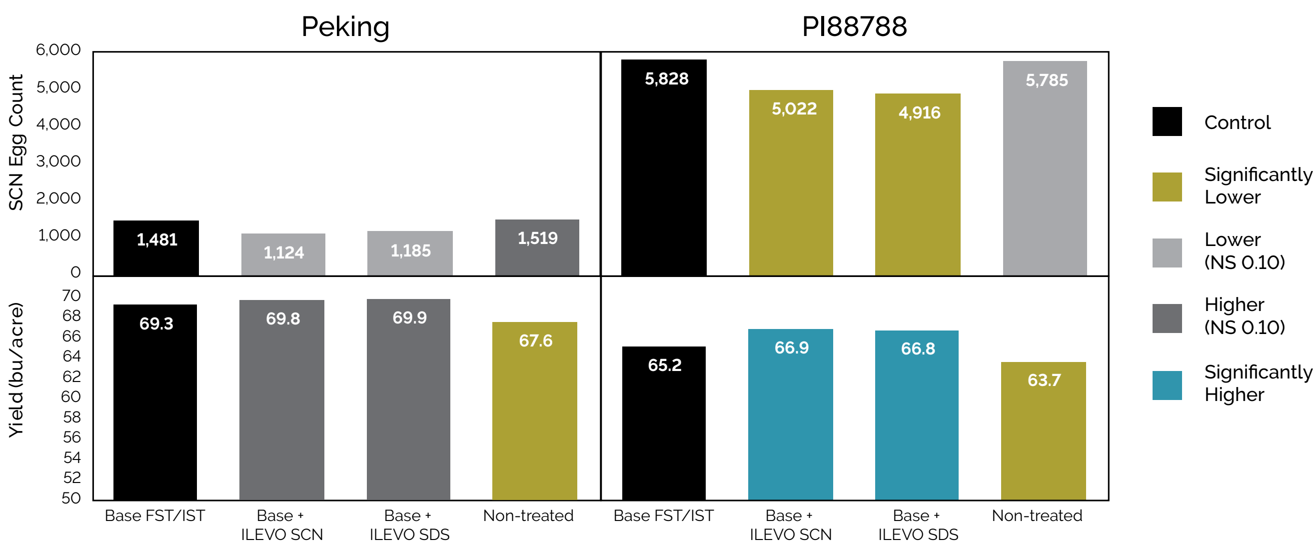


Figure 3. Average SCN egg counts and yield in locations with high SCN pressure.

Discussion

- This study further demonstrates that SCN populations capable of reproducing on PI88788 varieties are becoming more common and are found in many fields across the RM 2 through 4 growing region. The use of varieties with different sources of genetic resistance and the use of nematicide seed treatments are critical for limiting yield loss from SCN parasitism.
- In fields where PI88788 performance may be challenged due to resistant SCN populations, ILEVO® nematicide seed treatment can provide significant yield recovery under moderate pressure. In these environments, the PI88788 isoline with ILEVO seed treatment yielded statistically the same (within 0.5 bu/acre) as the Peking isoline with ILEVO seed treatment.
- ILEVO nematicide seed treatment provided benefit to PI88788 genetics under high SCN pressure as well, but selecting varieties with the Peking source of resistance will be a key management tactic in these environments.

return to table of contents

fusarium head blight

Madeline Henrickson, *Agronomy Sciences Intern*

Pathogen Facts

- Several species of fusarium are capable of causing disease, but fusarium head blight (FHB) is caused by the fungus *Fusarium graminearum (Gibberella zeae),* which also causes Gibberella stalk and ear rot in corn.
- This pathogen overwinters on the soil and stubble of susceptible host crops (like corn and wheat).
- Infected grain has reduced quality due to the DON vomitoxin (deoxynivalenol) produced by this pathogen.
    - Grains contaminated with mycotoxins are a threat to humans and livestock that consume them.

Figure 1. Wheat head showing bleaching symptoms after infection from *Fusarium graminearum.*

Conditions Favoring Disease

- Disease either over-winters in infected seed or on crop debris.
- Spores are carried to wheat via wind during initial infection.
- Infection occurs during the flowering stage. The anthers and pollen serve as a food source for the germinating fungus.
- This disease is more severe in no-till fields, particularly in wheat following corn due to larger amounts of primary inoculum.

Figure 2. Variation in wheat head infection by *Fusarium graminearum.*
Photo courtesy of Matt Montgomery, Field Agronomist.

Symptoms

- Wheat heads will bleach prematurely, either partially or fully.
- Warm weather can stimulate the development of light pink sporodochia on the rachis and glumes of spikelets.
    - Later in the season, blueish-black spherical fruiting bodies will form.
- Grain will shrink and wrinkle, becoming shriveled and varying in color from pink to brown to soft gray.
    - Reduced grain size also results in a lower test weight.
- When temperatures range from 77-86 °F (25-30 °C), symptoms will show 3 days after infection.

Figure 3. Wheat head infected with *Fusarium graminearum.* Both pink colored spores and darker fruiting bodies are visible.

Management Considerations

- *Fusarium graminearum* overwinters in crop debris, so production practices that reduce the amount of crop residue on the surface, such as tillage and crop rotation, will decrease the amount of primary inoculum.
- Selecting tolerant cultivars and varieties can lessen the severity of infection.
- Some combines can be adjusted to flush out lightweight infected grain, reducing seedborne spread of the disease.
- During the flowering period, foliar fungicides can be applied to mitigate the impacts of fusarium head blight.
    - Farmers must consider the cost of the application and market value of their grain before determining if fungicides will be an economical solution.

return to table of contents

powdery mildew of cereals

Madeline Henrickson, *Agronomy Sciences Intern*

Pathogen Facts

- This fungal disease, caused by the obligate biotroph *Blumeria graminis*, is one of the most common diseases of wheat.
- Powdery mildew can be devastating, reducing yields up to 25%.
- This pathogen produces overwintering structures called "chasmothecia" that persist on infected crop residue.

Figure 1. Powdery mildew mycelium at the base of wheat stems where airflow is minimal and relative humidity is high. *Photo courtesy of Mary Burrows, Montana State University, Bugwood.org.*

Conditions Favoring Disease

- High relative humidity (70-95%) and moderate temperatures of 60-70 °F (16-21 °C) are conducive for disease development.
- Dense canopies increase humidity near leaf surfaces and facilitate the spread of the pathogen.
- Rapidly growing tissue and new growth is more susceptible to infection.
- Infection severity typically diminishes as temperatures increase during late spring and early summer.

Symptoms and Signs

- Symptoms begin as minor, yellow flecks on foliage closer to the soil surface, making them difficult to distinguish.
- As the disease progresses, fluffy, white mycelium begins to grow on lower leaves, progressing up the plant and eventually reaching the wheat head.
- Lesions on the head turn gray with age before developing into darker-colored overwintering structures (chasmothecia).

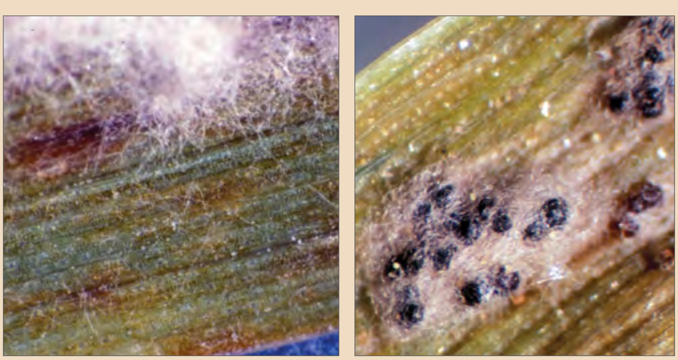


Figure 2. Mycelium and overwintering structures of *Blumeria graminis. Photos courtesy of Department of Plant Pathology, North Carolina State University, Bugwood.org.*

Figure 3. Powdery mildew on wheat (note the tiny, black chasmothecia nested inside some of the patches of mycelium). *Photo courtesy of Gerald Holmes, Cal. Polytechnic State Univ. at San Luis Obispo, Bugwood.org.*

Management Considerations

- Practices that decrease canopy density, such as implementing lower planting populations and avoiding excess nutrient applications, will also disfavor the pathogen development.
- Increasing the diversity of crop rotations and eliminating volunteer plants removes host crops and decreases the inoculum in the cropping system.
- Resistant varieties can be used to help combat this disease.
- Seed treatments and fungicide applications are also available to prevent the spread of this disease.
  - » Fungicides should be applied early in the season at the flag leaf stage.

septoria tritici blotch

Madeline Henrickson, *Agronomy Sciences Intern*

Pathogen Facts

- *Zymoseptoria tritici* is the name of the anamorph of the causative pathogen, and *Mycosphaerella graminicola* is the name of the teleomorph.
- This pathogen was discovered in 1842 and is now considered the second ranking global pathogen of wheat.

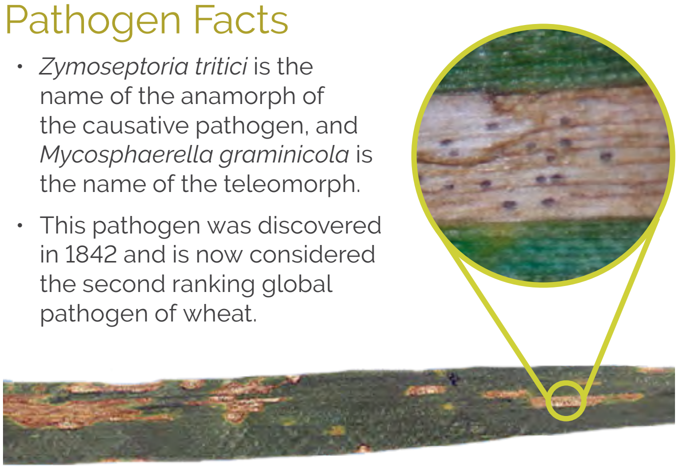


Figure 1. *Zymoseptoria tritici* on wheat leaves; note how leaf veins delimit the lesions and pycnidia is visible in lesions. *Photo courtesy of Matthew Montgomery, Field Agronomist.*

Symptoms and Signs

- The primary inoculum is spread from infected crop residues via airborne spores and raindrop splash.
- Beginning symptoms start right after seed emergence as chlorotic spots develop.
- These irregular or elliptical lesions become tan and develop dark fruiting bodies, pycnidia, within lesions.
- Pycnidia will produce whitish ooze as spores disperse. Lesions are delimited by leaf veins, developing in substomatal cavities, which cause them to be evenly spaced.
- Secondary inoculum is spread through direct contact with infected plants and wind dispersal of spores.

