PIONEER®

CORTEVA™ agriscience

AGRONOMY

2020 RESEARCH SUMMARY

RESEARCH SUMMARY

ADVANCED TECHNOLOGIES

CLIMATE AND WEATHER EFFECTS

CORN GROWTH AND DEVELOPMENT

CORN MANAGEMENT

CORN PLANTING PRACTICES

CORN DISEASES

ONOMY

SOIL FERTILITY

INSECT MANAGEMENT

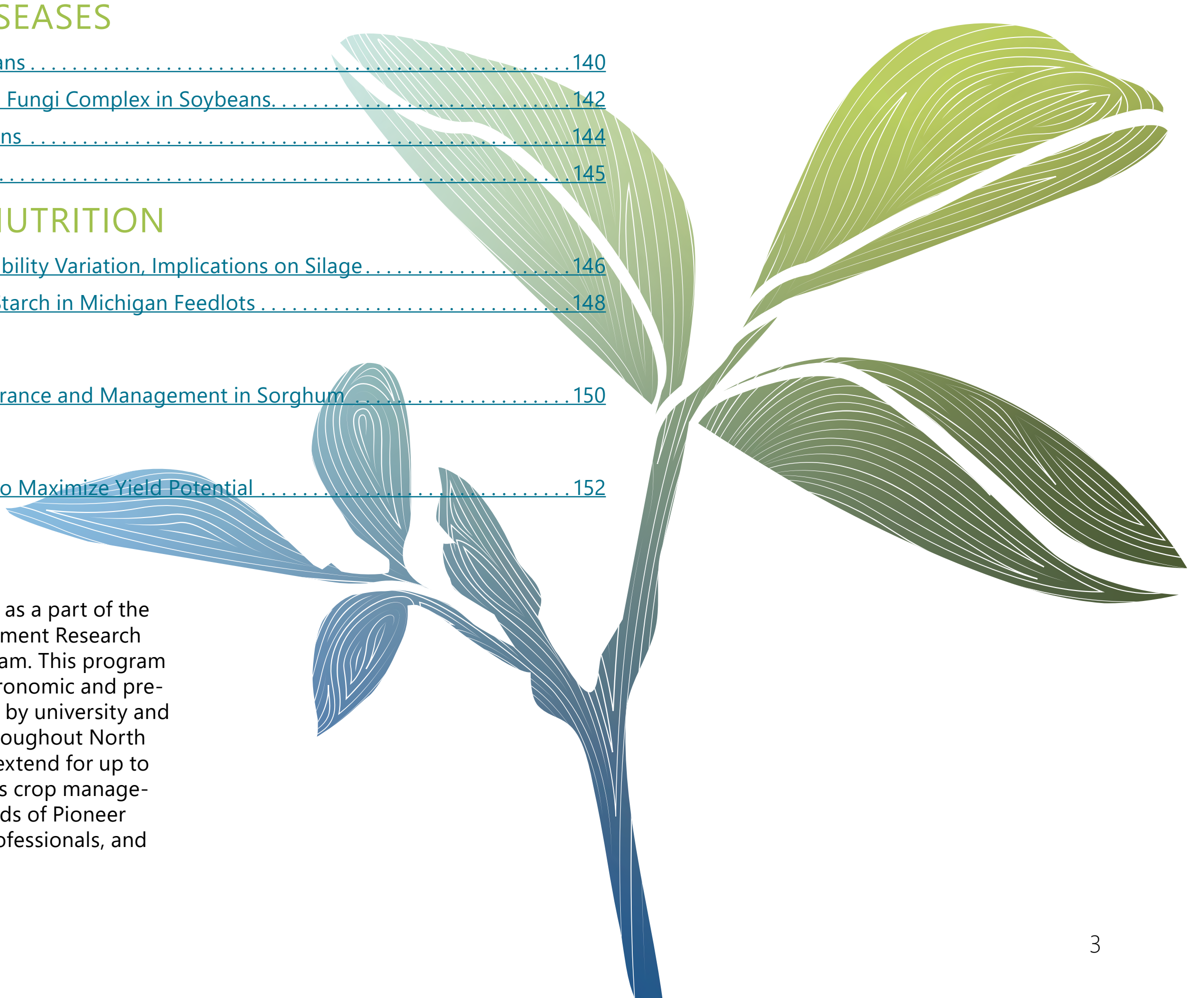
SOYBEAN MANAGEMENT

SOYBEAN DISEASES

LIVESTOCK NUTRITION

SORGHUM

WHEAT



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

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AGRONOMY SCIENCES

Dan Berning, *Agronomy Manager*

Dan earned his B.S. in Agriculture degree at Kansas State University. In the fall of 1989, he started his career with Pioneer as an Area Agronomist supporting the sales team and their customers in western Kansas and southern Colorado. He became the Pioneer Field Sales Agronomist in northeast and north-central Nebraska in 1994. In 1998, he was promoted to Field Sales Agronomy Manager for the Plains Sales Area. Dan has had the privilege of supporting the Pioneer sales team and customers across the Western Corn Belt in the roles of Technical Information Manager, Technical Services Manager, and now as the Agronomy Manager.

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

Brewer received his undergraduate in Biology from Delta State University and his M.S. and Ph.D. in Agronomy from Mississippi State University. His primary areas of interest are soil fertility, crop physiology, and crop genetics. He challenges current practices and thoughts in crop production. He works closely with field sales and research to drive application of innovative tools and technologies on farm.

Matt Clover, Ph.D., *Agronomy Manager*

Matt is responsible for helping guide on-farm trials planning, protocol development, analysis, and communication of trial results. Matt leverages his experience in soil fertility to bolster expertise of the Agronomy Sciences team and support Pioneer agronomists, and sales teams. Matt earned his Ph.D. in soil fertility from Iowa State University and his M.S. and B.S. degrees from the University of Illinois in Crop Sciences; he is a Certified Professional Soil Scientist (CPSSc). Matt came to Pioneer in April 2017 after a 9-year career in the fertilizer industry with various roles in agronomy, and research and development.

Matt Essick, M.S., *Agronomy Manager*

Matt is from a small community in northwest Iowa and earned his B.S. in Agricultural Business and M.S. in Agronomy from Iowa State University. Matt joined Pioneer as a Management Assistant working at the Cherokee, Iowa, soybean production plant. He transitioned to a Pioneer Sales Representative where he gained hands-on experience in both sales and agronomy before becoming a Territory Manager for Pioneer. Matt transitioned to an Area Agronomist and then to a Product Agronomist before joining the Agronomy Sciences Team. Matt is responsible for the Northern U.S.

Eric Galdi, *Agronomy Systems Manager*

Eric is a native of Wisconsin and obtained his B.S. degree in Soils and Crop Science from University of Wisconsin – Platteville and is currently pursuing his M.S. degree in Agronomy from Iowa State University. He provided nutrient/manure management and precision agriculture services to growers in Wisconsin before joining Pioneer in 2009. He has held various roles at Pioneer in corn research and Encirca® Services before joining the Agronomy Science team.

The Pioneer Agronomy Sciences group supports and coordinates the efforts of agronomy field teams around the globe in order to provide Pioneer customers with the best possible management insights to help maximize productivity on their farms. Members of the Agronomy Sciences team bring together expertise on a wide range of agronomic specialties and experience in industry, academia, and agricultural production.

The current agronomy support and research structure at Pioneer can be traced back to the creation of the Technical Services Department at Pioneer in 1962. Initially consisting of five agronomists, the Technical Services team conducted winter corn production meetings that attracted thousands of farmers and provided customers with Pioneer Corn Services Bulletins, a major source of information about growing corn. In 1986, the Agronomy Services Support Department was created to provide information and crop management research support to the expanding team of Pioneer agronomists. This department continued to evolve into what is today called the Agronomy Sciences group. Many things have changed over the past 30 years, but the core mission of this group has remained the same.

Pioneer has product agronomists who work on IMPACT testing and provide product knowledge positioning insights and training to account managers, sales professionals, and dealers as well as field agronomists who lead agronomy training efforts and on-farm Pioneer Agronomy trials. The Agronomy Sciences team helps coordinate these trials and leads efforts to develop and archive agronomy information resources in the online Agronomy Library.

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

Mary is a native of northern Wisconsin and earned her B.S. in Agronomy from the University of Minnesota – Twin Cities and M.S. and Ph.D. in Weed Science from Purdue University. After working in the crop protection and seed industries as a Technical Service Agronomist, she joined Pioneer in 2008 as an Area Agronomist and later became Product Agronomist for northwest Indiana. She is now the Agronomy Manager for the Eastern U.S.

