DUPONT

PIONEER

AGRONOMY SCIENCES RESEARCH SUMMARY

PIONEER GrowingPoint

2018

Agronomy Sciences

Introduction

2017 will likely be remembered as a growing season in which crop yields generally exceeded expectations but not without significant challenges along the way for many growers. After a good start to the planting season, cold and wet conditions during May brought planting to a halt across much of the Midwest. Prolonged periods of unfavorable weather led to significant planting delays and extensive replanting. The challenges did not end there, as drought conditions affected parts of the Midwest and northern plains during the summer, while heavy rains led to flooding in other areas.

Successful crop management under constantly shifting conditions requires smart and efficient use of resources driven by sound agronomic knowledge. At DuPont Pioneer, our commitment to improved crop management is the foundation of our GrowingPoint™ agronomy research structure – an industry leading network of agronomists and researchers across North America. The mission of this team is to help maximize grower productivity by delivering useful insights built on rigorous, innovative research. This includes studies in growers' fields and at research sites across North America, as well as numerous collaborative studies with university scientists.

This Agronomy Sciences Research 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 and Pioneer® GrowingPoint® agronomy app. We hope that the resources available in this book and online will help you drive yield and profitability in 2018.

Mark Jeschke, Editor

Corn Breeding History

Corn Planting Practices

Corn Growth and Development

Corn Disease Management

Corn Management

Corn Harvest Practices

Phosphorous and Potassium Fertility

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Micronutrient Fertility

Insects and Other Pests

Soybean Management

Soybean Diseases, Insects, and Weeds

Forage Management

Sorghum Production

Wheat Management

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

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The Agronomy Sciences Team

The DuPont Pioneer Agronomy Sciences group supports and coordinates the efforts of agronomy field teams around the globe in order to provide DuPont Pioneer customers 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 DuPont 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™ plot testing and provide product knowledge positioning insights as well as training to DuPont Pioneer account managers, Pioneer sales professionals, and dealers, as well as field agronomists who lead agronomy training efforts and on-farm Pioneer® GrowingPoint® 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 and the Pioneer® GrowingPoint® agronomy app.

Paul Carter, Ph.D., *Senior Agronomy Sciences Manager*

Paul earned his B.S. degree at North Dakota State University and his M.S. and Ph.D. degrees from the University of Minnesota; he was Extension Agronomist and Professor at the University of Wisconsin-Madison before joining DuPont Pioneer. His research experience includes impacts of frost and wind damage on crop recovery, seeding practices, crop rotations, and tillage systems. Paul is a Fellow in both the American Society of Agronomy and the Crop Science Society of America and received the Agronomic Industry Award from the American Society of Agronomy.

Matt Clover, Ph.D., *Agronomy Research 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 and support Pioneer agronomists and sales teams and Encirca® services. 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 and research and development.

Eric Galdi, *Crop Data and Decision Support Scientist*

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 DuPont Pioneer in 2009. He has held various roles at DuPont Pioneer in corn research and Encirca® Services before joining the Agronomy Sciences team.

Mary Gumz, Ph.D., *Agronomy Research 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 Information 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 Information Manager. His primary role is development and delivery of useful and timely agronomy information based on DuPont Pioneer and university agronomy research. Mark authors and edits many of the agronomy resources available in the DuPont Pioneer agronomy library and through the Pioneer® GrowingPoint® agronomy app. Mark is originally from northern Illinois and is actively involved in the family corn and soybean farm near Rock City, Illinois.

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Jeff Mathesius, M.S., MBA, *Agronomy Research Manager*

Jeff is a native of Illinois and obtained his B.S. degree in Agronomy from Illinois State University, M.S. degree in Soil Fertility from the University of Illinois, and MBA from Iowa State University. He started with DuPont Pioneer in 2001 and has had various roles including Small Plot Research, Six Sigma Black Belt, Agronomy Sciences, and Field Agronomist. Jeff is currently the DuPont Pioneer Agronomy Research Manager covering the Western U.S.

Luke Northway, *Senior Analyst*

Luke double majored in Management Information Systems and Agricultural Business at Iowa State University and is currently pursuing his MBA from the University of Iowa. He started with DuPont Pioneer in 2007 as a support person for FIS and Pioneer® FIT Mapping System. He now works on the Agronomy Sciences team as Product Owner of Performance Explorer, Trials Planning, and mobile Trials Data Entry.

Dan Poston, Ph.D., *Agronomy Research Manager*

Dan holds a B.S. and M.S. from Clemson University and a Ph.D. from Virginia Tech. Dr. Poston grew up in the coastal plains of South Carolina. Most of his professional career has been spent as a soybean agronomist and weed scientist with Mississippi State University at the Delta Research and Extension Center in Stoneville, Mississippi. Dr. Poston joined DuPont Pioneer in 2008 as an Area Agronomist and transitioned to the Agronomy Research Manager role in 2010 supporting 13 southeastern states.

Rick Radliff, M.S., *Senior Manager - Agronomy Sciences*

Rick Radliff oversees the Agronomy Sciences Team whose geography includes the U.S., Canada, and the globe. His team is responsible for support of Encirca® Services, coordination of over 150 DuPont Pioneer agronomists who implement more than 10,000 Pioneer® GrowingPoint® agronomy on-farm trials yearly, and his team publishes the results to help growers drive greater productivity. Rick's team also works closely with many universities to collaborate on research to provide growers with cutting-edge crop management advice. Prior to joining Pioneer in 1999, he worked in Technical Services in the crop protection industry. Rick received his B.S. in Plant and Soil Science and M.S. in Weed Science from Southern Illinois University - Carbondale.

April Battani, *Graphics Specialist*

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 DuPont Pioneer in 2012 as a Publishing Assistant for Agronomy Sciences. She currently works as a Graphics Specialist for both the Agronomy Sciences and 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.

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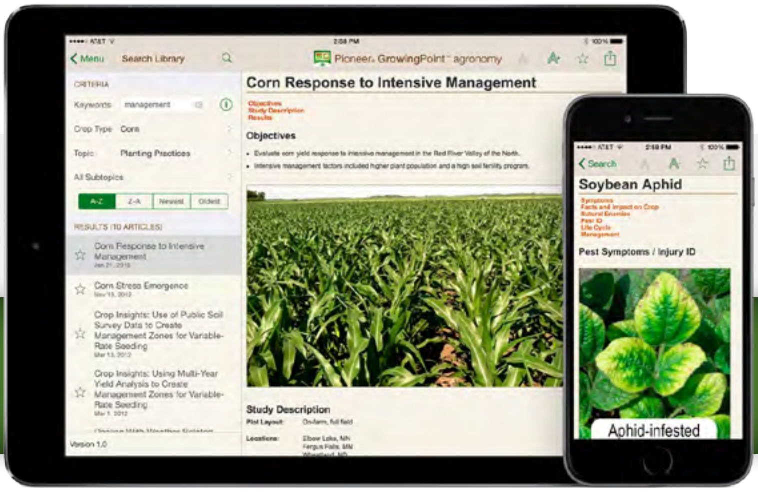

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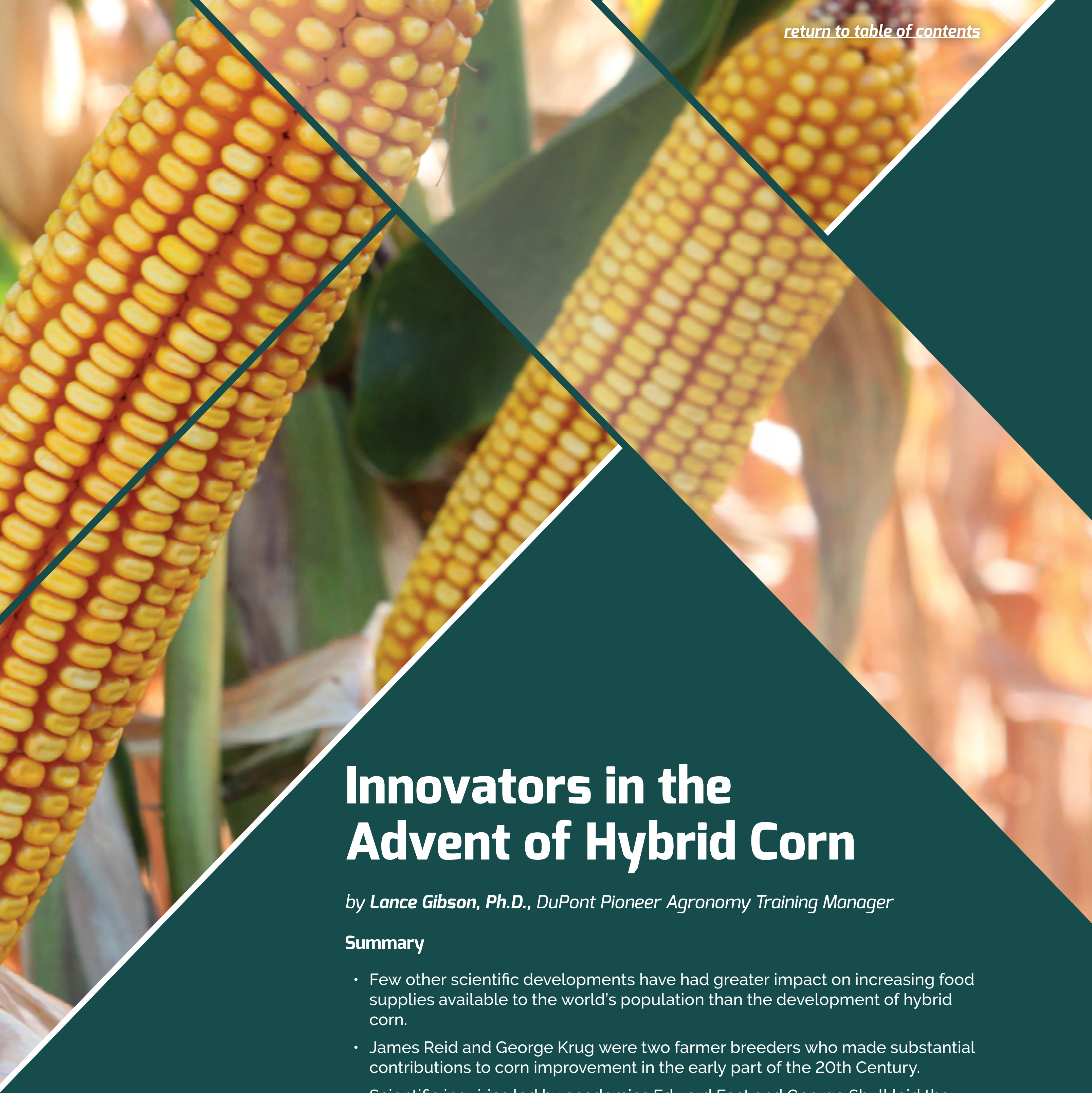

Innovators in the Advent of Hybrid Corn

by ***Lance Gibson, Ph.D.,*** *DuPont Pioneer Agronomy Training Manager*

Summary

- Few other scientific developments have had greater impact on increasing food supplies available to the world's population than the development of hybrid corn.
- James Reid and George Krug were two farmer breeders who made substantial contributions to corn improvement in the early part of the 20th Century.
- Scientific inquiries led by academics Edward East and George Shull laid the groundwork for hybrid corn production.
- Herbert Hayes started inbreeding corn in 1909 and developed the inbreds used in the first practical corn hybrid.
- No person was more important to commercialization and farmer acceptance of hybrid corn than Henry A. Wallace, the founder of what has become DuPont Pioneer.
- The Hi-Bred Corn Company was organized and incorporated in Iowa on April 20, 1926. This was the first strictly hybrid seed company and the predecessor of DuPont Pioneer.

Introduction

The development and wide-scale adoption of hybrid crops is one of humankind's greatest achievements, resulting in a multi-fold productivity increase over pre-hybrid genetics. Few other scientific developments have had greater impact on increasing the food supplies available to the world's population than has the development of hybrid corn. The pure-line breeding methods used to create inbred parents for hybrids were applied to variety development for self-pollinating species, allowing the transformation of a couple of minor crops, soybean, and rapeseed (the predecessor to canola) into world leaders. These methods also made vast contributions to the improvement of wheat and other cereal grains. The discovery and use of male sterility systems brought hybridization to many other crops with spectacular success. Seed companies and public research programs continue to actively seek new ways of hybridizing crops by overcoming the natural limitations to self-pollination. The use of hybrids has seen a steady rate of increase over many decades and will continue to expand in the future.

This article on the discovery, development, and commercialization of hybrid corn is intended to provide awareness of some of the trailblazers who contributed to the discovery and adoption of the hybrid breeding system that continues to support the development of innovative Pioneer® brand crop genetics. Buildings on the DuPont Pioneer campus in Johnston, Iowa, are named for many of these historic innovators.

Early History of Corn Production

A discussion of how corn genetics were selected and passed between seasons before hybrids were introduced is required to fully understand the history of hybrid corn development. Based on archaeological and DNA evidence, maize was domesticated in Mexico sometime between 6,000 and 10,000 years ago.

Prehistoric people collected the large kernels of the wild ancestors of today's corn that would provide them sustenance for their daily activities. At some point, they discovered that kernels could be planted back in the soil for annual harvest. Each year, they would select seeds of favored types for planting the next season. Over the millennia, this annual selection slowly changed corn into the crop we recognize today.

Over time, indigenous farmers in the Americas developed methods of composite breeding and mass selection where seeds from good ears or plants were saved each year for planting in the next season. As long as it was kept isolated from other corn types, the seed produced from a distinct strain would be true to type from one generation to the next. Many distinct corn types and strains were developed using these methods.

As corn evolved into an easily grown and productive crop, it became a major component of the diet and was spread throughout the Americas. The American natives shared corn with new arrivals to North America from Europe. The colonists also brought the crops of their birthplaces, such as wheat, oats, barley, and rye. While they favored the traditional crops for direct consumption, they quickly learned that corn made excellent feed for livestock. As immigrants to North America moved into the Central U.S., corn became the lead crop, eventually expanding to a peak of over 113 million acres planted in 1932. Explorers of the Americas from Europe returned home with corn seeds and distributed the crop all over the world.

Figure 1. Teosinte (*Zea mays* subsp. *Mexicana*), an ancestor of modern corn native to Mexico and Central America.

Immigrants to the American colonies and farmers around the world refined the indigenous corn selection processes to develop many farmer-bred open-pollinated varieties. The best varieties were traded locally, spread with mass migrations during settlement of the interior lands of North America, and widely sold with the introduction of the postal service and catalog sales. The peak of farmer corn breeding occurred in the late 1800s and early 1900s when grower associations and land grant colleges established "corn shows" for exhibiting "perfect" corn ears selected by farmers. These contests were hosted at the county, state, national, and international levels and brought high esteem and widespread acclaim to the winners.

Important Farmer Breeders

Of the many farmer breeders, two stand out for their substantial contributions to corn improvement. The first is James Reid of Illinois who improved "Reid Yellow Dent" using mass selection from 1866 to 1910. The second is George Krug, who bred his own open-pollinated variety from 1906 until the early 1930s.

James Reid

Reid Yellow Dent was an open-pollinated variety first introduced to Illinois by Robert Reid. His son, James, improved the variety by carefully selecting ears based on agronomic, ear, and kernel traits. Agronomic selection was placed on medium maturity (100 to 110 days); adaptability to Corn Belt conditions; vigorous plant growth; tall and leafy plants; and mature, dry seed at harvest time. Ears were selected for medium size (9 to 10 inches long and 7 to 8 inches around); 18 to 22 tightly-aligned kernel rows; a small, dark-red cob; slight tapering from butt to tip; filling of the ears over the tip; and a small shank to ease hand husking. Reid desired solid, deep, narrow- to medium-width, smooth kernels with bright yellow color and dented, light-colored crown. Both Robert and James gave seed to their neighbors to ensure the purity of Reid Yellow Dent by limiting pollen contamination from other strains of corn.

Figure 2. Reid Yellow Dent, an open-pollinated variety used widely up until the adoption of hybrid corn in the 1930s.

Fifty years of selection and promotion advanced Reid Yellow Dent into the dominant U.S. variety. Other farm breeders throughout the U.S. began selecting from Reid Yellow Dent in the late 1800s to create their own versions. It was adapted to nearly every state and comprised up to 75% of U.S. corn acres. University experiment stations began creating Reid Yellow Dent varieties in the early 1900s. Inbreds developed from several Reid Yellow Dent varieties became parents of the first commercial hybrids.

George Krug

George Krug, a corn farmer from Woodford County in central Illinois, developed the most improved strain of Reid corn. He began experimenting with seed corn to improve production on his 100-acre farm. Krug combined a Nebraska strain of Reid's Yellow Dent corn with Iowa Gold Mine to make his own strain. At first, he did not realize how good his corn was as he had not entered it in a show or tested it against other varieties. With the encouragement of his local agent, Krug entered his variety in the county farm bureau yield test beginning in 1919. Ears of Krug's corn were uneven in size and kernel shape, yet it produced the best yield among 118 entries in 1920 and 1921. It yielded 10 bu/acre better than the most touted "show type" corn. Krug spent an additional 10 years improving his variety, and it was fervently desired by farmers throughout the U.S. It won the Iowa corn yield tests in 1926 and became the most widely-used open-pollinated corn in many areas. Krug's corn seed was even shipped for growing to South Africa, Romania, and Argentina.

Dawn of Scientific Breeding

Application of science to agriculture in the U.S. began with the passing of the Morrill Act of 1862, which created the framework for land-grant colleges in each state. The Hatch Act of 1887 further authorized the establishment of an agricultural experiment station, affiliated with each land grant college of agriculture. At first, college professors concentrated on selecting the best corn to use as seed and joined in promoting, organizing, and judging corn shows. Initial efforts at improving corn genetics were slow but started to gain traction in the early 1900s. By 1910, corn shows were very popular in the U.S. Corn Belt. Farmers would enter 10 of their best ears of corn, and judges rated them on appearance. It was thought that the best-looking corn would also produce the best yields. By the early 1900s, breeders and extension educators were promoting selection techniques considered to be an improvement over traditional farmer methods.

Some in the breeding and scientific community began to question the relationship between selection of show ears and improvements in corn yield. Observations over many years and data collected by the U.S. Department of Agriculture showed corn yields were not improving. In response, agricultural colleges began sponsoring yield tests starting around 1915 for direct comparison of varieties under controlled conditions.

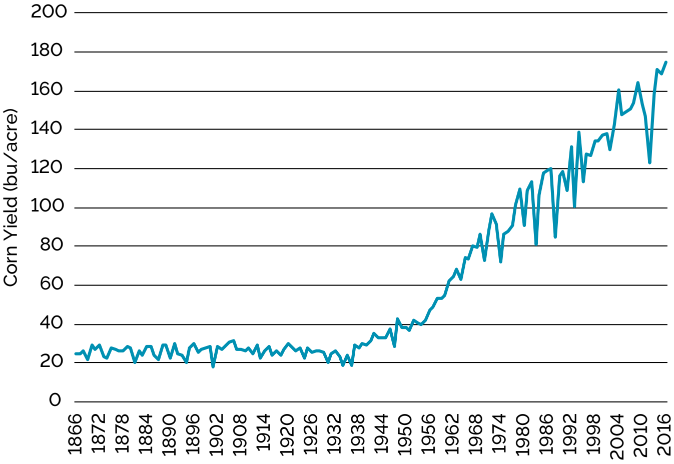

Figure 3. United States average corn yield, showing the lack of yield improvement up through the 1930s and dramatic gains during the hybrid corn era (Source: USDA-NASS).

The corn yield tests and other research observations suggested mass selection was likely protecting the crop from yield declines and improving some minor agronomic characteristics but was doing very little to improve productivity. Qualitative traits, such as kernel or cob color, could be readily selected, but quantitative traits, such as yield, were not very responsive to these breeding efforts. Average corn yields in the U.S. had remained stagnant (at a little over 20 bu/acre) for nearly 70 years between passage of the Morrill Act and the early 1930s (Figure 3). The yield tests began to put attention on choosing corn for yield rather than selecting seed corn from the most beautiful ears.

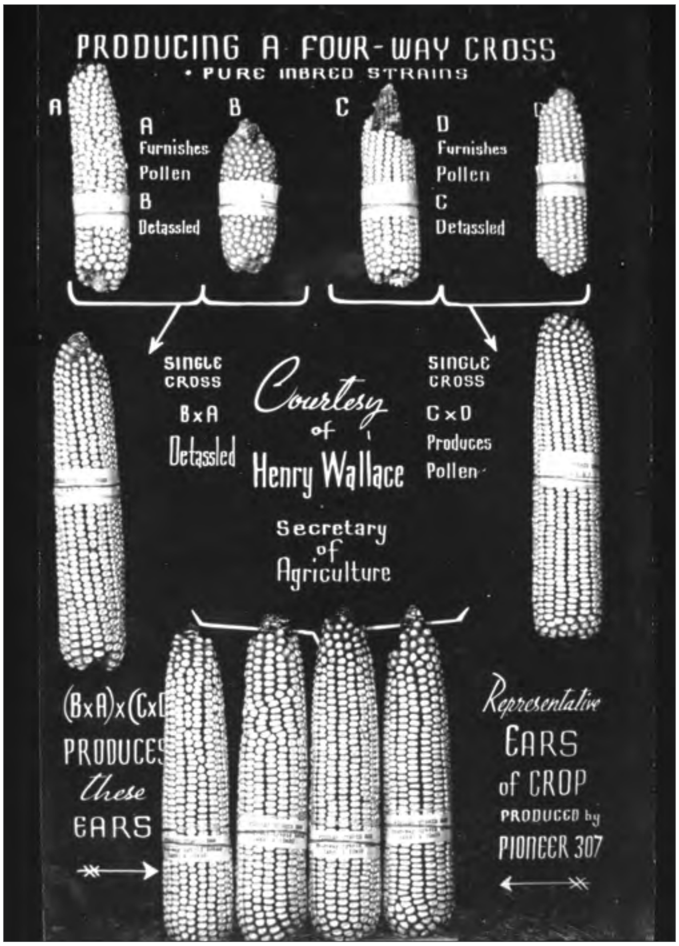

Figure 4. Vintage poster showing crosses involved in creating a double-cross, or four-way cross, hybrid.

Early Hybrid Corn Research

It was the basic scientific inquiries of academics Edward East and George Shull that brought hybrid corn to the scene. East and Shull individually initiated research on selfing individual corn plants to produce purified lines – East at Connecticut State College in New Haven and Shull at Cold Spring Harbor Laboratory on Long Island in New York. Their pursuits did not turn out as planned as they quickly discovered that just a couple generations of inbreeding resulted in plants with significantly less yield and vigor than the original parent. However, Shull crossed inbred lines he had created and made an interesting discovery. The hybrid offspring had growth superior to the inbred parents and had comparable or better yields as well as greater uniformity among plants than the varieties from which the inbreds were derived. He published a scientific paper on these results in 1908. Shull had observed the effects of heterosis in corn and began immediately applying it in further breeding investigations. In a paper published the next year, he outlined procedures that later became standard in hybrid corn breeding programs.

Both East and Shull had doubts about the practicality of corn hybrids for wide-scale use as inbred lines produced very little seed. East, in particular, thought the need to generate new seed each year and its cost would cancel the benefit of higher yields from hybrids. East's students, Herbert Hayes and Donald Jones, were not as negative toward the discovery and pushed forward in a quest to make hybrids feasible.

Hayes started inbreeding corn at Connecticut State College in 1909 and became a firm believer in the untapped potential of hybrid corn after harvesting 200 bu/acre yields in consecutive years. He would go on to develop the inbreds used in the first practical corn hybrid, the Burr-Leaming double-cross hybrid. Hayes moved on to the University of Minnesota in 1915 as a small grain and corn breeder, contributing greatly to research on the most efficient procedures for breeding corn hybrids and training many plant breeders.

As a graduate student, Jones originated the idea that would eliminate low seed production of inbred lines as a limitation to the wider use of hybrid corn. He devised a scheme where he crossed two inbred lines to make one hybrid and two other distinct lines to create a second hybrid. He then used these two single-cross hybrids as parents to make a second generation, double-cross hybrid.

Jones began his research work at the Connecticut Agricultural Experiment Station in New Haven in 1914. By 1917, he found that the heterozygous single-crosses made suitable parents for field-scale seed production, and the four-way, double-cross hybrids yielded about as much as the two-way, single crosses. The four-way crosses were more variable than single-cross hybrids but much less so than open-pollinated varieties. Plentiful seed production made the scheme practical for field use. Over the next several decades, corn breeders improved seed production in inbred lines so that single-cross hybrids could be practically grown and sold by the 1950s.

Henry Wallace

No person was more important to commercialization and farmer acceptance of hybrid corn than Henry A. Wallace, the founder of what has become DuPont Pioneer. He was one of a handful of people in the world who initially recognized the immense opportunities that could be gained by growing hybrid corn. Wallace began experimenting with corn in high school with the goal of developing a hybrid that would produce high grain yield. At age 16, he field-tested prize-winning show corn against corn less beautiful in appearance. The results challenged conventional thinking at the time by demonstrating there was no relationship between yield and appearance of the ears.

Figure 5. Henry Wallace inspecting corn ears.

Wallace attended Iowa State College, graduating in 1910. While in college, he became fascinated with the relatively new science of genetics. After graduation, Wallace began working on corn-breeding experiments and started breeding hybrid corn in 1920 after visiting Edward East and Donald Jones at the Connecticut Agricultural Experiment Station. The mathematically inclined Wallace taught himself statistics and applied it to his experiments. By 1923, he had produced a high-yielding hybrid he called "Copper Cross". In 1924, it became the first hybrid to win the gold medal in the Iowa Corn Yield Contest conducted by Iowa State.

Convinced that hybrid corn had a bright future, Wallace continued to produce and market small quantities of hybrid seed. He also promoted hybrid corn through frequent writings in his family's magazine, *Wallaces Farmer*, a top agriculture periodical. Continued success of his hybrids convinced Wallace to expand operations and bring new human and financial resources into the business. With the help of several friends, the Hi-Bred Corn Company was organized and incorporated in Iowa on April 20, 1926. This was the first strictly hybrid seed company and the predecessor of DuPont Pioneer. Wallace was selected as U.S. Secretary of Agriculture by Franklin D. Roosevelt in 1932 and elected Vice President of the United States in 1940.

Figure 6. Pioneer® hybrid 307, a double cross hybrid sold from 1936 until 1963.

Hybrid adoption was slow during the first decade after their commercial introduction by Henry Wallace in 1924. Farmers were not used to purchasing new seed each year, the seed was expensive to produce, and it was in short supply. The situation began to quickly change in the mid-1930s. Yield tests and farmer experience during the "Dust Bowl" years from 1934 to 1940 demonstrated hybrids to be vastly superior to open-pollinated varieties under severe drought. The first widespread plantings of hybrid corn began in 1935 when 6% of Iowa corn acreage was planted to hybrids. Once farmers had solid evidence of the benefits of hybrid corn, the transition away from open-pollinated varieties was astonishingly rapid. By 1942, nearly all Iowa acres were planted to hybrid corn. Adoption of the new hybrids quickly spread around the world. The high yields, stress tolerance, and pest resistance of hybrids made growing corn feasible in areas where it had not been grown before.

Expansion of Hybridization and Related Innovations

Hybrids have been so superior in agronomics, yield, and return on investment for furthering genetic gain that they have been sought after in most major crops. Discovery and application of male sterility systems resulted in commercial introduction of hybrids for sorghum in 1956, sunflower in 1959, and canola in 1989. Hybrids were immediately embraced by farmers for all three crops, but widespread commercialization of hybrids has yet to be realized for some crops with flower morphological constraints that limit cross pollination. Hybrids may never be feasible for crops that are highly predisposed to self-pollination, such as soybean.

Several key developments beyond the uncovering and exploitation of heterosis were vitally important to the initial adoption of hybrid crops. Yield tests established by state agricultural experiment stations were essential to proving the superior qualities of hybrids to farmers. The experimental design principles and statistical techniques developed by R.A. Fisher provided powerful analytical tools used in quantifying genetic improvements. New laboratory and breeding techniques resulted in effective screening of desirable traits and combination of these traits into improved parent lines.

Important Innovators

Before closing out this retrospective on hybrid corn, there are three additional scientists worthy of note for their enduring contributions to the development of hybrid corn and study of corn genetics. Each of these has a building named after them on the DuPont Pioneer campus.

George Washington Carver

George Washington Carver, the great scientist and inventor widely credited with development and promotion of peanuts and other alternatives to cotton production in the Southern U.S., had a personal relationship with a young Henry A. Wallace. Carver was a student, and Wallace's father was a professor at Iowa State College in Ames. The young Wallace often went on plant collecting trips with Carver in fields around Ames. Wallace credited Carver with introducing him to the "mysteries of plant fertilization" and deepening his appreciation of plants "in a way he could never forget."

Rollins Emerson

Rollins Emerson is known as the father of maize genetics. He began his career at the University of Nebraska in 1899 and took a leave of absence in 1910 to pursue additional studies with Edward East, who had recently moved from Connecticut State College to Harvard University. He returned to Nebraska and began studying trait heritability as well as quantitative genetics in corn. He continued this work at Cornell University in 1914 as professor and head of the department of plant breeding until he retired in 1942. Emerson's laboratory trained many of the world's foremost geneticists of the 20th century.

Barbara McClintock

Barbara McClintock, one of Emerson's students, developed the technique for visualizing corn chromosomes under a microscope and used microscopy to demonstrate many fundamental genetic ideas. She produced the first genetic map for corn, linking chromosomal regions to physical traits. McClintock was awarded the 1983 Nobel Prize in Physiology or Medicine for the discovery of genetic transposition, the ability of genes to change position on chromosomes.

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Corn Stand Evaluation and Replant Considerations

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

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

- Cold or wet soils
- Insect feeding
- Unfavorable weather conditions

Start by assessing the density and health of the current stand.

Stand Counts

- Take several sample counts to represent the field.
- Sample a length of row equal to 1/1000th 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 flood 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, assess plant density and health 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.

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

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:

- Is the stand consistent; are 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 the 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 (Source: Emerson Nafziger, Eric Adee, and Lyle Paul, Univ. of Illinois).

Planting Date	Plant Population (1,000 plants/acre)						
	10	15	20	25	30	35	40
	---------- % of maximum yield ----------						
April 1	54	68	78	88	95	99	99
April 10	57	70	81	91	97	100	100
April 20	58	71	81	91	97	100	99
April 30	58	70	80	89	95	97	96
May 9	55	68	77	86	91	93	91
May 19	50	63	72	80	85	86	84
May 29	44	56	65	73	77	78	75
June 8	35	47	56	63	67	67	64

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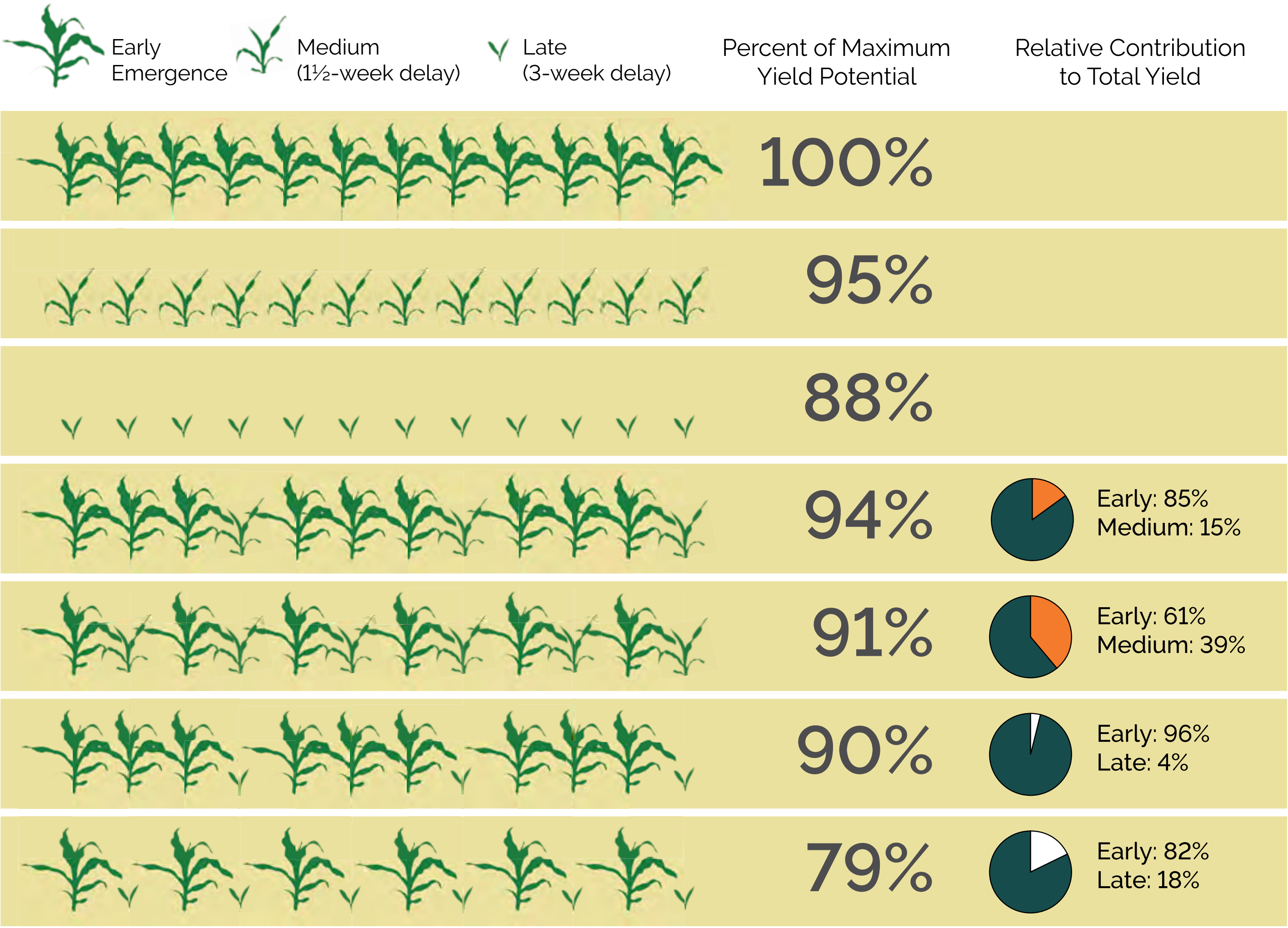
Other Factors to Evaluate

- **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.

Example of an uneven stand.



Data from Carter, P.R., E.D. Nafziger, and J.G. Lauer, 2002. Uneven emergence in corn, North Central Regional Extension Publication No. 344.

Figure 1. Yield potential of delayed and uneven corn stands.

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Maturity Selection for Delayed Planting in Indiana

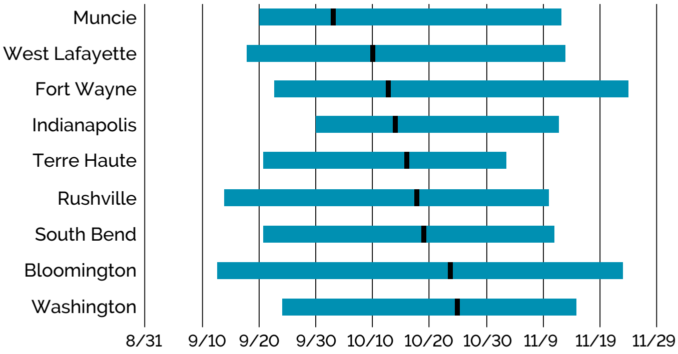

Figure 2. Earliest, latest, and average dates of first fall frost (<32 °F) in several Indiana locations (Source: Midwest Regional Climate Center).

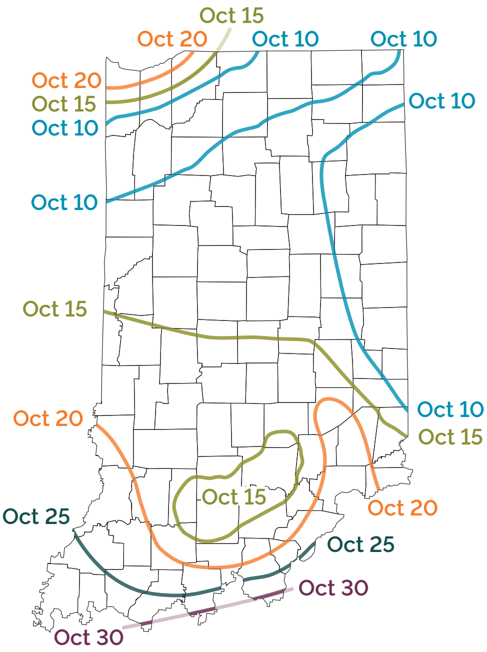

Figure 3. Dates at which there is a 50% probability of an autumn freeze of 32 °F or less (Source: USDA-NASS).

Table 2. Average accumulated GDUs between planting dates and average first-frost date for several locations in Indiana.

Location	Frost Date	Emergence Date 5/20	5/25	5/30	6/4	6/9	6/14
		——————— *GDUs* ———————					
Muncie	10/3	2801	2716	2624	2526	2422	2313
W. Lafayette	10/10	2916	2836	2748	2651	2548	2439
Fort Wayne	10/13	2837	2757	2670	2577	2476	2370
Indianapolis	10/14	3120	3028	2928	2821	2708	2589
Terre Haute	10/16	3121	3031	2933	2827	2715	2598
Rushville	10/18	3062	2974	2879	2777	2669	2556
South Bend	10/19	2748	2678	2599	2512	2418	2318
Bloomington	10/24	3127	3039	2943	2840	2731	2617
Washington	10/25	3407	3309	3202	3089	2969	2844

- A frequent question pertaining to replanting corn is what is the maximum hybrid CRM that can be planted and still reach physiological maturity.
- When considering which hybrid to replant, consider growing degree unit (GDU) accumulation between the planting date and average first-frost date and hybrid GDU requirements to reach physiological maturity.
- Research has shown that corn can adjust its growth and development, requiring fewer GDUs to reach maturity when planted late. Late-planted corn showed a reduction in GDU requirements of about six GDU per day of planting delay.

Maturity Selection for Delayed Planting in Nebraska

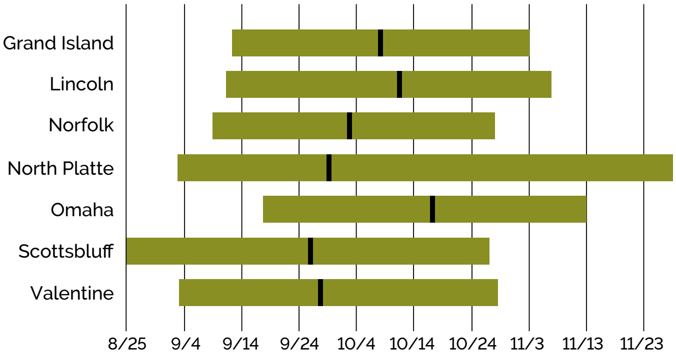

Figure 4. Earliest, latest, and average dates of first fall frost (<32 °F) in several Nebraska locations over the past 50 years (Source: High Plains Regional Climate Center).

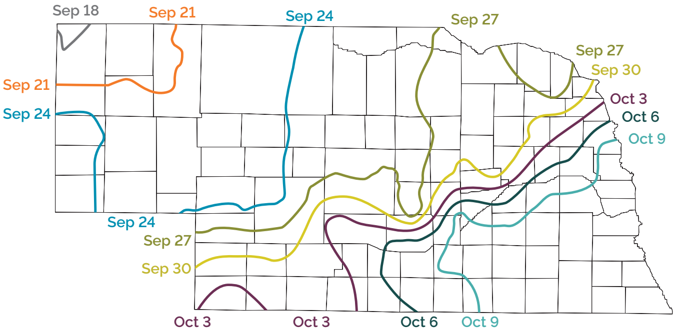

Figure 5. Dates at which there is an 80% probability of an autumn freeze of 28 °F or less.

Table 3. Average accumulated GDUs between emergence dates and average first-frost date for several locations in Nebraska (Source: High Plains Regional Climate Center).

Location	Frost Date	Emergence Date 5/20	5/25	5/30	6/4	6/9
		——————— *GDUs* ———————				
Grand Island	10/8	3014	2946	2869	2784	2691
Lincoln	10/12	3041	2971	2893	2806	2710
Norfolk	10/3	2684	2621	2549	2469	2381
North Platte	9/29	2477	2425	2365	2297	2222
Omaha	10/17	3031	2958	2876	2786	2688
Scottsbluff	9/26	2410	2360	2303	2238	2165
Valentine	9/28	2583	2526	2463	2391	2313

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Corn Plant Population Research

*by **Mark Jeschke, Ph.D.**, Agronomy Information Manager, and **Gaurav Bhalla, Ph.D.**, Data Scientist*

DuPont Pioneer Research

- DuPont Pioneer has been conducting plant population studies with corn hybrids for over three decades.
- Pioneer has conducted plant population research at over 320 locations throughout the U.S. and Canada in the last 6 years (Figure 1).

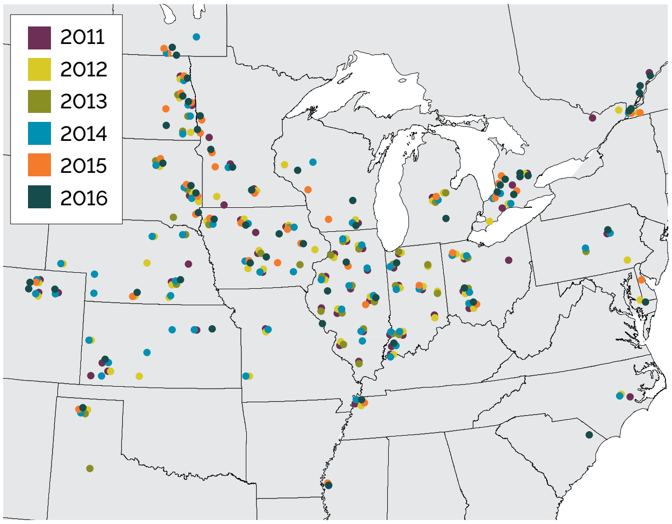

Figure 1. DuPont Pioneer plant population test locations in North America, 2011-2016.

- DuPont Pioneer researchers target representative environments based on maturity zone, expected yield (high or low), specific stresses, and other unique location characteristics. Research trials are all conducted in 30-inch rows.
- Additionally, hundreds of on-farm Pioneer® GrowingPoint® agronomy seeding rate trials are conducted each year, comparing multiple corn products at up to four seeding rates at each location (Figure 2).

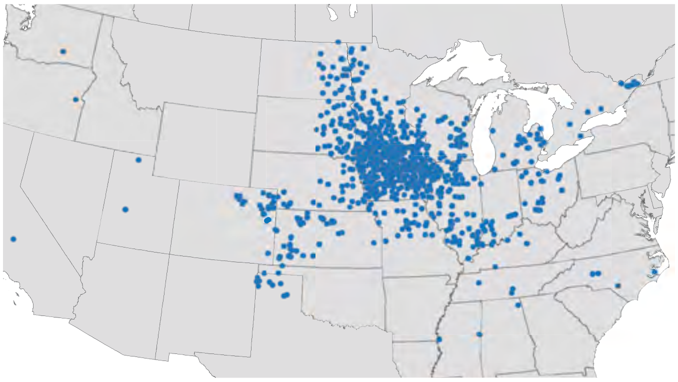

Figure 2. Pioneer GrowingPoint agronomy on-farm seeding rate trials at 974 locations in North America in 2016.

- Growers can use the multi-year and multi-location results to identify the best potential planting rates specific to their hybrid, location, and management practices.

Optimum Seeding Rate by Yield Level

- Like previous DuPont Pioneer studies, the 2009 to 2016 trials across the U.S. and Canada show that corn hybrid re-sponse to plant population varies by yield level (Figure 3).
- The seeding rate required to maximize yield increases as yield level increases.
- The economic optimum seeding rate varies from about 30,000 seeds/acre for locations yielding 150 bu/acre to over 37,000 seeds/acre for yields of 240 bu/acre.

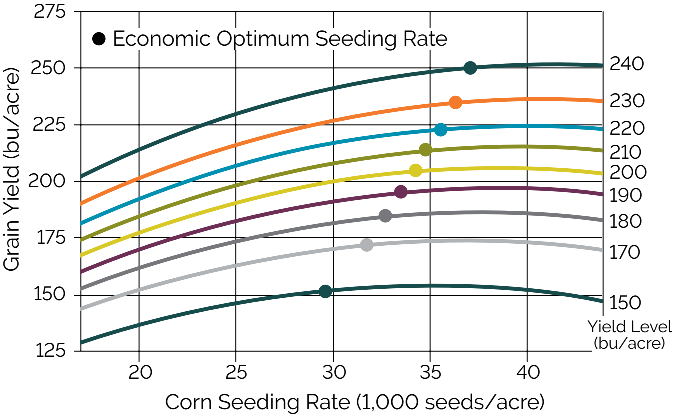

Figure 3. Corn yield response to population and optimum economic seeding rate by location yield level, 2009-2016.

Averaged across all hybrids tested. Economic optimums based on a corn grain price of $3.50/bu and a seed cost of $3.00 per 1,000 seeds; assumes % overplant to achieve target population.

Optimum Seeding Rate by Hybrid Maturity

- Previous research has shown that early maturity hybrids (<100 CRM) may require higher populations to maximize yield. Although this trend can still be detected when examining the response curves closely, it is a smaller difference than in the past (Figure 4).

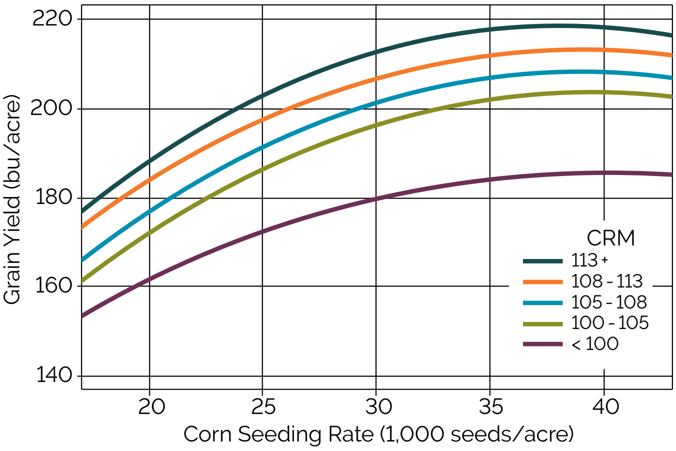

Figure 4. Yield response to plant population for corn hybrids from five maturity (CRM) ranges, 2009 to 2016.

Averaged across all hybrids tested.

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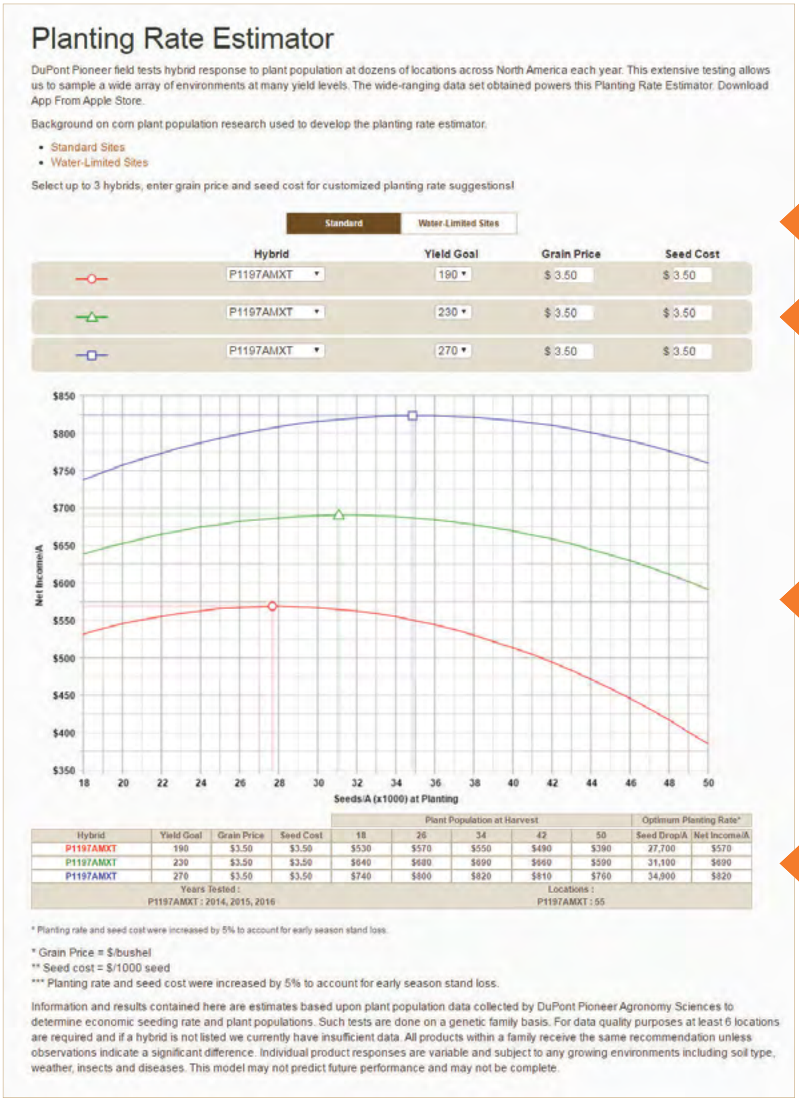
Planting Rate Estimator

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

Planting Rate Estimator Features

- The Planting Rate Estimator has the ability to display population response curves for a wide range of yield levels, which can provide guidelines for creating variable rate seeding prescriptions.
    - » It is possible to display plant population response curves at 10 bu/acre increments for all yield levels where there was a statistically significant response based on the available research data.
    - » The yield levels available for display will vary among hybrids based on the available research data.
- The Planting Rate Estimator provides flexibility in customizing the graph display.
    - » Users can display up to three response curves based on any combination of hybrids, yield levels, grain prices, and seed costs.
- Users also have the option of selecting a "Water-Limited Sites" version of the planting rate estimator, which includes data from studies conducted in drought environments in the Western U.S.
- Growers should use the Planting Rate Estimator as an initial guide and work with your Pioneer sales professional for refinements based on local observations and on-farm trials.



Planting Rate Estimator

DuPont Pioneer field tests hybrid response to plant population at dozens of locations across North America each year. This extensive testing allows us to sample a wide array of environments at many yield levels. The wide-ranging data set obtained powers this Planting Rate Estimator. Download App From Apple Store.

Background on corn plant population research used to develop the planting rate estimator.

- Standard Sites
- Water-Limited Sites

Select up to 3 hybrids, enter grain price and seed cost for customized planting rate suggestions!

	Hybrid	Yield Goal	Grain Price	Seed Cost
—○—	P1197AMXT	190	$ 3.50	$ 3.50
—△—	P1197AMXT	230	$ 3.50	$ 3.50
—□—	P1197AMXT	270	$ 3.50	$ 3.50

				Plant Population at Harvest					Optimum Planting Rate*	
Hybrid	Yield Goal	Grain Price	Seed Cost	18	26	34	42	50	Seed Drop/A	Net Income/A
P1197AMXT	190	$3.50	$3.50	$530	$570	$550	$490	$390	27,700	$570
P1197AMXT	230	$3.50	$3.50	$640	$680	$690	$660	$590	31,100	$690
P1197AMXT	270	$3.50	$3.50	$740	$800	$820	$810	$760	34,900	$820
Years Tested : P1197AMXT : 2014, 2015, 2016							Locations : P1197AMXT : 55			

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

* Grain Price = $/bushel
** Seed cost = $/1000 seed
*** Planting rate and seed cost were increased by 5% to account for early season stand loss.

Information and results contained here are estimates based upon plant population data collected by DuPont Pioneer Agronomy Sciences to determine economic seeding rate and plant populations. Such tests are done on a genetic family basis. For data quality purposes at least 6 locations are required and if a hybrid is not listed we currently have insufficient data. All products within a family receive the same recommendation unless observations indicate a significant difference. Individual product responses are variable and subject to any growing environments including soil type, weather, insects and diseases. This model may not predict future performance and may not be complete.

View plant population responses from either standard or water-limited research sites.

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

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

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

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Corn Plant Population Research

Water-Limited Sites

*by **Mark Jeschke, Ph.D.**, Agronomy Information Manager, and **Gaurav Bhalla, Ph.D.**, Data Scientist*

DuPont Pioneer Research

- DuPont Pioneer has been conducting plant population studies with corn hybrids for over three decades.
- These studies test for complex G x E x M (genetics x environment x management) interactions, which frequently play a key role in maximizing yield potential and reducing risk.
- Over the past several years, Pioneer has conducted plant population research focused specifically on lower-yielding water-limited environments (Figure 1).

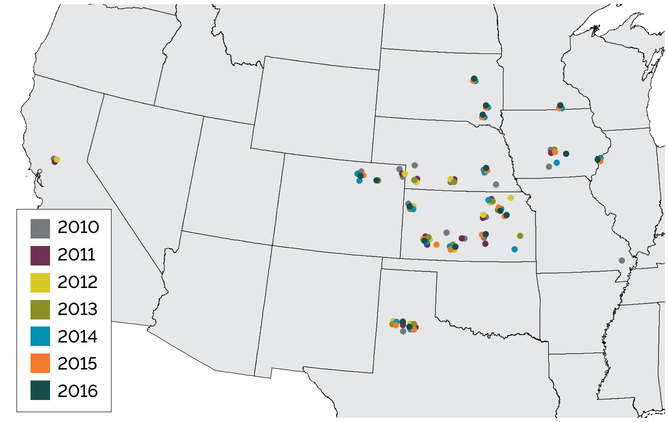

Figure 1. DuPont Pioneer plant population water-limited test locations in North America, 2010-2016.

- DuPont Pioneer researchers target representative environments based on maturity zone, expected yield (high or low), specific stresses (drought, pest pressure, high residue, early planting, etc.), and other unique location characteristics. Research trials are all conducted in 30-inch rows.
- Growers can use the multi-year and multi-location results to identify the best potential planting rates specific to their hybrid, location, and management practices.

Optimum Seeding Rate by Yield Level

- Like previous DuPont Pioneer studies, the 2010 to 2016 trials at water-limited sites show that corn hybrid response to plant population varies by yield level (Figure 2).
- The seeding rate required to maximize yield increases as yield level increases.
- The economic optimum seeding rate varies from less than 22,000 seeds/acre for locations yielding 90 bu/acre to around 24,000 seeds/acre for yields of 150 bu/acre.
- The economic optimum is the seeding rate that generates the most income when seed cost and grain price are factored in.

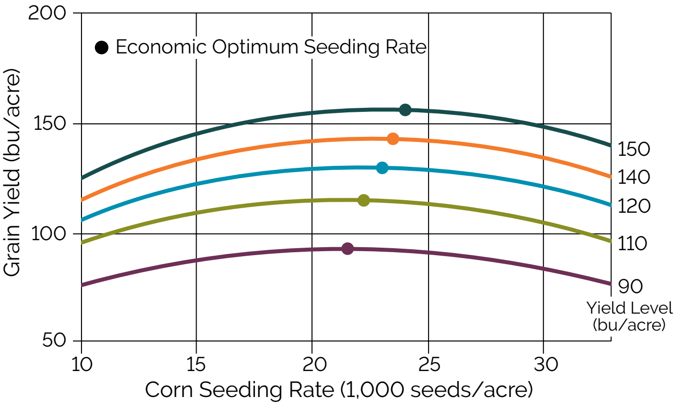

Figure 2. Corn yield response to population and optimum economic seeding rate by location yield level at water-limited sites, 2010-2016.

Averaged across all hybrids tested. Economic optimums based on a corn grain price of $3.50/bu and a seed cost of $3.00 per 1,000 seeds; assumes 5% overplant to achieve target population.

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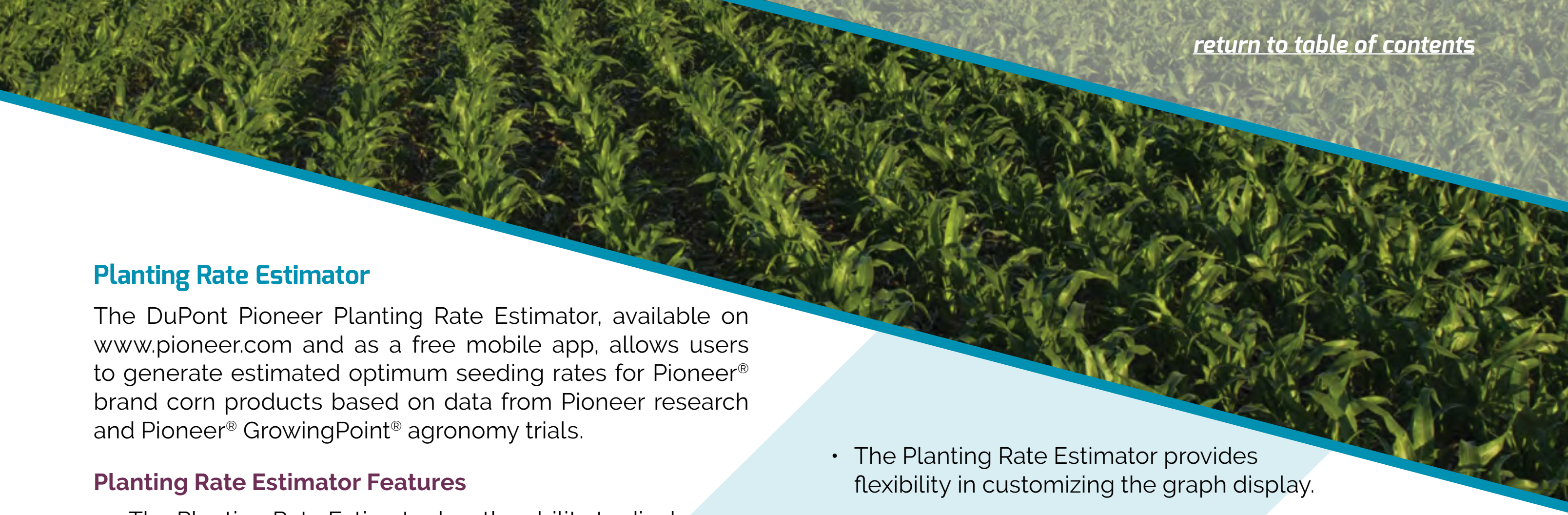

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- Users also have the option of selecting a "Water-Limited Sites" version of the planting rate estimator, which includes data from studies conducted in drought environments in the Western U.S.
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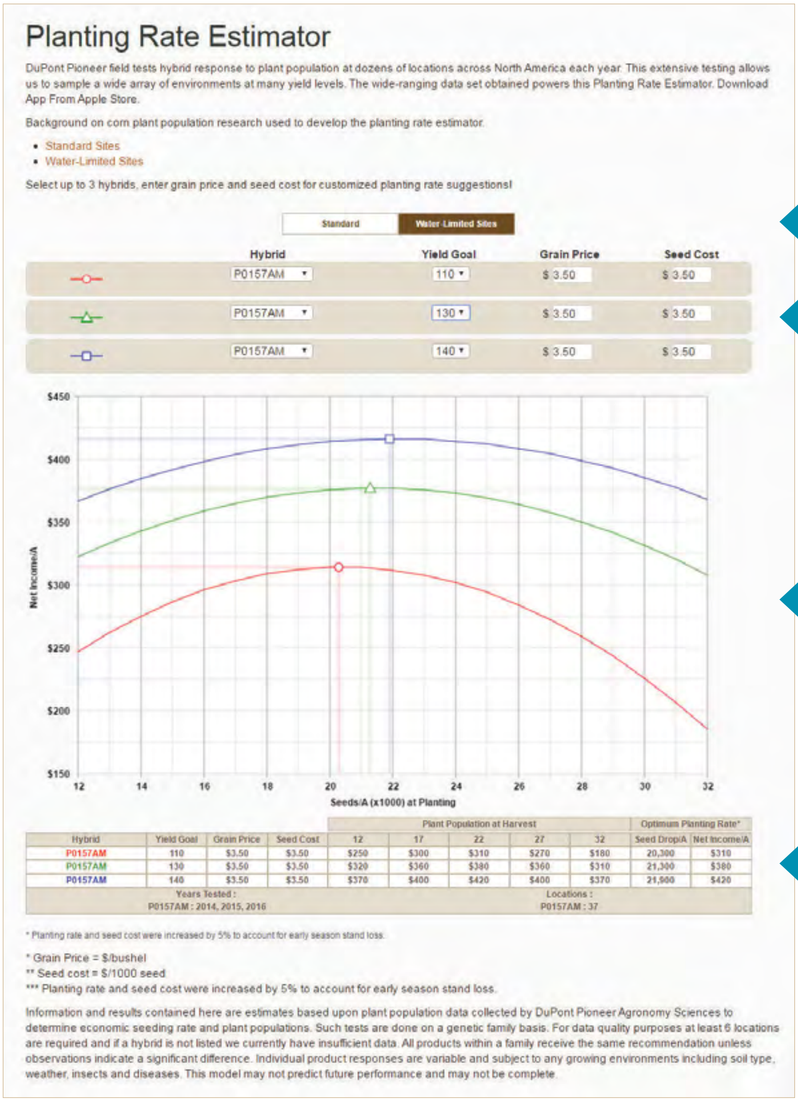

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Background on corn plant population research used to develop the planting rate estimator.

- Standard Sites
- Water-Limited Sites

Select up to 3 hybrids, enter grain price and seed cost for customized planting rate suggestions!

	Hybrid	Yield Goal	Grain Price	Seed Cost
─○─	P0157AM ▾	110 ▾	$ 3.50	$ 3.50
─△─	P0157AM ▾	130 ▾	$ 3.50	$ 3.50
─□─	P0157AM ▾	140 ▾	$ 3.50	$ 3.50

				Plant Population at Harvest					Optimum Planting Rate*	
Hybrid	Yield Goal	Grain Price	Seed Cost	12	17	22	27	32	Seed Drop/A	Net Income/A
P0157AM	110	$3.50	$3.50	$250	$300	$310	$270	$180	20,300	$310
P0157AM	130	$3.50	$3.50	$320	$360	$380	$360	$310	21,300	$380
P0157AM	140	$3.50	$3.50	$370	$400	$420	$400	$370	21,900	$420
Years Tested : P0157AM : 2014, 2015, 2016							Locations : P0157AM : 37			

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

* Grain Price = $/bushel
** Seed cost = $/1000 seed
*** Planting rate and seed cost were increased by 5% to account for early season stand loss.

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

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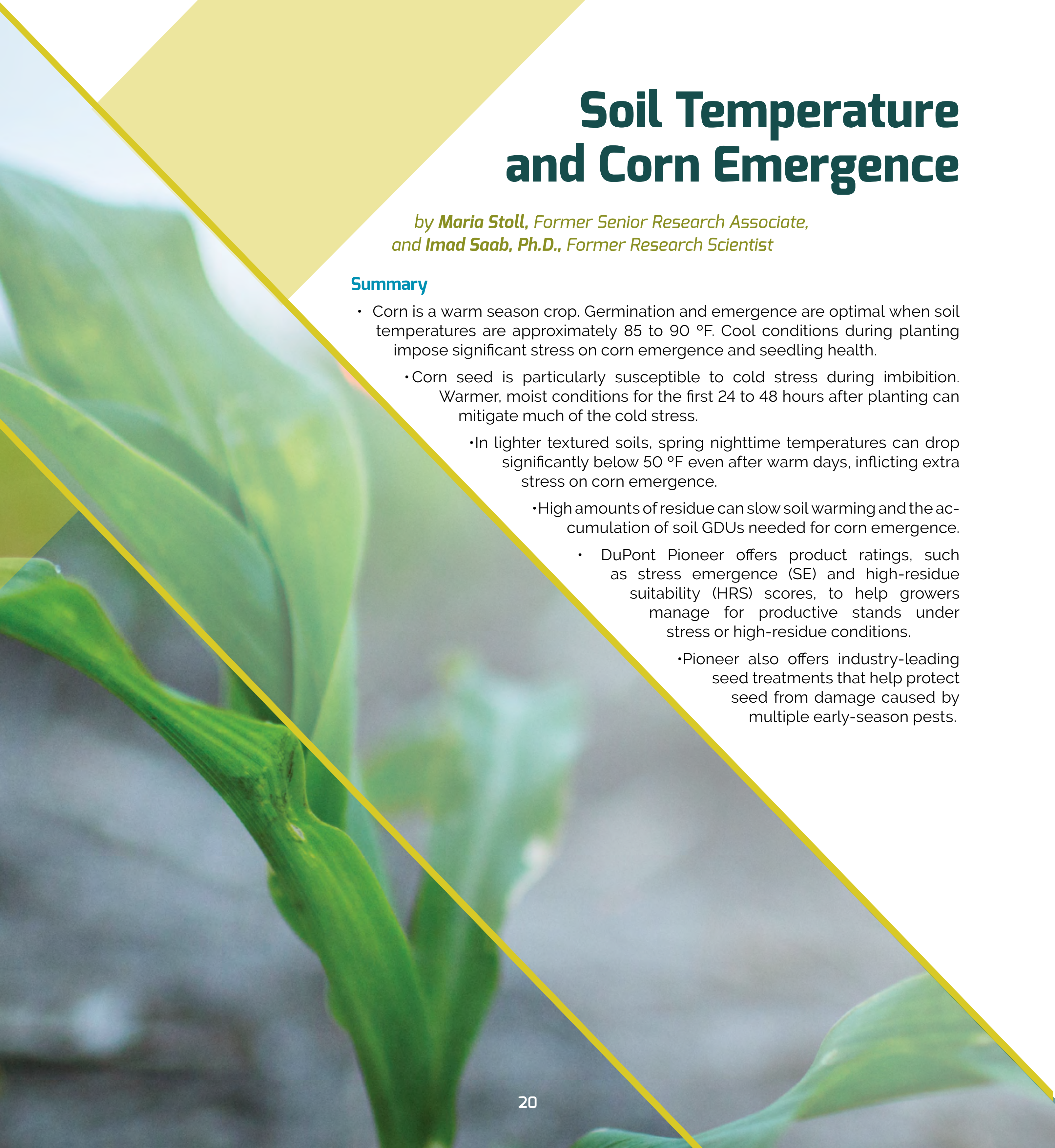

Soil Temperature and Corn Emergence

by **Maria Stoll,** Former Senior Research Associate,
and **Imad Saab, Ph.D.,** Former Research Scientist

Summary

- Corn is a warm season crop. Germination and emergence are optimal when soil temperatures are approximately 85 to 90 °F. Cool conditions during planting impose significant stress on corn emergence and seedling health.
- Corn seed is particularly susceptible to cold stress during imbibition. Warmer, moist conditions for the first 24 to 48 hours after planting can mitigate much of the cold stress.
- In lighter textured soils, spring nighttime temperatures can drop significantly below 50 °F even after warm days, inflicting extra stress on corn emergence.
- High amounts of residue can slow soil warming and the accumulation of soil GDUs needed for corn emergence.
- DuPont Pioneer offers product ratings, such as stress emergence (SE) and high-residue suitability (HRS) scores, to help growers manage for productive stands under stress or high-residue conditions.
- Pioneer also offers industry-leading seed treatments that help protect seed from damage caused by multiple early-season pests.

Introduction

Successful corn emergence is a combination of three key factors: environment, genetics, and seed quality (Figure 1).

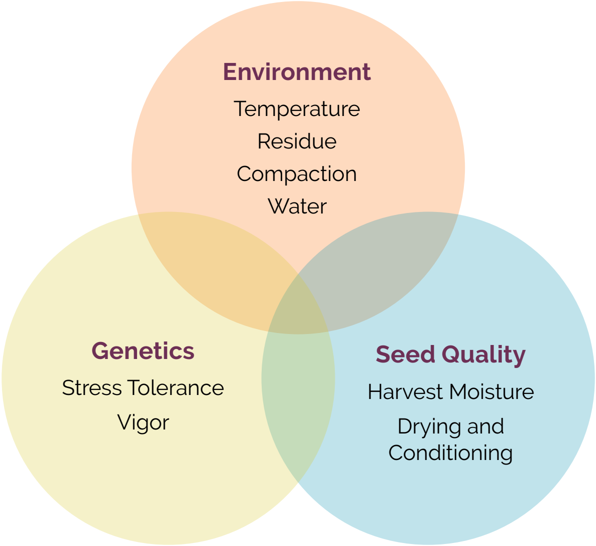

Figure 1. Some critical environmental, genetic, and seed quality factors that affect stand establishment.

Hybrid genetics provide the basis for tolerance to cold stress. High seed quality helps ensure that the seed will perform up to its genetic ability. DuPont Pioneer concentrates on selecting the best genetics for consistent performance across a wide range of environments and producing high-quality seed. However, even with the best genetics and highest seed quality, environmental factors can still dictate stand establishment. Pioneer provides research-based advice, which can help growers make informed decisions and better manage their field operations to maximize stands.

Soil temperatures at planting are a key environmental component of stand establishment. It is generally recommended that growers plant when soil temperatures are at or above 50 °F. However, soil conditions after planting are also critical (Figure 2).

Figure 2. Low soil temperatures after planting greatly reduced stands at a stress emergence site near Eau Claire, WI, in 2011.

This article will discuss how the level and timing of cold stress affects seed germination as well as emergence and how growers can mitigate these stresses when planting in challenging environments.

Optimal Temperature for Early Corn Growth

Corn is a warm season crop and does best under warm conditions. In North America, early-season planting typically puts stress on the corn seedlings. To help understand optimal corn growth, 3 hybrids of early, mid, and late maturities were germinated in temperatures ranging from 59 to 95 °F (15 to 35 °C). Growth rates of both roots and shoots were measured. All three hybrids were averaged to determine the optimal temperature for corn growth. Both shoots and roots exhibited the fastest growth rate at 86 °F (30 °C) and continued to grow rapidly at 95 °F (35 °C), suggesting optimal seedling germination and emergence occurs at much higher soil temperatures than are common in most corn-producing areas (Figure 3). Growers can expect much slower emergence and growth at the cool soil temperatures that are typical during U.S. and Canada corn planting.

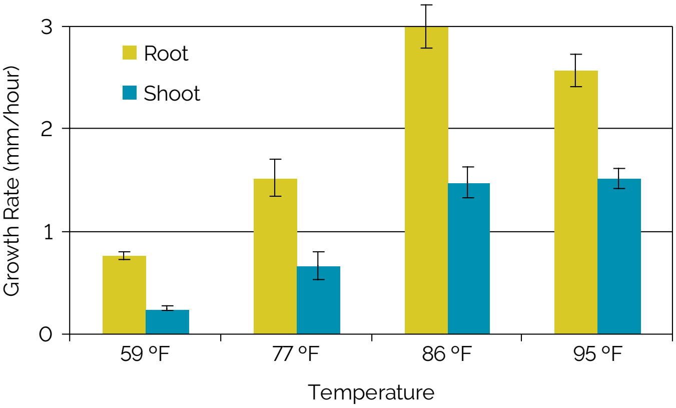

Figure 3. Average early root and shoot growth rates for 3 hybrids under 4 soil temperatures ranging from 59 to 95 °F.

Genetic Differentiation for Emergence in Cold Soils

Soil temperatures after planting are often a good indication of stress level, and stands may be reduced when average soil temperatures are below 50 °F (Figure 4). Pioneer provides stress emergence (SE) scores for all North American commercial hybrids to help growers manage early-season risk. Choosing hybrids with higher SE scores can help reduce genetic vulnerability to stand loss due to cold soil temperatures.

In 2009, a wide range of stress emergence conditions and soil temperatures were seen in the DuPont Pioneer stress emergence field plots. To demonstrate how stress emergence scores relate to stand establishment in the field, hybrids were grouped by "low SE", those with an SE rating of 3 or 4, and "high SE", those with an SE rating of 6 or 7.

Seventy low SE hybrids and 146 high SE hybrids were represented in the trials. Early stand counts for all hybrids within each group were averaged at each location. As stress level increased, both the low SE and high SE hybrids experienced stand loss. However, the hybrids with a SE score of 6 or 7 were able to maintain higher stands as compared to those with a low SE score (Figure 4).

Planting date remains a critical management factor to help growers minimize the risks associated with sub-optimal conditions for germination.

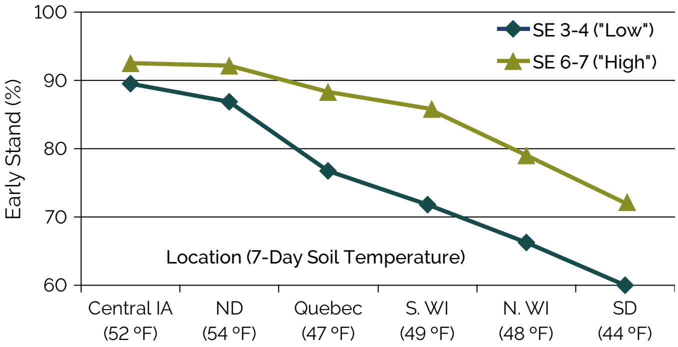

Figure 4. Average stand establishment for high and low SE score hybrids in six stress emergence locations in 2009. Locations are sorted from least stressful (left) to most stressful (right) based on average early stand.

Planting into cold, wet soils inflicts stress on corn seed emergence, as does planting just ahead of a cold spell. In some years, corn may be planted prior to a cold rain or snow, resulting in the seed sitting in cold, saturated soils (Figure 5).

Figure 5. Snowfall soon after planting imposes a very high level of stress on corn emergence due to the seed imbibing chilled water or prolonged exposure to cold, saturated soils.

Timing of Cold Stress Impacts Germination

To help understand the importance of the timing of cold stress, 2 hybrids with SE scores of 4 (below average) and 7 (above average) were allowed to germinate in rolled towels for 0, 24, or 48 hours at 77 °F (25 °C). The hybrids were then subjected to a stress of melting ice for 3 days and allowed to recover for 4 days at 77 °F (25 °C). Hybrids were evaluated for the number of normal seedlings reported as percent germination (Figure 6).

Both hybrids showed significant stand loss when the cold stress was imposed immediately (0 hours). However, the hybrid with a higher SE score had a higher percent germination than the hybrid with a low SE score. Germination rates for both hybrids were greatly improved if allowed to uptake water and germinate at warmer temperatures for at least 24 hours before the ice was added.

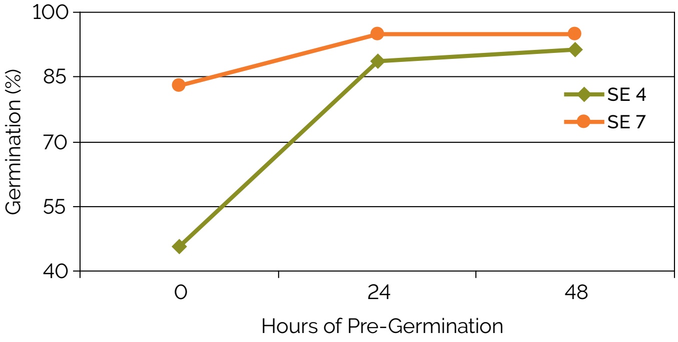

Figure 6. Germination of two hybrids with stress emergence scores of 4 (below average) and 7 (above average) following imbibitional chilling induced by melting ice. Ice was applied immediately after planting (0 hours) or after 24 hours or 48 hours of pre-germination in warm conditions.

Data suggests that planting just before a stress event, such as a cold rain or snow, can cause significant stand loss. The chances of establishing a good stand are greatly improved if hybrids are allowed to germinate at least one day in warmer, moist conditions before a cold-stress event. Also, choosing a hybrid with a higher stress emergence score can help moderate stand losses due to cold stress.

One reason why temperature during imbibition is critical to corn emergence is the fact that seed imbibes most of the water needed for germination very rapidly. To illustrate the rapid timing of water uptake, seed was submerged in 50 °F water for 3 hours and weighed at intervals of 30, 60, 120, and 180 minutes to determine water uptake (Figure 7).