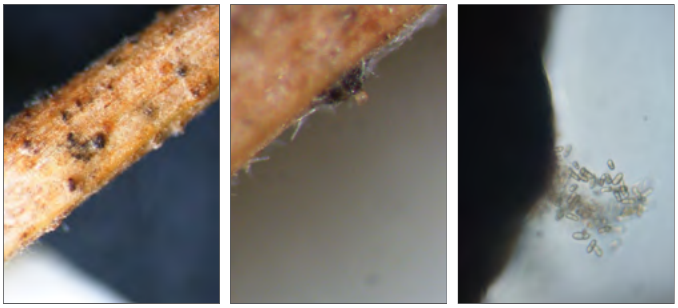


Figure 2. Ascospores of *Zymoseptoria tritici* emerging from a pseudothecia (dark-colored overwintering structure). *Photo courtesy of Mary Burrows, Montana State University, Bugwood.org.*

Figure 3. Asexual spores of *Zymoseptoria tritici. Photo courtesy of Paul Bachi, University of Kentucky Research and Education Center, Bugwood.org.*

Conditions Favoring Disease

- This pathogen persists in the system from infected seed, residues, and cereal crops that are overwintering.
- Disease is polycyclic, re-infecting as long as the conditions are cool and wet, which is favorable for this pathogen.

Management Considerations

- Resistant cultivars are economical, but their effectiveness varies greatly from one region to the next.
- *Zymoseptoria tritici* overwinters in crop debris, so practices that reduce the amount of crop residue on the surface, such as tillage, late planting, and crop rotation, will decrease the amount of primary inoculum.
- Foliar sprays are available, but this pathogen quickly develops resistance to fungicides.

Figure 4. Tan *Zymoseptoria tritici* lesions on wheat leaves. *Photo courtesy of Mary Burrows, Montana State University, Bugwood.org.*

tan spot of wheat

__Madeline Henrickson,__ Agronomy Sciences Intern

Pathogen Facts

- Tan spot, also known as yellow leaf spot, is caused by the fungal pathogen *Pyrenophora tritici-repentis.*
- This disease is polycyclic, meaning multiple infections can happen throughout the growing season.

Figure 1. Wheat leaf with tan spot lesions during different stages of maturity. *Photo courtesy of Sam Tragesser, Senior Research Associate.*

Symptoms and Signs

- Initial symptoms are tan, necrotic spots surrounded by a yellow halo.
- As lesions expand, they take on a more angular, diamond shape and typically have a darker center.
- Lesions coalesce and form large, tan, blotchy areas of necrosis.
- From tillering to ripening, a red/dirty smudge can be seen on ripening kernels.
- On straw stems, dark-colored overwintering structures can be visible in the fall.

Figure 2. Wheat stems with dark-colored overwintering structures. *Photo courtesy of Emmanuel Byamukama, South Dakota State University, Bugwood.org.*

Conditions Favoring Disease

- Tan spot is favored by wet, windy weather that is conducive for spore development and distribution.
- Because this disease is polycyclic, infection can occur at any time during the growing season.
- This disease overwinters on crop residue and grassy hosts.
- When leaf wetness reaches or exceeds 24 hours, the disease develops and spreads rapidly.

Management Considerations

- Varieties with moderate levels of resistance are available.
- *Pyrenophora tritici-repentis* overwinters in crop debris, so production practices ,such as tillage and crop rotation, that reduce the amount of crop residue on the surface will decrease the amount of primary inoculum.
- Foliar fungicides can be applied to mitigate the impacts of tan spot.
  - » Farmers must consider the variety susceptibility, weather forecasts, cost of the application, and the market value of their grain before determining if fungicides will be an economical solution.

Figure 3. Wheat leaf with irregular-shaped tan spot lesions. *Photo courtesy of Mourad Louadfel, Homemade, Bugwood.org*

Figure 4. Wheat plants in field displaying typical tan spot symptoms. *Photo courtesy of Emmanuel Byamukama, South Dakota State University, Bugwood.org,*

wheat leaf rust

Madeline Henrickson, *Agronomy Sciences Intern*

Pathogen Facts

- Wheat leaf rust is caused by the fungal pathogen *Puccinia triticina.*
- Unlike other major foliar diseases in North America, leaf rust does not overwinter in fields.
  - » Rusts develop in southern states and move by windblown spores that travel northward with prevailing weather systems.
- Light to moderate yield losses of 1 to 20% have been observed as a result of this disease.

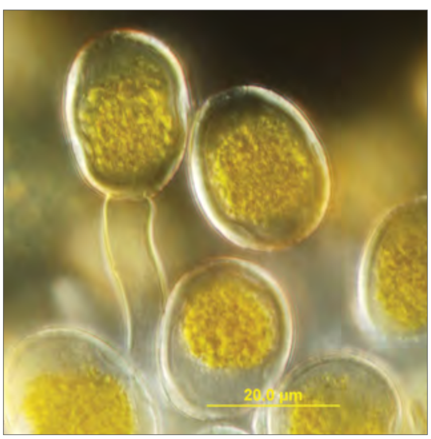


Figure 1. *Puccinia triticina* asexual uredin-iospores. *Photo courtesy of Bruce Watt, Univ. of Maine, Bugwood.org.*

Symptoms and Signs

- Initial symptoms are circular to oval yellow spots on upper leaf surfaces.
- These develop into orange, circular-shaped pustules that give off an orange dusting of spores if disturbed.
- Photosynthesis is reduced as functional leaf area decreases, which can reduce head fill and yield.
- Infection is most critical during the jointing and flowering stages of the wheat life cycle.

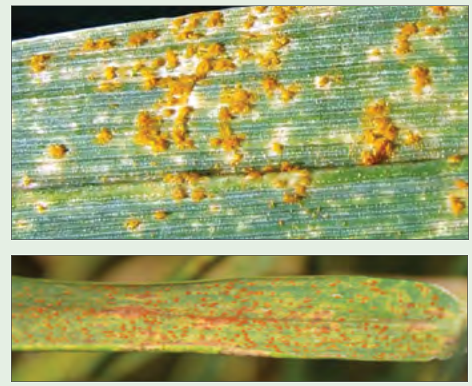


Figure 2. Wheat leaves with leaf rust pustules. *Photo courtesy of Donald Groth, Louisiana State University AgCenter, Bugwood.org (top) and Emmanuel Byamukama, South Dakota State Univ., Bugwood.org (bottom).*

Conditions Favoring Disease

- Optimum temperature for Puccinia triticina growth is warm, ranging from 60 to 80 °F (approximately 15 to 25 °C).
- If winter temperatures are mild, then rust can overwinter in fields on infected wheat plants.
- Windborne spores travel from southern regions and are deposited via rain.

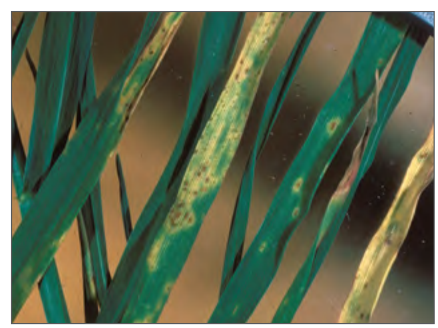


Figure 3. Leaf rust in cereal rye. *Photo courtesy of University of Georgia Plant Pathology, University of Georgia, Bugwood.org.*

Management Considerations

- Wheat breeders are constantly making varieties with varying levels of resistance to this pathogen.
  - » Rust has the ability to develop resistance quickly due to dynamic, ever-changing resistance genes.
- If infection occurs on the flag leaf, then foliar fungicide applications may be justified.

Figure 4. Wheat plot with different levels of resistance to leaf rust. *Photo courtesy of Donald Groth, Louisiana State University AgCenter, Bugwood.org.*

return to table of contents

stripe rust of wheat

Madeline Henrickson, *Agronomy Sciences Intern*

Pathogen Facts

- Stripe rust, also called yellow rust, is caused by the fungal pathogen *Puccinia striiformis.*
- This disease can be distinguished from stem and leaf rust by the formation of the pustules as well as the coloration of the urediniospores.
- This pathogen is common in areas with higher elevations due to the cooler climate with frequent leaf wetness.

Figure 1. *Puccinia striiformis* infection of wheat. *Photo courtesy of Sam Tragesser, Senior Research Associate.*

Symptoms and Signs

- Initial symptoms are circular to oval yellow spots on upper leaf surfaces at the infection sites.
- These develop into yellow-orange pustules bearing urediniospores that dust off when disturbed.
- Lesions elongate, forming a notable stripe shape on leaf surfaces.
- Photosynthesis is reduced as functional leaf area decreases, which can reduce head fill and yield.
- Darker-colored teliospores form later in the season.

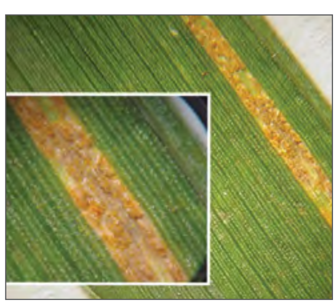


Figure 2. Urediniospores from *Puccinia striiformis. Photo courtesy of Matt Montgomery, Field Agronomist.*

Figure 3. Stripe rust pustules forming elongated lesions. *Photo courtesy of Craig Herzog, Senior Agronomist.*

Conditions Favoring Disease

- Stripe rust can develop at lower temperatures than other rust diseases. Development is favored by 50 to 64 °F (0 to 18 °C) temperatures with at least 6 hours of dew present.
- Stripe rust can survive winter temperatures above 23 °F (-5 °C).
- Urediniospores can travel long distances, spreading from field to field via wind.