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

Mark earned his B.S. and M.S. degrees in Crop Sciences at the University of Illinois at Urbana-Champaign and Ph.D. in Agronomy at the University of Wisconsin-Madison. Mark joined Pioneer in 2007 and currently serves as Agronomy Manager. His primary role is development and delivery of useful and timely agronomy information based on Pioneer and university agronomy research. Mark authors and edits many of the agronomy resources available in the Pioneer agronomy library. Mark is originally from northern Illinois and is actively involved in the family corn and soybean farm near Rock City, Illinois.

Brent Wilson, M.S., *Product Line & Agronomy Leader*

Brent Wilson serves as Leader of Product Management and Agronomy for the Pioneer brand in the U.S. In the past 30+ years with Pioneer, he has held various roles associated with crop management in both the sales and research areas. His current role is to support the team of Field and Product Agronomists with systems, processes, and information to advance the best products, learn those products, and position them with our customers with a high degree of crop management information. Brent holds a B.S. in Agronomy and Pest Management from Iowa State University and Master's of Agronomy from Iowa State University.

April Battani, *Graphic Designer*

April earned both a B.A. in Graphic Design and a B.A. in Creative Advertising from Drake University in Des Moines, Iowa. She started with Pioneer in 2012 as a Publishing Assistant for Agronomy Sciences. She currently works as a Graphic Designer for both the Agronomy Sciences 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.

Madeline Henrickson, *Agronomy Sciences Intern 2019*

Madeline is a senior at Michigan State University majoring in Crop and Soil Sciences. Following her graduation in December 2019, Madeline plans to pursue a Master's degree in plant pathology.

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2019 GROWING SEASON IN REVIEW

To describe the 2019 growing season as a challenging year for crop production would be something of an understatement. The difficulties in 2019 were relentless, starting before the crop was even in the ground and continuing right up through harvest. The dominant feature of 2019 was an excess of precipitation. It was the wettest year on record for the continental U.S. over the January to October time frame. Most of the corn and soybean producing areas of the U.S. experienced above average or record high precipitation (Figure 1).

The trouble began in March with the historic bomb cyclone that caused devastating flooding in Nebraska and Iowa and storm damage in several other states. April brought another historic storm, with high winds and heavy snow affecting large parts of Minnesota and South Dakota. And in May, it just never seemed to stop raining, causing widespread planting delays and ultimately resulting in over 19 million acres going unplanted. September delivered some much-needed heat and sun to move crops toward maturity. Wet conditions returned for harvest though, with ag Twitter providing a seemingly endless photo gallery of combines and grain carts slogging through mud or covered in snow.

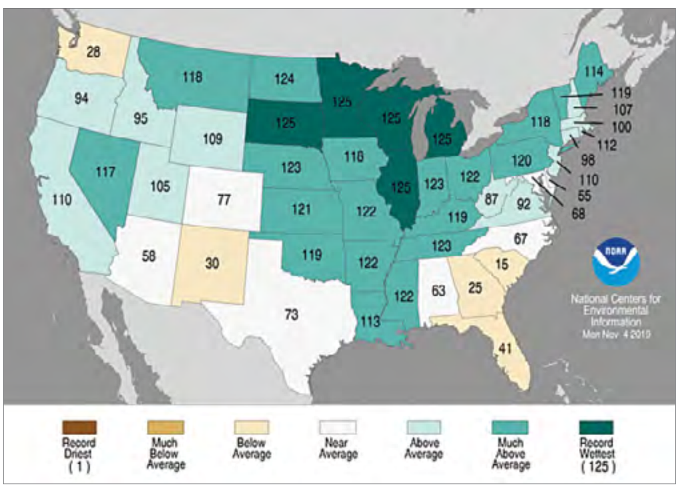

Figure 1. Statewide precipitation ranks for January-October 2019; ranking period 1895-2019.

2019 was undoubtedly an anomalous year but it was also, in part, reflective of long-term shifts in climate that have been underway for years. These trends will likely continue in the future, creating challenges similar to those of 2019 with greater frequency. Much of the crop production area in the U.S. has gotten wetter over the past century, particularly during the spring (Figure 2). The frequency of heavy downpours has also significantly increased for much of the U.S. Increasing the resiliency of soils and crop management systems against frequent and intense rainfall will be a central challenge for crop production going forward.

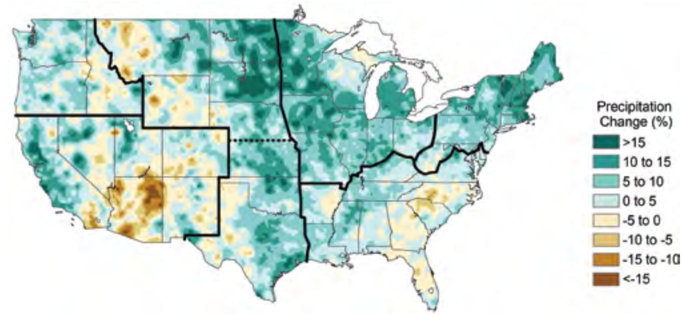

Figure 2. Percent precipitation changes for 1991-2012 compared to the 1901-1960 average (Peterson et al., 2013).

Despite all the challenges to crop production in 2019, crops that managed to avoid the worst of the extreme weather often yielded surprisingly well, which is a testament to the remarkable advancements in crop genetics, seed treatments, and agronomic management. Successful crop management under constantly evolving conditions requires smart and efficient use of resources, driven by sound agronomic knowledge. A commitment to improved crop management is a core component of the Pioneer brand, exemplified by our industry-leading network of agronomists across North America. The mission of this team is to help maximize grower productivity by delivering useful insights built on rigorous, innovative research. Pioneer agronomists work to help crop producers manage factors within their control and maximize productivity within the environmental constraints unique to a given growing season, be they favorable or not.

This Agronomy Research Summary is the latest edition of an annual compilation of Pioneer agronomy information and research results. Highlights of the 2020 edition include an overview of the latest in remote sensing technologies being deployed to help improve crop management decisions, insights into changing climate patterns and their implications for crop production, new information on emerging crop management threats such as soybean gall midge and tar spot in corn, results of regional surveys on corn rootworm and soybean cyst nematode conducted by Pioneer agronomists, and key findings from several university research studies.

This Agronomy 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 at www.pioneer.com. We hope that resources available in this book and online will help you drive productivity, efficiency, and profitability in 2020.

Mark Jeschke, Ph.D.
Agronomy Manager

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"For most of its history, remote sensing in agriculture *has existed in the realm of technologies that offer* ***tremendous potential*** but are too expensive and cumbersome to deploy on a wide scale. ***That is no longer the case:*** **high-quality**, **cost-effective**, *and* **convenient** *remote sensing* tools and technology ***are available now.***"

Remote Sensing Applications in Crop Production

Mary Gumz, Ph.D., *Agronomy Manager,* ***T.C. Huffman,*** *Area Digital Services Manager,* ***Eric Galdi,*** *Agronomy Systems Manager, and* ***Mark Jeschke, Ph.D.***, *Agronomy Manager*

SUMMARY

- Advances in satellite and unmanned aerial system technology have made remote sensing a useful, convenient, and cost-effective tool available to all crop producers.
- Farmers can easily access high-frequency, high-resolution satellite imagery of all of their fields through the Granular Insights app.
  - » The Vegetation Index feature allows users to track crop progress throughout the growing season.
  - » Granular Insights also provides tools to help quickly convert the intake of satellite imagery into insights for scouting and crop management decisions.
- Corteva Agriscience currently operates the largest small, unmanned aerial systems (sUAS) fleet in the world with over 575 aircraft in operation.
  - » sUAS are valuable tools for enhanced crop scouting, particularly later in the growing season when movement and visibility within the field is more restricted.
  - » When used in conjunction with Granular Insights, sUAS can be used to take a closer look at anomalies revealed by satellite imagery.
- Satellite and aerial remote sensing can greatly increase the speed and efficiency of field scouting and subsequent crop-management decision making.

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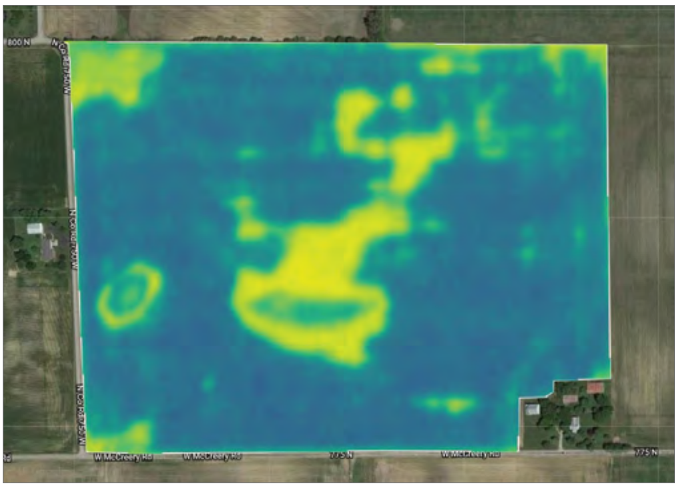
REMOTE SENSING

Remote sensing involves detecting and measuring the physical characteristics of an object from a distance. In crop production applications, this typically entails assessing attributes of a growing crop from an aerial- or satellite-based platform by measuring reflectance of solar radiation from the crop canopy. Remote sensing offers the advantage of enabling measurements to be taken quickly over a large area, which can reveal spatial variation that may not be apparent via ground-based observation. Repeated measurements over time can detect changes in crop condition during the growing season.