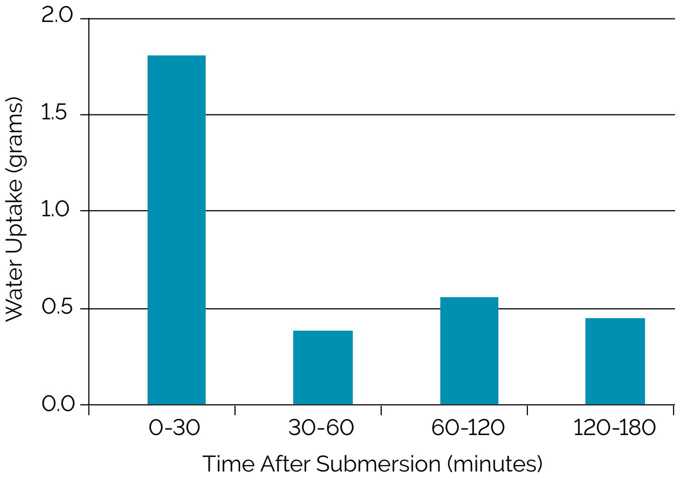

Figure 7. Amount of water uptake by corn seed during the first 3 hours after submersion in 50 °F water.

The data show that seed imbibes the most water within the first 30 minutes after exposure to saturated conditions. If this early imbibition occurs at cold temperatures, it could kill the seed or result in abnormal seedlings. Growers should not only consider soil temperature at planting but also the expected temperature when seed begins rapidly soaking up water. Seed planted in warmer, dry soils can still be injured if the dry period is followed by a cold, wet event.

Soil Temperature Fluctuations and Emergence

Growers are often able to plant fields with sandier soils earlier in the spring because they dry out faster than heavier soils. However, reduced stands after early planting have often been noted in sandier soils. Sandy soils are more porous and have lower waterholding capacity than heavier soils. As such, they tend to experience wider temperature fluctuations, especially on clear nights with cold air temperatures.

In 2009, soil temperatures were recorded at a 2-inch depth in a stress emergence location with sandy soils near Eau Claire, WI. Daytime soil temperatures reached acceptable levels for corn development (over 50 °F) for the first week after planting. However, the early morning soil temperatures dipped to as low as 35 °F, and on some days, the soil temperature difference between 6 AM and 6 PM was close to 20 °F (Figure 8). An average 25% stand loss was observed at this location, suggesting that day to night temperature fluctuation after planting can pose an added stress on germinating corn. Growers should be aware of expected nighttime temperatures when choosing a planting date.

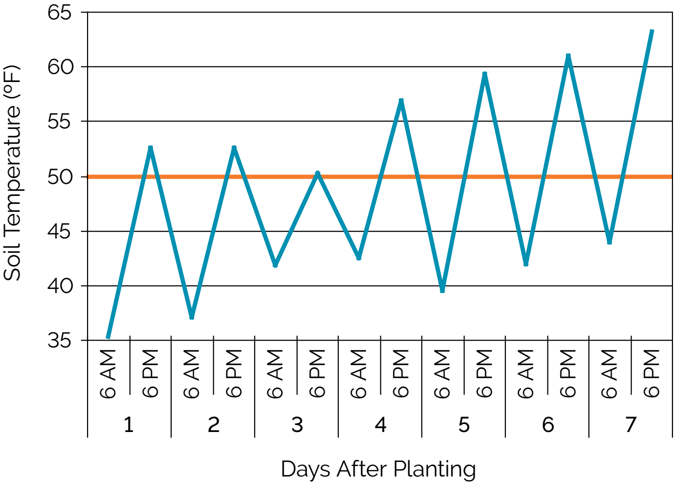

Figure 8. Soils temperatures at 6 AM and 6 PM for 7 days after planting in a stress emergence field location near Eau Claire, WI, in 2009.

Impact of Crop Residue on Soil Temperature

Another factor to consider when choosing planting date is the amount of residue in the field. High amounts of residue can present management challenges. Residue tends to hold excess water and significantly lower soil temperature in the spring, depriving seed of critical heat units needed for rapid emergence. These conditions can also promote seedling disease, particularly in fields that are not well drained or have a history of seedling blights.

In 2011, soil temperature data loggers were placed in a field near Perry, IA, to assess early soil temperatures in a strip-till field. One data logger was placed in the tilled planting strip (low residue), and one was placed in between the rows under high residue. Soil GDUs were calculated from the data logger temperatures to approximate how long emergence would take under low and high residue conditions. In general, approximately 100-120 soil GDUs are needed after planting for corn emergence (Nielsen, 2014). From April 1 to April 30, soils under low residue were able to accumulate 99 soil GDUs. During the same timeframe, neighboring soils under heavy residue accumulated only 28 soil GDUs.

Figure 9. An 11 °F difference was observed midday in late May 2011 in central Iowa between soils under no residue (left) and soils under heavy residue (right).

Even in late May after the crop had emerged, an 11 °F midday temperature difference was noted in the same field between soil under low residue and soil under heavy residue using a soil thermometer (Figure 9). Using a row cleaner to clear residue off the row in high residue fields allows for warmer daytime soil temperatures and faster GDU accumulation.

Tips to Help Mitigate Early-Season Stress Effects on Emergence

Delayed emergence due to cold, wet conditions lengthens the duration during which seed and seedlings are most vulnerable to early season insects and diseases. Seed treatments can help protect stands from both disease and insect pests. The PPST 250 seed treatment, which is standard on all Pioneer® brand corn hybrids in the U.S., includes fungicide (multiple modes of action), insecticide, and biological components. In areas with high nematode or insect pressure, such as cut worm or wireworm, growers can choose the added protection of Poncho® 1250 + VOTiVO® seed treatment. For more information on seed treatments offered by Pioneer, contact your local sales rep or visit: *http://www.pioneer.com*.

Planting date is one of the most important factors in stand establishment. The likelihood of reduced stands is greatest when planting into cold, wet soils or directly before cold, wet weather is expected. To help mitigate risk, consider the following tips:

- If a cold spell is expected around planting time, it is advisable to stop planting one or two days in advance. Allow seed to begin hydration in warmer soils in order to minimize damage due to cold imbibition.
- In sandy fields, be aware that low nighttime temperatures can dip soil temperatures below advisable planting levels. Large temperature swings in lighter soils can also hurt emergence.
- If planting in fields with high amounts of residue, consider strip-tillage, or use a row cleaner to allow soils to warm up faster.
- Selecting hybrids with higher stress emergence scores and the right seed treatment can help reduce the risks associated with planting in cold-stress conditions.

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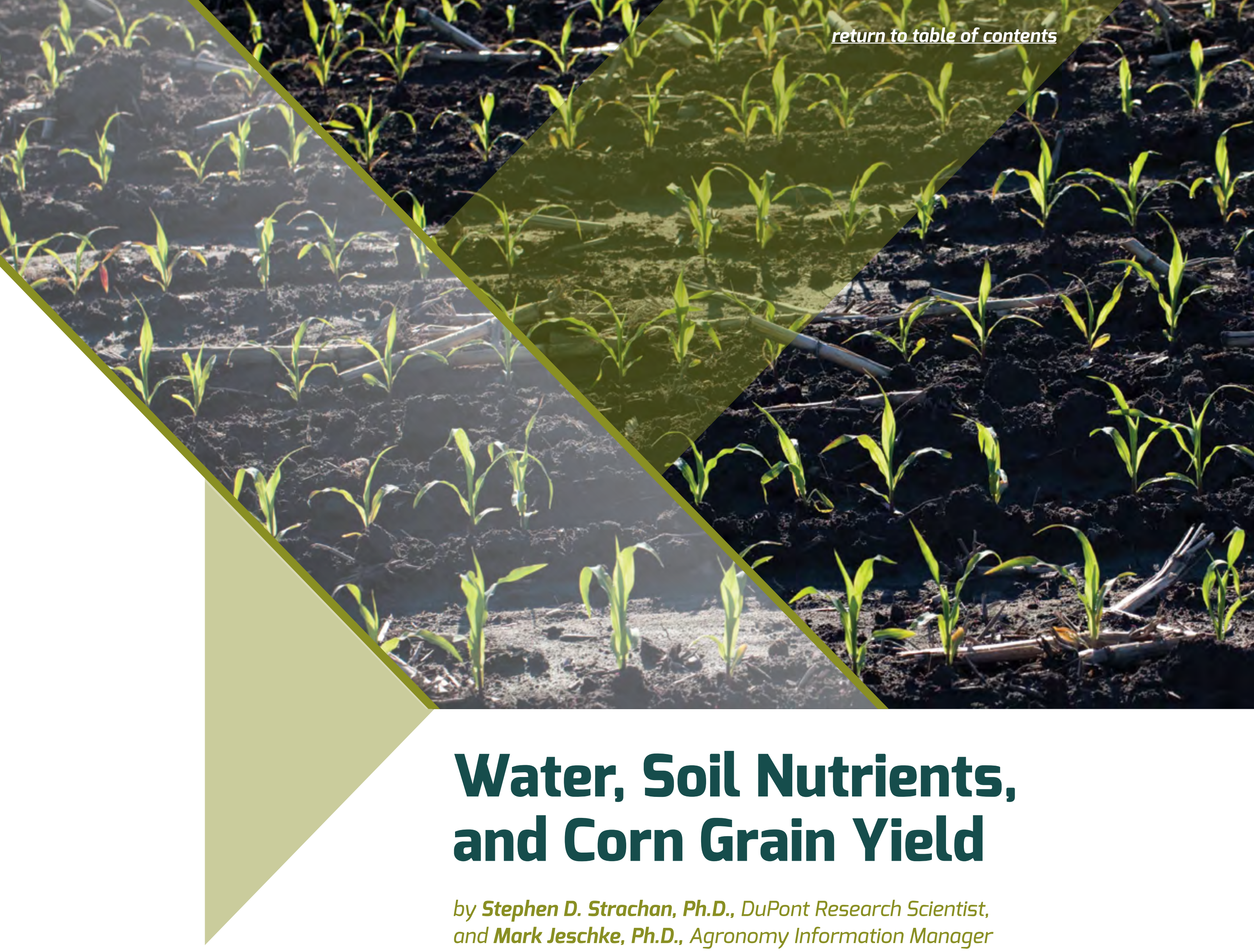

Water, Soil Nutrients, and Corn Grain Yield

by **Stephen D. Strachan, Ph.D.,** DuPont Research Scientist,
and **Mark Jeschke, Ph.D.,** Agronomy Information Manager

Summary

- High-producing corn hybrids are well-adapted to efficiently take up and utilize water and nutrients from soil.
- The chemical structure of water allows water to dissolve plant nutrients and carry these nutrients from the soil, through the corn plant, and into the harvested grain.
- Evaporation from plant leaf tissue and hydration of nutrient ions and organic molecules in growing points, such as developing kernels, pull water – like a chain – from the soil into and throughout the corn plant.
- As water is pulled throughout the corn plant, nutrients dissolved in this water are carried toward these same locations.
- Water uptake and plant nutrient uptake are tightly related – limited water uptake reduces total nutrient uptake.
- Corn requires a minimum of approximately 25 inches of water during the growing season to achieve maximum grain yield.
- At a population of 32,000 plants per acre, approximately 21 gallons of water is taken up by each plant where it is either transpired through the plant or is used to support growth and grain production.
- DuPont Pioneer has been focusing on improving water-use efficiency in corn for over 60 years. Grain production per inch of rain has increased dramatically from the 1950s to today.

Introduction

High-producing corn hybrids are well-adapted to efficiently extract nutrients from soil and incorporate these nutrients into biochemical processes for grain production (Figure 1). One of the jobs of a corn producer is to help create and support environmental conditions that maximize plant growth and grain production. There are two primary requirements for success. First, the fertility program must create a soil environment that contains adequate amounts and the proper balance of the different plant nutrients. Farmers, fertilizer dealers, and crop consultants understand this part of the grain production process well. Second, these nutrients must move into and throughout the corn plant to create grain. Corn producers may not understand the process of nutrient and water movement throughout the corn plant as well.

The problems corn plants face as they harvest nutrients scattered throughout the soil and concentrate these nutrients in the grain are similar to the problems you face during harvest. Grain grows on corn plants scattered throughout the corn field, and you must concentrate this grain into the bin. You must first extract the grain from corn ears located throughout an entire field. You collect this grain with a combine. In an analogous manner, corn roots and organisms associated with corn roots collect nutrients scattered throughout the soil profile. For your business, you must also move this harvested grain from the field and concentrate this grain in a storage bin as you prepare this grain for market. Often a grain cart is part of your grain transportation operation. For the corn plant, the plant moves nutrients and concentrates these nutrients in the ear as the corn plant moves water. Water is the “grain cart” in the corn plant’s nutrient harvest process. In this article, we shall discuss how water solubilizes plant nutrients and how water moves these nutrients from the soil to the ear.

Figure 1. The highest yielding corn hybrids are best adapted to utilize water from soil. Water and nutrient uptake and translocation in the corn plant are highly associated; limited water uptake reduces total nutrient uptake.

Physical Properties of Water

The chemical structure of water molecules creates six physical properties of water relevant to plant growth and grain production:

1. Excellent solvent to carry ions and nutrients
2. A strong force of cohesion (water molecules stick to other water molecules)
3. A strong force of adhesion (water molecules stick to other molecules that are not water molecules)
4. The volume of a given weight of water does not change as the pressure changes
5. A very high capacity to absorb heat
6. Liquid water expands as it freezes

These six properties support life in all organisms. However, for this article, we shall focus on only the first three.

Chemical Structure of Water

Water consists of two hydrogen atoms of and one oxygen atom. Each hydrogen atom consists of one positively charged proton in the nucleus and one negatively charged electron spinning around the nucleus. The oxygen atom consists of eight protons and eight neutrons that comprise a nucleus encircled by eight electrons (Figure 2).

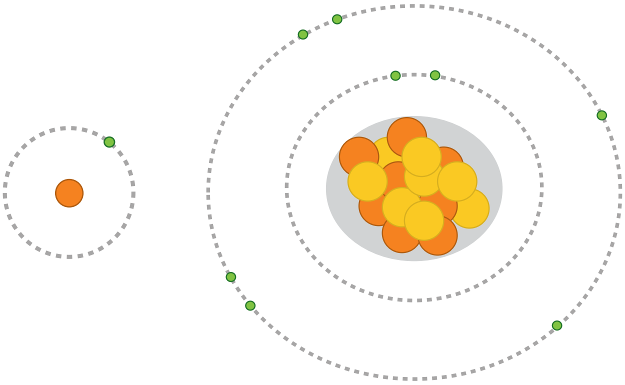

Figure 2. Diagram of a hydrogen atom with one electron encircling one proton on the left and an oxygen atom with eight electrons encircling a nucleus consisting of eight protons and eight neutrons on the right.

As two hydrogen atoms combine with one oxygen atom to produce one molecule of water, the two electrons from the two hydrogen atoms and six electrons from the outermost electron shell of the oxygen atom encircle the two hydrogen nuclei and one oxygen nucleus, forming a stable molecule (Figure 3).

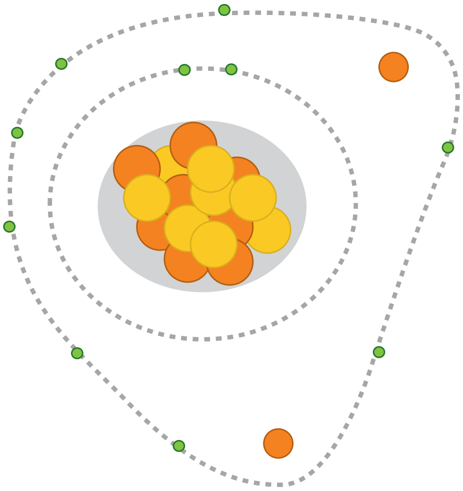

Figure 3. Diagram of a water molecule showing eight electrons (green) encircling the two hydrogen nuclei and the oxygen nucleus.

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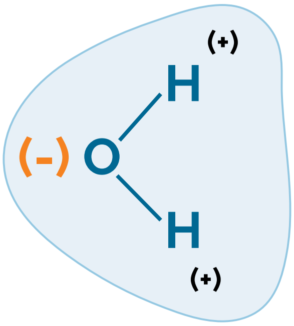
The oxygen atom has a much higher affinity for electrons than the two hydrogen atoms; consequently, the eight electrons encircling the water molecule tend to spend a greater amount of time near the oxygen nucleus and less time near the two hydrogen nuclei. This distribution of electron density causes the electronic charge to be more negative near the oxygen atom and more positive near the two hydrogen atoms of the water molecule. Individual water molecules, therefore, exist as dipoles, molecules containing regions of partial negative and partial positive charges (Figure 4).



The high electron density on the oxygen side of the water molecule provides a net negative charge to this side of the molecule.

The low electron density around each hydrogen atom provides a net positive charge around each hydrogen atom equal to one-half of the negative charge in the region near the oxygen atom.

Figure 4. The water molecule exists as a dipole, a molecule containing regions of partial negative and partial positive charges.

Water is an Excellent Solvent for Plant Nutrients

The dipole nature of the water molecule allows water molecules to arrange themselves in appropriate ways to dissolve positively charged cations and negatively charged anions. For positively charged nutrients, such as potassium (K^+) and calcium (Ca^{2+}), the positive charge is dispersed through the partially negatively-charged portions (oxygen side) of water molecules (Figure 5).

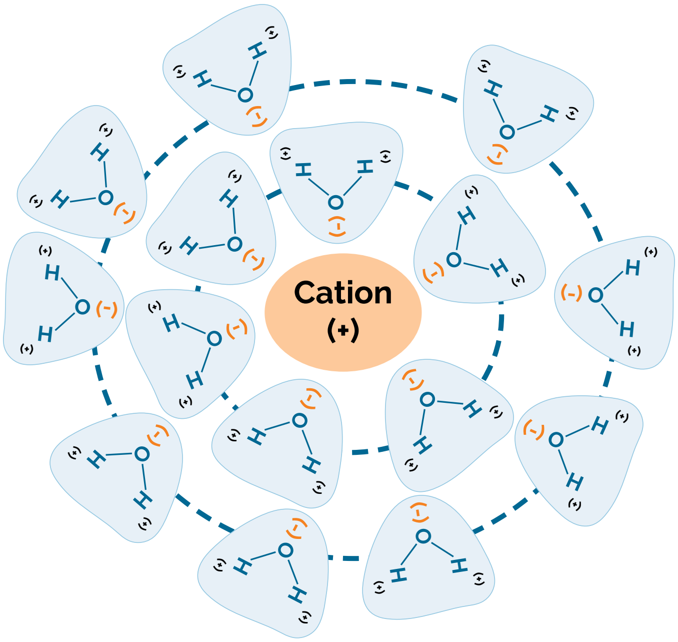


Figure 5. To dissolve cations, negative portions of water molecules face toward the cation to disperse the positive charge (opposites attract).

For negatively charged nutrients, such as nitrate (NO_3^-) and phosphate ($H_2PO_4^-$), the negative charge is dispersed through the partially positively-charged portions (hydrogen side) of water molecules (Figure 6).

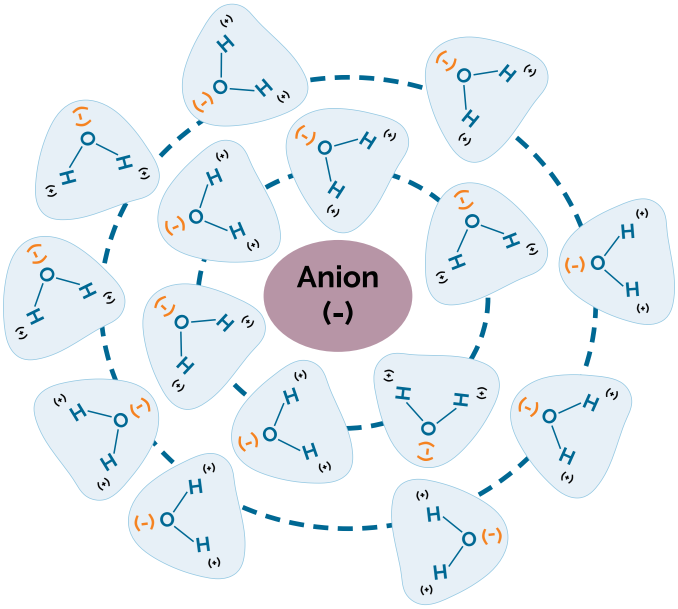


Figure 6. To dissolve anions, positive portions of water molecules face toward the anion to disperse the negative charge (opposites attract).

For both types of nutrients, concentric spheres of water molecules surround each ion. The innermost sphere of water consists of just a few water molecules, and forces related to ionic charge dispersal for each water molecule are very strong. A second sphere of water molecules forms outside the innermost sphere. Forces related to ionic charge dispersal for each water molecule in the second sphere are less because there are more water molecules to disperse the ionic charge. Additional spheres of water molecules continue to surround the ion as ionic and other forces dictate. These innermost spheres of water molecules are highly associated with the ion. As these innermost spheres of water molecules move, so too do the nutrients.

Forces of attraction between nutrient ions, soil, and water molecules determine nutrient behavior and mobility in soil (Table 1). Cations such as K+ tend to bond to negatively charged soil particles, are not abundant in the soil water phase, and tend to have low mobility. Anions, such as NO_3^-, do not readily bond to soil, are more abundant in the soil water phase, and are more mobile in soil water. Phosphorus is an exception, as it exists as an anion but has low water solubility, making it relatively immobile in soil.

Water Has a Strong Force of Cohesion

The dipolar structure of water creates an attractive force between a partially positively-charged hydrogen atom of one water molecule and a partially negatively-charged oxygen atom in a neighboring water molecule. This attraction, called "hydrogen bonding", aligns water molecules in a manner similar to how north and south poles align magnets.

Table 1. Essential nutrients for plant growth, forms available for plant uptake, and relative mobility in soil water.

Nutrient	Plant-Available Form(s)	Soil Mobility
Nitrogen	NO_3^- NH_4^+	Mobile Immobile
Phosphorus	HPO_4^{2-}, $H_2PO_4^-$	Immobile
Potassium	K^+	Somewhat mobile
Sulfur	SO_4^-	Mobile
Calcium	Ca^{2+}	Somewhat mobile
Magnesium	Mg^{2+}	Immobile
Boron	H_3BO_3, BO_3^-	Very mobile
Chlorine	Cl^-	Mobile
Copper	Cu^{2+}	Immobile
Iron	Fe^{2+}, Fe^{3+}	Immobile
Manganese	Mn^{2+}	Mobile
Molybdenum	MoO_4^-	Somewhat mobile
Zinc	Zn^{2+}	Immobile

Magnets have a single pole at each end, so magnets can form only a line. Water molecules have two positive poles and one negative pole. This additional positive pole allows water molecules to link together to form a complex 3-dimensional network (Figure 7).

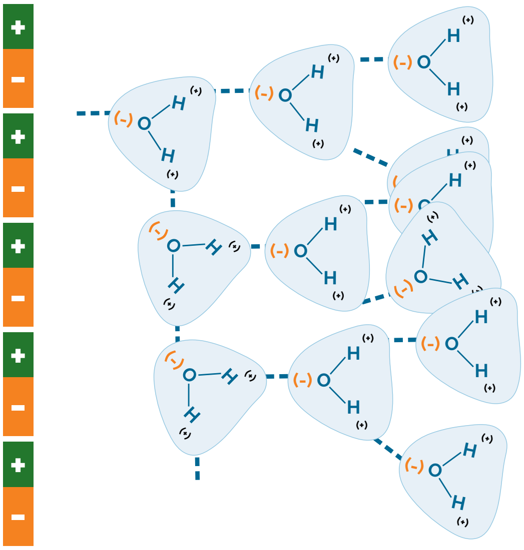


Figure 7. The positive and negative regions of water molecules allow water molecules to attract each other just like the positive and negative poles of magnets.

Hydrogen bonding forces associated with this 3-dimentional network allow water molecules to act like links in a chain. Water molecules can be "pulled" from one location to another just like a chain can be pulled to move materials from one location to another. Hydrogen bonding is therefore responsible for the force of cohesion, the ability of water molecules to stick to each other.

You, as a farmer, move corn grain by pulling the grain cart with a tractor. What force does the corn plant use to pull water with dissolved nutrients into and throughout the corn plant?

Forces Governing the Movement of Water in Soil and Plants

Water movement in soil and plants is not a random process. Five primary forces act on individual water molecules. These forces, in rank order from most to least powerful, are:

1. Evaporation: the conversion of liquid water to water vapor
2. Hydration: water tightly associated with clay mineral structure or molecular constituents in the corn plant
3. Ionic attraction: charge dispersal of dissolved ions or ions bound to cation exchange sites
4. Hydrogen bonding: formed from the polar character of hydrogen and oxygen atoms in the water molecule
5. Gravity

Sunlight provides the ultimate power for the force of evaporation, the most powerful force water molecules must obey as water moves from soil and throughout the corn plant (Figure 8).

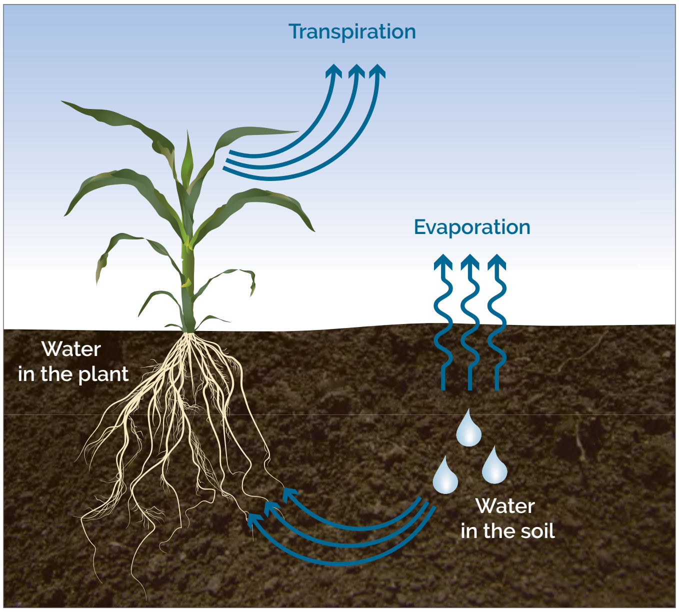


Figure 8. Water in the corn plant and in the soil continuously strive to maintain an equilibrium with water in the atmosphere but cannot because water in the atmosphere keeps moving away from the corn plant and soil.

Molecules of liquid water and water vapor strive to maintain a constant state of equilibrium. As water molecules evaporate from the corn leaf surface or from stomata in corn leaves into the surrounding atmosphere, this liquid water deficit in the corn leaf must be replaced with new water molecules. As this water deficit is replaced, water is pulled (just like a chain) from the vascular tissue of the corn plant. The movement of water from the vascular tissue to the leaf creates a water deficit in the vascular tissue. Water is pulled from corn roots to the vascular tissue to eliminate this deficit in the vascular tissue. The corn plant now has a water deficit in the corn root, so water is pulled from the surrounding soil into the root.

The second most powerful force for pulling water through the corn plant is the hydration of molecules and cellular constituents in growing points of the plant, such as the developing kernels in the ear. This hydration process is dependent on the ability of water molecules to adhere to other molecules (the force of adhesion). Ionic attraction of charged ions, such as potassium, and the force of hydrogen bonding to organic molecules, such as sugar, and proteins create this force of hydration. The force of evaporation pulls water up through the vascular tissue. The pulling force created by hydration of organic materials in the developing kernels is sufficient to pull water from the vascular tissue to the ear. If the corn plant is not under heat stress and there is plenty of water in the soil, the developing kernels can siphon water from the vascular tissue to provide the water and nutrients needed to support maximum growth and yield. However, if the amount of water that can be extracted from the soil is low and the corn plant is facing a "heat stress" environment, the force of evaporation dominates. The corn plant shuttles water to support evaporative demand and less water is shuttled to support kernel and ear growth. The result of this water and nutrient deficit to the ear is reduced yield.

Water Use Efficiency and Corn Hybrid Selection

Corn requires a minimum of approximately 25 inches of water during the growing season to achieve maximum grain yield. At a population of 32,000 plants/acre, approximately 21.2 gallons of water either transpire through the corn plant or are associated with biochemical and physical processes of that corn plant from planting until physiological maturity (black layer). Water carries nutrients from the soil into and throughout the corn plant and eventually deposits needed nutrients in the harvested ear. Water uptake and plant nutrient uptake are tightly related; limited water uptake reduces total nutrient uptake.

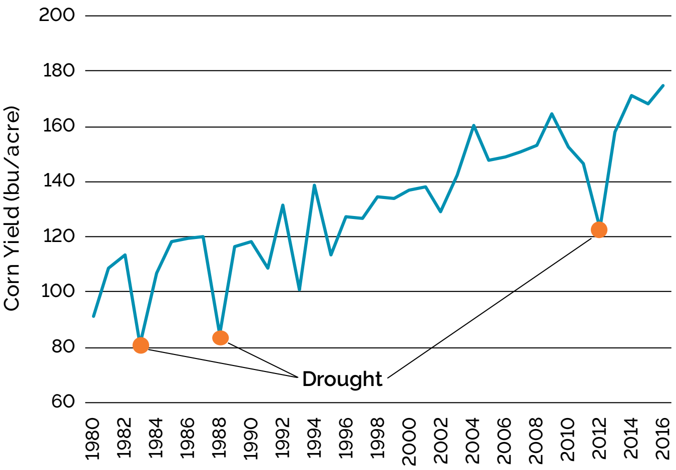


Figure 9. Average U.S. corn yield, 1980-2016 (USDA-NASS). Widespread drought in 1983, 1988, and 2012 resulted in sharp drops in corn yield.

In soils with adequate fertility, the ability of the hybrid to use water efficiently is a big factor in determining the hybrid's yield potential across a range of environments. "Rain makes grain." When examining long-term U.S. corn yield trends, years in which there was widespread drought immediately stand out (Figure 9).

Improved drought tolerance in corn has been one of the primary objectives of plant breeders at DuPont Pioneer over the past 60 years. DuPont Pioneer established the first dedicated drought-breeding station in York, Nebraska, in 1957. Since then, DuPont Pioneer has expanded drought research around the globe. The progress that has been made in improving water-use efficiency in corn is evident in yield trends relative to growing-season precipitation in rain-fed corn production. For example, in Champaign County, Illinois, where all, or nearly all, corn is produced without irrigation, corn yield per inch of rainfall during the period of April through September has increased from around four bushels in the 1950s to around seven bushels today (Figure 10).

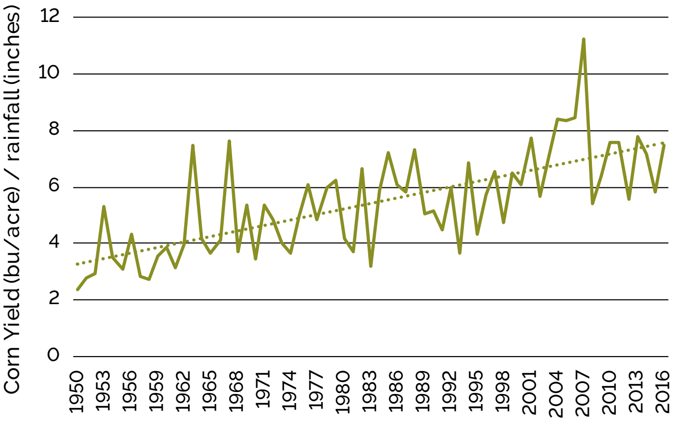


Figure 10. Corn yield per inch of growing season precipitation (April-September) from 1950 - 2016 in Champaign County, Illinois (Yield data: USDA-NASS; rainfall data: Nat. Weather Service).

Currently, DuPont Pioneer conducts field research on hybrid drought tolerance at multiple managed stress environments in North and South America; Europe; India; South Africa; and other locations around the globe with dependable levels of drought stress. Pioneer® brand Optimum® AQUAmax® hybrids, which are developed and tested to help deliver a yield advantage in water-limited environments, represent the most recent output of this ongoing research effort.

Summary

All water molecules within the soil, plant, and atmosphere strive to maintain a dynamic equilibrium in the midst of constantly changing environmental factors. Water is pulled from the soil, through the corn plant, and into the atmosphere. As this water is pulled, it carries the necessary nutrients to support plant growth. Water uptake and plant nutrient uptake are tightly related; limited water uptake reduces total nutrient uptake. In high-fertility soils, the ability of the hybrid to use water efficiently is a big factor in determining the hybrid's yield potential across a range of environments. As corn breeders develop new hybrids that require less water to achieve maximum yield potential, agronomists, fertilizer dealers, and farmers will need to develop agronomic practices for the corn plant to transport water and nutrients more efficiently in order to achieve higher grain yields for these new genetics across a range of environments.

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Water Retention and Nutrient Availability in Soil:

Drainage and Compaction

by **Stephen D. Strachan, Ph.D.**, *DuPont Research Scientist*,
and **Mark Jeschke, Ph.D.**, *Agronomy Information Manager*

Summary

- Soil texture, bulk density, and organic matter content determine soil water-holding capacity.
- Water's adhesive and cohesive properties create forces to retain plant-available water within the root zone.
- Soil compaction increases bulk density; determines pore size and volume distribution; and ultimately, limits water and nutrient uptake in corn plants.
- Increased soil compaction reduces the rate of water penetration to recharge a soil during a rainfall or irrigation event; reduces gaseous exchange and limits oxygen uptake by corn roots within the soil profile by reducing the macropore concentration; and limits the ability of corn roots to grow into new soil to extract water and nutrients.
- Increasing soil compaction is an unavoidable result of corn production. Ways to manage soil compaction include:
    - Match implement sizes to drive on the same wheel tracks.
    - Do not randomly drive across fields with heavy implements, but follow established wheel tracks.
    - Till soils at the proper moisture content.
    - Reduce the number of tillage operations per growing season.
    - Properly match equipment loads and weight distribution to tillage operations.
    - Mange your operation to increase soil organic matter.
    - Plant rotational or winter cover crops with root structures that tend to reduce soil compaction as these roots grow.

Introduction

Water held in soil is essential for corn growth. Each rainfall and irrigation event replenishes soil water as growing corn plants deplete this water. Soil texture, bulk density, and organic matter primarily determine the soil's water-holding capacity. The physical properties of water and soil govern a soil's ability to retain water and the corn plant's ability to extract this water. Soil compaction is a "hidden yield robber" (Figure 1). Land management that minimizes soil compaction and increases organic matter creates the greatest opportunity for soil to retain the maximum amount of plant-available water and nutrients to support corn growth and yield.

Figure 1. Areas of stunted yellow corn in a field likely resulting from soil compaction created during the previous harvest. Soil compaction can restrict root growth of corn as well as reduce the ability of soil to retain and supply water.

How Does Soil Retain Water?

Three physical properties of water – ionic interactions with nutrients and other ions; a strong force of cohesion; and a strong force of adhesion – create the forces that hold water within the plant root zone (Strachan and Jeschke, 2017). Cohesion is the ability of water molecules to stick to other water molecules. Adhesion is the ability of water molecules to stick to other molecules that are not water molecules. These forces interact with soil-bound cations, clay minerals, organic matter, and other solid materials that constitute soil colloids. If these forces were not present, the force of gravity would pull water molecules deeper into the soil profile where they are no longer available for plant uptake. Soil pores retain plant-available water. Soil texture, organic matter content, and bulk density determine the distribution and size of soil pores (Hillel, 1980).

The soil mineral fraction consists of silicates as well as aluminum hydroxy silicates, and soil organic matter contains oxygen as well as nitrogen atoms essential for retaining water. Oxygen and nitrogen atoms in both soil constituents are capable of hydrogen bonding with hydrogen atoms of water molecules. In addition, the chemical structure of aluminum hydroxy silicates in the soil mineral fraction as well as the molecular structure of organic acids and other materials in soil organic matter create net negative charges that are dispersed among water molecules located next to these soil constituents. Negative charges associated with soil minerals and organic matter also create cation exchange sites. Cations associated with these sites produce positive charges that are also dispersed among the water molecules located next to these cations. The combined forces of ionic charge dispersal and hydrogen bonding hold water molecules very tightly within the soil matrix and negate the downward force of gravity (Figure 2).

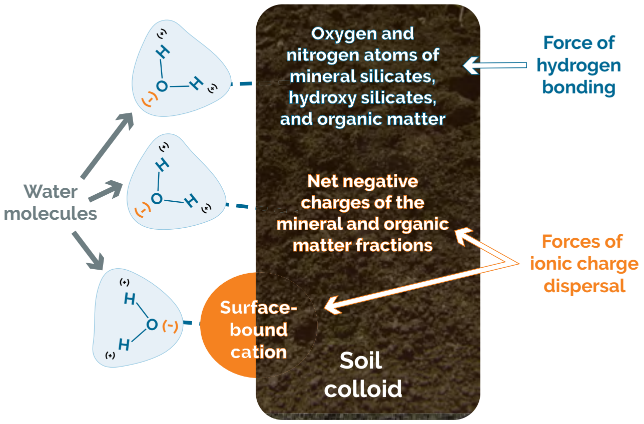

Figure 2. A combination of forces resulting from hydrogen bonding and ionic charge dispersal hold the first ring of water molecules very tightly to soil. Corn roots cannot easily extract these water molecules from soil.

Additional rings of water molecules surround the innermost ring of water molecules tightly associated with soil colloids (Figure 3).

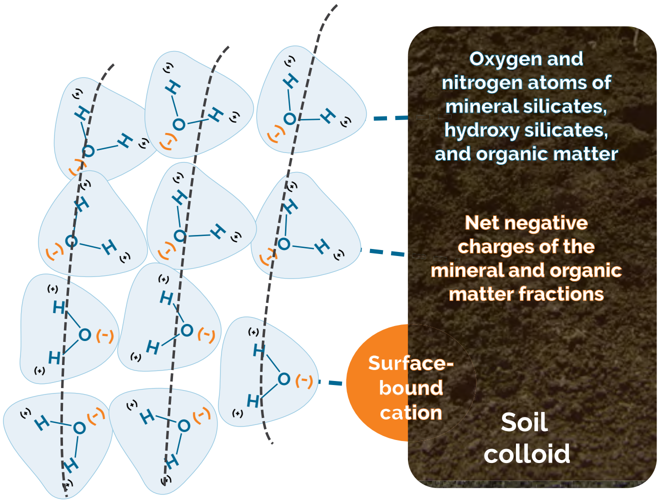

Figure 3. Multiple rings of water molecules form around each soil colloid. As each ring of water forms farther from the soil colloid, forces pulling water molecules toward the soil colloid diminish. Rings of water farthest removed from soil colloids are more available for plant uptake.

These additional rings of water are held in place through the forces of hydrogen bonding or ionic charge dispersal. Ionic charge dispersal is a stronger force expressed over short distances because as more water molecules disperse an ionic charge, the ionic force per interaction decreases. As rings of water molecules further from the soil colloid form, the weaker force of hydrogen bonding becomes the more dominant force. Water present in rings further from soil colloids are not as tightly associated with soil colloids and is therefore more readily available for plant uptake by corn roots. Figure 3 depicts only a few rings of water molecules. In the "real world," there are many layers of water molecules with different levels of different forces pulling on these molecules.

The size of the opening at the base of the soil pore determines the pore's ability to retain water (Hillel, 1980). Water molecules stretch across a pore space formed between soil colloids much like a chain stretches between two poles (Figure 4).

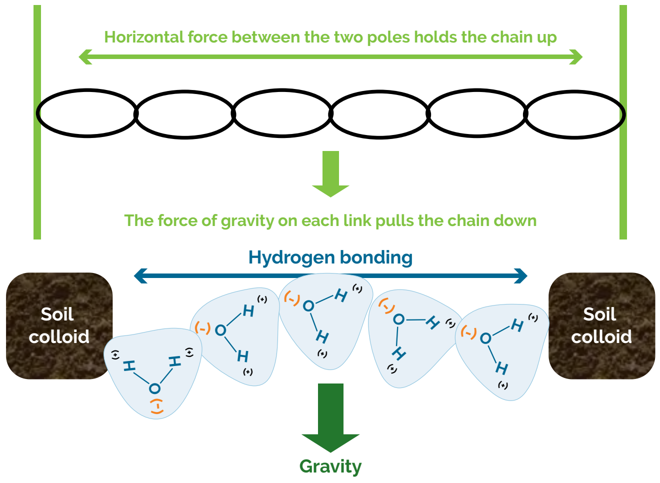

Figure 4. Water molecules behave like links in a chain.

For very small openings, the combined forces of ionic charge dispersal and hydrogen bonding hold these water molecules in place. As the pore opening increases, the weaker force of hydrogen bonding becomes more dominant (Figure 5).

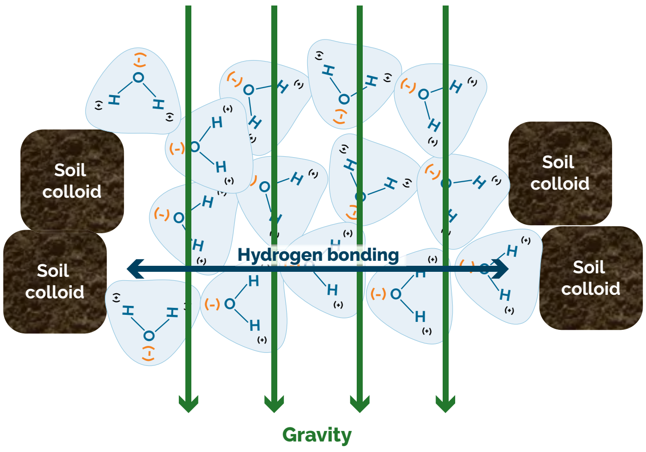

Figure 5. Multiple forces are pulling on all water molecules in the soil profile.

The chain of water molecules breaks when the downward force of gravity is greater than the lateral and upward forces of hydrogen bonding. When the chain breaks, water drains from the soil pore (Figure 6).

Corn field showing wheel tracks from combine and grain cart operation during harvest.

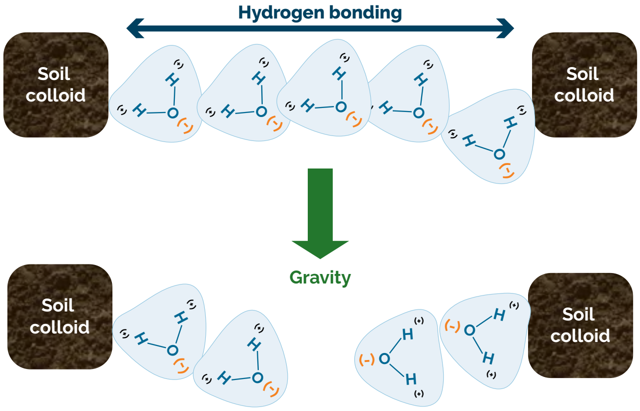

Figure 6. For soil pores with larger openings at their base, the force of gravity is stronger, and water drains from the center of the pore.

If the soil pore is small, water remains in the pore. If the pore is larger, water drains from the center of the pore. Liquid water associated with crushed ice in an excellent model to show how soil pores retain water (Figure 7).

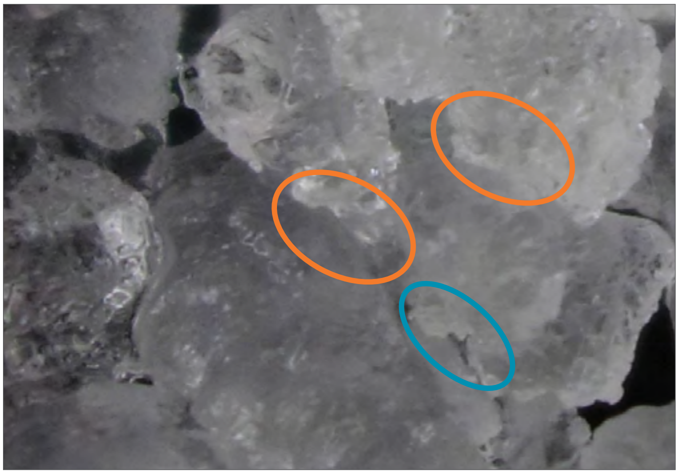

Figure 7. Model of liquid water in crushed ice illustrating how soil pores retain water. Micropores (orange ovals) are full with water while macropores (blue oval) retain water only along edges of solid surfaces.

Macropores and micropores comprise approximately 40 to 50% of the volume of an undisturbed, well-granulated silt loam soil (Brady, 1990). The amount of water present in this soil depends on when the last rainfall or irrigation event occurred and the water demand of the corn crop (Figure 8).

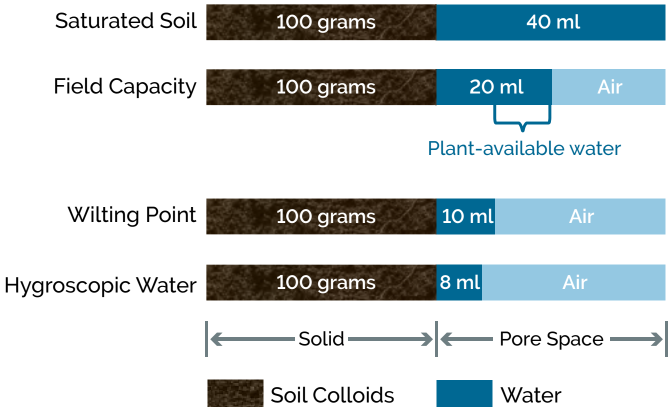

Figure 8. Volumes of water and air associated with soil pores in 100g of a well-granulated silt loam soil.

All soil pores contain water shortly after a substantial rainfall or irrigation event. The force of gravity pulls water molecules downward and drains water from the macropores. This continuous mass of water moves via saturated flow. As the water drains, the retentive forces exerted by soil colloids and the water molecules themselves eventually negate the force of gravity. When these forces are in balance, the soil is at field capacity for water retention. Subsequent water movement is via unsaturated flow, a very slow process for water movement. Soils at field capacity can stay at or very near field capacity for a long time if there is no water demand from growing plants. The balancing of these retentive forces with gravity and the very slow water movement of unsaturated flow allow soils to "recharge" with water during the winter months in preparation for the growing season.

Corn field with uneven growth due to compaction in wheel tracks

Corn roots pull water from soil until the retentive forces exerted by soil colloids equal the pulling forces of plant roots. When these soil retentive forces become greater, they overpower corn root pulling forces and corn plants wilt. Although water is still present in the soil, soil colloids hold this water so tightly that this water is not available for plant uptake. Proper water management must, therefore, focus on how to maximize the time that water levels in the soil are between field capacity and wilting point levels. This includes tiling as well as other forms of drainage to drain saturated or nearly saturated soils more quickly and irrigation to meet evapotranspiration and corn crop demand. If the water content of the soil goes below the wilting point, the first water added to this soil must address soil demand. After the needs of the soil are satisfied, additional irrigation water addresses plant demand.

Soil Compaction Determines Pore Size and Volume Distribution and Ultimately the Amount of Soil Water and Nutrients Available to the Corn Plant

Highly productive, well-aggregated, agricultural soils tend to consist of about 50% solids and about 50% pore space with an equal distribution of macropores and micropores in this pore space (Brady, 1990). This ratio of macropores to micropores allows soil to store ample water for plant growth while allowing for gaseous exchange in the soil profile to provide oxygen to plant roots. Soil minerals have a particle density of about 2.6 g/ml, so a soil consisting of 50% pore volume will have a bulk density near 1.3 g/ml.

A noticeable reduction in the percent of macropores is apparent if soil bulk density of a silt loam soil approaches 1.6 g/ml and macropores are almost non-existent as the bulk density approaches 2.0 g/ml. Modern corn production requires heavy machinery to pass over the soil. Soil is compacted with each machinery operation. Based on published studies, soil in corn production increases bulk density (more compacted) by 19% and decreases pore volume by 15% when compared to undisturbed soil of the same soil type (Brady, 1990). The soil's first response to compaction is to decrease the size, percentage, and distribution of macropores.

Compaction reduces the soil's ability to supply water to the corn plant because:

1. Compacted soils drain slower, allowing less water to penetrate the soil profile during rainfall or irrigation.
2. A reduction in macropores slows the rate of gaseous exchange and water movement associated with root uptake.
3. Compacted soils limit the ability of corn roots to grow into new soil to extract water and nutrients.

Compacted soils drain slower allowing less water to penetrate the soil during rainfall or irrigation. One method to view how compaction limits water movement is to view the wet edge of water as a mass of water moves through the soil profile. Figure 9 shows the leading edge of water movement as this water passes through and around a zone of highly compacted soil placed within a zone of soil not compacted. The rate of water infiltration depends on the amount and size of the macropores. As a comparison, it is much easier to pump water through a 1-in hose that it is to pump water through the tiny orifice of a spray nozzle. As the amount of compaction increases, the percent of macropores decrease. If the more compacted zone is a uniform sheet near the soil surface, the rate of water infiltration deeper into the root zone of the soil profile is restricted during rainfall or irrigation, potentially reducing the ability to fully "recharge" the water-holding capacity of the soil. Improper tillage of soils that are worked a bit too wet can cause a sheeted zone of compaction near the soil surface.

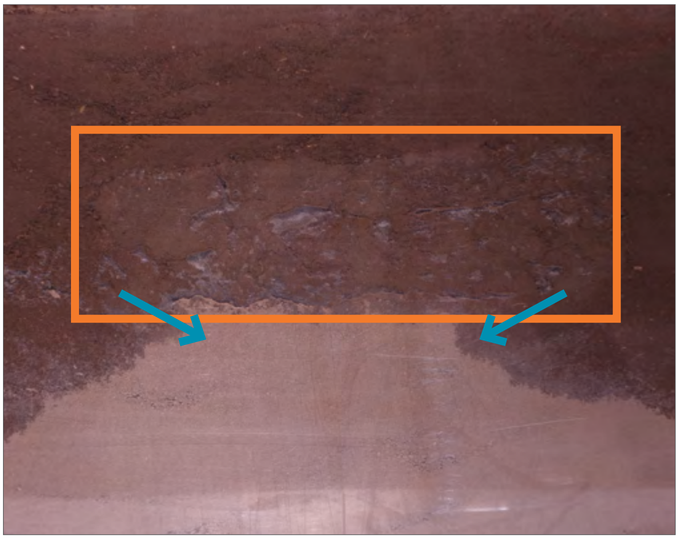

Figure 9. Water as it drains through the soil profile, is limited by a zone of highly compacted soil (outlined by the orange box). Water drains through less compacted soil more quickly and eventually begins to move below the zone of high compaction (blue arrows).

A reduction in macropores slows the rate of gaseous exchange and water movement associated with root uptake. There are two critical problems if the pore volume is predominantly micropores (Hillel, 1980). First, roots require oxygen for proper growth. If all soil pores are filled with water, there is no opportunity for gaseous exchange in the soil profile, so there is limited opportunity for roots to extract critical amounts of oxygen from the soil atmosphere. Second, plant-available water moves primarily via unsaturated flow. Corn roots penetrate about 1% of the total soil volume as the corn plant grows. As corn roots grow through the soil profile, they extract plant-available water within the soil zone immediately surrounding the roots. The soil responds by allowing water further from the roots to be pulled toward the corn roots via unsaturated flow. During unsaturated flow, water movement is very slow and becomes even slower as the pore size decreases. Corn plants growing in the same soil type are, therefore, more likely to show and respond to greater water stress in the more compacted soil.

Compacted soils limit the ability of corn roots to grow into new soil to extract water and nutrients. One way to illustrate the effect of compaction on corn root growth is with the following greenhouse study. Seeds of corn were planted into soil compacted to bulk densities of 1.17 g/ml, 1.25 g/ml, and 1.38 g/ml in soil columns. Corn plants were harvested at V5. Shoot growth and leaf stature differed little among corn plants growing in these three soil treatments. However, root growth decreased dramatically as soil compaction increased (Figure 10). In compacted soils, limited root growth limits the opportunity for water and nutrient uptake.

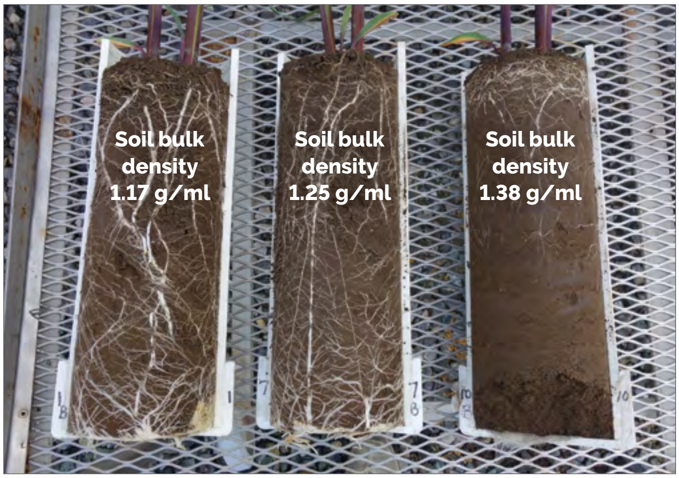

Figure 10. Root growth of corn plants (V5 growth stage) growing in soil compacted to different bulk densities before corn seeds were planted. Roots were washed, and dry weights were recorded for each soil treatment. Root dry weights were 2.47 g, 1.77 g, and 1.43 g for the 1.17 g/ml, 1.25 g/ml, and 1.38 g/ml soil bulk density growing conditions, respectively.

Soil Compaction is an Unavoidable Result of Corn Production

Each pass of an implement in corn production compacts the soil. Soil compaction cannot be eliminated, so it must be managed. Ways to manage soil compaction include:

- Whenever practical, match implement sizes so that various implements follow the same wheel tracks.
- Do not randomly drive across fields with heavy equipment, such as full grain carts; follow already established wheel tracks when possible.
- Till soils and conduct field operations when moisture conditions are correct for tillage operations; wetter soils are more prone to compaction.
- Reduce the number of tillage operations per growing season. Tillage reduces compaction in the tilled zone but often increases soil compaction just below the zone of tillage.
- Properly match equipment weights and load distributions with tillage operations.
- Manage your operation to increase soil organic matter content.
- Plant rotational crops or winter cover crops with root structures that tend to reduce soil compaction as these roots proliferate throughout the soil.

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Green Crimp in Corn

by **Mark Jeschke, Ph.D.,** *Agronomy Information Manager,*
Nicole Jansen, *Product Agronomist,* **Jonathan Propheter,** *Field Agronomist,*
and **Eric Alinger,** *Field Agronomist*

Summary

- Green crimp is the bending or crimping of the corn stalk under high winds while the plant is still green and actively growing, a phenomenon less commonly observed than other forms of wind damage, such as brittle snap and stalk lodging, following physiological maturity.
- Green crimp can be distinguished from brittle snap by the fact that stalk bending occurs at the internode and does not sever the vascular tissue, which allows the portion of the plant above the bend to continue some degree of growth.
- Effects on corn yield and harvestability depend on the severity and timing of wind damage to the plants.
- Green crimp during vegetative stages (V12 to VT) most commonly occurs immediately below, at, or above the primary ear node and is likely associated with weakness of the stalk during rapid growth.
- Green crimp during mid- to late-reproductive growth often occurs lower on the stalk and may be associated with weakening of the stalk due to remobilization of carbohydrates from the stalk to the developing ear.
- Fields that have experienced green crimp should be harvested as early as possible to maximize the harvestable yield.
- Management practices, such as timely planting, avoiding excessive planting densities, and selecting a diverse package of hybrids, can help reduce the risk of green crimp occurring.

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Introduction

High winds can damage growing corn in a number of ways, one of which is bending or crimping of the stalk, a phenomenon often referred to as *green crimp*. Green crimp can resemble stalk lodging but occurs while the plant is still green and actively growing, whereas stalk lodging typically refers to crimping or breaking of the stalk after physiological maturity and is often associated with stalk rots. Green crimp can be distinguished from brittle snap, also referred to as *green snap*, by the fact that stalk bending occurs at the internode and does not sever the vascular tissue, which allows the portion of the plant above the bend to continue some degree of growth. Brittle snap typically occurs at a node and involves the complete breakage of the stalk.

Figure 1. Plants at the R1 growth stage (silking) showing varying degrees of bending and recovery following a severe wind event in Illinois (July 14, 2016).

Green Crimp

- Bending/crimping of the stalk internode
- Does not sever vascular tissue
- Can occur from around V12 through physiological maturity
- If green crimp occurs during vegetative growth, the plant can recover to some extent.
- Can negatively affect both yield and harvestability, depending on timing and severity of damage

Brittle/Green Snap

- Breakage of the stalk, severing vascular tissue
- Occurs immediately below, at, or above the primary ear node
- Occurs most often during rapid vegetative growth (V5-V8 and V12-R1)
- Most productive fields are commonly the most susceptible due to rapid growth rate.
- Can result in complete loss of harvestable yield

Stalk Lodging

- Crimping or breakage of the stalk following physiological maturity after grain fill is complete
- Often associated with stalk rots
- Reduces harvestability

Damage to Plants

Green crimp effects on corn yield and harvestability depend on the severity and timing of damage to the plants. Occurrence of green crimp has been observed from late vegetative growth stages through mid-reproductive growth, approximately V12 to R4. Plants that are still undergoing vegetative growth at the time of green crimp occurrence are capable of some degree of recovery. As with root lodging during vegetative growth, affected plants will bend back toward vertical, which can result in crooked and odd-looking stalks (Figure 1). Damage at this stage can range from slight bending or leaning to a complete folding over of the stalk. Yield effects tend to correlate to the severity of the damage – a slight bending of the stalk may have little or no effect, whereas a complete folding over of the stalk is likely to be more detrimental.

Green crimp has the greatest potential to affect yield when it occurs around tasseling and silking. At this point, the plant has completed vegetative growth, so it is no longer capable of righting itself following a wind event. It is just beginning reproductive growth, so the effects on kernel set and grain fill will be maximized.

Injury to the plant at this time can also potentially disrupt ear development, making it particularly detrimental to yield. In 2016, instances of abnormal ear development were observed at multiple locations across the Corn Belt following severe storms and high winds. High winds caused some fields to lodge or lean over. In many fields, these storms occurred close to tassel and pollination stages. In some cases, wind damage to plants resulted in abortion of the primary ear that triggered development of an ear at the secondary node, a phenomenon likely due to hormonal disruption in plants following injury (Elmore et al., 2016). Ears growing at the secondary node often exhibited some degree of abnormality, and the delay in silking resulted in poor pollination. Yield losses associated with green crimp occurrence around tasseling and silking can vary widely based on severity of damage and other environmental stresses that may be affecting the plants.

Green crimp during grain fill is much more analogous to stalk lodging; it often occurs lower on the stalk and is likely associated with weakening of the stalk due to remobilization of carbohydrates from the stalk to the developing ear. While the term *stalk lodging* typically refers to crimping of the stalk below the ear after physiological maturity, green crimp during grain fill manifests in much the same way. A key distinction is that stalk lodging as defined here affects only the harvestability of the ear, not its actual yield since grain fill is already complete at this point. Green crimp affects harvestability and yield since the damage takes place prior to physiological maturity before grain fill is complete.

The later that green crimp occurs during grain fill, the less potential there is for yield to be affected. Yield losses of 5 to 15% have been observed with green crimp that occurred when corn was past ½ milkline. Yield losses due to green crimp that occurs later during reproductive growth are often less than expected relative to the appearance of the crop.

Figure 2. Green crimp and brittle snap resulting from high winds between the V12 and VT growth stages commonly occur on the stalk near the primary ear node. **Top:** Green crimp following a wind storm in Illinois in 2016. **Above:** Brittle snap following storms in Texas in 2011.

Hybrid Differences

As with most adverse weather effects on corn, the nature and severity of green crimp symptoms will often differ among hybrids. These differences may be attributable to specific genetic characteristics of a hybrid or may be due to the growth stage and plant stature of a given hybrid at the time of a severe weather event. Plants that are taller and have larger leaves are generally more susceptible to all types of wind damage. Similar to brittle snap, green crimp is most commonly observed in fields with high yield potential where the plants are undergoing rapid growth.

Contributing Environmental Factors

Late Vegetative Through Early Reproductive Stages

Green crimp occurring between the V12 and VT growth stages appears to be influenced by many of same factors related to brittle snap. From V12 through tasseling, the corn plant is undergoing its most rapid stage of growth. It will increase in size to its mature height of 7 to 10 ft in approximately 21 to 28 days, or about 2 to 4 in of growth per day. A key factor increasing susceptibility to all types of wind damage at this stage is the enlargement in leaf surface area and plant height, which increases wind resistance during a period of potentially severe thunderstorms and wind events (late June, July, or early August depending on the planting date and growing season). The most common sites for both green crimp and brittle snap at this stage are immediately below, at, or above the primary ear node. Upon reaching mature height, the plant becomes more resistant to wind damage as cell walls are strengthened by the deposition of lignin and other structural materials.

Field observations in 2016 and 2017 suggest some degree of correlation between hybrid susceptibility to green crimp and brittle snap. Pioneer® brand corn products are rated for genetic resistance to brittle snap. Hybrids in which green crimp was observed often had relatively low ratings for resistance to brittle snap. Whether damage from severe wind manifests as green crimp or as brittle snap, it may be related to moisture conditions at the time of the wind event. Cells of plants with ample moisture are more turgid and less able to bend without breaking, which can lead to brittle snap under high winds. Conversely, moisture deficit conditions resulting in less turgidity may favor bending of the stalk under high winds rather than breakage. Cell turgidity can be influenced by soil moisture conditions ahead of the wind event as well as the time of day when the wind occurs. Brittle snap is often associated with thunderstorms that occur in the early morning hours when temperatures are cooler and plant cells are more turgid.

Mid- to Late-Reproductive Growth Stages

Green crimp during mid- to late-reproductive growth may be associated with weakening of the stalk due to remobilization of carbohydrates from the stalk to the developing ear. As the plant goes through vegetative growth, photosynthate is directed to the stalk for temporary storage. Upon successful pollination, ear development places a great demand on the plant for carbohydrates. When the carbohydrate demands of the developing kernels exceed the supply produced by the leaves, stalk and root storage reserves are tapped. University studies indicate that during grain fill, about 60 to 70% of the non-fiber carbohydrates in the stalk are moved to other parts of the plant but primarily the ear (Daynard et al., 1969; Jones and Simmons, 1983). This stalk depletion begins approximately two to three weeks following silking. Environmental stresses, which decrease the amount of photosynthate produced by the plant, can force plants to extract even greater percentages of stalk carbohydrates, which preserves grain-fill rates at the expense of the stalk.

Figure 3. Green crimp in corn in Hall County, Nebraska (August 27, 2017).

Stress factors that reduce photosynthesis during grain fill will lead to greater remobilization of carbohydrates, which may increase the risk of green crimp. Foliar diseases are one such factor that can reduce plant photosynthesis by reducing effective leaf area. Low solar radiation during grain fill has also been associated with incidence of green crimp. Photosynthesis is most efficient in full sunlight.

Figure 4. Green crimp in corn in the California Central Valley in 2017.

Studies show that the rate of photosynthesis increases directly with intensity of sunlight. One experiment indicated that photosynthesis rates are reduced more than 50% on an overcast day compared to a day with bright sunshine (Moss et al., 1960). Prolonged cloudy conditions during ear fill often result in severely depleted stalk reserves. In 2017, corn growers in the California Central Valley experienced the effects of prolonged heat and lower than normal solar radiation, creating the perfect conditions for weakened stalks (Figure 4) (Jansen, 2017).

Management Considerations

For a field that has experienced green crimp, the best management option available is to harvest it as early as possible to maximize the harvestable yield. The longer the crop stays in the field, the more stalk quality will degrade, which can result in greater harvest losses.

A number of management practices can help reduce the risk of green crimp occurring. Planting a package of hybrids with a range of maturities is always advisable to spread risk associated with stress events during the growing season. Hybrids that differ in maturity go through their windows of susceptibility to stress factors at different times. Planting a package of diverse hybrids spreads the risk of injury, as it is unlikely that all hybrids will be at the same stage of development at the time of any one storm.

Timely planting may also help reduce risk of green crimp. Occurrence of green crimp in Illinois in 2016 and California in 2017 tended to be associated with later-planted corn. Later planting tends to result in taller plants, which will be more susceptible to wind damage. Early planting may also help plants advance through the rapid growth phase during vegetative growth when they are more susceptible to green crimp and brittle snap before the latter part of the summer when stress conditions and severe weather are more likely.

Carefully managing seeding rate for hybrids in which green crimp has previously been observed can reduce the risk of it occurring again. Avoiding higher than optimum seeding rates can reduce the stress load on plants from intraspecific competition, allowing them to be more resilient against stressful weather events.

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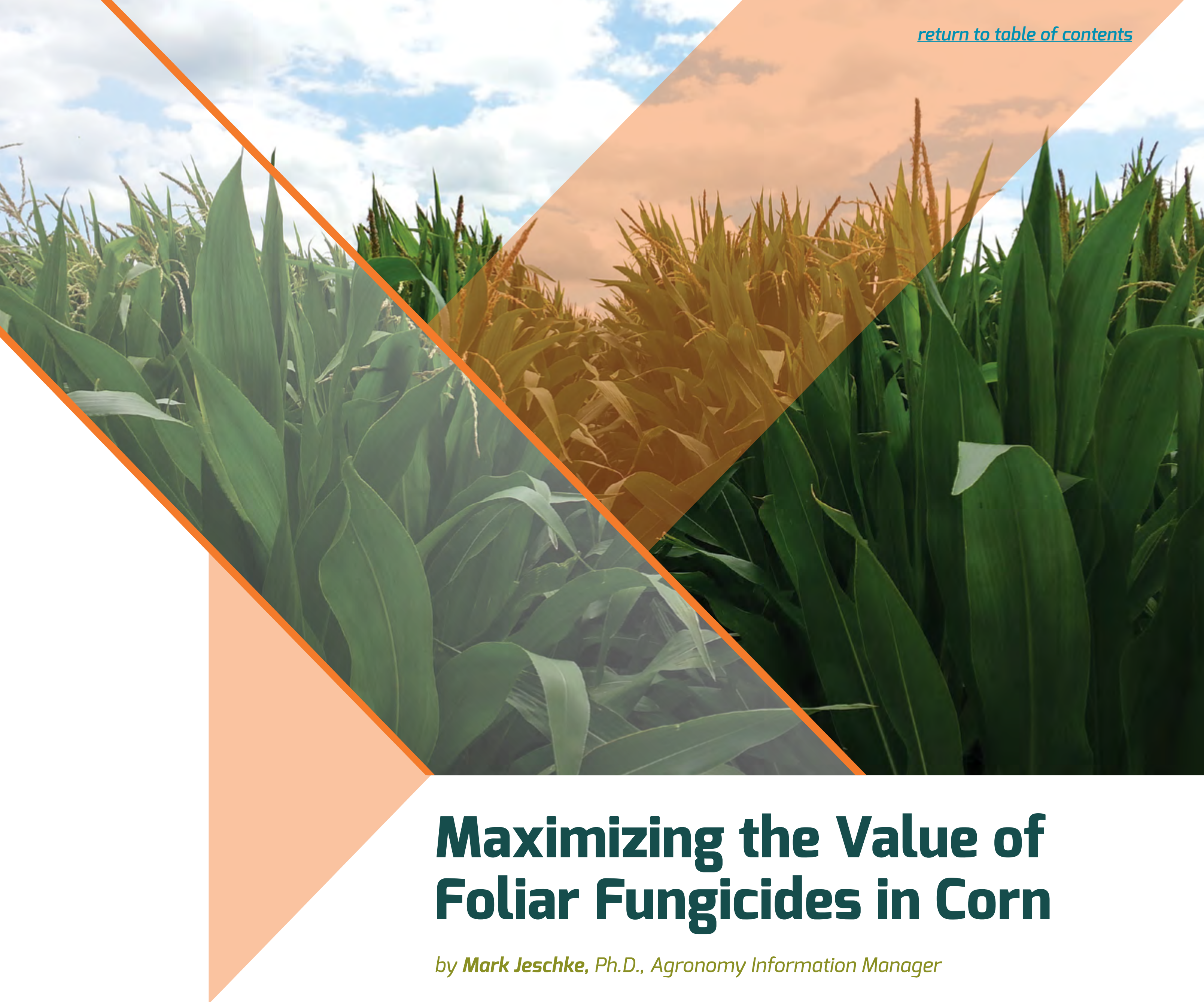

Maximizing the Value of Foliar Fungicides in Corn

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

Summary

- DuPont Pioneer has conducted extensive research to better understand the value of foliar fungicide treatments in corn production.
- Corn yield increased an average of 8.3 bu/acre in response to a foliar fungicide application across 1,476 on-farm trials conducted from 2007 to 2016.
- The average yield response to foliar fungicide application among on-farm trials was greater with practices that leave large amounts of residue on the soil surface, such as corn-following-corn, and no-till or strip-till.
- Fungicide yield response varied greatly among 10 small-plot research locations in 2009, from 0.6 bu/acre to 22.6 bu/acre, due to differences in disease pressure.
- Results of a three-year University of Tennessee/DuPont Pioneer study showed that the probability of using a fungicide profitably is directly related to the susceptibility of a hybrid to the predominant leaf diseases in the field.
- Among DuPont Pioneer on-farm trials, grain moisture of fungicide-treated corn was only slightly higher (+0.39 points) than non-treated corn.
- 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.

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Introduction

Over the span of only a few years, foliar fungicide treatments have progressed from a mostly new and untested practice to a trusted component of many growers' management systems. This has occurred as research results and grower experience have demonstrated that fungicides can be very effective tools for managing foliar diseases and protecting yield in corn. However, studies have also shown that fungicide applications do not always result in an economic benefit for growers. Extensive DuPont Pioneer research conducted over the last 10 years has demonstrated that the value of fungicide applications depends on disease pressure, hybrid susceptibility, previous crop, and tillage.

This article summarizes the key findings of three major foliar fungicide research projects conducted between 2007 and 2016. These studies involved several different foliar fungicide products and included both aerial and ground applications, but all were focused on application timings between tasseling and brown silk (VT-R2).

- **On-Farm Fungicide Trial Survey:** Survey of on-farm foliar fungicide side-by-side trials conducted between 2007 and 2016.
- **DuPont Pioneer Small-Plot Research:** 2009 study conducted to identify factors influencing yield response of multiple hybrids to foliar fungicide application across several Midwestern sites.
- **University of Tennessee/Pioneer Small-Plot Research:** 2006 to 2008 study comparing foliar fungicide response among hybrids with differing levels of genetic resistance to gray leaf spot (GLS) at a site chosen specifically due to its history of high GLS pressure.

Yield Response to Fungicide Treatment

Between 2007 and 2016, DuPont Pioneer researchers conducted a total of 1,476 on-farm fungicide trials comparing yield and moisture of non-treated corn to corn treated with a foliar fungicide between tasseling and brown silk. Across these trials, the average yield response to fungicide application was an increase of 8.3 bu/acre (Figure 1).

A positive yield response to fungicide application occurred in 82 % of the trials. Yield response varied widely among many of the trials, as was expected given differences in weather conditions, disease pressure, and trial locations.

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

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

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

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

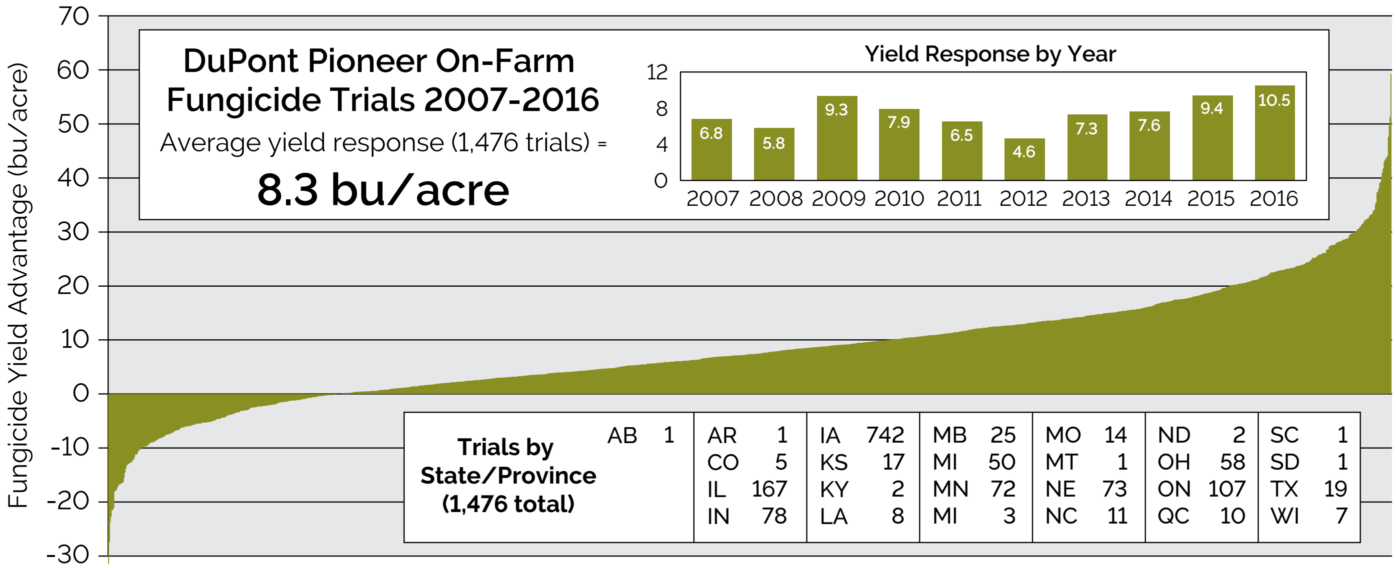

Figure 1. Corn yield response to foliar fungicide application in 1,476 DuPont Pioneer on-farm trials conducted from 2007 - 2016.

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

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

At a break-even yield response of 4 bu/acre, 65% of the Pioneer on-farm trials conducted over 10 years would have seen an economic benefit from fungicide application (Figure 1). However, at a break-even point of 8 bu/acre, the success rate drops to only 48%.

Factors Influencing Yield Response

Disease Pressure

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

There are two basic types of disease cycles among the fungal diseases that infect corn leaves. Most of the pathogens, such as northern leaf blight (NLB), 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 U.S., and spores are windblown long distances into the Corn Belt. Disease onset depends on weather systems that carry the spores northward combined with favorable conditions for infection. Secondary spread occurs similarly to the other leaf diseases.

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

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

A positive return from a fungicide application is more likely when conditions favor foliar disease development.

Pioneer on-farm research trials conducted in Iowa from 2007 to 2014 demonstrated the extent to which corn yield response to foliar fungicides can vary year to year due to weather conditions. Disease pressure is generally lower under drought conditions, as development and spread of several common foliar diseases is favored by moisture and humidity. 2011 and 2012 were both abnormally dry years in Iowa, whereas 2007 to 2010, 2013, and 2014 all experienced normal to above-normal precipitation in most parts of the state. The average yield response to foliar fungicides in on-farm trials conducted during the two drought years of 2011 and 2012 was well below the average response observed in years with greater precipitation (Figure 2).

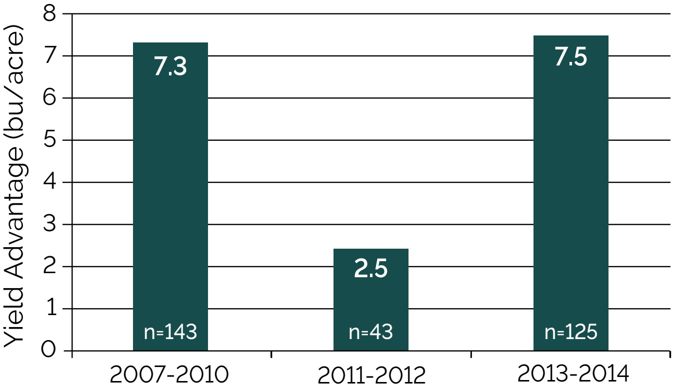

Figure 2. Average corn yield response to foliar fungicides in Iowa on-farm trials in drought years (2011-2012) compared to years with normal or above-normal precipitation (2007-2010 and 2013-2014).

Hybrid Disease Susceptibility

In Pioneer and university studies with multiple hybrids of varying disease resistance, the probability of using a fungicide profitably has often been directly related to the susceptibility of a hybrid to the predominant leaf diseases. Pioneer® brand hybrids are rated on a scale of 1 to 9 for their level of genetic resistance to major foliar diseases, with 1 to 3 indicating a susceptible hybrid, 4 to 5 moderately resistant,

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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 (Figure 3).