Management Considerations

- Planting resistant wheat varieties is the primary method to reduce losses to stripe rust.
- There are two types of genetic resistance to stripe rust: seedling resistance and adult plant resistance.
  - » Seedling resistance is effective throughout the life of the plant but is usually only against some races of the pathogen.
  - » Adult plant resistance develops as plants mature.
- If growing a susceptible variety and infection occurs on the flag leaf, then foliar fungicide application may be justified.
- Decreasing irrigation in fields also limits the amount of water available for leaf wetness, disfavoring disease development.

return to table of contents

wheat management to maximize yield potential

Brian Bunton, *Field Agronomist*

Adequate Stands for Top Production

- Stand establishment is critical for achieving high yields and having good weed control. Seeding rates should consider the amount of seeds per acre rather than pounds of seed per acre. Rates from 1.2 to 1.8 million seeds/acre should be acceptable depending on tillage and planting date.
- Stand establishment of 27 to 35 plants/ft^2 with 3 to 5 tillers/plant is optimal. To maximize potential yield, there should be at least 40 heads/ft^2 with the optimum numbers between 60 and 80 heads/ft^2. Final stands of 15 to 18 plants/ft^2 or less are candidates for replanting to corn or soybeans.
- Rule of thumb for yield potential: 1.3 to 1.6 bu/acre per head/ft^2.

Nitrogen Management

- Wheat uses 1.1 to 1.5lbs of nitrogen for each bushel of expected yield and utilizes 70 to 75% of the total nitrogen requirement between Feekes growth stages 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.
  - High rates 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 green-up and another 60 lbs/acre at Feekes growth stage 4 to 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 induce tillering and consequently increase the number of heads/ft^2. In this situation, a split application may help. Apply 60 lbs/acre of nitrogen for a first application (before green-up) and another 40 lbs/acre at Feekes growth stage 4 to 5 (before jointing).
- A split application of nitrogen is suggested and has shown positive yield results, especially on light or sandy soils.
- Nitrogen application rates may 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.

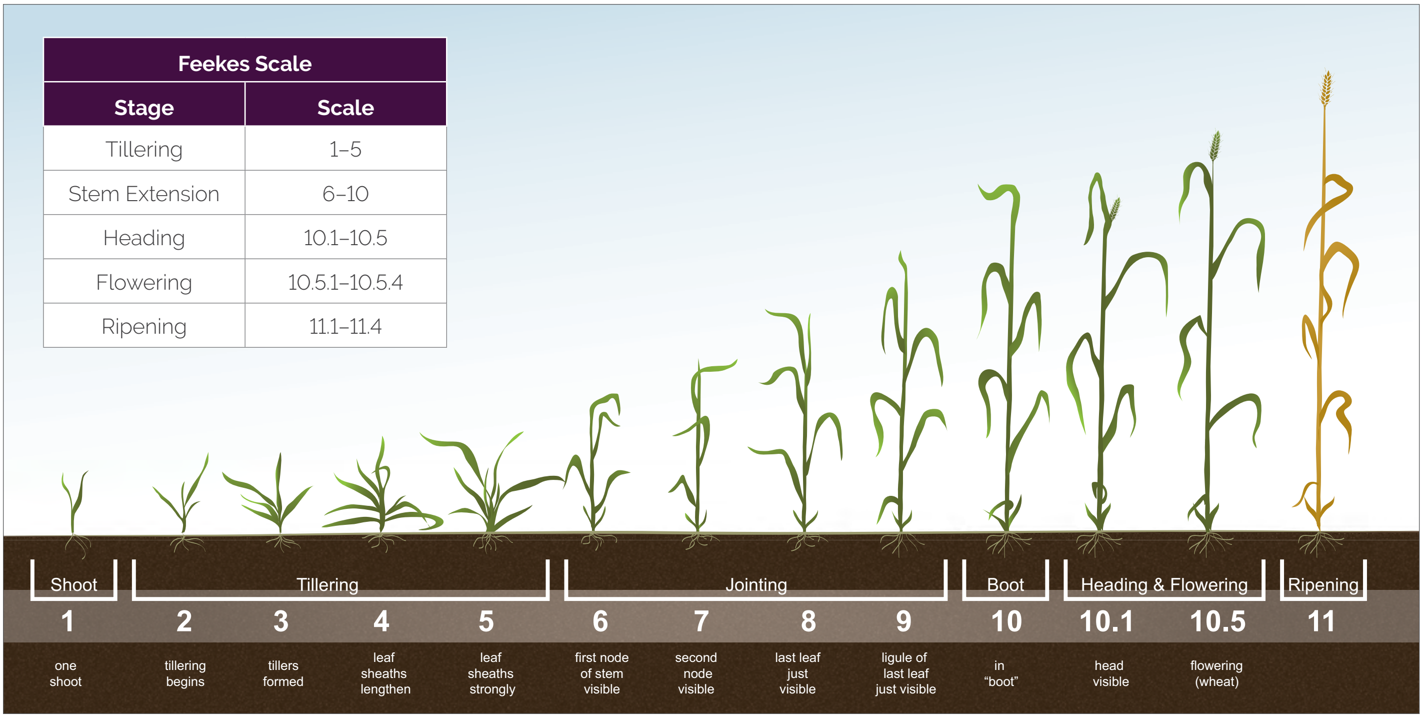
Table 1. Recommended topdress nitrogen fertilizer rates for wheat at various yield levels and soil textures (Mansfield and Hawkins, 1992).

Cation Exchange Capacity	Nitrogen Rate When Yield Goal (bu/acre) is:					
	30-44	45-54	55-64	65-74	75-85	>85
meq/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

Pest Management

- **Insects:** Scouting is critical. If aphid populations exceed thresholds (10 per foot of row with early green-up 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 optimal yield and flag-leaf disease control, apply DuPont™ Aproach® Prima fungicide at 6.8 fl oz/acre at Feekes stage 9.
- **Weeds:** Start clean, stay clean! Keep fields clean early, and do not let weeds get too big. Use a burndown herbicide well before planting in no-till environments to eliminate weeds and volunteer corn. Use multiple tillage passes in a conventional tillage program, if needed, to start clean. The best weed control after seeding is a good stand of wheat.
- **Recommendation:** Quelex® herbicide with Arylex™ active. Apply 0.75 ounces of Quelex herbicide per acre to actively growing wheat from 2-leaf to flag-leaf emergence stage. For best results, apply when weeds are actively growing in the 2- to 4-leaf stage or less than 4 in tall. Be sure to read and follow all label directions.
- Do not apply a total of more than 0.75 oz of Quelex herbicide per acre per season. Consider the fall weed-management program before proceeding with spring treatments.
- Consult your local Pioneer sales professional or Corteva Agriscience crop protection representative for local, specific recommendations.

Feekes Scale	
Stage	**Scale**
Tillering	1–5
Stem Extension	6–10
Heading	10.1–10.5
Flowering	10.5.1–10.5.4
Ripening	11.1–11.4



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

Photo courtesy of Purdue Extension.

Ripening Stage

Feekes 11.0

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

Photo courtesy of Jonah Johnson, Corteva Agriscience.

return to table of contents

high yield sorghum production

Mark Jeschke, Ph.D., Agronomy Manager

National Sorghum Producers Yield Contest

- The National Sorghum Producers (NSP) Yield Contest provides a benchmark for yields that are attainable under optimal conditions and management.
- The NSP Yield Contest recognizes three national winners annually in each of five production divisions in east and west regions:
  - Irrigated Tillage
  - Irrigated No-Till
  - Dryland Tillage
  - Dryland No-Till
  - Food Grade
- Average yields of national winners in each division are shown in Figure 1.

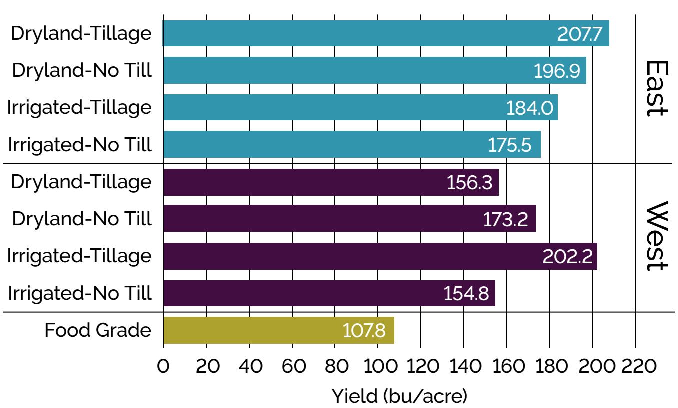


Figure 1. Average yield of 2019 NSP Yield Contest national winners by contest category.

Hybrid Selection

- Selecting the right hybrid is likely the most important management decision of all those made by contest winners.
- Maximizing yield 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.
- Pioneer® brand products were used in 22 out of 25 NSP Yield Contest national winners in 2012-2017 (Figure 2).
- Seven different Pioneer brand sorghum hybrids were national winners in 2019 in 11 different states (Table 1).
- All eight national winners that exceeded 200 bu/acre were planted to Pioneer brand sorghum hybrids (Figure 2).

Table 1. 2019 NSP Yield Contest national winning entries using Pioneer brand products.

Entrant Name	Division	State	Hybrid	Yield (bu/a)
Santino Santini	Dry Till East	NJ	84G62	212.57
Gage Porter	Dry Till East	MO	84G62	209.06
Harry Johnston	Dry Till East	PA	84G62	201.32
Chris Santini	Dry NT East	NJ	84G62	206.80
Ella Johnston	Dry NT East	PA	84G62	204.70
Galt Porter	Dry NT East	MO	84G62	179.05
Sanduff Farms	Irr Till East	NJ	84G62	199.66
Tom Krull	Irr Till East	MI	87P06	178.59
Jeff Scates	Irr Till East	IL	84G62	173.63
River Hollow Farms	Irr NT East	NJ	84G62	206.18
John Scates	Irr NT East	IL	84G62	181.41
Frank G. Hrupsa	Irr NT East	DE	84G62	138.93
Nicholas Schoenthal	Dry Till West	MO	84G62	156.76
Dodson Family Farms	Dry Till West	TX	83P27	140.13
Ki Gamble	Dry NT West	KS	85P44	194.99
Lyle Fisher	Dry NT West	NE	84P72	187.50
Livingston Farms LLC	Dry NT West	CO	87P06	137.21
Kimberly Gamble	Irr Till West	KS	84G62	204.54
Michael Ball	Irr Till West	ID	85Y40	203.08
Chad Dane	Irr Till West	NE	84P72	198.90
Gaunt Farms	Irr NT West	KS	84G62	156.11
Lynn Born	Irr NT West	TX	84P68	148.09

return to table of contents

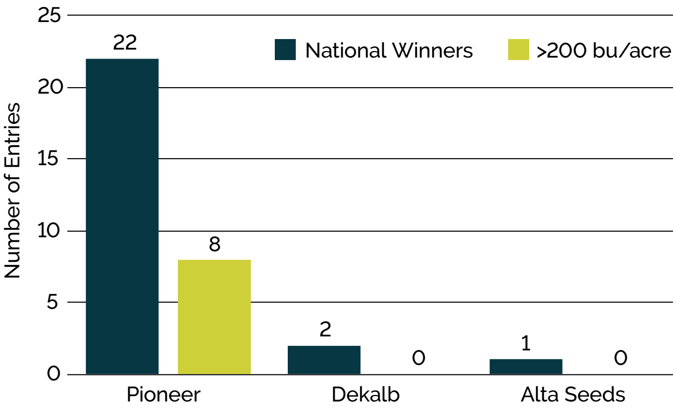


Figure 2. Seed brand planted by NSP Yield Contest national winners and winners yielding above 200 bu/acre in 2019.