Granular Insights Vegetation Index map showing spatial variation in crop health across a field.

Remote sensing technology has been around for a long time, dating back to the launch of the first earth-imaging satellite Landsat 1 in 1972. Throughout most of that history, the practical application of remote sensing for crop management has been limited by the cost, frequency, and resolution of imagery. Today, however, advances in technology have made remote sensing a useful, convenient, and cost-effective tool available to all crop producers. This article discusses some of the basics of satellite and aerial imagery; applications available through Granular Insights and Pioneer agronomists; and some examples of crop-growth problems detected and diagnosed through remote sensing to guide field scouting.

PRINCIPLES OF CROP IMAGERY

Remote sensing in crop production involves quantifying wavelengths of solar radiation reflected by a crop canopy. Incoming solar radiation can be absorbed, transmitted (pass through the canopy), or reflected. Plants vary in their reflectance properties. Different species can have different reflectance patterns, but reflectance can also be indicative of the condition of the plant. Plants suffering some sort of stress, such as drought or nutrient deficiency, can have a reflectance pattern that differs from that of healthy plants.

Remote sensing technology can quantify reflectance wavelengths within as well as outside of the visible light spectrum (400 to 750 nm). The wavelength bands most commonly used for measurements of vegetation are the red, green, blue, and near-infrared (NIR) bands (Figure 1). All plants have a peak in reflectance in the green band (520 to 600 nm). Reflectance is lowest in the blue band (450 to 520) and red band (630 to 680 nm) as these are the wavelengths absorbed for photosynthesis.

The NIR band lies just outside the visible spectrum (760 to 900 nm) and is a very useful band for measuring plant condition. There can be substantial variation in NIR reflectance by plants. Green, healthy plants generally reflect more radiation in the NIR band than plants experiencing some sort of stress.

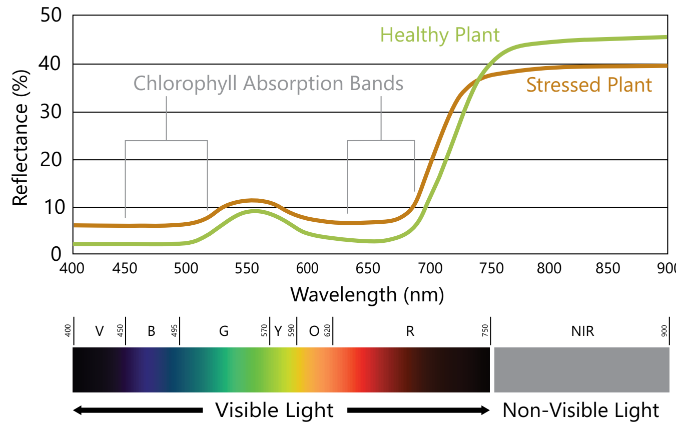


Figure 1. Generalized electromagnetic radiation reflectance profiles of healthy and stressed plants.

Vegetation Indices

The relative amount of reflectance in the different bands can be used as indicators of plant health, referred to as vegetation indices. Many different vegetation indices have been developed over the years geared toward different applications. The most commonly used vegetation index is the normalized difference vegetation index (NDVI), which has been used across a wide range of applications since its development in the early 1970s (Rouse et al., 1974). NDVI is calculated based on reflectance in the red and NIR bands,

$$NDVI = (\rho_{NIR} - \rho_{RED}) / (\rho_{NIR} + \rho_{RED})$$

where ρ_{NIR} and ρ_{RED} represent spectral reflectance in the NIR and red bands. The main disadvantage to using NDVI in crop production applications is that it approaches saturation asymptotically under moderate to high plant biomass levels, which means that small variations in crop health may not be adequately captured in the index value. In practice, NDVI is generally effective at characterizing spatial variability in plant health, providing a snapshot of the good and bad parts of a field. NDVI is not as good for tracking changes in crop condition over time as it takes a large change in the ρ_{NIR} to alter the NDVI.

The Vegetation Index in Granular Insights (Figure 2) utilizes a variation on NDVI called the wide dynamic range vegetation index (WDRVI) (Gitelson, 2004). WDRVI enhances the dynamic range of NDVI by applying a weighting parameter α to the NIR reflectance (ρ_{NIR}).

$$WDRVI = (\alpha * \rho_{NIR} - \rho_{RED}) / (\alpha * \rho_{NIR} + \rho_{RED})$$

The application of the weighting parameter linearizes the relationship between the index value and ρNIR, which increases the sensitivity of the index to small variations in high-density vegetation. The Vegetation Index in Granular Insights utilizes a weighting parameter of α=0.2, which was determined through empirical studies to provide WDRVI estimates that best characterize LAI (leaf area index) in cropping systems. This allows WDRVI to capture more subtle differences in leaf health and better detect changes in crop condition over time.

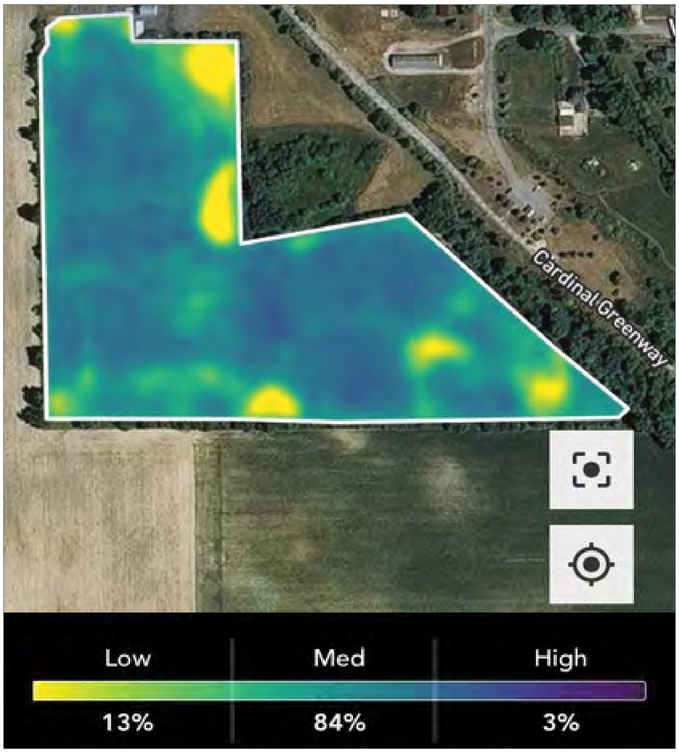


Figure 2. Granular Insights Vegetation Index map showing spatial variation in crop health across a field based on the wide dynamic range vegetation index (WDRVI). The user's position in the field indicated by the blue dot.

REMOTE SENSING IN AGRICULTURE

Satellite Imagery

The era of satellite-based remote sensing began with the launch of Landsat 1 in 1972 as a part of the Earth Resources Satellite Program. This was the first satellite deployed with the sole purpose of studying and monitoring Earth's surface. Landsat 1 was equipped with 2 sensor arrays operating in 7 total spectral bands and had a spatial resolution of 80 m. Additional remote sensing satellites were deployed in subsequent years, but their utility for crop production was limited by their coarse spatial resolution and infrequent images. (Landsat 1 had a repeat cycle of 18 days.)

Aerial Imagery

Initial research using aircraft-based remote sensing platforms for crop production also began in earnest in the 1970s. Research demonstrated the utility of infrared aerial photography for identifying stressed areas of agricultural crops. This technique was widely used in irrigated areas and for high-value crops, such as fruits and vegetables. Advances in precision agriculture technology in the 1990s and 2000s led to widespread interest in using both satellite- and aircraft-based remote sensing as a basis for site-specific management (Peterson et al., 1998). An aircraft-based platform has the advantage of greater spatial resolution as well as greater scheduling flexibility and lack of cloud interference in the imagery. However, the cost and complexity associated with flying manned, fixed-wing aircraft limits their viability as a remote sensing platform, particularly given that much of the potential value in remote sensing derives from getting imagery frequently throughout the growing season so problems can be detected and addressed as they manifest.