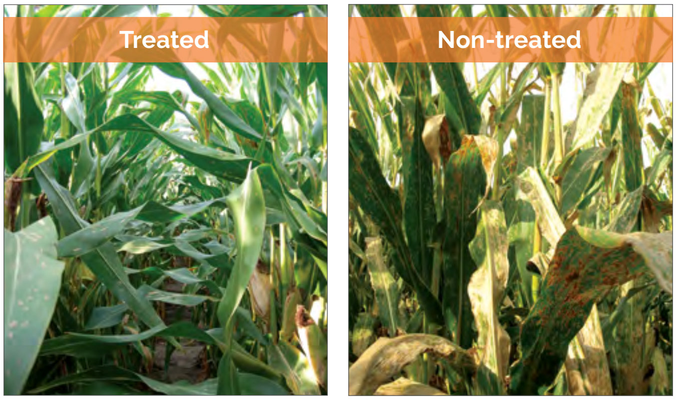

Figure 3. A hybrid susceptible to common rust (3 on a 1-9 scale) treated with a fungicide (left) compared to the same hybrid, non-treated, showing severe common rust symptoms (right). As expected, yield was greatly improved by the fungicide application due to high disease pressure at this DuPont Pioneer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

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

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

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

*Pioneer hybrids are rated for disease resistance on a 1-9 scale, with 9 being the most resistant.

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 likely cover the cost of product and application (Figure 4). Under more moderate disease pressure, a fungicide application would likely not provide an economic benefit on a resistant hybrid.

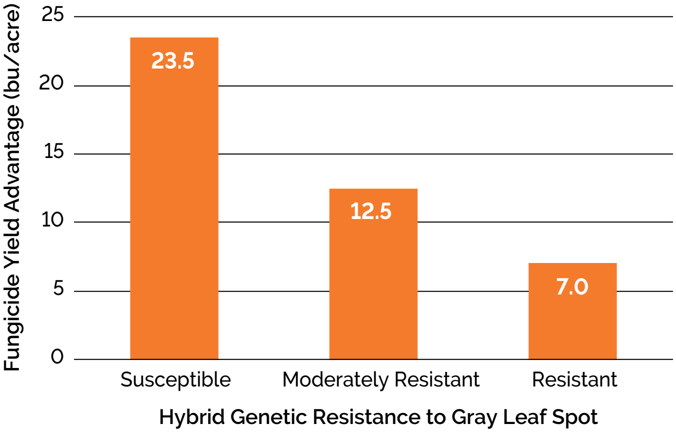

Figure 4. Average yield increase of hybrids susceptible, moderately resistant, and resistant to gray leaf spot due to foliar fungicide application in a 3-year University of Tennessee/DuPont Pioneer research study.

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

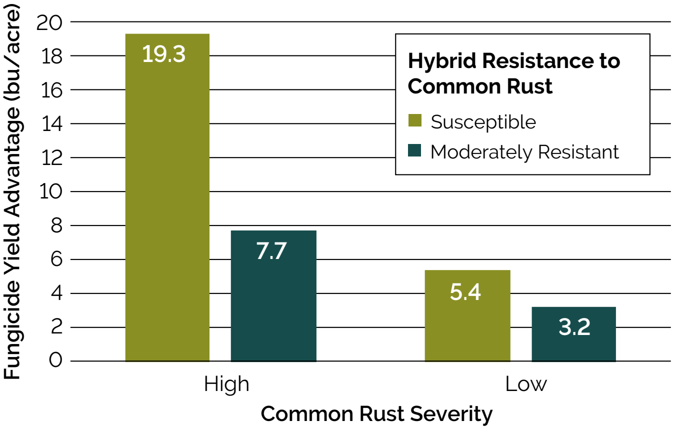

Figure 5. Average fungicide yield response of hybrids with low resistance (3 on a 1-9 scale) and moderate resistance (4-6) to common rust in Pioneer small-plot trials.

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

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

Previous Crop and Tillage

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

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

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

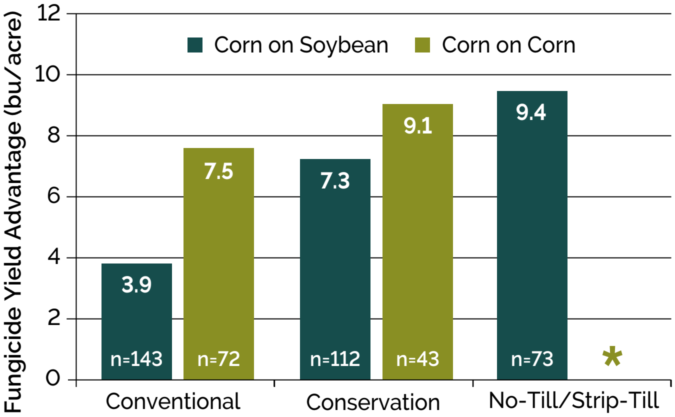

Figure 7. Average yield response to foliar fungicide application as influenced by tillage and previous crop in on-farm trials (374 trials, 2007 - 2014). n = number of locations, * = insufficient data.

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

Other Considerations

Grain Moisture

One concern with fungicide treatments in corn is the potential for increased grain moisture at harvest, resulting in higher drying costs. Observations have varied among university trials with some showing a small increase in moisture in treated versus non-treated corn and some showing no difference. Among Pioneer on-farm trials, grain moisture of fungicide-treated corn was only slightly higher (+0.39 points) than non-treated corn. This difference was not greatly affected by overall moisture level at harvest.

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

Hybrid Maturity and Planting Date

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

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Common and Southern Rust in Corn

by **Mark Jeschke, Ph.D.,** *Agronomy Information 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 hybrid 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 temperatures and humidities, 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.

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Introduction

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.

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

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 is 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.

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.

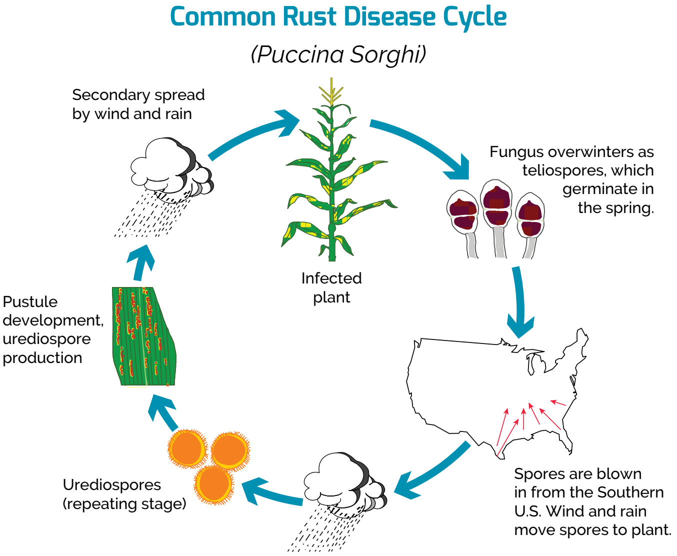

Figure 2. Common rust disease cycle.

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

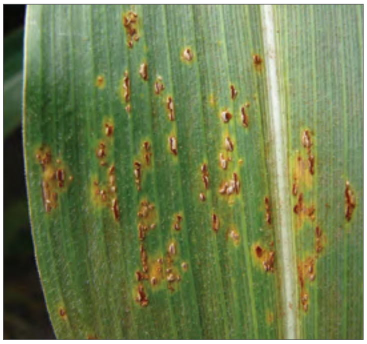

Figure 3. Common rust pustules on a corn leaf.

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 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 onto growing corn plants. Infection of these plants produces spores that serve as secondary inoculum and can be disseminated over hundreds of miles by wind.

Southern Rust Disease Cycle

(Puccinea polysora)

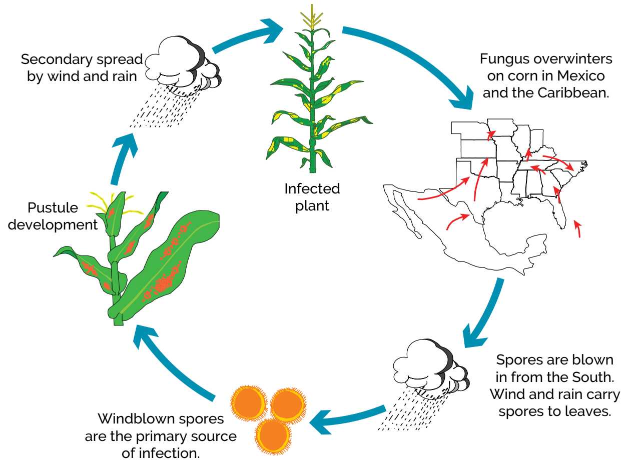

Figure 4. Southern rust disease cycle.

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.

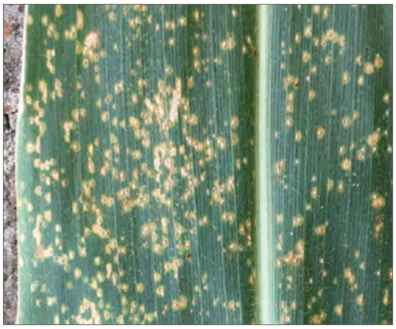

Figure 5. Southern rust pustules on a corn leaf.

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 6). Southern rust was prevalent at the DuPont Pioneer 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.

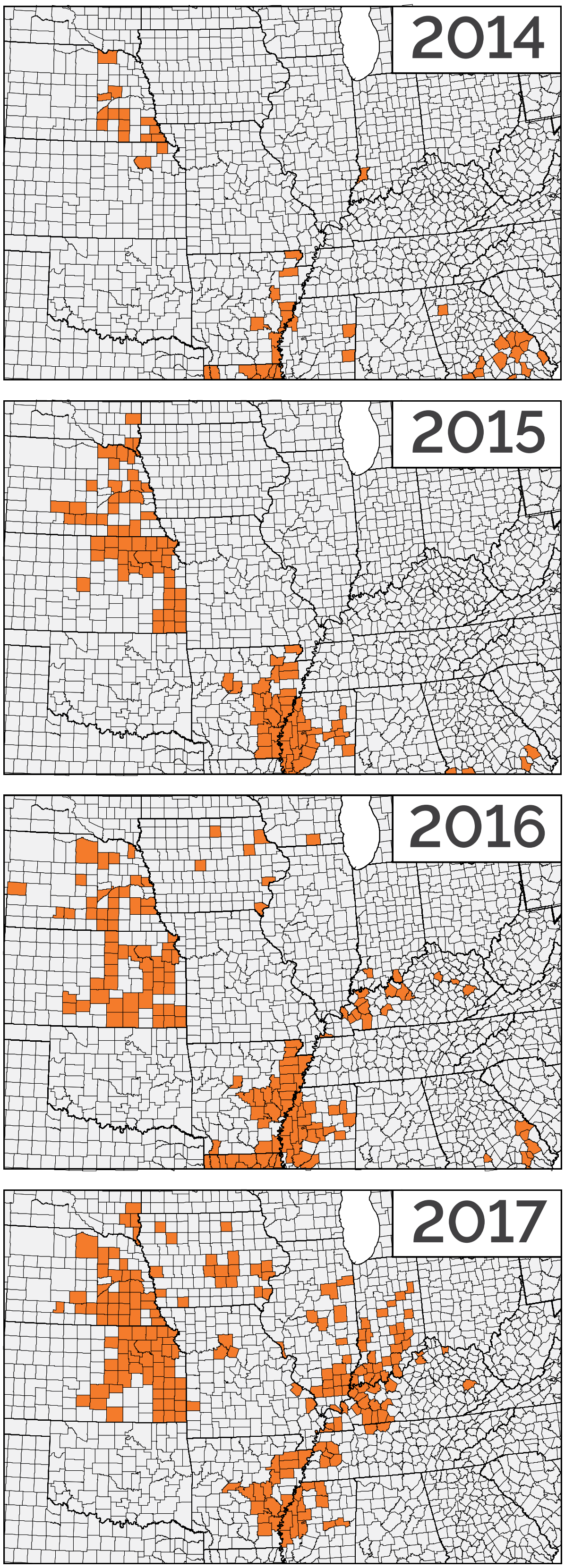

Figure 6. Confirmed detections of southern rust in corn through the first week of September during the 2014 to 2017 growing seasons (Source: http://www.ipipe.org).

Table 1. Distinguishing characteristics of common rust 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). DuPont Pioneer fungicide research trial locations in Illinois and Indiana experienced intense common rust pressure in 2009. At 1 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).

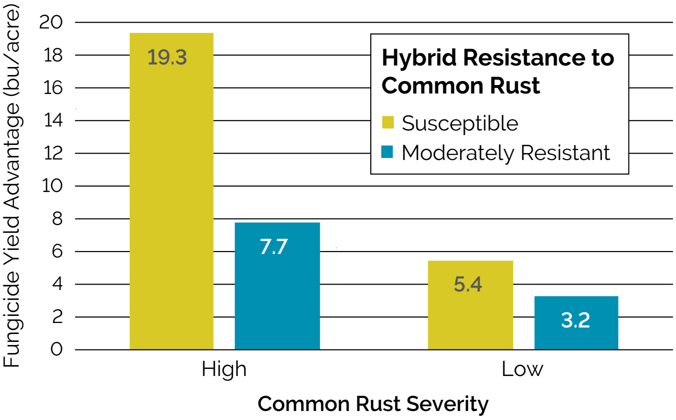

Figure 7. Average fungicide yield response of hybrids with low resistance (3 on a 1-9 scale) and moderate resistance (4-6) to common rust in DuPont Pioneer research trials in 2009.

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 DuPont Pioneer research location in Illinois 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 DuPont 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 timely and effective management decisions.

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 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).

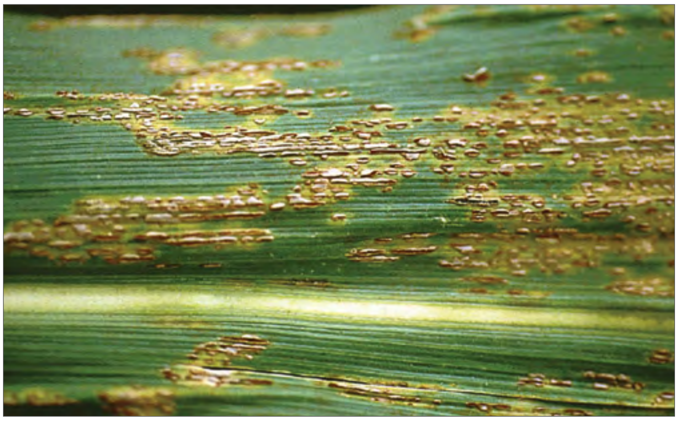

Figure 10. Typical symptoms of common rust (top) and southern rust (bottom) on corn leaves.

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, 2017).

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

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 by 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. If lodging occurs, harvest losses 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.

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Goss's Bacterial Wilt and Leaf Blight

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

Disease Facts

- Disease is caused by a bacterial pathogen that over-winters in residue of corn and several grasses.
- Historically, damage to corn had been confined mostly to the Great Plains states.
- In recent years, significant crop damage has also been reported in Central Corn Belt states (see map at right).
- Depending on conditions, disease may cause only minor problems or devastating damage with grain yield losses approaching 50%.

Goss's Wilt Development

- Plant wounding from wind, sandblasting, and especially hail provide openings for bacteria.
- Insects are not known to be a factor in spread or development of this disease.
- Wet weather and high humidity encourage development.
- There are two phases of the disease:
  - » Systemic wilt (less common)
  - » Later season foliar blight

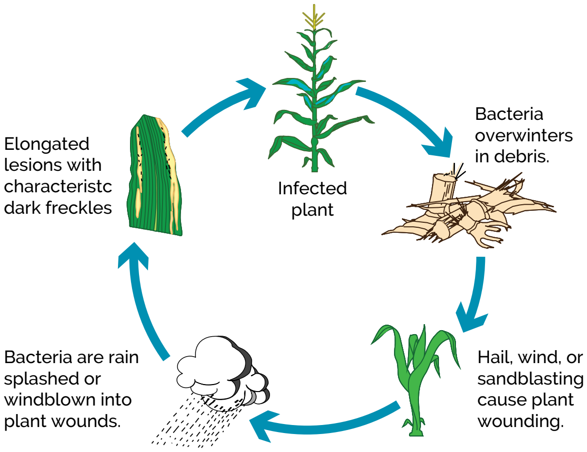

Figure 1. Goss's wilt disease cycle.

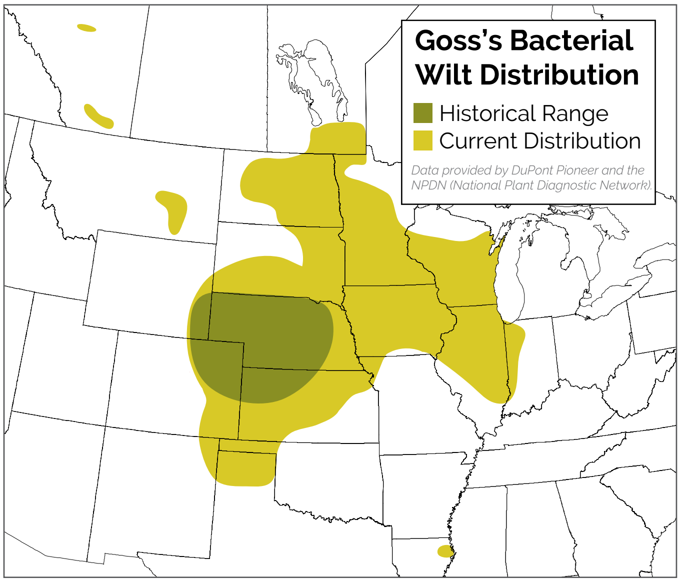

Figure 2. General area of Goss's wilt occurence in corn in North America.

Systemic Wilt Phase

- Less common than foliar phase
- Can cause large losses, especially in susceptible hybrids
- May cause a slimy stalk rot, especially in seedlings
- May cause plant death
- Plants wilt due to vascular infection with bacteria.
- Vascular bundles may have orange coloration that turns brown to black after disease progresses.

Figure 3. Vascular bundle discoloration. *Photo courtesy of T. Jackson, University of Nebraska-Lincoln.*

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Distinguishing Features of Goss's Wilt Lesions

- **Freckles:** dark green to black water-soaked spots, often near lesion edges (white arrows)
- **Shiny Exudate:** bacteria ooze to leaf surface and may appear shiny after drying (black arrows).

Figure 4. Distinguishing features of Goss's wilt lesions include dark green to black freckles (white arrows) along with shiny exudate (black arrows).

Later Season Foliar Blight

- Water-soaked streaks may appear first followed by gray or brown/tan lesions.
- Lesions are elongated with wavy margins that follow leaf veins (Figure 5).
- General lesion shape may resemble Stewart's wilt lesions (Figure 6).
- Foliar lesions may progress to foliar blighting, killing large amounts of the canopy, and predisposing plants to stalk rots.

Goss's Wilt Management

Genetic Resistance

- Primary management method
- DuPont Pioneer researchers inoculate, screen, and rate hybrids for resistance.
- Hybrids are also rated under natural infestations in affected states.
- See your local Pioneer sales professional for help in selecting appropriate hybrids for your field.

Reduce Corn Residue

- Disease can become problematic in corn on corn, high-residue fields.
- Crop rotation is effective in reducing residue.
- Tillage encourages residue breakdown.

Control Grassy Weeds

- Several grassy weeds are hosts for the bacteria, including green foxtail, barnyardgrass, shatter-cane, and others.

Prevention/Avoidance

- Harvest and till affected fields last, and clean equipment to avoid spreading the pathogen to uninfested fields.

Fungicide application is NOT effective for this bacterial disease.

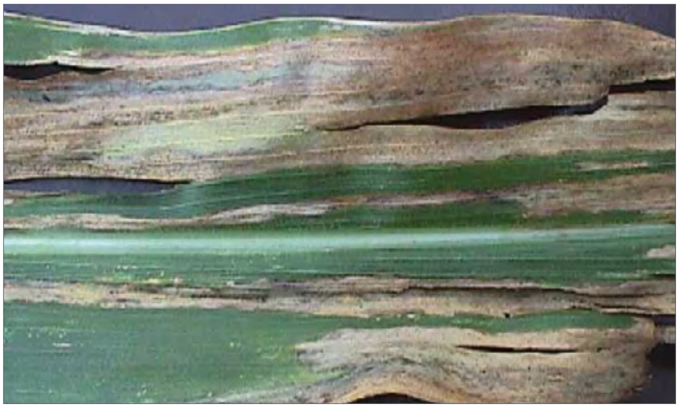

Figure 5. Goss's wilt symptoms on corn leaf.

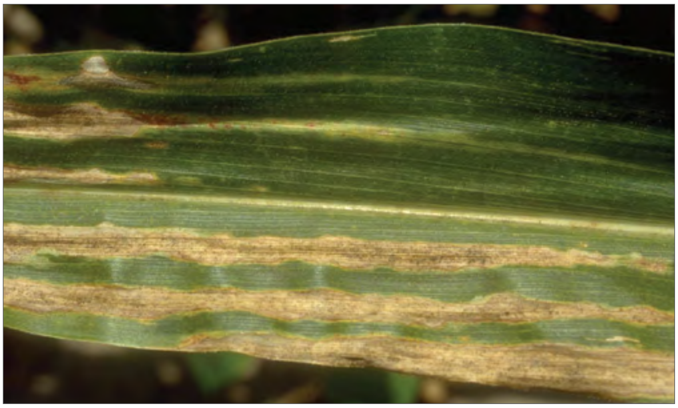

Figure 6. Stewart's wilt symptoms on corn leaf.

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Common Corn Ear Rots

*by **Michael Rupert,** Former Agronomy Research Manager*

Diplodia Ear Rot (No Mycotoxins)

- Wet weather during grain fill and upright ears with tight husks promote Diplodia.
- Diplodia may cause ear rot, stalk rot, or seedling blight.
- Corn is only known host.
- Wet weather plus moderate temperatures allow infection to occur if spores are present during early silking to two to three weeks after silking.
- Diplodia is highly dependent on quantity of infected, unburied corn residue (stalks, cobs, and kernels).

Gibberella Ear Rot (Mycotoxins May Occur)

- Infects other cereals; causes head scab of wheat
- Overwinters in infected crop residue
- Spores are spread from crop residue to corn ears by wind and rain splash.
- Infection of corn ears occurs through young silks.
- Infection favored by cool, wet weather during and after pollination (optimum temps: 65 to 70 °F)

Fusarium Ear Rot (Produces Mycotoxins)

- Most common fungal disease on corn ears
- Fungi survive on residue of corn and other plants.
- Most severe when weather is warm and dry
- Disease enters ear primarily through wounds from hail or insect feeding.
- 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

Aspergillus Ear Rot (Mycotoxins May Occur)

- Most common under drought conditions, high temperatures (80 to 100 °F), and high relative humidity (85%) during pollination and grain fill
- Gray-green, olive, yellow-green, or yellow-brown powdery mold growth on and between kernels
- Surface mold can develop anywhere on the ear.
- Symptoms are often found at damaged areas of ear.

Less Common Corn Ear Rots

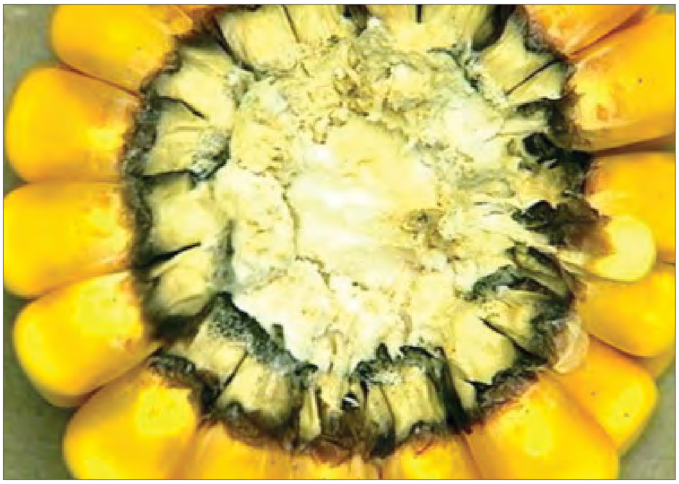
by **Jennifer Chaky, M.S.**, Research Scientist

Penicillium Ear Rot (Mycotoxins May Occur)

- Blue-green fungal growth on and between kernels usually near the ear tip is characteristic of this disease.
- Fungal disease of ears often associated with damage from insects or other physical injury
- Infected kernels may become bleached or streaked.
- Common and damaging fungus of stored grain; can grow on kernels with moisture greater than 18%

Nigrospora Ear Rot (No Mycotoxins)

- Kernels have a dark gray or black discoloration from fungal mycelium and spores, mostly at the base of kernels.
- Infection may first be noticed when cobs shred from the butt end during mechanical harvest.
- Usually more severe at the base of ears and ears are often chaffy and lightweight
- Affected ears are often from plants that have been weakened from frost, drought, root injury, leaf blights, stalk rots, or poor nutrition.



Cladosporium Ear Rot (No Mycotoxins)

- Kernels have a gray to black or greenish-black appearance, and sometimes a powdery mold growth is present.
  - » Also causes black streaks on kernels
- This fungal disease is often seen on ears damaged from frost, insects, or other mechanical injury.
- Wet weather during ear maturation and delayed harvest may favor this fungal growth.

Trichoderma Ear Rot (No Mycotoxins)

- Typical symptoms include a dark green fungal growth on and between husks and kernels, often involving the entire ear.
- Fungal disease of ears usually associated with injury to the developing ear, including damage from bird or insect feeding or other mechanical injury
  - » For this reason, damage is not found on every ear but rather, is usually more scattered within a field.

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Managing Corn for Greater Yield

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

Summary

- Improved hybrids and production practices are helping corn growers increase yields. Over the past 20 years, U.S. corn yields have increased by an average of 1.9 bu/acre per year.
- Winning non-irrigated yields in the NCGA National Corn Yield Contest have increased at more than twice the U.S. average rate in the last 10 years.
- Selecting the right hybrid can affect yield by over 30 bu/acre, making this decision among the most critical of all controllable factors.
- 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.
- Rotating crops is an important practice to help keep yields consistently high. Rotation can break damaging insect and disease cycles that reduce crop yields.
- Maintaining adequate nitrogen fertility levels throughout key corn development stages is critical in achieving highest yields. Split applications can help reduce losses by supplying 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.

NCGA National Corn Yield Contest

The NCGA National Corn Yield Contest achieved some notable milestones during the past few seasons. A new corn yield world record was set in 3 of the past 4 years: 454.98 bu/acre in 2013, 503.72 bu/acre in 2014, and 532.03 bu/acre in 2015. A total of 25 entries exceeded 400 bu/acre over the past 4 years. The average yields of national winners also reached record highs in both the irrigated and non-irrigated classes in 2015 and 2014, respectively (Figure 1).

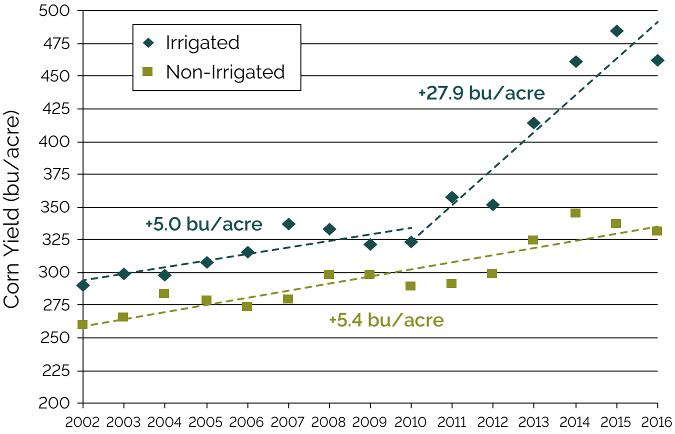

Figure 1. Average corn grain yield of NCGA National Corn Yield Contest national winners in irrigated and non-irrigated classes, 2002 - 2016.

The most remarkable achievement in the National Corn Yield Contest in recent years has been the dramatic increase in top yields in the irrigated classes. The average annual yield gain in the non-irrigated classes over the last 15 years was 5.4 bu/acre/year, well above the 1.8 bu/acre/year U.S. average yield gain over the same time period. From 2002 to 2010, top yields in irrigated classes increased at a similar annual rate, around 5.0 bu/acre/year. However, since 2010, the average yield gain in the irrigated classes has been over 27 bu/acre/year (Figure 1).

Yields above 300 bu/acre were achieved in a total of 373 entries in 35 states across all classes from 2013 to 2016 (Table 1). Of these 373 entries, 239 were in irrigated classes and 134 in non-irrigated classes. This article summarizes basic management practices employed in NCGA National Corn Yield Contest entries that exceeded 300 bu/acre over the past 4 years and discusses how these practices can contribute to higher yields for all corn growers.

Table 1. Locations of NCGA National Corn Yield Contest entries over 300 bu/acre in 2013, 2014, 2015, and 2016.

State	2013	2014	2015	2016	State	2013	2014	2015	2016
AL	0	2	2	1	NE	5	5	7	1
AR	2	4	1	1	NJ	0	4	7	0
CA	3	1	0	2	NM	1	1	0	2
CO	1	2	3	2	NY	1	0	1	0
DE	0	6	3	2	OH	6	0	0	0
FL	2	2	3	0	OK	1	1	2	3
GA	5	6	7	4	OR	0	1	1	1
IA	2	2	5	7	PA	0	2	3	0
ID	0	3	1	1	SC	0	8	3	5
IL	3	11	9	5	SD	0	1	0	0
IN	7	4	3	1	TN	1	12	0	3
KS	4	7	4	1	TX	7	10	6	4
KY	1	4	1	0	UT	1	2	6	3
MA	0	1	2	1	VA	3	4	4	3
MD	1	9	5	4	WA	0	0	2	2
MI	2	1	4	1	WI	0	0	1	1
MO	4	16	2	1	WV	7	3	0	2
NC	0	1	0	1	**All**	**70**	**136**	**101**	**66**

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 full stands and allows earlier planting, which moves pollination earlier to minimize stress during this critical period.
- Above-average drought tolerance. This will provide insurance against periods of drought that most non-irrigated fields experience.

- Resistance to local diseases. Leaf, stalk, and ear diseases disrupt normal plant function, divert plant energy, and reduce standability and yield.
- Traits that provide resistance to major insects, such as corn borer, corn rootworm, black cutworm, and western bean cutworm. Insect pests reduce yield by decreasing stands, disrupting plant functions, feeding on kernels, and increasing lodging and dropped ears.
- Good standability to minimize harvest losses.

Table 2. 2016 NCGA National Corn Yield Contest national winners using Pioneer® brand products.

Entrant Name Category	State	Hybrid/Brand[1]	Yield (bu/acre)
John Gause A Non-Irrigated	SC	P1498AM™ (AM, LL, RR2)	318.67
Patrick Hammes AA Non-Irrigated	IA	P1197AM™ (AM, LL, RR2)	320.29
Dan Gause A NT/ST Non-Irrigated	SC	P1916YHR (YGCB, HX1, LL, RR2)	346.05
Daniel Gause A NT/ST Non-Irrigated	SC	P1498AM™ (AM, LL, RR2)	345.28
William Thomas A NT/ST Non-Irrigated	SC	P1775YHR (YGCB, HX1, LL, RR2)	336.54
Tim/Dan/Joe Durick AA NT/ST Non-Irrigated	IA	P1751AMT™ (RW, YGCB, HX1, LL, RR2)	333.50
David Hula NT/ST Irrigated	VA	P1197AM™ (AM, LL, RR2)	485.03

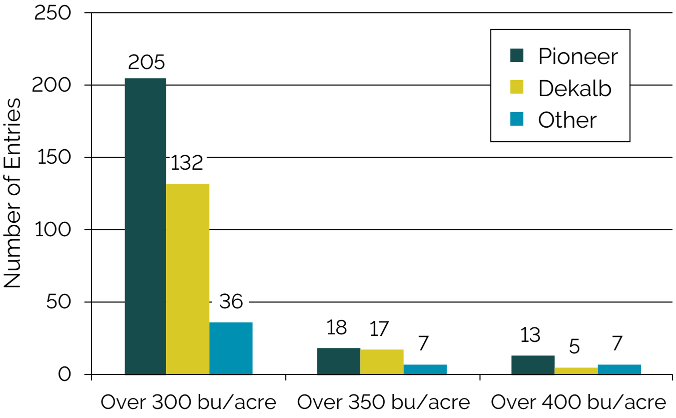

Figure 2. Seed brand planted in National Corn Yield Contest entries exceeding 300, 350, and 400 bu/acre, 2013-2016.

The brands of seed corn used in the highest yielding contest entries in 2013 through 2016 are shown in Figure 2. Pioneer® brand products were used in the majority of entries exceeding 300 bu/acre.

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.

Harvest populations in irrigated and non-irrigated National Corn Yield Contest entries over 300 bu/acre from 2013 through 2016 are shown in Figure 3. The average harvest population of irrigated entries (37,900 plants/acre) was slightly greater than that of non-irrigated entries (36,200 plants/acre) over four years. However, yields over 300 bu/acre were achieved over a wide range of populations, from 25,000 to 55,000 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 final yield.

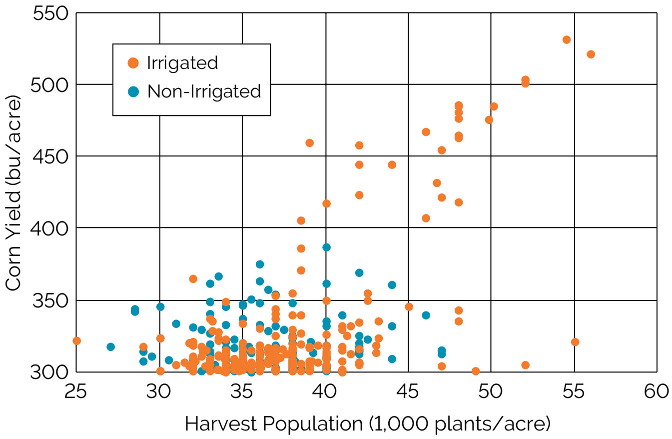

Figure 3. Harvest populations and corn yield of irrigated and non-irrigated NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2016.

One of the most interesting aspects of the relationship between yield and plant population of high yield entries in the National Corn Yield Contest is the emergence of two distinct patterns when data from the last four years are combined (Figure 4). For entries between 300 and 400 bu/acre, there is no consistent relationship between harvest population and yield; populations cover a wide range, with the majority between 32,000 and 42,000 plants/acre. For entries above 400 bu/acre, however, there emerges a roughly linear relationship between population and yield, with each 5,000 plants/acre increase in population corresponding to a 30 bu/acre increase in yield.

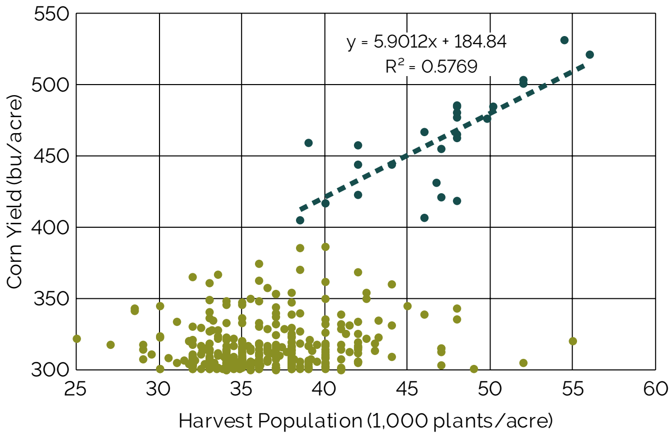

Figure 4. Harvest populations and corn yield of NCGA National Corn Yield Contest entries yielding between 300 and 400 bu/acre and above 400 bu/acre, 2013-2016.

When harvest population and yield per acre are used to calculate yield per plant, the resulting data show a decline in grain weight per plant as population increases, as would be expected (Figure 5). However, for exceptionally high-yielding entries, the rate of this decline was not as steep. These results show that the key to success for top-performing entries over the last few years has been to maintain greater yield per plant at high population densities. The fact that yields over 400 bu/acre have only been achieved under irrigation suggests that optimal water management is critical to maintaining high individual plant yield at high population density.

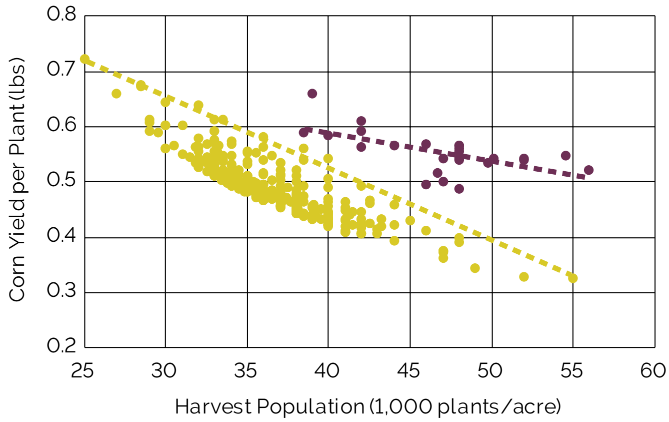

Figure 5. Harvest populations and yield per plant of NCGA National Corn Yield Contest entries yielding between 300 and 400 bu/acre and above 400 bu/acre, 2013-2016.

Row Width

The vast majority of corn acres in the U.S. are currently planted in 30-inch rows, accounting for over 85% of corn production. A majority of 300 bu/acre contest entries were planted in 30-inch rows (78%) (Figure 6). Narrower row configurations (15-inch, 20-inch, or 30-inch twin) were used in 15% of entries, and wider single or twin-row configurations were used in 7% of entries.

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

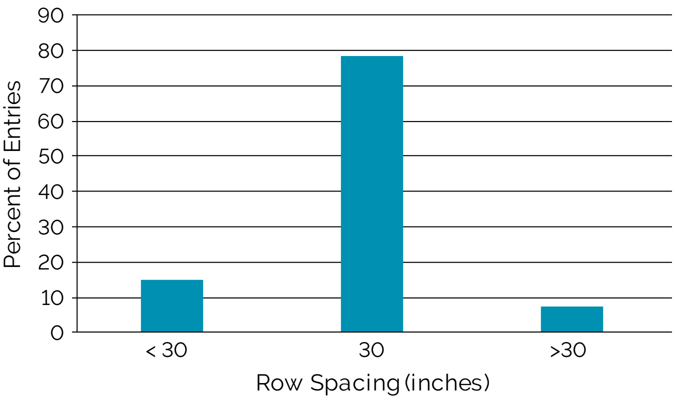

Figure 6. Row width used in NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2016.

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 dates for entries exceeding 300 bu/acre ranged from March 10 to May 30, although mid-April to early-May planting dates were most common for locations in the Central Corn Belt (Figure 7).

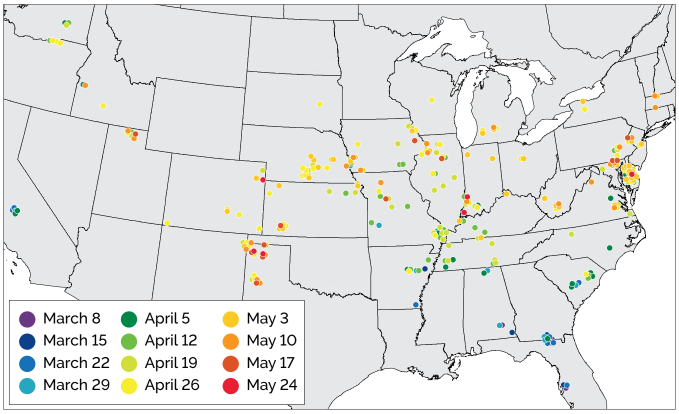

Figure 7. Planting date, grouped by week, of NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2016.

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 (62%) were planted to a crop other than corn the previous growing season (Figure 8).

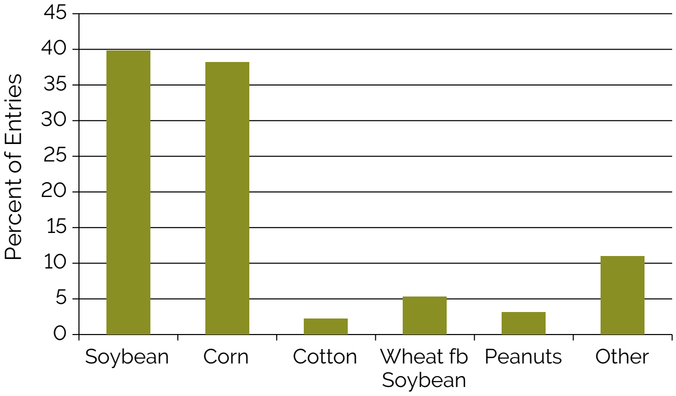

Figure 8. Previous crop in NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2016.

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

Three of the six classes in the NCGA National Corn Yield Contest specify no-till or strip-till practices; however, over 60% of the contest entries over 300 bu/acre employed conventional, minimum, or mulch tillage (Figure 9). Of these entries, most included some form of deep tillage. Deep tillage implements included rippers, chisel plows, and subsoilers. When fields are adequately dry, deep tillage can alleviate deep compaction and break up claypans as well as hardpans that restrict corn root growth. Deep roots are especially important as soil moisture is depleted during mid to late summer.

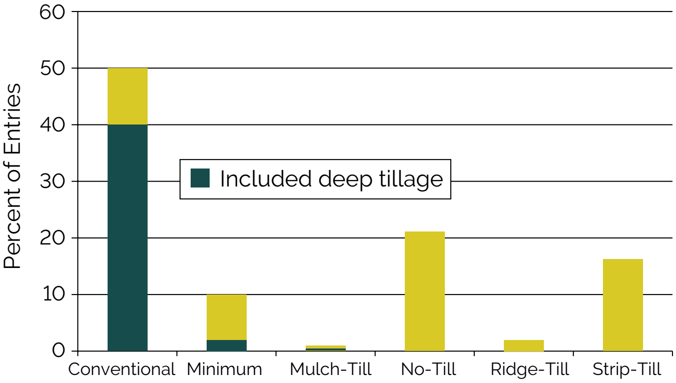

Figure 9. Tillage practices in NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2016.

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 one pound of N per bushel harvested, and stover production requires a half-pound for each bushel of grain produced. This means that the total N needed for a 300 bu/acre corn crop is around 450 lbs/acre. Only a portion of this amount needs to be supplied by N fertilizer; N is also supplied by the soil through mineralization of soil organic matter. On highly productive soils, N mineralization will often supply the majority of N needed by the crop. Credits can be taken for previous legume crop, manure application, and N in irrigation water. Nitrogen application rates of entries exceeding 300 bu/acre are shown in Figure 10.

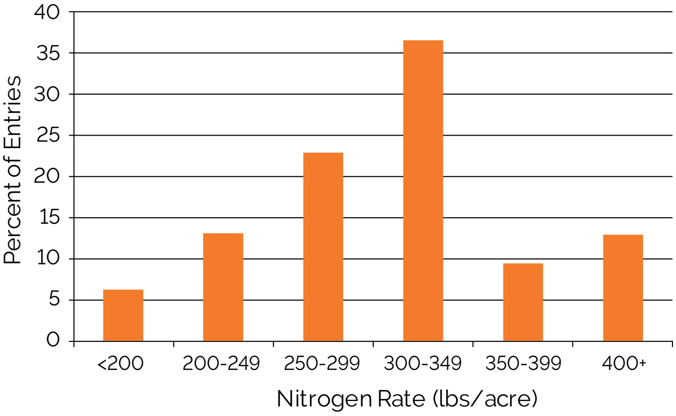

Figure 10. Nitrogen rates (total lbs/acre N applied) of NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2016. (Note that N rates above 300 lb/acre are usually appropriate only for contest plots and high-yielding irrigated fields.)

The N application rates of 300 bu/acre entries varied greatly, but a majority 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 is able to obtain from the soil through increased mineralization of organic N and improved corn 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 11. Very few included fall-applied N. Many applied N before or at planting. Over 80% of 300 bu/acre entries included some form of in-season N application, either sidedressed or applied with irrigation (Figure 12). Nearly 90% included multiple applications.

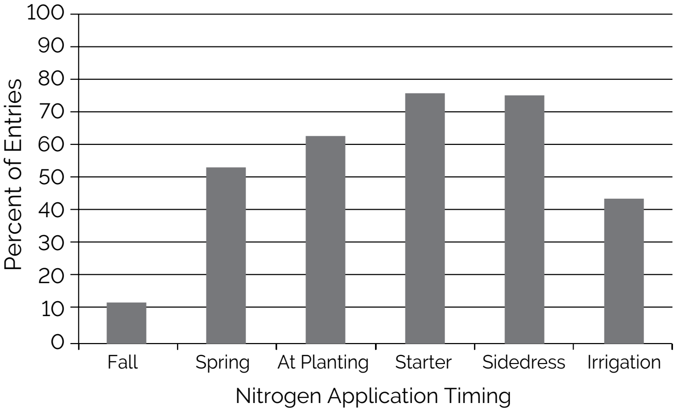

Figure 11. Nitrogen fertilizer application timing of NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2016.

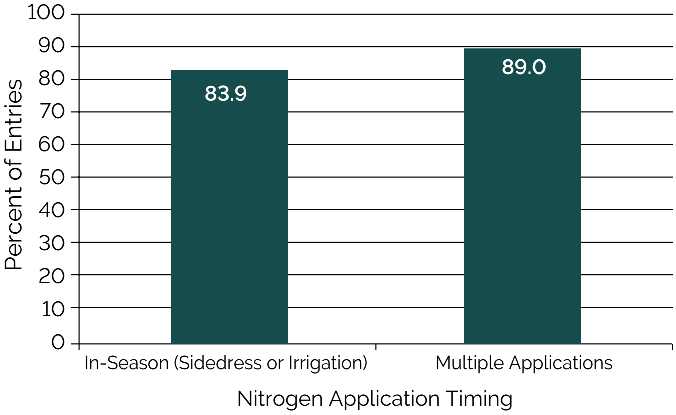

Figure 12. Nitrogen management programs of NCGA National Corn Yield Contest entries exceeding 300 bu/acre that included in-season application(s) and multiple application timings.

Phosphorus and Potassium

Assuming soils are maintained at adequate levels, growers should add at least the level of P and K that will be removed by the crop. In addition, these nutrients should be available in the root zone of the developing seedling. Corn grain removes about 0.43 lbs of P_2O_5 and 0.27 lbs of K_2O equivalents per bushel, according to the International Plant Nutrition Institute (IPNI). That means that a 300 bu/acre corn crop will remove about 129 lbs of P_2O_5 and 81 lbs of K_2O per acre.

Recent evidence suggests that P and K fertilizer rates in some areas may not be keeping pace with increasing crop yields that are accompanied by higher nutrient removal. DuPont Pioneer agronomists and Encirca® certified services agents collected soil samples from 8,925 fields in 12 Corn Belt states between fall 2015 and spring 2016 (Schulte and Heggenstaller, 2016). Results of this survey showed that P and K levels below state optimum levels were common across the Corn Belt (Figure 13 and 14).

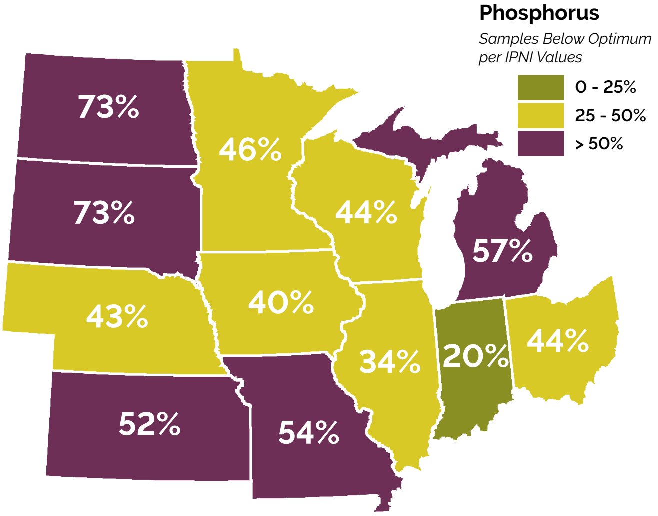

Figure 13. Percent of soil samples that fell below state optimum levels for P in the Corn Belt in 2016.

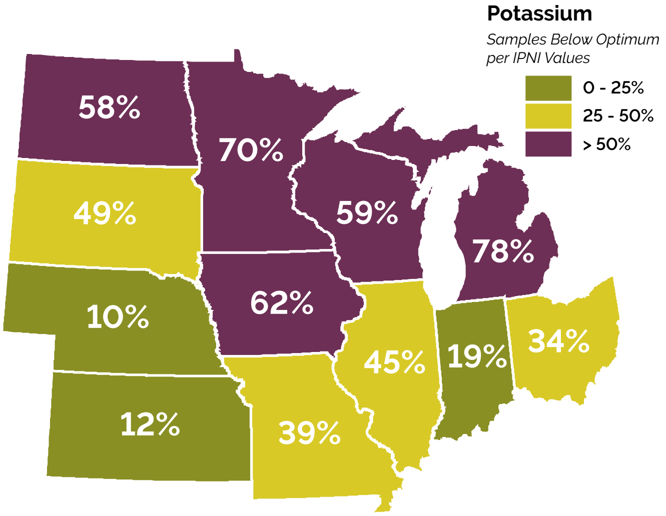

Figure 14. Percent of soil samples that fell below state optimum levels for K in the Corn Belt in 2016.

Micronutrients

Micronutrients were applied on approximately half of the 300 bu/acre entries (Figure 15). The nutrients most commonly applied were sulfur (S) and zinc (Zn), with some entries including boron (B), magnesium (Mg), manganese (Mn), or copper (Cu). Micronutrients are sufficient in most soils to meet crop needs. However, some sandy soils and other low organic matter soils are naturally deficient in micronutrients, and high pH soils may make some micronutrients less available and therefore, deficient (Butzen, 2010). Additionally, as yields increase, micronutrient removal increases as well, potentially causing deficiencies.

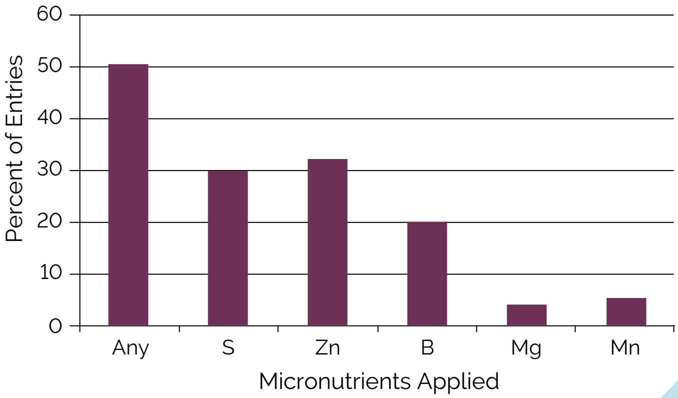

Figure 15. Micronutrients applied in NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2016.

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Early-Season Growth and Development Impact on Corn Yield in North Dakota

by **Joel Ransom, Ph.D.,** North Dakota State University

Objectives

- Quantify the impact of early-season soil temperature and early-season management practices on corn yield in North Dakota.
- Compare the performance of two Pioneer® brand corn products with differing early stress-emergence ratings under these diverse spring growing conditions.

Study Description

- A 2-year field research study was conducted as part of the DuPont Pioneer Crop Management Research Awards (CMRA) Program with Dr. Joel Ransom at North Dakota State University.
- Field experiments were established in 2015 near Prosper, ND, and in 2016 near Casselton, ND.
- Treatments were combinations of planting dates, Pioneer brand corn products (differing in maturity and stress emergence rating), and early-season management practices, including nitrogen (N) fertilization timing and mulch.

Planting Dates:

- » April 23 and May 22 in 2015
- » May 2 and May 24 in 2016

Hybrid/Brand[1]:

- » P8640AM™ (AM, LL, RR2), 86 CRM, stress emergence rating[4] = 5
- » P9526AM™ (AM, LL, RR2), 95 CRM, stress emergence rating = 6

Early-Season Management Practices:

- » 0 N (non-fertilized check)
- » 150 lbs N at planting (fertilized check)
- » 150 lbs N at planting + 18-36-0 liquid fertilizer with seed
- » 150 lbs N at planting + clear plastic mulch for 3 wks after planting
- » 150 lbs N at planting + straw mulch for 3 wks after planting
- » 150 lbs N broadcast 3 wks after emergence
- » 150 lbs N broadcast 6 wks after emergence
- » 150 lbs N broadcast 9 wks after emergence

Results

- Corn yields averaged over all treatments were 175 and 225 bu/acre in 2015 and 2016, respectively. These yields were well above the state-wide average and the yields in 2016 were considered exceptional.

Planting Dates

- Planting date did not significantly affect corn yield in either year (Figure 1).
- Though the recommended planting date in North Dakota is May 1st, there was frost damage on the emerged leaves of the early-planted corn both years. This damage may have negated the potential benefit from earlier planting.

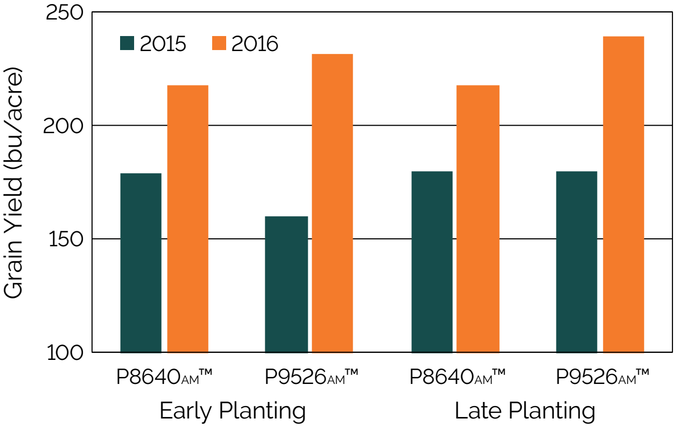

Figure 1. Effect of planting date and hybrid on yield, averaged across management treatments, 2015 and 2016.

Hybrid/Brand

- Yields did not significantly differ between corn products in 2015.
- The later-maturing product, P9526AM™, significantly out-yielded P8640AM™ in 2016 (Figure 1). Conditions were ideal for corn development in 2016, allowing the later-maturing hybrid to effectively express its higher yield potential.
- The lower yield of P9526AM™ at the early planting in 2015 may have been associated with greater frost damage, as it was slightly ahead of P8640AM™ when the frost occurred.

Early-Season Management Practices:

- Yield differences among early-season management treatments were mostly limited to differences between fertilized treatments and the non-fertilized check in both years (Table 1).
- Nitrogen mineralization rates were extremely high in both years, resulting in yields of the unfertilized check treatments of 167 and 191 bu/acre in 2015 and 2016, respectively.
- Because of the high natural level of nitrogen fertility, the addition of nitrogen as late as nine weeks after planting resulted in similar yields to applying nitrogen at planting.

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Table 1. Effect of early-season management on grain yield, averaged over planting date and hybrid, 2015 and 2016.

Early-Season Management	Year	
	2015	2016
	—— *(bu/acre)* ——	
0 N (non-fertilized check)	167	191
150 N at planting (fertilized check)	177	234
150 N at planting + 18-36-0 in-furrow	161	233
150 N + clear plastic for 3 wks	178	228
150 N + straw mulch for 3 wks	173	232
150 N 3 wks after emergence	181	234
150 N 6 wks after emergence	183	234
150 N 9 wks after emergence	177	229
LSD 0.10	10	9

Early-Season Management Practices (Continued):

- Only the treatment with 18-36-0 applied in-furrow differed significantly from other fertilized treatments and only in 2015. The yield reduction was associated with a lower plant population in this treatment and was most noticeable at the early planting date (Table 2).
- Applying liquid fertilizer with the seed is a commonly recommended practice, as it places nutrients close to the roots of the developing seedling.
- Reduced emergence with this treatment in 2015 may have resulted from too much salt near the seed combined with other conditions unfavorable for emergence (cold soils and a wet soil surface). Only a slight stand reduction occurred at the later planting date with this treatment in 2015, and there was no negative effect in 2016 regardless of planting date.
- Warming the soil with plastic mulch or keeping it cooler with straw mulch had a measurable effect on early-season growth rate (data not shown); although, there was no significant impact on grain yield in either year as a result of these treatments (Table 1).

Conclusion

Early-season management can be critical to establishing a foundation for high-yield potential in corn. The current recommended optimum planting period for corn in North Dakota is May 1 to May 20. Yield did not significantly differ between the two planting dates in either year. The lack of response to earlier planting may be associated with frost damage to the earlier-planted treatments. Though corn recovers well from frost that does not damage the growing point, the leaf damage may have delayed plant development to be similar to that of corn planted at the later date.

Table 2. Effect of early-season management at two planting dates on plant population averaged over hybrids, 2015.

Early-Season Management	Planting Date	
	23 April	22 May
	—— *(plants/acre)* ——	
0 N (non-fertilized check)	33,730	33,580
150 N at planting (fertilized check)	33,360	32,540
150 N at planting + 18-36-0 in-furrow	25,020	29,110
150 N + clear plastic for 3 wks	34,250	31,720
150 N + straw mulch for 3 wks	32,090	32,760
150 N applied 3 wks after emergence	32,690	34,400
150 N applied 6 wks after emergence	31,650	32,910
150 N applied 9 wks after emergence	33,060	34,480
Average	31,980	32,690
LSD 0.10 date x mgmt interaction	2,763	

Hybrid selection is important to maximizing yield in a given environment. The two corn products included in this work had slightly different stress emergence ratings and nine days difference in relative maturity. Though we observed greater early growth with P9526AM™, this did not translate to higher yield in 2015 due to early-season frost damage. Under more favorable growing conditions in 2016, the later-maturing hybrid was able to significantly out-yield the earlier-maturing hybrid. This difference could not be solely attributed to vigorous early emergence, as the more stress tolerant hybrid was later maturing and had inherently greater yield potential.

In favorable growing seasons with soils like those of the experimental sites in 2015 and 2016 with high levels of N mineralization and native fertility, there is no yield penalty for delaying the application of nitrogen up to nine weeks after planting. Unfortunately, these environments are not typical of most soils and growing seasons in North Dakota. Other research has shown the value of relatively late applications of nitrogen applied as a rescue treatment when there is a high level of nitrogen loss earlier in the season.

Adding fertilizer with the seed at planting can negatively affect plant population under stressful conditions for germination and emergence. Providing some separation between the seed and the fertilizer may help mitigate the risk of stand reduction.

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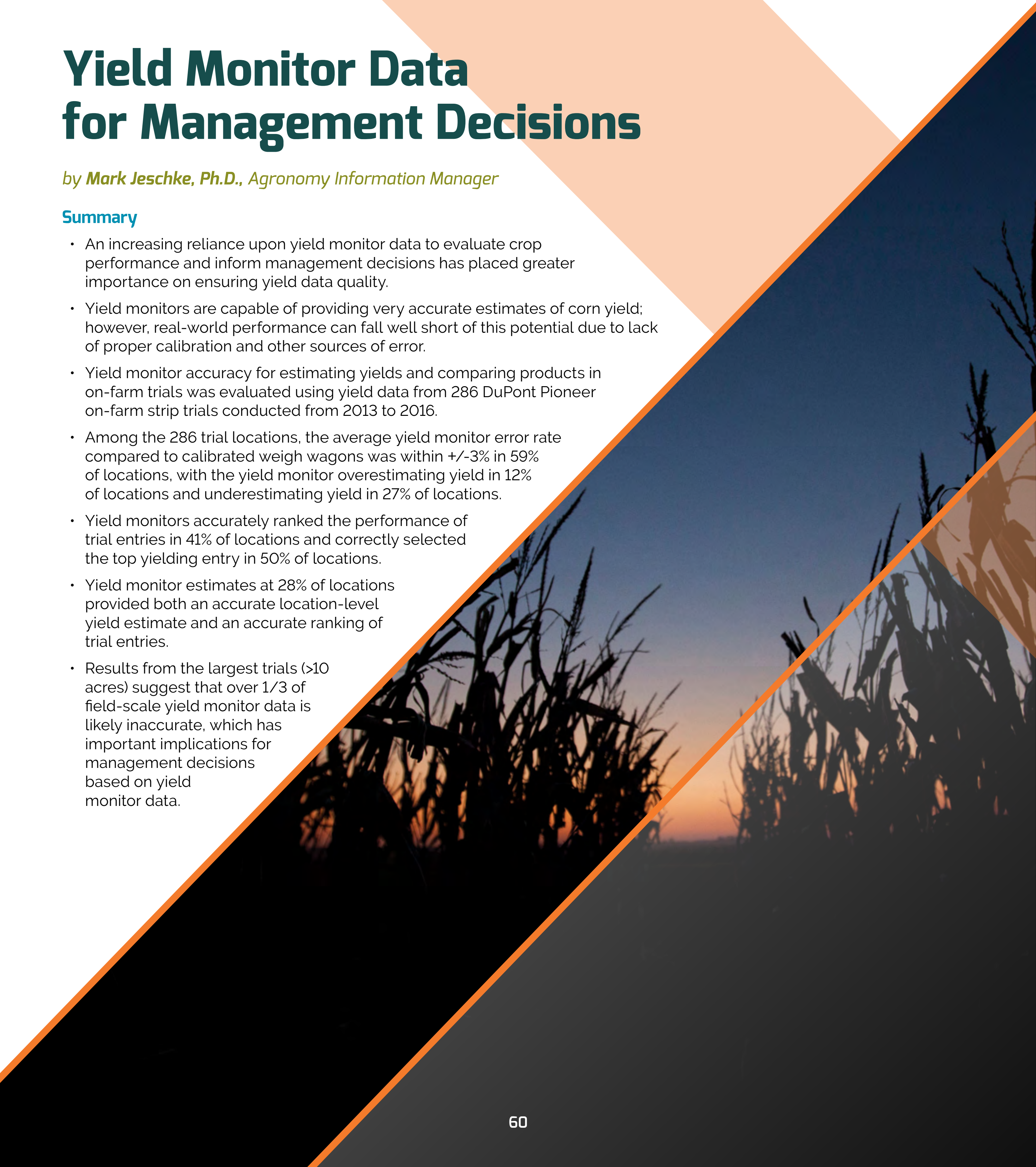
Yield Monitor Data for Management Decisions

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

Summary

- An increasing reliance upon yield monitor data to evaluate crop performance and inform management decisions has placed greater importance on ensuring yield data quality.
- Yield monitors are capable of providing very accurate estimates of corn yield; however, real-world performance can fall well short of this potential due to lack of proper calibration and other sources of error.
- Yield monitor accuracy for estimating yields and comparing products in on-farm trials was evaluated using yield data from 286 DuPont Pioneer on-farm strip trials conducted from 2013 to 2016.
- Among the 286 trial locations, the average yield monitor error rate compared to calibrated weigh wagons was within +/-3% in 59% of locations, with the yield monitor overestimating yield in 12% of locations and underestimating yield in 27% of locations.
- Yield monitors accurately ranked the performance of trial entries in 41% of locations and correctly selected the top yielding entry in 50% of locations.
- Yield monitor estimates at 28% of locations provided both an accurate location-level yield estimate and an accurate ranking of trial entries.
- Results from the largest trials (>10 acres) suggest that over 1/3 of field-scale yield monitor data is likely inaccurate, which has important implications for management decisions based on yield monitor data.



Introduction

The widespread adoption of yield monitor systems over the past 20 years has facilitated data-driven decision making in corn production in a way that was not possible before. Yield monitors do not directly measure yield, rather they estimate relative yield based on mass flow rate. Coupled with a GPS receiver, yield monitors provide an assessment of spatial variability in relative yield across a landscape.

Historically, calibrated weigh wagons and portable moisture meters have been used in the seed industry to measure grain weight and estimate grain moisture of strip plot entries. Performance data for Pioneer® brand corn products in on-farm strip trials is still almost entirely based on weigh wagon measurements. However, yield monitors are commonly used to measure performance in agronomic trials, which often include both genetic and management components and are often larger in size. Out of over 6,000 DuPont Pioneer on-farm agronomic trials conducted from 2013 to 2016, 57% recorded weigh wagon data, 39% yield monitor data, and 4% both.

Recent advances in transfer and aggregation of spatial farm data have allowed yield monitor data to be increasingly leveraged to assess performance of genetics and management practices over large scales. Given the increasing reliance upon yield monitor data to evaluate crop performance and provide a basis for management decisions, it is important to determine the accuracy of the yield monitor data being collected. In the mid 1990s, DuPont Pioneer researchers conducted an evaluation of yield monitor accuracy compared to weigh wagons in on-farm strip trials (Doerge, 1997), the scope of which was limited by the relative scarcity of yield monitors during the first few seasons following their commercial introduction. The purpose of this article is to revisit this topic and assess the current state of yield monitor accuracy based on a more recent and much larger dataset of on-farm strip trials.

Yield Monitor Accuracy – Potential vs. Reality

Research has shown that yield monitors are capable of providing very accurate estimates of corn yield. A 3-year study conducted across 6 locations in South Dakota found very close agreement between yields measured using a weigh wagon and a well-calibrated yield monitor ($r^2 = 0.967$) (Nelson et al., 2015). Likewise, Professor Robert Nielsen at Purdue University has reported that yield estimates in field-scale research trials from yield monitors are typically within 1% of corn yield as measured by a weigh wagon or farm scale in his research (Nielsen, 2017).

However, despite this high level of achievable accuracy, there is reason to suspect that much of the yield data being collected by growers using yield monitors falls well short of this potential. Proper calibration is critical for producing accurate yield estimates with yield monitors. If a yield monitor is not calibrated to the characteristics of the grain being harvested or not calibrated at all, yield estimates can be skewed. Errors rates of 7 to 10% are not uncommon for corn harvested late in the season if the yield monitor was calibrated only at the beginning of the harvest season due to changes in grain moisture content (Nielsen, 2017). A 2015 University of Wisconsin study sought to determine real-world yield monitor accuracy by conducting random spot-checks of combines during harvest (Luck, 2017). Of the 4 combines tested, 2 had error rates of 1 to 3%, and 2 had errors rates in the 6 to 9% range.

Methods

Yield monitor accuracy for estimating yields and comparing products in on-farm trials was evaluated using yield data from DuPont Pioneer on-farm strip trials conducted from 2013 to 2016 in which yield data were collected using both a weigh wagon and a yield monitor. These trials included a total of 3,923 entries across 286 locations in 15 states and 1 Canadian province. The brand of yield monitors used in the trials was not recorded. Likewise, the calibration status of the yield monitors at the time the trials were harvested is not known but can be inferred to some extent based on the accuracy of yield estimates compared to weigh wagon measurements. Given the large number of trial locations, the dataset is likely a reasonably representative sample of yield data being collected by growers. If anything, the accuracy of the yield monitor data might be better than average given that it comes from on-farm trials where yield data accuracy is presumably prioritized.

The size of the on-farm trials included in the analysis varied widely. The number of entries per trial ranged from 1 to 49, with the majority of trials including between 8 and 16 entries. Strip length ranged from 200 to 4,700 ft, and strip width ranged from 10 to 50 ft. With proper calibration, a yield estimate within 1 to 3% of the total grain harvested in a field is generally considered achievable (Darr, 2016). For the purposes of this analysis, a yield monitor estimate within 3% of the weigh wagon yield was considered "accurate."

Results

Overall Accuracy

A linear regression of yield monitor estimates versus their corresponding weigh wagon measurements for all 3,923 individual comparisons produced an r^2 of 0.8453 (Figure 1), indicating that overall yield monitor accuracy fell well short of potential accuracy as shown by Nelson et al. (2015) ($r^2 = 0.967$). The slope of the regression was 0.94, indicating a slight tendency to overestimate yield at low yield levels and underestimate yield at high yield levels. Yield monitor estimates for 55% of individual entries were within 3% of weigh wagon measurements.

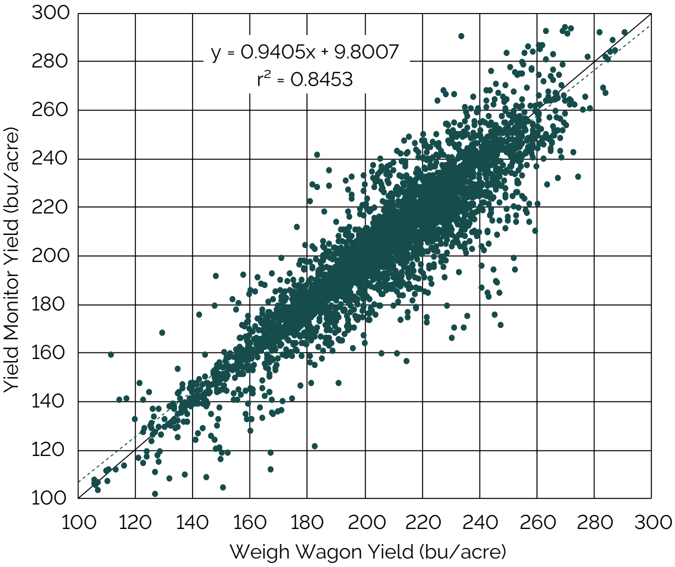


Figure 1. Relationship of yield monitor and weigh wagon corn yields from 3,923 comparisons at 286 locations, 2013-2016.

Location Accuracy

Among the 286 trial locations, the average yield monitor error rate was within +/-3% in 59% of locations, with the yield monitor overestimating yield in 12% of locations and underestimating yield in 27% of locations (Figure 2). Average yield estimates were more than 10% off in 7% of locations.

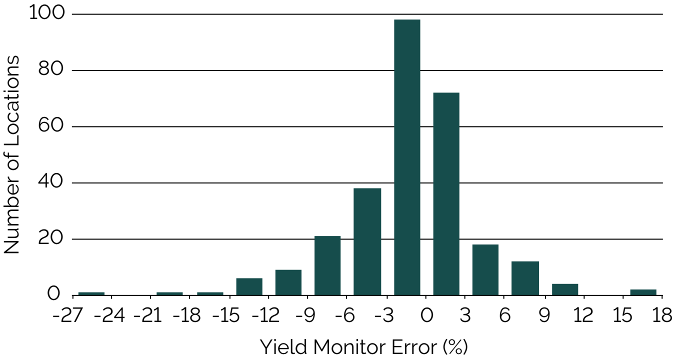


Figure 2. Average yield monitor error rate based on comparison to weigh wagon measurements at 286 locations, 2013-2016.

Accuracy of Entry Ranking

With the increasing reliance on yield monitor data as a basis for evaluating hybrids and agronomic practices in on-farm trials, it is important to understand the effectiveness of this technology for making accurate comparisons. In a 1996 study comparing yield monitor estimates to weigh wagon measurements in Pioneer on-farm strip trials, Spearman Rank Correlation was used to evaluate the accuracy of yield monitors in ranking the performance of entries in the trials (Doerge, 1997). The correlation coefficient (r) in this test can range from 1, indicating perfect correlation between the yield monitor and weigh wagon rankings, to -1, indicating inverse correlation. A correlation coefficient of zero indicates no correlation. A minimum threshold of 0.93 was used for designating the ranking of entries in a trial as "accurate."

In the 1996 study, across 19 study locations with an average of around 16 entries per location, the average correlation between yield monitor estimates and weigh wagon measurements for ranking entries was 0.78. Yield monitor rankings at 6 out of 19 locations (32%) qualified as accurate. The yield monitor correctly selected the top-yielding entry in 8 of 19 locations (42%).

This same methodology was applied to a subset of 150 locations from the current study with a similar number of entries per location as those in the 1996 study (12 to 20 entries). Yield monitor accuracy at ranking entries was slightly better in the current study than in the 1996 study.

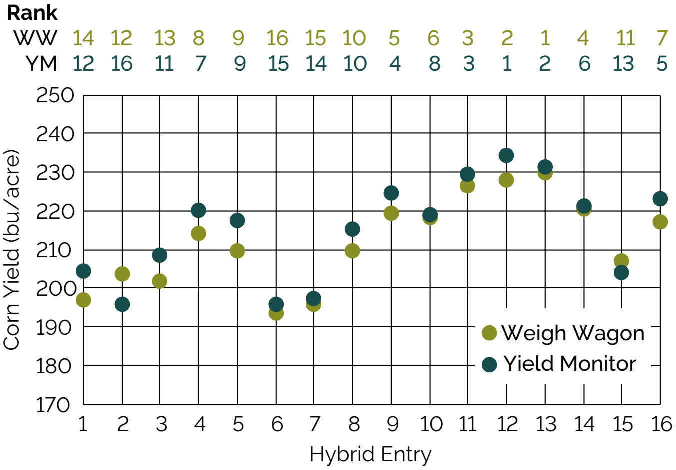


Figure 3. Example of an on-farm trial location in which both the yield estimates and ranking of entries by the yield monitor were highly accurate (Average error = 1.5%, r = 0.93; trial located in eastern Iowa, 2015).

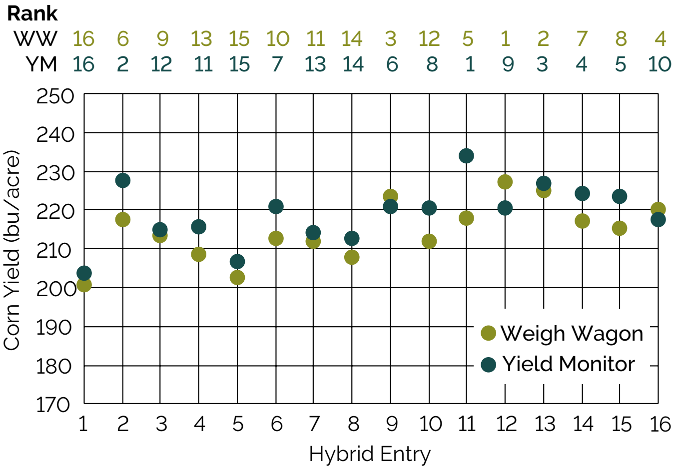


Figure 4. Example of an on-farm trial location in which the location average yield estimate was accurate, but the ranking of entries was only moderately accurate (Average error = 2.0%, r = 0.70; trial located in eastern Iowa, 2014).

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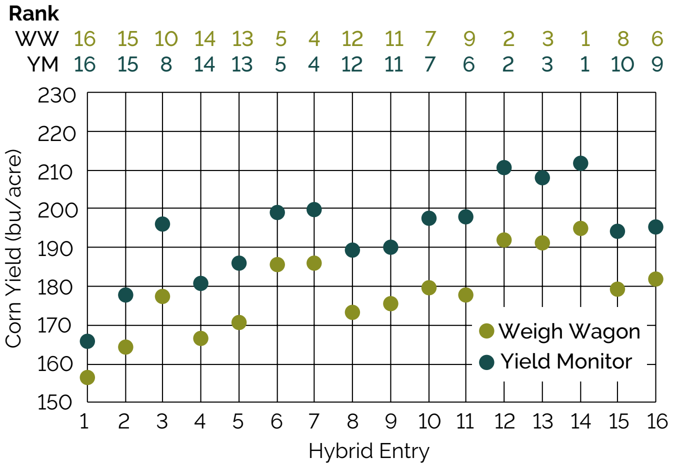

Figure 5. Example of an on-farm trial location in which the ranking of entries by the yield monitor was highly accurate, but the yield estimates were inaccurate (Average error = 8.7%, r = 0.96; trial located in northeast Nebraska, 2013).

The average correlation coefficient across locations was 0.80, with accurate yield monitor ranking of entries at 41% of locations. The yield monitor correctly selected the top-yielding entry in 75 of 150 locations (50%). Examples of individual trials from the current study with differing levels of yield monitor accuracy in estimating overall yields and ranking entries are shown in Figures 3, 4, and 5.

Among these 150 locations, the average location-level yield monitor error rate was within +/-3% at 92 locations (61%). Yield monitor estimates at 28% of locations provided both an accurate location-level yield estimate and an accurate ranking of trial entries (Figure 6).

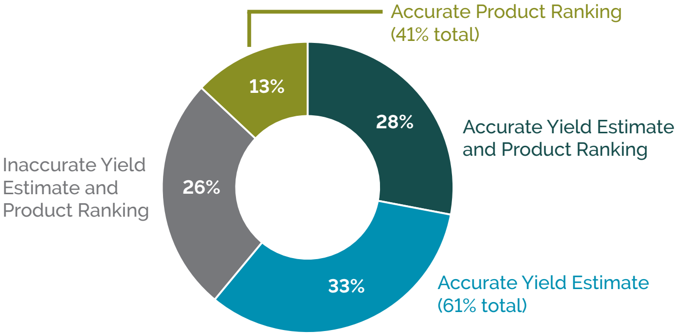

Figure 6. Overview of yield monitor data accuracy in DuPont Pioneer on-farm trials, 2013-2016.