Seeding Rate

- Seeding rate of NSP Yield Contest winning entries varied among divisions (Figure 3).
- Average seeding rate of national winners in eastern region divisions was 106,000 seeds/acre compared to 65,000 seeds/acre in western region divisions.
- In general, average seeding rate of national winners was greater than that of contest entries in most divisions.

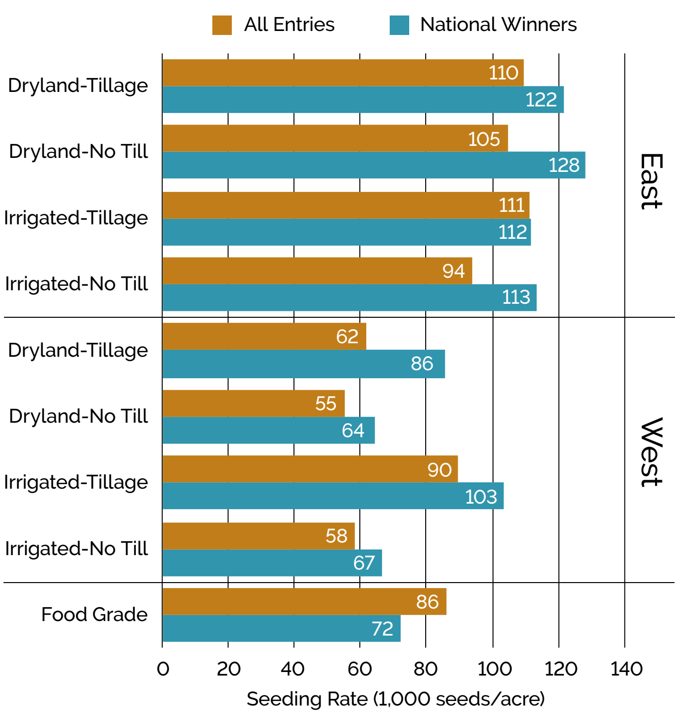


Figure 3. Average seeding rate of NSP Yield Contest national winners and all contest entries in each division in 2019.

Row Spacing

- The most common row width used in the NSP Yield Contest was 30-inch rows, which was used in 55% of contest entries (Figure 4).
- 15-inch rows was the second most popular row width, accounting for 18% of entries.

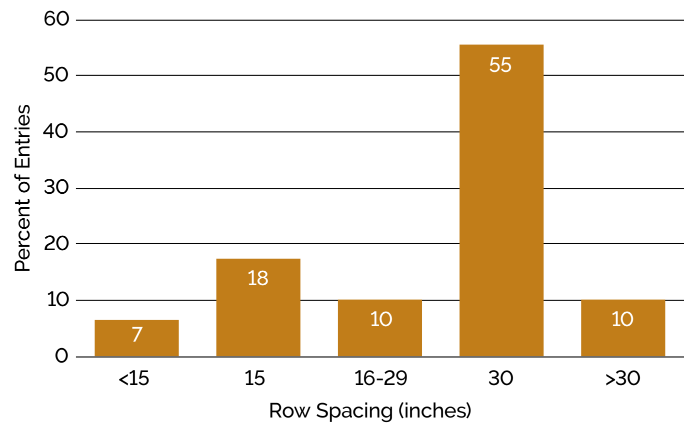


Figure 4. Row spacings used in NSP Yield Contest entries in 2019.

Nitrogen Fertilizer

- Although sorghum is considered a relatively low-input crop compared to corn, nitrogen is the nutrient that most frequently limits sorghum production.
- Sorghum requires approximately 1.1-1.5 lbs of nitrogen per bushel harvested, so total nitrogen needed per acre can depend on expected yield.
- Only a portion of this amount needs to be supplied through nitrogen fertilizer; N is also supplied by the soil through mineralization of soil organic matter.
- The most common nitrogen fertilizer rates among 2019 NSP Yield Contest entries ranged from 101-150 lbs/acre (Figure 5).

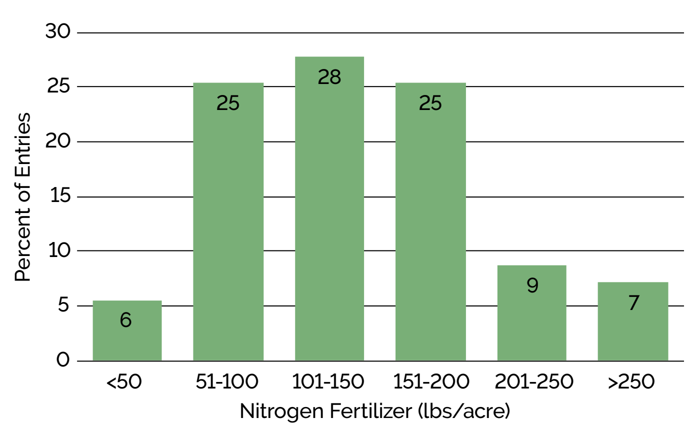


Figure 5. Nitrogen fertilizer application rates used in NSP Yield Contest entries in 2019.

authors

return to table of contents

Julie Abendroth, Ph.D., *Project Leader*

Eric Alinger, *Field Agronomist*

Jake Bates, *Field Agronomist*

Brian Bunton, *Field Agronomist*

Steve Butzen, M.S., *Agronomy Information Consultant*

Crystal Dau, *Field Agronomist*

Michael DeFelice, Ph.D., *Former Senior Manager: Herbicide, Ag Traits, & Seed Treatments*

Bill Dolezal, Ph.D., *Former Research Fellow*

Ross Ennen, M.S., *Senior Research Associate*

Scott Eversgerd, *Field Agronomist*

Li Feng, Ph.D., *Research Scientist*

Kevin Fry, *Field Agronomist*

Adam Gaspar, Ph.D., *Global Biology Leader Seed Applied Technologies*

Justin Gray, *Senior Research Associate*

Grant Groene, *Global Seed Agronomy Lead*

Kevin Hahn, Ph.D., *Field Development Senior Consultant*

Dennis Holland, *Product Agronomist*

Dave Johnson, Ph.D., *Research Scientist*

Adam Krull, DVM, PhD., *Senior Nutritionist*

Don Kyle, *Soybean Breeder*

Nate LeVan, *Field Agronomist*

Bill Long, *Field Agronomist*

Bill Mahanna, Ph.D., *Global Nutritional Sciences Manager*

Charlie Messina, Ph.D., *Corteva Laureate*

Chris Parry, Ph.D., *Research Scientist*

Kirk Reese, *Former Agronomy Research Manager*

Samantha Reicks, *Agronomy Sciences Intern*

Marlin E. Rice, Ph.D., *R&D Academic Engagement Leader*

Landon Ries, Ph.D., *Research Scientist*

Jose Rotundo, Ph.D., *Research Scientist*

Adda Sayers, M.S., *Former Research Scientist*

Stephen Strachan, Ph.D., *Former Research Scientist*

Leroy Svec, *Former Research Scientist*

Samantha Teten, *Agronomy Sciences Intern*

Ryan Van Roekel, Ph.D., *Field Agronomist*

Hannah Weber, *Agronomy Intern*

Jeff Wessel, *Former Pioneer Agronomy Trials Manager*

Alex Woodall, *Field Agronomist*

Chris Zwiener, *Product Life Cycle Manager*

University Authors

Samuel Banks*,*
Ohio State University

Ignacio Ciampitti, Ph.D., *Associate Professor,*
Department of Agronomy,
Kansas State University

Allen Geyer, M.S., *Senior Research Associate,*
Department of Horticulture and Crop Sciences,
Ohio State University

Alex Lindsay, Ph.D., *Assistant Professor,*
Department of Horticulture and Crop Sciences,
Ohio State University

Emerson Nafziger, Ph.D., *Professor,*
Crop Sciences,
University of Illinois

Matheus Ogando do Granja, *Visiting Scholar,*
Department of Horticulture and Crop Sciences,
Ohio State University

Ashley Richie,
Ohio State University

Santiago Tamagno, Ph.D.,
Kansas State University

Peter Thomison, Ph.D., *Assistant Professor,*
Department of Horticulture and Crop Sciences,
Ohio State University

Editing and Proofing

Kari Schmidt

return to table of contents

agronomy sciences

The Pioneer Agronomy Sciences group supports and coordinates the efforts of agronomy field teams around the globe in order to provide Pioneer customers with the best possible management insights to help maximize productivity on their farms. Members of the Agronomy Sciences team bring together expertise on a wide range of agronomic specialties and experience in industry, academia, and agricultural production.

The current agronomy support and research structure at Pioneer can be traced back to the creation of the Technical Services Department at Pioneer in 1962. Initially consisting of five agronomists, the Technical Services team conducted winter corn production meetings that attracted thousands of farmers and provided customers with Pioneer Corn Services Bulletins, a major source of information about growing corn. In 1986, the Agronomy Services Support Department was created to provide information and crop management research support to the expanding team of Pioneer agronomists. This department continued to evolve into what is today called the Agronomy Sciences group. Many things have changed over the past 30 years, but the core mission of this group has remained the same.