Today, advances in both satellite and aircraft technology have made remote sensing both practical and cost-effective for crop producers in a way that it never has been before. Better and cheaper satellite technology has allowed the deployment of constellations of multiple satellites that provide higher spatial and temporal resolution. In 2013, a total of 18 remote sensing satellites had been put into orbit; by 2017, that number had increased to 177. Likewise, the development of inexpensive and user-friendly small unmanned aerial systems (sUAS) has now made aircraft-based remote sensing a very practical and useful tool for crop production (Figure 3).

Figure 3. Rapid advancements in small, unmanned aerial systems have made aerial imagery applications in agriculture much more useful, economical, and accessible compared to older, manned aircraft-based platforms.

Modern remote sensing technologies can make on-the-ground scouting much more efficient by directing scouting efforts to fields and areas within fields where an anomaly in crop progress has been detected. Frequent satellite-based crop imagery can alert farmers to potential problems as they appear. Once a problem has been detected, sUAS can be used to get a closer look at the field and either diagnose the problem or determine that scouting is necessary.

GRANULAR INSIGHTS

Satellite Imagery

High-frequency, high-resolution satellite imagery is now readily available to farmers through the Granular Insights app. Granular Insights allows farmers to easily monitor all of their fields through a desktop computer or mobile device. Granular Insights utilizes satellite imagery from Planet Labs, generated by a constellation of over 160 satellites. The large number of satellites allows a very high frequency of imagery – multiple times per week depending on cloud cover. A spatial resolution as fine as three meters greatly improves the ability to monitor spatial variation in crop progress relative to older, coarser-resolution imagery.

> "Granular Insights allows farmers to easily monitor all of their fields through a desktop computer or mobile device."

User Features

Granular Insights also provides tools to help quickly convert the intake of crop imagery into insights for scouting and crop-management decisions. Imagery data is analyzed to detect changes in crop condition that suggest there may be a problem in a field that requires attention, which is then used to create Scout Priority[beta] field rankings. Users are provided weekly email notifications with a ranked list of the top fields by crop in need of scouting based on the Scout Priority[beta] score. This allows for targeted scouting without the need to manually sort through and visually inspect numerous images. The "Find Me" feature enables efficient, directed scouting by showing a GPS-enabled blue dot on the field image to track the user's location and guide them to where the problem is in the field (Figure 2).

UAS SCOUTING AND DATA COLLECTION

Rapid advancement in sUAS technology over the past several years has been a game-changer for aerial remote sensing in crop research and production. Corteva Agriscience currently operates the largest sUAS fleet in the world with over 575 aircraft in operation. Initial applications of sUAS-based data collection in crop research began several years ago, and sUAS are now widely implemented throughout the Corteva Agriscience research organization. Use of sUAS has expanded into field sales and seed production as well. All Corteva Agriscience UAS pilots are FAA-licensed and complete a comprehensive pilot training program.

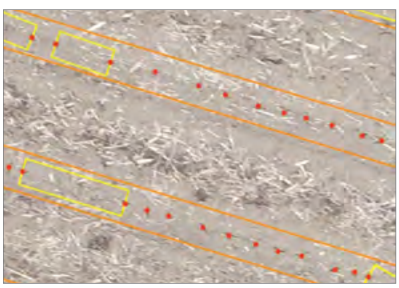


Figure 4. Corteva Agriscience image analysis software is able to detect individual plants (marked with red dots) and gaps in stand (marked with yellow boxes), providing a robust characterization of stand establishment.

Stand Evaluation

One of the most important applications of sUAS technology that spans research, field sales, and seed production at Corteva Agriscience is crop stand evaluation. Imagery-based stand evaluation provides vast improvements in speed and efficiency over traditional stand counting. Proprietary software technology is able to detect individual plants in images, quickly providing an assessment of stand establishment (Figure 4). In addition to measuring plants per unit area, imagery-based stand evaluation also allows rapid quantification of gaps in the stand.

Stand evaluation using sUAS allows stand-count data to be sampled from all parts of a field in a short amount of time, providing a more complete picture of overall stand establishment than can be achieved using traditional methods. A typical stand evaluation flight plan can cover an average-sized field in around 10 to 15 minutes (Figure 5). Each sample point encompasses a sample area of around $\frac{1}{10}$ of an acre within an image, compared to the typical sample size of $\frac{1}{1000}$ of an acre using traditional methods.

Enhanced Scouting

sUAS are valuable tools for enhanced crop scouting, particularly later in the growing season when crops are taller and movement and visibility within the field is more restricted. An overhead view can reveal localized crop health issues and patterns in the field that may not be visible from the ground. When used in conjunction with Granular Insights imagery, sUAS can be used to take a closer look at anomalies revealed by satellite imagery.

Figure 5. A typical stand evaluation flight plan showing 18 $\frac{1}{10}$ acre sample points distributed throughout the field.

sUAS imagery can also be used to assess crop health across an entire field. Corteva Agriscience has partnered with DroneDeploy to bring advanced, real-time mapping capabilities to its sUAS fleet. Using this software, an agronomist can survey a 160-acre field in less than 15 minutes, quickly spotting variations in plant health. The software provides real-time stitching of video feed imagery and can generate a plant health evaluation map based on sUAS imagery (Figure 6).

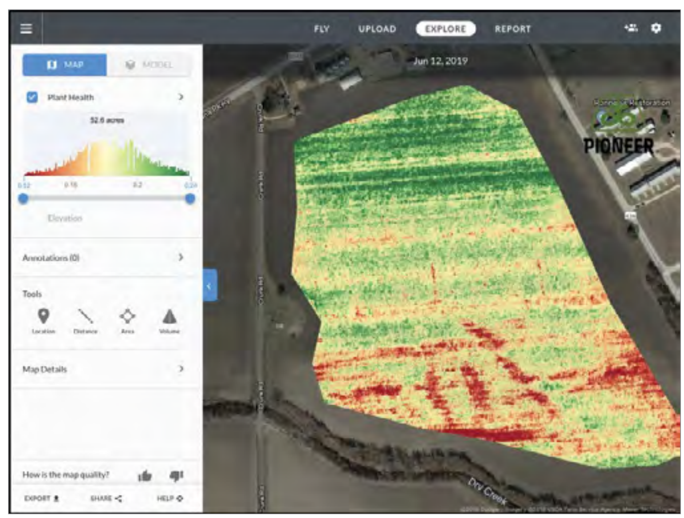


Figure 6. DroneDeploy plant health evaluation map based on sUAS imagery.

REMOTE SENSING APPLICATIONS

Satellite and aerial remote sensing can greatly increase the speed and efficiency of field scouting a well as subsequent crop management decision making. The following sections include a few examples of crop management scenarios in which satellite and aerial imagery provided valuable crop management insights.

Management Zone Diagnostics – Oklahoma

In this field, both Granular Insights and DroneDeploy crop health imagery revealed an area of better crop health relative to the rest of the field in the northeast corner (Figure 7). The

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difference was determined to be due to the cropping history of the field. The northeast portion of the field was a pasture 15 years prior, and the soil in this area had higher organic matter levels – around 3%, compared to 1.5- to 2.0% for the rest of the field.

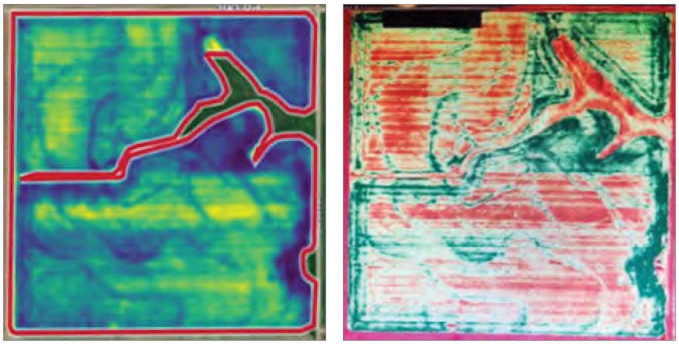


Figure 7. Granular Insights (left) and DroneDeploy (right) crop health imagery both showing an area of greater crop health in the northeast quarter of the field.

Corn Rootworm Damage – Ohio

Granular Insights imagery showed that this field had a small area of relatively poor crop health developing in the northwest corner of the field (Figure 8). Viewing the change in crop health over the prior weeks showed that this was a recent development. DroneDeploy crop health imagery focused on this portion of the field taken several days later confirmed these findings and showed that the area of poor crop health had expanded. It was determined that on-the-ground scouting was needed to diagnose the problem. Scouting revealed that the decline in crop health was caused by corn rootworm injury (Figure 9).