Factors Influencing Yield Monitor Accuracy

In order to further evaluate factors influencing yield monitor accuracy, additional analysis was conducted on a subset of the data that excluded locations in which the average yield monitor error rate was greater than 3%. The rationale for this approach was that locations in which the yield monitor estimates consistently trended more than 3% above or below the weigh wagon measurements likely reflected a lack of proper yield monitor calibration. This approach does not necessarily eliminate poor calibration as a source of error but likely substantially reduces it. This subset of locations (hereafter referred to as the "calibrated subset") included 170 of the 286 total locations (59%).

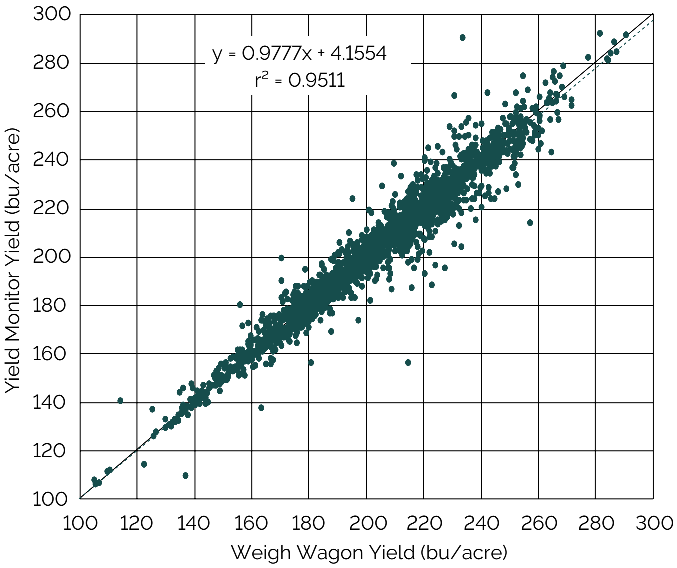

Figure 7. Relationship of yield monitor and weigh wagon corn yields from 2,346 comparisons at 170 locations where the location average error rate was less than 3%, 2013-2016.

A linear regression of yield monitor estimates versus weigh wagon measurements for the calibrated subset produced an r^2 of 0.9511 (Figure 7), a substantial improvement from the r^2 of 0.8453 for the full dataset. However, there were still 21% of individual entries with yield monitor error rates greater than 3%. The accuracy of entry ranking was only slightly improved with the calibrated subset of locations. Among 92 locations with between 12 and 20 entries, the average correlation coefficient was 0.83, with 46% of locations meeting the threshold for "accurate" ranking of entries ($r > 0.93$). The yield monitor accurately picked the top entry in 57% of locations. The fact that there was not more of an improvement in ranking accuracy suggests that: 1) there remains error in the dataset attributable to poor calibration, 2) there are other sources of error influencing yield estimates, or 3) some combination of the two.

Load Size

Previous research, including the 1996 study, has noted greater yield monitor error in on-farm strip trials in which the strip lengths and, consequently, the load sizes were relatively small. At the time of the 1996 study, the minimum recommended load size for Pioneer on-farm strip trials was 4,000 lbs (Peterson, 1996).

For most of the entries in the calibrated subset of the current study, load size ranged from around 2,000 to 22,000 lbs.

Results show some evidence of decreasing error rate with greater load size, although outliers were still present with load sizes greater than 10,000 lbs (Figure 8).

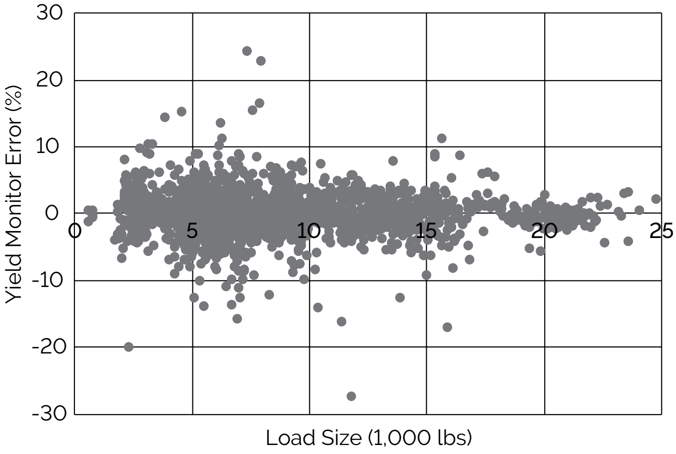

Figure 8. Yield monitor error (%) as influenced by load size.

Grain Moisture

One of the most common sources of yield monitor error is grain characteristics (moisture and test weight) that differ substantially from the grain harvested for calibration. In practice, this most commonly occurs when the yield monitor is calibrated at the start of harvest when the grain is relatively wet and not recalibrated for drier grain later in the harvest season. Analysis of data from on-farm strip trials does not provide a great deal of insight on the amount of yield monitor error attributable to lack of recalibration during the harvest season because the trials are generally harvested in a single day and typically do not include hybrids with a wide range of grain moisture. A limited number of trials in the current study did include hybrids covering a wide span of comparative relative maturity (CRM) and harvest moisture – an example of which is shown in Figure 9.

In this trial, the yield monitor estimate was very accurate for the wettest hybrid, but the error rate increased as grain moisture decreased. The driest hybrid was 9 points drier than the wettest, and yield monitor error for this hybrid exceeded 12%. Experts recommend recalibration when grain moisture changes by more than 4 points.

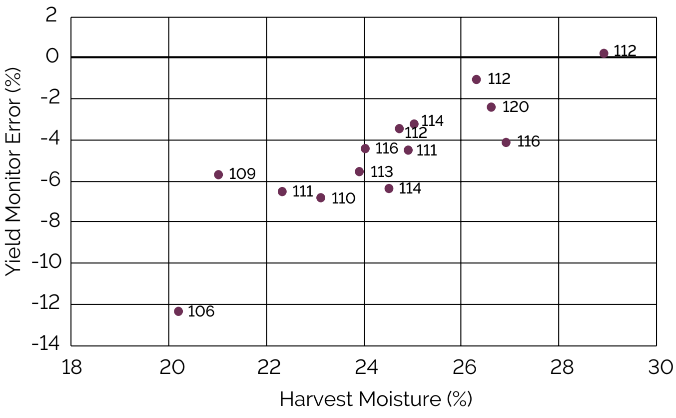

Figure 9. Yield monitor error as influenced by grain moisture in an on-farm trial conducted in Indiana in 2015. Data point labels indicate the CRM of individual hybrid entries.

Hybrid

Results of the current study did not provide evidence of a higher rate of yield monitor error associated with any specific corn hybrid family. The calibrated subset of locations included 26 Pioneer® brand hybrid families harvested at 30 or more locations. There were no hybrid families that read consistently high or low on yield monitors. For all of these hybrid families, the average error rate across locations was within +/-1% (Figure 10).

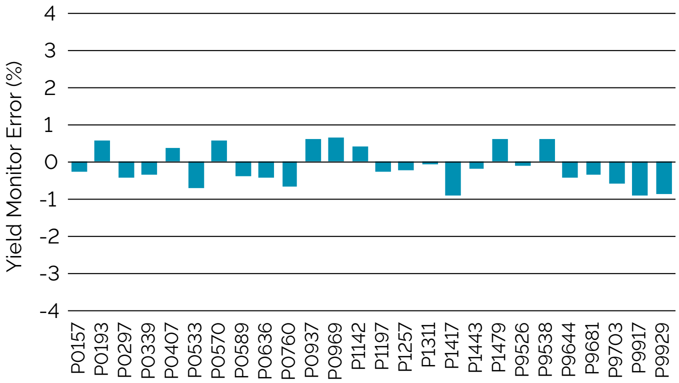

Figure 10. Average yield monitor error rates associated with Pioneer® brand hybrid families included in 30 or more on-farm trials.[3]

Implications for Field Scale Accuracy

Results of this analysis have shown that yield monitors have the capability of providing accurate yield data in on-farm strip trials but that, in reality, yield estimates and product comparisons derived from yield monitors are often inaccurate at the location level due to error in the data. However, the primary utility of yield monitors is, and always has been, assessing spatial variability in relative yield at the field scale. What insights can the results of this study provide regarding yield monitor accuracy at the field scale?

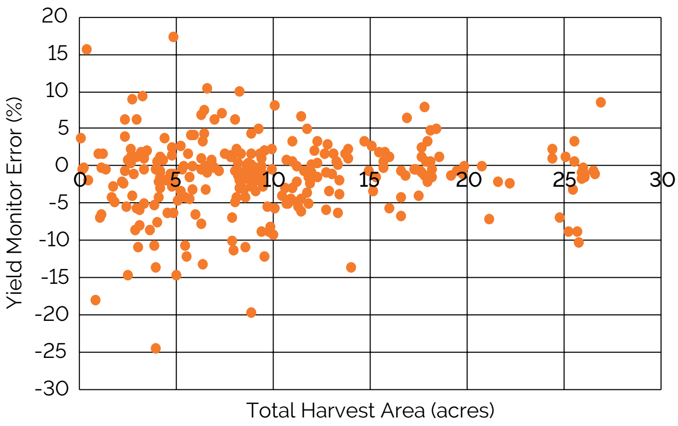

Figure 11. Average yield monitor error rate and total harvested area of on-farm trial locations.

Total harvested area of trial locations in this study ranged from less than 1 to greater than 25 acres. Locations with the greatest average yield monitor error (>10%) tended to be less than 10 acres (Figure 11). However, error rates greater than 3% were still common for trials larger than 10 acres, occurring at 38% of locations.

These results suggest that over ⅓ of field-scale yield monitor data is likely inaccurate (error rate >3%). This has important implications for management decisions based on yield monitor data, both at the farm level and beyond. As improvements in data collection and transfer make the aggregation of yield data into larger area-level datasets more seamless, the fact that a substantial portion of the data feeding into these systems are inaccurate undermines the reliability of analyses and summaries based on these data. Post-calibration using scale tickets is a fix that is often applied to align the yield monitor estimate for total yield of a field in line with the actual weight of grain harvested; however, this method applies a uniform correction across the entire field, which may not reflect the actual spatial variation of yield in the field. The oft-repeated adage regarding computer systems of "garbage in equals garbage out" is frequently, and quite fittingly, applied to yield monitor data. As the industry becomes increasingly reliant on yield monitor data for performance insights and management decisions, the "garbage out" becomes more of a concern.

Practices to Improve Yield Monitor Accuracy

The following guidelines, adapted from *Yield Monitor Systems* (Darr, 2016), can help maximize yield monitor accuracy in on-farm trials.

Mass Flow Sensor

The mass flow sensor must be calibrated to ensure accurate yield data. In general, the mass flow sensor should be recalibrated anytime there is a significant change in crop conditions. These include the following conditions:

- After a long period of inactivity, such as at the beginning of a new season
- Switching between crop types
- Significant changes in crop moisture of more than 4%
- Significant test weight changes
- Changes in crop conditions that cause a shift in normal operating speeds, including lodged or downed crops, high moisture crops, or significant changes in ground conditions

Calibration Procedure: Specific calibration procedures change based on the manufacturer, but several general recommendations fit all brands:

- Calibrate for at least the minimum number of loads recommended by the yield monitor manufacturer.
- Each calibration load should be at least 3,000 lbs, greater than 5,000 lbs is preferred.
- Calibration loads should be taken as single passes, when possible, to avoid errors associated with grain flow delay.
- Each calibration load should be conducted at a different mass flow rate. This can be controlled either by slowing down the maximum speed of the combine or by maintaining a set speed and reducing the active header width.
- The calibration flow rates should cover the entire range of flow rates that are expected in the target crop.
- After calibration, you can use "regions" or "loads" to monitor the accuracy of the calibration.

Moisture Sensor

The moisture sensor should also be recalibrated periodically or when there is a significant change in crop conditions.

Calibration Procedure: Specific calibration procedures change based on the manufacturer, but several general recommendations fit all brands:

- Start a new combine "load." This will create a new log that can be used to calibrate the grain moisture.
- Harvest an entire grain tank of grain.
- Stop the harvester, and randomly sample the grain tank from several locations.
- Record the load moisture from the yield monitor.
- Calculate the actual moisture content of the grain tank sample using an accurate moisture tester. Handheld moisture meters are generally not accurate enough for this measurement unless it has been calibrated against a higher accuracy meter. To reduce errors, record three separate moisture readings from the single grain sample, and use the average as the actual moisture.
- Enter the difference between the actual moisture and the yield monitor load moisture as a moisture offset.

Temperature calibration requires a similar offset adjustment. Make sure to calibrate temperature when the combine is not operating and has been in a constant shaded environment for a couple of hours.

Best Management Practices for Test Plots

While yield monitors can be excellent tools for field-scale evaluation, care must be taken when using these same tools for small-scale comparisons, such as test plot strips. The following steps will help to improve yield monitor performance in short test strips, but well calibrated weigh wagons are still recommended for greater accuracy.

- Operate at normal combine speed. Test plots often have shorter rows, which can lead to operators slowing down. The mass flow sensor is calibrated for normal crop flow, so to maintain accuracy, the test plot should be conducted under the same conditions.
- Conduct rolling starts. To get the combine up to steady state grain flow as quickly as possible, make sure the combine is moving at a normal speed when first engaging the crop. This is known as a "rolling start."
- Be wary of significant moisture differences. If the test plot has significant grain moisture differences (more than 5% differences), then hand samples of the plots should be collected to verify the moisture content. For every 1% error in grain moisture, the yield calculation will be off by 2.5 bu/acre.
- Avoid changing terrain. If the test plot field has rolling terrain, you should harvest all plots in the same direction. This will reduce the impact of field slope on yield data errors.
- Maintain an accurate header width. When harvesting a test plot with a platform header, be sure to maintain a consistent cutting width throughout the plot.

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Considerations for Managing Ear Drop in Corn

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

Conditions That Can Cause Ear Drop

- **Moisture Stress at Silking:** The shank develops quickly during a 2-week period surrounding pollination. Severe drought and heat stress at that time can hinder shank development.
- **Favorable Weather after Drought Stress:** Ear drop is most common when drought/heat stress during ear and shank development is followed by favorable weather during grain fill. Weak shanks formed during pollination are unable to hold on to heavier ears.
- **Rapid Dry Down:** Cells at the point of ear attachment become more brittle during rapid dry down, making them vulnerable to ear drop.
- **Disease:** Stalk rot pathogens can weaken ear shanks.

Figure 1. Fungal disease in the shank was a contributing factor that caused this ear to drop.

Why Does Ear Drop Differ Among Hybrids?

- Certain hybrids are able to set more kernels during drought stress. In some cases, hybrids with excellent drought tolerance can set large ears but have relatively weak shanks.
- Timing of drought/heat stress can affect certain relative maturities differently during the shank development stage.
- DuPont Pioneer plant breeders and agronomists actively select against hybrids vulnerable to ear drop.

Tips for Harvesting Vulnerable Fields

- In standing corn, adjust header height as close to the ear as possible. This reduces stress on the ear shank.
- Keep ground speed around 3.0 miles/hour.
- Slow down the speed of the corn head to minimize shaking of the plant as it enters the head.
- Measure losses, and make corrective machine adjustments whenever crop conditions change.

What Is the Yield Impact of Dropped Ears?

- Yield loss can be estimated by counting the number of dropped ears in 1/100th acre.
- Harvest swath length equal to 1/100th of an acre is shown below for various header widths and row spacings.

Swath Width Equal to 1/100 Acre (ft, in)

Rows	Row Spacing (inches)				
	20	22	30	36	38
6	43’ 7”	39’ 7”	29’ 0”	24’ 2”	22’ 11”
8	32’ 8”	29’ 8”	21’ 9”	18’ 2”	17’ 2”
12	21’ 9”	19’ 10”	14’ 6”	12’ 1”	11’ 6”
16	16’ 4”	14’ 10”	10’ 11”		
18	14’ 6”	13’ 2”			

Estimated Yield Loss Resulting From Dropped Ears*

Yield Level	Dropped Ears Per 1/100 Acre				
	2	4	6	8	10
	------------------- *bu/acre* -------------------				
250	1.5	2.9	4.4	5.9	7.4
225	1.3	2.6	4.0	5.3	6.6
200	1.2	2.4	3.5	4.7	5.9
175	1.0	2.1	3.1	4.1	5.1
150	0.9	1.8	2.6	3.5	4.4
125	0.7	1.5	2.2	2.9	3.7

** Based on population of 34,000 plants/acre.*

Yield Impact of Volunteer Corn

- Volunteer corn can reduce yield like any other weed species by competing with the crop for available resources, such as light, nutrients, and water.
- Volunteer corn plants from dropped ears are more likely to emerge in clumps than as randomly dispersed plants.
- Plants in a clump must compete with each other in a limited space for the same light, water, and nutrients, making them less competitive with the crop than randomly dispersed plants.

Predictions of Corn Yield Loss Due to Volunteer Corn Ear Clumps Based on University of Minnesota Research Data

Volunteer Corn Density (ear clumps/acre)	Yield Loss (%)
100	0.2
500	1.2
1,000	2.4

Stahl, L.A.B., M.J. Haar, J.K. Getting, R.P. Miller, and T.R. Hoverstad. 2007. Effect of glyphosate-resistant volunteer corn on glyphosate-resistant corn. Proc. North Central Weed Sci. Soc. 62:48.

Volunteer Corn Management Options

Selective Use of Fall Tillage

- In southern corn producing areas where the growing season is longer, early fall tillage can stimulate germination and emergence of volunteer corn prior to the winter freeze, thus reducing the amount of potential emergence the following spring.
- If early fall tillage is not feasible or soil conditions are not conductive for seed germination, another strategy is to avoid fall tillage altogether. Incorporation of seeds into the soil provides a favorable protective environment for winter survival; whereas, seed left exposed on the surface are more susceptible to decay or predation.

- Fall tillage will likely be counterproductive if the soil is too dry for corn seeds to germinate and emerge before the winter freeze.

Spring Tillage

- Spring tillage can effectively manage germinated and emerged seedlings.
- However, if conditions prior to spring tillage are not conducive to germination and a large quantity of viable seed remains on the surface, tillage may effectively "plant" more volunteers than it controls.
- Vertical tillage implements intended primarily to manage residue with minimal soil disturbance are less effective at removing emerged volunteer plants and may make things worse by shattering ears and spreading seed.

Crop Rotation

- Rotating to a different crop expands herbicide options for controlling volunteer plants. Selective grass herbicides, such as Assure® II, effectively control volunteer corn in soybean.

Herbicides

- The ACCase herbicides, such as Assure II, Fusilade®, Fusion®, Poast®, and Poast Plus®, can be used to control volunteer corn in soybean but have intervals ranging from 30 to 120 days after herbicide application before corn can be planted.
- Select Max® has a plant/replant interval of only six days for corn and thus, is the only ACCase herbicide that can be used for control of volunteer corn before planting.

Herbicide Options for Controlling Volunteer Corn Ahead of Corn Planting

Herbicide	Notes
Select Max	• Labeled rate: 6 fl oz/acre • Do not plant earlier than 6 days after application. • Applications should include NIS and AMS
Gramoxone Inteon® + metribuzin	• Labeled rate: 24-48 fl oz/acre (Gramoxone Inteon) + 2-5⅓ oz/acre (metribuzin 75) • No restriction on planting timing following application

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Managing for Delayed Corn Crop Development

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

Summary

- Corn development and maturity may be delayed in seasons with late planting and/or cool summer temperatures.
- Freezing temperatures occurring before normal crop maturity (i.e., prior to kernel "black layer" development) may reduce corn yields.
- The impact on corn yield from an early freeze depends on the stage of corn growth, low temperature reached, duration of the low-temperature period, and other factors.
    - Corn leaf tissue can be killed by a few hours near 32 °F and in even less time at temperatures below 32 °F.
    - Temperatures below 32 °F for several hours would likely kill all the leaves and may stop ear development.
- When grain is wet at harvest or impacted by an early, killing freeze, quality may be reduced. Subsequent harvest, handling, drying, and storage of this grain requires extra care to prevent further quality reductions.
- Cylinder/rotor speed and concave clearance are the combine adjustments most critical to reduce grain damage and threshing losses with wet/immature grain.
- Drying temperatures need to be limited on corn of 25 to 30% moisture content or higher to avoid scorching grain and causing stress cracks that increase kernel breakage.
- Follow optimum grain storage procedures to minimize quality issues with wet or immature grain.
    - Screen grain. "Core" the bin, and level grain mass after filling.
    - Maintain aeration until grain mass equilibrates.
    - Monitor grain in storage by checking every two weeks.

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Introduction

Corn maturity may be delayed by late planting and/or below-normal summer temperatures. When slow corn development continues into the fall, corn grain may be significantly wetter at harvest. This can result in higher drying costs, mechanical damage to grain, and if a killing frost occurs before corn reaches maturity, yield reductions. This article discusses the possible impacts of cool temperatures and an early freeze on corn development, grain yield, field drydown, harvest, artificial drying, and storage.

Effect of Planting Delays

Because growing degree unit (GDU) accumulation in early to mid-May is similar to GDU accumulation in late September when corn is maturing, each day of planting delay could result in a commensurate 1-day delay in maturity. However, corn is able to adjust to late planting by reducing its total GDU requirement slightly, by about 5 GDUs for each day planting is delayed beyond May 1. This means that corn maturity is usually delayed by only about 1 day for each 1.5 days of planting delay.

Effect of Cool Summer Temperatures

Cool or moderate summer temperatures are rarely more than one or two degrees below normal when considering the entire summer period. Such conditions would result in a deficit of 90 to 180 GDUs that has to be made up in late summer/early fall. This would result in about a 1- to 2-week delay in corn maturity in the Central Corn Belt and up to 3 weeks in northern corn-growing areas.

Corn Maturity Development

During the ear-fill stage of corn development, kernels 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).

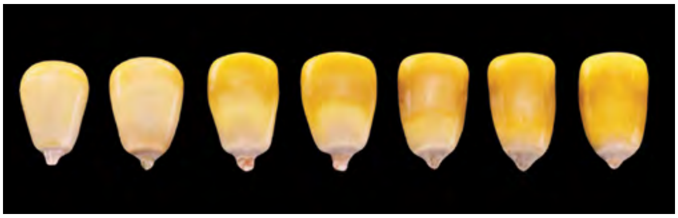


Figure 1. Progression of milk line in corn kernels from R5, or early dent, **(left)** to R6, or physiological maturity, **(right)**.

Corn physiological maturity is complete when an abscission layer, "black layer", forms at the tip of the kernel, halting further nutrient transport into the kernel and marking the end of yield accumulation (Figure 2).

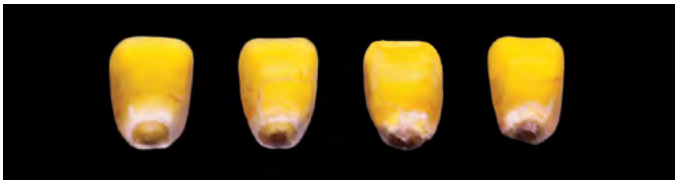


Figure 2. Progression of black layer development in corn kernels (at tip of kernels), indicating physiological maturity (R6).

As corn reaches the R6 stage, moisture content of the kernel is at about 30 to 35%. At this point, grain quality can still be reduced due to combining, drying, and handling of wet grain, but the crop is no longer at risk of yield loss due to frost.

Yield Reduction Caused by an Early Freeze

The impact on corn yield from an early freeze is dependent on stage of corn growth, low temperature reached, duration of the low temperature period, and other factors (Lauer, 2004). A freeze event with temperatures below 32 °F for several hours would likely kill all the leaves and may stop ear development entirely. Should this occur, growers need to determine the ear development stage at the time of the freeze to estimate percent yield loss (Table 1 and Figure 3).

Table 1. Potential grain yield losses after frost.

Corn Development Stage	Killing Frost (leaves, ear shank, and stalk)	Light Frost (leaves only)
	percent yield loss	
R4 (soft dough)	55%	35%
R5 (dent)	40%	25%
R5.5 (50% kernel milk)	12%	5%
R6 (black layer/no milk line)	0%	0%

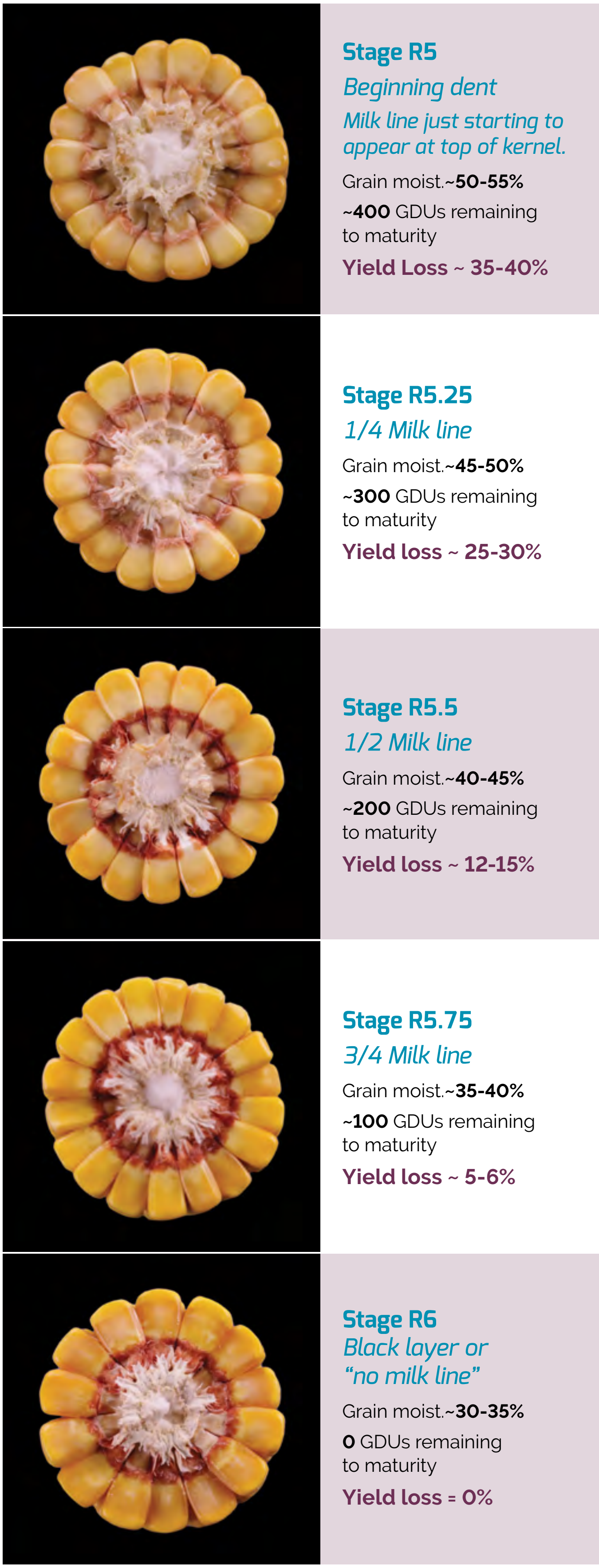
Derived from Afuakwa and Crookston (1984).

Corn leaf tissue can be killed by a few hours near 32 °F and in even less time at temperatures below 32 °F. At temperatures between 32 to 40 °F, the extent of damage may vary considerably, depending on microclimate effects, the aspect of the field slope, and whether or not atmospheric conditions favor a radiation frost. In such cases, it is possible that only upper leaves in the canopy would be killed, while leaves lower in the canopy survive and remain photosynthetically active. If the leaf tissue is killed, it will be evident in one to two days as a water-soaked appearance, which will eventually turn brown. Therefore, it is best to wait five to seven days before making an assessment of percentage leaf damage for purposes of estimating yield reduction.

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 late in the season, field drydown is slower due to cooler air temperatures. For example, according to Ohio State University Extension, corn drying rates of 1% per day in September will usually drop to ½ to ¾% by early to mid-October, ¼ to ½% per day by late October to early November, and only ¼% or less by mid-November (Thomison, 2011).

DuPont 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% (DuPont Pioneer, unpublished). If a hard freeze occurs that stops corn development prior to maturity, these field drying rates may be affected. For example, corn frosted as early as the dough stage may require four to nine extra days to reach the same harvest moisture as corn not frosted (Maier and Parsons, 1996).



Stage R5
Beginning dent
Milk line just starting to appear at top of kernel.
Grain moist.~**50-55%**
~**400** GDUs remaining to maturity
Yield Loss ~ 35-40%

Stage R5.25
1/4 Milk line
Grain moist.~**45-50%**
~**300** GDUs remaining to maturity
Yield loss ~ 25-30%

Stage R5.5
1/2 Milk line
Grain moist.~**40-45%**
~**200** GDUs remaining to maturity
Yield loss ~ 12-15%

Stage R5.75
3/4 Milk line
Grain moist.~**35-40%**
~**100** GDUs remaining to maturity
Yield loss ~ 5-6%

Stage R6
Black layer or “no milk line”
Grain moist.~**30-35%**
0 GDUs remaining to maturity
Yield loss = 0%

Figure 3. Kernel growth stages and approximate grain moisture, GDUs to maturity (black layer or “no milk line”), and yield loss from a hard, killing frost that stops kernel development.

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 and broken kernels can trim bushels of saleable grain.

Pre-Harvest Tips

In seasons with delayed corn crop development, many growers will have to deal with wetter than normal grain at harvest. Several steps can be taken prior to harvest to make this job go more smoothly (Lauer 2009).

- If you have recorded silking dates by field, use these notes to predict the order in which fields will reach black layer and harvestable moisture. This will help in setting up a harvest schedule. However, be sure to base the schedule on crop condition as well as grain moisture, taking into account stalk quality and insect or disease damage.
- Where such options exist locally, consider harvesting (or selling) more of your crop as silage or high moisture corn.
- Explore locking in a price for the additional fuel needed for grain drying. Compare the fuel costs vs. possible dockage for shrink if wet corn is delivered to the elevator.
- Consider some field drying if grain moisture levels are high, but do not wait too long. Wet field conditions can keep combines out of the field as crops deteriorate, and snow and ice may increase harvest losses due to ear droppage and stalk breakage.

Harvest Management of Wet/Immature Grain

Combine Adjustments: Grain above 30% moisture can be difficult to remove from the cob and is easily cracked and damaged by over-threshing in the cylinder or rotor of the combine. Cylinder/rotor speed and concave clearance are the adjustments most critical to reduce grain damage and threshing losses. At high grain moisture growers may have to strike a balance between damaged grain and higher than normal grain loss from unshelled cobs.

With very wet grain, some ag engineers suggest beginning harvest with combine settings that would likely under-thresh a typical, lower moisture crop (Brook and Harrigan, 1997):

- Set cylinder/rotor speed near the low end of the suggested range.
- Set concave clearance near the widest recommended setting.
- Open the chaffer and sieve to the maximum recommended openings.
- Check with the combine manufacturer for machine-specific recommendations. (Combine mechanics or other dealership staff are often a good source for this information.)
- Begin with above settings, but check immediately and re-adjust as necessary to achieve best results. Continue to check and readjust as crop conditions change.
- For more tips on combine settings for wet grain, go to: *http://www.ipm.msu.edu/pdf/HarvGrain&Dmg.pdf.*

Drying Wet/Immature Grain

Properly drying very wet, lower quality corn is essential to avoid further quality reductions. Growers should screen lower quality grain prior to drying, using a rotary screen, gravity screen, or perforated auger housing section. This will help prevent foreign material and broken kernel fragments (or "fines") from blocking air flow essential to uniform grain drying and storage. Next, growers should plan to dry lower quality grain 1 or 2 points lower than the normal 14 to 15% often recommended for long-term storage. This is because of greater variations of moisture content within the grain mass and increased physical kernel damage and broken cobs, which could magnify mold problems.

According to extension specialists at North Dakota State University, energy efficiency is increased at maximum temperatures in high temperature drying systems, but these temperatures could scorch very wet or immature kernels. In addition, high temperature drying causes stress cracks in the kernel, which allows more breakage during handling and storage. The amount of stress cracking depends on initial grain moisture, rate of moisture removal, maximum grain temperature reached in the dryer, and rate of grain cooling. Therefore, drying temperatures need to be limited on corn of 25 to 30% moisture content (or higher).

With natural-air or low-temperature drying systems, it will be difficult to adequately dry corn wetter than 26% grain moisture. The maximum moisture content for natural air drying of corn is 21% using an airflow rate of at least 1 cubic foot per minute per bushel of corn (Hellevang, 2009).

Consider these investments to help manage harvest, drying, and storing wet, lower-quality grain:

Moistures tester – $300 to $2,000

"Bee's wings" and fines cleaner – $1,500 to $3,000

Moisture controllers for the grain dryer – $2,500 to $5,000

Temperature cables in the grain bin – $2,500 to $5,000

The University of Wisconsin gives these additional grain drying tips (Lauer, 2009):

- Fine-tune your dryer so that over- or under-drying does not occur. Over-heating the grain in the dryer or filling the bin too fast for drying to occur will increase costs and decrease grain quality, thus reducing profitability.
- Hire and train the skilled labor that will be required to monitor dryers, fans, augers, and other equipment during the drying process.

To reduce drying time and speed harvest, some growers have discussed partially drying and aerating corn while holding it for further drying after completion of harvest. This strategy requires skill and intensive management, especially with low-quality grain. For more tips on grain drying to maximize grain quality, see Appendix I on the following page.

Storing Wet/Immature Grain

Low test weight, lower quality grain is harder to store because it is breakage-prone and subject to mold and "hot spot" occurrence in the bin. Because the storage life of this grain may be only half that of normal corn at the same moisture content, consider selling this grain early rather than storing long-term.

To minimize storage problems, begin by screen-cleaning grain before binning to remove as much of the fine material, cob pieces, and broken kernels as possible. After filling, "core" the bin (remove up to 10% of the total bin capacity) to eliminate broken kernels and fines that accumulate in the center. Next, level the grain in the bin to minimize moisture accumulation at the top of the grain. Finally, cool grain as soon as it is dry to within 10 °F of air temperature, and continue to aerate for 10 to 14 days to ensure grain moisture "equilibrium" has been achieved.

Monitoring lower quality grain on a twice-monthly basis is essential to ensure that grain condition is maintained. For more tips on grain storage and monitoring procedures, see Appendix I and II on the following page.

Conclusions

When growers have fields of wet or immature corn in October, deciding when to start combining is difficult. Experiences during several late-harvest years suggest that excessive delays may not be a good idea for these reasons:

- Delaying starting may also delay finishing at a reasonable date. Most growers require about six weeks to harvest the entire crop in a normal year and another two weeks to complete fertilization and tillage. This means growers must start the first week of October to finish before December.
- Drying corn with ambient temperature in the 20s requires more energy than drying corn with ambient temperatures in the 40s.
- Harvesting in the winter limits fall tillage and fertilization, reducing options for crop rotation the following spring.
- Finally, there are safety concerns and potential for increased damage to machinery when harvesting on frozen soils and driving on snow or ice-covered roads.

For these reasons, timely harvest is usually advantageous, even though drying costs may be increased.

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Appendix I - Optimal Management Practices for Drying and Storage (John Gnadke, AGS, Inc.)

Appendix I, Table 1. Continuous Flow Grain Dryers[a].

	Operating Plenum Temp.[b]	Grain Temp. Maximum
Food corn	130 – 140 °F	100 °F
Wet milling corn	170 – 190 °F	130 °F
Livestock feed	170 – 190 °F	130 °F

[a] To maintain high capacity and grain quality, keep your grain dryer clean. [b] Temperature ranges must be within 15-20 °F anywhere within your plenum.

In-Bin Drying

In-bin with stirring equipment - for best results, the operating temperature should be 95 to 105 °F.

In-bin with low temperature heaters (LP or electric) should be operated on a humidity controller. This will condition the ambient air to the proper relative humidity (RH). For best results, the RH setting is approximately 70%.

Natural Air In-Bin

Fan size: 1.5 CFM of air per bushel

Clean grain to 2% or less BCFM.

Wet grain moisture: 20% for best results

Roof venting: 1.5 ft^2 per fan HP

In-Bin Continuous Flow

Clean grain to 2% or less BCFM.

Operating temperature: 130 to 160 °F.

Keep grain depth from 4'-6' for highest capacity of this unit.

Proper roof vent is a must (1.5 ft^2 per fan HP).

Grain discharge temperature will be 95 to 115 °F.

In-Bin Cooling

If stress fractures are a part of a grain contract, take special steps to prevent this from occurring (grain temperature: 95 to 105 °F).

If wet grain is 20% or less, steep for 12 hours before cooling.

If wet grain is 22 to 24%, steep for 18 to 24 hours before cooling.

If ambient air temps fall below 40 °F at night, then DO NOT operate cooling fans.

Operating cooling fans at 40 °F or above will reduce stress on grain (may require day-time operation of these cooling bins).

Cooling Grain to Proper Storage Temperatures

Cool grain to 35 °F (DO NOT freeze food corn as it can cause additional stress on the grain).

Freezing grain at 18 to 20% moisture can cause ice crystals to form on the kernels.

When temperature rises in March or April, ice crystals will melt and cause grain to go out of condition very quickly.

Final Note

All stored grain should be checked every two weeks!

Appendix II - Grain Storage Principles (John Gnadke, AGS, Inc.)

Initial Storage

- Dry grain to the "equilibrium" moisture level (15%).
- Use LOW temperature drying to minimize stress cracks.
- For ideal grain storage, target 2% cracked/broken
- Level the grain in the bin to minimize moisture accumulation at the top of the bin (core or use a mechanical "spreader").
- "Core" the bin by removing 10% of the total bin capacity after filling to remove fines that accumulate in the center. In the coring process, try to keep the bin as level as possible.
- Cool grain as soon as it is dry to within 10 °F of air temperature.
- Aerate the grain for 10 to 14 days after filling to ensure grain "equilibrium" has been achieved – based on ¼ CFM.
- Monitor grain temperature and moisture regularly (minimum every two weeks, preferably on a continuous basis with "in-bin" probes <u>and</u> visual inspection).
- Monitor grain for insect and rodent infestation on a regular basis (minimum every two weeks).

Long-Term Storage

- Keep cooling grain on a regular basis until grain temperature reaches 35 °F. Never cool grain below 32 °F.
- Check grain regularly (minimum every two weeks) while in storage. 1) Lock out power. 2) Climb into the bin, look, feel, smell, and walk on the surface. 3) If automated controls are used, bi-weekly inspections are still recommended to ensure controls are functioning properly.
- Aerate on a regular basis while in storage; discontinue fan run-time when temperatures fall below 32 °F.

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Potassium Fertilizers for Crop Production

by ***Samantha Reicks,*** *Agronomy Sciences Intern*

Importance of Potassium

Potassium (K) is one of three macronutrients that all plants require for growth. Potassium is needed to move sugars and other forms of energy throughout the plant, allow gas exchange with the atmosphere through the stomata, and aid in cell wall strength. In dry conditions, potassium helps the plant stay rigid and upright. Adequate potassium fertility is essential to maximizing crop yields.

Forms of Potassium Fertilizers

Analyses of potassium fertilizers are typically reported as percent K_2O (potassium oxide), a potassium form that is not actually present in fertilizers but is used as an industry standard measure. In a standard fertilizer analysis, the third number is the percent of K_2O by weight in the fertilizer. To convert amounts of K_2O to K^+, use the following equations:

$$\text{lbs } K^+ = 0.8 \times \text{lbs } K_2O$$
$$\text{lbs } K_2O = 1.2 \times \text{lbs } K^+$$

KCl – Muriate of Potash (0-0-60)

- Most common form of potassium fertilizer, soluble in water
- Will cause injury if placed too close to the seed

K_2SO_4 – Sulfate of Potash (0-0-50)

- Three times less soluble than KCl
- Provides sulfur as well as potassium to the plant

K_2SO_4 $MgSO_4$ – Sulfate of Potash-Magnesia (0-0-22)

- Soluble in the soil when the soil is moist
- Less than 3% chloride, less likely to burn seedlings
- Provides sulfur, potassium, and magnesium to the plant

KNO_3 – Potassium Nitrate (13-0-44)

- Soluble form of potassium and nitrogen

KOH – Potassium Hydroxide (0-0-70)

- Provides the same availability as KCl
- Used in solution fertilizers

Manure

- Potassium levels in manure differ between animal species. Sheep and poultry have the highest amount of potassium in manure compared to other livestock.
- The diet of the animals will affect the amount of potassium in the manure. If the grain the animal is digesting has high amounts of potassium, the manure will as well.
- Potassium is most abundant in the liquid portion of manure due to the solubility of the nutrient. Dry manure will not have as much potassium.

Figure 1. Fertilizer buggy spreading poultry manure following soybean harvest.

Application of Potassium

- Biennial potassium applications can be equally as effective as annual applications, as long as the biennial application rate accounts for the nutrient needs of two crops.
- Spring application is just as beneficial as applying in the fall, unless soil test levels are in the very low range. Soils with a low CEC may benefit from K application closer to planting to reduce the amount of fertilizer leached.
- When starter N+K_2O fertilizer is used, do not apply more than 80 lbs/acre to prevent salt injury. If more K_2O is needed, broadcast, and incorporate before planting.
- Nutrient removal due to silage harvest or stover removal should be considered when determining fertilizer rate recommendations, as both will remove more potassium than grain harvest alone. Delaying harvest and removal can reduce nutrient removal rates.

Method of Application

Banding

- Specific cases where banded and starter K applications may be beneficial include:
    - Heavy or wet soils that are slow to warm in the spring
    - Soils that are high testing for K, on average, but are characterized by a high degree soil test variability
    - No-till, strip-till, and zone-till for which K is typically banded at planting
- Use only half of the broadcast recommended rate when banding. This will not limit yield.

Broadcast

- This is the recommended application method for soybeans when the fertilizer is applied in the spring.
- Incorporation is recommended.

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Potassium Behavior in Soil

by **Samantha Reicks,** Agronomy Sciences Intern

- Potassium is an essential plant nutrient that plays a role in a wide range of physiological processes - from regulation of the stomata to enzyme activation.
- Potassium is held in the soil by the cation exchange capacity. Soils with finer particles, such as clay, and organic matter are able to hold more positively charged ions than soils with larger particles, such as sand.

States of Potassium

Potassium in Soil Solution (1-2%)

- Potassium dissolved in soil water; available for plant uptake
- Exists in equilibrium with the exchangeable, fixed, and mineral states; replenished by the exchangeable supply as potassium is removed through plant uptake

Exchangeable Potassium (1-2%)

- Potassium held on exchange sites of soil clay and organic matter; available for plant uptake
- Readily released into soil solution when the concentration of potassium dissolved in soil water decreases

Fixed (Non-Exchangeable) Potassium (1-9%)

- Potassium trapped inside clay materials; not immediately available to plants
- Moves to more available forms when the soil solution is depleted of potassium

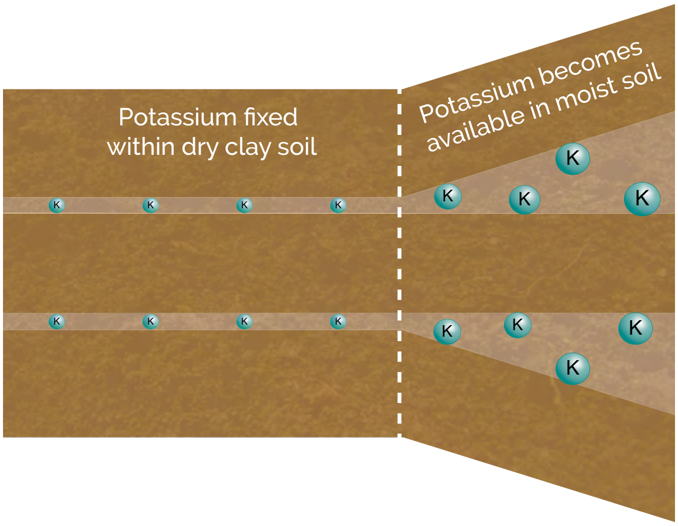

Figure 1. Fixed potassium inside clay becomes available as water is added to soil.

Mineral Potassium (90-98%)

- Potassium contained in feldspar and mica sand, and rocks; not available for plant uptake
- Not measured in soil tests
- Potassium can be held in this state for many years before it is released through weathering of minerals.

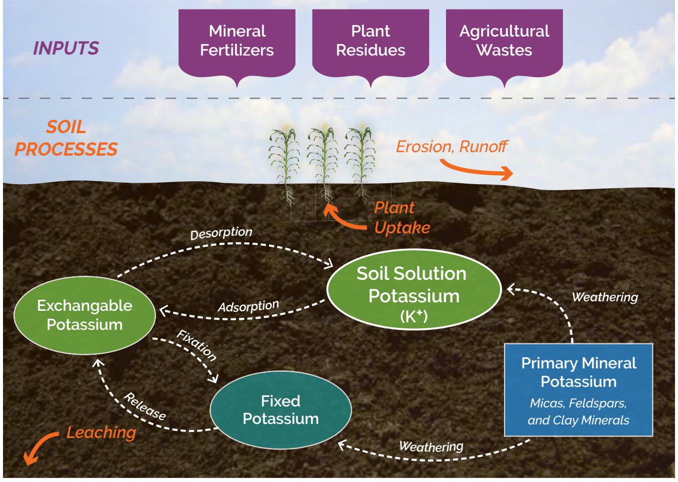

Figure 2. Soil potassium cycle.

Potassium Reactions in the Soil

Adsorption: Binding of potassium to negatively charged sites on soil particles through weak electrostatic attraction

Desorption: Release of exchangeable potassium from soil particles

Fixation: Incorporation of potassium between layers of clay in the soil, making it temporarily unavailable for plant uptake; occurs when soil potassium is high and when soil is dry, causing clay layers to collapse

Release: Dissolution of potassium that occurs when soil minerals dissolve

Weathering: Disintegration of rock and minerals by precipitation, organisms, and/or temperature

Cation Exchange Capacity (CEC)

Potassium is held in soil by charges known as CEC.

Charges in the Soil

- CEC is the quantity of the negatively charged particles in the soil, measured in milliequivalence per 100 g (meq/100g).
- The higher the number, the more attraction there is between the negatively and positively charged particles.

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Nutrient Mobility in Soil Solution

- Forces of attraction between nutrient ions, soil, and water molecules determine their behavior and mobility in soil.
- Cations, such as K^+, bond to negatively charged soil particles, thus are not as abundant in soil water and are not highly mobile.
- Anions, such as NO_3^-, do not as readily bond to soil, therefore are more abundant and more mobile in soil water.
- Phosphorus is an exception as it exists as an anion but has low water solubility, making it relatively immobile in the soil.

Table 1. Essential nutrients for plant growth, forms available for plant uptake, and relative mobility in soil water.

Nutrient	Plant-Available Form(s)	Soil Mobility
Nitrogen	NO_3^- NH_4^+	Mobile Immobile
Phosphorus	HPO_4^{2-}, $H_2PO_4^-$	Immobile
Potassium	**K^+**	**Somewhat mobile**
Sulfur	SO_4^-	Mobile
Calcium	Ca^{2+}	Somewhat mobile
Magnesium	Mg^{2+}	Immobile
Boron	H_3BO_3, BO_3^-	Very mobile
Chlorine	Cl^-	Mobile
Copper	Cu^{2+}	Immobile
Iron	Fe^{2+}, Fe^{3+}	Immobile
Manganese	Mn^{2+}	Mobile
Molybdenum	MoO_4^-	Somewhat mobile
Zinc	Zn^{2+}	Immobile

Factors Affecting Potassium Availability

Cation Competition

- Cations that are attracted to the soil by CEC include calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and aluminum (Al^{3+}).
- Of these elements, Mg^{2+} is most likely to bind to the exchange sites; a high concentration of competing cations when potassium concentrations are low can reduce the adsorption of potassium.
- Cations that are available in CEC are contingent on environmental factors, including parent material, soil pH, climate, and soil inputs.

Soil Moisture

- More potassium is available when the soil is moist. Potassium can move more freely in the soil solution between the plants and the soil surfaces. Exchangeable potassium can replenish the solution with greater ease.

Temperature

- As temperature decreases, it is harder for plants to take up potassium.

Weathering

- Excess fertilizer can become fixed in soil. Available forms of potassium become fixed as the clay dries out.
- Old soils that are very weathered lose their mineral form of potassium and can no longer supply the soil solution with this nutrient.

Luxury Consumption

- Plants will take up excess potassium if the soil allows, even if the plant does not need it.
- This does not harm the plant, but it can be an economic concern if too much fertilizer is being applied.

Potassium Loss from the Soil

- Potassium very seldom leaches from the soil. It is most abundant in its mineral form, and available forms are most often taken up by plants promptly.
- Erosion rarely affects potassium loss from the soil.
- Potassium (K_2O) in the grain is removed from the field during harvest.
  - 200 bu/acre corn grain removes about 50 lbs K_2O/acre.
  - 60 bu/acre soybean grain removes about 80 lbs K_2O/acre.
  - 45 bu/acre wheat removes about 15 lbs K_2O/acre.
- Corn silage and stover removal also removes potassium from the system. Rain prior to stover removal allows potassium from the plant sap to reenter the soil.
- When potassium fertilizer or manure is applied in large amounts to soil with low CEC, such as sandy soils, the potassium is not able to bond in the soil and can be leached.

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Phosphorus Fertilizers for Crop Production

by ***Samantha Reicks,*** *Agronomy Sciences Intern*

Importance of Phosphorus

Phosphorus is one of three macronutrients essential for plant growth. It plays critical roles in photosynthesis, respiration, and energy storage and transfer. Phosphorus is also a component of DNA and is involved in cell division.

Measuring Phosphorus

- Analyses of phosphorus fertilizers are typically reported as percent P_2O_5, a phosphate form that is not actually present in fertilizers, but is used as an industry standard measure. In a standard fertilizer analysis, the second number is the percent of P_2O_5 by weight in the fertilizer.
- To determine the amount of phosphorus present in the fertilizer, multiply the amount of P_2O_5 by 0.44.
- The more soluble a phosphorus fertilizer is, the more likely it will be taken up by the plant.

Forms of Phosphorus Fertilizers

Phosphorus fertilizers are produced from mined phosphate rocks. Rock phosphate is insoluble in high and neutral pH soils and must be dissolved with acid before it can act as an active ingredient in fertilizers. Many phosphorus fertilizers are rock phosphates that have been treated with acid, as shown in Figure 1.

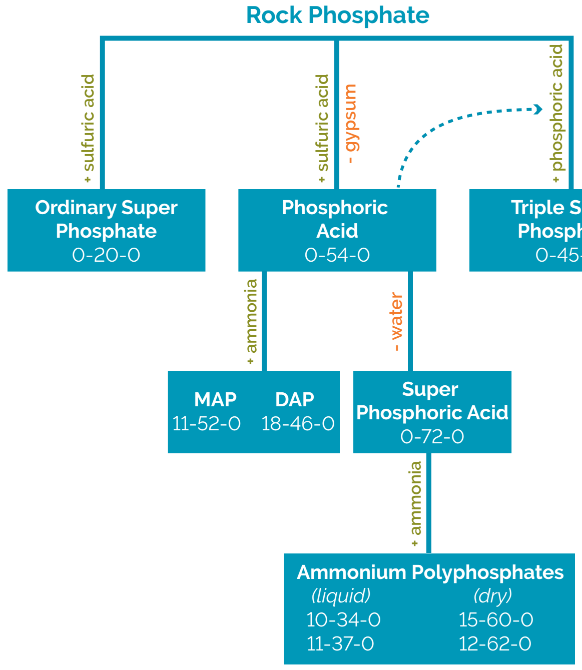

Figure 1. Rock phosphate is mined and treated to produce various forms of phosphorus fertilizer.

Ordinary Super Phosphate

- Analysis of 0-20-0
- Up to 90% water soluble
- Also contains up to 10% sulfur

Monoammonium Phosphate (MAP)

- Analysis of 11-52-0 (P_2O_5 analysis can range from 48% to 61%)
- 100% water soluble
- Used in starter fertilizer as well as fertilizer blends

Diammonium Phosphate (DAP)

- Analysis of 18-46-0
- 100% water soluble
- Used in the solid form in fertilizer blends and broadcast applications
- Injures seedling if placed too close when applied in a band

Ammonium Polyphosphate

- Analysis of 10-34-0 (P_2O_5 analysis may range from 34% to 62%)
- Commonly used in the liquid form in fertilizer blends and when the fertilizer is placed near the seed

Concentrated/Triple Superphosphate

- Analysis of 0-46-0
- Up to 90% water soluble
- Less than 3% sulfur

Manure

- Different animals, farms, and storage practices offer varying amounts of phosphorus.
- Not as soluble as processed fertilizers, meaning phosphorus will not be readily obtainable and should not be used as a starter fertilizer

Environmental Considerations

- Limited mobility of phosphorus in the soil prevents it from leaching.
- When phosphorus is applied to the surface and is not incorporated, runoff is more likely to occur. Runoff can be more common with hilly land and erosion.
- Placing the fertilizer at least half an inch in the soil can prevent runoff losses.

Preparing for Application

- Spring application is just as efficient as applying in the fall, unless soil test levels are in the very low range.
- Biennial phosphorus and potassium applications are equally as effective as annual applications in non phosphorus-fixing soils. If biennial applications are employed, the application rate should account for the nutrient needs of two crops.
- A significant amount of phosphorus is needed for early growth. Applying phosphorus after the crop has begun to grow will limit the amount the plant is able to take in, due to phosphorus being immobile in the soil and the roots growing away from the surface. Corn brace roots may take in phosphorus when they enter the soil.
- Optimum phosphorus sources and application methods will vary based on the needs from the crop, root structure, the amount of phosphorus already in the soil, and the soil characteristics.

Banding

- Placing phosphorus fertilizer in a band in the soil limits contact between soil and fertilizer, which can reduce fixation in the soil.
- Scenarios where this application method may be beneficial include soils with low phosphorus levels; soils with highly variable phosphorus levels; soils that are slow to warm in the spring; high and low pH soils; and no-till and conservation tillage.
- Roots must to be able to reach the band of fertilizer to be beneficial for the plant as the fertilizer will not move down toward the root. When a root begins to take in phosphorus, the plant will translocate the nutrient to the rest of the plant.
- If applied as a starter, the fertilizer should be placed at least one inch away from the seed to avoid injury.

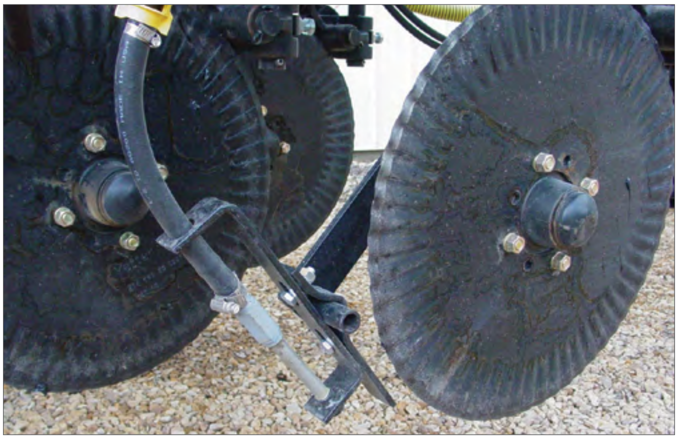

Figure 2. Row unit for banding fertilizer.

Broadcast

- Phosphorus is more likely to fix in the soil and become unavailable to plants when it is broadcast.
- Incorporating the fertilizer creates a more uniform distribution in the soil, providing more opportunities for the roots and fertilizer to come in contact.
- Conventional tillage incorporates the fertilizer into the soil more thoroughly than conservation tillage. Conservation tillage leaves more of the fertilizer near the surface of the soil.
- Conservation tillage is most effective when the seedbed is warm, the soil surface is moist, and levels of phosphorus in the soil are already high.
- When the fertility of a field is high, the difference between conventional and conservational tillage is not determinant of yield differences.
- Top dressing is used in pastures and other locations where incorporation is not tangible. The majority of phosphorus will remain near the surface of the soil.
- Phosphorus applied in no-till fields without being incorporated can lead to root structures that occupy the most space near the soil surface, called *root proliferation*. Take into consideration that most of the phosphorus is near the surface, but soil tests measure the average level in the soil.

Fate of Phosphorus in Soil

- Moisture in the soil dissolves phosphorus fertilizer after it is applied. Phosphorus in the soil can:
  - » Adsorb to the roots of the plant
  - » Become immobilized by soil microorganisms
  - » Adsorb to the soil and become active phosphorus, which replenishes the solution phosphorus very slowly
  - » Adsorb to the soil and become fixed phosphorus, rendering it unavailable to plants. Small amounts of unavailable, adsorbed phosphorus slowly become available to plants over time but has little effect overall on soil fertility.
  - » React with other ions in the soil. This is a pH dependent process. Phosphorus in acidic soils reacts with iron and aluminum, and calcium in soils with a high pH. An ideal range for phosphorus availability is 6.0 to 7.0.
  - » Runoff the surface if the soil to which it is fixed erodes.

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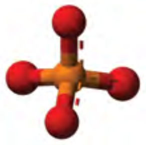
Phosphorus Behavior in Soil

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

- Phosphorus is essential for plant growth and is second only to nitrogen in the frequency that it limits yield in crop production.
- Phosphorus plays a critical role in energy storage and transfer in plants and is a component of DNA and RNA.

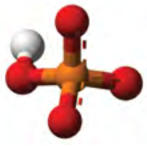
Molecular Forms

- Phosphorus is highly reactive and does not exist in elemental form in nature.
- Phosphorus is present as phosphate in natural systems, which results when phosphorus exposed to air binds with oxygen.
- The simplest form of phosphate is PO_4^{-3} (orthophosphate), which is the predominant form of phosphorus taken up by plants.



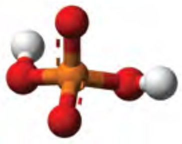
orthophosphate

- Phosphate exists in different ionic forms depending on the pH of the soil:
  - » HPO_4^{-2} (hydrogen phosphate) in basic soils
  - » $H_2PO_4^-$ (dihydrogen phosphate) in acid soils



hydrogen phosphate

- Analyses of phosphorus fertilizers are typically reported as percent P_2O_5, a phosphate form that is produced during fertilizer analysis but does not exist in either fertilizer or soils.



dihydrogen phosphate

Phosphorus Reactions in Soil

- **Adsorption:** Binding of phosphates to soil particles; also referred to as *fixation*.
- **Desorption:** Release of phosphates from soil particles.
- **Precipitation:** Reaction of phosphate with another substance to form a solid mineral.
- **Dissolution:** Release of phosphorus that occurs when soil minerals dissolve; occurs slowly over long periods of time.
- **Mineralization:** Conversion of organic phosphorus to inorganic phosphate by microorganisms breaking down organic compounds.
- **Immobilization:** Conversion of inorganic phosphate to organic phosphate and incorporation into the living cells of soil microorganisms.

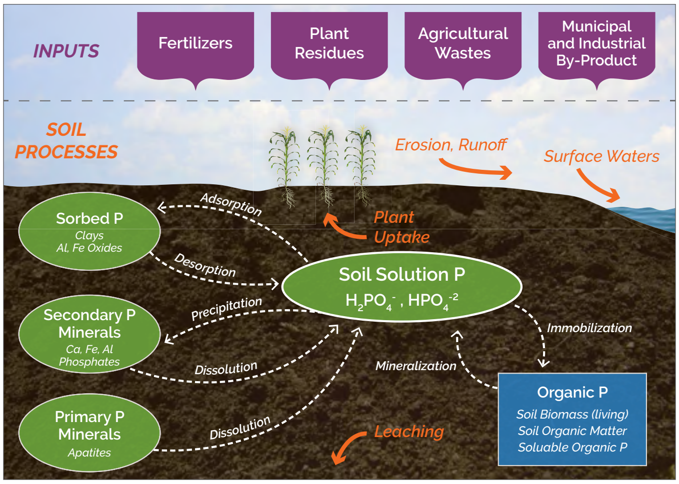


Figure 1. Soil phosphorus cycle.

Phosphorus States in Soil

Fixed Phosphorus

- Largest pool of phosphorus in the soil; unavailable for plant uptake; also referred to as *non-labile phosphorus*.
- Dissolution of fixed phosphorus into the active pool occurs very slowly over time; phosphorus can remain in the fixed pool for years and have little effect on the fertility of the soil.
- Composed of insoluble inorganic phosphate compounds (primary minerals) and organic phosphorus compounds.

Active Phosphorus

- Phosphorus in solid phase that is relatively easily released into the soil solution; also referred to as *labile phosphorus*.
- Consists of inorganic phosphate adsorbed to soil particles, secondary phosphate minerals (phosphate bound to cations, such as calcium and aluminum), and organic phosphorus that is readily mineralized.
- Replenishes phosphorus in the soil solution as it is removed by plants and is the main source of phosphorus for crop uptake.

Solution Phosphorus

- By far the smallest of the three pools, usually less than one pound/acre.
- Phosphorus in the soil solution with limited mobility that is available for uptake by plants.
- Composed mostly of inorganic phosphate, small amount of organic phosphorus.
- Rapidly depleted by plant uptake and continuously replenished by the active phosphorus pool.

Mobility in Soil Solution

- Forces of attraction between nutrient ions and soil and water molecule determines their behavior and mobility in soil.
- Cations such as K^+ bond to negatively charged soil particles, thus are not as abundant in soil water and tend to have low mobility.
- Anions, such as NO_3^-, do not as readily bond to soil, therefore are more abundant and more mobile in soil water.
- **Phosphorus is an exception, as it exists as an anion but has low water solubility, making it relatively immobile in the soil.**

Factors Affecting Phosphorus Availability

Soil pH

- The optimum soil pH range for phosphorus availability is 6.0 to 7.0.
- At lower pH levels, phosphate tends to bind with aluminum or iron compounds in the soil, making less available for plant uptake.
- At higher pH levels, phosphate tends to precipitate with calcium.

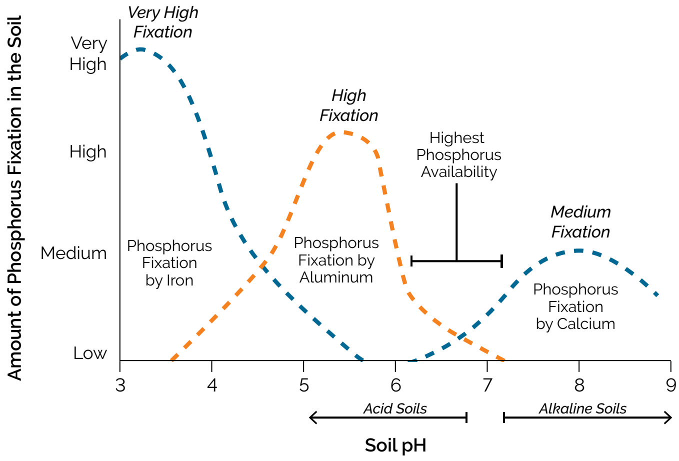


Figure 2. The effect of soil pH on phosphorus availability.

Soil Mineral Type

- Volcanic soils and highly weathered soils (such as Ultisols and Oxisols) have high phosphorus sorption capacity and thus, lower phosphorus availability.
- Less-weathered and organic soils have lower sorption capacity.

Clay Content

- As the amount of clay in the soil increases, sorption capacity increases as well. Clay particles have a large amount of surface area where phosphate sorption can take place.

Organic Matter

- Mineralization of organic matter provides a significant portion of phosphorus for crops, so higher organic matter levels will tend to result in greater phosphorus availability.

Table 1. Essential nutrients for plant growth, forms available for plant uptake, and relative mobility in soil water.

Nutrient	Plant-Available Form(s)	Soil Mobility
Nitrogen	NO_3^- NH_4^+	Mobile Immobile
Phosphorus	HPO_4^{2-}, $H_2PO_4^-$	**Immobile**
Potassium	K^+	Somewhat mobile
Sulfur	SO_4^-	Mobile
Calcium	Ca^{2+}	Somewhat mobile
Magnesium	Mg^{2+}	Immobile
Boron	H_3BO_3, BO_3^-	Very mobile
Chlorine	Cl^-	Mobile
Copper	Cu^{2+}	Immobile
Iron	Fe^{2+}, Fe^{3+}	Immobile
Manganese	Mn^{2+}	Mobile
Molybdenum	MoO_4^-	Somewhat mobile
Zinc	Zn^{2+}	Immobile

Other Anions

- Phosphate availability is higher when other anions, such as bicarbonate, carbonate, silicate, sulfate, or molybdate, are abundant in the soil solution.
- These anions compete for sorption sites on soil particles, which reduces the amount of phosphate that can be adsorbed.

Climatic and Soil Conditions

- Conditions like temperature, moisture, soil aeration (oxygen levels), and salinity (salt content/electrical conductivity) can affect the rate of phosphorus mineralization from organic matter decomposition.
- Organic matter decomposes, releasing phosphorus more quickly in warm, humid climates and slower in cool, dry climates.
- Phosphorus is released faster when soil is well aerated (higher oxygen levels) than when it is saturated.

Plant Uptake

- Despite the relatively small amount of phosphate in the soil solution at any given time, plants can take up substantial amounts due to replenishment of the solution phosphorus pool through desorption from soil particles and dissolution from soil minerals.
- Uptake of phosphate by plants creates a strong diffusion gradient that moves phosphate toward plant roots at a higher rate relative to water uptake driven by transpiration.

Phosphorus Loss from Soils

- Given the immobility of phosphorus in soil, it does not readily leach out of the root zone; however, leaching can occur when soil phosphorus levels are very high, particularly in fields with tile drainage.
- Phosphorus loss is more commonly associated with erosion and runoff. Phosphate bound to soil particles is carried away with eroded sediment.

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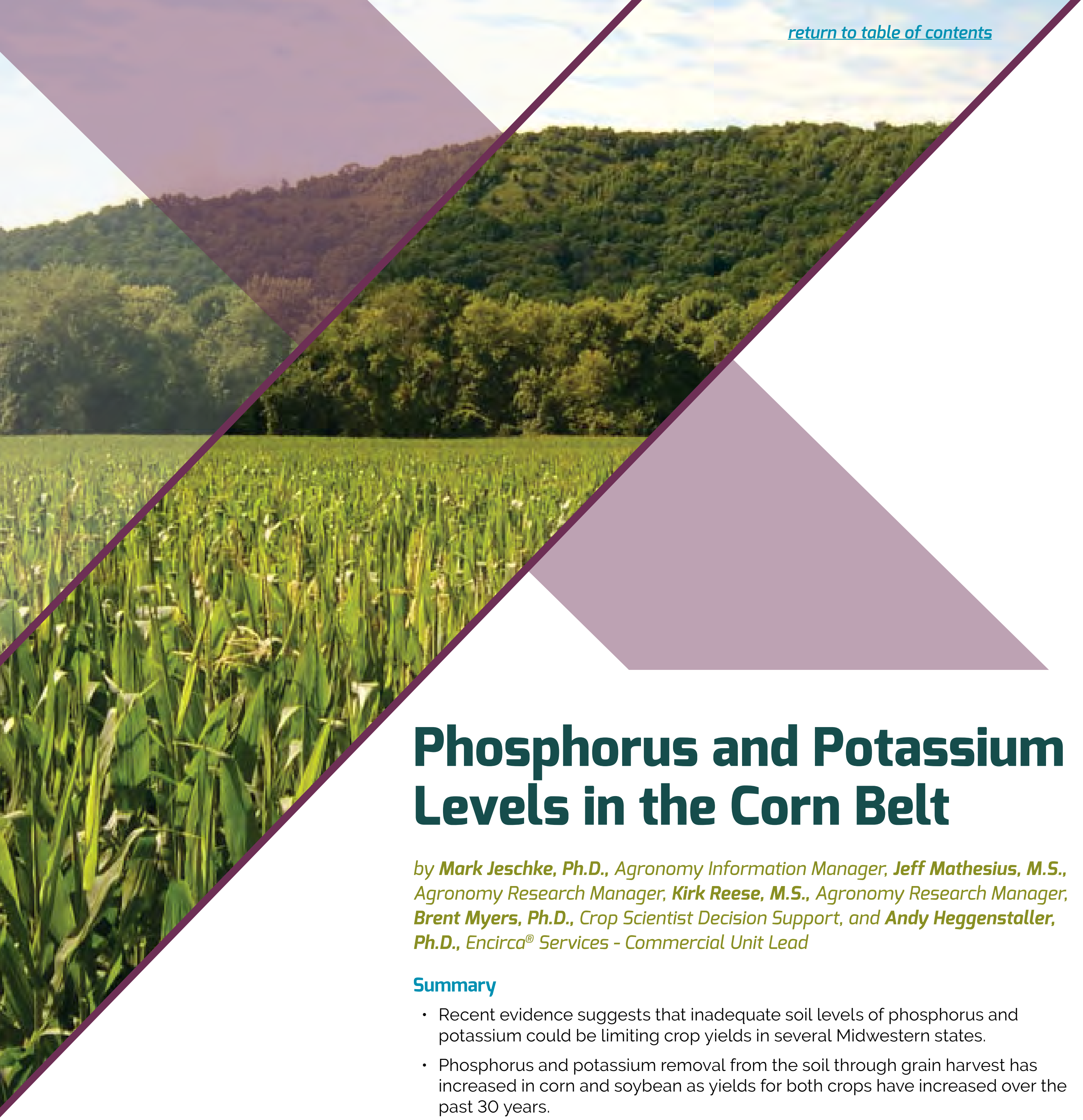

Phosphorus and Potassium Levels in the Corn Belt

by **Mark Jeschke, Ph.D.,** *Agronomy Information Manager,* **Jeff Mathesius, M.S.,** *Agronomy Research Manager,* **Kirk Reese, M.S.,** *Agronomy Research Manager,* **Brent Myers, Ph.D.,** *Crop Scientist Decision Support, and* **Andy Heggenstaller, Ph.D.,** *Encirca® Services - Commercial Unit Lead*

Summary

- Recent evidence suggests that inadequate soil levels of phosphorus and potassium could be limiting crop yields in several Midwestern states.
- Phosphorus and potassium removal from the soil through grain harvest has increased in corn and soybean as yields for both crops have increased over the past 30 years.
- While corn and soybean yields have risen substantially, phosphorus and potassium fertilizer applications have remained relatively flat or declined in some areas, which raises the question of whether deficient soils could be limiting further gains in yield.
- DuPont Pioneer agronomists and Encirca certified services agents conducted a large survey of soil fertility levels across the Midwestern U.S. in 2016.
- Results of the soil fertility survey showed that insufficient phosphorus and potassium levels were common, with substantial variation in fertility levels among states.
- Corn yield data collected from survey locations in fall of 2016 showed that yields trend lower in areas where phosphorous and potassium fall below critical levels.

Introduction

Balanced soil fertility management is critical for achieving crop genetic yield potential and maximizing profitability. In a DuPont Pioneer survey of over 1,500 growers, improved soil fertility management was second only to improved hybrid/variety genetics among management practices, which growers viewed as most critical to increasing yields.

Recent evidence suggests that inadequate soil levels of phosphorus and potassium could be limiting crop yields. A survey conducted by the International Plant Nutrition Institute (IPNI) in 2015 of soil samples submitted to labs across the U.S. showed that samples testing below the critical levels of phosphorus (P) and potassium (K) for major crops were common in several states (Murrell and Fixen, 2015).

In order to further evaluate current soil fertility levels and potential limiting effects on crop yields, DuPont Pioneer agronomists and Encirca certified services agents conducted a large survey of soil fertility levels across the Midwestern U.S. in 2016. This survey included a total of 22,402 samples collected from 8,925 fields across 12 states.

Evidence of Fertility Deficiencies

A 2015 IPNI survey of soil test levels in North America summarized median soil test levels and the frequency of samples testing below critical levels for key plant nutrients. Results of this survey showed that the frequency of samples testing below state critical levels ranged from 31 to 83% for phosphorus and 9 to 65% for potassium (Table 1).

Table 1. Critical levels for P (Bray and Kurtz P1 equivalent) and K (ammonium acetate equivalent) and percent of samples testing below critical levels for major crops in a 2015 IPNI survey (Murrell and Fixen, 2015).

State	Critical Level		Below Critical	
	P	K	P	K
	—— ppm ——		*—— % ——*	
Illinois	20	145	39	37
Indiana	15	100	31	26
Iowa	20	170	40	39
Kansas	20	130	47	19
Michigan	25	150	36	63
Minnesota	20	160	47	47
Missouri	22	110	54	30
Nebraska	15	125	35	9
North Dakota	20	160	83	16
Ohio	20	125	48	35
South Dakota	20	160	65	20
Wisconsin	25	170	48	65

Historical Yield and Soil Fertility Trends

Crop removal of phosphorus and potassium has increased over the past 30 years.

Phosphorus and potassium removal from the soil through grain harvest has increased in both corn (Table 2) and soybean (Table 3) as yields for both crops have increased over the past 30 years. Increases in yield, and corresponding increases in phosphorus and potassium removal, have been particularly great in the Northern and Western Corn Belt. Yield increases were not as great on a percentage basis over this time frame in the Central and Eastern Corn Belt, mostly because initial yields at the start of the 30-year period were greater in these states.

What is a Critical Level?

The critical soil test level for a given nutrient is defined as the level below which a profitable yield response in the year of application would be expected based on university research (Fixen et al., 2006). Critical levels can vary by geography based on factors like soil characteristics, climate, major crops grown in the area, and cultural practices.

A fertilizer application plan based on soil test results can differ depending on a grower's approach to fertility management:

- The **nutrient sufficiency approach** involves applying just enough fertilizer to maximize profitability in the current year. For soils testing above the critical level, no additional fertilizer is applied.
- The **build-maintenance approach** involves building soil fertility levels up to the critical level and, once this level is reached, applying fertilizer at rates equivalent to the amount of nutrients removed by the crop.

Soil test level categorizations and fertility management recommendations can vary among state universities, and not all universities use the critical level concept as a part of their soil fertility system. The critical levels for phosphorus and potassiumused in this DuPont Pioneer study were first published by IPNI in 2006 as a way to bring together the various university soil fertility rating systems into a single system of state-level critical values to allow analysis of broad soil fertility trends across geographies and over time (Fixen et al., 2006).

University soil fertility recommendations sometimes vary among different areas within a state based on different soil characteristics and major crops. Always consult your local university soil fertility guide for the most relevant and detailed information on soil fertility management practices in your area.

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Table 2. Average corn yield and calculated crop removal of phosphorus and potassium for select corn-producing states in 1986 and 2016, and percent increase over the 30-yr period.

State	Corn Yield[a]		P Removal[b]		K Removal[c]		
	1986	2016	1986	2016	1986	2016	Increase
	bu/acre		*lbs/acre*		*lbs/acre*		*%*
South Dakota	78	140	27	49	19	35	**80**
North Dakota	78	132	27	46	19	33	**70**
Minnesota	112	177	39	62	28	44	**58**
Nebraska	114	177	40	62	29	44	**55**
Michigan	100	152	35	53	25	38	**52**
Missouri	97	145	34	51	24	36	**50**
Iowa	122	181	43	63	30	45	**48**
Ohio	112	162	39	57	28	41	**44**
Wisconsin	109	156	38	55	27	39	**44**
Kansas	107	154	38	54	27	38	**43**
Illinois	122	175	43	61	31	44	**43**
Indiana	116	165	41	58	29	41	**42**

[a] USDA-NASS. Average yields for 1986 and 2016 represent trendline values based on a linear regression of average state yields from 1960-2016.

[b] Removal rate of 0.35 lbs/bu P_2O_5 (IPNI, 2014).

[c] Removal rate of 0.25 lbs/bu K_2O (IPNI, 2014).

Table 3. Average soybean yield and calculated crop removal of phosphorus and potassium for select soybean-producing states in 1986 and 2016, and percent increase over the 30-yr period.

State	Soybean Yield[a]		P Removal[b]		K Removal[c]		
	1986	2016	1986	2016	1986	2016	Increase
	bu/acre		*lbs/acre*		*lbs/acre*		*%*
Wisconsin	32	48	24	35	39	58	**49**
Nebraska	36	53	26	39	43	63	**47**
North Dakota	25	36	18	26	29	43	**46**
South Dakota	28	41	21	30	34	49	**44**
Michigan	32	45	23	33	38	54	**42**
Minnesota	33	46	24	34	39	56	**42**
Ohio	36	49	26	36	43	59	**38**
Kansas	26	36	19	27	32	44	**38**
Indiana	38	52	27	38	45	62	**37**
Iowa	39	53	28	39	47	63	**36**
Illinois	38	51	28	37	46	61	**35**
Missouri	30	41	22	30	36	49	**34**

[a] USDA-NASS. Average yields for 1986 and 2016 represent trendline values based on a linear regression of average state yields from 1960-2016.