Pioneer has product agronomists who work on IMPACT testing and provide product knowledge positioning insights and training to account managers, sales professionals, and dealers as well as field agronomists who lead agronomy training efforts and on-farm Pioneer Agronomy trials. The Agronomy Sciences team helps coordinate these trials and leads efforts to develop and archive agronomy information resources in the online Agronomy Library.

Dan Berning, *Agronomy Manager*

Dan earned his B.S. in agriculture at Kansas State University. In the fall of 1989, he started his career with Pioneer as an Area Agronomist, supporting the sales team and their customers in western Kansas and southern Colorado. He became the Pioneer Field Sales Agronomist in northeast and north-central Nebraska in 1994. In 1998, he was promoted to Field Sales Agronomy Manager for the Plains Sales Area. Dan has had the privilege of supporting the Pioneer sales team and customers across the Western Corn Belt in the roles of Technical Information Manager, Technical Services Manager, and now as the Agronomy Manager.

Brewer Blessitt, Ph.D., *Agronomy Manager*

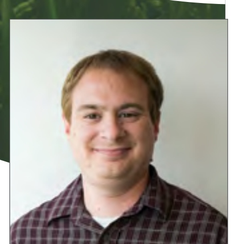
Brewer received his undergraduate in biology from Delta State University and his M.S. and Ph.D. in agronomy from Mississippi State University. His primary areas of interest are soil fertility, crop physiology, and crop genetics. He challenges current practices and thoughts in crop production. He works closely with field sales and research to drive application of innovative tools and technologies on farm.

Matt Clover, Ph.D., *Agronomy Manager*

Matt is responsible for helping guide on-farm trials planning, protocol development, analysis, and communication of trial results. Matt leverages his experience in soil fertility to bolster expertise of the Agronomy Sciences team to support Pioneer agronomists and sales teams. Matt earned his Ph.D. in soil fertility from Iowa State University and his M.S. and B.S. degrees from the University of Illinois in crop sciences; he is a Certified Professional Soil Scientist (CPSSc). Matt came to Pioneer in April 2017 after a 9-year career in the fertilizer industry with various roles in agronomy, as well as research and development.

Matt Essick, M.S., *Agronomy Manager*

Matt is from a small community in northwest Iowa and earned his B.S. in agricultural business and M.S. in agronomy from Iowa State University. Matt joined Pioneer as a Management Assistant working at the Cherokee, Iowa, soybean production plant. He transitioned to a Pioneer Sales Representative where he gained hands-on experience in both sales and agronomy before becoming a Territory Manager for Pioneer. Matt transitioned to an Area Agronomist and then to a Product Agronomist before joining the Agronomy Sciences Team. Matt is responsible for the Northern U.S.



Eric Galdi, *Agronomy Systems Manager*

Eric is a native of Wisconsin and obtained his B.S. degree in soils and crop science from University of Wisconsin – Platteville and is currently pursuing his M.S. degree in Agronomy from Iowa State University. He provided nutrient/manure management and precision agriculture services to growers in Wisconsin before joining Pioneer in 2009. He has held various roles at Pioneer in corn research and Encirca® Services before joining the Agronomy Science team.

Mary Gumz, Ph.D., *Agronomy Manager*

Mary is a native of northern Wisconsin and earned her B.S. in agronomy from the University of Minnesota – Twin Cities and M.S. and Ph.D. in weed science from Purdue University. After working in the crop protection and seed industries as a Technical Service Agronomist, she joined Pioneer in 2008 as an Area Agronomist and later became Product Agronomist for northwest Indiana. She is now the Agronomy Manager for the Eastern U.S.

Mark Jeschke, Ph.D., *Agronomy Manager*

Mark earned his B.S. and M.S. degrees in crop sciences at the University of Illinois at Urbana-Champaign and Ph.D. in agronomy at the University of Wisconsin-Madison. Mark joined Pioneer in 2007 and currently serves as Agronomy Manager. His primary role is development and delivery of useful and timely agronomy information based on Pioneer and university agronomy research. Mark authors and edits many of the agronomy resources available in the Pioneer agronomy library. Mark is originally from northern Illinois and is actively involved in the family corn and soybean farm near Rock City, Illinois.

Brent Wilson, M.S., *Product Line & Agronomy Leader*

Brent Wilson serves as Leader of Product Management and Agronomy for the Pioneer brand in the U.S. In the past 30+ years with Pioneer, he has held various roles associated with crop management in both the sales and research areas. His current role is to support the team of Field and Product Agronomists with systems, processes, and information to advance the best products, learn those products, and position them with our customers with a high degree of crop management information. Brent holds a B.S. in agronomy and pest management from Iowa State University and Master's of agronomy from Iowa State University.

April Battani, *Graphic Designer*

April earned both a B.A. in graphic design and a B.A. in creative advertising from Drake University in Des Moines, Iowa. She started with Pioneer in 2012 as a Publishing Assistant for Agronomy Sciences. She currently works as a Graphic Designer for both the Agronomy Sciences as well as Sales and Agronomy Training teams. Her role includes the design, publication, and project management of web-based and printed materials, including the Agronomy Sciences Research Summary books produced annually. In addition, April provides individually tailored illustrations and charts for internal sales, marketing, and research clients.

Madeline Henrickson, *Agronomy Sciences Intern 2020*

Madeline is a senior at Michigan State University majoring in crop and soil sciences. Following her graduation in December 2019, Madeline plans to pursue a Master's degree in plant pathology.

Sources

Abendroth, L.J., R.W. Elmore, M.J. Boyer, and S.K. Marlay. 2011. Corn growth and development. PMR 1009. Iowa State Univ. Ext., Ames, Iowa.

Agrios, G.N. 1988. How plants defend themselves against pathogens. In: Plant Pathology. 3rd ed. Academic Press, Inc., San Diego, CA. p. 97-115.

Ahrens, W.H., editor, 1994. Herbicide handbook. 7th ed. Weed Sci. Soc. Am. Champaign, IL. p. 352.

Alyssa, C. 2013. Fusarium head blight. PennState Ext., University Park, PA. https://extension.psu.edu/fusarium-head-blight

Anderson, W.P. 1996. Weed science: principles and applications. 3rd ed. West Publishing Company, Minneapolis/St. Paul, MN. p. 388.

Anonymous. 1998-1999. EPA-approved herbicide labels produced by their respective manufacturers.

Anonymous. 1999. Crop protection reference. 15th ed. C & P Press, New York. p. 2465.

Ashton, F.M. and T.J. Monaco. 1991. Weed science: principles and practices. 3rd ed. John Wiley & Sons, Inc., New York. p. 466.

Ayyappath, R., J.F. Witkowski, and L.G. Higley. 1996. Population changes of spider mites (Acari: Tertranychidae) following insecticide application in corn. Environ. Entomol. 25:933-937.

Bergstrom, G.C. 2020. Anthracnose leaf blight. Cornell Univ. Coop. Ext., Ithaca, NY. https://fieldcrops.cals.cornell.edu/sites/fieldcrops.cals.cornell.edu/files/shared/documents/anthracnoseleaf_factsheet.pdf (accessed 2020).

Berzsenyi, Z., B. Gyorffy, T. Arendas, P. Bonis, and D.Q. Lap. 1997. Studies on the phytotoxicity of herbicides in maize (*Zea mays L.*) as affected by temperatures and antidotes. Acta Agronomica Hungarica. 45(4) 443-448.

Bissonnette, S. 2000. Fungal leaf disease showing up in corn. The Bulletin. Univ. of Illinois Ext., Urbana, IL. http://ipm.uiuc.edu/bulletin/pastpest/articles/200014h.html

Bissonnette, S. 2015. CORN DISEASE ALERT: New fungal leaf disease "tar spot" Phyllachora maydis identified in 3 northern Illinois counties. The Bulletin. Univ. of Illinois Ext., Urbana, IL. https://farmdoc.illinois.edu/field-crop-production/diseases/corn-disease-alert-new-fungal-leaf-disease-tar-spot-phyllachora-maydis-identified-in-3-northern-illinois-counties.html

Boldt, L.D., and M. Barrett. 1989. Factors in alachlor and metolachlor injury to corn (*Zea mays*) seedlings. Weed Technol. 3:303-306.

Bradley, C.A. 2009. Soybean white mold fungicide trial results from northern Illinois agronomy research center. The Bulletin 25:4. Univ. of Illinois, Urbana, IL. http://bulletin.ipm.illinois.edu/print.php?id=1252

Bradley, C.A. 2009a. Conditions favorable for sclerotinia stem rot (white mold) on soybean. The Bulletin 18:8. Univ. of Illinois, Urbana, IL. http://bulletin.ipm.illinois.edu/print.php?id=1195

Burnet, M.W.M., A.R. Barr, and S.B. Powles. 1994. Choroacetamide resistance in rigid ryegrass (*Lolium rigidum*). Weed Sci. 42:153-157.

Butzen, S. 2007. Managing forage sorghum and sorghum-sudan. Field Facts 7:5. Pioneer, Johnston, IA.

Butzen, S. 2010. Micronutrients for crop production. Crop Insights 20:9. Pioneer, Johnston, IA.

Butzen, S. 2012. Best management practices for corn-after-corn production. Crop Insights 22:6. Pioneer, Johnston, IA.

Butzen, S. 2018. Measuring and reducing corn field losses. Crop Insights 28:8. Pioneer, Johnston, IA. https://www.pioneer.com/home/site/us/agronomy/library/measure-reduce-corn-field-losses/

Bynum, E.D., Jr., T.L. Archer, and F.W. Plapp, Jr. 1990. Action of insecticides to spider mites (Acari: Tertranychidae) on corn in the Texas high plains: toxicity, resistance, and synergistic combinations. J. Econ. Entomol. 83:1236-1242.

Bynum, E.D., Jr., T.L. Archer, and F.W. Plapp, Jr. 1990. Comparison of Banks grass mite and twospotted spider mite (Acari: Tetranychidae): responses to insecticides alone and in synergistic combinations. J. Econ. Entomol. 90:1125-1130.

CAHNRS & WSU Extension. 2020. Stripe rust. Wheat & small grains. Washington State Univ. College of Ag., Human, and Natural Resource Sciences. http://smallgrains.wsu.edu/disease-resources/foliar-fungal-diseases/stripe-rust/ (accessed 1 May 2020).