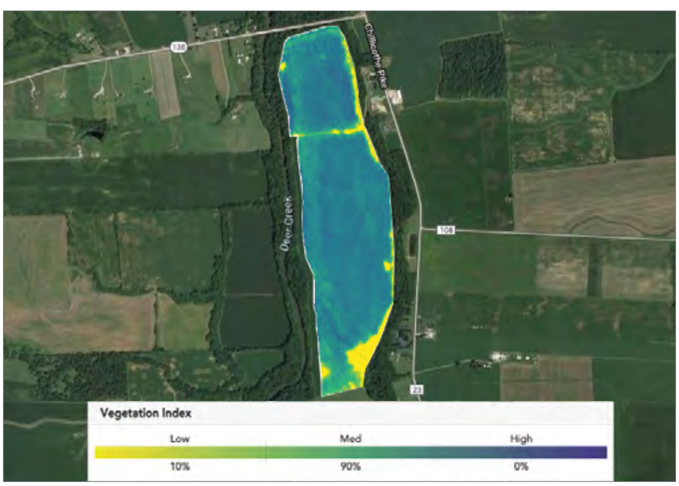


Figure 8. Granular Insights Vegetation Index map on July 6 showing a small area of declining crop health in the northwest corner of the field.

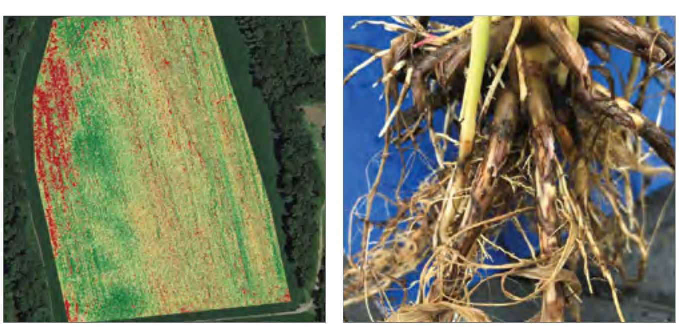


Figure 9. DroneDeploy crop health imagery on July 12 confirmed an area of poor crop health in the field (left). Scouting revealed corn rootworm injury in this area (right).

Storm Damage – Illinois

In this field, Granular Insights imagery showed alternating bands of good and reduced crop health in the field (Figure 10). The field was planted with two hybrids in a split-planter configuration and follow-up scouting revealed extensive wind damage to one of the two hybrids, accounting for the banded pattern in the imagery.

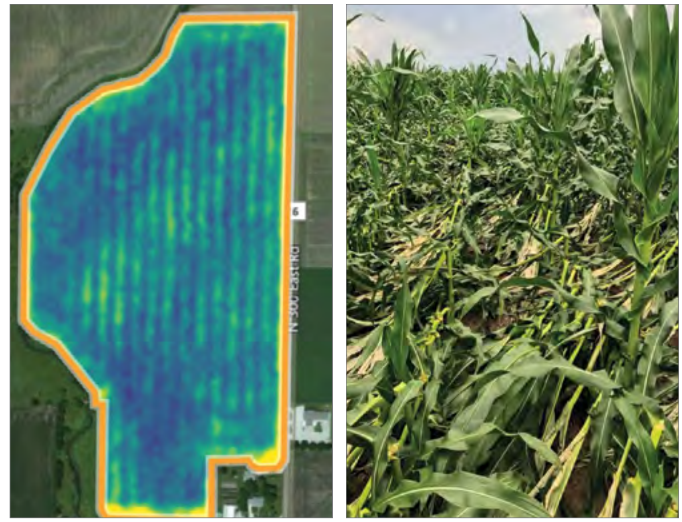
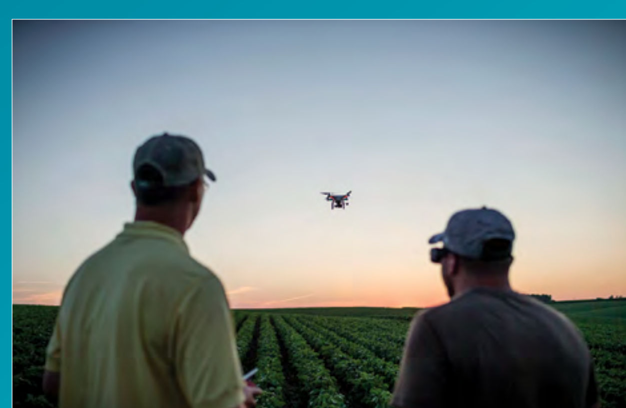


Figure 10. Granular Insights imagery showing alternating bands of reduced crop health in a field in Illinois (left) and wind damage discovered in the field (right).

CONCLUSION

For most of its history, remote sensing in agriculture has existed in the realm of technologies that offer tremendous potential but are too expensive and cumbersome to deploy on a wide scale. That is no longer the case – high-quality, cost-effective, and convenient remote sensing tools and technology are available now. Granular Insights allows farmers to proactively monitor crop progress on a computer or mobile device using near-daily imagery from the world's largest constellation of remote sensing satellites. Aerial imagery from Corteva Agriscience's industry-leading sUAS fleet, coupled with DroneDeploy advanced mapping software, can reveal yield-limiting stresses and help guide field scouting. Information derived from implementation of these technologies allows for faster and more informed crop management decision making.



"Yield memory is a promising concept with potential to help researchers to quantify the degree of change in yield spatial patterns over time."

Yield Memory – A Novel Concept to Assess Yield Variability

Rai A. Schwalbert, Ph.D., *and* ***Ignacio A. Ciampitti, Ph.D.,***
Department of Agronomy, Kansas State University

SUMMARY

- The availability of many years of spatial crop yield, weather, and soil data provides the opportunity to incorporate changes over time into yield analytics.
- A study was conducted by Rai Schwalbert and Ignacio Ciampitti at Kansas State University to better understand changes in field crop yield over time.
- Results showed that higher-yielding environments tended to have more spatially homogeneous yields within a growing season.
- However, high-yielding environments also tended to have lower yield memory – that is, less consistency in spatial patterns of yield from year to year.
- Yield variations in high-yielding environments were largely driven by weather variables, such as GDU accumulation and vapor pressure deficit.
- The contribution of soil variables in explaining yield differences was greater in low-yield environments. Soil variables tend to have more spatially consistent effects from year to year compared to weather.

EXPANDING MEASURES OF CROP YIELD

Crop yield is the most common performance metric used in field crop breeding and research. Yield can be understood as an expression of the genotype and its complex relationships with the environment. When studying this interaction, the notion of yield stability across different environments starts becoming important. The standard yield measure expressed as output per unit area, despite its ease of interpretation, sometimes provides too static of a metric for describing such complex interactions. The current availability of abundant remote sensing and yield data has greatly increased yield measurement and prediction capabilities. Researchers routinely use satellite data to forecast yield on different scales, ranging from sub-field to national-level estimates. These tools give us an opportunity to also start incorporating the time dimension into yield analytics.

RESEARCH OBJECTIVES

A study was conducted by Rai A. Schwalbert and Ignacio A. Ciampitti at Kansas State University as part of the Pioneer Crop Management Research Award program to better understand changes in field-crop yield over time. Objectives of this study were to:

1. Forecast corn and soybean yield at MODIS resolution (250 m) for U.S. corn and soybean producing regions.
2. Group regions with similar yield average and coefficient of variation over the last 10 years.
3. Develop a novel concept of "yield memory" that encompasses the standard yield concept and the time dimension.
4. Associate yield memory to soil and weather factors to explain different degrees of variation in yield spatial patterns over the past 10 years.

ANALYSIS METHODS

Study Area

The study focused on all areas that were mapped as corn or soybean over the 10-year period from 2008 to 2017 in the contiguous U.S.

Database

Data sources[1] used in this analysis are listed below:

1. Cropland data layer (CDL): Annual raster-format land-use map created by the USDA-NASS
2. Historical state- and county-level corn yield data (USDA-NASS, 2008-2017)
3. Enhanced Vegetation Index (EVI) images: 250 m resolution satellite images
4. Average temperature and growing degree units (GDU)
5. Vapor pressure deficit (VPD) data
6. Soil data: Percent clay, available water content (AWC), organic matter content (OMC), and pH

For each year considered in this study, the cropland data layer was re-projected to the MODIS sinusoidal projection, and only pixels containing 100% corn or 100% soybean coverage were kept. All of the information from the other raster layers (weather and soil) were extracted to the re-projected cropland data layers.

A 250-m resolution multi-band raster layer containing the following information was produced for each year of the study period: multitemporal EVI, accumulated precipitation, accumulated GDU, average temperature, average VPD, soil pH (0 to 30 cm), clay content (0 to 30 cm), available water capacity (0 to 30 cm) and organic matter content (0 to 30 cm). Since yield data were gathered at the county level, it was not possible to merge that information on this raster layer.