[b] Removal rate of 0.73 lbs/bu P_2O_5 (IPNI, 2014).

[c] Removal rate of 1.2 lbs/bu K_2O (IPNI, 2014).

Phosphorus and potassium fertilizer application rates have remained relatively flat or declined in some areas.

Table 4. Trends in potassium fertilizer applied per planted acre of corn (1986-2010) and soybean (1990-2015).

State	**Corn[a]**			**Soybean[b]**		
	1986	2010	change	1990	2015	change
	— lbs P_2O_5/acre —			*— lbs P_2O_5/acre —*		
Wisconsin	51	25	-26	14	14	0
Michigan	55	31	-24	28	10	-17
Ohio	72	61	-11	14	15	+1
Iowa	48	42	-6	4	14	+10
Indiana	67	61	-5	11	18	+6
Illinois	67	65	-2	12	15	+4
Minnesota	45	45	0	4	11	+8
Kansas[c]	30	30	+1	4	13	+9
Nebraska	23	29	+6	5	23	+19
North Dakota[d]	36	44	+7	12	24	+12
Missouri	43	53	+10	8	24	+16
South Dakota	20	43	+23	8	25	+17

[a] USDA-NASS. Average quantities for 1986 and 2010 represent trendline values based on a linear regression of P applied per planted acre of corn from 1986-2010. Years selected based on data availability.

[b] USDA-NASS. Average quantities for 1990 and 2015 represent trendline values based on a linear regression of P applied per planted acre of soybean from 1990-2015. Years selected based on data availability.

[c] No data available prior to 1995 for P application to corn.

[d] No data available prior to 2000 for P application to corn.

Table 5. Trends in potassium fertilizer applied per planted acre of corn (1986-2010) and soybean (1990-2015).

State	**Corn[a]**			**Soybean[b]**		
	1986	2010	change	1990	2015	change
	— lbs K_2O/acre —			*— lbs K_2O/acre —*		
Wisconsin	71	42	-29	40	58	+17
Michigan	91	72	-20	61	47	-14
Ohio	97	80	-18	43	53	+10
Minnesota	57	47	-10	7	15	+7
Missouri	59	55	-4	13	37	+23
Nebraska	7	3	-3	1	5	+3
Illinois	90	89	-1	25	46	+21
Iowa	56	58	+1	6	26	+20
South Dakota	6	10	+4	1	7	+5
Kansas[c]	7	13	+6	3	5	+3
North Dakota[d]	8	17	+8	2	4	+2
Indiana	91	110	+19	34	52	+18

[a] USDA-NASS. Average quantities for 1986 and 2010 represent trendline values based on a linear regression of K applied per planted acre of corn from 1986-2010. Years selected based on data availability.

[b] USDA-NASS. Average quantities for 1990 and 2015 represent trendline values based on a linear regression of K applied per planted acre of soybean from 1990-2015. Years selected based on data availability.

[c] No data available prior to 1995 for K application to corn.

[d] No data available prior to 2000 for K application to corn.

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While corn and soybean yields have risen substantially over the last 30 years, phosphorus and potassium fertilizer applications have not necessarily kept pace. Fertilizer usage data from USDA-NASS show that average quantities of phosphorus and potassium applied per planted acre of corn have remained relatively flat or declined in some states over the past 30 years (Table 4 and 5). In some cases, these trends have been offset by increases in phosphorus and potassium applied to soybean acres. Most states have experienced an increase in phosphorus and potassium fertilizer applied to soybean over a similar time period.

The fact that corn and soybean yields have substantially increased over the past 30 years without substantial increases in phosphorus and potassium applications in some cases can be regarded as favorable, in that gains in productivity have been achieved without a corresponding increase in inputs. However, it raises the question of whether these higher yields have been achieved, in part, by mining soils of phosphorus and potassium and whether deficient soils could be limiting further gains in yield.

Comparison of results from the 2015 IPNI survey to those of a similar survey conducted in 2001 provides an indication of soil fertility trends over the past 15 years. These surveys show that the frequency of samples testing below the state critical level for phosphorus increased in Wisconsin, Illinois, Michigan, Ohio, and Indiana (Table 6).

Table 6. Phosphorus median test levels and percent of samples below critical levels in IPNI surveys conducted in 2001 and 2015.

State	Median Test Level*		Samples Below Critical Level		
	2001	2015	2001	2015	change
	—— *ppm* ——		—— *%* ——		
Wisconsin	41	27	24	48	24
Illinois	36	25	17	39	22
Michigan	50	37	17	36	19
Ohio	28	21	31	48	17
Indiana	33	24	15	31	16
Nebraska	21	21	32	35	3
Iowa	25	25	39	40	1
Kansas	20	21	50	47	-3
Missouri	17	20	61	54	-7
North Dakota	10	11	90	83	-7
Minnesota	16	21	60	47	-13
South Dakota	11	15	80	65	-15

* Median Bray and Kurtz P1 equivalent levels.

Conversely, survey results suggest an improvement in phosphorus fertility levels in Minnesota and South Dakota during this period. Changes were not as great for potassium, where only one state (Kansas) had an increase in samples below the critical level (Table 7). Illinois, Iowa, and Wisconsin all had a decrease in samples below the critical level. Several other states remained relatively unchanged.

These results are not indicative of an across-the-board drawing down of soil phosphorus and potassium levels in recent years. Fertility levels appear to have declined in some areas, improved in others, and stayed relatively constant in many cases. While it does not appear that the overall soil fertility picture has gotten significantly worse, these results do indicate a continuing opportunity to improve crop yields by remedying deficiencies where they exist, particularly as crop nutrient demands continue to go up with higher yielding hybrids and varieties.

Table 7. Potassium median test levels and percent of samples below critical levels in IPNI surveys conducted in 2001 and 2015.

State	Median Test Level*		Samples Below Critical Level		
	2001	2015	2001	2015	change
	—— *ppm* ——		—— *%* ——		
Kansas	331	208	10	19	9
South Dakota	279	241	17	20	3
Nebraska	373	306	7	9	2
North Dakota	275	247	14	16	2
Ohio	151	145	33	35	2
Michigan	129	129	63	63	0
Indiana	130	134	28	26	-2
Missouri	147	144	32	30	-2
Minnesota	159	165	51	47	-4
Illinois	150	164	47	37	-10
Wisconsin	111	141	80	65	-15
Iowa	153	189	59	39	-20

* Median ammonium acetate equivalent soil K levels.

DuPont Pioneer Soil Fertility Survey

In order to further evaluate current soil fertility levels and potential limiting effects on crop yields, DuPont Pioneer Agronomists and Encirca certified services agents conducted a large survey of soil fertility levels across the Midwestern U.S. in 2016. Fields included in the survey were either enrolled in the Encirca® Yield services or planted with an on-farm agronomy research trial in 2016 (Figure 1).

Survey Methods

Samples were collected in fall of 2015 and spring of 2016, with the majority of sampling taking place between March and June of 2016; therefore, the samples are generally reflective of soil phosphorus and potassium available for the 2016 crop. All sample fields were planted to corn in 2016. Samples consisted of six soil cores collected from the upper six inches of the soil profile using an 8-inch soil probe. In order to maintain consistency among samples, all soil samples were submitted to Waypoint Analytical labs in Atlantic, IA, and Champaign, IL, for analysis. Samples were analyzed for pH, phosphorus, potassium, sulfur, iron, manganese, zinc, copper, and boron; although this summary focuses specifically on phosphorus and potassium. Phosphorus and potassium test results were compared to IPNI critical levels for corn production for each state to determine the percent of samples in each state that fell below recommended levels.

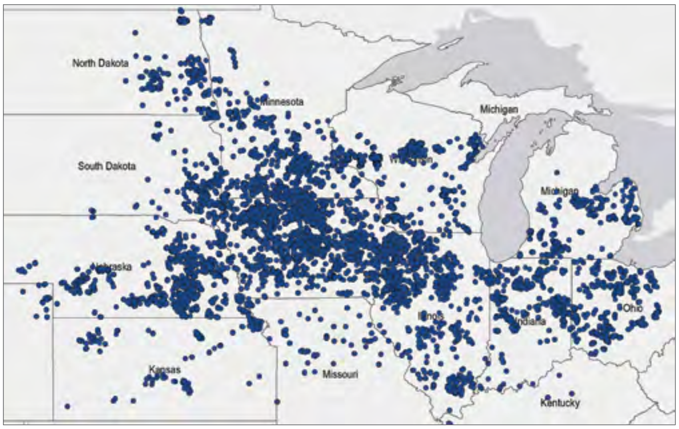

Figure 1. Locations of fields sampled as a part of the DuPont Pioneer soil fertility survey. A total of 22,402 samples were collected from 8,925 fields across 12 states.

Survey Results

Results of the DuPont Pioneer soil fertility survey showed that insufficient phosphorus and potassium levels were common throughout the Midwestern U.S., with very few instances in which the frequency of samples testing below critical levels within a state was less than 25%. Results for both phosphorus and potassium varied widely among states (Figure 2 and 3).

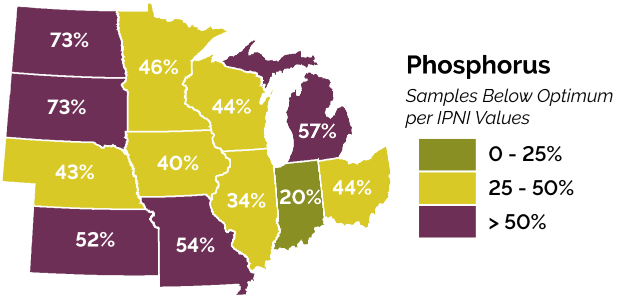

Figure 2. Percent of soil samples that were below critical levels for P in 2016 DuPont Pioneer sampling.

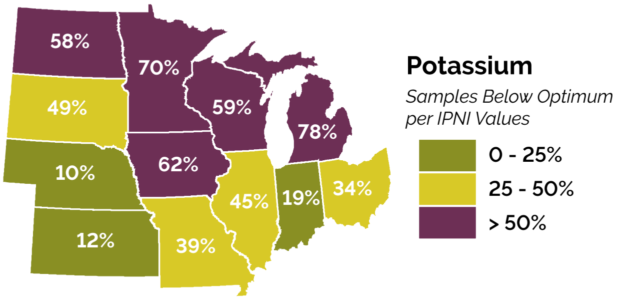

Figure 3. Percent of soil samples that were below critical levels for K in 2016 DuPont Pioneer sampling.

Survey results for phosphorus largely aligned with results from the 2015 IPNI survey. In both surveys, North Dakota and South Dakota had that highest frequency of sub-optimal soil phosphorus levels (above 60% for both states in both surveys), and Indiana had the lowest frequency of sub-optimal levels. Michigan had a higher frequency of samples below the critical level for phosphorus in the DuPont Pioneer survey (57%) than in the IPNI survey (36%), which could be a result of different sampling distribution.

Survey results for potassium showed Indiana, Nebraska, and Kansas with the lowest frequency of sub-optimal potassium levels (below 25%) and North Dakota, Minnesota, Iowa, Wisconsin, and Michigan all above 50%. For several states, results were very similar to those of the 2015 IPNI survey; however, North Dakota, South Dakota, Iowa, Minnesota, and Michigan all stood out as having much higher frequency of sub-optimal potassium levels in the DuPont Pioneer Survey than the IPNI survey. These discrepancies may be partly attributable to differences in sampling distributions within the states.

Yield Analysis

The soil samples collected in this study were intersected with 2016 corn yield maps by selecting a 50-ft radius of yield data around the soil sampling point and then calculating an average yield value for that area. A quadratic plateau function was fit to these data to look for trends in the response of corn yield to phosphorus and potassium soil test levels. The relationship between potassium and phosphorus and yield, respectively, shows similar yield response thresholds as those presented by Iowa State Extension (Mallarino et al., 2013) with no evidence of yield response beyond optimum phosphorus and potassium soil test levels (Figure 4).

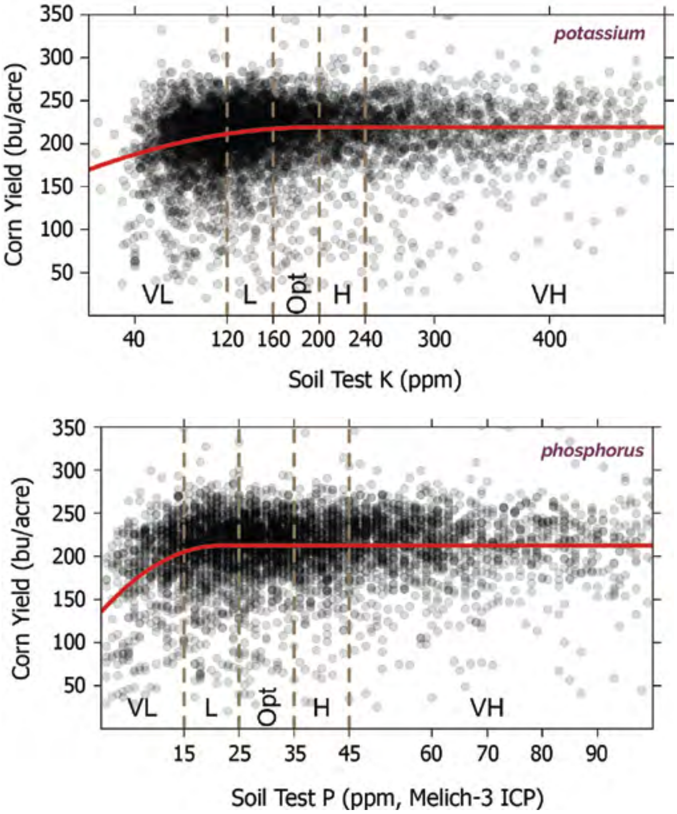

Figure 4. Corn yield relationship to soil test potassium (top) and phosphorus (bottom) in the 2016 DuPont Pioneer soil fertility survey compared to Iowa State soil fertility ranges (Mallarino et al., 2013).

Five Tips for Managing Soil Fertility:

1. Know your soil test levels.
2. Do not reduce nutrient application rates in low-testing soils, even if the fields are rented.
3. Do not apply buildup rates within two years that are higher than needed to optimize yield goals.
4. Do not fertilize in high-testing soils if budgets are tight.
5. Avoid practices that inhibit root development and nutrient uptake.

Thanks to Scott Murrell and Paul Fixen of the International Plant Nutrition Institute for their review and input on this manuscript.

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Molybdenum Fertility in Crop Production

by **Samantha Reicks,** *Agronomy Sciences Intern, and* **Mark Jeschke, Ph.D.,** *Agronomy Information Manager*

Function in Plants

42
Mo
Molybdenum
95.95

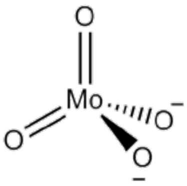
- Molybdenum is a micronutrient required in very small amounts for plant growth.
- Molybdenum is a component of the enzyme nitrogen reductase, which regulates the nitrogen reduction process in plants. This process involves the conversion of nitrate (NO_3) to the amino form ($-NH_2$) to build proteins.
- In legumes, such as alfalfa and soybean, molybdenum is also a component of nitrogenase, an enzyme needed for nitrogen fixation.

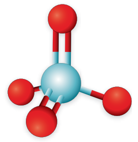
Crop Requirements

- Most crops require less than 1.0 ppm of molybdenum. Of the 17 essential nutrients, molybdenum and nickel are needed in the smallest quantities.
- Leguminous crops, such as alfalfa and soybean, require more molybdenum than grasses and other non-legumes.
- Molybdenum deficiency is very rare in corn.
- Molybdenum deficiency can occur in soybean in acidic as well as highly-weathered soils and can result in significant yield reductions.

Availability in Soil

- Molybdenum is taken up by plants in the anion form molybdate (MoO_4^{2-}).
- Molybdate is released by the weathering of soil minerals.
- Soils typically contain between 0.25 and 5.0 ppm total molybdenum.
- Molybdenum is the only plant micronutrient that becomes more available as pH increases (Figure 1). Solubility increases 100x for every point increase in pH.





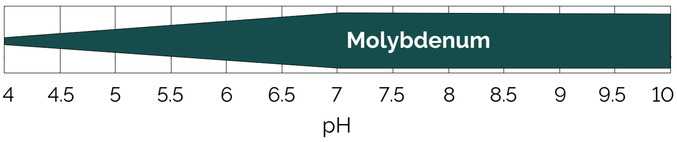


Figure 1. Relative availability of molybdenum by soil pH.

- Deficiencies rarely occur in soils with a pH greater than 6.2.
- High concentrations of sulfate in the soil can limit molybdenum availability, as sulfate (SO_4) and molybdate (MoO_4^{2-}) compete for root uptake sites.
- Addition of phosphate can promote plant uptake of molybdenum by causing molybdate adsorbed to soil solids to be released.

Deficiencies in Crops

Soybean showing nitrogen deficiency. Molybdenum deficiency will manifest as nitrogen deficiency.

- Since molybdenum is essential for nitrogen metabolism, a deficiency of molybdenum will manifest in plants as nitrogen deficiency with leaves that are light green or yellow.
- Leaves may yellow, cup, or roll, have scorching in leaf margins, and when older can become chlorotic
- Molybdenum is mobile in plants, so deficiency symptoms can appear over the entire plant, often appearing first on the oldest leaves.

Molybdenum Fertilization

- In most soils, liming to increase the soil pH can increase the concentration of available molybdate and eliminate deficiencies, making liming the best molybdenum fertility strategy in most cases.
- In soils where liming is not practical and molybdenum concentrations are low, molybdenum fertilizers can be applied.
  - » Sodium molybdate is the most common form of molybdenum fertilizer. It can be banded or broadcast on the soil, applied with a foliar treatment, or incorporated in a seed treatment (Table 1).
  - » Soluble molybdenum sources, ammonium molybdate and sodium molybdate, are suitable for foliar application and are typically applied at a rate of two to three oz/acre.
  - » Seed treatments that include molybdenum fertilizer are frequently used in areas with molybdenum deficiencies. A rate of 0.5 oz/acre is usually adequate.

Table 1. Fertilizer sources of molybdenum.

Source	Formula	Mo (%)	Solubility
Ammonium molybdate	$(NH_4)_6Mo_7O_{24}\cdot 2H_2O$	54	400 g/L
Molybdenum trioxide	MoO_3	66	3 g/L
Sodium molybdate	$Na_2MoO_4\cdot 2H_2O$	39	653 g/L

- Soybean yield responses to molybdenum fertilizer have been documented in soils with pH between 5.6 and 6.0 (Rasnake, 1982).
- At soil pH levels below 5.5, molybdenum fertilizers may not be effective.

Boron Fertility in Crop Production

by ***Samantha Reicks,*** *Agronomy Sciences Intern, and* ***Mark Jeschke, Ph.D.,*** *Agronomy Information Manager*

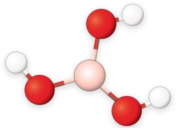
Function in Plants

5
B
Boron
10.81

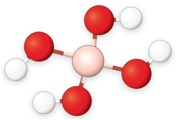
- The primary role of boron in plants is forming the structure of cell walls. Boron is also important in the transport of sugars, cell division, amino acid production, flower initiation, and pollen development.
- Boron plays a role in ensuring colonization of roots with mycorrhizal fungi. Mycorrhizal fungi assist plants in taking up important nutrients like phosphorus and zinc.
- A 200 bu/acre corn crop takes up 0.21 lbs/acre of boron. A 75 bu/acre soybean crop takes up 0.12 lbs/acre of boron.

Availability in Soil

- The plant available forms of boron, $B(OH)_3$ and $B(OH)_4^-$, are mobile in the soil solution.
- Availability of boron is greatest in moderately acidic soils that have a pH ranging from 5 to 7 (Figure 1).



$B(OH)_3$



$B(OH)_4^-$

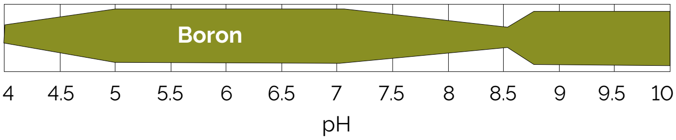


Figure 1. Relative availability of boron by soil pH.

- Soil organic matter is the primary source of boron for plant uptake. Weather conditions that favor organic matter decomposition (warm, ample moisture) will tend to increase boron availability
- Boron does not bond tightly with soil particles and is subject to leaching. Boron can become deficient in areas where the nutrient is readily leached and is not replenished through organic matter decomposition.

Boron Deficiency in Crops

- Boron is not mobile within plants, meaning that deficiencies will appear in the newest growth. It is possible to have excess boron in older leaves and a deficiency in newer leaves on the same plant.
- Plants with deficiencies can show symptoms of light general chlorosis and deformed leaves with areas of discoloration.
- Growing points of plants may be stunted or stop growing, and the plant will have fewer flowers and seeds.

Figure 2. Alfalfa is one of the crops most likely to benefit from boron applications.

- Boron deficiencies are most common in alfalfa and clover.
- In alfalfa, internodes shorten, resulting in nodes and leaves that are very close together, giving the plant a "rosette" effect.
- Boron deficiency in corn can manifest as narrow white streaks on leaves, shortened upper internodes, small abnormal ears, and small abnormal tassels with anthers that fail to produce pollen.
- Soil sampling can be used to identify boron deficiencies.
- Drought conditions tend to favor boron deficiencies by reducing release of boron from organic matter and plant uptake.

Boron Fertilizers

Forms of Boron

- In the major crop production areas of North America, the micronutrients most often supplied by fertilization include boron, zinc, manganese, and iron.
- Common forms of boron fertilizer are borax and boric acid.

Boron Application

- Granular forms of boron can be top dressed or broadcast. Boron can be easily mixed with other granular fertilizers to ensure even distribution.
- Boron should not be banded, as high concentrations near the seed can be toxic.
- Foliar applications of boron are possible, but boron is not mobile in the plant, meaning that the application will only be effective on the leaves it is applied to.
- Application rates typically range from 0.5 to 1.0 lbs/acre of boron for crops like corn, soybean, and cotton but can be as high as 3 lbs/acre for highly responsive crops, such as alfalfa or sunflower.
- Boron toxicity can result when applications exceed recommended rates.

Iron Fertility in Crop Production

*by **Samantha Reicks,** Agronomy Sciences Intern, and **Mark Jeschke, Ph.D.,** Agronomy Information Manager*

Function in Plants

- Iron (Fe) plays an important role in the production and movement of energy in the plant, involving the formation of chlorophyll, proteins, and enzymes needed during respiration.
- A 200 bu/acre corn crop takes up 2.5 lbs/acre of iron. A 75 bu/acre soybean crop takes up 1.7 lbs/acre of iron.

26
Fe
Iron
55.845

Availability in Soil

- Iron is abundant in most soils, but most of it exists in forms unavailable for plant uptake.
- Iron exists in the soil solution as ferrous (Fe^{2+}) and ferric ions (Fe^{3+}).
    - Soybeans are only able to take in Fe^{2+} and must excrete acids from their roots to convert Fe^{3+} in the soil to Fe^{2+}.
    - Corn is able to take in both forms of iron, and converts Fe^{3+} to Fe^{2+} inside of the plant.
- Soluble forms of iron are more abundant in acidic soils. At pH levels above 7.5, iron deficiencies are more common, particularly in poorly-drained calcareous soils.

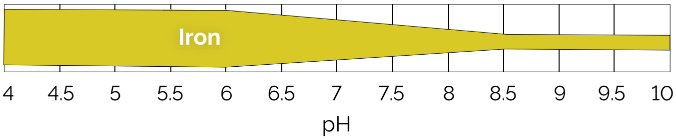


Figure 1. Relative availability of iron by soil pH.

Factors Associated With Iron Deficiency

High pH Soils

- Iron deficiency chlorosis (IDC) is a complex plant disorder associated with high pH soils and soils containing soluble salts where chemical conditions reduce the availability of iron.
- High pH soils above 8.0 contain much more Fe^{3+} than Fe^{2+}. Soybeans will begin showing a deficiency before corn, as soybeans will be unable to take up Fe^{3+}.
- Soils with calcium carbonate and bicarbonate neutralize acids and make it hard for plants to convert Fe into a usable form.

Soil Temperature and Moisture

- Wet soils trap carbon dioxide, which turns into bicarbonate and raises the pH of the soil.
- Compaction and low soil temperatures contribute to iron chlorosis.

Other Nutrients

- High levels of sodium and excess salts restrict the uptake of iron in corn.
- As nitrate is taken into a soybean plant, the plant must release a bicarbonate molecule. This raises the pH of the surrounding soil, which makes iron uptake difficult.

Figure 2. Green veins and light green/yellow tissue between veins indicates iron deficiency chlorosis in corn and soybeans.

Symptoms

- Iron deficiency symptoms are similar across plant species and appear as yellowing and stunting of younger leaves. Because iron does not translocate in the plant, new growth is most affected.
- Deficiency symptoms in soybeans can appear a few weeks after emergence as interveinal chlorosis on the first trifoliate leaves.
- Leaves may turn yellow with dark green veins, and the plant may be stunted. Under severe iron deficiency, leaf edges become necrotic (turn brown), and the necrosis may progress until entire leaves or even plants are dead.
- Corn leaves will have light green and yellow stripes between veins.
- The symptoms tend to show up in irregularly shaped spots randomly distributed across a field.
- Iron deficiency looks similar to manganese and magnesium deficiencies. Manganese deficiency is not particularly common in corn, and magnesium deficiency occurs on the oldest leaves of the plant rather than the newest.

Managing Iron Deficiency

- Inorganic iron sources added to soil are rapidly converted to insoluble forms and provide little crop benefit.
- Organic chelate fertilizers, such as Fe-EDDHA, can benefit plants but are often cost-prohibitive.
- Several management practices can be used to address iron deficiency chlorosis, including variety selection, delayed planting, and avoidance of herbicides that slow growth or cause leaf area loss.

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Zinc Fertility in Crop Production

*by **Samantha Reicks,** Agronomy Sciences Intern, and **Mark Jeschke, Ph.D.,** Agronomy Information Manager*

Function in Plants

- Zinc (Zn) is an element used by crops in small quantities (usually less than 0.5 lbs/acre).
- Zinc has several important functions in plants, including major roles in enzyme reactions, photosynthesis, DNA transcription, and auxin activity.

30
Zn
Zinc
65.38

Availability in Soil

- Most zinc in soils is held in unavailable forms, such as metallic oxides and other mineral complexes.
- Plant-available zinc exists as the cation Zn^{2+} in soil solution.
- Zinc concentration in soil is affected by the composition and weathering of the parent material, soil organic matter level, soil pH, and concentrations of other nutrients.
- Course-textured and highly-weathered soils generally have lower concentrations of available zinc. Newer soils that have not been weathered and soils that originate from igneous rocks are likely to contain greater amounts of zinc.
- Decomposition of soil organic matter can increase zinc availability by forming soluble organic zinc complexes. Soils with low organic matter or highly eroded topsoil generally have less available zinc.
- Muck or peat soils may also show deficiencies as strong natural chelation can make zinc unavailable.
- Zinc is most soluble and therefore, available to the plant at a pH of 5 to 7. Zinc is less soluble in alkaline soils due to increased adsorption to clay minerals.

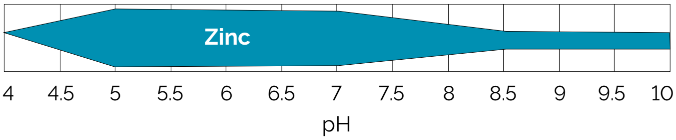

Figure 1. Relative availability of zinc by soil pH.

- Antagonism with other cations, such as iron (Fe^{2+}) and copper (Cu^{2+}), can inhibit plant uptake of zinc.
- High levels of phosphorus in a soil, often associated with excess manure application, can cause the appearance of zinc deficiencies in crops on marginally zinc-deficient soils.

Deficiencies in Crops

- Crops vary in frequency of zinc deficiencies and response to zinc fertilization.
    - Corn, sorghum, and rice are among the most responsive crops.
    - Deficiencies are less common in soybeans, cotton, and alfalfa.

Figure 2. Zinc deficiency in corn is characterized by interveinal striping in center of the leaf surrounded by green margins.

- Early zinc deficiency may be induced by cold, wet soil conditions that limit corn root growth and available zinc. In such cases, zinc deficiency may be exhibited on early leaves but not on later leaves.

Deficiency Symptoms

- Fields showing zinc deficiency are seldom affected uniformly. Zinc deficiency symptoms may also vary from field to field, depending primarily on the timing and severity of the deficiency.
- During the second or third week in the growing season, symptoms of zinc deficiencies may begin to show up. If the deficiency is severe, the symptoms may persist.
- In corn, pale and light green stripes will be present in the newer leaves on the half closer to the collar. Nodes will be spaced closer together than a healthy plant. Severe deficiencies can be identified by broader bands of pale tissue, wilting, and necrosis in the leaves.
- In soybeans, yellow to brown chlorosis will be visible on uppermost leaves. This is often mistaken for sunscald and iron deficiency. A tissue sample will validate the deficiency in the crop.

Figure 3. Corn leaf showing zinc deficiency symptoms.

Corn Following Sugarbeets Syndrome

- Corn planted following sugarbeets can exhibit zinc deficiency due to a reduction in the population of soil mycorrhizae, which aid in the absorption of phosphorous (P) and zinc into the roots.
- Even at high or very high soil test levels, starter fertilizer is recommended in this rotation scheme.
  - » When applying any form of zinc in direct contact with the seed, check with the supplier to ensure that the application will not be toxic to the seed and negatively impact germination.

Testing for Zinc

- Soil testing for zinc deficiency is among the most reliable of all micronutrients; this method is most often recommended to determine zinc sufficiency. Plant analysis may also be used.
- Soil test providers may have specific instructions for soil and plant sampling for zinc.
- Avoid using tools or containers that are galvanized or made of rubber when collecting samples, as these materials contain zinc.
- A sufficient amount of zinc is about 20 to 70 ppm in the plant tissue. A soil test of 0.8 to 1.0 ppm would imply that zinc is sufficient in the field.
- If a deficiency is found, recommendations are generally to apply 1 to 2 lbs actual zinc per acre as a banded application or 5 to 10 lbs as a broadcast application.

Figure 4. Corn leaf showing zinc deficiency symptoms.

Forms of Zinc

There are many fertilizer sources effective in correcting zinc deficiencies. These sources can be grouped as:

- Soluble inorganic products
  - » Zinc sulfate (35% Zn)
    - Dry material that can be broadcast or banded as a starter
    - Easily mixed with other dry fertilizers
  - » Zinc ammonium complex (10% Zn)
    - Liquid fertilizer
    - Will blend with other fertilizers
- Insoluble inorganic products
  - » Zinc oxide (78 to 80% Zn)
    - Ground into dust as the granular form; only somewhat soluble
    - May be applied as a suspension
  - » Zinc carbonate (52% Zn)
- Zinc oxysulfate (20 to 25% Zn, 10 to 70% water solubility)
- Organic chelates (12% Zn): ZnEDTA and ZnHEDTA
- Organic non-chelates (natural organic complexes)

Table 1. Common zinc fertilzer sources.

Zinc Fertilizer	% Zinc	Comments
Zinc sulfate ($ZnSO_4$)	~ 35%	Most common zinc fertilizer. Water soluble. May be banded, broadcast, and foliar-applied
Zinc-ammonia complex	10%	May be included with liquid starters like 10-34-0
Zinc oxide (ZnO)	70-80%	Low solubility. Must be finely ground to be effective
Zinc oxysulfates	Variable	ZnO partially acidulated with sulfuric acid to increase solubility
Synthetic zinc chelates (e.g., ZnEDTA)	9-14%	Up to five times more effective than soluble inorganic sources on a zinc content basis
Organic residues	Variable	Manure and other organic residues are very good sources of zinc

Applying Zinc

Application Methods

- Banding zinc fertilizer two inches to the side and two inches below the seed allows immediate uptake of the nutrient and is placed far enough away from the seedling to prevent damage.
- Broadcasting and incorporating zinc before planting can supply nutrients for the growing season. This method is also desirable if the farmer would like to apply enough zinc for several years.
- Foliar applications are usually reserved for unexpected deficiencies. This method is uncommon due to inconsistent application results.

Responses to Applications

- Responses to zinc application will be the greatest in corn, slightly in soybeans, and minimal in alfalfa, wheat, oats, and other grasses.
- Fallow syndrome from not growing crops the previous year will increase the crop's response to fertilizer application. The mycorrhizal fungi will not be able to assist in breaking down zinc from the soil and making it available to plants. Applied fertilizer will be available to the plant.

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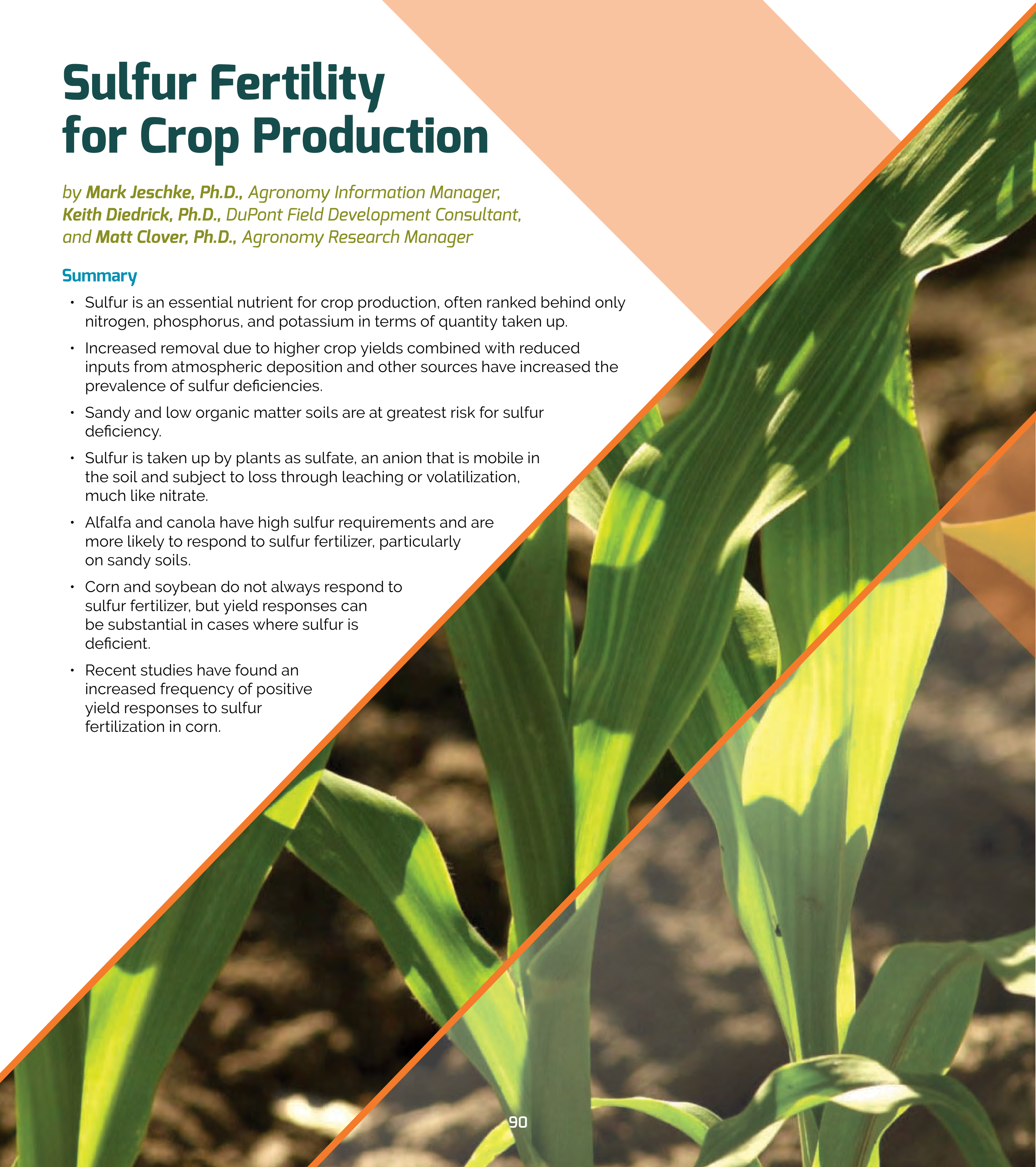
Sulfur Fertility for Crop Production

by **Mark Jeschke, Ph.D.,** *Agronomy Information Manager,*
Keith Diedrick, Ph.D., *DuPont Field Development Consultant,*
and **Matt Clover, Ph.D.,** *Agronomy Research Manager*

Summary

- Sulfur is an essential nutrient for crop production, often ranked behind only nitrogen, phosphorus, and potassium in terms of quantity taken up.
- Increased removal due to higher crop yields combined with reduced inputs from atmospheric deposition and other sources have increased the prevalence of sulfur deficiencies.
- Sandy and low organic matter soils are at greatest risk for sulfur deficiency.
- Sulfur is taken up by plants as sulfate, an anion that is mobile in the soil and subject to loss through leaching or volatilization, much like nitrate.
- Alfalfa and canola have high sulfur requirements and are more likely to respond to sulfur fertilizer, particularly on sandy soils.
- Corn and soybean do not always respond to sulfur fertilizer, but yield responses can be substantial in cases where sulfur is deficient.
- Recent studies have found an increased frequency of positive yield responses to sulfur fertilization in corn.



Introduction

Sulfur is 1 of the 17 elements essential to crop production. It is typically considered a secondary macronutrient (along with calcium and magnesium) but is essential for maximum crop yield and quality. Sulfur is often ranked immediately behind nitrogen, phosphorus, and potassium in terms of quantity taken up. Sulfur is a component of the amino acids cysteine and methionine, making it essential for protein synthesis in plants. Plants contain a large variety of other organic sulfur compounds, such as glutathione, sulfolipids, and secondary sulfur compounds, which play an important role in physiology and protection against environmental stress and pests.

Sulfur fertility has historically not been a major concern for growers on most soils, as soil organic matter, atmospheric deposition, manure application, and incidental sulfur contained in fertilizers have typically supplied sufficient sulfur for crop production. However, reductions in the amount of sulfur contributed by these factors combined with increased sulfur removal with greater crop yields have made sulfur deficiencies more common.

Essential Elements for Crop Production

Supplied by Air and Water: carbon, hydrogen, oxygen

Primary Macronutrients: nitrogen, phosphorus, potassium

Secondary Macronutrients: sulfur, calcium, magnesium

Micronutrients: boron, chlorine, copper, iron, mangnese, molybdenum, zinc, nickel

Sources of Sulfur

Organic Matter

Sulfur can exist in soils in a number of organic and inorganic forms. In well-drained agricultural soils, organic sulfur typically accounts for over 95% of the total sulfur, although this ratio can vary greatly with soil type. Organic sulfur is converted to inorganic sulfate through mineralization, making it available for plant uptake. Mineralization is the primary source of plant-available sulfur in non-fertilized soils. Soil organic matter content greatly affects the amount of sulfur available to the crop through mineralization. One percent organic matter will supply about 2 to 3 lbs of available sulfur annually.

The microbial processes responsible for sulfur mineralization are highly dependent upon soil conditions. Warm, moist soils are much more favorable for soil microbial activity than cold or saturated soils. Earlier planting into colder soils may reduce the availability of sulfur during early growth stages. This may result in sulfur deficiency symptoms early in the growing season that will eventually disappear as sulfur becomes more available due to increased microbial activity as soils warm up.

Like nitrate, sulfate is an anion, making it mobile in the soil and subject to loss through leaching. Frequent rainfall events can move sulfate downward in the soil profile making it inaccessible to plants, particularly young plants with small and shallow root systems. In saturated soils, sulfate can be reduced to hydrogen sulfide and lost to the atmosphere.

Figure 1. Yellowing between leaf veins is a symptom of sulfur deficiency in corn.

Soil Minerals

Inorganic sulfur contained in soil minerals is typically much less abundant than organic sulfur in most agricultural soils. However, reduced inorganic forms, such as sulfides, can be an important source of sulfur in soils where they are contained in the parent material. Reduced sulfur compounds must be oxidized to sulfate by soil microorganisms or chemical processes in order to be available for crop uptake.

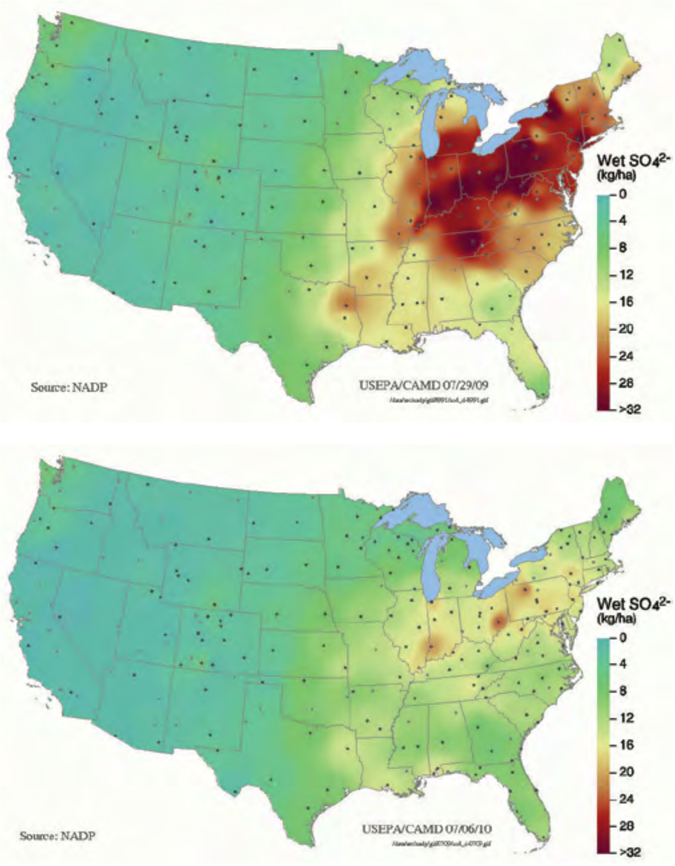


Figure 2. Average annual sulfate deposition from precipitation, 1989-1991 (top) compared to 2007-2009 (above). (Source: National Atmospheric Deposition Program.)

Atmospheric Deposition

Industrial pollution, despite its myriad negative effects, has provided a benefit to agricultural production in some areas as a source of sulfur. Sulfur is emitted into the atmosphere primarily through burning of fossil fuels. These emissions can travel long distances in the atmosphere and are eventually deposited as sulfur dioxide or as sulfates, often in precipitation. Air pollution control efforts have greatly reduced the amount of sulfur emissions and, consequently, the amount of sulfur deposition from the atmosphere. This change has been greatest in eastern regions of the U.S. (Figure 2) and Canada (Figure 3), where deposition from industrial emissions formerly contributed large amounts of sulfur to the soil. Little change has occurred in western states and provinces where atmospheric deposition was never a substantial source of sulfur in the first place.

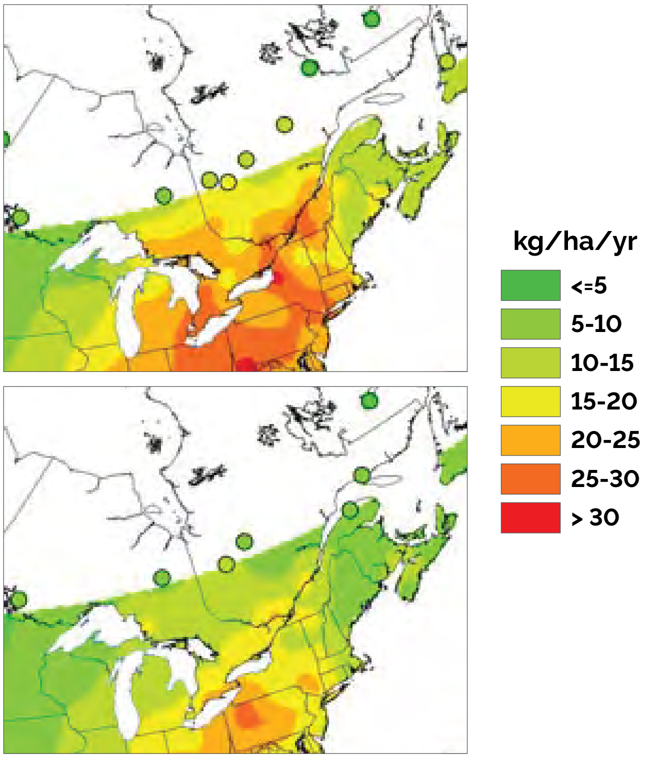


Figure 3. Average annual sulfate deposition from precipitation in eastern Canada, 1990-1994 (top) compared to 2000-2004 (above). (Source: 2006-2007 Progress Report on The Canada-Wide Acid Rain Strategy for Post-2000.)

Manure

Manure application can be an important source of sulfur for soils. Most livestock manure contains approximately 0.25% to 0.30% sulfur. Sulfur content is greater, however, in sheep manure (0.35%) and poultry manure (0.50%). Reductions in the number of livestock operations have eliminated manure as a source of sulfur in many areas.

Irrigation Water

Irrigation water can be an important source of sulfur for crop production, in some cases providing enough sulfur to meet crop requirements. However, water sources can vary widely in sulfate content. Growers should test their water supply to accurately determine sulfur concentration.

Table 1. Sulfur (S) content of several common sulfur fertilizers (Dick et al., 2008).

Fertilizer	N-P-K	S
	-------- % --------	
Elemental sulfur	0-0-0	88-98
Ammonium thiosulfate	12-0-0	26
Ammonium sulfate	21-0-0	24
Potassium-magnesium sulfate	0-0-18.2	22
Calcium sulfate (gypsum)	0-0-0	18
Potassium sulfate	0-0-41.5	18
Magnesium sulfate	0-0-0	14
Ordinary superphosphate	0-20-0	11-12
Co-granulated monoammonium phosphate + sulfur	12-40-0	6.5-10

Fertilizers

The increasing use of high analysis fertilizers has decreased the amount of incidental sulfur applied to crops. Some older fertilizers contained a substantial amount of sulfur as a byproduct of the production process. An example is ordinary superphosphate (0-20-0), which contains 11 to 12% sulfur in addition to phosphorus, whereas newer triple superphosate (0-46-0) contains less than 3% sulfur.

The sulfur contents of several common fertilizers are listed in Table 1. Sulfate-containing fertilizers provide sulfur in a form that is readily available for plant uptake and can be used to quickly correct a sulfur deficiency. Elemental sulfur must be oxidized in the soil before it can be taken up by plants, which increases the amount of time needed for it to be available, but provides sulfur in a slow-release form that is less susceptible to leaching losses than sulfate fertilizers.

The rate of elemental sulfur oxidation is influenced by fertilizer type and environmental factors. Particle size and sulfur percentage of the fertilizer granule influence the rate of oxidation. Typically, the smaller the particle size and the lower the sulfur content of the fertilizer, the faster that sulfur source will oxidize. Since oxidation is a biological process, soil temperature, moisture, pH, and organic matter percentage also influence the rate of oxidation. Oxidation rates are fastest in warm, moist, alkaline soils with higher organic matter levels.

Some fertilizers have the potential to lower soil pH, especially sulfur and phosphorus combined with the ammonium-based nitrogen fertilizers like ammonium sulfate, monoammonium phosphate (MAP), and diammonium phosphate (DAP). The oxidation process of sulfur releases acidity, as does the nitrification of ammonium (conversion of ammonium to nitrate in the soil by bacteria). Monitoring pH with soil testing is recommended to determine lime needs if sulfur and ammonium-containing fertilizers are used often.

Table 2 shows calcium carbonate ($CaCO_3$) equivalents necessary to neutralize one pound of sulfur or ammonium fertilizer. Soil buffering capacity and the uptake of anions and cations by plants can reduce these equivalents, but growers should be aware of the potential effects of fertilizers on soil pH.

Table 2. Calcium carbonate ($CaCO_3$) equivalents necessary to neutralize 1 lb of sulfur (S) or ammonium fertilizer (N).

Fertilizer Source	$CaCO_3$ Equivalent per Pound of N or S (lbs)
Elemental sulfur	3.2
Ammonium sulfate	7.2
Ammonium thiosulfate	4.8
Monoammonium phosphate	7.2
Diamonnium phosphate	5.4
Anhydrous ammonia	3.6
Ammonium nitrate	3.6
Urea	3.6
Microessentials Fertilizer Products	**$CaCO_3$ Equivalent per Pound of Product (lbs)**
MES10 (12-40-0-10)	1.01
MES15 (12-33-0-15)	1.16
MES9 (10-46-0-9)	0.93

Adapted from Adams, 1984 and McLaughlin, 2013.

Determining if Sulfur is Deficient

Plants deficient in sulfur will exhibit visual symptoms. Sulfur deficiency in corn can result in a general yellowing of the plant, similar to nitrogen deficiency; or as interveinal chlorosis, similar to magnesium or zinc deficiency. Sulfur is not easily translocated in plants, so symptoms will appear first and be most pronounced on the younger, upper leaves. Deficiencies of mobile nutrients, such as nitrogen, will appear first on the lower leaves as nutrients are remobilized to growing plant tissues.

Sulfur deficiency symptoms follow a similar pattern in other crops, such as soybean, wheat, and alfalfa, with yellowing of the plant beginning with the youngest tissue. In canola, early season deficiency symptoms include yellowing between leaf veins, cupped leaves, and stunting. Late season symptoms are slender, cupped leaves that may be purple along the edges, delayed flowering, and pale yellow or white flowers.

Historically, sulfur deficiencies were thought to be a concern strictly on sandy soils, but in recent years, deficiencies have become more prevalent across a variety of soil types. Sulfur deficiencies may appear on hilltops or slopes where soils are eroded and low in organic matter. Deficiencies are more common on sandy or other low organic soils because of their reduced ability to supply sulfur and losses due to leaching.

Sulfur deficiency symptoms are typically not uniform across the field, more often appearing in spots or streaks. Symptoms may appear in places where soils are colder or wetter, such as low spots or high residue areas. This is because the rate of sulfur mineralization and the supply of available sulfate are reduced in those areas.

Because of the similarities between sulfur deficiency symptoms and other nutrient deficiency symptoms, a plant tissue analysis may be necessary to determine if observed symptoms are indeed due to a lack of sulfur. A soil test is available for sulfur; however, soil testing procedures for nutrients contained in organic matter are not highly reliable in making fertility decisions. For this reason, soil testing for sulfur is only recommended on sandy soils. Soil tests should include a topsoil sample as well as a subsoil sample to a depth of at least two feet.

Sulfur as Part of a Fertility Program

Yield response to sulfur fertilizer varies greatly across crops, soil types, and geographic regions; therefore, growers should check university recommendations to get the best information for their specific area and cropping system. Historically, regular application of sulfur has not been recommended unless it is determined that the soil supply is insufficient to meet crop needs. Though sulfur deficiencies have increased in recent years, it is still advisable to determine if there is a need for additional sulfur before making it part of a fertility program.

Alfalfa and canola have relatively high sulfur requirements (Table 3) and are more likely to need supplemental sulfur, particularly when grown on sandy soils. Historically, corn and soybean on fine-textured soils have rarely responded to sulfur fertilization. A two-year Iowa State University study found no yield response in corn or soybean to sulfur application at six sites in Iowa (Sawyer and Barker, 2002). However, more recent Iowa State studies have found much more frequent yield benefits in corn with a positive yield response to sulfur fertilization at 17 of 20 sites in 2007, 11 of 25 sites in 2008, and 6 of 11 sites in 2009 (Sawyer et al., 2009, 2010). Among responsive sites in 2007 and 2008, the average yield increase with sulfur fertilization was 15 bu/acre on fine-textured soils and 28 bu/acre on coarse-textured soils. A University of Illinois study in 2009 found yield responses in corn ranging from 0 to 50 bu/acre (Fernandez, 2010). These results demonstrate the need to consider local soil characteristics in determining a sulfur fertility plan but also show that yield response can be substantial in cases where sulfur is deficient.

Table 3. Sulfur (S) requirements of selected crops.

Crop	Yield		S (lbs/acre)
Alfalfa	10 tons/acre		54
Canola	60 bu/acre		20
Corn	200 bu/acre	grain	16
		stalks	14
Soybeans	70 bu/acre	grain	13
		stover	12
Wheat	80 bu/acre	grain	8
		straw	11

Source: The Mosaic Company, http://www.microessentials.com/MicroEssentials_Nutrient_Utilization_01optimized.pdf

European Corn Borer After 20 Years of Bt Corn

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

Summary

- European corn borer was once one of the most destructive pests of corn in North America; however, its impact has declined with the widespread adoption of Bt corn.
- Despite the reduced importance of European corn borer as a pest in corn, populations are still present, and outbreaks can still occur and cause significant yield losses in unprotected corn.
- European corn borer can produce one generation per year (univoltine) or multiple generations (bivoltine or poly-voltine) depending on growing season length.
- The major damage caused by European corn borer is due to tunneling in stalks, ear shanks, and ears. Tunneling disrupts water as well as nutrient transport in the plant and increases risk of stalk lodging and ear drop.
- Population levels of European corn borer can vary greatly from year to year, and outbreaks are difficult to predict.
- Scouting to determine infestation levels and timing of larvae activity is necessary for effective management of European corn borer in non-Bt corn.
- Insecticides can be an effective tool for managing European corn borer; however, proper timing of applications is critical.

Introduction

European corn borer *(Ostrinia nubilalis)* is an insect pest of corn native to Europe and western Asia. Its first documented occurrence in North America was near Boston, Massachusetts, in 1917 where it is believed to have entered the continent via broom corn imported from Italy and Hungary. Populations spread west across the U.S. and north into Canada. By the 1920s, European corn borer had become an important pest of corn in the Midwestern U.S., and today it can be found throughout corn production areas east of the Rocky Mountains.

Figure 1. A late-stage European corn borer larva.

Pest Status

For many years, European corn borer was one of the most destructive and economically important pests of corn in North America, with total crop losses averaging over $1 billion per year (Mason et al., 1996). However, its importance as a pest has declined with the widespread adoption of Bt corn over the past 20 years. Following initial introduction in 1996, Bt corn adoption has gradually increased and now accounts for nearly 80% of corn acres planted in the U.S. (Figure 2). Nearly all Bt corn in the U.S. includes one or more traits for European corn borer protection.

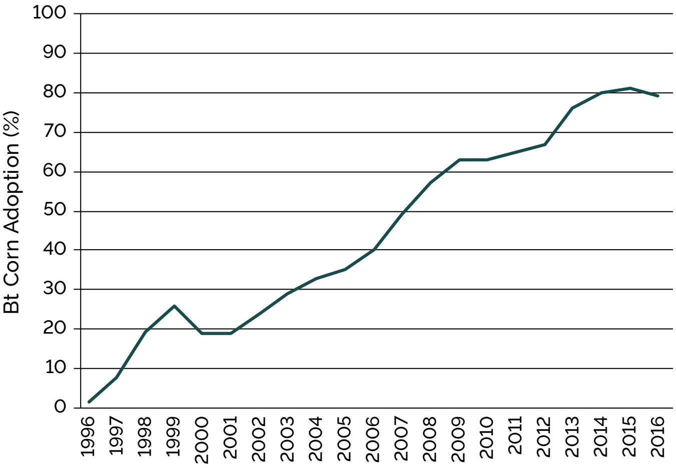


Figure 2. Adoption of Bt corn in the United States, 1996-2016 (USDA-ERS, 2017).

The reduced importance of European corn borer as a pest in corn has been a result of both the high proportion of corn acres protected by Bt traits and the reduction of overall population levels that this has caused. The potential for widespread planting of Bt corn to suppress population levels of European corn borer was initially unclear, particularly due to its relatively wide host range. In addition to corn, European corn borer has over 200 other host plants, including several crop and weed species. However, research has shown suppression of European corn borer population levels associated with Bt corn use in several Midwestern states (Hutchison et al., 2010). The greatest beneficiaries of the lower European corn borer population levels have been growers planting non-Bt corn since they have realized a lower risk of yield loss due to crop damage without incurring the additional cost of planting Bt corn.

Figure 3. Side-by-side comparison of European corn borer damage in non-Bt (left) and Bt corn (right) in Nebraska.

Bt hybrids have continued to provide effective protection against European corn borer damage, and the overall threat to corn yield posed by European corn borer is generally lower now than it was prior to the introduction of Bt corn. However, populations are still present, and outbreaks can still occur and cause significant yield losses in unprotected corn. A DuPont Pioneer research location in eastern Iowa in 2016, included a block planted with corn hybrids lacking European corn borer protection. This site experienced high European corn borer pressure in 2016 resulting in extensive damage to the non-Bt corn. Yield in these plots was reduced by around 60 bu/acre relative to the rest of the site, which was planted with Bt hybrids (Figure 4).

This site provided a clear demonstration that European corn borer is still capable of causing large yield losses in non-protected corn. Given the location of this trial in eastern Iowa, a high percentage of the corn in the surrounding area would likely have had Bt protection for European corn borer, indicating that significant damage is still possible even in areas with high Bt corn adoption. In areas where Bt adoption is lower or has declined, the risk of damage and yield loss could be greater. Several recent anecdotal reports from agronomists have noted localized increases in European corn borer populations in areas where growers have switched away from Bt corn to reduce costs (Begemann, 2017; Potter and Ostlie, 2017; Unglesbee, 2016).

The potential for European corn borer to cause economic damage in corn will likely never be eliminated. The ability of populations to subsist on a wide range of host species other than corn has allowed, and will continue to allow, populations to persist in corn-producing areas, albeit at lower levels than during the pre-Bt corn era. It is therefore important to maintain familiarity with European corn borer life cycle, identification, crop damage, and management options, particularly for growers planting non-Bt corn.

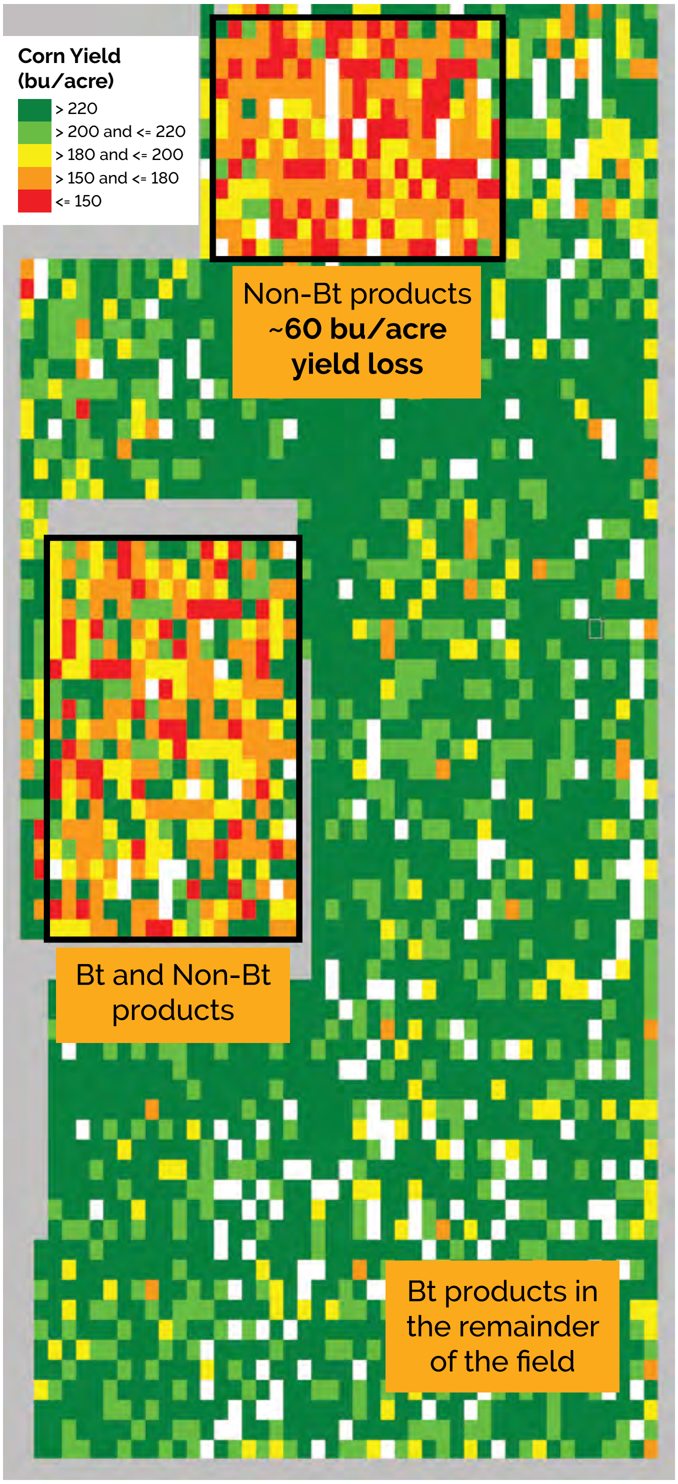


Figure 4. Plot yield map of a DuPont Pioneer research location in eastern Iowa in 2016. Yield was reduced by approximately 60 bu/acre on average in plots lacking European corn borer protection. Each rectangle represents a 5-ft x 17.5-ft plot (1.5 m x 5.3 m).

Life Cycle

Number of Generations

European corn borer can produce one generation per year (univoltine) or multiple generations (bivoltine or poly-voltine) depending on the length of the growing season (Figure 5). Following its initial introduction in North America, European corn borer populations produced only one generation per year. A two-generation per year population emerged in the Eastern and North-Central U.S. in the 1930s and spread rapidly through the Central and Western Corn Belt in the 1940s. This two-generation life cycle predominates in most of the Corn Belt today. The vast majority of corn acres in North America lie within the region affected by two generations of European corn borer annually. Univoltine populations are most common in the Northern U.S. and southern Canada. In the Southern U.S., the longer growing season allows three and, in the far south, four generations each year.

Northern regions of the Corn Belt may be affected by both univoltine and bivoltine populations. The proportion of univoltine and bivoltine individuals in a population can vary from season to season based on growing conditions. A longer growing season with a warm spring and extended fall season will likely result in a higher proportion of bivoltine individuals the following season. Conversely, a shorter growing season with a cool spring and early fall will tend to result in more univoltine corn borers the following season.

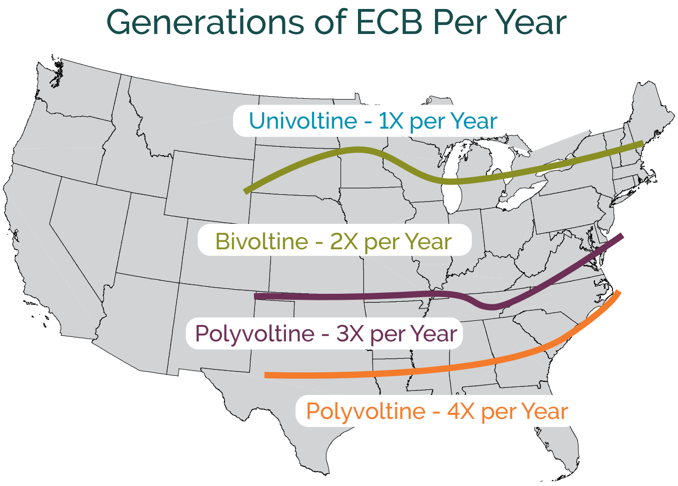


Figure 5. Approximate geographic range of univoltine, bivoltine, and polyvoltine populations of European corn borer ECB in the U.S.

European corn borers overwinter in corn stalk residue as full-grown larvae in suspended development (diapause). When temperatures reach 50 °F (10 °C) in the spring, development resumes. Larvae pupate and emerge as adult moths, usually in late May or early June in the Central Corn Belt. The pupal stage of the corn borer is rarely observed as the pupae remain inside the cornstalk. The pupae are smooth, typically dark brown in color, and ⅓ to ⅝ of an inch in length. Adults fly to grassy areas to mate and then to selected corn fields to lay their eggs. These first-generation moths target the tallest corn fields for egg deposition.

European corn borer eggs are laid in an overlapping cluster, resembling fish scales, usually on the underside of leaves. Eggs are white when first laid. Each egg is about half the size of a pin head. After three to five days, the eggs change from white to a yellowish color. The appearance of a black spot in each egg indicates that the larvae are nearing hatch (Figure 6). Hatch typically occurs 7 to 10 days after eggs are laid but is temperature-dependent, so timing can vary due to weather conditions.

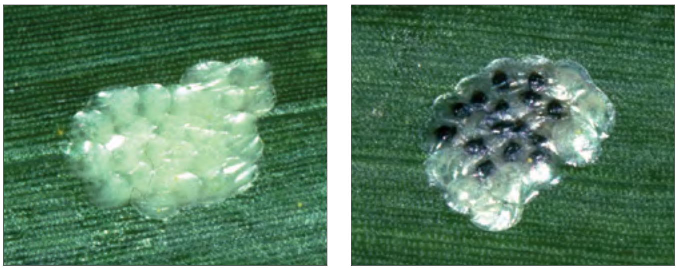


Figure 6. European corn borer eggs are laid in an overlapping cluster, resembling fish scales. Eggs are white when first laid (left). As the European corn borer larvae grow within the eggs, the presence of their black heads indicates that the larvae are nearing hatch (right).

Figure 7. During the larval stage, there are five developmental stages called *instars*. The first two feed on leaf tissue, the third will bore into the stalk, and the fourth and fifth feed only on the stalk

First Generation

Newly-hatched larvae will migrate toward the whorl to feed. First instar larvae will feed on young, developing leaf tissue without eating all the way through the leaf, resulting in injury patterns referred to as “window paning” (Figure 8).

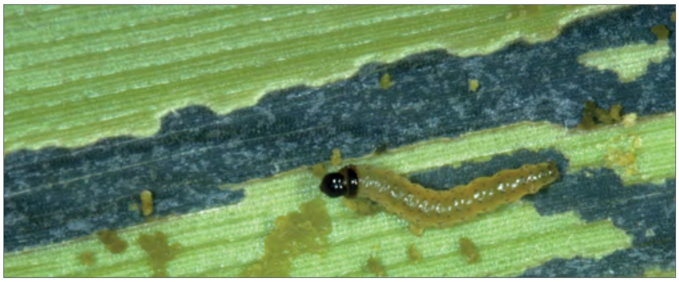


Figure 8. Larvae will feed on young, developing leaf tissue without eating all the way through the leaf. The black head and lack of distinctive spots or stripes helps distinguish European corn borer from other corn caterpillars.

As larvae develop, their feeding will penetrate completely through the leaf, leaving a random “shot hole” feeding pattern (Figure 9). These holes become visible as the leaves grow out of the whorl. Leaves that are fed upon while still in the whorl will often emerge with multiple holes in a transverse pattern across the leaf.

Figure 9. “Shot hole” feeding pattern caused by European corn borer in South Dakota.

Third instar larvae will begin feeding in the whorl before boring into the stalk. Larvae will go through the fourth and fifth instars inside the stalk, completing their growth about three weeks after hatching. Fifth instar larvae are around one inch in length. Upon reaching the fifth instar, univoltine larvae will enter diapause (developmental inactivity). Bivoltine larvae will pupate inside the stalk during July and early August (Figure 10).

Figure 10. European corn borer larvae transform into the pupal stage inside the cornstalk. Pupae are dark brown, and the outline of the head, wings, and abdomen can be seen.

Second Generation

Second generation adult emergence and egg laying begins during late July and continues through the end of August. Eggs of the second generation usually hatch in five to seven days depending on weather conditions. Newly-hatched second generation larvae generally feed on the leaf axil, closer to the stalk, rather than the blade of the leaf. The larvae also feed on pollen that has collected in the leaf axil. Second generation larvae do not begin feeding on the stalk of the corn plant until the fourth instar, due to the hardness of the maturing stalks. Second generation larvae feed on the tassel and ear shanks, which can result in ear drop. In the fall, fifth instar larvae will enter diapause and overwinter inside the stalks.

Population Levels and Outbreaks

One constant in European corn borer history is the difficulty of predicting outbreaks. This is because infestation levels in one year have much less impact on the following year’s numbers than do conditions during moth flights, mating, egg laying, and hatch. When inclement weather accompanies these European corn borer activities, larval survival may be greatly reduced. Under optimal conditions, each female moth can produce over 400 eggs and spread them over many plants and fields, allowing European corn borer populations to swell rapidly.

Historically, European corn borer has exhibited a tendency for population cycling in which population levels spike every six to eight years. This pattern has been attributed to *Nosema pyrausta*, a pathogen that infects European corn borer and has the effect of regulating populations (Lewis et al., 2009). This pattern of population cycling has persisted to some extent during the era of Bt corn, although at generally lower population levels (Hutchison et al., 2010).

Identification

European corn borer larvae can be distinguished from other corn caterpillars by their dark brown or black head and lack of distinctive spots or stripes. Early instar larvae are dull white. Mature larvae are about ¾ to 1 inch (19 to 25 mm) long, are dull white to grayish in color, and have small brown halo-shaped spots running the length of the body. Their skin is smooth and free of hairs, and they have 4 prolegs on their 3rd, 4th, 5th, 6th and 10th abdominal segments. Female moths are pale yellow-brown and typically around 1 inch (25 mm) in length. Male moths are smaller with darker bands than the female. Both have front wings with jagged bands or lines across the wings (Figure 11).

European Corn Borer

- Young larvae are dull white; older larvae have darker halo-shaped spots.
- Dark brown or black head

Western Bean Cutworm

- Head is solid orange.
- Two dark brown stripes behind the head

Corn Earworm

- Larval color is highly variable.
- Alternating dark and light stripes running the length of the body

Sod Webworm

- Usually found in leaves
- Accompanied by slight webbing

Southwestern Corn Borer

- Southern areas of U.S. only
- Dark spots on white body or pure white in late fall

Lesser Corn Stalk Borer

- Purple bands
- Found sporadically, rarely a significant pest of corn

Damage and Impact on Corn Yield

The major damage caused by European corn borer is due to tunneling in stalks, ear shanks, and ears. Tunneling disrupts water as well as nutrient transport in the plant and increases risk of stalk lodging and ear drop. In addition, damage may allow higher levels of stalk rots and ear molds. The magnitude of the yield reduction due to corn borer tunneling depends primarily on the growth stage of the corn plant when attacked, the growing environment, and hybrid tolerance or resistance. Larval feeding during mid- to late vegetative (V6-V16) and early reproductive stages (VT-R3) can reduce yield more than larval feeding in later reproductive stages. Environmental stresses, such as drought or disease, affect borer-damaged plants more than undamaged ones.

Figure 11. European corn borer adult male (left) and female (right).

To help determine yield loss levels due to European corn borer, DuPont Pioneer researchers tested hybrids with Bt insect protection for European corn borer vs. their non-Bt counterparts in replicated research trials. These studies were conducted in 119 locations over 6 years. Plots were evaluated for corn borer damage by examining 10 consecutive plants in each plot.

Stalks were split on these 10 plants, and the number and total length of tunnels were recorded. Plots were harvested for yield, moisture, and test weight measurements. Results showed that hybrids with Bt insect protection for European corn borer had an average yield advantage of approximately 7% for every corn borer cavity per plant (Figure 12). This relationship was demonstrated at low as well as high infestation levels.

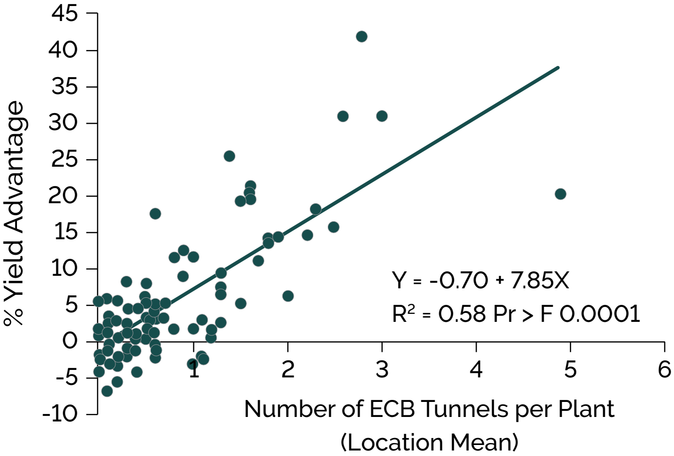


Figure 12. Relationship of European corn borer (ECB) tunnels/plant to the yield advantage of Pioneer® brand corn products with a Bt trait for European corn borer protection over hybrids without insect protection, 119 environments, 6 years.

Scouting and Management in Non-Bt Corn

Scouting to determine infestation levels and timing of larvae activity is critical for effective management of European corn borer in non-Bt corn. With normal temperatures, the ideal "window" of treatment will only be about four to six days and, once larvae are in the stalk, insecticide treatments will be ineffective.

First Generation

Corn borer moths mate in grassy areas and fly into corn fields to lay their eggs. Female moths in flight are attracted to the tallest corn in an area, so earlier-planted fields are at greater risk for infestations of first-generation larvae. Trapping of European corn borer moths during mating activity can be a helpful tool to guide field scouting. Black light and pheromone traps can both be used to monitor moth activity. However, moth trapping is not predictive of infestation levels or crop damage. It can help guide scouting efforts but cannot serve as a substitute for scouting.

Corn of less than 18 inches extended leaf height is safe from corn borer feeding, because of DIMBOA (2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one), a naturally occurring antibiotic present in corn, wheat, and other grass species. The concentration of DIMBOA is greatest in seedlings and decreases as the plant ages. As corn grows above 18 inches, the natural resistance of the plant is diminished, and feeding damage can occur. Begin scouting fields for signs of shot holes in the leaves about 200 heat units after corn reaches 18 inches in extended leaf height.

Good random samples taken throughout the field are needed to accurately estimate European corn borer populations. Moths and egg laying may be concentrated along field edges, grass waterways, or access roads, so sampling along these edges will not provide an accurate estimate of the field population. Female moths are selective about where in the field they deposit their eggs; consequently, infestations tend to be clustered, rather than uniform across the field. The first sample should be collected at least 100 feet in from the edge of the field. Plants should be sampled across the entire field, using care to sample areas that may have different plant heights, age, or density. If more than one hybrid is planted in the same field, consider each hybrid as a separate field for scouting purposes. Scout 20 random plants at each of 5 locations in the field for feeding. Pull out and unroll at least two whorls at each of the five locations to estimate borers per plant.

If a majority of the larvae found are less than ¼ inch long, then wait 3 to 5 days for additional larvae to hatch before treating. However, be sure to treat before larvae are $^{11}/_{16}$ inch long (about the length of a dime). After this stage, larvae leave the whorl and tunnel into the stalk where an insecticide application will not kill them. Wet excretory material protruding from entry holes indicates that stalk boring has begun.

Second Generation

Egg mass counts are the preferred method of scouting for second generation European corn borer. Begin scouting for egg masses in corn when corn borer moths are being collected in light or pheromone traps. Continue scouting every three to five days, especially during the early part of the moth flight period. Egg laying may extend over a period of three to four weeks. Concentrate sampling efforts on fields with the highest likelihood of infestation – late planted fields and/or those that are green, succulent, shedding pollen, or have green silks in late July and early August.

Scout for egg masses on a minimum of 50 randomly-selected plants from several different parts of the field. Look for egg masses on the underside of leaves above and below the ear leaf. Egg masses are usually laid on the underside of the leaves near the midrib on the middle ⅓ of the plant. Count the number of plants with egg masses and the number of egg masses per plant. Multiply the number of infested plants by two to get the percent infestation. Insecticide treatments should be applied when the majority of eggs are in the black head stage or hatching. If eggs have already hatched, look for entry holes and frass on the stalks. Split stalks, if necessary, to determine if larvae have entered the stalk where they will not be affected by an insecticide treatment.

Insecticide Treatments and Economic Thresholds

Properly timed insecticide applications can provide effective control of first generation European corn borer. Managing the second generation is more difficult; an insecticide treatment will likely provide around 65% control. Economic thresholds for insecticide treatment vary based on several factors:

- Percent of plants with whorl feeding damage, egg masses, or larvae
- Corn growth stage
- Cost of treatment
- Expected value of the crop

Corn yield loss per borer will be greater with earlier infestations relative to the crop growth stage (Table 1). Additional stress factors, such as drought and foliar disease, can exacerbate yield losses from European corn borer damage. Numerous universities have economic threshold worksheets that can provide an estimate of the potential value of an insecticide treatment.