Calvin, D. 2000. Two-spotted spider mite on soybeans and field corn. PennState Ext., University Park, PA. https://extension.psu.edu/two-spotted-spider-mite-on-soybeans-and-field-corn

Carter, P.R., E.D. Nafziger, and J.G. Lauer. 1989. Uneven emergence in corn. North Central Reg. Ext. Pub. No. 344. http://corn.agronomy.wisc.edu/Pubs/UWEX/NCR344.pdf

Castro, M.O., T. Hartman, T. Coutinho, J.M. Lang, K. Korus, J.E. Leach, T. Jackson-Ziems, and K. Broders. 2020. Current understanding of the history, global spread, ecology, evolution, and management of the corn bacterial leaf streak pathogen, Xanthomonas vasicola pv. Vasculorum. Phytopathology 110:1124-1131. https://doi.org/10.1094/PHYTO-01-20-0018-PER

Cerwick, S.F.., and A.J. Cavalieri. 1984. Unpublished. Pioneer, Johnston, IA.

Chandler, L.D., T.L. Archer, C.R. Ward, and W.M. Lyle. 1979. Influences of irrigation practices on spider mite densities on field corn. Environ. Entomol. 8:196-201.

Colquhoun, J. 2006. Herbicide persistence and carryover. A3819. Univ. of Wisc. Ext., Madison, WI. http://corn.agronomy.wisc.edu/Management/pdfs/A3819.pdf

Crop Protection Network. 2019. Tan spot of wheat. Crop Prot. Net. https://cropprotectionnetwork.org/resources/articles/diseases/tan-spot-of-wheat

Crop Protection Network. 2020. Anthracnose leaf blight of corn. Crop Prot. Net. https://cropprotectionnetwork.org/resources/articles/diseases/anthracnose-leaf-blight-of-corn (accessed 2020).

Crop Protection Network. 2020. Physoderma brown spot of corn. Crop Prot. Net. https://cropprotectionnetwork.org/resources/articles/diseases/physoderma-brown-spot-of-corn (accessed 21 July 2020).

Dann, E.K., B.W. Diers, and R. Hammerschmidt. 1999. Suppression of sclerotinia stem rot of soybean by lactofen herbicide treatment. Phytopathology 89:598-562.

Department of Primary Industries and Regional Development. 2015. Diagnosing powdery mildew in cereals. Agriculture and Food Dept. of Prim. Ind. and Region. Devt., South Perth, WA, AU. https://www.agric.wa.gov.au/mycrop/diagnosing-powdery-mildew-cereals

Elmore, R.W., and W.F. Roeth. 1999. Corn kernel weight and grain yield stability during post-maturity drydown. J. Prod. Agric. 12:300-305.

FDA. 2000. Guidance for industry: action levels for poisonous or deleterious substances in human food and animal feed. FDA, Washington, DC. https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-action-levels-poisonous-or-deleterious-substances-human-food-and-animal-feed

Feng, P.C.C., C.A. CaJacob, S.J. Martino-Catt, R.E. Cerny, G.A. Elmore, G.R. Heck, J. Huang, W.M. Kruger, M. Malven, J.A. Miklos, and S.R. Padgette. 2010. Glyphosate resistant crops: developing the next-generation products. In: V.K. Nandula, editor, Glyphosate resistance in crops and weeds. John Wiley & Sons, Inc., Hoboken, NJ. p. 45–66.

Foth, H.D., and L.M. Turk. 1972. Fundamentals of soil science. 5th ed. John Wiley & Sons, Inc, New York, NY.

Godfrey, L.D. 2011. Spider mites: integrated pest management for home gardeners and landscape professionals. Pest Notes 7405. Univ. of California, Davis, CA. http://ipm.ucanr.edu/PDF/PESTNOTES/pnspidermites.pdf

Gonsolus, J.L., and W.S. Curran. 1998. Herbicide mode of action and injury symptoms. No. 377. North Cent. Reg. Ext. Univ. of Minn., St. Paul, MN. p. 17.

Goos, R.J., and B.E. Johnson. 2001. Seed treatment, seeding rate, and cultivar effects on iron deficiency chlorosis of soybean. J. Plant Nutr. 24:1255-1268. https://doi.org/10.1081/PLN-100106980

Grains Research & Development Corporation. 2019. Protecting cereal crops from powdery mildew. Grains Res. & Devt. Corp., Barton, ACT, AU. https://grdc.com.au/news-and-media/newsletters/paddock-practices/protecting-cereal-crops-from-powdery-mildew

Groves, C., and D. Smith. 2013. Sudden death syndrome of soybean. XGT1015. Univ. of Wisconsin Ext., Madison, WI. https://fyi.extension.wisc.edu/fieldcroppathology/files/2013/04/Sudden-Death-Syndrome-of-Soybean.pdf

Hagan, A.K. 2017. Fungicides compared for the control of southern rust and yield response in late-planted irrigated corn. Timely Information PP-775. Alabama A&M and Auburn Univ. Ext.

Hansen, N.C., M.A. Schmitt, J.E. Anderson, and J.S. Strock. 2003. Iron deficiency of soybean in the Upper Midwest and associated soil properties. Agron. J. 95:1595-1601. https://doi.org/10.2134/agronj2003.1595

Hao, J., D. Wang, and R. Hammerschmidt. 2010. Using biological agents to control soybean white mold. 2010 Michigan Soybean Checkoff. Michigan Soybean Promotion Committee. http://www.michigansoybean.org/MSPCSite/Research/ FY10ResSum.pdf

Heap, I.M. 1997. The occurrence of herbicide-resistant weeds worldwide. Pestic. Sci. 51:235-243.

Heap, I.M. 2020. The international herbicide-resistant weed database. www.weedscience.org (accessed 5 June 2020).

Hershman, D. 2009. Cercospora leaf blight in Kentucky. Plant Pathology Fact Sheet PPFS-AG-S-20. Univ. of Kentucky Coop. Ext. Svcs., Burkesville, KY. https://plantpathology.ca.uky.edu/files/ppfs-ag-s-20.pdf

Hetherington, P.R., T.L. Reynolds, G. Marshall, and R.C. Kirkwood. 1999. The absorption, translocation and distribution of the herbicide glyphosate in maize expressing the CP-4 transgene. J. of Exp. Bot. 50:1567-1576.

Hungria, M., and R.S. Araujo. 1994. Manual de métodos empregados em estudos de microbiologia agrícola. Embrapa-Serviço de Produção e Informação, Brasilia, Brazil.

IPNI. 2014. IPNI estimates of nutrient uptake and removal. IPNI. http://www.ipni.net/article/IPNI-3296

Jeschke, M. 2017. Maximizing the value of foliar fungicides in corn. Crop Insights 27:3. Pioneer, Johnston, IA. https://www.pioneer.com/home/site/us/agronomy/max-value-foliar-fungicides-corn/

Jeschke, M. 2018. Row width in corn grain production. Crop Insights 28:3. Pioneer, Johnston, IA.

Jeschke, M.R. 2017. Maximizing the Value of Foliar Fungicides in Corn. Crop Insights 27:3. Pioneer. Johnston, IA.

Jeschke, M.R. 2020. Maximizing the Value of Foliar Fungicides in Corn. Crop Insights 30:7. Pioneer. Johnston, IA.

Jones, V.P. 1990. Developing sampling plans for spider mites (Acari: Tertranychidae): those who don't remember the past may have to repeat it. J. Econ. Entomol. 83:1656-166.

Kaiser, D.E., J.A. Lamb, and P.R. Bloom. 2011. Managing iron deficiency chlorosis in soybean. AG-FO-08672-A. Univ. of Minn. Ext., St, Paul, MN. https://www.mssoy.org/uploads/files/kaiser-univ-of-minn.pdf

Kleczewski, N. 2018. Tar spot on corn: Setting the record straight. Illinois Field Crop Disease Hub. Univ. of Illinois Ext., Urbana, IL. http://cropdisease.cropsciences.illinois.edu/?p=822

Kleczewski, N., and D. Smith. 2018. Corn hybrid response to tar spot. The Bulletin. Univ. of Illinois Ext., Urbana, IL. https://farmdoc.illinois.edu/field-crop-production/crop_production/corn-hybrid-response-to-tar-spot.html

Knittle, K.H., and J.S. Burris. 1976. Effect of kernel maturation on subsequent seedling vigor in maize. Crop Sci. 16:851-855.

Kolmer, J. 2020. Wheat leaf rust. Ag. Res. Service U.S. Dept. of Ag., Washington, D.C. https://www.ars.usda.gov/midwest-area/stpaul/cereal-disease-lab/docs/cereal-rusts/wheat-leaf-rust/

Kunkel, D.L., J.C. Steffens, and R.R. Bellinder. 1991. Effect of temperature and safeners on glutathione levels and glutathione S-transferase activity in maize. Z. Naturforsch. 46:856-860.

Kyle, D. 2014. Effect of Cobra® herbicide application on soybean yield in the absence of white mold or weed pressure. Research Update. Pioneer, Johnston, IA. https://www.pioneer.com/home/site/us/pioneer_growingpoint_agronomy/2014/cobra-herbicide-on-soybean/

Licht, M., C. Hurburgh, M. Kots, P. Blake, and M. Hanna. 2017. Is there loss of corn dry matter in the field after maturity? In Proceedings of the 29th Annual Integrated Crop Management Conference, Iowa State University, Ames, Iowa.

Lutt. N., M. Jeschke, and S. Strachan. 2016. High night temperature effects on corn yield. Crop Insights 26:16. Pioneer, Johnston, IA. https://www.pioneer.com/home/site/us/agronomy/library/night-temperature-effects-corn-yield/

Ma, B.L., L.M. Dwyer, C. Costa, E.R. Cober, and M.J. Morrison. 2001. Early prediction of soybean yield from canopy reflectance measurements. Agron. J. 93:1227-1234.

Mahanna, W., editor. 2019. Pioneer silage zone manual 3rd Ed. Pioneer, Johnston, IA.