Yield Forecast Model

An empirical relationship between USDA-NASS yield and multitemporal enhanced vegetation index was performed individually for each year at county level (EVI was averaged to county level).

Yield Prediction

Since the yield forecast model was trained in a coarse scale (county-level), yield was forecast using a 15-km grid layer rather than the MODIS native resolution (250 m). A 15-km scale avoided losing too much spatial information while the predictions were less affected by the difference of scale between the model training and application (related to 250 m), and it was helpful for further data manipulation because it avoided problems with missing data in the temporal dimension (pixels were rarely tagged as corn or soybean in all ten out of ten years). All of the analyses were performed using different scales (10 km, 15 km, 50 km and county-level) to check the impact of the scale on the output.

The year-specific yield forecast models were applied on each one of the 15 km layers, and the predicted yield was normalized as relative yield.

relative yield = (yield - min yield)/(max yield - min yield)

Yield layers were geographically stacked, and the average and the coefficient of variation were calculated for each cell over time. Only pixels tagged as crop in at least 4 out of 10 years were used.

Cluster Analyses

Cluster analyses were performed for each crop individually. Dissimilarity matrices with Euclidean distance were built for crop variables (average yield and CV) and for spatial variables (latitude and longitude). For the purposes of this study, the clusters are referred to as **yield factor domains.**

Within-Cluster Spatial and Temporal Stability

Contribution of persistent and non-persistent factors to yield gaps for corn and soybean were explored within each cluster. Yield gap (Yg) was assumed as the difference between the 95th percentile yield and average yields. For building the yield gap profile, yield gap was estimated for different length of years, denoted by L. The yield maps were averaged using all possible combinations for different length of the record (in number of seasons), and the Yg was estimated for L varying from 1 to 10. The steepness of the curve and the distance between lines provide insights into how persistent spatial yield differences are throughout the study period and, thus, how important persistent factors like soil quality or farmer skill are in explaining the overall yield gap. The area between the two lines was calculated to numerically quantify the persistence of yield gap over the time within each cluster. This metric was termed **yield memory** (Figure 1).

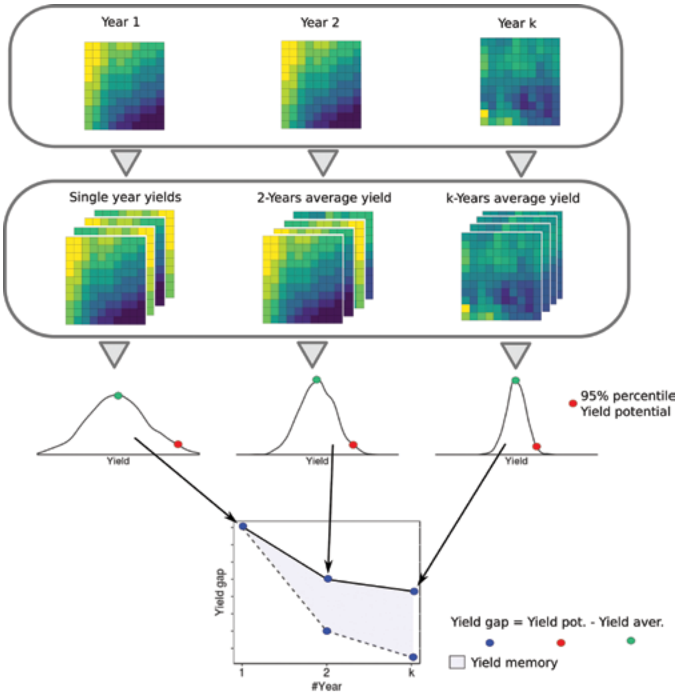


Figure 1. Summary of procedure to compute yield gap profiles and yield memory. Images from multiple years are averaged to create maps of average yields for varying periods of time. The maps are then used to compute the difference between maximum and average yields for the yield factor domains, and this difference is plotted versus the number of years used in the average (solid line). The dashed line portrays the expected change in yield gap with increasing years if yield patterns were entirely random in space. The shaded area between the lines represents the yield memory.

Within each cluster, a random forest algorithm with weather and soil variables as predictors was used to check the importance of each factor in explaining differences in yield. The importance of each weather and soil variable was computed from permuting the out-of-bag data (data that was not used for building the trees). For each tree, the prediction error of the out-of-bag portion of the data was recorded. Then the same was done after permuting each predictor variable. The difference between the two was then averaged over all trees and normalized by the standard deviation of the differences. The framework presented in Figure 2 summarizes the main steps of all analyses performed in this study.

RESULTS

The cluster analysis with spatial constraint produced 30 yield factor domains (YFD) for corn and 21 for soybean. Despite the difference in the total number of clusters between the crops, many of the yield factor domains broke out into roughly similar geographical areas. This can be easily visualized for YFD 24 and 16; for YFD 21 and 14; and for YFD 13 and 7, for corn and soybean respectively (Figure 3).

Two important trends were documented among the yield factor domains for both crops:

1. The higher the yield, the lower the CV (coefficient of variation) of yield over the years and within the same year.
2. There was a negative correlation between average yield and yield memory. In other words, yield factor domains that had higher yields over the years tended to have a higher variability in spatial pattern from year to year. For example, YFD 24 for corn (comprising northern Iowa and