Table 1. Yield losses caused by European corn borer damage (ECB) at various corn growth stages (Boyd and Bailey, 2001).

Corn Growth Stage	Yield Loss per ECB per Plant
V10	5.9%
V16	5.0%
Pollinating (R1)	4.0%
Blister (R2)	3.1%
Dough (R4)	2.3%

Summary

Bt corn has been and continues to be a very effective management tool, providing protection against European corn borer. The widespread adoption of Bt corn in the Midwestern U.S. over the last 20 years has suppressed population levels and reduced the importance of European corn borer as a pest of corn. However, the wide host range of European corn borer allows it to persist as an ever-present threat to corn production. Outbreaks and yield loss can still occur in unprotected corn. It is important that growers planting non-Bt corn maintain familiarity with European corn borer life cycle, identification, crop damage, and management options in order to avoid significant yield losses in the event of an outbreak.

Western Bean Cutworm

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

Pest Facts and Impact on Crop

- Species name: *Striacosta albicosta*
- Major larval feeding coincides with the ear development.
- Direct feeding on the ears reduces grain yield.
- Infestations of several larvae per ear can reduce grain yield up to 15 to 20%.
- Feeding may allow mold and other fungal spores to colonize the ear, further reducing grain quality and potentially producing mycotoxins.
- Larvae are pests of dry beans in the Western U.S. and Great Lakes region and of corn in the Corn Belt.

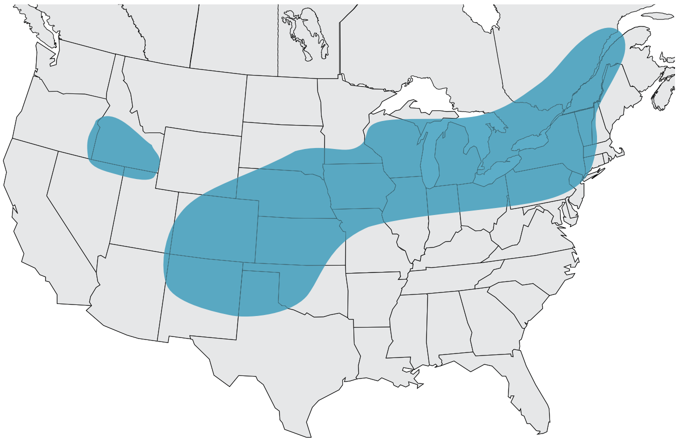


Figure 1. Western bean cutworm historically occurred in cornfields of the Great Plains but has moved into the Central and Eastern Corn Belt.

Pest Symptoms

- Leaf and whorl feeding by small stage larvae
- Ear penetration and kernel damage by large stage larvae
- Secondary infestation by ear molds after protection from shuck covering has been breached

Figure 2. Damage from western bean cutworm.

Feeding by western bean cutworm.

Western bean cutworm damage to ears.

Pest Identification

- Western bean cutworm: No straight, lateral lines or black tubercles (warts) along the sides
- Fall armyworm: Thin white lines down middle of back and four large, dark tubercles on "tail" section
- Corn earworm: Lateral, thick pale stripe and dark tubercles

Western bean cutworm larva.

Fall armyworm larva.

Corn earworm larva.

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Western Bean Cutworm Annual Life Cycle in Corn

Image courtesy of Purdue University

Adults emerge from soil in late June, mate, and lay eggs. → Larvae feed on pollen and foliage, then move to ear. → At grain maturity, larva moves to soil and overwinters.

Integrated Pest Management

- **Populations:** Several factors may contribute to increased populations, including mild winters, reduced use of foliar insecticides in corn, and reduced or no tillage.
- **Trapping:** Use pheromone traps to determine when to start scouting for eggs, usually during VT-R2 stages.
- **Scouting:** Check the upper flag leaf for egg masses after traps indicate moth flight; check 40 plants per field.
- **Ear Molds:** If ear molds are a problem, timely harvest and drying may be desirable to prevent mycotoxin formation.
- **In-Plant Protection:**
  - Due to various factors, including pest pressure, reduced susceptibility, and insect resistance in some pest populations, for the 2018 planting season and beyond, all references to control or suppression of western bean cutworm are being completely removed from bag tags, competitive trait tables, product use guides, and other customer facing materials for products that include the Herculex® I (HX1) trait but lack another effective mode of action for western bean cutworm.
  - However, Pioneer® brand Optimum® Leptra® and Optimum® AcreMax® Leptra® insect protection provide an effective mode of action for in-plant protection against western bean cutworm.
- **Insecticides:** Time application to coincide with egg hatch.
  - Protection is most effective when egg hatch occurs during pollination.
  - When egg hatch occurs at brown silk stage or later, the larva can move quickly to the ears since fresh pollen is not available on which to feed.
- **Economic Thresholds:** A foliar insecticide should be considered if the percent of infested plants is reached or exceeded based on crop value ($/bu) and management costs ($/acre).

Western Bean Cutworm Economic Thresholds: % Plants Infested with Eggs

	Management Cost ($/acre)						
Crop Value	$4	$6	$8	$10	$12	$14	$16
$3	7%	11%	15%	18%	22%	26%	29%
$4	5%	8%	11%	14%	16%	19%	22%
$5	4%	7%	9%	11%	13%	15%	18%

Source: University of Nebraska. Thresholds based on yield of 220 bu/acre, 30,000 plants/acre, 85 eggs/mass, and 8% larval survival.

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Western Bean Cutworm Monitoring

by **Jeff Mathesius, M.S.**, *Agronomy Research Manager,*
and **Mark Jeschke, Ph.D.**, *Agronomy Information Manager*

Background and Objectives

- Western bean cutworm *(Striacosta albicosta)* historically occurred in cornfields of the Great Plains, but has moved into the Central and Eastern Corn Belt.
- Due to various factors, including pest pressure, reduced susceptibility, and insect resistance in some pest populations, products that include the Herculex® I (HX1) trait, but lack another effective mode of action for western bean cutworm are no longer labeled for control or suppression of western bean cutworm.
- Pioneer® brand Optimum® Leptra® and Optimum® AcreMax® Leptra® insect protection provide an effective mode of action for in-plant protection against western bean cutworm.
- Several factors may contribute to increased western bean cutworm populations, including mild winters, continuous corn production, reduced use of foliar insecticides in corn, and reduced or no tillage.
- A survey was conducted in 2017 to estimate western bean cutworm populations in fields throughout the Corn Belt and Northeastern U.S.

Study Description

- **Year:** 2017
- **Locations:** 185 fields in Colorado, Illinois, Indiana, Kansas, Massachusetts, Michigan, Missouri, Nebraska, New York, Ohio, Pennsylvania, Vermont, and Wisconsin
- **Sampling Methods:**
  - » Great Lakes IPM insect monitoring supplies were used for western bean cutworm population sampling in 2017.
  - » IPS-G004-12 Green Bucket Traps were placed adjacent to corn fields starting in late June to early July.
  - » SC-WBC L206-12 Lures were used to attract moths and HC-8001 Hercon Vaportape strips were used to kill the moths once caught
  - » Moth counts were taken weekly for up to eight weeks. In areas with higher pressure moth counts were taken daily.
  - » During July and August, a subset of locations monitored egg masses to determined percentage of plants infested (data not reported here).

Results

- Average total moth counts were considerably higher in fields that had been planted to corn for three or more years (Figure 1).
- Peak moth flight was recorded in mid- to late-July at most trapping locations. Peak flight did not occur until mid-August for a few locations in New York and Vermont (Figure 2).
- Western bean cutworm moths were captured at nearly all trapping locations. The highest total moth counts were recorded at locations in the historical range of western bean cutworm in Nebraska, Kansas, and Colorado (Figure 3).

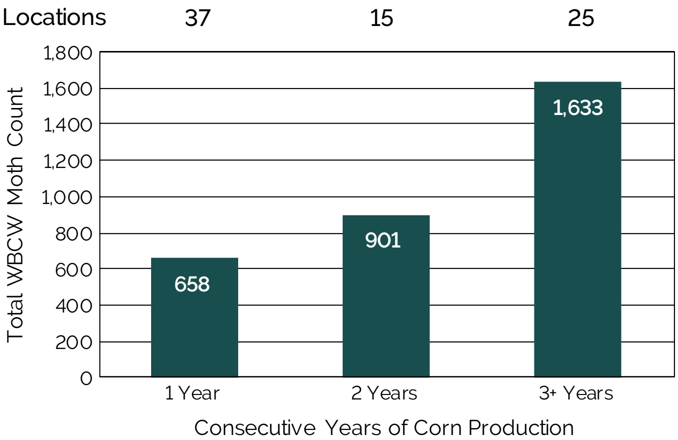

Figure 1. Western bean cutworm moth counts as influenced by field corn production history in the 2017 survey.

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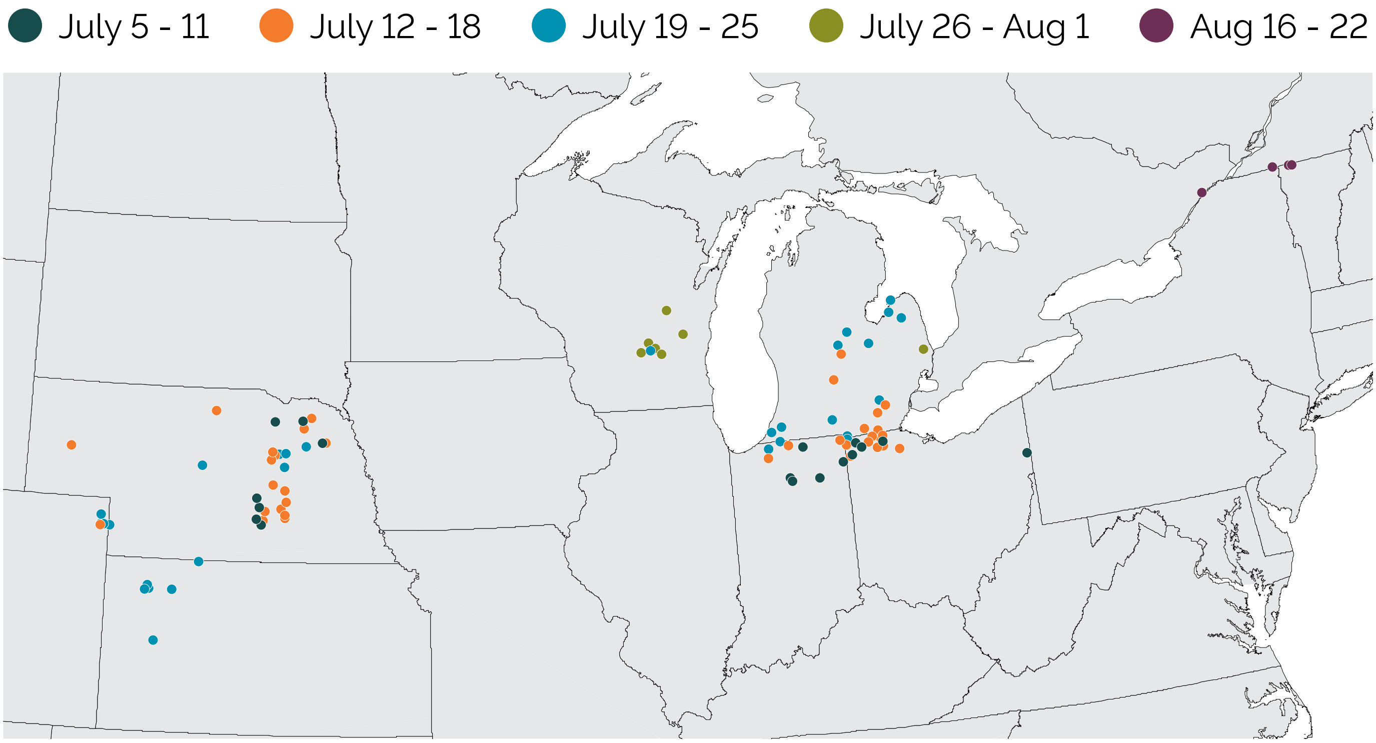

Figure 2. Date of peak moth flight at 2017 western bean cutworm trapping locations.

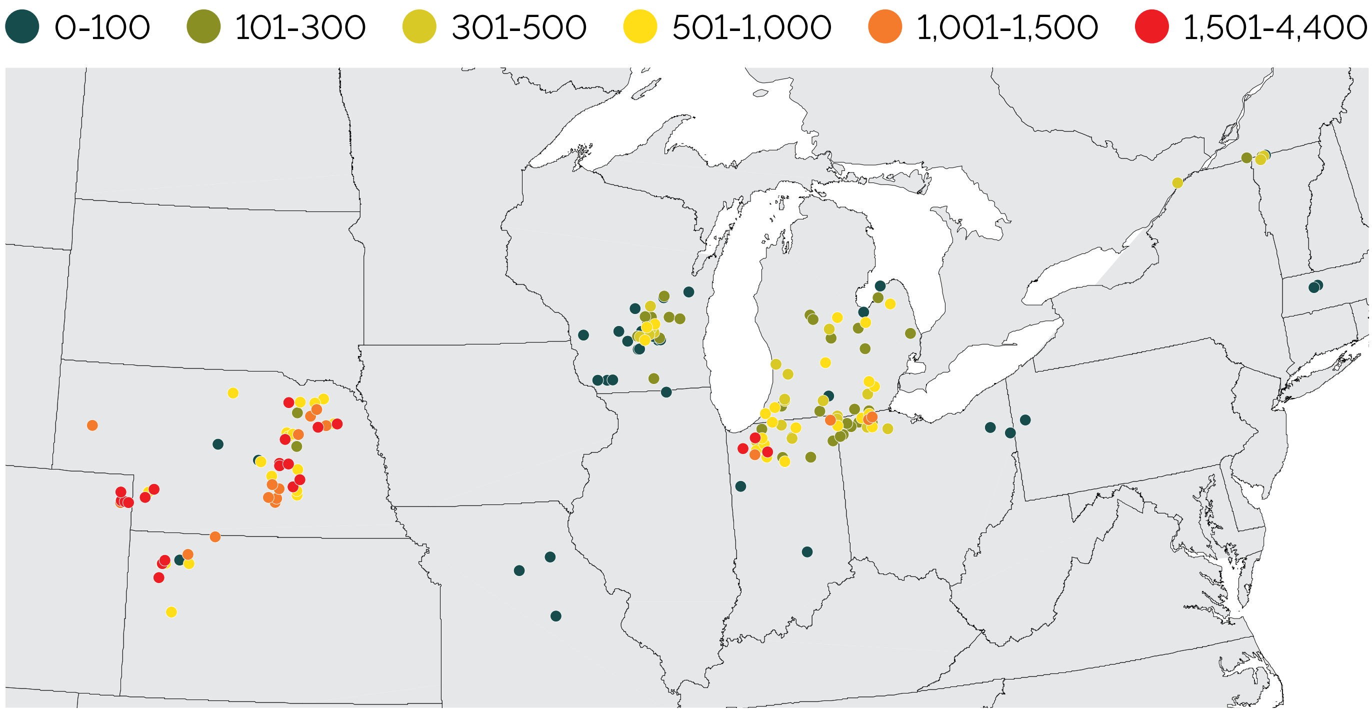

Figure 3. Total moth trapping counts at 2017 western bean cutworm trapping locations.

Estimating Corn Rootworm Beetle Populations With Sticky Traps

*by **Jeff Mathesius, M.S.**, Agronomy Research Manager*

Objectives

- Quantifying corn rootworm beetle populations in the summer allows growers to make better informed decisions regarding management options the following season.
- A survey was conducted in 2017 to estimate corn rootworm population levels in fields throughout the Central and Northern Corn Belt using Pherocon® AM/NB sticky traps.

Study Description

Year:	2017
Locations:	685 fields in Iowa, Illinois, Kansas, Minnesota, Missouri, Nebraska, South Dakota, and Wisconsin

Sampling Methods:

- Sticky traps placed in field beginning at blister stage (R2)
- Sticky traps placed per field: 1 or 6
- Beetles counted on each trap at 7-day intervals with the average per trap recorded
- Trapping continued for 4 to 8 consecutive weeks
- Trapping was conducted in both continuous corn and corn soybean rotated fields

Western corn rootworm.

Northern corn rootworm.

Results

- Corn rootworm population levels were categorized at zero, low, moderate, or high for each sampling location in 2017:
    - » Zero = no beetles collected
    - » Low = traps average <21 beetles/week
    - » Moderate = traps average 21-50 beetles/week
    - » High = traps average >50 beetles/week
- Maximum corn rootworm beetle population levels observed by location across all weeks (Figure 1 and Figure 2):
    - » **7.2%** of locations had <u>zero</u> adults collected
    - » **75.9%** of locations had <u>low</u> populations
    - » **10.5%** of locations had <u>moderate</u> populations
    - » **6.4%** of locations had <u>high</u> populations
- Previous crop appeared to influence beetle populations. Across all locations, the average maximum count for corn after corn was 19.8; whereas, corn after soybean was 5.5 (Table 1 and Figure 3):

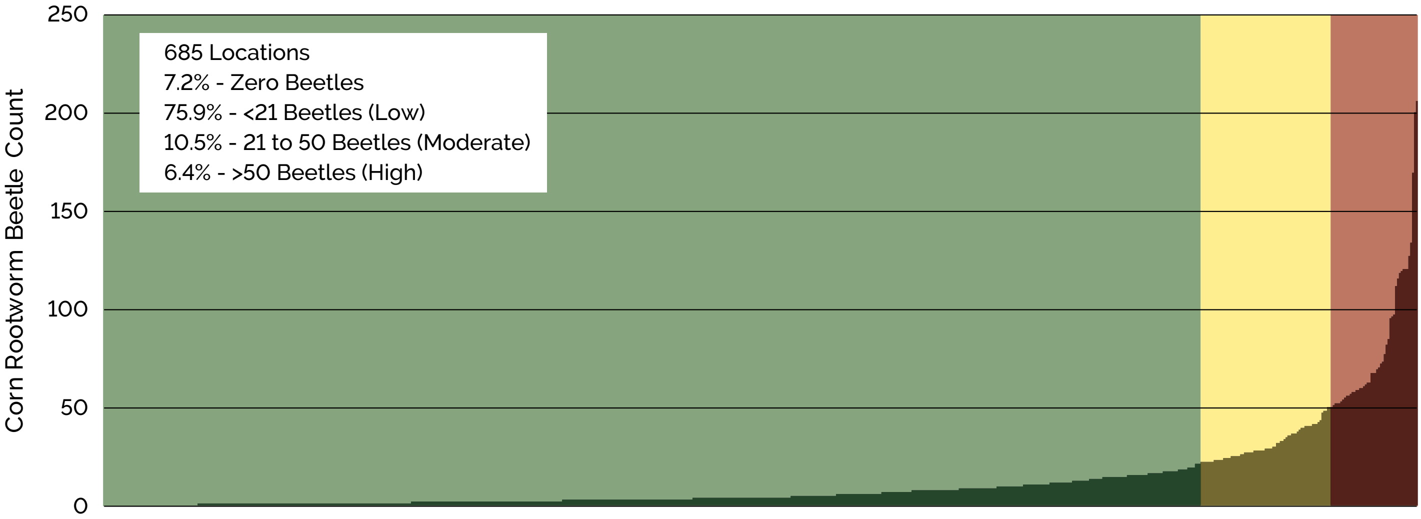

Figure 1. Population levels observed at corn rootworm beetle trapping locations in 2017.

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Results (cont.)

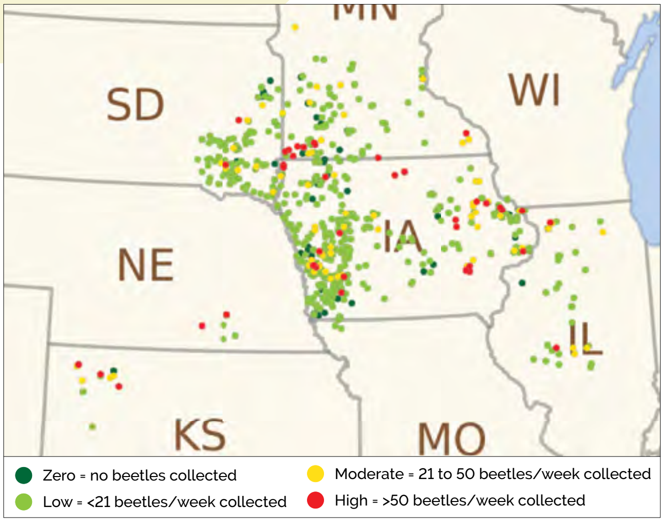


Figure 2. Maximum population levels observed at corn rootworm beetle trapping locations in 2017.

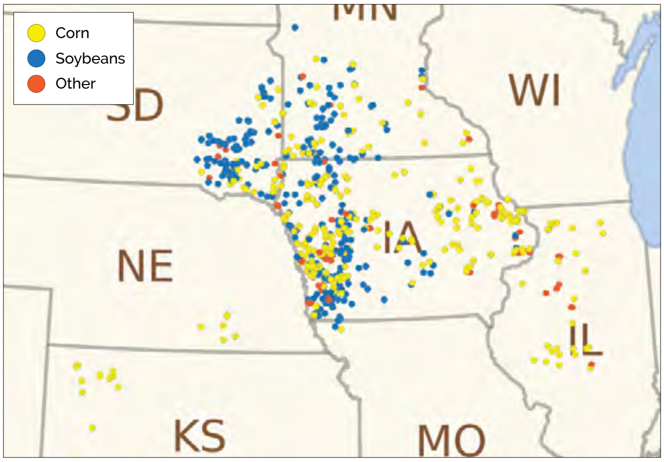


Figure 3. Previous crop at corn rootworm beetle trapping locations in 2017.

Action Thresholds

Traps average **<21 beetles** per week

- **Low** rootworm populations anticipated next year
- Select a control option for low populations:
  - » Rotate to another crop.
  - » Plant corn rootworm Bt corn product.
  - » Plant non-Bt rootworm Pioneer® brand corn products with Poncho® 1250/VOTiVO® insecticide seed treatment.
  - » Plant non-Bt rootworm product with soil insecticide.

Traps average **21-50 beetles** in a single week

- **Moderate** rootworm populations anticipated next year
- Select a control option for moderate populations:
  - » Rotate to another crop.
  - » Plant corn rootworm Bt corn product.
  - » Apply soil insecticide at planting for larvae.

Traps average **>50 beetles** in a single week

- **High** rootworm populations anticipated next year
- Select a control option for high populations:
  - » Rotate to another crop.
  - » Apply foliar insecticide in the current year to control adult beetles prior to egg-laying and use a rootworm resistant Bt corn or soil-applied insecticide the following year.
  - » Consult with your Pioneer sales professional, university extension, crop consultants, or other local experts for recommendations if considering planting a corn rootworm Bt corn product and adding a soil-applied insecticide.

Table 1. Effect of previous crop on maximum beetle count averaged across all locations.

Previous Crop	Average Beetle Count	Locs
Corn	19.8	339
Soybeans	5.5	294

Management Considerations

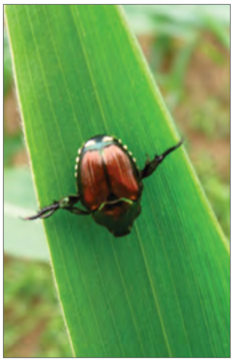
- **Although DuPont Pioneer studies have shown that the HXRW trait remains an effective tool for corn rootworm management, DuPont Pioneer and university research suggests that continuous, uninterrupted use of the same corn rootworm Bt technology can lead to decreased corn rootworm susceptibility to that technology and may result in reduced product efficacy against these insects.**
- To help maintain the efficacy of Bt corn rootworm products, it is essential to develop a multi-faceted rootworm management plan.
- Your Pioneer sales professional or local extension professionals can assist you in developing best management practices for your operation.
- Please contact your authorized Pioneer sales representative or consult with your local university extension for more information regarding insect resistance management as well as best management practices and to understand whether there has been insect resistance documented in your area.

Japanese Beetle

*by **Chuck Bremer, Ph.D.,** Former Agronomy E-Business Information Manager*

Pest Facts

- Latin name is *Popillia japonica*
- Native to Japan; found in United States in 1916
- Most damage is from adult feeding; however, the larval grub also can feed on roots.
- Late-planted fields are at greater risk.
- Japanese beetles are often found in field edges or areas of delayed growth.
- Over 300 hosts: corn, soybean, ornamentals, fruit trees, grapes, and weeds
- One generation per year



Key Characteristics

- Half-inch adults are shiny, metallic green with bronze wing covers and six white hair tufts on each side of their abdomen

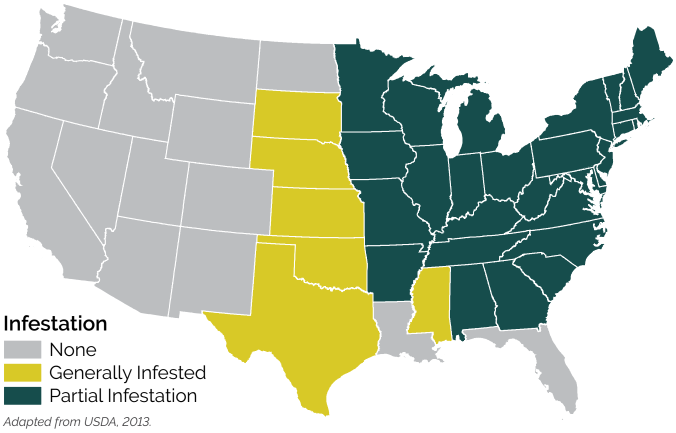
Figure 1. Japanese beetle.

Related/Confused Species

1. Masked chafer: light color
2. Green june beetle: twice the size, no white tufts
3. False Japanese beetle/sand chafer: dull, no white tufts

Distribution

- Well established east of the Mississippi River, the Japanese beetle is also present in most other corn and soybean growing states.



Adapted from USDA, 2013.

Figure 2. Japanese beetle infestation according to USDA data in 2013.

Pest Injury Symptoms / Impact on Crop

- Clipped corn silks may reduce pollination and yield.
- Skeletonized or lacy leaf patterns between veins are symptoms of either corn or soybean feeding.
- Leaf feeding is typically insignificant in corn.
- Leaf feeding may be more significant in soybeans, causing defoliation prior to pod fill.

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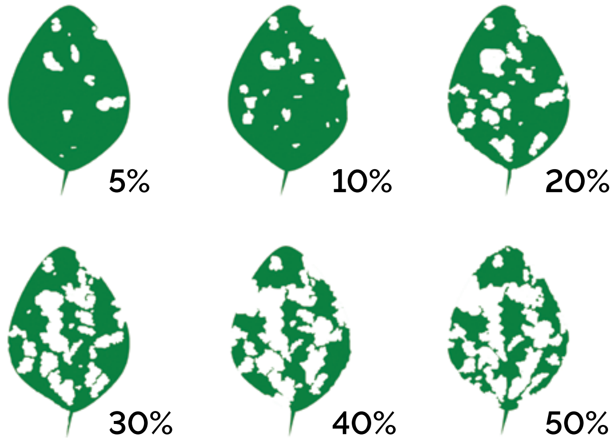
Economic Thresholds

Treatment Thresholds for Corn Insecticides:

- Silks clipped to within ½ inch of the ear tip
- Less than 50% of plants pollinated
- Beetles are present and feeding.

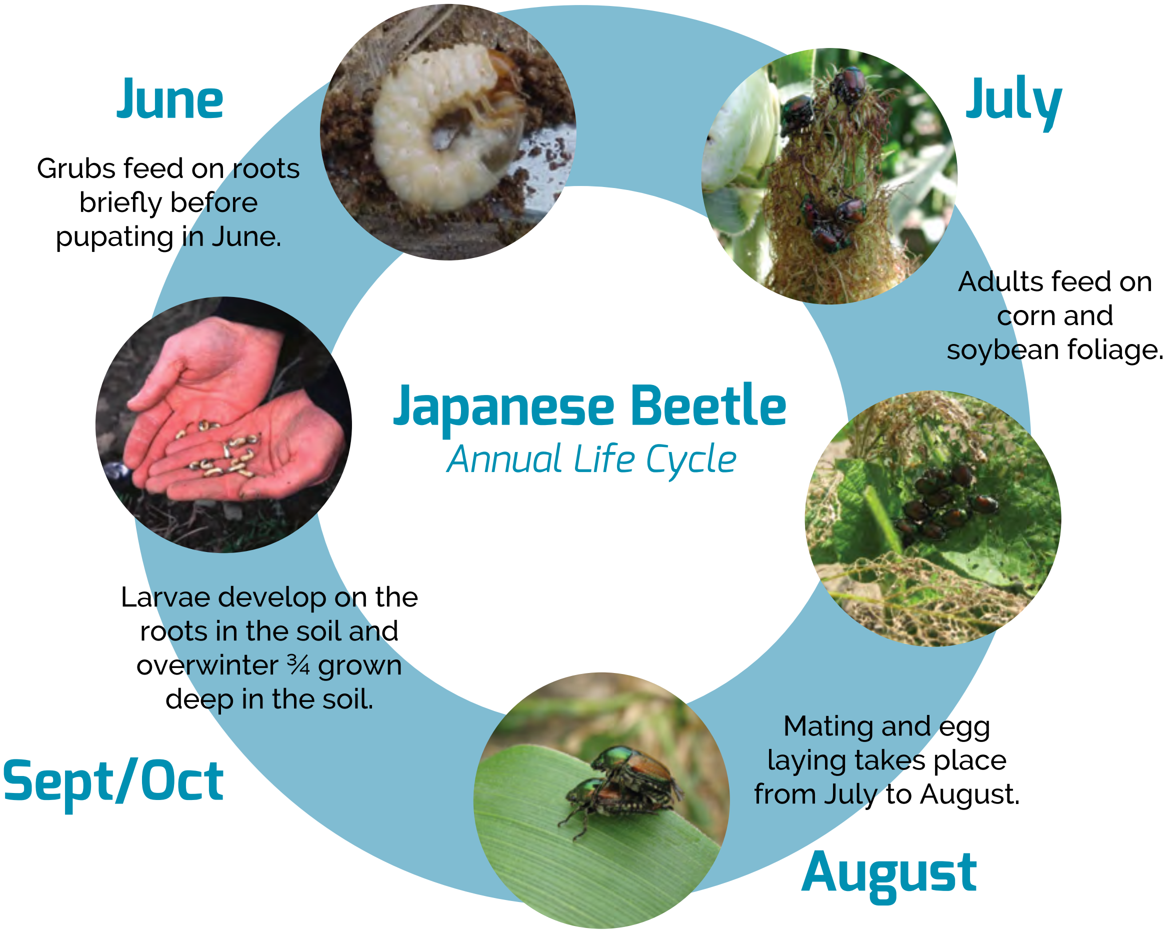


Economic Thresholds for Soybeans:

- » Up to V7 = 40 to 50% defoliation
- » Flowering, pod development, pod fill = 15 to 20% defoliation
- » Pod fill to harvest = greater than 25%

Management Considerations

- Favorable conditions:
  - » Adults prefer lighter soil for egg laying.
  - » First entry into an area is usually near transportation, such as railroads or major highways.
- There are no significant natural enemies in the United States.
- IPM Practices:
  - » No transgenic or native gene resistance is currently available for either soybeans or corn.
  - » Trapping is NOT recommended as it has a tendency to attract the beetles.
  - » Scouting should begin in corn in July and August and switch to soybeans during August.
  - » Use percent pollination and presence of uncut silks as a guide when deciding treatment of corn. Leaf feeding is rarely significant in corn.
  - » Use percent defoliation and amount of pod fill remaining to help decide economics of insecticide treatment for soybeans.



Japanese Beetle

Annual Life Cycle

June

Grubs feed on roots briefly before pupating in June.

July

Adults feed on corn and soybean foliage.

August

Mating and egg laying takes place from July to August.

Sept/Oct

Larvae develop on the roots in the soil and overwinter ¾ grown deep in the soil.

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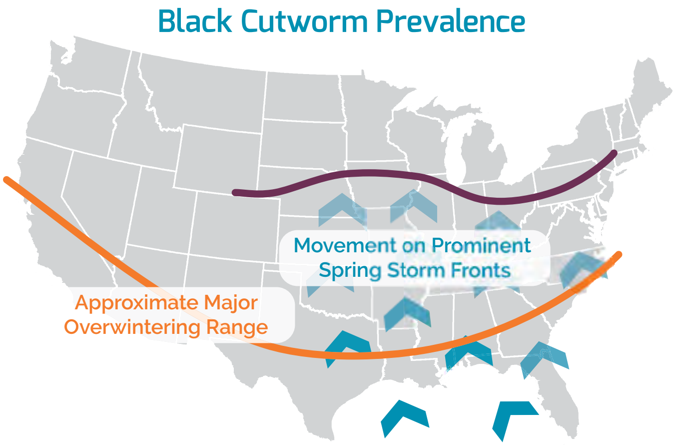
Black Cutworm

*by **Chuck Bremer, Ph.D.**, Former Agronomy E-Business Information Manager*

Pest Facts and Impact on Crop

- Latin name: *Agrotis ipsilon*
- The black cutworm is the major cutworm of the Corn Belt – similar species are found worldwide.
- Black cutworms eat many plants, including corn, cotton, tobacco, vegetables, weeds, and turf grasses.



Pest Symptoms

- Small larvae chew holes in leaves.
- Fourth stage or older larvae exceed the width of a dime in length and can begin cutting V1 to V5 stage plants.
- Drilling into V6 to V8 stage plants can kill growing point
- Cutting mostly above ground in wet soil, mostly below ground in dry soil

Figure 1. Black cutworm damage to corn plant.

Figure 2. Recovering corn seedling after being cut above the growing point by black cutworm.

Pest ID

- Key characteristics
  - Adult forewings with dagger-shaped marking and kidney-shaped spot
  - Larvae are black/gray and grow to 1 ⅝ in.

Figure 3. Black cutworm and larvae.

Related/Similar Appearing Species:

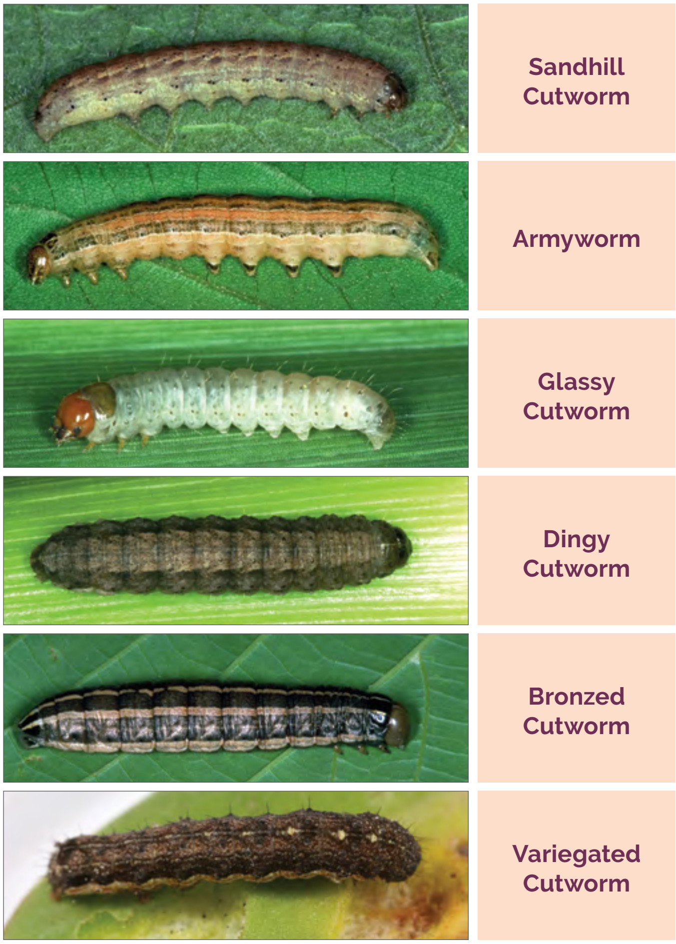


Figure 4. Species related to or similar in appearance to black cutworm.

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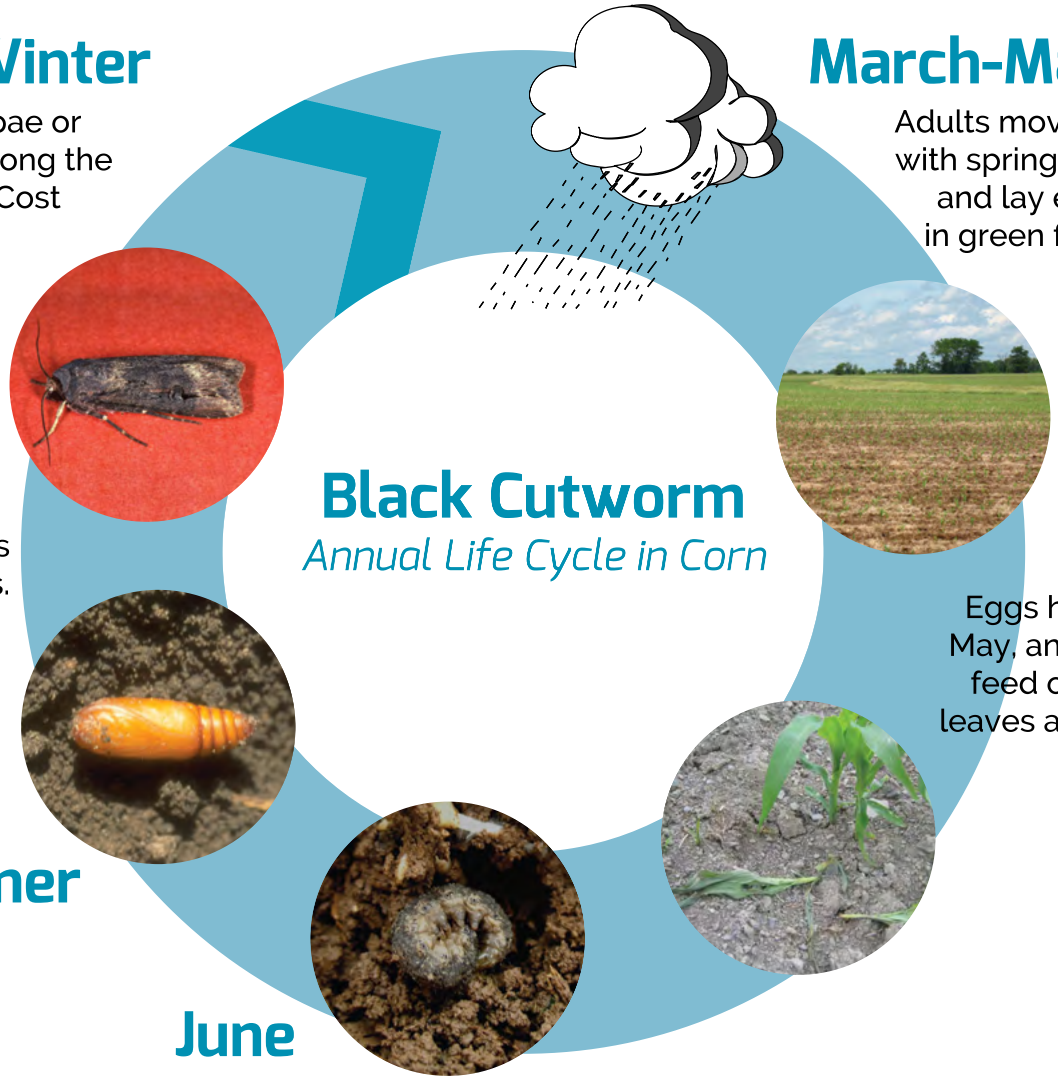

Black Cutworm

Annual Life Cycle in Corn

Winter

As pupae or
adults along the
Gulf Cost

March-May

Adults move north
with spring storms
and lay eggs
in green fields.

Eggs hatch in
May, and larvae
feed on corn
leaves and roots.

June

Summer

Emerged
adults
move to
other crops
to lay eggs.

Management

- Favorable conditions for pest occurrence are spring storms prior to tillage and planting, and delivering moths to the area.
  - Monitor moth flight reports.
  - Kill existing vegetation nine or more days prior to planting to reduce larval survival.
  - Natural enemies are generally birds and other predators, though they are not usually effective.
- IPM practices
  - Pheromone trapping is used to determine when the pest is present.
  - Intensively scout fields that are at risk.
  - Reduced tillage or other practices that leave a food source for the young larvae increase risk.
  - Insecticide seed treatments at high rates may give some control, but lower rates are not as effective.
  - Broadcast pesticide or bait application may be used as a rescue treatment.

Management with Pioneer® Brand Products

- Pioneer® brand corn products with the Herculex® I trait have very good protection against black cutworm.

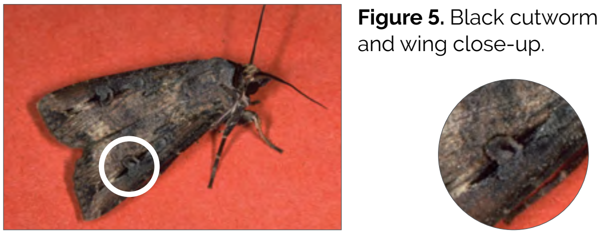

Figure 5. Black cutworm moth and wing close-up.

Figure 6. A Pioneer brand hybrid with the Herculex® I trait (right), compared to a susceptible hybrid (left) under black cutworm pressure. Orange stakes indicate cut plants.

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Slug Damage to Corn and Soybeans

by **Gary Brinkman,** Field Agronomist

Summary

- Slug problems are usually associated with heavy crop residue, which holds moisture.
- There is currently no economic threshold based on slug numbers or feeding damage.
- The primary management strategy for slugs is to employ a tillage practice that removes crop residue or incorporates it into the soil.
- In fields with heavy corn residue and a history of slugs, delaying planting until soils warm and germination as well as plant growth are more rapid improves the chances that soybeans will outgrow potential damage.
- When plant stands are reduced, the grower should monitor stand counts and replant where necessary.

Favorable Conditions

Moist, high residue environments are a slug's delight. Slugs are sporadic pests of corn primarily associated with no-till practices and heavy crop residue. Their outbreaks are increased by cool, moist springs, mild winters, and manure. While not widespread most years, slug injury to corn and soybeans was severe in some states in 2010 and localized outbreaks were reported in some areas in 2015, 2016, and 2017. Corn and soybean fields planted into heavy crop residue are most likely to see damage from slugs. If eggs hatch at crop emergence, slugs can cut off corn coleoptiles and soybean hypocotyls, resulting in severe stand losses.

Figure 1. Adult gray garden slug.

Characteristics and Life Cycle

The adult gray garden slug is one to two inches long when fully extended. It varies from gray to pale cream and has a light mottled pattern of spots and streaks. The young are the same shape and coloration as the adults. The "slime" they give off is a protectant against environmental stressors. Slugs are nocturnal, meaning they emerge and feed above ground after dark.

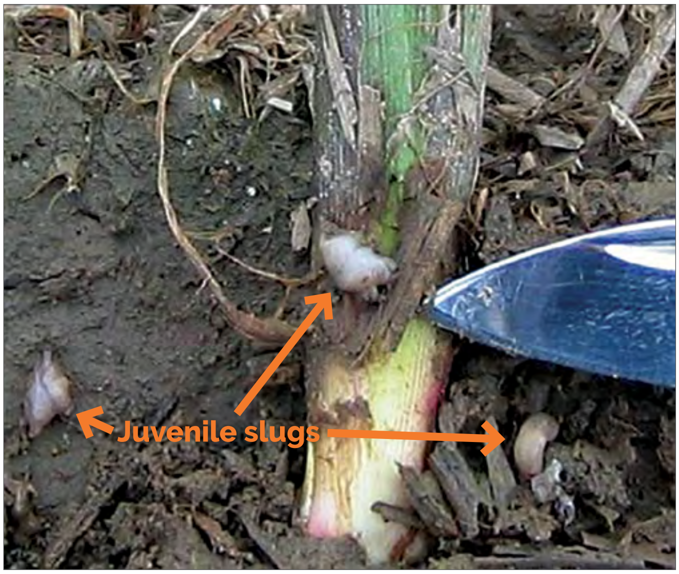
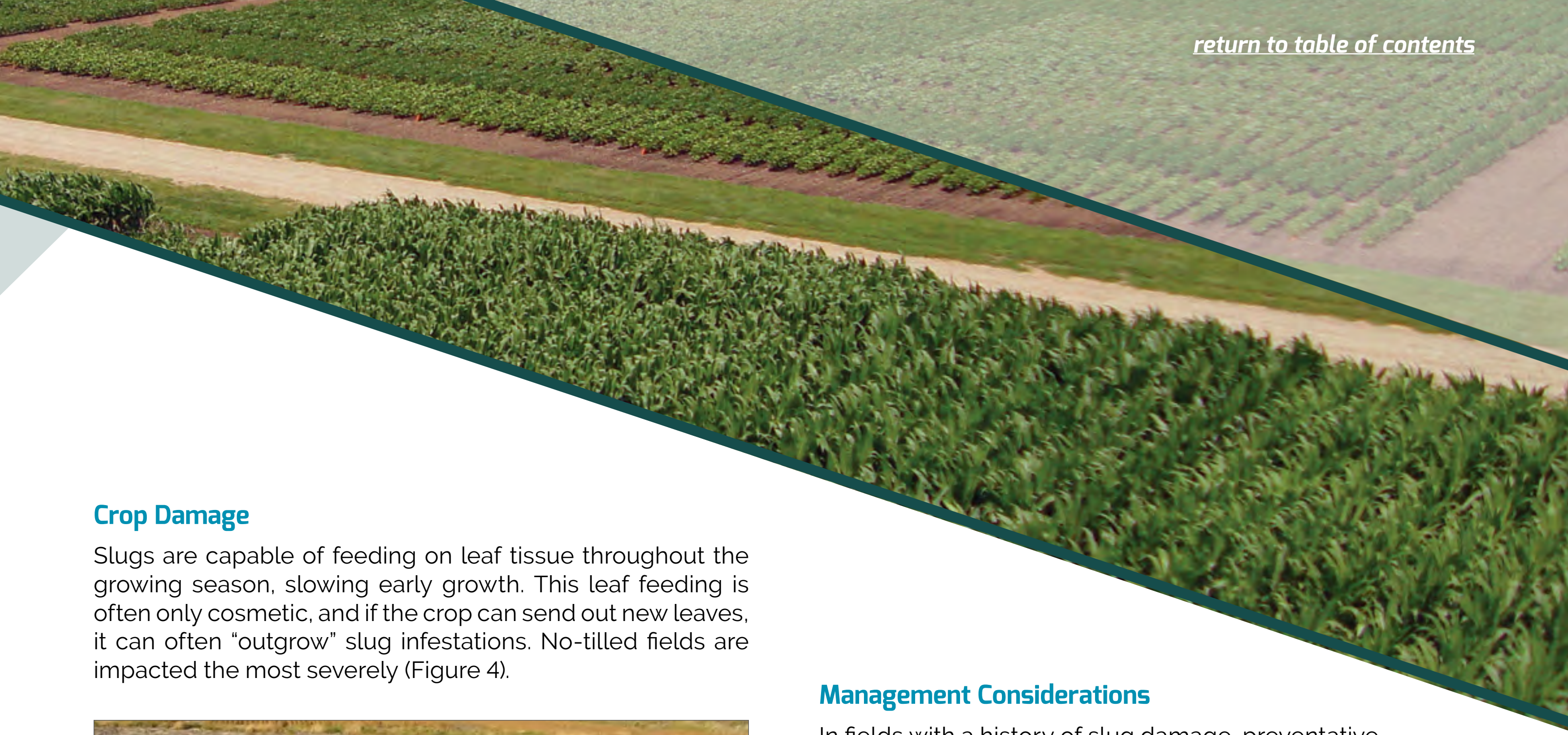


Figure 2. Three small slugs present on and near a corn plant.

Figure 3. Leaf damage caused by juvenile slugs.

The life cycle of the slug starts with eggs. Females lay eggs in masses in the soil during the fall, which are held together by a sticky secretion that turns yellow before hatching. Eggs hatch in about one month, producing small slugs that closely resemble adults except in size. Slugs primarily overwinter as eggs; however, adults can also overwinter. Overlapping generations occur because of the slug's ability for summer-long breeding during favorable conditions. They can live about 12 to 15 months. There is one generation per year.



Crop Damage

Slugs are capable of feeding on leaf tissue throughout the growing season, slowing early growth. This leaf feeding is often only cosmetic, and if the crop can send out new leaves, it can often "outgrow" slug infestations. No-tilled fields are impacted the most severely (Figure 4).

Figure 4. No-tilled field in Barron County, Wisconsin. *Photo courtesy of Jim Boersma.*

Slugs are mollusks and not susceptible to Bt proteins that control many above and below ground insects. Heavy slug feeding on brace roots can result in root lodging under windy conditions (Figure 5).

Figure 5. Slug damage to root systems of a hybrid with Bt corn rootworm protection, which does not protect against slug damage. *Photo courtesy of Dave Johnson.*

Management Considerations

In fields with a history of slug damage, preventative practices to reduce risk of damage include:

- Incorporate crop residue into the soil and delay planting until soils warm up for rapid germination and emergence.
- Current insecticide seed treatments have no effect on slug populations as slugs are not insects but mollusks.
- There are baits, such as Sluggo® (iron phosphate), that can be applied in a band following planting. Slugs need to ingest this material, so it should be applied close to the row. Then, slugs will have good access to the bait when they come above ground at night to feed.
- Metaldehyde is a molluscide that can give satisfactory control of slugs. Metaldehyde destroys the slime-producing cells of slugs and causes their death.
- Some growers have reported success with applications of 28% UAN solutions, but this nitrogen source can burn corn leaves. Early applications at V3 are preferred so new leaves can emerge and not delay maturity.
- If periods of dry weather develop, slug severity usually tapers off quickly.
- Tile drainage on very heavy or poorly drained soils will help reduce excessive moisture, the preferred environment of slugs.
- Removing corn stalks for bedding also removes the heavy residue cover that helps keep soils moist, which is critical to a slug's life cycle.
- An excellent slug factsheet by Ohio State extension entomologists Ronald B. Hammond, Andy Michel, and James B. Eisley can be found at: *https://ohioline.osu.edu/factsheet/ENT-20.*
- See Ohio State University Extension Bulletin 545, Control of Insect Pests of Field Crops for those molluscicides labeled for slugs or for all materials labeled on corn and soybean. Bulletin 545 can be accessed at *https://agcrops.osu.edu/sites/agcrops/files/publication-files/545%281%29.pdf.*

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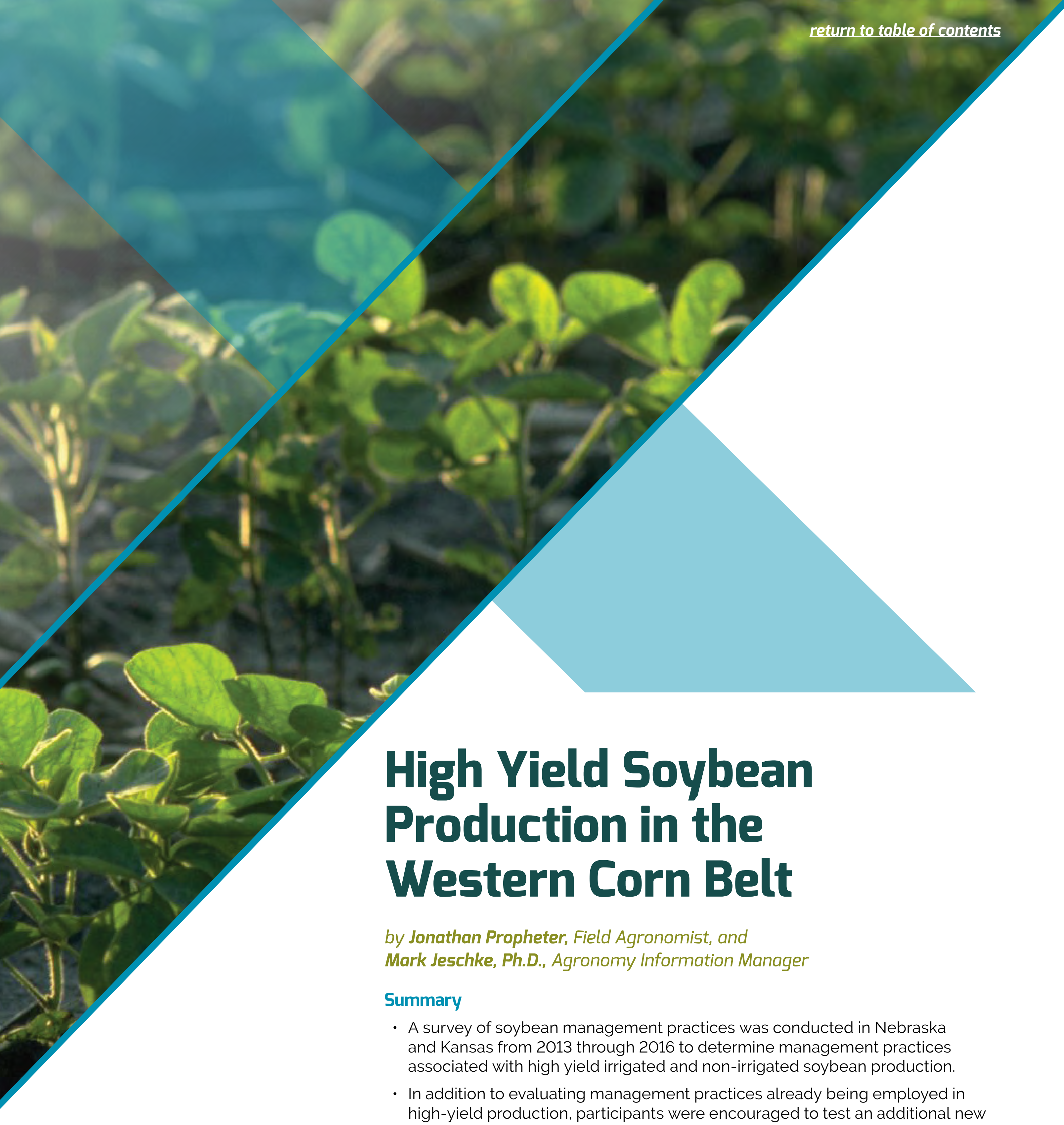

High Yield Soybean Production in the Western Corn Belt

by **Jonathan Propheter,** *Field Agronomist, and*
Mark Jeschke, Ph.D., *Agronomy Information Manager*

Summary

- A survey of soybean management practices was conducted in Nebraska and Kansas from 2013 through 2016 to determine management practices associated with high yield irrigated and non-irrigated soybean production.
- In addition to evaluating management practices already being employed in high-yield production, participants were encouraged to test an additional new management practice in an attempt to raise yields even further.
- Many participants achieved soybean yields between 70 and 90 bu/acre with four entries exceeding 100 bu/acre.
- Some management practices, such as timely planting and the use of a full seed treatment package, were common among participants.
- Many other management practices, such as tillage, seeding rate, and foliar fungicide and insecticide use, varied widely among participants, emphasizing the lack of a one-size-fits-all solution for higher soybean yields.

Introduction

Soybean yields have increased dramatically over the past 40 years, essentially doubling from a U.S. average of 26.1 bu/acre in 1976 to 52.1 bu/acre in 2016 (USDA-NASS 2017). Despite this increase, there remains a widespread perception among growers of underperformance with regard to yield gains in soybean, particularly in relation to corn, which has had a higher rate of gain over the same time period. One factor that has likely contributed to this difference is a different approach to management between the two crops. In a corn-soybean rotation, corn has typically been the more intensively managed crop with soybean historically serving as a lower-input rotational crop. Soybeans are often planted later than corn and rely on soil nutrients left over from the previous corn crop.

This approach to soybean management has begun to shift in recent years with the development of newer soybean varieties with greater genetic yield potential and the publicity surrounding several new record-setting soybean contest yields. This has resulted in increased interest in evaluating and implementing management practices that will contribute to higher soybean yields.

High Yield Soybean Challenge

A survey of soybean management practices, referred to as the Pioneer® GrowingPoint® Agronomy High Yield Soybean Challenge, was conducted across a total of 698 locations in Nebraska and Kansas from 2013 through 2016 (Figure 1). The purpose of this survey was to determine management practices associated with high yield irrigated and non-irrigated soybean production. In additional to evaluating management practices already being employed, participants were encouraged to test an additional new management practice in their high yield challenge entry in an attempt to raise yields even further.

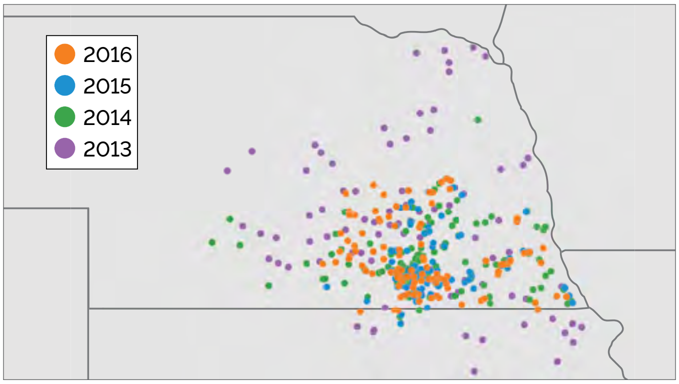

Figure 1. Locations of Pioneer GrowingPoint Agronomy High Yield Soybean Challenge fields, 2013-2016.

All entries consisted of a minimum of 1.25 acres and were planted to a Pioneer® brand soybean variety. Yield and agronomic management data were collected for each location.

Yield Results

Most of the high yield challenge entries (637 of 698) were under full irrigation. Yields under irrigation were typically 10-20 bu/acre more than in non-irrigated entries. Average yields of both irrigated and non-irrigated entries increased from 2013 to 2016 (Figure 2).

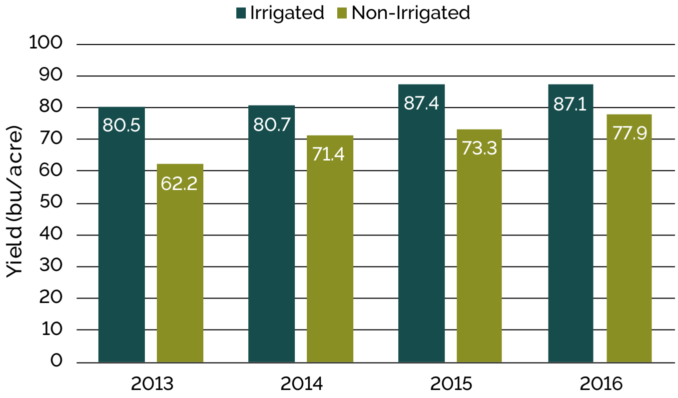

Figure 2. Average yield of irrigated and non-irrigated high yield soybean entries, 2013-2016.

This positive yield trend was likely a result of new high yield potential soybean varieties as well as management and growing conditions. Over the 4 years of the survey, there was nearly a complete turnover from older M and Y series varieties to newer Pioneer® brand T series soybean varieties, going from 4% of entries planted to T series soybean varieties in 2013 to 100% in 2016 (Figure 3). Entries planted to T series soybean varieties were 6.3 bu/acre higher yielding on average and accounted for most of the highest yields achieved in the survey, including 78% of entries over 95 bu/acre and 100% of entries over 100 bu/acre.

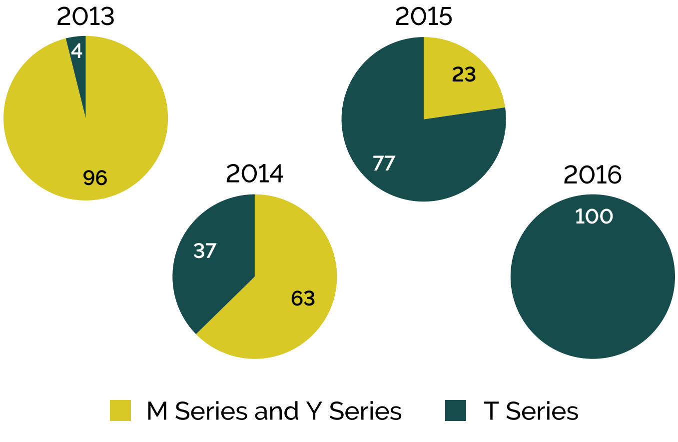

Figure 3. Variety series of Pioneer brand soybean varieties used in high yield soybean entries, 2013-2016

Yield levels of individual entries are shown in Figure 4. The majority of high yield challenge entries (72%) yielded between 70 and 90 bu/acre, with 14% of entries above 90 bu/acre. A total of 4 entries over the 4 years of the survey topped 100 bu/acre. Yield, Pioneer brand soybean variety, name, location, and management details of top-yielding entries are shown on the following page.

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Pioneer® GrowingPoint® Agronomy High Yield Soybean Challenge Entries Over 100 bu/acre (2013-2016):

101.9 bu/acre Pioneer® variety[2] P27T59R

Mark Koperski – Farwell, NE

- **Planting Date:** May 9, 2016
- **Previous Crop:** Corn
- **Tillage:** Ridge-Till
- **Irrigation:** Limited
- **Seeding Rate:** 170,000 seeds/acre
- **Row Spacing:** 36 inches
- **Pioneer Premium Seed Treatment Offering:** Yes
- **Foliar Fungicide:** No
- **Foliar Insecticide:** No
- **Harvest Date:** September 30, 2016

101.5 bu/acre Pioneer® variety P27T59R

Matthew King – Central City, NE

- **Planting Date:** April 30, 2016
- **Previous Crop:** Corn
- **Tillage:** Ridge-Till
- **Irrigation:** Full
- **Seeding Rate:** 200,000 seeds/acre
- **Row Spacing:** 30 inches
- **Pioneer Premium Seed Treatment Offering:** Yes
- **Foliar Fungicide:** Yes
- **Foliar Insecticide:** Yes
- **Harvest Date:** October 18, 2016

101.5 bu/acre Pioneer® variety P27T91PR^

Keith Bankson – Hordville, NE

- **Planting Date:** May 6, 2016
- **Previous Crop:** Corn
- **Tillage:** Strip-Till
- **Irrigation:** Full
- **Seeding Rate:** 162,000 seeds/acre
- **Row Spacing:** 30 inches
- **Pioneer Premium Seed Treatment Offering:** Yes
- **Foliar Fungicide:** Yes
- **Foliar Insecticide:** Yes
- **Harvest Date:** October 14, 2016

101.3 bu/acre Pioneer® variety P28T08R

Willoughby Farms – Wood River, NE

- **Planting Date:** May 9, 2016
- **Previous Crop:** Corn
- **Tillage:** Minimum Tillage
- **Irrigation:** Full
- **Seeding Rate:** 175,000 seeds/acre
- **Row Spacing:** 30 inches
- **Pioneer Premium Seed Treatment Offering:** Yes
- **Foliar Fungicide:** No
- **Foliar Insecticide:** Yes
- **Harvest Date:** September 27, 2016

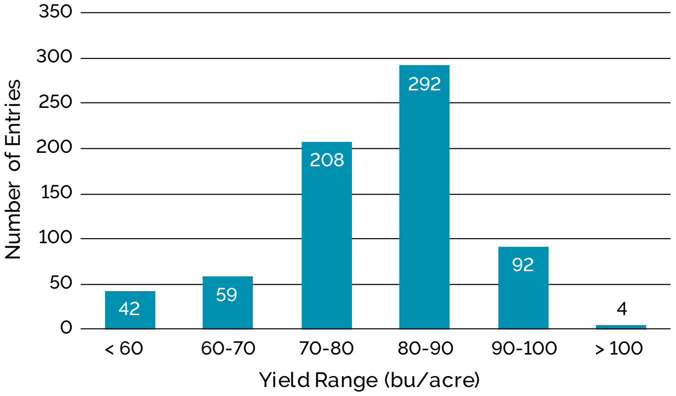

Figure 4. Yield range of high yield soybean entries, 2013-2016.

Yields of high yield challenge entries were generally well-above average for their geography. Average yields of both irrigated and non-irrigated entries were around 20 bu/acre greater than their respective county average yields for irrigated and non-irrigated production (Figure 5).

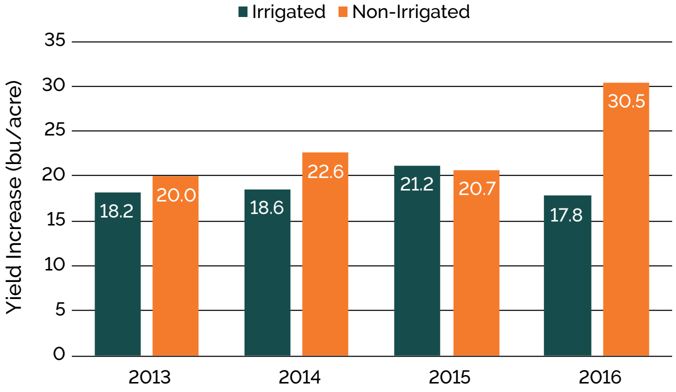

Figure 5. Irrigated and non-irrigated high yield soybean entries difference from respective county average soybean yields.

Management Practices

Tillage

The most common tillage system used in the high yield soybean challenge was no-till, accounting for nearly half of all entries followed by ridge-till and conventional tillage (Figure 6).

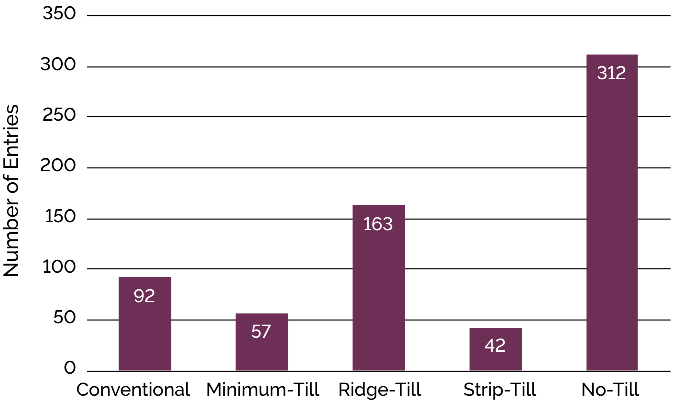

Figure 6. Tillage used in high yield soybean entries.

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The average yield of no-till entries was lower than that of entries that included some kind of tillage; no-till entries averaged 76 bu/acre, while other tillage systems averaged between 81 and 85 bu/acre. The impact of excessive residue in no-till is likely a contributing factor to this difference in yield. Challenges with managing residue in no-till have been observed in the survey area. Improved nutrient placement in tilled systems may also be a contributing factor.

Row Spacing

The most common row spacing in high yield challenge entries by far was 30-inch rows (Figure 7). While much more common in other soybean producing areas, 15-inch and narrower row spacings accounted for less than 20% of entries.

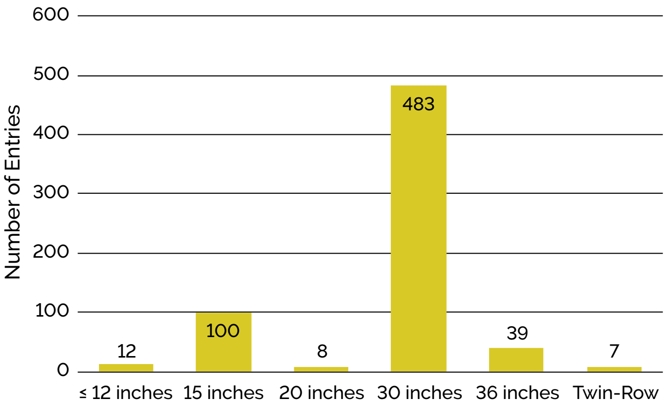

Figure 7. Row spacings used in high yield soybean entries.

In a recent DuPont Pioneer summary of soybean row spacing studies, 15-inch and drilled soybeans yielded around 4 bu/acre greater than soybeans in 30-inch rows (Jeschke and Lutt, 2016). However, studies included in this summary were all located in the Central and Eastern Corn Belt, where solar radiation during reproductive growth tends to be more of a limiting factor and narrower rows would be expected to provide an advantage. Results of the high yield soybean challenge clearly show that high yields are attainable in 30-inch rows in Nebraska and Kansas. All 4 of the entries that exceeded 100 bu/acre were planted in 30-inch or wider rows.

The popularity of ridge- and strip-till systems has likely contributed to soybean acres staying in or moving to 30-inch rows. The ability to cover acreage more quickly using a larger 30-inch row planter is likely a factor as well. Even if one assumes a slight yield reduction with 30-inch rows compared to narrower rows, this could be offset by the yield benefit of more timely planting.

Pioneer Premium Seed Treatment Offering

Nearly all high yield soybean challenge entries used seed with the Pioneer Premium Seed Treatment offering (Figure 8). The Pioneer Premium Seed Treatment offering helps emerging soybean plants ward off early season insect and disease issues, particularly when planting earlier into cool, wet soils or high residues. In DuPont Pioneer research trials conducted in 2013 and 2014, the Pioneer Premium Seed Treatment offering increased soybean yield by 4.5 bu/acre versus non-treated soybean varieties in responsive environments.

Foliar Fungicide and Insecticide

Foliar fungicides and foliar insecticides were both used on close to half of the entries (Figure 8). A total of 42% of entries included both treatments with 6% receiving a fungicide only, 6% an insecticide only, and 46% receiving neither. The average yield of soybeans receiving both treatments was 3.3 bu/acre greater than entries receiving no treatment. A survey of DuPont Pioneer on-farm side-by-side comparisons from 2007 to 2011 showed an average yield response of 5.3 bu/acre with similar results observed in DuPont Pioneer small-plot research trials (Jeschke and Ahlers, 2015).

High yield soybean challenge results from 2013 to 2015 showed a 4.2 bu/acre advantage of the full fungicide plus insecticide treatment. In 2016, insect and disease pressure in soybeans was generally lower, and fewer entries had a foliar treatment applied, which reduced the 4-year average yield advantage of the full treatment. Insecticide application should not necessarily be a routine treatment. Treatment decisions should be based on insect thresholds evaluated from a combined insect number perspective, rather than any single insect species.

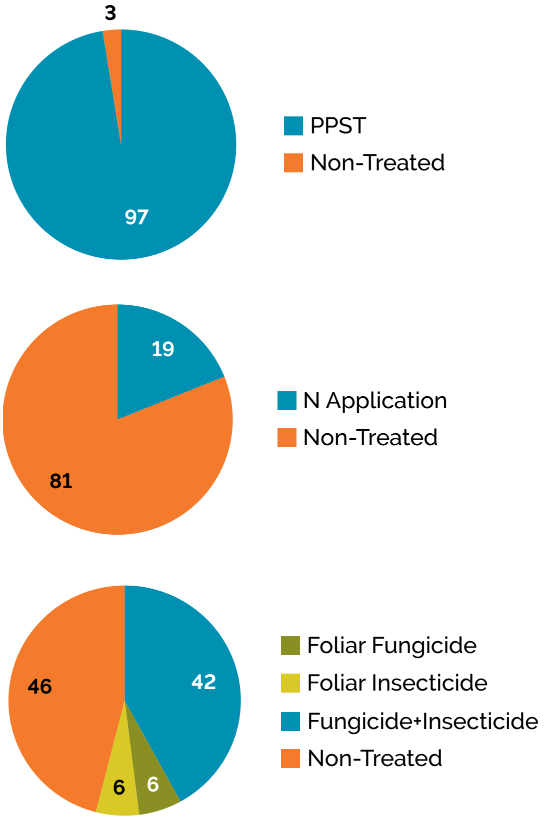

Figure 8. Frequency of use of Pioneer Premium Seed Treatment offering, foliar fungicide, foliar insecticide, and supplemental nitrogen in high yield soybean entries.

Supplemental Nitrogen

Of the 354 entries with nitrogen management practices reported, nearly 19% included a supplemental nitrogen application (Figure 8). Around half of these entries had nitrogen applied prior to planting; the other half had an in-season application. The average yield of entries that received supplemental nitrogen was slightly greater than that of non-treated entries; however, results did not indicate that supplemental nitrogen would likely provide an economic benefit. These results align with those of previous DuPont Pioneer and university research that indicate economic benefit of supplemental nitrogen on soybeans is unlikely outside of low organic matter soils or poor nodulation situations (Schmidt, 2013).

Planting Date

Over the four years of the high yield soybean challenge, the average planting date was May 11th. Irrigated locations were planted three to seven days earlier on average than non-irrigated locations (Table 1).

Table 1. Average planting dates, 2013-2016.

Year	Irrigated	Non-Irrigated
2013	May 15	May 19
2014	May 7	May 11
2015	May 5	May 12
2016	May 10	May 13

Yields tended to decline with later planting. The average yield with early May planting (May 1 to 10) was 84.5 bu/acre, compared to 78.1 bu/acre with late May planting (May 21 to 30). However, yields exceeding 90 bu/acre were achieved over a wide planting window – from April 5 through May 24 (Figure 9). The 4 entries over 100 bu/acre were planted between April 30 and May 9, all in 2016. Optimum planting date changes with annual weather conditions; however, planting in the early portion of the planting season generally maximizes yield. Several DuPont Pioneer studies have shown the value of planting as early as practical with a full-season soybean variety. It is possible to plant too early every year and associated risks, such as residue management, SDS management, and late freeze risk, must be considered.

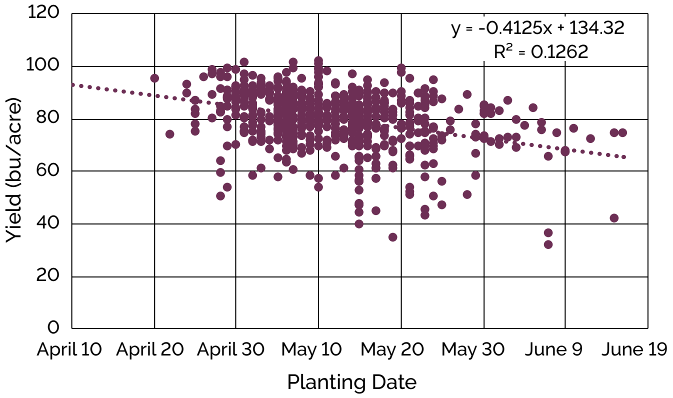

Figure 9. Soybean yield by planting date of high yield soybean entries.

Seeding Rate

Seeding rate of high yield soybean challenge entries ranged from 120,000 to 210,000 seeds/acre with an average seeding rate of 174,000 seeds/acre. The majority of entries had seeding rates between 160,000 and 190,000 seeds/acre (Figure 10). Data from the high yield soybean challenge show that higher seeding rates are used with higher yield level production practices. Seeding rates in the high yield soybean challenge were generally greater than typical soybean seeding rates in the Western Corn Belt according to results of a 2015 DuPont Pioneer survey. Yields in the high yield soybean challenge were also generally around 20 bu/acre above average. Establishing an adequate stand is critical to maximizing soybean yield potential.

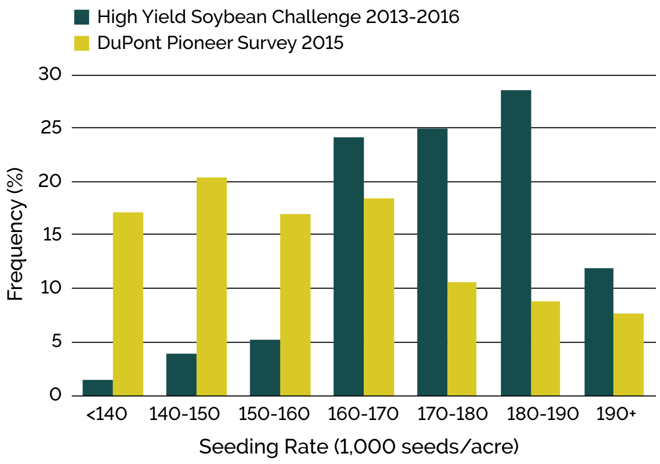

Figure 10. Seeding rate distribution on entries in the high yield soybean challenge (2013-2016) and by percent of soybean acres planted in the Western U.S. Source: 2015 DuPont Pioneer brand concentration survey.

Soybean yields tended to increase with seeding rate, although yields over 90 bu/acre were achieved over a wide range of seeding rates – from 140,000 to 210,000 seeds/acre (Figure 11). Establishing healthy, uniform stands is important to maximize soybean profitability even though soybeans respond to reduced stands better than many other crops. Because there are many factors that affect soybean stand establishment, optimum seeding rates vary considerably by region, cropping practice, and field.