Mahoney, K.J., R.E. Nurse, W.J. Everman, C.L. Sprague, and P.H. Sikkema. 2014 Tolerance of corn (*Zea mays L.*) to early and late glyphosate applications. Amer. J. of Plant Sci. 5(18):2748-2754. http://dx.doi.org/10.4236/ajps.2014.518291

Malvick, D. 2018. Sudden death syndrome on soybean. Univ. of Minnesota Ext., St. Paul, MN. https://extension.umn.edu/pest-management/sudden-death-syndrome-soybean

Mansfield, C., and S. Hawkins. 1992. Wheat production and fertilization in Indiana. Agronomy Guide. AY-244-W. Purdue Univ. Coop. Ext. Svcs., West Lafayette, IN. https://www.extension.purdue.edu/extmedia/AY/AY-244-W.html

Marsalis, M.A., and N.P. Goldberg. 2017. Leaf, stem, and stripe rust diseases of wheat. Guide A-415. New Mexico State Univ., Las Cruces, NM. https://aces.nmsu.edu/pubs/_a/A415/welcome.html

Martinez, A., J. Youmans, and J. Buck. 2017. Stripe rust (yellow rust) of wheat. Circular 960. Univ. of Georgia Ext., Athens, GA. https://extension.uga.edu/publications/detail.html?number=C960&title=Stripe%20Rust%20(Yellow%20Rust)%20of%20Wheat

Mueller, D., A. Robertson, A. Sisson, and G. Tylka. 2010. Soybean diseases. CSI 0004. Iowa Soybean Assoc., Ankeny, IA, and Iowa State Univ. Ext., Ames, IA.

Mueller, D.S., A.E. Dorrance, R.C. Dersken, E. Ozkan, J.E. Kurle, C.R. Grau, J.M. Gaska, G.L. Hartman, C.A. Bradley, and W.L. Pederson. 2001. Efficacy of fungicides on Sclerotinia sclerotium and their potential for control of sclerotinia stem rot on soybean. Plant Disease 86:26-31.

Mueller, D.S., C.A. Bradley, C.R. Grau, J.M. Gaska, J.E. Kurle, and W.L. Pederson. 2004. Application of thiophanate-methyl at different host growth stages for management of Sclerotinia stem rot in soybean. Crop Prot. 23:983-988.

Mueller, J. 2012. Effect of iron chelate on soybean performance in fields prone to IDC. Research Update 2:48. Pioneer, Johnston, IA. https://www.pioneer.com/us/agronomy/iron_chelate_soy.html

Munkvold, G., and D.E. Farnham. 1999. Rust and other diseases are accelerating corn maturity. Integrated Crop Management News 2153. Iowa State Univ. Ext., Ames, IA. http://www.ipm.iastate.edu/ipm/icm/1999/9-13-1999/rustaccel.html

Naeve, S.L. 2006. Iron deficiency chlorosis in soybean: soybean seeding rate and companion crop effects. Agron. J. 98:1575-1581. https://doi.org/10.2134/agronj2006.0096

Nafziger, E. 2020. Replanting corn and soybeans. farmdoc daily (10):89. Dept. of Ag. and Consumer Econ., Univ. of Illinois, Urbana, IL. https://farmdocdaily.illinois.edu/2020/05/replanting-corn-and-soybeans.html

Nafziger, E.D. 1984. Unpublished.

Nafziger, E.D. 2009. Soybean. In: Illinois Agronomy Handbook. 24th ed. Crop Science Ext. and Outreach. Univ. of Illinois, Urbana, IL. p. 27-36. http://extension.cropsciences.illinois.edu/handbook/pdfs/chapter03.pdf

Nafziger, E.D. 2018. Will the August 1 crop yield predictions hold up? The Bulletin. Univ. of Illinois Ext., Urbana, IL. http://bulletin.ipm.illinois.edu/?p=4339

Nelson, K.A., K.A. Renner, and R. Hammerschmidt. 2001. Effects of protoporphyrinogen oxidase inhibitors on soybean (*Glycine max L.*) response, Sclerotinia sclerotium disease development, and phytoalexin production by soybean. Weed Tech. 16:353- 359.

Nelson, K.A., K.A. Renner, and R. Hammerschmidt. 2002. Cultivar and herbicide selection affects soybean development and the incidence of sclerotinia stem rot. Agron. J. 94:1270-1281.

Nielsen, R.L. 2013. Jumbled kernel symptom in corn & late glyphosate applications. Purdue Univ., West Lafayette, IN. http://www.ppdl.purdue.edu/PPDL/weeklypics/12-13-10.html

Nielsen, R.L., G. Brown, K. Wuethrich, and A. Halter. 1996. Kernel dry weight loss during post-maturity drydown intervals in corn. Purdue Univ., West Lafayette, IN. https://www.agry.purdue.edu/ext/corn/research/rpt94-01.htm

O'Bryan, K., and J. Haegele. 2015. Performance of Pioneer® brand soybeans with ILeVO® fungicide seed treatment against SDS. Research Update 5:4. Pioneer, Johnston, IA.

O'Reilly, C. 2020. Forage options to replace silage corn. Field Crop News. Ontario Ministry of Agr., Food, and Rural Affairs. https://fieldcropnews.com/2020/08/forage-options-to-replace-silage-corn/

Oplinger, E.S., C.R. Grau, J.E. Kurle, J.M. Gaska, and N. Kurtzweil. 1999. Foliar treatments for control of white mold in soybean. http://www.soils.wisc.edu/extension/wcmc/proceedings/3B. oplinger.pdf

Paulson, J. 2015. Growing and feeding BMR sorghum. Midwest Forage Assoc. http://www.midwestforage.org/pdf/927.pdf.pdf

Pedersen, P. 2009. Soybean growth and development. Iowa State Univ. Ext., Ames, IA. https://crops.extension.iastate.edu/files/article/SoybeanGrowthandDevelopment_0.pdf

Pilcher, C., M. Price, and S. Endicott. 2018. Informing future management decisions for corn rootworm. Research Update 8:19. Pioneer, Johnston, IA.

Ponomarenko, A., S.B. Goodwin, and G.H.J. Kema. 2011. Zymoseptoria tritici blotch (STB) of wheat. Amer. Phytopathological Soc., St. Paul, MN. https://www.apsnet.org/edcenter/disandpath/fungalasco/pdlessons/Pages/Septoria.aspx

Ponomarenko, A., S.B. Goodwin, and G.H.J. Kema. 2011. Zymoseptoria tritici blotch (STB) of wheat. Amer. Phytopathological Soc., St. Paul, MN. https://www.apsnet.org/edcenter/disandpath/fungalasco/pdlessons/Pages/Septoria.aspx

Poston, D. 2014a. Corn hybrid response to DuPont™ Aproach® Prima fungicide in Georgia. Research Update. Pioneer, Johnston, IA. https://www.pioneer.com/home/site/us/agronomy/library/template.CONTENT/guid.0475F03C-8773-01C1-8ED1-7E26AF93AC13

Poston, D. 2014b. DuPont™ Aproach® and Aproach® Prima fungicides applied using chemigation. Research Update. Pioneer, Johnston, IA. https://www.pioneer.com/home/site/us/agronomy/library/template.CONTENT/guid.ED8C6DE9-E18A-2EDF-F780-5321360878E6

Prestemon, A. 2013. Harvest timing effect on corn yield and moisture. Research Update. Pioneer, Johnston, IA. https://www.pioneer.com/home/site/us/pioneer_growingpoint_agronomy/2013/corn_harvest_timing_effects/

Pryor, R., B. Anderson, and P. Hay. 2013. Tips for growing forage sorghum. CropWatch. Univ. of Nebr.-Lincoln., Lincoln, NE. https://cropwatch.unl.edu/tips-growing-forage-sorghum-unl-cropwatch-oct-22-2013

Ramsey, W. 2013. Feeding forage sorghum. Inside the Zone Newsletter. Pioneer, Johnston, IA.

Reese, K.D., and G. Jones. 1996. Unpublished. Pioneer, Johnston, IA.

Retzinger, E.J., and C. Mallory-Smith. 1997. Classification of herbicides by site of action for weed resistance management strategies. Weed Technol. 11:384-393.

Rice, M.E. 2015. Corn rootworm silk feeding. Crop Focus. Pioneer, Johnston, IA. https://www.pioneer.com/home/site/us/agronomy/crop-management/corn-insect-disease/corn-rootworm-silk-feeding.

Robertson, A., K. Broders, R. French, T. Jackson-Ziems, D. Jardine, K. Korus, J. Lang, and J. Leach. 2017. Bacterial leaf streak. Corn disease management CPN-2008. Crop Prot. Net. https://crop-protection-network.s3.amazonaws.com/publications/cpn-2008-bacterial-leaf-streak.pdf

Roth, G., and J.K. Harper. 1995. Forage sorghum. Agronomy Facts 48. PennState Ext., University Park, PA. https://extension.psu.edu/forage-sorghum

Ruhl, G., M.K. Romberg, S. Bissonnette, D. Plewa, T. Creswell, and K.A. Wise. 2016. First report of tar spot on corn caused by *Phyllachora maydis* in the United States. Plant Dis. 100(7):1496.

Salgado, J.D., and P.A. Paul. 2016. Leaf blotch diseases of wheat—Zymoseptoria tritici blotch, *Stagonospora nodorum* blotch and tan spot. Ohioline. Ohio State Univ. Ext., Columbus, OH. https://ohioline.osu.edu/factsheet/plpath-cer-07

Saul, R.A., and J.L. Steele. 1966. Why damaged shelled corn costs more to dry. Agric. Eng. 47:326-329.

Schlund, S., T. Hartman, and T. Jackson-Ziems. 2017. Bacterial leaf streak of corn. CropWatch. Univ. of Nebraska-Lincoln, Lincoln, NE. https://cropwatch.unl.edu/2017/bacterial-leaf-streak-corn

Schmale, D., and G. Bergstrom. 2010. Fusarium head blight (FHB) or scab. Amer. Phytopathological Soc. https://www.apsnet.org/edcenter/disandpath/fungalasco/pdlessons/Pages/Fusarium.aspx

Senseman, S.A., editor. 2007. Herbicide handbook. 9th ed. Weed Science Society of America, Lawrence, KS.