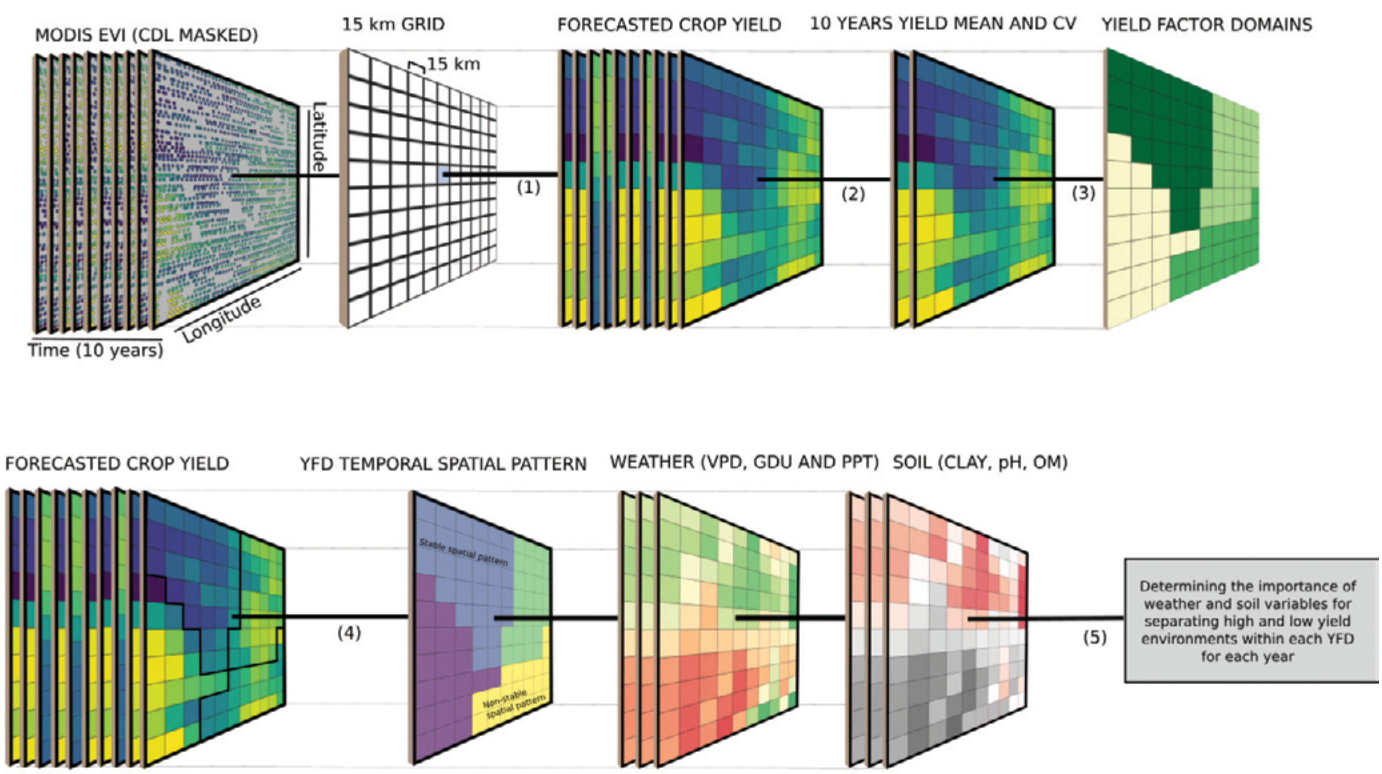
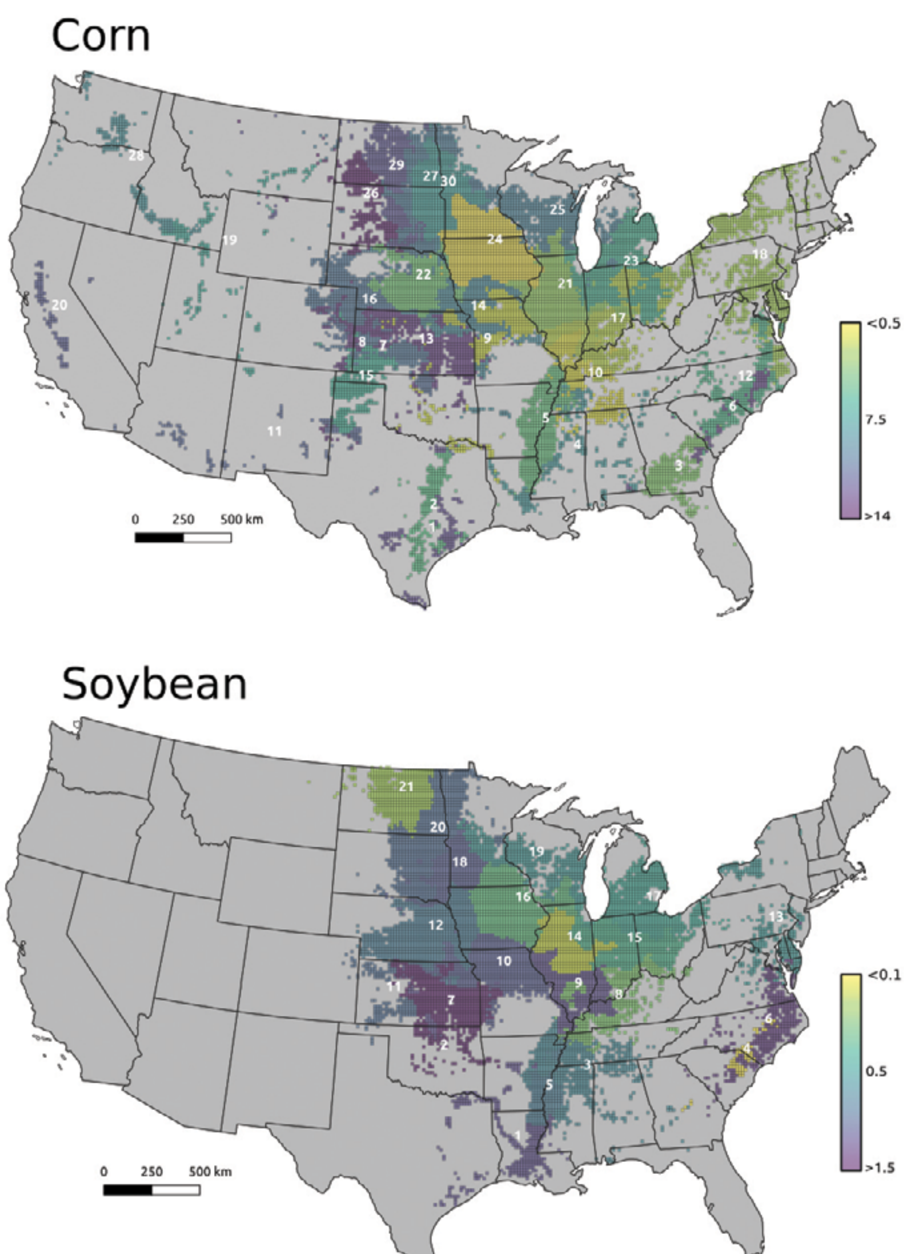


Figure 2. Steps of analysis framework: (1) crop yield forecast and data aggregation to 15 km, (2) data summarization (mean and coefficient and variation), (3) spatial constraint clustering, (4) estimate of the stability of the spatial pattern over years, and (5) evaluation of the influence of weather and soil attributes on the stability of spatial patterns.

southern Minnesota) had the highest yield among all the yield factor domains and the lowest yield memory, while YFD 14 for soybean (central to north Illinois) had the same behavior. Conversely, YFD 13 for corn and 7 for soybean (mostly within Kansas) had lower yields and higher yield memory.

Another way to estimate the persistence of the spatial pattern across years is to use one year (ranked year) to split the yields from a region into classes and then to verify if the classes are consistent over the remaining years. For this study, 2017 was used as the ranked year, and the yields from this year were divided into deciles. The same division was performed for the remaining years (Figure 4). The significant overlap between the distributions indicates that the relative ranking of yields across pixels tends to vary from one year to the next; however, the more evident positive trend for low-yielding yield factor domains (YFD 13 for corn and 7 for soybean) indicates a higher level of persistence with high (low) yielding pixels in one year more likely than average to be high (low) in other years. The absence of positive trend and the higher overlap among the distributions for higher-yielding yield factor domains (YFD 21 for corn and 14 for soybean) indicate a lack of persistence for those clusters.



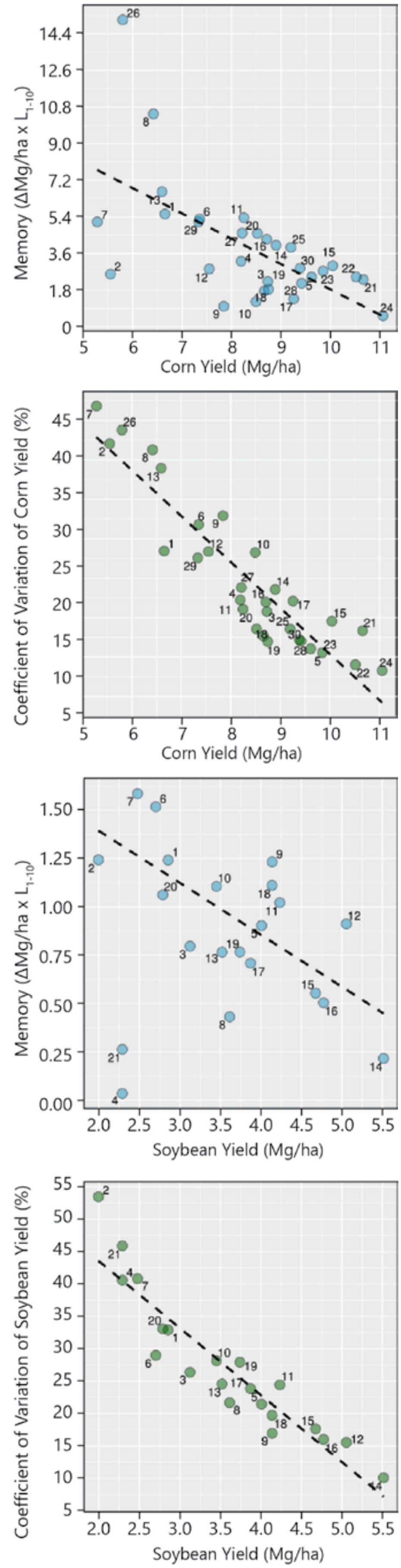


Figure 3. Thematic maps with yield factor domains for corn and soybean at 15-km resolution. Color scale representing the yield memory: dark blue means high memory, yellow means low memory. Panels in the right section portraying the relationship between average yield and yield memory and average yield and coefficient of variation of yield for corn and soybean.

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A random forest classification model provided weights for the importance of each weather and soil variable for explaining differences between high- and low- yield environments. Weather variables generally had greater weights compared to the soil ones (Figure 5). Growing degree units (GDU) was the most important factor splitting the environments in high-yield corn environments and both high- and low-yielding soybean environments. Vapor pressure deficit (VPD) was the second most important weather variable, except in low-yielding corn environments where it was the most important.

The soil variables presented a greater contribution to explaining the yield differences in low-yield environments for both corn and soybean. This makes sense since those environments had a higher yield memory and soil variables tend to have more consistent effects from year to year compared to weather.