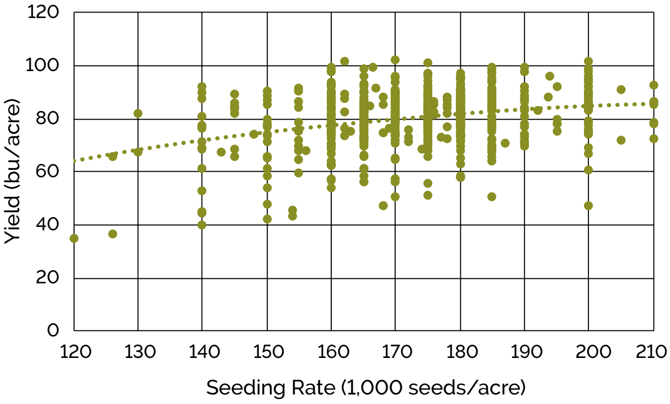

Figure 11. Soybean yield by seeding rate of high yield soybean entries.

Agronomic advantages of maintaining moderate to high seeding rates:

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

Crop Rotation

Nearly half of the high yield soybean challenge entries were in a corn-soybean rotation. Another 30% had a crop other than soybeans in the field the prior 2 seasons, and 25% were planted to a different crop for 3 years or more. Yield tended to be greater in entries with more than 1 season between soybean crops – a 7.1 bu/acre increase compared to entries rotated away from soybeans for a single season (Figure 12).

Figure 12. Yields of high yield soybean entries according to number of prior consecutive years planted to a crop other than soybean.

Multiple university studies have shown that soybean yields tend to be greater when a field is rotated away from soybeans for more than one consecutive season. However, results of a University of Nebraska-Lincoln study suggested that the yield benefit of extended rotations may diminish as productivity levels increase (Grassini et al., 2017).

Soil Fertility

A subset of high yield soybean entries reported soil test levels for phosphorus (101 entries) and potassium (50 entries). In nearly all cases, fertility levels were at or above recommended levels for soybean production. University of Nebraska guidelines indicate that soybean yield response to fertilization is unlikely at phosphorus levels above 12 ppm (Bray P1) and potassium levels above 124 ppm (Shaver, 2014). However, soil fertility guidelines are commonly based on crop needs and removal rates at yield levels below those achieved in the high yield soybean challenge and may be insufficient for high yield production.

Table 2. Soil test range for phosphorus (Bray P1) and potassium for entries reporting soil fertility data.

Phosphorus		Potassium	
Range	Entries	Range	Entries
ppm	*number*	0-100	0
< 15	5	101-150	1
15-20	16	151-250	8
21-25	26	251-350	20
26-30	26	> 350	21
> 30	28	> 30	28

Nebraska soils typically do not require additional potassium for soybean production. Fertilizer applications in high yield soybean entries were generally focused on insuring adequate levels of phosphorus. A total of 99 entries indicated a pre-plant fertilizer application of monoammonium phosphate (11-52-0), Microessentials® SZ™ (12-40-0-10S-1Zn), or other similar phosphorus-containing fertilizer blend.

Harvest Timing and Grain Moisture

Grain buyers pay growers for soybeans based on a weight of 60 lbs/bu and a grain moisture level of 13%. Delivering soybeans below or above that level reduces profits. Soybeans over 13% moisture can be docked for being too wet. Soybeans below 13% moisture result in fewer effective bushels for which the grower is paid. For example, delivering soybeans at 10% moisture rather than 13% would be equivalent to a 3.3% reduction in yield.

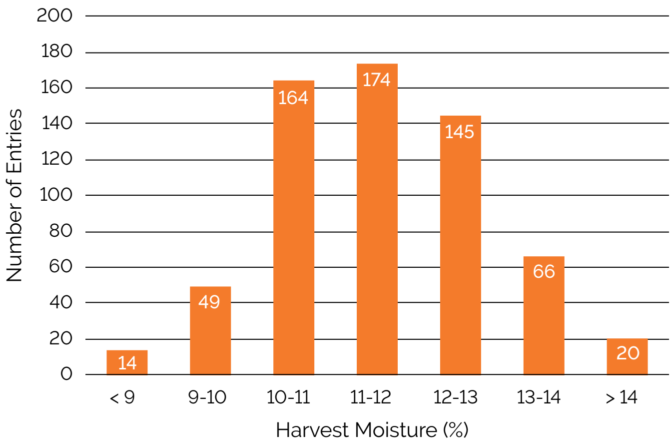

Figure 13. Harvest moisture of high yield soybean entries.

A 2016 University of Nebraska-Lincoln study of soybean deliveries to elevators in Hamilton and York County, NE, found that soybeans delivered at 1 to 4 points below target moisture were common (Pryor et al., 2016). Data from the high yield soybean challenge showed very similar results with over half of entries reporting harvest moisture between 10 and 12% (Figure 13). Yields tended to decline with later harvest dates (Figure 14) and with lower harvest moisture.

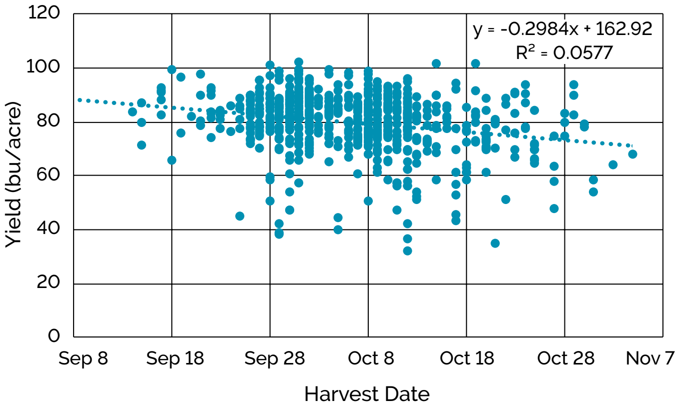

Figure 14. Soybean yield by harvest date of high yield soybean entries.

The observed decline in yield with lower harvest moisture, however, was greater than what would be expected purely due to lower grain weight alone (Table 3). This suggests that other factors associated with later harvest may also have contributed, such as pod shattering and grain loss at harvest.

Table 3. Expected and observed soybean yield reduction associated with sub-optimum grain moisture at harvest.

Harvest Moisture (%)	Yield Reduction (%)	
	Expected	Observed
12	1.1	2.6
11	2.3	5.4
10	3.3	8.5
9	4.4	11.9

Summary of Management Trends

Variety Selection: Adoption of new, high yield potential soybean varieties likely contributed to the 8.6 bu/acre increase in average yield from 2013 to 2016.

Seed Treatment: Nearly all growers (97%) used soybean varieties treated with Pioneer Premium Seed Treatment offering.

Planting Date: May 11 was the average planting date over four years. Soybeans planted in early May yielded 6.4 bu/acre higher on average than those planted in late May.

Seeding Rate: Seeding rates were generally higher than typical for the Western Corn Belt with an average seeding rate of 174,000 seeds/acre.

Crop Rotation: Yield tended to be greater in entries with more than 1 season between soybean crops – a 7.1 bu/acre increase compared to entries in a corn-soybean rotation.

Tillage: Around half of the entries were in no-till, but those with some form of tillage tended to be higher yielding.

Foliar Fungicide and Insecticide: Around half of the entries used a foliar fungicide and/or insecticide. Entries treated with both yielded 3.3 bu/acre greater on average.

Harvest Timing and Grain Moisture: Yields tended to decline with later harvest dates and with lower harvest moisture.

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Plantability Testing for Larger Soybean Seed

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

Soybean Seed Size

Soybean seed size is influenced by both genetics and the environment. Under similar growing conditions, varieties will differ from each other in the seed size they produce – small, medium, or large. Genetic effects on size of seed are largely predictable, but weather conditions and their effects on seed size are not. Consequently, growers are sometimes faced with using seed sizes that are above or below the norm. With appropriate planter adjustments, however, excellent planting accuracy and stands can be achieved, even with large or small seed.

This article, produced in a collaborative effort between DuPont Pioneer and equipment providers, offers management tips to help growers maximize planter performance and ensure the highest possible planting accuracy with larger soybean seed. Refer to your planter manufacturer's owner's manual for complete recommendations.

Seed Delivery

Central Commodity System (CCS™), Bulk Fill, or Air Seed Delivery (ASD) planter systems may be challenged by larger seed as well as treated seed. To help ensure a high level of performance, proper attention must be given to:

- **Planter Lubricants:** The liberal use of talc, graphite, or a talc/graphite blend, specific by planter type, is critical. Thorough mixing of these lubricants in seed generally produces the best results.
- **Seed Treatment:** The planter performance of untreated versus treated seed may be different. Generally, larger seed combined with treatment will require a higher level of management. Tank pressure, fan speeds, and other adjustments should be made for the specific seed/treatment combination that is being planted. Refer to the planter operator's manual for recommendations.
- **Ground Speed:** High population settings, especially when combined with high ground speed, may provide challenges. With higher ground speeds, the metering units are operating at faster RPM's, making it more challenging to keep seed in place as the unit rotates. If meters are "starving" for seed, a reduction in ground speed may provide a solution. Do not exceed the planter manufacturer's recommendations for ground speed.

Seed Metering

Kinze® Brush Meter: Brush meters have two discs available for soybeans. When the size falls on the split, typically you will need the 48-cell (dark blue) plate.

Table 1. Kinze brush meter plates for soybean.

Crop	Plate Color-Code (Disc Part No.)	Upper Brush Retainer	Cells	Seed Size Range	Lubricant
Soybean	Black (GA5794)	GD11122	60	2,200-4,000	Graphite/talc
Specialty soybean	Dark blue (GA6184)	GD11122	48	1,400-2,200	Graphite/talc

Kinze EdgeVac®: Kinze recommends graphite and does not generally support talc/graphite blends except for extremely high-humidity conditions.

Case IH® Vacuum Planter: The soybean seed disk with 130 holes can create a low vacuum issue when the larger soybeans touch each other. This causes the soybean seeds to sit in the pocket incorrectly. Use the soybean disk with 80 holes. If the maximum planting speed is too slow with the 80-hole soybean disk, use a 100-hole soybean disk.

Table 2. Case IH vacuum planter disks for soybean.

Description	Part Number
3.5 mm 100-hole soybean disk	87698876
4.5 mm 100-hole soybean disk	87698875

John Deere® Vacuum: Start with eight inches of vacuum, and adjust to match seed size/treatment. John Deere recommends talc only and does not support the use of graphite or talc/graphite blends.

John Deere Radial Bean Meter: There are three standard soybean seed size settings. Refer to operator's manual for the correct setting to match the seed that is being planted.

Soybean Plantability Testing by Pioneer

- Pioneer conducted plantability tests of 2016-produced soybean seed using seven different planter metering units.
- Seed tested included 10 sources, ranging in size from 1,985 to 2,726 seeds/lb.
- *Planter-stand seed drop of 1,000 seeds would represent perfect plantability.*

Kinze® Brush Meter: 60-Cell Plate

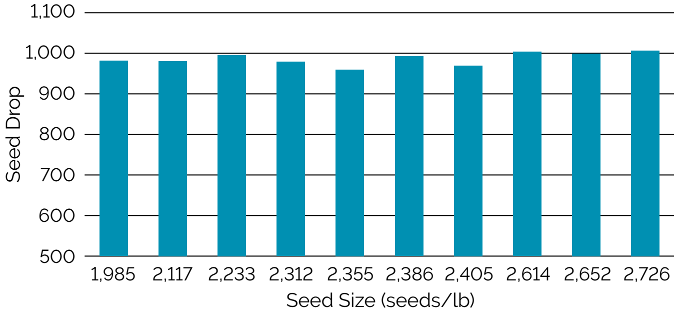

Figure 1. Seed drop using a Kinze brush meter with a 60-cell plate for soybean seed ranging from 1,985 to 2,726 seeds/lb.

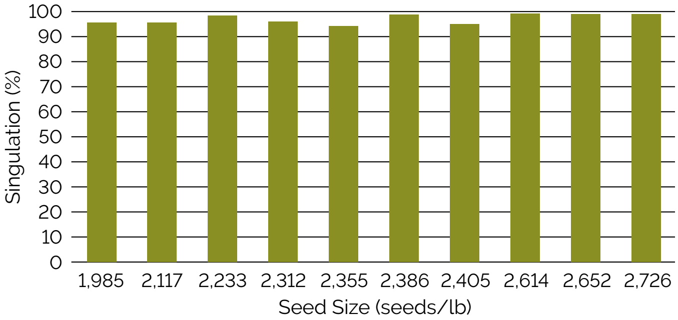

Figure 2. Singulation using a Kinze brush meter with a 60-cell plate for soybean seed ranging from 1,985 to 2,726 seeds/lb.

Kinze Brush Meter: 48-Cell Plate

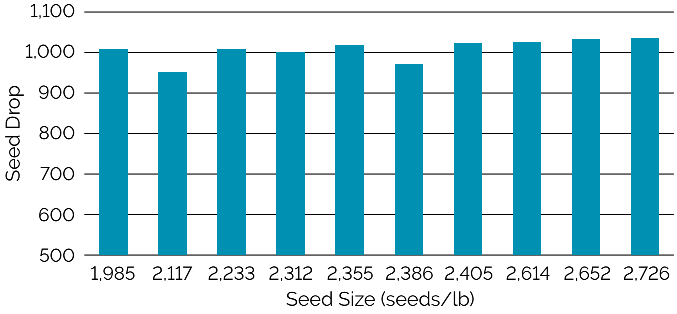

Figure 3. Seed drop using a Kinze brush meter with a 48-cell plate for soybean seed ranging from 1,985 to 2,726 seeds/lb.

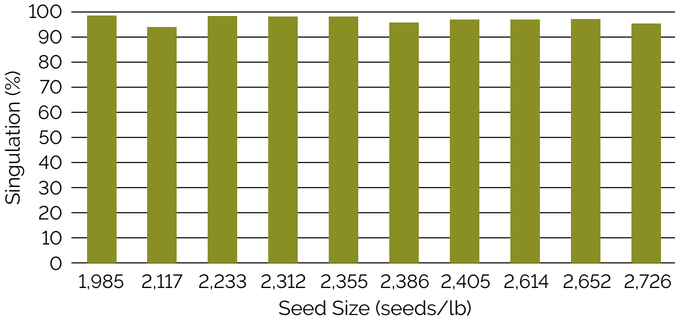

Figure 4. Singulation using a Kinze brush meter with a 48-cell plate for soybean seed ranging from 1,985 to 2,726 seeds/lb.

Case IH® Vacuum ASM: 100-Cell Soybean Disk

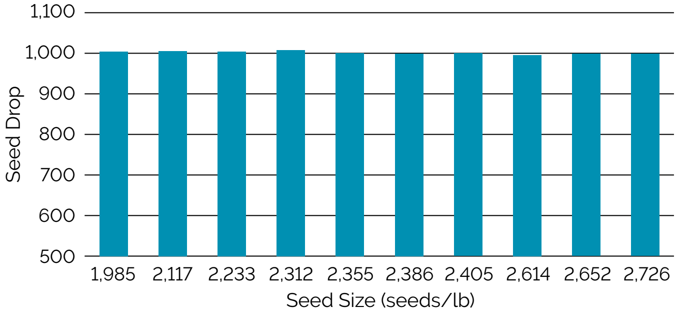

Figure 5. Seed drop using a Case IH vacuum meter for soybean seed ranging from 1,985 to 2,726 seeds/lb.

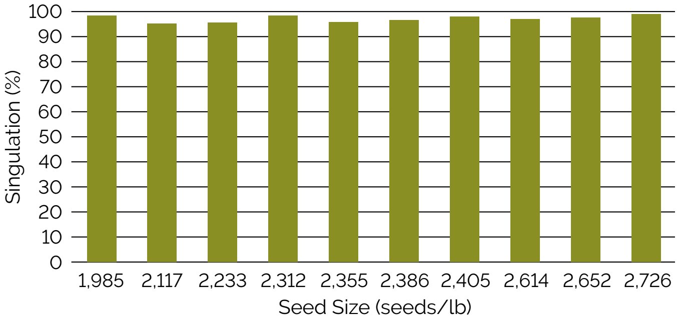

Figure 6. Singulation using a Case IH vacuum meter for soybean seed ranging from 1,985 to 2,726 seeds/lb.

John Deere Vacuum: 108-Cell Soybean Disk

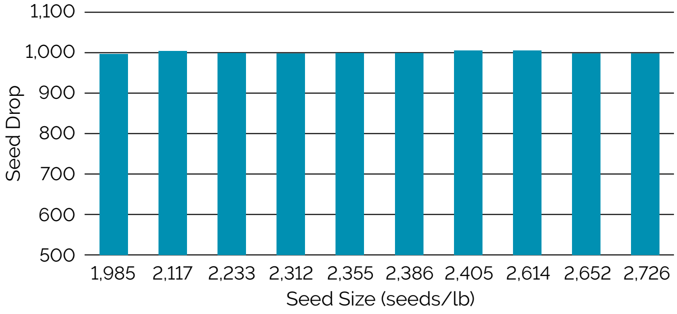

Figure 7. Seed drop using a John Deere vacuum meter for soybean seed ranging from 1,985 to 2,726 seeds/lb.

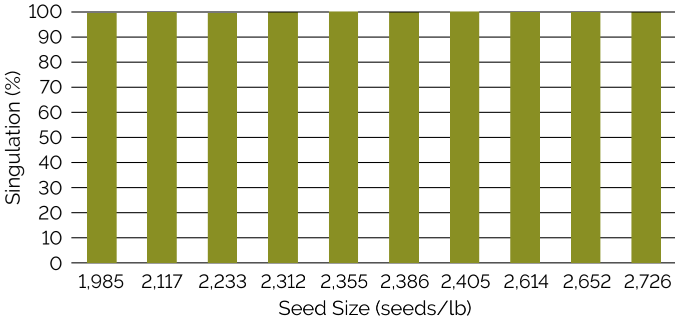

Figure 8. Singulation using a John Deere vacuum meter for soybean seed ranging from 1,985 to 2,726 seeds/lb.

John Deere® Radial Bean Meter: Seed Setting "C"

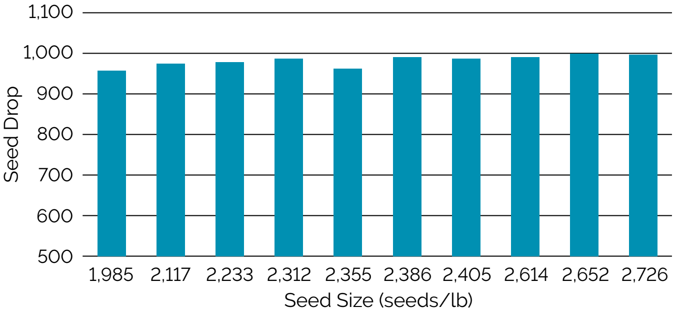

Figure 9. Seed drop using a John Deere radial bean meter for soybean seed ranging from 1,985 to 2,726 seeds/lb.

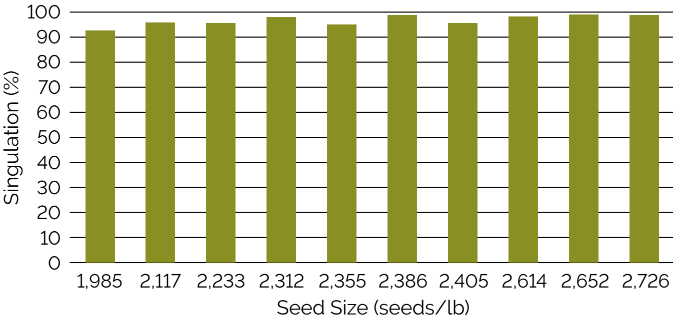

Figure 10. Singulation using a John Deere radial bean meter for soybean seed ranging from 1,985 to 2,726 seeds/lb.

Precision Planting eSet® Vacuum

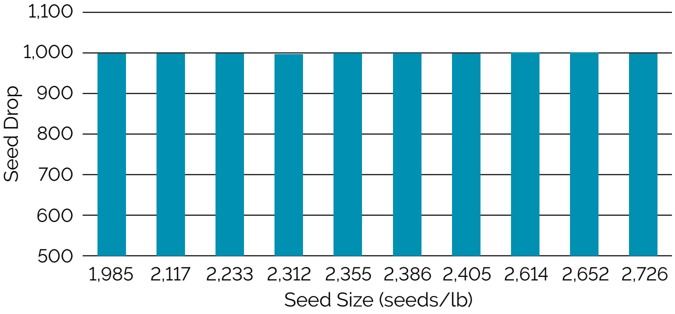

Figure 11. Seed drop using a Precision Planting eSet vacuum meter for soybean seed ranging from 1,985 to 2,726 seeds/lb.

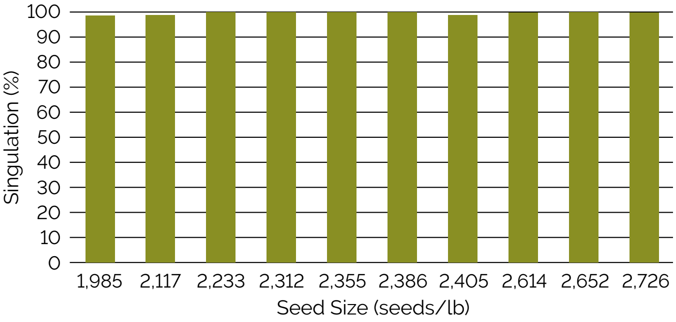

Figure 12. Singulation using a Precision Planting eSet vacuum meter for soybean seed ranging from 1,985 to 2,726 seeds/lb.

AGCO White® Air

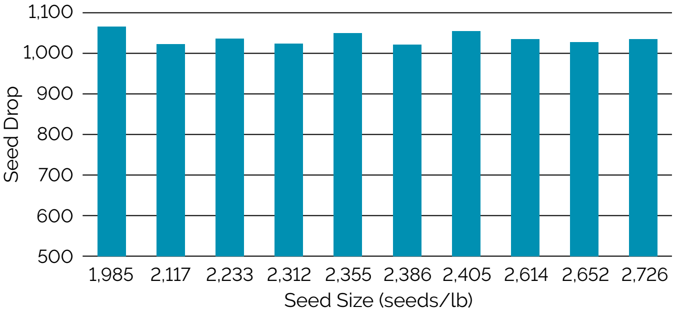

Figure 13. Seed drop using a White air meter for soybean seed ranging from 1,985 to 2,726 seeds/lb.

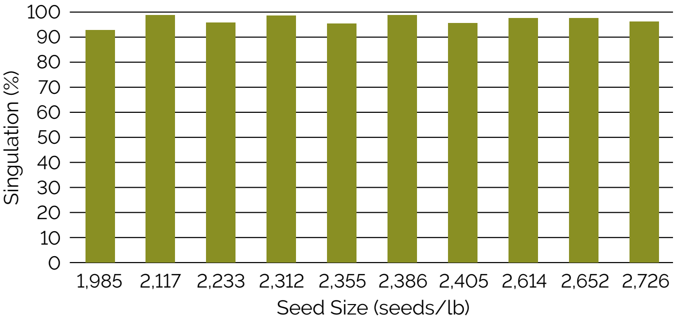

Figure 14. Singulation using a White air meter for soybean seed ranging from 1,985 to 2,726 seeds/lb.

Plantability Testing - Conclusions

- Seed size had very little effect on seed drop and singulation for any of the meters tested over the range of 1,985 to 2,726 seeds/lb.
- Results indicate that acceptable plantability could be achieved with seed as large as 1,985 seeds/lb with proper planter settings or plate selection on any of the planters tested.

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Effects of Cold Temperatures Following Soybean Planting

*by **Mark Jeschke, Ph.D.,** Agronomy Information Manager,*
***Adam Gaspar, Ph.D.,** Field Agronomist, and **Ryan Van Roekel, Ph.D.,** Field Agronomist*

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® GrowingPoint® 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, wet conditions at and after planting can injure developing seedlings; delay germination and emergence; and reduce stand establishment.

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.

Pioneer® brand soybean varieties are rated for field emergence, which is based on speed and strength of emergence in sub-optimal temperatures.

Imbibition 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 a drop in soil temperature or cold 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 hours) can be lethal, especially on lighter-textured soils.
- 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, making them good buffers to protect the three potential growing points between them and more resistant to injury when temperatures approach freezing.
- Freezing damage that extends below the cotyledons will result in the death of the plant.

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.

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 soybean seedlings against *Fusarium virguliforme* infection and can reduce the incidence of SDS in early-planted soybean.

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 hours 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 soybean 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.

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Reducing Harvest Losses in Soybeans

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

Introduction

Minimizing soybean harvest losses can mean substantially higher yields and profits. Extension agricultural engineers suggest that good harvest practices can reduce losses to near 3%, or only 1 to 2 bu/acre. However, delayed harvest or poorly adjusted equipment can result in losses of 10% or more. Since soybeans dry very quickly, close monitoring of grain moisture is required for timely harvest. In addition, combines must be properly adjusted, frequently checked, and carefully operated to minimize losses.

Timely Harvest of Soybeans Important

Soybeans should be harvested the first time they reach 13 to 14% moisture. Moistures above 13% incur a price discount, but moistures below 13% result in less weight at the elevator. The loss of saleable weight can be more substantial than typical discounts for wetter grain, so growers should avoid delivering overdry soybeans. In addition to lost income, harvest losses are also increased when soybeans are harvested too dry.

Soybeans dry very quickly after reaching maturity. At physiological maturity (R7), grain moisture is over 50%, but a harvestable moisture of near 13% can be reached in as little as 2 weeks under good drying conditions. In order to time harvest perfectly, it is necessary to monitor soybean drying very closely. At full maturity (R8), 95% of pods have reached their mature pod color. From this point, only 5 to 10 good drying days are needed before harvest. Begin checking grain moisture before all of the leaves have dropped off all of the plants since various stresses can cause soybeans to retain some leaves. It is not uncommon to see a few green leaves and stems on some plants after the pods are fully ripe and the soybeans are dry enough for harvest.

When harvest is delayed, a number of potential losses may occur, including increased tendency to shatter. Soybeans at harvest stage lose and re-absorb moisture readily and after several such cycles of wetting and drying, are predisposed to shatter. In addition, delayed harvest often results in losses from increased lodging and reduced grain quality.

Research on Field Losses Due to Harvest Delays

A study conducted at the University of Wisconsin investigated the effects of delayed harvest on soybean field losses. Two varieties from three maturity groups were grown for three years at Arlington, Wisconsin. Initial harvest for each maturity group began three to seven days beyond the R8 stage (full maturity). Other plots were left in the field for periods of two, four, and six weeks beyond the first harvest date. Yield losses as a percent of total yield are shown in Table 1.

Table 1. Effect of harvest delay on soybean field losses.

Harvest Delay	Year 1	Year 2	Year 3	3-Year Average
	- - - - - - - - - *% yield lost* - - - - - - - - -			
None	4.1	6.7	7.5	6.1
2 Weeks	5.0	9.9	9.2	8.1
4 Weeks	6.3	16.1	12.1	11.5
6 Weeks	6.8	18.1	19.9	13.9
Average	5.6	12.7	11.4	9.9

Source: University of Wisconsin.

Yield loss was greatly affected by year. In year one, field losses after two to six weeks of harvest delay were only slightly higher than normal field losses with no delay. However, losses due to harvest delay in both years two and three were over twice that of year one. Losses increased with weeks of delay in all years tested.

Preharvest, shatter, and stem losses increased with harvest delays, but stubble and threshing losses remained constant across delays. Gathering unit losses accounted for 60% of total losses.

Monitoring Harvest Losses

Four soybeans in a one foot square area are equal to a one bushel loss per acre. Harvest losses should be checked in front of the combine, behind the header, and in back of the combine to pinpoint causes of loss. Ag engineers suggest checking losses in a rectangular area across the entire width of the harvest swath. A 10 ft^2 rectangle is suggested as a standard size. Forty soybeans in a 10 ft^2 area translates into a 1 bu/acre loss. A 10 ft^2 frame can be built out of rope with small metal stakes (heavy wire or nails) at the corners to insert into the ground. The length of the frame should be the width of the combine header. The width of the frame needed to equal 10 ft^2 of area is shown in Table 2.

Table 2. Width and length of rope required for various combine header sizes to create a 10 ft^2 frame.

Width of Combine Header (Length of Rope Frame)	Width of Rope Frame
15 ft	8 in
18 ft	6 ¾ in
20 ft	6 in
22 ft	5 ½ in
24 ft	5 in
26 ft	4 ⅝ in
28 ft	4 ¼ in
30 ft	4 in

A convenient means of measuring losses is to stop the combine and back up about 20 ft. Losses are determined in 3 areas: in the standing soybeans, behind the combine, and 5 to 10 ft behind the standing soybeans. Set the frame across the entire swath width in the standing soybeans. Soybeans, pods, or broken stems on the ground in this area represent preharvest losses. Count the number of soybeans shelled and in pods on the ground within the frame. Forty soybeans is equal to one bu/acre yield loss.

Now move the frame to an area behind the combine, and count again. Be sure to sort through all crop residues to reveal shelled soybeans and unthreshed pods beneath. Also count soybeans in pods on stubble. These soybeans behind the combine represent total losses. The difference between total losses and preharvest losses represents harvesting losses.

Harvesting losses can be further divided into “gathering” or “cutter-bar” losses and machine losses by checking just behind the standing beans. To make this measurement, set the frame across the entire swath width about 5 to 10 ft behind the standing soybeans. Count and record the number of individual soybeans within the frame that are shelled and in pods, including stubble. This count minus the preharvest count equals the gathering loss. Machine loss is calculated as follows:

Total loss - preharvest loss - gathering loss = machine loss

Reducing Harvesting Loss with Proper Adjustment

Though the type of equipment used can impact harvest loss, all equipment must be properly adjusted and carefully operated to minimize losses. Soybeans that never get inside the combine can account for 80 to 85% of harvest losses. These losses occur due to shatter or lost stalks at the header or left on stubble below the cut-height. Other losses occur due to improper threshing and separation at the cylinder as well as screens. Harvesting losses can be minimized with proper maintenance and adjustment:

- Be sure knife sections and ledger plates are sharp and that wear plates, hold-down clips, and guards are properly adjusted. Chains and bearings should be properly lubricated and belts tight.
- Proper reel speed in relation to ground speed will reduce gathering losses. Shatter increases if the reel turns too fast; stalks may be dropped if the reel turns too slow. Use a reel speed about 25% faster than ground speed.
- The reel axle should be 6 to 12 in ahead of the sickle in most cases. Operate a bat reel just low enough to tip cut stalks onto the platform. The tips of the fingers on a pickup reel should clear the cutterbar by about two inches.
- Cut soybeans as low as possible to minimize stubble losses. Excessive stubble heights can result in significant losses, as shown in Table 3.

Table 3. Percent loss resulting from excessive stubble heights.

Height of Cut	% Loss
0 in (hand-harvested)	0%
3.5 in	5.4%
5.0 in	9.4%
6.5 in	12.2%

- Adjust the rotor- or cylinder-concave clearance according to your operator’s manual. Then adjust rotor or cylinder speed for threshing conditions. Generally, operate the rotor or cylinder at the lowest speeds that effectively thresh the soybeans. When beans are tough, rotor or cylinder speed may have to be increased. Decrease rotor or cylinder speed as beans dry to reduce breakage.
- Keep forward speed at about three miles/hour for most combines. Slow down for uneven soil surface or other abnormal conditions.
- Stubble losses can also be reduced by planting and cultivating practices. Height of lowest pods is increased by growing soybeans in narrow rows or by higher plant populations within the row.

Reducing Yield Loss from Pod Shattering in Soybean

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

Pod Shattering in Soybean

- Seed shattering (or pod dehiscence) is an essential characteristic for the survival of many wild plant species. Plants release and scatter seeds to propagate the next generation.
- A critical feature of the domestication and breeding of crop species, such as soybean, has been to eliminate this characteristic to the extent possible, selecting for genetic lines that retain the seeds on the plant so that they can be harvested.
- Pod shattering in modern soybean varieties can be influenced by genetics as well multiple environmental factors.
- Carefully managing variety selection and harvest practices can help to reduce yield loss due to pod shattering.

Yield Impacts of Pod Shattering

- Yield loss from pod shattering can be subdivided into two components: pre-harvest loss from pod shattering that occurs in the field prior to harvest and gathering loss that results from pods that shatter at the header during harvest.
- Extension agricultural engineers suggest that good harvest practices can reduce losses to near 3%, or only 1 to 2 bu/acre. However, delayed harvest or poorly-adjusted equipment can result in losses of 10% or more.
- Yield losses can be calculated by counting seeds on the ground. Every 4 beans/ft^2 corresponds to a yield loss of ~1 bu/acre.

Varietal Differences

Genetic Basis of Resistance to Pod Shattering

- Soybean varieties have genotypic differences in their resistance to pod shattering.
- Research has shown that resistance to pod shattering in soybean is a qualitative heritable trait (Caviness, 1969) controlled by multiple genes (Carpenter and Fehr, 1986; Tukamuhabwa et al., 2000).
- Physical characteristics of the pods, including pod length, pod wall thickness, and lignification of the cells along the suture lines of the pod valves, influence resistance to shattering (Dong et al., 2014; Krisnawati and Adie, 2017)

Rating of Pioneer® Brand Soybean Varieties

- Pioneer brand soybean varieties are rated on a 1 to 9 scale for their resistance to shattering.
  - 9 = Excellent tolerance to shattering
  - 1 = Poor tolerance to shattering
- These ratings are based on data collected over multiple locations and years in field experiments managed to induce shattering.

Factors That Can Influence Pod Shattering

Environmental Conditions

- Drought conditions during pod development can increase the risk of pod shattering, a phenomenon that was widely observed during the 2012 drought.
- Drought conditions during pod development result in weak pod sutures more prone to splitting, particularly when the pods and beans are re-wet by rainfall following maturity.
- Drought stress effects on pod shatter can be exacerbated by infestations of two-spotted spider mites *(Tetranychus urticae)*, which can compound plant stress and accelerate senescence (Ostlie and Potter, 2012).
- High temperatures at maturity can increase shattering (Bara et al., 2013).
- Late-season hail can damage pods and cause shattering (Figure 1).

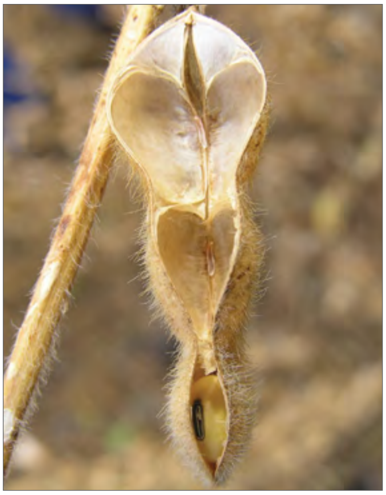

Figure 1. A soybean pod that has been split open as a result of hail damage at the R7 growth stage (beginning maturity).

Insect Damage

- Pod feeding from insect pests, such as bean leaf beetles and grasshoppers, can damage pods, resulting in seed loss (Figure 2).

Delayed Harvest

- The risk of yield losses from pod shattering becomes greater when harvest is delayed more than ~10 days beyond maturity.
- Shattering losses can increase significantly when soybean seed moisture drops below 11%.
- Repeated wetting/drying cycles between soybean maturity and harvest can cause pods to split and drop seed.

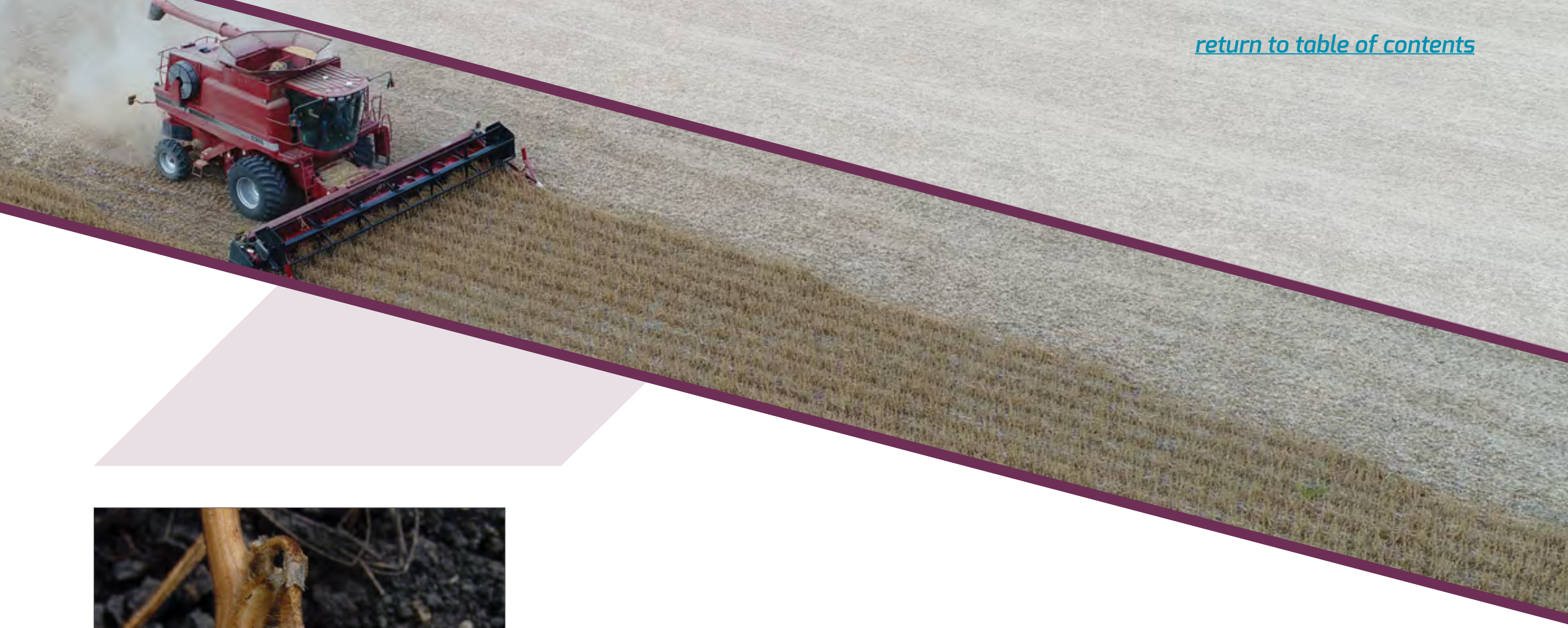

Figure 2. Soybean pod damaged by bean leaf beetles and/or grasshoppers.

Managing to Reduce Shatter Losses

- The most important management practice for minimizing soybean yield loss from pod shattering is timely harvest following maturity.
- Soybeans dry very quickly after reaching maturity. At physiological maturity (R7), grain moisture is over 50%, but a harvestable moisture of near 13% can be reached in as little as 2 weeks under good drying conditions.
- A University of Wisconsin study showed that yield losses can increase when harvest is delayed more than two weeks after harvest maturity (Figure 3).
- In order to time harvest perfectly, it is necessary to monitor soybean drying very closely. At full maturity (R8), 95% of pods have reached their mature pod color. From this point, only 5 to 10 good drying days are needed before harvest.

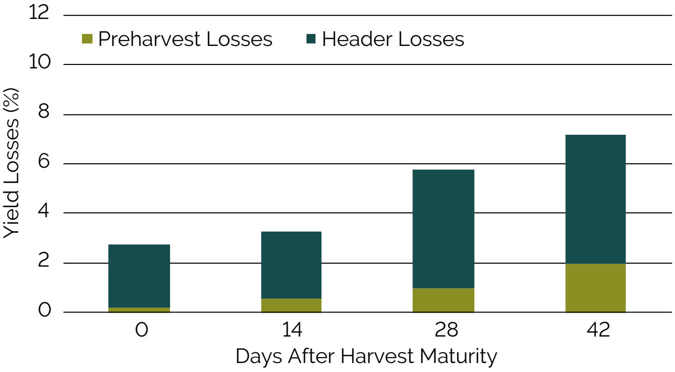

Figure 3. Preharvest and header losses associated with delayed soybean harvest (Philbrook and Oplinger, 1989).

Variety Selection

- Timely harvest begins with variety selection; planting varieties with a range of relative maturities can help align maturity with harvest and make sure fields do not reach maturity too far ahead of when they can be harvested.
- Each major soybean maturity group is subdivided into 10 relative maturity ratings. Each 1/10 subdivision corresponds to roughly 1 additional day to reach full maturity; for example, a 2.5 variety will reach maturity approximately 4 days after a 2.1 variety.
- The optimum maturity range for a given operation will depend on length of time harvest typically takes.
- Consult your Pioneer sales professional for recommendations on maturity range and specific varieties suited to your operation.

Combine Speed and Settings

- Slowing down harvest speed can help reduce gathering losses. Keep forward speed at about three miles per hour for most combines. Slow down for uneven soil surface or other abnormal conditions.
- Equipment must be properly adjusted and carefully operated to minimize losses. Soybeans that never get inside the combine can account for 80 to 85% of harvest losses.
    - » Be sure knife sections as well as ledger plates are sharp and that wear plates, hold-down clips, and guards are properly adjusted. Chains and bearings should be properly lubricated and belts tight.
    - » Proper reel speed in relation to ground speed will reduce gathering losses. Shatter increases if the reel turns too fast; stalks may be dropped if the reel turns too slow. Use a reel speed about 25% faster than ground speed.
    - » The reel axle should be 6 to 12 in ahead of the sickle in most cases. Operate a bat reel just low enough to tip cut stalks onto the platform. The tips of the fingers on a pickup reel should clear the cutterbar by about two inches.

Managing Delayed or Frost-Damaged Soybeans

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

Introduction

Soybean maturity is determined primarily by daylength, but planting date affects soybean maturity as well. Agronomists estimate that soybean maturity can be delayed by about one day for every four days of planting delay beyond the normal date. Growing conditions, such as abnormally cool summer temperatures, can also affect soybean growth, development, and maturity. When crop maturity is delayed, the risk of damage due to a fall frost increases, especially in northern states where the full growing season is commonly used. This article will discuss managing delayed soybeans and those damaged by a freeze prior to crop maturity.

Freeze Damage to Soybeans

Soybean plant tissue is more tolerant of freezing temperatures than that of some other crops, such as corn. However, temperatures below 32 °F can damage leaves, and temperatures below 30 °F for an extended period can damage stems, pods, and seeds. The severity of damage depends on the growth stage of the soybeans, the low temperature reached, and the duration of the freezing temperatures.

Oftentimes, a first fall frost is light and limited in duration. Such a frost is most likely to damage only the leaves in the upper canopy of the plant. In such cases, soybean pods and seeds can continue to develop, and yield may be only minimally affected. However, a more severe freeze that damages stems, pods, and seeds has the potential to reduce both the yield and quality of the crop.

Soybean Reproductive Growth Stages

Soybean researchers have divided soybean reproductive development into eight stages – two each for flowering, pod development, seed development, and maturity. Because flowering, pod development, and early seed development occur in July and August, soybeans are rarely exposed to a frost at these stages. However, soybeans are exposed to potential frost damage at the full-seed and maturity stages in a late-planted season and/or one with cool summer temperatures, especially in northern states. Should a frost occur before maturity, growers need to determine the soybean growth stage at the time of the freeze to estimate potential yield loss (Table 1 and Figure 1).

Assessing Soybean Damage

Frost damage within a soybean field may vary considerably, depending on microclimate effects, landscape position in the field, canopy density, and other factors. Generally, thick plant canopies formed by narrow rows and/or high plant populations tend to hold the soil heat better and protect the lower portion of the plants and pods to some extent. After a frost, it is best to wait two or more days before making a crop assessment to allow damage to be fully expressed.

Table 1. Description of soybean growth stages R6 to R8.

Stage	Description of Soybean Growth Stage
R6 – Full Seed	"Green bean" stage. A pod containing a green seed that fills the pod cavity found at one of the top four nodes of the main stem.
R7 – Beginning Maturity	One normal pod on the main stem has mature color (brown or tan). At this stage, almost all pods and seeds have lost their green color. About 50% of leaves have turned from green to yellow.
R8 – Full Maturity	95% of pods have reached their mature color. From this stage, harvest moisture (13-16%) is usually reached in about 5-10 days.

If only a light frost occurs, damage may be confined to the upper leaves in the canopy. After a waiting period, damaged leaves will appear wilted and dried but usually remain on the plant. Undamaged leaves (likely lower in the canopy or in higher landscape positions in the field) should still appear green and healthy. Some maturity delay (several days) may be expected on damaged plants, and small pods near the top of the plant may abort or fail to fill normally.

If a more severe freeze occurs, leaves in the lower canopy may also be damaged, as well as stems and pods. Frost-damaged stems turn dark green to brown. Beans that were still green and soft at the time of the freeze will shrivel, reducing soybean yield (seed size and test weight), quality, and drying rate. If beans had reached physiological maturity (R7) prior to the freeze, these yellow beans should dry normally, and quality should not be affected.

Soybeans are graded by USDA standards to determine the quantity of damaged seeds (e.g., heat damaged), splits, foreign material, off-color (e.g., green) beans, and loads with a musty or sour odor. With delayed maturity or frosted soybeans, loads could be discounted for most or all of the above criteria. For that reason, care must be taken in harvest, handling, drying, and storing of the crop.

Harvesting/Drying Freeze-Damaged Soybeans

If soybeans have been frosted prior to maturity or have higher than normal moisture at harvest, combine settings may have to be adjusted to minimize harvest losses. Reduce the concave clearance, and then begin to increase rotor or cylinder speed if more aggressive threshing is needed for wet, tough soybeans. Check behind the combine, and readjust settings as conditions change throughout the day or season.

R6 – Full Seed Stage

"Green bean" stage
- bean fills pod cavity

Seed moist. ~ 75 - 80%

~ 25 days remaining until full maturity

Yield loss ~ 20 to 35%

R7 – Beginning Maturity Stage

All green color lost from seeds and pods

Seed moist. ~ 55 - 60%

~ 8 - 10 days remaining until full maturity

Yield loss ~ 0 to 5%

R6.5 – Mid-Way from Full Seed to Maturity

Pod/seed color between green and yellow

Seed moist. ~ 65 - 70%

~16 - 18 days remaining until full maturity

Yield loss ~ 10 to 15%

R8 – Full Maturity Stage

95% of pods are mature color (but about 5-10 days are still needed to reach harvest moisture)

Seed moist. ~ 25 - 35%

Yield loss ~ 0%

Figure 1. Soybean growth stages and approximate seed moisture, days to maturity and yield loss from a hard, killing frost that stops seed development.

Harvesting/Drying Freeze-Damaged Soybeans (cont.)

Soybeans should be at 16% seed moisture or below for ideal threshing, but with delayed maturity or early frost, some fields may be wetter than this late in the season. In those cases, harvesting at 18% or slightly higher moistures can be attempted if soybeans are sufficiently defoliated, but drying is required. Dryer temperatures need to be significantly lower for soybeans than for corn, as too much heat causes excessive seed coat cracking and eventual splits. Keeping the relative humidity of the drying air above 40% minimizes cracking, but this greatly limits dryer temperature and may not allow the through-put needed.

Storing Freeze-Damaged Soybeans

A normal soybean crop should be dried to 13% for a 6-month storage period and 12% for 12 months of storage. For lower quality soybeans, experts suggest drying grain one or two points below that required for a normal crop, monitoring grain closely while in storage (at least twice monthly), and storing this grain for only six months rather than a year.

Studies have shown that green soybeans, if properly dried, have the same storage properties as normal soybeans. However, preliminary studies have also shown that green beans do not lose their internal green color, although the surface color may lighten or mottle somewhat after weeks or months in storage. For this reason, growers may want to screen grain prior to storage to remove smaller green beans to help avoid significant discounts at the elevator.

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Second-Year Soybean Production

*by **Dan Emmert,** Field Agronomist, and **Mark Jeschke, Ph.D.,** Agronomy Information Manager*

Soybeans Following Soybeans

- High soybean prices relative to corn can favor shifting acreage away from corn to more soybean production.
- In some cases, this may involve planting fields to soybeans in two consecutive years.
- Planting soybeans in the same field in consecutive seasons is generally not recommended by extension agronomists; however, there are several management considerations that can help maximize productivity for growers pursuing this strategy.

Yield Potential

- Growers should expect lower yields in second year soybeans.
- Research results have varied, but a yield reduction of 3 to 5% compared to soybeans following corn is not an unreasonable expectation.
    - » 2.3% average yield reduction in an 8-year Univ. of Kentucky study with individual year reductions up to 13% (Grove, 2017).
    - » 6.5% average yield reduction in a 4-year study in Ontario (OMAFRA, 2009).
    - » 0% average yield reduction in a long-term Univ. of Wisconsin study (Lauer et al., 1997).
- Plant stress caused by environmental conditions, diseases, or insects can easily increase yield losses in second year soybeans.

Management Considerations

Field Selection

- Avoid poorly-drained soils due to higher risk of *Pythium, Phytophthora,* sudden death syndrome (SDS), and brown stem rot.
- Consider cover crops in fields with slopes prone to erosion; soybeans produce less residue than corn and decompose more quickly.

Variety Selection

- Avoid planting a field to the same soybean variety two years in a row.
- Select soybean varieties with high levels of disease resistance.
- Test for soybean cyst nematod (SCN) and select SCN-resistant varieties.
    - » SCN proliferates in long-term soybean cropping systems.
    - » Resistant varieties can reduce SCN reproduction by 70 to 80%.

Seed Treatments

- Use a fungicide seed treatment to protect against diseases, such as *Pythium* and *Phytophthora,* that can increase in severity under continuous soybean production.
- Pioneer® brand soybeans treated with ILeVO® fungicide seed treatment provides control of sudden death syndrome and certain soil-borne nematodes, such as SCN and root knot nematodes.
    - » Soybeans treated with ILeVO fungicide treatment produced significantly higher grain yield (4.9 bu/acre) in high SCN environments in DuPont Pioneer testing (O'Bryan and Burnison, 2016).
    - » In moderate SDS environments, the addition of ILeVO fungicide treatment increased grain yield 4.5 bu/acre.

Soil Fertility

- Growers often routinely rely on carryover fertilizers for soybean when rotated with well-fertilized corn. Soybean after soybean may require additional fertilizer, especially potassium.

Disease Management

- Many diseases can overwinter on soybean residue. Some can be managed with fungicide; some cannot.
    - » Stem canker and pod and stem blight can overwinter on residue, but fungicides are not as effective on these.
    - » Septoria brown spot and frogeye leaf spot are two diseases that can be managed with foliar fungicides.
- Scout fields regularly to check for disease problems.

Weed Management

- Any weed escapes in the previous soybean crop are likely to result in greater weed management challenges in second-year soybean.
- Use multiple modes of action.
- Soil residual herbicides applied pre-emergence and with a post-emergence application can help manage problem weeds.

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Integrated Management of White Mold in Soybean Production

by **Jeff Wessel,** *Former Agronomy Trials Manager,*
Steve Butzen, M.S., *Agronomy Information Consultant,*
and **Mark Jeschke, Ph.D.,** *Agronomy Information 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.

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. 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.

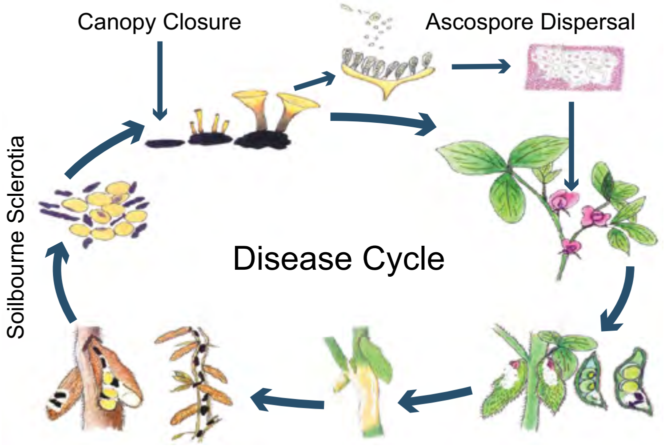
Disease Description and Life Cycle

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).



Disease and sclerotia development occur from R3 to R8 growth stages.
Illustration by Marilyn Hovis

Figure 3. White mold disease cycle. Illustration by Marilyn Hovis.

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. DuPont 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.

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 per acre. Exceptionally 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.

Figure 4. White mold infection.

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) 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® fungicide (Table 1)), a biological fungicide (Contans® fungicide), and the herbicide lactofen (Cobra® herbicide and Phoenix® herbicide).

Application Timing

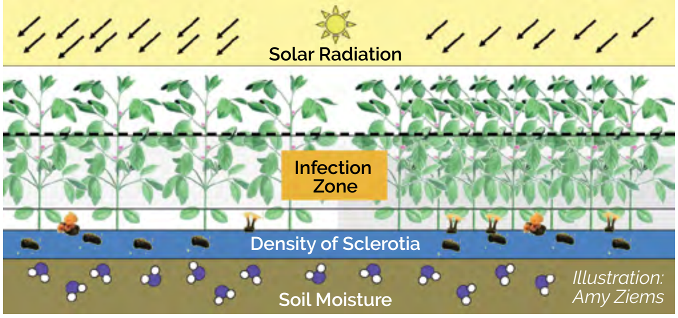
Optimum application time of fungicides and lactofen for white mold control in soybeans is approximately the R1 growth stage, also known as the beginning bloom or first flower stage (Mueller et al., 2004; University of Wisconsin – Madison, 2008). For much of the U.S. Corn Belt, the R1 stage coincides 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

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 soybeans 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.



Dense canopy favors white mold pathogen.

Figure 5. Depiction of environmental conditions and canopy zone conducive to white mold infection. Illustration by Amy Ziems.

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.

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, DuPont Aproach fungicide reduced white mold severity and increased yield by 7.2 bu/acre (Table 2).

Table 2. Performance [a, b] of DuPont Aproach vs. untreated check in six comparisons (Ohio, Michigan, and Illinois; 2009-2011).

Treatment	% Reduction in Severity of White Mold *	Yield Advantage (bu/acre) **
DuPont Aproach Fungicide vs. Non-treated	27.6 %	7.2 bu/acre

* % 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.

**** 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.

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 2-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.

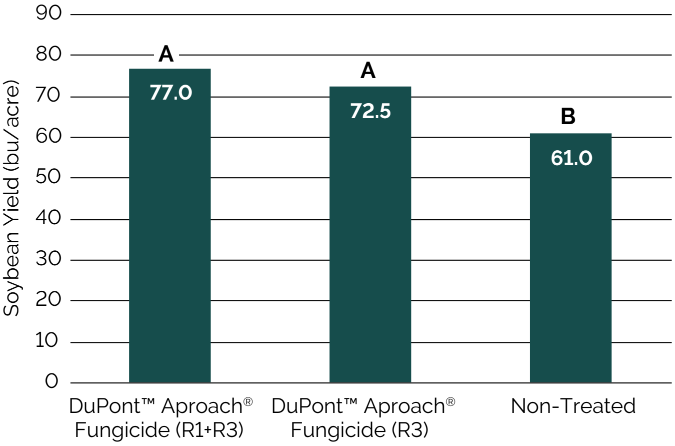


Figure 6. Yield of soybeans treated with DuPont Aproach fungicide at the R3 growth stage and the R1 and R3 growth stages compared to non-treated soybeans in a Univ. of Wisconsin trial at Hancock, WI, in 2016 (Smith et al., 2016).

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 at 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.

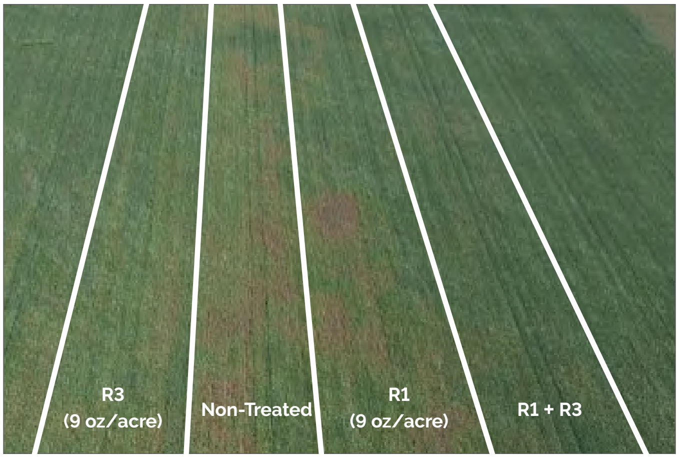


Figure 7. DuPont on-farm fungicide research trial near Edgar, WI comparing DuPont™ Aproach® Fungicide applied at R1, R3, and R1+R3 growth stages to a non-treated check under heavy white mold pressure (September 11, 2017).

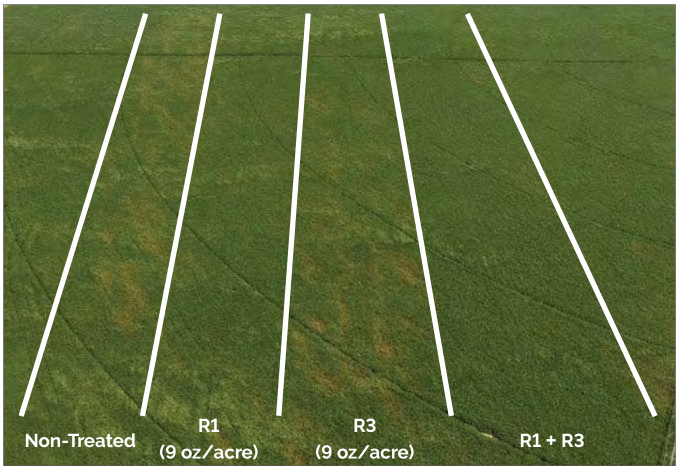


Figure 8. DuPont on-farm fungicide research trial near Orchard, NE comparing DuPont Aproach fungicide applied at R1, R3, and R1+R3 growth stages to a non-treated check under heavy white mold pressure (August 23, 2017).

Topsin®: Topsin 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®; 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® and Cobra®: Endura 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 application also increased yields.

Cobra: Lactofen, the active ingredient in Cobra and Phoenix®, is a herbicide 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 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 treatments, yield increases were larger and more consistent with applications at R1 (Figure 6). Despite heavy disease pressure (48% incidence), Cobra 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 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 have tended to be highly variable (Nelson et al., 2002).

Herbicides with PPO inhibiting sites of action, such as Cobra, 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, yield loss may result in the absence of disease (Dann et al., 1999). Producers should use caution when considering the wide-spread use of Cobra, especially on moderately resistant varieties when environmental conditions do not favor disease.

Contans® WG: Contans 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 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 should be applied at least three months prior to white mold infection, and soil-incorporated immediately following application to a depth of at least four inches. Contans 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 may be fall- or spring-applied, fall applications have performed better than those done in spring.

Figure 9. Foliar fungicide application to soybeans.

Future Tools to Help Manage White Mold

Variety Improvement: DuPont Pioneer 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. DuPont Pioneer 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.

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Diaporthe/Phomopsis Fungi Complex in Soybeans

by **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 entry way 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).
- 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 a red/brown mark on the hypocotyl. This looks similar to Phomopsis seed decay.

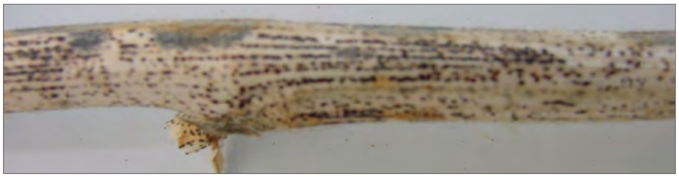

Figure 2. Soybean infected with pod and stem blight disease have black specks that are in linear rows.

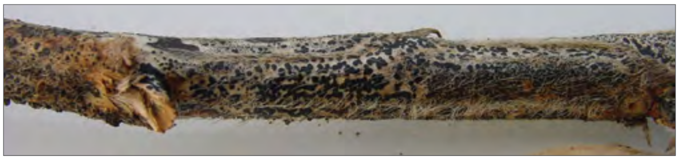

Figure 3. Anthracnose infected soybean stem with black lesions in an unorganized pattern.

Figure 4. Black, dusty microsclerotia in an unorganized pattern on the outer stem are a characteristic symptom of charcoal rot.

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 and streaks on the lower part of the stem near the soil.
- Small black specks of pycnidia may occur on the seeds.

Figure 5. Dark zone lines on the lower stem are an indicator of *Diaporthe* fungal infection.

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, sudden death syndrome, and 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.

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Soybean Aphid Management

by **Chuck Bremer, Ph.D.,** *Former Agronomy E-Business Information Manager,* and **Steve Butzen, M.S.,** *Agronomy Information Consultant*

Summary

- The soybean aphid, *Aphis glycines* Matsumura, is the only aphid known to extensively colonize soybean fields in North America.
- This pest is a potential threat to virtually all soybeans grown in the U.S. and Canada. However, some states are more at risk of economic infestations than others (Figure 1).
- In addition to geographical considerations, soybean fields at highest risk include those planted late and those that experience hot, dry weather that stresses the crop.
- Because soybean aphid populations can increase rapidly, growers should scout regularly, monitor population levels, and be prepared to treat if necessary.
- Soybean aphids have many natural insect enemies, such as lady beetles and their larvae, that can help keep moderate populations in check. Fungal diseases are also emerging as important factors in aphid population regulation.
- This article will address soybean aphid damage, life cycle, response to climate, and management. Spraying considerations, the DuPont Pioneer antibiosis ratings, biocontrol, insecticide timing, and ongoing research are also discussed.

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Introduction

Soybean aphid was first detected in North America near Lake Michigan during the 2000 growing season and quickly spread to become a major insect pest of soybeans. Annual population levels are determined primarily by weather and interactions of aphids with their natural enemies, particularly the multi-colored Asian lady beetle and entomopthora fungi. The number of aphids present on buckthorn in early spring has often correlated with aphid outbreaks. However, prevailing summer weather patterns also determine if aphids will reach damaging levels.

In high infestation years, growers have managed aphids primarily by scouting and application of insecticides when aphid numbers exceed economic thresholds. Insecticide seed treatments may also provide some measure of early control. In addition, DuPont Pioneer researchers have rated Pioneer® brand soybean varieties for their ability to reduce aphid reproduction and are also working to develop genetic resistance as a future management tool.

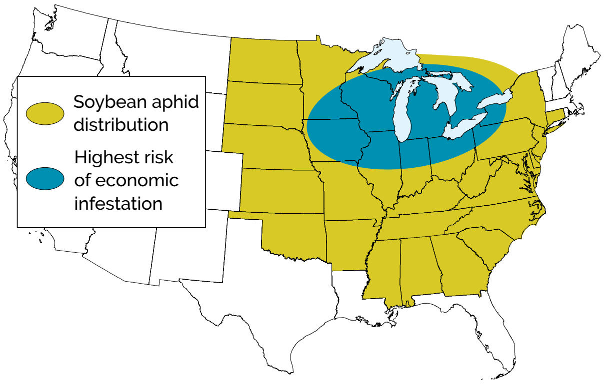


Figure 1. Soybean aphid distribution and area of increased risk.

Damage to Soybeans

Soybean aphids have needle-like sucking mouthparts, which they insert into soybean tissues to remove plant sap. From the seedling stage until blooming, aphids colonize tender leaves and branches of the plant. Later, the aphids move to the middle or lower parts of the plant and tend to colonize the underside of leaves as well as the stem. If aphid numbers are high, leaves may become yellow and distorted; the plant may become stunted; and plant parts may be covered with a dark, sooty mold. Yield losses often accompany these symptoms.

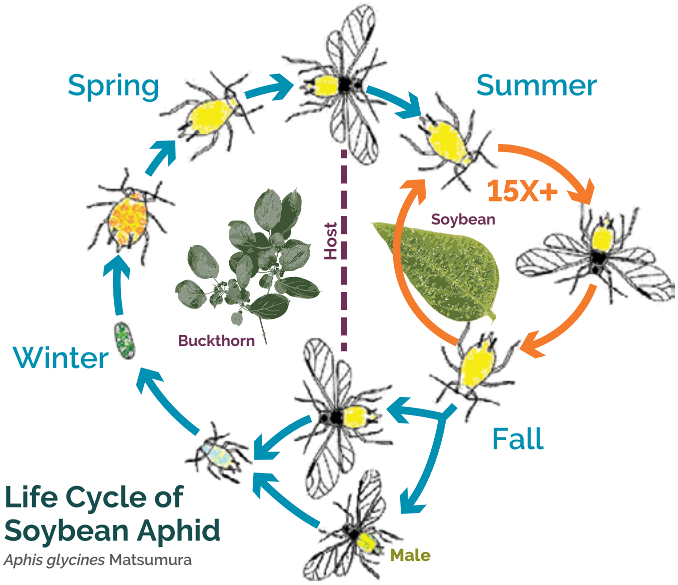
The soybean aphid is capable of transmitting viral diseases to soybeans, including alfalfa mosaic, soybean mosaic, bean yellow mosaic, peanut mottle, peanut stunt, and peanut stripe. Viruses can cause leaf mottling; various leaf, pod, and plant deformities; stunting; and discolored seed. Virus development usually results in yield losses.

Description and Life Cycle

Soybean aphids are small, yellow aphids with distinct black cornicles ("tail-pipes"). At only 1/16th of an inch long (the size of a pinhead or smaller), they cannot be distinguished from other aphids with the naked eye. The soybean aphid is the only aphid in North America known to extensively colonize soybean fields. Soybean aphids overwinter as eggs on a woody shrub species known as buckthorn – *Rhamnus davurica*, *R. cathartica*, and others of the *Rhamnus* genus. The eggs hatch in the spring into wingless types, which establish on buckthorn for two generations. The third generation emerges, produces wings, and migrates to soybean fields and other acceptable hosts in late May to early June. Acceptable hosts include alfalfa, crimson clover, red clover, snap bean, other clovers, and some weeds, such as nettles.

Figure 2. Black cornicles help identify soybean aphid.

Figure 3. Left: Winter host – *Rhamnus* sp. Also known as buckthorn. **Right:** Soybean aphid overwintering eggs under bud of buckthorn.



- **Late fall thru early spring is spent on buckthorn**
- **Late spring until fall is spent on soybean**
- **All individuals are female, except briefly in the fall**
- **All reproduction is parthenogenetic (clones) until after mating on the winter host**
- **Winged individuals are produced for moving between hosts and for dispersal during the summer**
- **Winter survival is as an egg under buckthorn leaf buds**

Figure 4. Life cycle of the soybean aphid (after David Voegtlin).

Soybean aphids can produce up to 15 generations during the summer on soybeans before migrating back to buckthorn in the fall as winged females. Once on buckthorn, winged females give birth to wingless females, which mate with males developed on soybeans to produce the overwintering eggs.

Effect of Climate

The environment plays a significant role in the yearly population dynamics of soybean aphids. Favorable overwintering sites and weather increase winter survival and can contribute to localized outbreaks in any given year. Large outbreaks as in 2001 and 2003 are mostly dependent on favorable temperatures during the growing season that allow for rapid reproduction and longer survival periods.

Research conducted by the University of Minnesota suggests temperatures above 95 °F (35 °C) limit soybean aphid reproduction and reduce the length of survivorship of any individual aphid to less than 10 days. Ideal temperature conditions of 77 to 82 °F (25 to 28 °C), on the other hand, allow soybean aphids to live for 20 or more days and maximize reproduction. This research and experience in the past few years indicate that temperature plays a major role in the doubling time of aphid populations and ultimately determining if they become a serious pest. Average temperatures between 75 and 85 °F (24 and 29 °C) can create a population doubling time of less than two days with high survival rates; temperatures above 90 °F (32 °C) result in doubling time of one week or more as well as low survival.

Favorable climate also enhances migration and movement of soybean aphids. Typical migration of winged soybean aphids has been documented at three to six miles per day. However, experience from 2001 and 2003 suggests that strong upper air currents from fronts and storm systems carry soybean aphids much longer distances, resulting in widespread infestations during large outbreak years.

Managing Soybean Aphids

Management decisions regarding soybean aphids are difficult due to the explosive potential of aphid populations and the interaction of aphids with climatic conditions and natural predators. Careful scouting is absolutely necessary to determine if treatment is needed and to time insecticide treatments to maximize their effectiveness.

Scouting

Soybean aphids tend to develop most quickly on vegetative stage soybeans, and their development slows on flowering/reproductive stage soybeans. The recommended time to begin scouting is when soybeans are in the late vegetative stage (usually late June/early July in Midwest states). Growers should continue their watch through pre-flower and flowering stages and treat if aphids reach the economic threshold.

Figure 5. Abundance of lady beetles (left) or their larvae (right) are often indicative of soybean aphid populations. These and other natural predators help control moderate infestations.

An economic threshold (ET) for the R1 to R5 growth stages is currently established at 250 aphids/plant (average of 20 to 30 plants per field) if populations are increasing. If this thresh-old is reached, treating within seven days is required to prevent populations from reaching the Economic Injury Level (EIL) where yield loss exceeds the cost of treatment. Scouting guidelines are shown on the following page. A "speed scouting", or sequential sampling method, has also been developed that can save time when the decision is relatively clear cut: *http://www.extension.umn.edu/agriculture/soybean/pest/docs/soybean-aphid-scouting.pdf*

Figure 6. Soybean aphids colonizing leaves (left) and stem (right) of soybean plant are at economic levels in these pictures.

Research studies have shown that insecticide application can be a useful strategy for reducing yield loss due to soybean aphids. Furthermore, careful timing of applications was found to be important to help minimize losses. Results are reported below for studies conducted in the large outbreak years of 2001 and 2003.

Research on Insecticide Application & Timing

Field-sized insecticide trials were established in 2001 at 73 locations and again in 2003 at 103 locations in several northern states where the soybean aphid had exceeded economic thresholds. When the results were grouped by spray date, the data reveal that highest yield increases were obtained when spraying occurred from mid-July through the first days of August in both cases (Figure 7). Treatments applied beyond this timeframe resulted in less yield response.

In 2001, less response occurred after August 10 while in 2003 the beneficial response lasted until August 20.

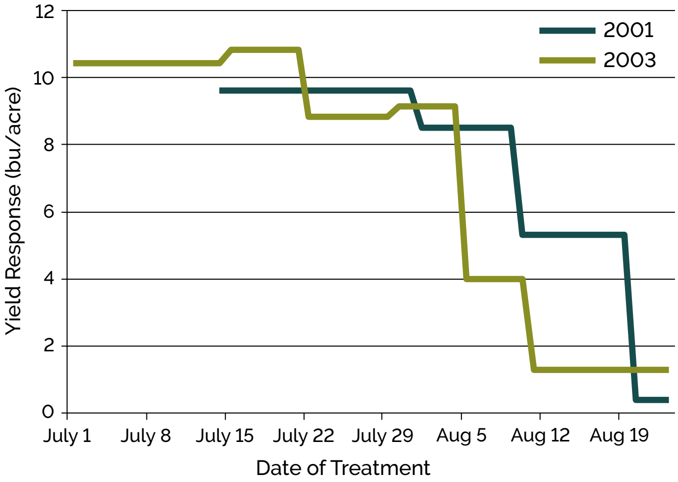


Figure 7. Soybean yield response to insecticide timing, 2001 and 2003 combined data. *Source: DuPont Pioneer.*

Scouting Guidelines

Aphid Reproduction Facts

- All spring and summer offspring are female, are born pregnant, and give live birth. Birth rate is 3 to 8 per day for 10 to 40 days.
- Generation time is typically 7 to 10 days. Populations can double in 1.4 to 1.9 days.
- Up to 15 generations may occur per season on soybeans. Aphids can disperse three to six miles per day.

Scouting Guidelines

- Entomologists suggest sampling 5 to 10 areas of the field (covering 80% of the field) and examining a total of 20 to 30 plants per field.
- *See specific extension guidelines in your state.*

Early Season Scouting Tips

- Scout along tree lines and field edges. Look for:
  - Aphids on the underside of the upper leaves
  - Ants tending aphid colonies
  - Presence of lady beetles and larvae

Mid-Season Scouting Tips – Look for:

  - Presence of honeydew and sooty mold
  - White "skins" remaining after aphids molt
  - Crowding and movement into lower canopy

Conditions Favoring Aphid Reproduction/Survival

- Mild Winters
- Favorable Overwintering Sites
  - Wooded areas with buckthorn species
- Favorable Summer Host Plants
  - Soybeans – Alfalfa – All Clovers
- Moderate Summer Temperatures
  - Optimum temperature for aphids is ~ 82 °F (28 °C) with temperature range from 68 to 86 °F (20 to 30 °C).
  - Temperatures of 95 °F (35 °C) and above limit reproduction and survival.

Conditions Favoring a Treatment Response

- Crop development stage at early flower to seed set
- Aphid levels increasing
- Weather favorable for aphid reproduction/survival
- Late-planted soybean fields
- Lack of beneficial insects
- Absence of parasitic fungi

This demonstrates that soybean growth and development, weather patterns, and aphid population dynamics can change from year to year. Growers should time spray applications based on soybean growth stage and careful scouting of each field, rather than on the calendar date. Differences in weather, including both temperature and moisture, will affect both the aphids as well as the growth of the plant and ultimately the population dynamics. Each year will be unique.

The soybean aphid actually grows and reproduces better under cooler temperatures; however, under hot, dry conditions, affected fields are at a much higher risk of yield loss due to soybean aphids. Drought places soybeans under stress, which can magnify the effects of aphid feeding. Just as importantly, pathogenic fungi may not establish on aphid colonies during hot, dry weather, allowing aphid populations to explode when cooler temperatures return. Spider mites may also establish on soybeans during hot, dry conditions, which further stresses the plant and compounds the aphid problem.

Spraying Considerations

Soybean aphids feed primarily under soybean leaves or on stems and pods contained within a very dense canopy of soybean foliage. This environment makes it challenging to deliver insecticide sprays directly onto the aphids.

Coverage

For optimal control of aphid populations, use high pressure and high volume of carrier to achieve thorough coverage and penetration of the crop canopy. Research by the University of Minnesota suggests that either ground or aerial applications are effective methods.

- **Ground Applications:** Use 20 to 40 gal of carrier per acre and 30 to 60 PSI.
- **Air Applications:** Use 3 to 5 gal of carrier per acre.

Timing Applications: It is important that each field be thoroughly scouted before a treatment is applied. When timing insecticide applications, consider the aphid population dynamics, crop stage, and climatic conditions. It is important to note that chemical applications made during vegetative stages will likely result in re-infestations at levels higher than adjacent areas not previously treated. Applications should be delayed until economic thresholds are attained.

Tank Mixing With Herbicides: Coverage and timing are key. Adding an insecticide as a tank mix partner with an early herbicide application may reduce beneficials and may not correspond with optimal timing for either the weed or the insect pest.

Pre-Harvest Interval: The pre-harvest interval (PHI) of insecticides labeled for soybean aphid ranges from 21 to 60 days. Applications made in late July and into early August will require an insecticide with a very short pre-harvest interval, particularly with early maturity soybean varieties.

Caution: Some insecticides are extremely toxic to fish and aquatic invertebrates. Use caution when applications are made to any area adjacent to a body of water.

Foliar Insecticides Labeled for Soybean Aphids

Insecticides labeled and commonly used for foliar application and control of soybean aphid are listed below (label may refer to soybean aphid or Chinese aphid). See labels for additional information on use of these insecticides. (Product labels may change. Always read and follow label instructions.)

Table 1. Select insecticides* labeled and commonly used for control of soybean aphids in soybeans.

Insecticide	Active Ingredient	Rate per Acre	PHI**
Asana® XL	esfenvalerate	5.8-9.6 fl oz	21
Baythroid® XL	beta-cyfluthrin	2.0-2.8 fl oz	21
Lorsban®-4E	chlorpyrifos	1-2 pt	28
DuPont™ Lannate® LV	methomyl	0.5-1.0 pt	14
Mustang® Maxx	zeta-cypermethrin	2.8-4.0 fl oz	21
Warrior II with Zeon Technology®	lambda-cyhalothrin	0.96-1.6 fl oz	30

All of these products are restricted-use insecticides.

Always read and follow product label directions.

*For more info see: https://entomology.unl.edu/insecticides-control-soybean-aphids.