Smith, D., S. Chapman, and B. Mueller. 2016. Wisconsin field crops pathology fungicide tests summary. Univ. of Wisconsin Ext., Madison, WI. https://fyi.uwex.edu/fieldcroppathology/ files/2016/12/2016-Fungicide-Test-Summary.pdf

Smith, D.L., C. Groves, B. Hudelson, and S. Lueloff. 2018. Bacterial leaf streak of corn confirmed for the first time in Wisconsin. Wisconsin Crop Manager Newsletter. Univ. of Wisconsin-Madison, Madison, WI. https://ipcm.wisc.edu/blog/2018/09/bacterial-leaf-streak-of-corn-confirmed-for-the-first-time-in-wisconsin/

Smith, K.L. 2020. Fungicide efficacy for control of soybean foliar diseases. CPN-1019-W. Crop Prot. Net. https://crop-protection-network.s3.amazonaws.com/publications/fungicide-efficacy-for-control-of-soybean-foliar-diseases-filename-2020-03-18-150123.pdf

Stephenson, G.R., and T. Yaacoby. 1991. Milestones in the development of herbicide safeners. Z. Naturforsch. 46:794-797.

Strachan, S., and K. Hahn. 2020. Degradation of herbicides under dry conditions. Field Facts 20:4. Pioneer, Johnston, IA.

Strachan, S.D. 2016. Relating silk emergence at pollination to kernel set at harvest. Crop Insights 26:9. Pioneer, Johnston, IA.

Telenko, D., M.I. Chilvers, N. Kleczewski, D.L. Smith, A.M. Byrne, P. Devillez, T. Diallo, R. Higgins, D. Joos, K. Kohn, J. Lauer, B. Mueller, M.P. Singh, W.D. Widdicombe, and L.A. Williams. 2019. How tar spot of corn impacted hybrid yields during the 2018 Midwest epidemic. Crop Prot. Net. https://cropprotectionnetwork.org/resources/features/how-tar-spot-of-corn-impacted-hybrid-yields-during-the-2018-midwest-epidemic

Thomison, P. 2017. Cool weather and corn dry down. C.O.R.N. Newsletter 2017-30. Ohio State Univ. Ext. Agron., Columbus, OH. https://agcrops.osu.edu/newsletter/corn-newsletter/2017-30/cool-weather-and-corn-dry-down

Thomison, P.R., R.W. Mullen, P.E. Lipps, T.A. Doerge, and A.B. Geyer. 2011. Corn response to harvest date as affected by plant population and hybrid. Agron. J. 103:1765–1772.

University of Wisconsin – Madison. 2008. White mold in Wisconsin. Univ. of Wisconsin-Madison, Madison, WI. http://www.plantpath. wisc.edu/soyhealth/weeds.htm

Unkovich, M., D.F. Herridge, M. Peoples, Cadish, B. Boddey, K. Giller, B. Alves, and P. Chalk. 2008. Measuring plant-associated nitrogen fixation in agricultural systems. Monograph No. 136. ACIAR, Canberra, ACT, AU.

Wegulo, S.N. 2011. Tan spot of cereals. Amer. Phytopathological Soc., St. Paul, MN. https://www.apsnet.org/edcenter/disandpath/fungalasco/pdlessons/Pages/TanSpot.aspx

Wegulo, S.N., R.N. Klein, and R.M. Harveson. 2012. Tan spot of wheat. NebGuide G429. Univ. of Nebraska Ext., Lincoln, NE. https://extensionpubs.unl.edu/publication/9000016363989/tan-spot-of-wheat/

Westphal, A., L. Xing, T.S. Abney, and G. Shaner. 2016. Diseases of soybean: sudden death syndrome. Bulletin BP-58-W. Purdue Univ. Ext., West Lafayette, IN. https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=2121&context=agext

White, D.G., editor. 1999. Compendium of corn diseases. 3rd ed. Amer. Phytopathological Soc. Press, St. Paul, MN.

Winkle, M.E., J.R.C. Leavitt, and O.C. Burnside. 1980. Acetanilide-antidote combinations for weed control in corn (*Zea mays*) and sorghum (Sorghum bicolor). Weed Sci. 28:699-704.

Wise, K. 2019. Fungicide efficacy for control of corn diseases. Corn disease management. CPN-2011-W. Crop Prot. Net. https://crop-protection-network.s3.amazonaws.com/publications/cpn-2011-corn-fungicide-efficacy-for-control-of-corn-diseases.pdf

Wise, K. 2020. Fungicide efficacy for control of corn diseases. CPN-2011-W. Crop Prot. Net. https://crop-protection-network.s3.amazonaws.com/publications/fungicide-efficacy-for-control-of-corn-diseases-filename-2020-03-18-150007.pdf

Wise, K., B. Kennedy, K. Mehl, and C.A. Bradley. 2018. Physoderma brown spot. PPFS-AG-C-07. Univ. of Kentucky Ext. Plant Pathology, Burkesville, KY. https://plantpathology.ca.uky.edu/files/ppfs-ag-c-07.pdf

Yang, X.B. 2009. Early planting and soybean disease considerations. ICM News. Iowa State Univ. Ext., Ames, IA. https://crops.extension.iastate.edu/cropnews/2009/04/early-planting-and-soybean-disease-considerations

Footnotes and Acknowledgments

[1] All Pioneer products are hybrids unless designated with AM1, AM, AMRW, AML, AMT, AMX, AMXT and Q, in which case they are brands.

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

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

[4] 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.

[5] Adapted from Purdue Univ. Ext. 2009. Two-spotted spider mite. Field Crops IPM. Purdue Univ. Ext., West Lafayette, IN. https://extension.entm.purdue.edu/fieldcropsipm/insects/corn-spidermite.php

[6] Adapted from Perring, T.M., T.L. Archer, D.L. Krieg, and J.W. Johnson. 1983. Relationships between the Banks grass mite (Acariformes: Tetranychidae) and physiological changes of maturing grain sorghum. Environ. Entomol. 12:1094-1098.

[7] Adapted from Peairs, F.B. 2014. Spider mites in corn. Fact Sheet No. 5.555. Colorado State Univ. Ext., Fort Collins, CO. https://extension.colostate.edu/docs/pubs/insect/05555.pdf. and Holzer and Kalisch, Univ. of Nebraska.

[8] Images courtesy of Wright, R.J., R.C. Seymour, L.G. Higley, and J.B. Campbell. 1993. Spider mite management in corn and soybeans. NebGuide #G1167. Univ. of Nebraska-Lincoln, Lincoln, NE. https://entomology.unl.edu/NEBGuides/G93-1167%20Spider%20Mite%20Management%20in%20Corn%20and%20Soybeans.pdf

[9] Table 3 from Archer, T.L., and E.D. Bynum, Jr. 1993. Yield loss to corn from feeding by the Banks grass mite and two-spotted spider mite (Acari: Tertranychidae). Exp. & Appl. Acarology 17:895-903.

[10] Adapted from Zukoff, S., R.J. Whitworth, J.P. Michaud, H.N. Davis, and B. McCornack. 2019. Corn insect management. MF810. Kansas State Univ. Ext., Manhattan, KS. https://bookstore.ksre.ksu.edu/pubs/Mf810.pdf.

return to table of contents

Trademarks

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 corn borer refuge must be planted with optimum acremax products.

AMXT - Optimum® AcreMax® XTreme contains a single-bag integrated refuge solution for above- and below-ground insects. The major component contains the Agrisure® RW trait, the YieldGard® Corn Borer gene, and the Herculex® XTRA genes. In EPA-designated cotton growing counties, a 20% separate corn borer refuge must be planted with Optimum AcreMax XTreme products.

YGCB,HX1,LL,RR2 (Optimum® Intrasect®) - Contains the YieldGard® Corn Borer gene and Herculex® I gene for resistance to corn borer.

AMT - Optimum® AcreMax® TRIsect® Insect Protection System with RW,YGCB,HX1,LL,RR2. Contains a single-bag refuge solution for above and below ground insects. The major component contains the Agrisure® RW trait, the YieldGard® Corn Borer gene, and the Herculex® I genes. In EPA-designated cotton growing counties, a 20% separate corn borer refuge must be planted with Optimum AcreMax TRIsect products.

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.

Q (Qrome®) - Contains a single-bag integrated refuge solution for above- and below-ground insects. The major component contains the Agrisure® RW trait, the YieldGard® Corn Borer gene, and the Herculex® XTRA genes. In EPA-designated cotton growing counties, a 20% separate corn borer refuge must be planted with Qrome products. Qrome® products are approved for cultivation in the U.S. and Canada. For additional information about the status of regulatory authorizations, visit http://www.biotradestatus.com/

Components of LumiGEN™ technologies for soybeans are applied at a Corteva Agriscience production facility, or by an independent sales representative of Corteva Agriscience or its affiliates. Not all sales representatives offer treatment services, and costs and other charges may vary. See your sales representative for details. Seed applied technologies exclusive to Corteva Agriscience and its affiliates.

Lumialza™ nematicide has not yet received regulatory approvals in any country outside the United States; approvals are pending.

The information presented here is not an offer for sale. This presentation is not intended as a substitute for the product label for the product(s) referenced herein. The information contained in this technical presentation is based on the latest to-date technical information available to DuPont, and DuPont reserves the right to update the information at any time.

The transgenic soybean event in Enlist E3® soybeans is jointly developed and owned by Dow AgroSciences LLC and M.S. Technologies, L.L.C. Enlist Duo® and Enlist One® herbicides are not registered for sale or use in all states or counties. Contact your state pesticide regulatory agency to determine if a product is registered for sale or use in your area. Enlist Duo and Enlist One are the only 2,4-D products authorized for use with Enlist crops. Consult Enlist herbicide labels for weed species controlled. Always read and follow label directions.

Do not export brand alfalfa seed or crops containing Roundup Ready® alfalfa technology including hay or hay products, to China pending import approval. In addition, due to the unique cropping practices, do not plant this product in Imperial County, California. Always read and follow pesticide label directions. Alfalfa with the Roundup Ready® alfalfa technology, provides crop safety for over-the-top applications of labeled glyphosate herbicides when applied according to label directions. Glyphosate agricultural herbicides will kill crops that are not tolerant to glyphosate. ACCIDENTAL APPLICATION OF INCOMPATIBLE HERBICIDES TO THIS VARIETY COULD RESULT IN TOTAL CROP LOSS.

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.

Roundup Ready®, 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.

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

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

Agrisure®, and Agrisure Viptera® are registered trademarks 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.

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.

Always follow stewardship practices in accordance with the Product Use Guide (PUG) or other product-specific stewardship requirements including grain marketing and pesticide label directions.

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.