**Pre-harvest interval for grain. Do not apply insecticide during this period.

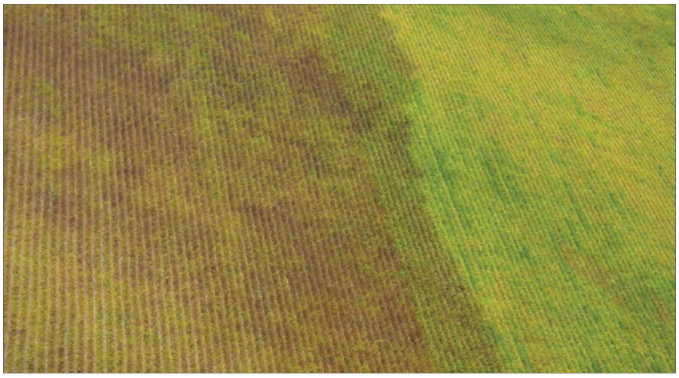


Figure 8. Aerial picture of unsprayed (left) vs. sprayed (right) field areas demonstrates the dramatic effect of soybean aphids and the benefit of treating.

Insecticide Seed Treatments for Soybean Aphid

In addition to foliar application of pesticides for control of soybean aphid, other methods may have some application. Insecticide seed treatments like the Pioneer® brand soybeans with Gaucho® insecticide, which is available as a component of Pioneer Premium Seed Treatment offerings, have been labeled for soybean aphid control and have shown some efficacy especially when fields are planted late. Soybean aphids do not immediately move from the overwintering host to soybean fields. This means use of a seed treatment for early planting may not be as effective as for late planting, as natural degradation of the insecticide will reduce effectiveness over time. However, seed treatments have been shown to provide effectiveness in delaying aphid increase, especially in late-planted situations. One would expect them to also have an effect on establishment of beneficials; however, this effect has not been extensively studied at this time.

Soybean Antibiosis Ratings — A Helpful Management Tool from DuPont Pioneer

Pioneer, in collaboration with Kansas State University, has developed a technique for screening soybean lines for their ability to naturally reduce the rate of growth, survival, and reproduction of soybean aphids that feed on soybean plants. This type of resistance is called "antibiosis." Antibiosis is measured by comparing the rate of aphid reproduction on different varieties. DuPont Pioneer soybean breeders are utilizing these breakthrough techniques to:

- Characterize current Pioneer® brand soybean varieties for their aphid antibiosis (a natural ability to ward off the pest by reducing its life span or inhibiting its reproduction)
- Identify sources of exceptional antibiosis and incorporate this trait into new Pioneer brand varieties.

Pioneer has provided aphid antibiosis ratings for its soybean varieties for several years. To obtain antibiosis ratings on Pioneer brand soybean varieties, see your local Pioneer sales professional or visit the Pioneer.com website.

How to Use Aphid Antibiosis Ratings for Pioneer Brand Soybean Varieties

- Because no soybean varieties currently on the market offer complete resistance to aphids, it is important that growers have a clear understanding of what aphid antibiosis ratings mean and how to practically utilize them. Using them correctly can save time and lead to more accurate decision making.
- An "Exceptional" antibiosis rating for a variety does not mean that aphids will not attack or damage the soybean plant. The ratings are relative comparisons, and according to our screening and characterization studies, aphids will reproduce faster on varieties rated "Below Average" or "Average" than they will on varieties with "Exceptional" or "Above Average" ratings.
- Because antibiosis rating is not correlated with ability to yield and because potential for aphid infestation is not predictable at planting, growers should not choose varieties for planting using the aphid antibiosis rating.
- Aphid antibiosis ratings should instead be used by growers to help in determining field scouting priorities and insecticide application decisions should an infestation of soybean aphids occur. For example, when aphid scouting is recommended in an area, fields planted to a variety with a "Below Average" rating should be scouted first and with greater frequency than fields planted to varieties with "Average," "Above Average," or "Exceptional" scores. Growers should use those varieties with "Below Average" ratings as early warning indicators for need to scout more widely.
- Growers should use these antibiosis ratings as an aphid management tool along with diligent scouting, timely insecticide application, and other recognized practices.

Biological Control of Soybean Aphids

In its native region of Asia, soybean aphid is rarely abundant because it has numerous natural enemies that attack and keep it in check. USDA and university scientists are interested in increasing natural enemies in North America as well. Their specific goal is to introduce exotic parasitoids that become established (survive and reproduce) in the Midwest and hold down aphid populations year to year. Successful examples of classical biocontrol in the U.S. include the introduction of parasitoids to control cereal leaf beetle and alfalfa weevil. Both of these non-native insects are now effectively suppressed by biological control and rarely have to be managed by growers.

After extensive testing, the USDA and land-grant researchers began releasing a host-specific parasitoid of soybean aphid called *Binodoxys communis* in 2007 and 2008. States participating in the release were South Dakota, Minnesota, Iowa, Wisconsin, Indiana, Michigan, and Illinois. This insect is a tiny, stingless wasp – about half the size of a grain of rice – that helps control soybean aphid populations in parts of Asia where both species naturally occur. The parasitoid wasp lays its eggs inside or on the soybean aphid, and when the eggs hatch, the larvae consume the living host from within. Scientists are closely monitoring the activity, survivability, and population levels of this organism over the next few years and will also test other biocontrol agents.

Figure 9. The *Binodoxys communis* is a parasitic wasp that attacks soybean aphids.

Ongoing Research on Soybean Aphids

Entomologists are continuing to closely study the soybean aphid as well as monitor infestation levels. Research is being conducted to better understand the life habit of this pest, identify natural enemies, and monitor their effect on the aphids, determine the potential yield loss from aphid infestations, and evaluate the effectiveness of insecticides and other management practices. Universities are also conducting field surveys to determine aphid presence and using traps to monitor movement from buckthorn to soybeans.

DuPont Pioneer researchers and others have identified several sources of single gene resistance to the soybean aphid. These are known as the *Rag* genes. These genes as well as native genes with antibiosis and antixenosis (avoidance) properties are targets of DuPont Pioneer breeders improving soybean aphid resistance in Pioneer® brand soybean varieties.

Because of the unpredictable nature of soybean aphid infestations, it is very important to DuPont Pioneer and its customers that such products be able to stand alone as top-performing products even when aphids are not a factor. Growers are encouraged to stay in contact with their Pioneer sales professional for updated information on diagnosing and managing soybean aphids in their area.

Figure 10. Aerial application of insecticide is a recommended control measure for soybean aphids.

Aphid Management Guidelines in Brief

- Consider using seed treated with an insecticide seed treatment to delay soybean aphid population establishment.
- Know the antibiosis rating of your Pioneer brand soybean varieties, and use those with the lowest rating as indicators for population increase.
- If soybeans have not yet reached R6 (full seed stage) in August and populations average over 250 per plant and still increasing, consider using an aerial insecticide application.
- Continue to scout and reapply if necessary.

More Information

- Soybean Aphid *(Aphis glycines)*. Soybean Research & Information Initiative website, a North Central Soybean Research Program: *http://www.soybeanresearchinfo.com/pests/aphid.html*
- University of Wisconsin Soybean Plant Health site: *http://www.plantpath.wisc.edu/soyhealth/aglycine.htm*
- North Central IPM Regional Soybean Aphid Suction Trap Network: *http://www.ncipmc.org/traps/index.cfm*

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Stink Bug Damage to Soybean

by **Greg Luce,** Former Agronomy Research Manager,
and **Mark Jeschke, Ph.D.,** Agronomy Information Manager

Stink bugs are found throughout the temperate and tropical areas of the world and are pests of many crops. In North America, plant-feeding stink bugs are most often associated with soybean, corn, tobacco, peaches, crucifers, tomatoes, small grains, red clover, and cotton. They can also be found feeding on many weed species.

Species, Identification, and Life Cycle

Redbanded stink bug.

In the U.S., many species of stink bugs are found, and several can infest soybean fields. The green stink bug, *Acrosternum hilare,* is the most common, but the brown stink bugs, *Euschistus* spp., can also be found attacking soybean pods and seeds. Stink bugs are typically more of a problem in the southern states, and additional species are found there. This includes the southern green stink bug, *Nezara viridula,* and the redbanded stink bug, *Piezodorus guildini.* The southern green stink bug can be distinguished from the green stink bug by a more rounded spine between their hind legs. The redbanded stink bug has a distinct red band across its back.

Green stink bug nymphs have a flashy display of black, green, and yellow or red, short, stubby, non-functional wing pads. The green stink bug adults are large (approximately ⅝ inch in length), light green, and shield-shaped with fully developed wings.

Figure 1. Green stink bug adult (green-colored) and nymphs (multi-colored) on soybean pods.

Stink bugs go through a simple metamorphosis, which includes egg, nymph, and adult stages. During warm months, female stink bugs lay eggs, which are stuck in clusters to leaves and stems. After hatching, the wingless nymphs molt several times before becoming full-sized, winged adults. Large nymphs or adults are the overwintering stage. Stink bugs normally complete only one life cycle per year in the northern states, one to three in the Midwest, and two to five in the South, depending on species and location.

Crop Damage and Symptoms

Stink bug nymphs emerging from eggs.

Stink bug nymphs and adults primarily attack the pods and seeds of soybean plants, using their piercing and sucking mouthparts to inject digestive enzymes into the plant and remove pre-digested plant fluids. Their injury may be difficult to assess before harvest because their mouthparts leave no obvious feeding scars. However, at harvest, the damage becomes obvious. Young seeds can be deformed, undersized, or even aborted, and older seeds will be discolored and shriveled.

In addition to extracting nutrients and reducing seed size, the stink bug feeding wound provides an avenue for diseases to gain entry into the pod, reducing seed quality. Affected beans may further deteriorate in storage, and the germination rate will also be reduced.

Green stink bug adult.

Stink bugs also feed on soybean plant stems, foliage, and blooms. On close examination, the location of feeding punctures can be identified by the presence of small brown or black spots. Indirectly, feeding damage by stink bugs can delay plant maturity and cause the abnormal production of leaflets and pods. This condition is referred to as “green stem syndrome.” Irregular shaped areas or patches in the field remain green with the rest of the field maturing normally. Plants within green areas tend to have green leaves, petioles, and stems. Plants may have few pods or may have pods at most nodes, but pods are small, dried, and contain few, if any, seeds.

Figure 2. Soybean field with stink bug feeding showing green stem syndrome.

Scouting and Management

Scouting for stink bugs should begin when soybeans start to bloom and continue until maturity. Monitoring field edges for movement of stink bugs into a field is one way to identify potential infestations early. Growers should intensify scouting and be ready for aggressive control in soybeans when corn begins to dry down, as stink bugs will move rapidly from corn into soybeans. This is especially true in southern areas where corn matures ahead of soybeans.

Either sweep nets or drop cloths can be used to sample for stink bugs. For 30-inch rows, shaking plants to dislodge bugs from the canopy unto a light-colored drop cloth placed between the rows is usually an effective sampling technique. Sweep nets are generally more appropriate for drilled or other narrow row spacings. It is important to sample several sites in a field because there can be tremendous variability in distribution within a field. For example, stink bugs may be concentrated on the edge of a field but sparse within the field. For that reason, check at least 5 different areas within a field with 20 sweep-net or drop-cloth samples per area. Combine counts of later-stage nymphs and adults when scouting.

A widely-used insecticide threshold is when adults or later-stage nymphs reach at least one per foot of row as soybean pods begin to fill with seeds. However, because treatment thresholds vary by state, growers may want to check with their state extension specialist for recommendations. Commonly used insecticides for stink bug control are shown in Table 1.

Table 1. Insecticides labeled for stink bug control in soybean.[a]

Active Ingredient(s)	Insecticide Products[b]	MOA[c]	PHI[d]
alpha-cypermethrin	Fastac® CS	3	21
beta-cyfluthrin	Baythroid® XL	3	21
bifenthrin	generics	3	18
carbaryl	Sevin®	1A	14
chlorpyrifos	Lorsban®-4E	1B	28
cyfluthrin	Tombstone™	3	45
deltamethrin	Delta Gold®	3	21
esfenvalerate	Asana® XL	3	21
gamma-cyhalothrin	Declare®, Proaxis®	3	45
lambda-cyhalothrin	Warrior II with Zeon Technology®	3	30
zeta-cypermethrin	Mustang® Maxx, Respect®	3	21
beta-cyfluthrin, imidacloprid	Leverage® 360	3, 4A	21
bifenthrin, chlorpyrifos	Tundra® Supreme	3, 1B	28
bifenthrin, imidacloprid	Brigadier®, Swagger®	3, 4A	21
bifenthrin, zeta-cypermethrin	Hero®, Steed™	3, 3	21
chlorantraniliprole, lambda-cyhalothrin	Besiege®	28, 3	30
chlorpyrifos, gamma-cyhalothrin	Cobalt®, Bolton™	1B, 3	30
chlorpyrifos, lambda-cyhalothrin	Cobalt® Advanced	1B, 3	30
chlorpyrifos, zeta-cypermethrin	Stallion® Brand	3, 3	28
diflubenzuron, lambda-cyhalothrin	DoubleTake™	15, 3	30
imidacloprid, lambda-cyhalothrin	Kilter™	3, 4A	30
lambda-cyhalothrin, thiamethoxam	Endigo® ZC	3, 4A	30
lambda-cyhalothrin, sulfoxaflor	Seeker™ Insecticide with Isoclast™ Active	3A, 4C	30

[a] Purdue University Soybean Insect Control Recommendations – 2017. Online at: https://extension.entm.purdue.edu/publications/E-77.pdf.

[b] All of these products are restricted-use insecticides except Sevin (carbaryl).

[c] IRAC Insecticide mode of action group.

[d] Pre-harvest interval for grain.

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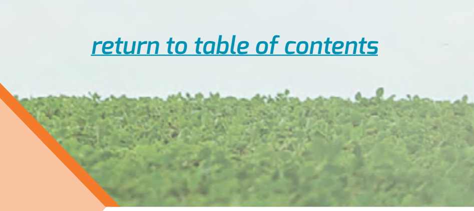

Palmer Amaranth in the North Central U.S.

*by **Mark Jeschke, Ph.D.**, Agronomy Information Manager, and **David Johnson, Ph.D.**, DuPont Technical Service Manager*

Palmer Amaranth: A Growing Problem

- Palmer amaranth has traditionally been a problematic weed in the Southeastern U.S., with the spread of glyphosate-resistant populations over the past several years creating severe management challenges.
- Recently, Palmer amaranth has been becoming a greater problem in Midwestern crop production.
  - » Palmer amaranth appears to be extending its range northward, much as waterhemp did in the 1990s.
  - » Populations, often glyphosate resistant, are becoming established in areas where Palmer amaranth has not previously been found, such as Minnesota and Iowa.

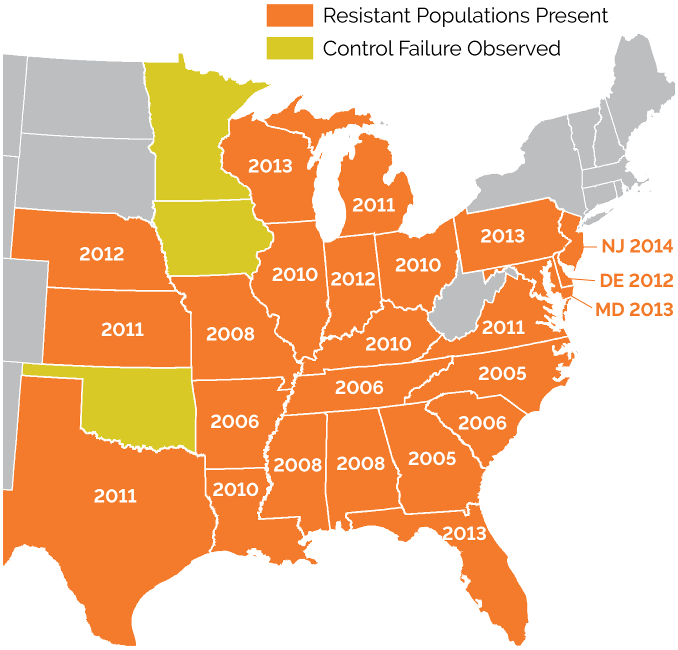

Figure 1. Confirmed and suspected cases of glyphosate-resistant Palmer amaranth and year of initial observation in north-central and southern states (Heap, 2017). Populations in some areas are also resistant to ALS, microtubule, PSII, HPPD, and PPO inhibiting herbicides.

Spread of Palmer Amaranth Into New Areas

- Palmer amaranth seed is believed to have moved north along with cotton seed and hulls brought from the Southern U.S. for use in dairy as well as beef rations and in seed for conservation plantings.
- Subsequent spreading of cattle manure and planting of conservation reserve program areas distributed Palmer amaranth seed in fields and allowed populations to become established.

Palmer Amaranth Identification

- Pigweeds can be highly variable in plant shape, leaf shape, and color, making identification a challenge.
- Waterhemp and Palmer amaranth are both dioecious (separate male and female plants), unlike other weedy pigweed species.

Palmer Amaranth

- Smooth, hairless stem
- Diamond-shaped leaves
- Poinsettia-like rosette leaf arrangement when viewed from above (Fig. 2)
- Long petioles, often longer than the leaves (Fig. 3)
- Spiny bracts on the seed heads of female plants (Fig. 4)

Waterhemp (Fig. 5)

- Smooth, hairless stem
- Leaves are often longer and narrower than other pigweeds.


Figure 2

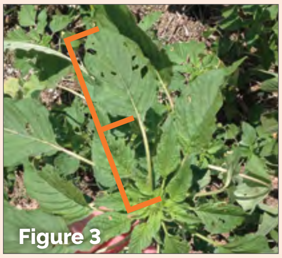
Figure 3


Figure 4

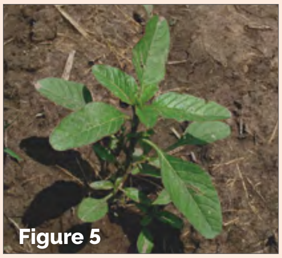
Figure 5

***Below:** Palmer amaranth (left) and waterhemp (right).*

What Makes Palmer Amaranth Such a Difficult Weed?

- Like all pigweeds, Palmer amaranth is a C4 species, making it very efficient at fixing carbon and well-adapted to high temperatures and intense sunlight.
- It originated in the Southwestern U.S. and has high water-use efficiency, allowing it to thrive in drought conditions.
- Female plants can produce over 500,000 seeds each.
- Plants can germinate and emerge throughout the summer, making them difficult to manage in crops.
- Cross-pollination between plants increases genetic diversity and favors development and spread of herbicide resistance.
- It has a very rapid growth rate and is generally considered the most competitive of the pigweeds. Plants can grow in excess of 2 inches per day during the summer.

Managing Palmer Amaranth

Scouting and Proper Identification

- Palmer amaranth's rapid growth rate, extended emergence window, and propensity for herbicide resistance make it the most challenging of the pigweed species to manage, so it is important to be able to distinguish it from other species.
- Pigweed species are difficult to tell apart during early vegetative growth stages, so fields need to be scouted later in the season for weed escapes to determine which pigweed species are present.
- Scouting guides can help with accurate identification:
    - » *http://www.extension.iastate.edu/publications/PM1786.pdf*
    - » *http://bulletin.ipm.illinois.edu/pastpest/articles/200122g.html*

Keys to Managing Palmer Amaranth

- Plant into a clean seedbed. Control early emerging weeds with tillage or a burndown treatment.
- Use a residual pre-emergence product that provides good control of Palmer amaranth.
- Apply post-emergence treatments at the weed size specified by the label. Post-emergence herbicides often need to be applied when plants are only a few inches tall for maximum effectiveness. Optimum spray time is when plants are four inches tall or less.
- Tank mix a residual product, such as DuPont™ EverpreX™ or DuPont™ Cinch® herbicide with post-emergence applications to reduce late-emerging plants.
- It is unlikely that herbicides will provide complete control. Cultivation or hand weeding may be necessary to prevent escaped plants from producing seed.

Herbicide Options for Glyphosate-Resistant Populations

- Several pre-emergence herbicide options are available in corn. Post-emergence options include herbicides containing atrazine; growth regulators, such as 2,4-D or dicamba; and 4-HPPD inhibitors, such as mesotrione.
- Several pre-emergence herbicide options are available in soybean. Products containing flumioxazin (such as DuPont™ Afforia®, Envive®, and Enlite® herbicides, or Surveil® herbicide from Dow AgroSciences) and/or metribuzin (DuPont™ Trivence® and Canopy® herbicides) have been shown to provide the best residual activity. Sulfentrazone-containing products (such as Sonic® herbicide from Dow AgroSciences) also provide control.
- Post-emergence control options in soybean are very limited.
    - » Resistance to ALS-inhibitors in Palmer amaranth is widespread.
    - » PPO-inhibitor herbicides are generally a viable option for control of emerged plants. Resistance to PPO-inhibitors has been confirmed in Palmer amaranth in some mid-south states.
    - » Dicamba (such as DuPont™ FeXapan™ plus VaporGrip® Technology) or glufosinate are other post-emergence options in Pioneer® brand soybeans with Roundup Ready 2 Xtend® technology and the LibertyLink® trait, respectively.

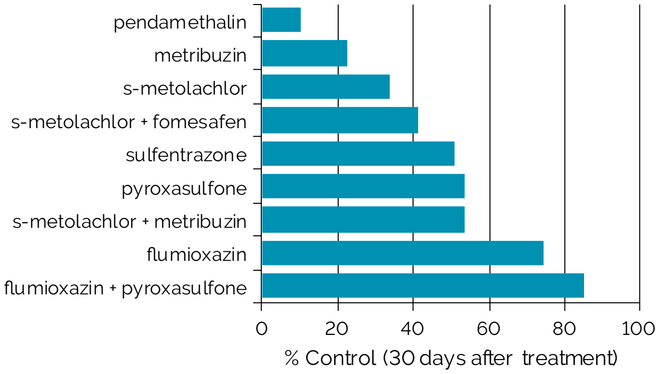

Figure 6. Average Palmer amaranth control with pre-emergence herbicides in a 2-year Michigan State University study (Powell and Sprague, 2012).

Table 1. Maximum recommended height or growth stage for best control of Palmer amaranth with post-emergence herbicides in soybean.

Active Ingredient	Herbicide	Weed Size
Dicamba	DuPont™ FeXapan™ herbicide plus VaporGrip® technology (22 fl oz)	4 inches
Fomesafen	Flexstar®/Reflex® (1 pt) Flexstar/Reflex (1.25 pt) Flexstar/Reflex (1.5 pt)	4 leaf 6 leaf 6 leaf
Lactofen	Cobra® (12.5 fl oz)	6 leaf
Glufosinate	Liberty® (32-43 fl oz)	3 inches

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Late-Planted Corn and Managing Forage Inventory

by ***Robert Larmer,*** *Associate Seller*

Introduction

The summer of 2017 has been challenging to say the least for agricultural operations across Eastern Canada. Excess rainfall in the spring led to much of the crop getting put into the ground later than expected. Since planting, conditions have been variable depending on your geography. In some areas, rain is now greatly needed. In others, every other day rain events have occured. Regardless of your current situation, now is the time to start preparing for what could be this fall to ensure that you have ample high-quality forage to feed until harvest and beyond.

Prepare for Later than Normal Corn Harvest

With much of the corn crop going into the ground later than what we have experienced the past few years, there needs to be an expectation among producers that harvest will also be later than normal. The cooler, wetter summer across much of Eastern Canada has done nothing to help this situation and in many areas, has delayed the maturity of the corn crop even further.

Traditionally it has been said that corn silage will reach harvest maturity approximately 45 days after silking occurs. This saying, however, was developed with much older corn genetics that did not have the late-season plant health that we see in today's hybrids. Harvest moisture recommendations have also changed to account for the potential starch deposition by the plant late in the season. Corn silage should be harvested at ¾ milkline in order to maximize starch deposition by the plant without sacrificing whole crop moisture or fibre digestibility. This will usually put whole crop moisture in the 62 to 68% range and generally occurs 50 to 60 days after silking. Much of the corn across Eastern Canada is silking now or getting ready to silk, and it is already August 8th. Adding 60 days puts the calendar at October 7th. Do you have enough corn silage in storage today to make it to an October harvest? Furthermore do you have enough to make it to November or December to give the new crop silage time to ferment before being fed?

Determining Remaining Inventory

The first step to determining if you need to take measures to extend the number of days you will be able to feed corn silage is to figure out how much you have left. The following tables and links are helpful in determining how much inventory remains.

Extending Your Current Silage Inventory

There are many options available to producers to attempt to extend the corn silage that is already in storage from last year. It is very important to work with your nutrition professional to determine which of the available options will be best for your herd from a performance and return on investment perspective. This will differ from herd to herd, depending on inventory of other forages as well as availability of other purchased feedstuffs.

The first and by far the simplest option is to alter the ratio of forages in your ration, reducing the total amount of corn silage being fed, and increasing other forages, usually haylage.

Bag Size	Well Packed Silage[a] (wet tons) 65% Moisture	Low Packed Silage[b] (wet tons) 65% Moisture	Ground Ear Corn[c] (wet bu) 35% Moisture	Ground Ear Corn[c] (wet tons) 35% Moisture	Processed High Moisture Shelled Corn[d] (bushels) 28% Moisture	Processed High Moisture Shelled Corn[d] (wet tons) 28% Moisture
8 X 100	115	93	2,011	84	3,116	104
8 X 200	230	187	4,021	168	6,233	208
9 X 100	145	118	2,672	111	4,199	140
9 X 200	291	236	5,344	223	8,397	280
10 X 100	180	146	4,088	170	6,440	215
10 X 200	359	292	8,168	340	12,880	429
12 X 100	259	210	7,012	292	9,274	309
12 X 200	517	420	14,024	584	18,548	618
14 X 100	352	286	10,006	417	12,623	421
14 X 200	704	572	21,012	876	25,246	842

Calculations based on University of Wisconsin Forage Ext. Silage Bag Calculator. *Actual capacity varies with moisture content, length of cut, and packing density. [a] Capacity based on 16 lbs. DM per cubic foot. [b] Capacity based on 13 lbs DM per cubic foot. [c] Capacity based on 33 lbs DM per cubic foot. [d] Capacity based on 42 lbs DM per cubic foot.

This change will result in lower protein requirements in the concentrate portion of your ration and a need for increased energy be it in the form of a starchy feed like high moisture or ground corn or from another source like bakery meal.

Another option that is very useful for replacing some corn silage in the ration is beet pulp. Many producers are already feeding this product, so it may be something as simple as working with your nutrition professional to determine if you can increase the feeding rate of the beet pulp in order to further reduce the amount of corn silage you are feeding. If beet pulp is not currently on farm, it can be purchased in either wet form (75% moisture) and stored in a bag or bunk like silage or it can be purchased in a dry pelleted form either in bags or bulk. The wet product generally becomes available in late August as beet harvest and processing begins.

Brewers grains, cotton seed, and distillers grains are some other commodities that are generally available in Eastern Canada and can supplement a ration as well as help to replace some of the energy portion of corn silage. Many of these are high in concentrates and do not help to replace the fibre portion of the corn silage. This can be done by increasing haylage, adding straw to the ration, or adding in a non-forage fibre source in conjunction like oat hulls, ground corn cobs, or soy hulls.

Approximate* Silage Pile Capacities

Silo Dimensions height X width X length **(feet)****	**Corn Silage[a] (wet tons) 65% Moisture**	**Haylage[b] (wet tons) 65% Moisture**
8 X 50 X 100	438	356
8 X 50 X 150	599	487
8 X 50 X 200	895	727
12 X 75 X 100	682	554
12 X 75 X 150	1,255	1,020
12 X 75 X 200	1,828	1,485
14 X 100 X 200	2,697	2,175
14 X 100 X 250	3,512	2,854
14 X 100 X 300	4,348	3,533
16 X 150 X 300	7,237	5,880
16 X 150 X 400	10,135	8,235
16 X 150 X 500	13,033	10,589
20 X 150 X 300	8,713	7,080
20 X 150 X 400	12,376	10,055
20 X 150 X 500	16,038	13,031

Calculations based on University of Wisconsin Forage Ext. Silage Bag Calculator.
* Actual capacity varies with moisture content, length of cut and packing density.
** Assumes a 1:3 slope for sidewalls, back and front ramps.
[a] Capacity based on 16 lbs DM per cubic foot.
[b] Capacity based on 13 lbs DM per cubic foot.

The direction you choose will be largely based on how long you need to extend your silage inventory, the availability of alternative products in your local area, and of course, the return on investment that these purchased feeds will provide for your operation.

Regardless of the approach that you think will work for your operation, it is important to work with your nutrition professional and ensure that the changes you hope to make will result in a balanced diet with a good return over feed cost that will allow your cows to continue to perform their potential.

The late spring; the cool; wet summer; as well as the many pests we have encountered this growing season have made for quite a challenge. Now is the time to ensure that you are prepared to face the potential challenge of a delayed harvest and plan to have old crop inventory to feed until new crop has had time to ferment.

Approximate* Silage Pile Capacities**

Silo Dimensions height X width X length **(feet)**	**Well Packed Silage[a] (wet tons) 65% Moisture**	**Low Packed Silage[b] (wet tons) 65% Moisture**
8 X 50 X 100	979	795
8 X 50 X 150	1,551	1,260
8 X 50 X 200	2,397	1,947
12 X 75 X 100	1,980	1,609
12 X 75 X 150	3,238	2,631
12 X 75 X 200	4,495	3,653
14 X 100 X 200	6,244	5,073
14 X 100 X 250	7,497	6,498
14 X 100 X 300	9,750	7,922
16 X 150 X 300	18,601	15,113
16 X 150 X 400	25,460	20,686
16 X 150 X 500	32,319	26,259
20 X 150 X 300	21,810	17,121
20 X 150 X 400	30,040	24,408
20 X 150 X 500	38,721	31,095

Calculations based on University of Wisconsin Forage Ext. Silage Bag Calculator.
* Actual capacity varies with moisture content, length of cut and packing density.
** DuPont Pioneer calculations are based on following assumptions:
  1. Sidewalls are with no slope
  2. Back wall exists
[a] Capacity based on 16 lbs DM per cubic foot.
[b] Capacity based on 13 lbs DM per cubic foot.

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2017 Spring Green-Up Alfalfa Assessment

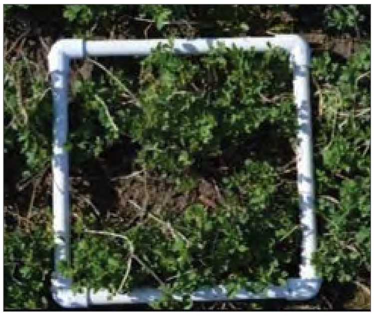
by **Ryan Bates,** Field Agronomist

Overview

- Assessing alfalfa fields as they green up in the spring is critical to assuring high-yielding alfalfa fields for the coming year. Fields with adequate stand counts and low levels of crown rot, winter kill, and alfalfa heaving will maximize yields.
- Alfalfa assessments were documented by Pioneer sales professionals in an "Alfalfa Assessment App" to evaluate alfalfa fields coming out of the winter. Over 100 fields were visited where plant counts were collected and crown rot severity, percent winter kill, and percent alfalfa heaving were estimated.

Alfalfa Assessment

- Early green-up assessment should find a minimum of four to five plants per square foot. Older stands have fewer plants per square foot; however, older plants produce more stems than younger plants.
- Healthy crowns are large as well as symmetrical and have many shoots. Weakened plants may grow but have only one or a few stems. Watch for delayed green-up, lopsided crowns, and uneven shoot growth. If any of these characteristics exist, investigate further by checking for root rots and broken roots.
- Watch for alfalfa heaving or plants that have the crowns pushed above the soil line. Alfalfa plants with only one inch or less of heaving that cannot easily be pulled from the ground likely still have their tap root intact and can remain productive; adjust cutting height to avoid damaging the crown. Alfalfa heaved greater than one inch that can be pulled easily from the ground have severed their tap root and will likely die later in the spring or summer.
- When alfalfa growth is four to six inches in height, use stem counts (stems per square foot) as the preferred density measure. A stem density of 55 stems per square foot has good yield potential. Expect some yield loss with stem counts between 40 and 50. Consider replacing the stand if there are less than 40 stems per square foot and the crown and root health is poor.



A square foot made out of PVC pipe is useful for assessing alfalfa fields. Collect multiple counts and plant health assessments across the field before making your management decision.

Alfalfa Assessment Takeaways in 2017

- Overall, alfalfa stands were slower to green up due to the cool, cloudy conditions in April.
- Winterkill and frost heaving were more common in fields or parts of fields with a late cutting versus those with the last cutting in August.
- Frost heaving was more severe in heavier soils and in wetter parts of the field.
- Crown rot, while common, was low to moderate in most fields.
- Alfalfa plant counts came back across the area on the lower end of the desired plant stand with weeds, such as dandelions, coming in.
- Many of the fields that were left as alfalfa will be candidates for rotation next year.

Alfalfa crowns split to observe the plant health. Note the crown rot developing and the differences in stem regrowth between the plants.

Image 1. (left) Frost heaving around 1 inch with tap root still intact. Alfalfa will survive and remain productive.
Image 2. (right) Frost heaving over an inch with severed tap root. Alfalfa will likely die later in the spring or summer.

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Assessment Results

- There was a total of 105 fields assessed, 81 in Wisconsin and 24 in Minnesota.
- Average alfalfa plants per square foot was six plants. Minnesota was slightly higher at 7 plants per square foot versus 5.9 plants per square foot in Wisconsin.
- Average estimated winterkill in fields was 10% and was similar in both Wisconsin and Minnesota.
- Average estimated frost heaving in fields was 10% in Wisconsin with very little frost heaving reported in Minnesota.
- Winterkill was reported in 55 (52%) fields, and frost heaving was reported in 51 (49%) fields.
- 29 (28%) fields reported both winterkill and frost heaving while 28 (27%) fields reported no winterkill or frost heaving.

Alfalfa assessments were made at green-up by Dupont Pioneer dairy account mangers, account managers, field agronomists, and pioneer sales professionals.

Average Viable Plants per Square Foot By County

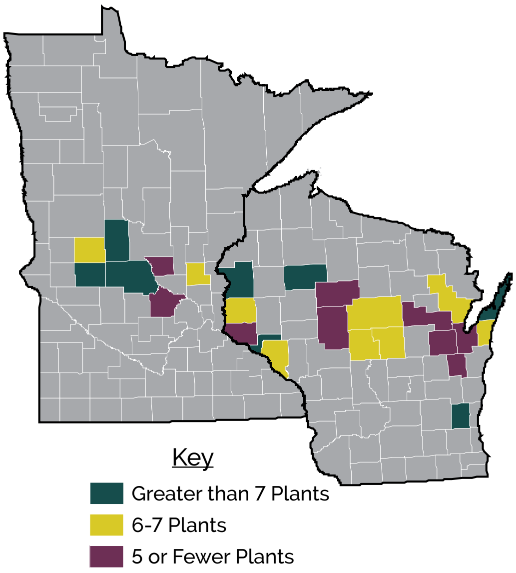

Figure 2. Average viable plants per square foot by county in 2017 Alfalfa Assessment. No assessments were reported in counties in white.

Average Estimated % of Field Winterkilled by County

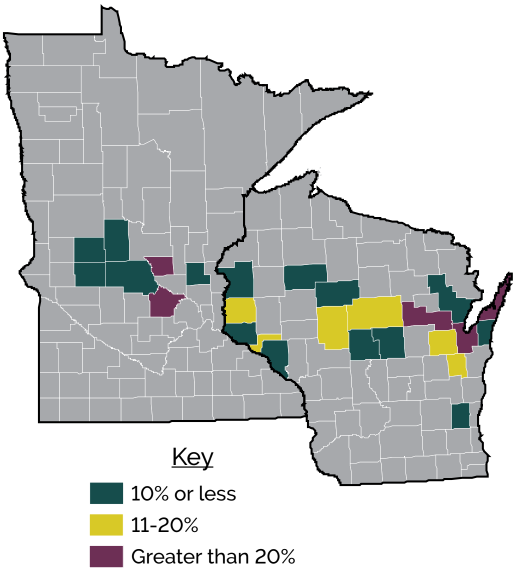

Figure 1. Average estimated % of field winterkill by county in 2017 Alfalfa Assessment. No assessments were reported in counties in white.

Average Estimated % of Frost Heaving in Field by County

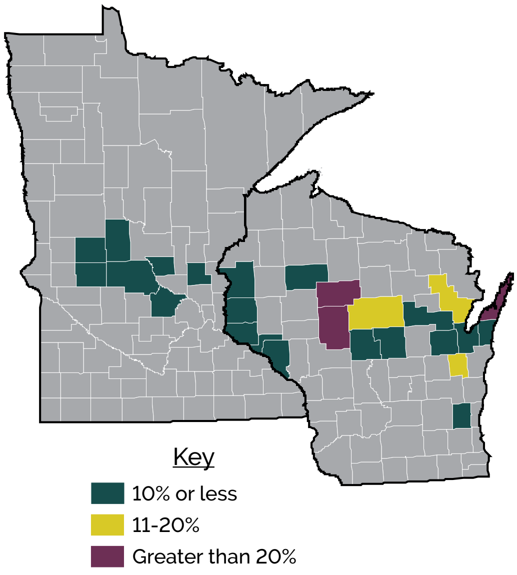

Figure 3. Average estimated % of frost heaving in fields by county in 2017 Alfalfa Assessment. No assessments were reported in counties in white.

High Yield Sorghum Production

*by **Mark Jeschke, Ph.D.,** Agronomy Information Manager, and **Nanticha Lutt,** Agronomy Sciences Intern*

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 eight production categories:
  - » Dryland Conventional-Till
  - » Dryland Double Crop
  - » Dryland No-Till
  - » Dryland Reduced Till
  - » Irrigated Conventional-Till
  - » Irrigated Double Crop
  - » Irrigated No-Till
  - » Irrigated Reduced-Till

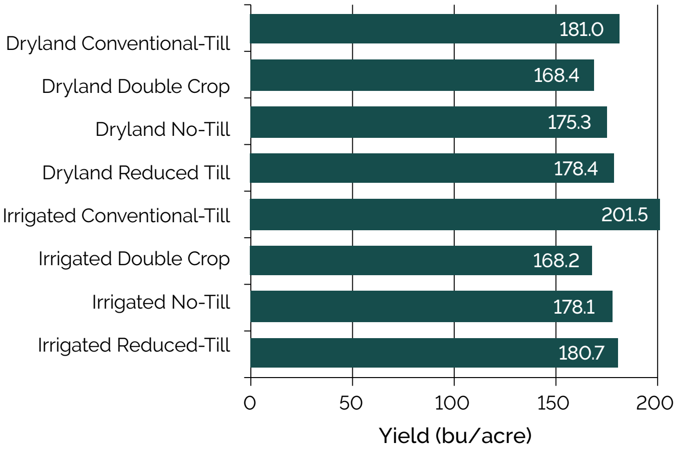

Figure 1. Average yield of 2016 NSP Yield Contest national winners in the eight contest categories.

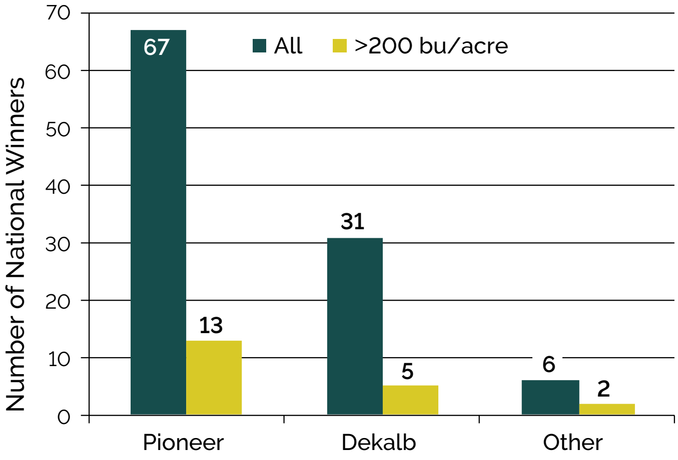

Figure 2. Seed brand planted by NSP Yield Contest national winners and winners yielding above 200 bu/acre, 2012-2016.

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 the majority of NSP Yield Contest national winners in 2012-2016 (Figure 2).
- Several Pioneer® brand sorghum hybrids have been national winners over the past five years, showcasing a diversity of product success (Table 1).
- Three of these hybrids were used in multiple entries that achieved yields above 200 bu/acre (Table 2).

Table 1. Pioneer® brand sorghum hybrids planted by NSP Yield Contest national winners, 2012-2016.

Hybrid	National Winners
84G62	35
84P80	16
85Y40	8
84P72	4
83P17	1
83P99	1
86G32	1
87P06	1

Table 2. Yields above 200 bu/acre attained with Pioneer® brand sorghum hybrids in the NSP Yield Contest, 2012-2016.

84G62	84P80	85Y40
233.39	245.94	237.93
215.00	210.09	209.68
210.85		208.40
210.71		205.08
209.07		
207.98		
206.92		

Seeding Rate

- The majority of winning entries in the NSP Yield Contest seeded sorghum at a rate between 80,000 and 130,000 seeds/acre, with some variation among categories (Figure 3).
- Among all contest entries, a wide range of sorghum seeding rates were used, but the most common rates were between 40,000 and 120,000 seeds/acre.

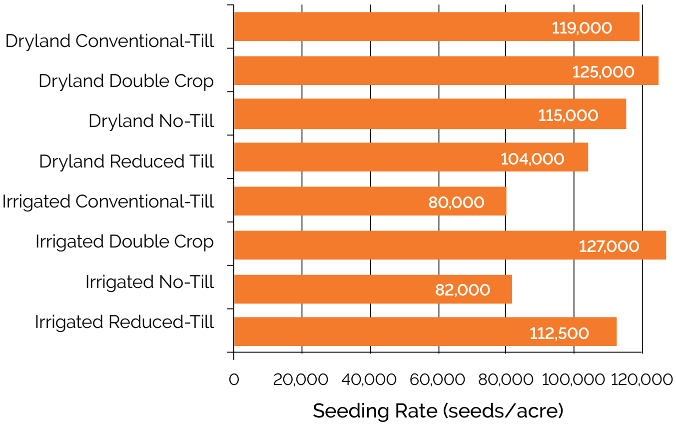

Figure 3. Average seeding rate of NSP Yield Contest national winners from 2016 by category.

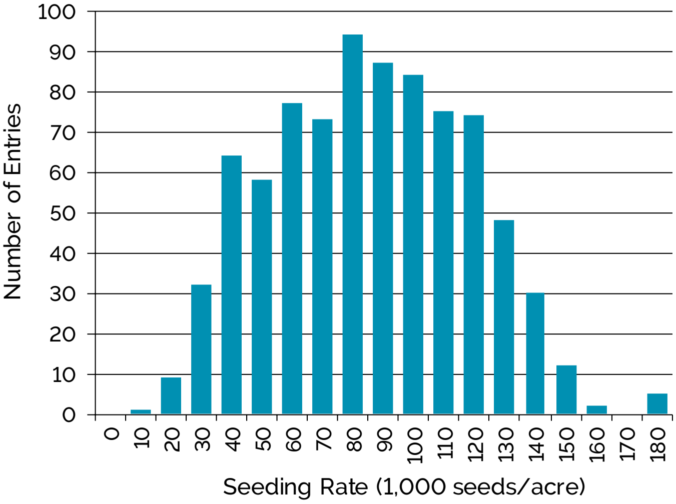

Figure 4. Frequency of seeding rates used among all contest entries in the NSP Yield Contest, 2012-2016

Row Width

- The most common row width used in the NSP Yield Contest was 30-inch rows, which was used in 61% of contest entries (Figure 5).
- 15-inch rows was the second most popular row width, accounting for 19% of entries.
- Narrower row configurations (<15 inches) comprised 7% of entries, 16 to 29 inch widths were represented at 6%, and 7% of contestants planted sorghum at wider row configurations above 30 inches.

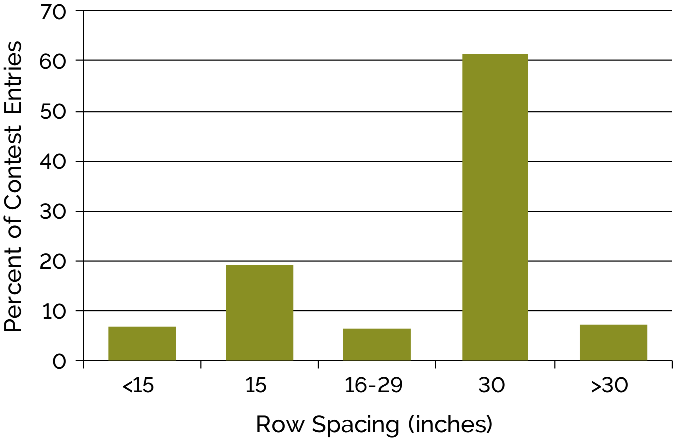

Figure 5. Row spacing of all entries in the NSP Yield Contest, 2012-2016.

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 to 1.5 lbs of nitrogen per bushel harvested, so a total nitrogen needed for the soil 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 2016 NSP Yield Contest entries ranged from 101 to 150 lbs/acre, with close to 35% of entries in this range (Figure 6).
- 26% of entries used a 50 to 100 lbs/acre nitrogen fertilization rate, while 30% applied nitrogen at a rate above 150 lbs/acre.

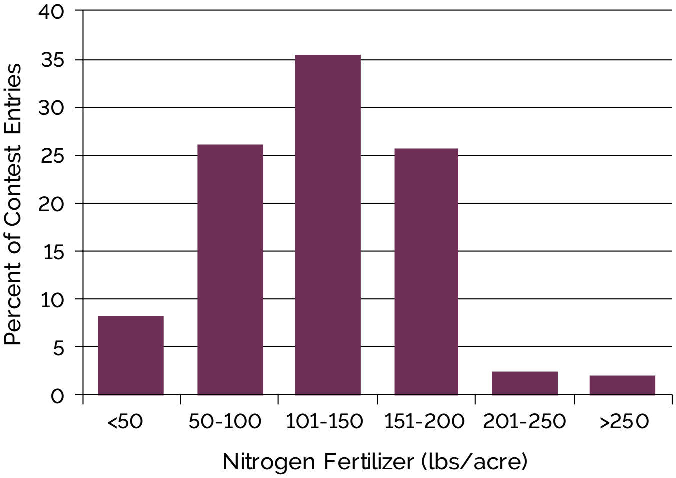

Figure 6. Nitrogen fertilizer rates for all entries in the NSP Yield Contest, 2016

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Genetic Purity of Grain Sorghum

*by **Pat Trudeau,** Senior Production Agronomist*

Introduction

In the production of grain sorghum hybrids, the methods used by the seed industry to produce the crop allows for the potential of "off-types" to be present in the seed. To produce the hybrid cross, a sterile male of one genetically distinct inbred parent is pollinated by another inbred parent. If pollen is received from a source other than the intended inbred, the result is an off-type.

There are five basic off-types recognized, which include **mutation, grain outcross, grain forage, open head forage,** and **johnsongrass outcross.**

The Five Groups of Off-Types

Mutation

Mutation is the most prevalent off-type within grain hybrids. Mutations occur naturally within the crossing of two inbreds. The mutation is identical to the hybrid with the exception of the number of plant-height controlling genes. The mutation will have the same head type, grain color, and genetic makeup as the hybrid; however, mutant plants are usually one to two feet taller than the grain hybrid. Soil moisture conditions during the growing season will dictate the height expression of the mutation.

Figure 1. Height mutant.

Grain Outcross

The grain outcross off-type is caused when pollen from another grain sorghum source pollinates the sterile female parent within the seed field. The sorghum contaminant may be an off-type within the parent seed itself or a commercial hybrid grown near the production area. The grain outcross will have a different head shape and/or color than the hybrid.

Grain Forage

The grain forage off-type is the result of pollen from a forage sorghum (silage type) plant crossing with the female seed parent within the seed field. This off-type can be the same height as a mutation but is generally two to four feet taller than the typical grain sorghum hybrid. The grain forage will typically have a compact head similar to grain sorghum, but the stalk is usually more robust. This off-type will produce very few tillers, but the plant height poses a problem during harvest of the grain sorghum. The heads of the grain forage are often unharvestable by the combine and could create a volunteer concern the following year. Volunteer plants will segregate as either grain sorghum plants or tall grain forage plants.

Figure 2. Forage sorghum outcross.

Open Head Forage

The open head forage off-type is the result of pollen from an open-headed forage plant cross-pollinating with the seed field. The pollen source is usually sudangrass but can also include shattercane or broomcorn. This non-rhizomatous grassy type plant is usually taller than grain sorghum. It produces many slender tillers with open heads that bear large amounts of viable seed, which can remain dormant for a long period of time. The open head forage off-type is objectionable, due to a grassy appearance and volunteer concerns.

Figure 3. Open-headed forage.

Johnsongrass Outcross

The johnsongrass outcross occurs when pollen from johnsongrass pollinates the sterile male plant in the seed production field. This cross-pollination does not readily take place due to the genetic differences between grain sorghum and johnsongrass. The johnsongrass outcross is rhizomatous, taller than grain sorghum, and has slender stalks, which produce many tillers. Johnsongrass outcrosses are almost always sterile and thus, do not usually produce viable seed. However, these outcrosses produce rhizomes, which can potentially survive mild winters and allow infestation to reoccur in subsequent growing seasons.

Figure 4. True johnsongrass.

Figure 5. Johnsongrass outcross.

The DuPont Pioneer Commitment to Quality Seed

The DuPont Pioneer commitment to produce high quality grain sorghum seed for customers entails keeping off-type contaminants at a minimum level. Pioneer works hard to ensure that sorghum producers get only top quality seed from each bag purchased. The process begins with selection of well-isolated seed fields and continues with the inspection as well as maintenance of isolation for potential contamination sources during the growing season, prior to and during bloom. Pioneer rogues seed fields up to 10 times to remove off-types. A final roguing and inspection takes place before the seed field can be harvested. Once the seed field is harvested, a composite sample of each individual seed field is tested in two separate winter grow-outs to determine the genetic purity of the seed. If off-type plants are present in unacceptable quantities, the entire field can be discarded prior to the conditioning process.

Table 1. Texas Dept. of Agriculture standards for certified grain sorghum seed as compared to DuPont Pioneer grain sorghum standards for off-type contamination.

Off-Type	Texas Dept. of Ag. Standard	DuPont Pioneer Standard
Rhizomatous outcross	5 per 10,000 seeds	0.6 per 10,000 seeds
Non-rhizomatous grassy outcross	10 per 10,000 seeds	2 per 10,000 seeds
Hegari or forage type outcross	8 to 10 per 10,000 seeds	5 per 10,000 seeds
Opposite colored heads	200 per 10,000 seeds	75 per 10,000 seeds

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Feeding Sugarcane Aphid and Sooty Mold Infested Sorghum

by ***Mike Kriegshauser,*** *Field Agronomist,* ***Jennifer Chaky, M.S.,*** *Research Scientist,* ***Bill Seglar, DVM,*** *Former Senior Nutritionist, and* ***Sandy Endicott, M.S.,*** *Senior Agronomy Manager*

Summary

- The sugarcane aphid has become a severe pest of North American sorghum production over the last few years and has spread across most sorghum areas within the U.S., Mexico, and throughout Central America.
- Aphid populations can grow exponentially due to their live-birth reproductive behavior.
- Aphids deposit a significant amount of "honeydew," a sticky, liquid excrement. Honeydew may serve as a food source for saphrophytic fungi, such as sooty molds, which turn the plant leaves black in color, reducing the photosynthetic capacity of the plant.
- Sugarcane aphid infestations followed by sooty molds result in protein and energy nutrient reductions in forage sorghum fed to cattle.
- Sugarcane aphid/sooty mold infested forage sorghum may have reduced palatability for the beef herd.

Introduction

The sugarcane aphid, *Melanaphis sacchari,* has become one of the most important insect pests of sorghum in the Southern U.S., Mexico, and throughout Central America. First documented in 1977, the sugarcane aphid became a serious insect pest in sorghum in 2013 and is capable of causing significant damage and reduction to grain yield in sorghum with losses of up to 100% (Catchot et al., 2015). Sorghum production intended for cattle feed needs to be managed closely to ensure quality feed is harvested.

Sugarcane aphids can reproduce without mating. Most sugarcane aphids are female and produce one to three live, pregnant offspring daily. Nymphs pass through four stages and can reach reproductive adult stage in five days, resulting in exponential growth rates under favorable conditions. The life span of the female is around 28 days with a range of 10 to 37 days.

Infested sorghum leaf with all stages of aphids present.

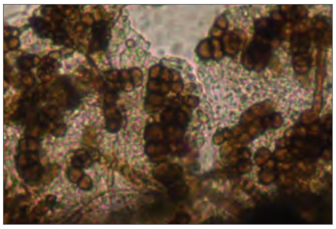
Sugarcane aphids: A winged adult, non-winged adults, and nymph.

Sooty Mold Complex

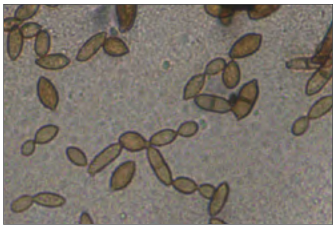
Sooty mold on sorghum resulting from a heavy infestation of sugarcane aphid.

Aphids leave behind "honeydew," a sticky, liquid excrement. The honeydew may serve as a food source for saprophytic fungi, such as sooty molds, which can turn the plant leaves black in color, thereby reducing the photosynthetic capacity of the plant.

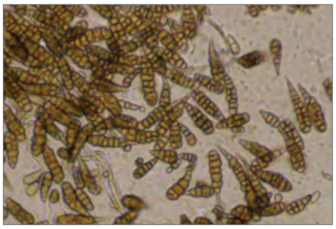
Sooty mold growth is often composed of a complex of fungi - the outward appearance of which is typically a dark mold growing across plant surfaces. Six sooty mold samples from the 2016 growing season were submitted for analysis to the DuPont Pioneer plant diagnostic lab in Johnston, Iowa, and to Kansas State University (KSU). These submissions represented locations from Lincoln County, Kansas, and Hale and San Patricio counties in Texas. Three different fungi were observed in all six samples: *Capnodium, Cladosporium,* and *Alternaria.* In addition, the sample from San Patricio County, Texas, also contained some *Leptoxyphium.*



Capnodium sp.



Cladosporium sp.



Alternaria sp.

Leptoxyphium sp.

Sooty mold fungi are saprophytic and survive, in these instances, superficially on the honeydew secretions of the sugarcane aphids feeding on the sorghum. They are not technically pathogens and therefore, are not directly affecting the health of the plants. Another important factor to note is that mycotoxins, various toxins produced by some species of fungi, are not known to be produced by the species of fungi observed from these sooty mold samples.

Animal Behavior and Feed Selection

Grazing beef cattle have been observed to preferentially feed on other available grass or broadleaf plants while avoiding aphid infested sorghum plants. When feeding on the aphid infested sorghum, the cattle preferred the stalks over the leaf material, probably due to lower amounts of sooty mold present. When given the choice between sorghum hybrids, the cattle chose the hybrid that had less sooty mold present (more aphid tolerance).

Sooty mold on forage sorghum stalks from a heavy infestation of sugarcane aphid.

Ensiling

Chopping sugarcane aphid infested sorghum can be challenging due to the honeydew presence. Several growers reported reduced ground speeds due to buildup of "sticky" material on the cutter bars and whole harvesting head. The exit chute of the chopper also had to be cleaned periodically to keep the forage flow accurate.

Best Ensiling Management Practices

When ensiling sugarcane aphid/sooty mold infested forage sorghum, it is imperative to intensify the best silage management practices that include:

- Harvest at the proper maturity
- Harvest at the proper moisture
- Chop at the proper length
- Pack firmly
- Cover securely
- Proper rate and method of feed out
- Inoculation

***Left:** Sugarcane aphid/sooty mold infested silage, note the improper cut, poor packing and face management. **Right:** An ideal bunker face.*

Feed Quality of Sugarcane Aphid Infested Sorghum

Sugarcane aphid infestations followed by sooty molds result in protein and energy nutrient reductions in forage sorghum fed to cattle. Aphids utilize plant nutrients for substrate while sooty mold can result in musty smelling forage that can depress cattle palatability.

Nutrient demands by gestating beef cows substantially increase during the last 60 to 90 days of pregnancy. Table 1 shows megacalories net energy for maintenance (NE_M) and crude protein (CP) requirements for 1,300 lbs (600 kg) beef cows based on 24 lbs (11 kg) of dry matter intake (DMI) for the first 2 trimesters and 26 lbs (11.8 kg) DMI the last trimester of pregnancy.

Table 1. Nutritional requirements for gestating beef cows.

Stage of Pregnancy	DMI required, lbs (kg)	NE_M Mcal	CP lbs (kg)
0 – 6 months	24 (11)	14.4	1.6 (0.7)
7 – 9 months	26 (11.8)	15.6	2.2 (1.0)

Beef cows grazing on forage sorghum are normally provided all of the energy and protein nutrients required during first six months of pregnancy. During the last trimester of pregnancy, supplemental protein and energy often are required to keep up the cow's body condition and complete fetal development of the calf.

The image below shows two sugarcane aphid and sooty mold infested forage sorghum samples from a field in Kansas in 2016. The sample on the left was infested to a lesser degree than the sample on the right.

Samples of sugarcane aphid/sooty mold infested silage.

Table 2 shows comparisons of NE_M and CP requirements for pregnant beef cows compared to the nutritional value (analysis from DuPont Pioneer forage lab) of the sugarcane aphid/sooty mold infested forage sorghum that came from the fresh crop samples shown in the image above.

Table 2. Nutrient contributions from less infested and more infested forage sorghum.

DMI lbs (kg)	Forage NE_M DM lbs (DM kg)	NE_M Provided Mcal	Forage CP % DM	CP Provided lbs (kg)
Less Infested Forage Sorghum				
24 (11)	0.45 (1.01)	10.8	5.8	1.4 (0.64)
26 (11.8)	0.45 (1.01)	11.7	5.8	1.5 (0.68)
More Infested Forage Sorghum				
24 (11)	0.27 (0.60)	6.48	5.0	1.2 (0.55)
26 (11.8)	0.27 (0.60)	7.02	5.0	1.3 (0.59)

Data findings revealed that both levels of sugarcane aphid /mold infested sorghum had NE_M and CP values that were substantially lower than what is typically seen with normal forage sorghum at 0.60 NE_M/DM lb (1.34 NE_M/DM kg) and 9.1% CP (NRC 1989 for beef). Laboratory results show that both the less and more infested forage sorghums fail to meet NE_M and CP needs for all three trimesters of pregnancy to maintain body weight on beef cows and develop a healthy fetus that will be strong at calving. Therefore, energy and protein supplementation is required for the first two trimesters, and even more aggressive supplementation is needed during the last trimester of pregnancy.

Other collected data showed that besides having significant molds identified in the crop, *Bacillus* spoilage microbes were present at high colony forming unit (cfu) population counts. *Bacillus* population counts are tolerable up to 100,000 cfu/gm forage. In contrast, the infested forage counts ranged from 1,000,000 to 10,000,000 cfu/gm forage. *Bacillus* respiratory activity generates considerable heat and is the primary microbe that causes hay bale fires. While hay fires are sporadic, a more common observation is the Maillard reaction, where the heat generation from *Bacillus* results in a portion of CP to be bound to the acid detergent fiber fraction (ADF) of fiber, resulting in a bound protein complex that is not digestible by cattle. Bound protein values are considered normal when less than 10%. In the Kansas samples, bound protein ranged from 23 to 26%.

Feeding Management Suggestions

Cows exposed to colder temperatures coupled with damp weather conditions need more energy and protein to meet their dietary maintenance. Dry matter intakes may increase up to 40% to meet the nutrient needs. However, the infested forage sorghum may have reduced palatability for the beef herd, thus lowering the cow's acceptance of the forage and further jeopardizing the cow's ability to consume its energy and protein needs.

Working with a nutritionist is advised when feeding compromised forages, such as sugarcane aphid/sooty mold infested forage sorghum crops. The nutritional consultant needs to assess the forage quality from each cattle producer's operation to determine the required energy and protein supplementation for the maintainence of the cow's body condition during pregnancy and for development of a healthy fetus. Monitoring body condition scores or weighing cows at various time points while feeding the sorghum crop is essential for making nutritional energy and protein adjustments.

Sugarcane Aphid Management

Best Management Practices

- Control volunteer sorghum and other grasses to remove sources of early infestation.
- Select and plant hybrids with good sugarcane aphid tolerance. Contact your local Pioneer sales representative for the latest information on hybrid characteristics.
  - » Shorter statured hybrids may allow for better aphid control when applying insecticides due to easier spray penetration deep into the canopy compared to taller hybrids.
- Use an effective insecticide seed treatment, such as Cruiser® insecticide seed treatment.
- Plant early.
- Scout fields early and weekly.
- Apply an approved insecticide when the action threshold is reached. Check with your local Pioneer sales representative or university extension for the thresholds in your area.
  - » Avoid using pyrethroid insecticides, which are harmful to beneficial insects and may cause aphid populations to rebound rapidly.
  - » Be aware of pre-harvest intervals for animal feed when applying insecticides. Read the label for complete information.

Insecticides for Sugarcane Aphid

Several insecticides are labeled for use on sorghum in the U.S. Insecticide trials conducted by Texas A&M University have shown that Sivanto™ 200 SL insecticide (flupyradifurone, Bayer CropScience) can provide significant reductions in aphid populations up to two weeks after application. Transform™ insecticide (sulfoxaflor, Dow AgroSciences) was previously used in some states, but its registration was canceled by the EPA in November 2015. Transform insecticide had a Section 18 label for the 2016 season from the EPA. Check with your local pesticide supplier for availability.

When applying insecticides by ground equipment, University of Arkansas researchers recommend that insecticides be applied at 10 gallons of water per acre. Growers should consult their cooperative extension service for a current list of registered chemicals in their respective states and updated results on the efficacy of sugarcane aphid insecticides. Read and follow all label directions before applying an insecticide.

Acknowledgments

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Field photos of sugarcane aphids on plant leaves are courtesy of DuPont Pioneer Mexico Agronomy team.

Photos of fungi are courtesy of Jennifer Chaky, DuPont Pioneer Research Scientist, Pathology.

Photos of sugarcane aphid infested sorghum plants and silage samples are courtesy of Mike Kriegshauser, DuPont Pioneer Field Agronomist, Kansas.

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PPST Offering for Pioneer® Brand Soft Red Winter Wheat

by **Keith O'Bryan, Ph.D.,** *Agronomy Research Manager - Seed Treatments*

Objectives

- Pioneer Premium Seed Treatment (PPST) offering for Pioneer® brand wheat products includes Dividend Extreme® (mefenoxam and difenconazole) and Vibrance® (sedaxane) fungicide seed treatments (FST) plus Cruiser 5FS® (thiamethoxam) insecticide seed treatment (IST).
- Dividend Extreme/Vibrance FST for wheat provides protection against numerous seed borne, soil borne, and foliar diseases, including *Pythium, Rhizoctonia,* and dwarf bunt. The addition of sedaxane FST provides enhanced activity against *Rhizoctonia* and *Fusarium.*
- Cruiser 5FS IST provides early-season protection of seedlings against injury by aphids, which can vector the barley yellow dwarf virus, Hessian fly, and wireworm.
- **Research trials were conducted in 2017 to evaluate performance of Dividend Extreme/Vibrance FST + Cruiser IST for wheat.**

Study Description

Year: 2017

Treatments:

1. Untreated
2. Standard FST (Dividend Extreme 2.0 fl oz/cwt + Vibrance 0.08 fl oz/cwt)
3. Standard FST + IST (Cruiser 5FS 1 fl oz/cwt)

Locations: 11 DuPont Pioneer research locations

Plots: 18 ft long; 7 in row spacing

Varieties: 2 adapted varieties per location

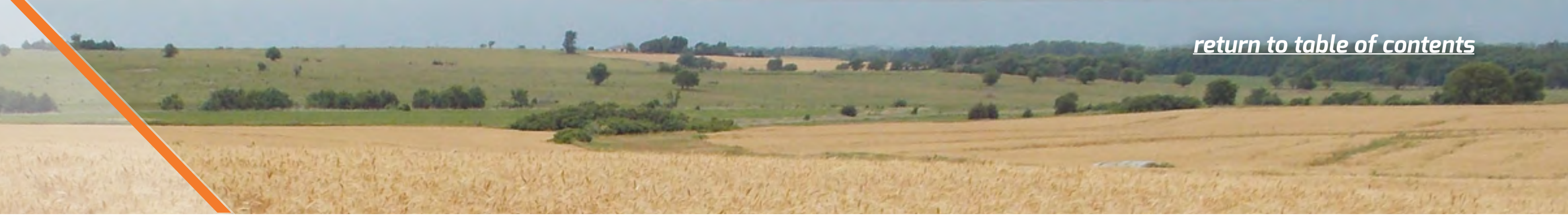
Replications: 4 replications per treatment per location

Number	Location Names	State
1	Chillicothe	OH
2	West Lafayette	IN
3	Atlanta	IN
4	Mascoutah	IL
5	Salem	IL
6	Charleston	MO
7	Mexico	MO
8	Hopkinsville	KY
9	Covington	OH
10	Henderson	KY
11	Greensburg	IN

Results

In 2017, across 11 replicated research locations, wheat grain yield for the standard FST + IST treatment yield was 6.3 bu/acre greater than the untreated check and 3.7 bu/acre greater than the FST-only treatment (P-value <0.003).

Figure 1. Seed treatment effect on soft red winter wheat grain yield across 11 locations in 2017.



Assessing Freeze Damage in Wheat

by **Scott Eversgerd,** *Field Agronomist*

There are three major factors that have the greatest impact on potential freeze damage to a growing wheat crop.

1. **Growth stage** when the freeze occurs. (Susceptibility increases greatly when head and growing point move above soil surface.)
2. **Actual temperature** of susceptible plant parts. (Temperatures will vary within the field and within the crop canopy.)
3. **Duration** of freezing temperatures.

Figure 1. Wheat plants with varying stages of tiller development.

- It will take 3 to 7 days after the weather event for any definitive signs to show up in the plant.
- Each individual wheat plant will have tillers in various stages of development, with the largest tillers being the most advanced. If one or two of the largest tillers are damaged, the smaller tillers can still produce a head with some compensation in size.

Figure 2. Developing wheat head.

- Evaluate the largest tillers by slicing the stem and finding the developing growing point. If the tiller is jointed, the head can be found just above it. In tillers that have not yet fully jointed, the growing point may still be above the soil surface.
- Evaluate for discoloration, developing heads that are not firm or "crisp," slimy tissue inside the stem, or a rotting odor.
- Try to calculate a projected head count per square foot to use as a guide in decision making.
    - » At least 50 viable wheat heads per square foot are desired in freeze-damaged wheat.

Table 1. Temperatures that cause injury to wheat at spring growth stages and symptoms and yield effect of spring freeze injury (Klein, 2006).

Growth Stage	Approximate Injurious Temperature (two hours)	Primary Symptoms	Yield Effect
Tillering	12 °F (-11 °C)	Leaf chlorosis; burning of leaf tips; silage odor; blue cast to fields	Slight to moderate
Jointing	24 °F (-4 °C)	Death of growing point; leaf yellowing or burning; lesions, splitting, or bending of lower stem; odor	Moderate to severe
Boot	28 °F (-2 °C)	Floret sterility; spike trapped in boot; damage to lower stem; leaf discoloration; odor	Moderate to severe
Heading	30 °F (-1 °C)	Floret sterility; white awns or white spikes; damage to lower stem; leaf discoloration	Severe
Flowering	30 °F (-1 °C)	Floret sterility; white awns or white spikes; damage to lower stem; leaf discoloration	Severe
Milk	28 °F (-2 °C)	White awns or white spikes; damage to lower stems; leaf discoloration; shrunken, roughened, or discolored kernels	Moderate to severe
Dough	28 °F (-2 °C)	Shriveled, discolored kernels; poor germination	Slight to moderate

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Stripe Rust in Winter Wheat

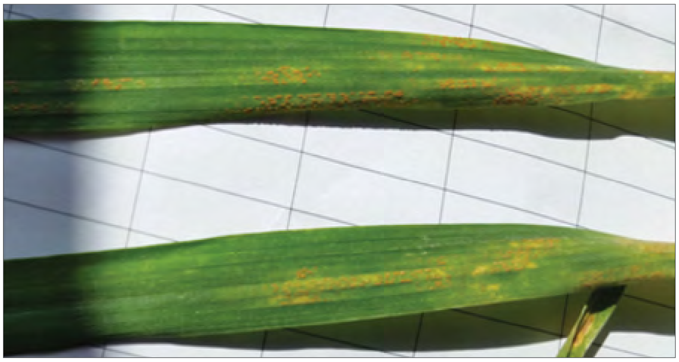
by **Dave Harwood,** *Technical Services Manager,* **Rachel Faust,** *Seed Marketing Segment Manager,* *and* **Laura Sharpe,** *Seed Treatment Specialist*

Disease Facts

- Stripe rust is caused by the fungus *Puccinia striiformis.*
- Stripe rust does not typically overwinter in Canada and the Northern U.S.; it travels on air currents from the Southern U.S.
- It affects the leaf and head of wheat.
- The lesion color (pustule) is yellow and stripe shaped.
- Is favored by cooler temperatures from 10 to 15 °C (50 to 60 °F).

Disease Symptoms

- Yellow-colored pustules form in stripes on the leaves, often looking like stitches from a sewing machine.



Disease Life Cycle

- Stripe rust takes 10 to 14 days to cycle, meaning under ideal conditions, a spore landing on a leaf and infecting the leaf can produce a lesion that spreads new spores in 10 to 14 days.
- Ideal temperatures are 10 to 15 °C (50 to 60 °F). At temperatures below 5 °C (40 °F), the fungus cannot produce new spores, and at temperatures above 29 °C (84 °F), the pathogen will die.
- Remember, the most critical leaf to protect is the flag leaf. Unless disease pressure is so high that tillers are being killed, the plant can tolerate infection without much yield loss.
- In the case of highly susceptible varieties if flag leaf lesions are observed on most plants, spraying is warranted as defoliation can occur rapidly.

We Saw it in 2016; Why Again in 2017?

- Another warmer than usual winter likely had the greatest impact for what we are seeing in fields.
- Adequate moisture in the Southern U.S. and a milder winter allowed stripe rust to overwinter further north, thus allowing for a more rapid build-up of inoculum this spring.
- The mild winter also allowed for better leaf survival of seedling wheat leaves providing greater leaf surface area for inoculum to be produced on.

Scouting Practices

- Scout your fields, and note the severity across the whole field. It is important to understand the scope of the infection, weather forecast, and variety susceptibility before making a decision on whether or not to spray.

Variety Differences

- There are significant differences in susceptibility to stripe rust in the Pioneer® brand wheat line up. See chart below. Among current Pioneer varieties, only Pioneer variety 25R46 is below average.

Pioneer® Brand Variety	Stripe Rust Score
25R34	8
25R39	8
25R40	8
25R46	2
25W31	5

NUMERIC RATINGS: 9 = Excellent; 1 = Poor

Disease Management

- Ontario researchers recommend that only triazole fungicides (e.g., Caramba®, Folicur®, Tilt®, and Prosaro®) be used at the boot stage or later because of increased risk of high DON levels with the use of a strobilurin (e.g., DuPont™ Acapela®, and Quadris®).
- Many fungicides provide excellent control of stripe rust; please read and follow label directions for rates, timing, and coverage recommendations.
- Depending on how the disease progresses in 2017; fungicide timing for head blight may also be well timed for stripe rust.

Conclusion

- Stripe rust thrives in cooler temperatures; warmer temperatures will decrease infection potential and spore production.
- Many fungicides can be used to control stripe rust; be sure to follow label directions.

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Footnotes

[1] All Pioneer products are hybrids unless designated with AM1, AM, AMT, AMRW, AMX and AMXT, in which case they are brands.

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

[3] Pioneer® brand products represented in Figure 10 on page 64: P0157AMX™ (AMX,LL,RR2), P0193AMX™ (AMX,LL,RR2), P0297AMXT™ (AMXT,LL,RR2), P0339AMXT™ (AMXT,LL,RR2), P0407AMXT™ (AMXT,LL,RR2), P0533AM1™ (AM1,LL,RR2), P0570AMXT™ (AMXT,LL,RR2), P0589AM™ (AM,LL,RR2), P0589AMXT™ (AMXT,LL,RR2), P0636AMX™ (AMX,LL,RR2), P0760AMXT™ (AMXT,LL,RR2), P0937AM™ (AM,LL,RR2), P0969AM™ (AM,LL,RR2), P0969AMXT™ (AMXT,LL,RR2), P1142AMX™ (AMX,LL,RR2), P1197AM™ (AM,LL,RR2), P1257AM™ (AM,LL,RR2), P1311AMXT™ (AMXT,LL,RR2), P1417AMX™ (AMX,LL,RR2), P1443AM™ (AM,LL,RR2), P1479AM™ (AM,LL,RR2), P9526AMX™ (AMX,LL,RR2), P9526AMXT™ (AMXT,LL,RR2), P9538AMXT™ (AMXT,LL,RR2), P9644AMX™ (AMX,LL,RR2), P9681AMX™ (AMX,LL,RR2), P9703AMX™ (AMX,LL,RR2), P9917AMX™ (AMX,LL,RR2), P9929AMXT™ (AMXT,LL,RR2)

[4] All products are expected to establish normal stands under average soil conditions. 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 7-9 indicate very good potential to establish normal stands under such conditions; a rating of 5-6 indicates average potential to establish normal stands under moderate stress conditions; and ratings of 1-4 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.

^ EXPORT APPROVAL NOTICE: These products are authorized for planting in the United States and Canada. While many import market authorizations are in place, grain and byproducts produced from grain containing this technology may not be authorized in some markets. Growers that use this product are required and agree to adhere to the stewardship requirements as outlined in the Pioneer Product Use Guide and product-specific stewardship requirements for this product. For questions regarding product stewardship and biotech traits, please contact your sales representative or refer to www.pioneer.com/stewardship. Growers are required to discuss trait acceptance and grain purchasing policies with their local grain handler prior to delivering grain containing biotech traits.

Photos on pages 61, and 135 courtesy of Deere and Co.

Photos on pages 67, 81, 122, and 130 courtesy of Case IH.

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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.

AM1 - Optimum® AcreMax® 1 Insect Protection System with an integrated corn rootworm refuge solution includes HXX, LL, RR2. Optimum AcreMax 1 products contain the LibertyLink® gene and can be sprayed with Liberty® herbicide. The required corn borer refuge can be planted up to half a mile away.

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.

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

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.

AVBL,YGCB,HX1,LL,RR2 - Optimum® AcreMax® 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.

YGCB, HX1, LL, RR2 - Optimum® Intrasect® contains the Herculex® I gene and the YieldGard® Corn Borer gene for resistance to corn borer.

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

Encirca® services provides estimates and management suggestions based on statistical and agronomic models. Encirca services is not a substitute for sound field monitoring and management practices. Individual results may vary and are subject to a variety of factors, including weather, disease and pest pressure, soil type, and management practices.

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.

RR2 - Contains the Roundup Ready® Corn 2 trait 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.

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

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

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

DO NOT APPLY DICAMBA HERBICIDE IN-CROP TO SOYBEANS WITH Roundup Ready 2 Xtend® technology unless you use a dicamba herbicide product that is specifically labeled for that use in the location where you intend to make the application. IT IS A VIOLATION OF FEDERAL AND STATE LAW TO MAKE AN IN-CROP APPLICATION OF ANY DICAMBA HERBICIDE PRODUCT ON SOYBEANS WITH Roundup Ready 2 Xtend® technology, OR ANY OTHER PESTICIDE APPLICATION, UNLESS THE PRODUCT LABELING SPECIFICALLY AUTHORIZES THE USE. Contact the U.S. EPA and your state pesticide regulatory agency with any questions about the approval status of dicamba herbicide products for in-crop use with soybeans with Roundup Ready 2 Xtend® technology. ALWAYS READ AND FOLLOW PESTICIDE LABEL DIRECTIONS. Soybeans with Roundup Ready 2 Xtend® technology contain genes that confer tolerance to glyphosate and dicamba. Glyphosate herbicides will kill crops that are not tolerant to glyphosate. Dicamba will kill crops that are not tolerant to dicamba. Roundup Ready 2 Xtend® is a registered trademark of Monsanto Technology LLC used under license. DuPont™ FeXapan™ is a restricted-use pesticide. DuPont™ FeXapan™ herbicide is not registered for sale or use in all states. Contact your local DuPont representative for details and availability.

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