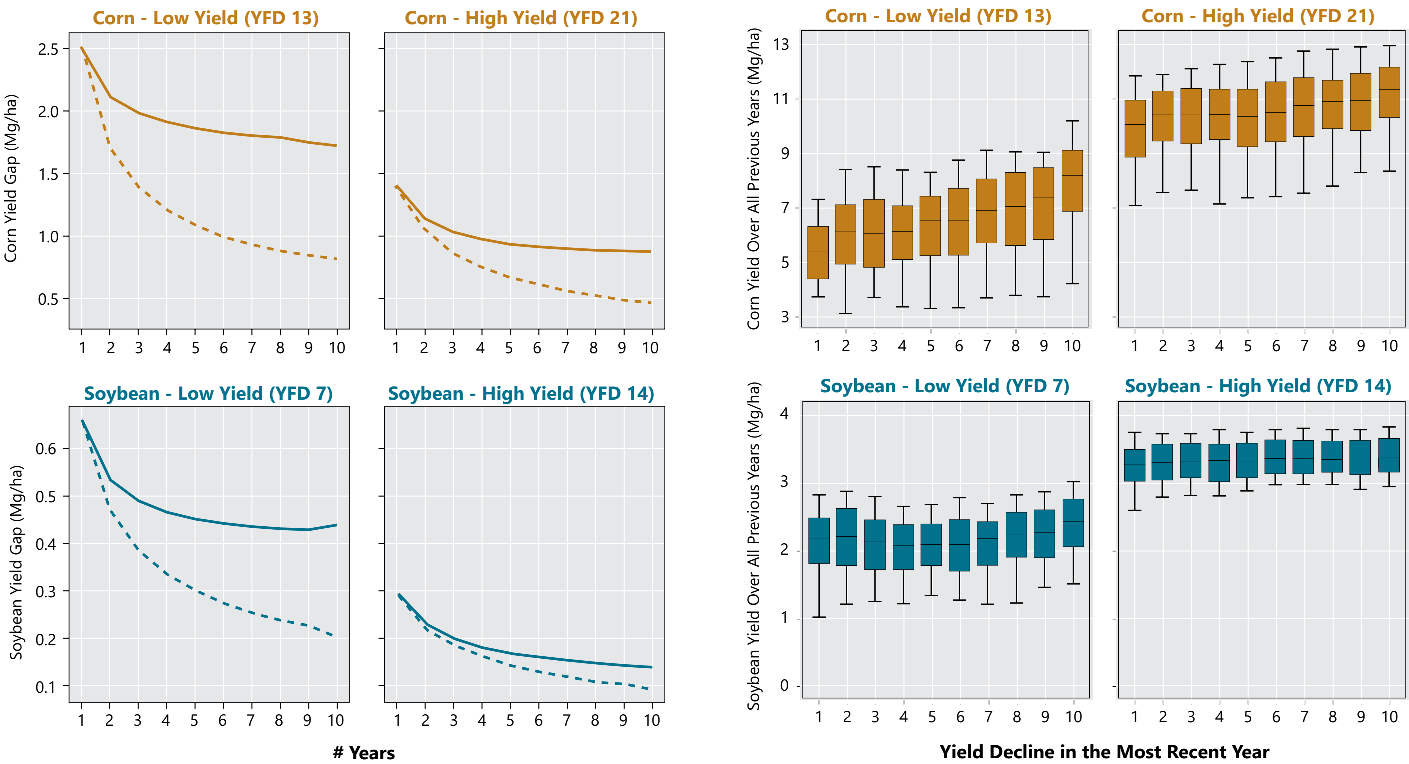
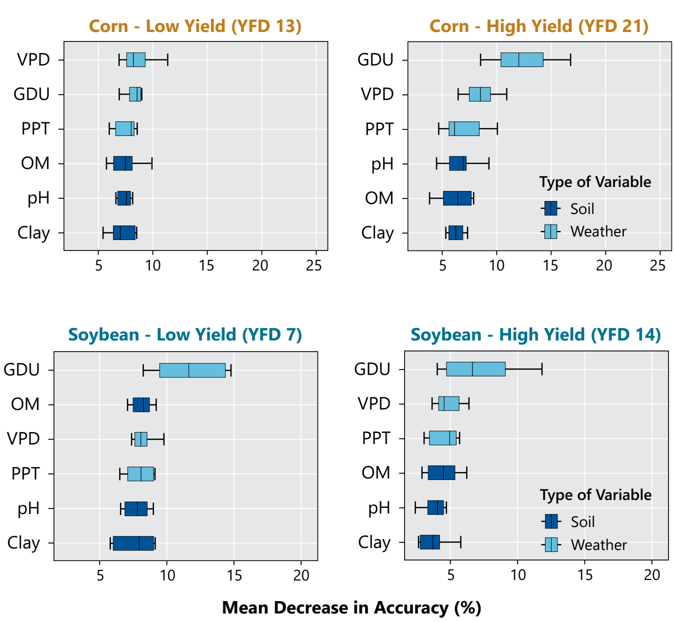


Figure 4. Yield gap profiles in yield factor domains 13 (low yield) and 21 (high yield) for corn plus 7 (low yield) and 14 (high yield) for soybean. Solid lines represent the decrease in yield gap as the number of years increases for the satellite-estimated yield. Dashed line represents the expected change in yield gap with increasing years if yield patterns were entirely random in space (computed by randomly re-ordering the spatial distribution of yields in each year). The boxplots show the yield distributions for 10 groups pixels where the groups are defined by the yield deciles in a single year (in this case, the last year of the study period - 2017). The yield distributions are calculated from yields on these fields from nine years prior to the year used to define the groups. Distributions are represented by the median (horizontal line); 25th and 75th percentiles (box); and 10th and 90th percentiles (whiskers).



CONCLUSIONS

Yield memory is a promising concept with potential to help researchers to quantify the degree of change in yield spatial patterns over time. It has value as a tool to help screen environments where factors of interest to researchers are the main drivers, leading to differences in yield from one growing season to the next.

Furthermore, in the U.S., this study found a significant negative correlation between corn and soybean yields and yield memory, indicating that regions with higher yields, despite having more homogeneous yields within a specific growing season, have a lower tendency to maintain spatial patterns from year to year. For high-yield memory regions, soil variables had greater weight in explaining yield differences compared to the low-yield memory cluster.

Figure 5. Mean decrease in accuracy (estimated by removing the variable from the random forest model) for each variable in yield factor domains 13 (low yield) and 21 (high yield) for corn plus 7 (low yield) and 14 (high yield) for soybean. Variables are ordered by importance.

Crop Management in a Changing Climate

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

> **"The unpredictability of weather** – not knowing at the start of a growing season what it will bring – is a ***constant challenge*** to optimizing crop management practices."

SUMMARY

- Understanding and incorporating long-term climate trends into crop management decisions can help minimize risk and increase the likelihood of success in crop production.
- Climate scientists have identified several shifts in climate associated with rising global temperatures that will affect agricultural production, many of which are already becoming apparent.
- One of the most significant climate trends for the Midwestern U.S. in recent years has been increased rainfall in the April to June time frame and more intense rainfall events.
- Average maximum temperatures during the summer have not increased in the Midwest, but night temperatures have gotten warmer.
- The average frost-free season in the Midwest and Great Plains has expanded by 9 to 10 days and is projected to continue to increase in the future.
- The potential effects of rising global temperatures on droughts in the Midwest are unclear. Projections suggest a more frequent pattern of excess moisture in the spring followed by dry spells in the summer.
- Weed and insect pressure varies yearly but is expected to worsen overall with more diligent management necessary.
- As current climate trends continue to intensify, the need for active adaptation measures will increase, especially in regards to protecting soils and crops against a more volatile climate with a higher frequency of extreme events.

INTRODUCTION

It would be difficult to name an industry more thoroughly dependent upon weather than agriculture. Weather conditions during a growing season can have an enormous impact on the yield potential of a crop; the growth and spread of weeds, diseases, and insect species; and the ability to plant and harvest a crop in a timely manner. Looking back at years when there were severe drops in crop yields (e.g., 1983, 1988, 1993, and 2012), anyone involved in crop production during those years will immediately recall the abnormal weather conditions that caused them.

The unpredictability of weather – not knowing at the start of a growing season what it will bring – is a constant challenge to optimizing crop management practices. Understanding and incorporating long-term climate trends into crop management decisions is important for minimizing risk and increasing the likelihood of successful outcomes in any given growing season. One of the most important factors influencing climatic trends around the world right now is rising global temperatures. Climate scientists have identified several shifts in climate trends associated with rising temperatures that will affect agricultural production, many of which are already becoming apparent. Whether some of these changes can be judged as positive or negative may depend on individual circumstances and perspective. The important point for agriculture is that they will tend to produce weather patterns that are different from what we have come to expect based on the recent past with increasing frequency and may require adaptation in crop management in order to maintain productivity. A general trend toward increased climate volatility will require greater resilience of crop production systems against extreme weather events.

This article will review some of the changes in climate associated with rising global temperatures and discuss implications for agricultural production, focused primarily on the Midwestern U.S., including observed and projected changes in weather patterns and potential impacts on crop growth as well as management.

TEMPERATURE AND CLIMATE

Global average surface temperature has risen by about 1.6 °F or 0.9 °C since the late 19th century (Figure 1). A large body of evidence supports the conclusion that this rise in temperature is a result of human activity and primarily due to the production of greenhouse gases (Santer et al., 2019).

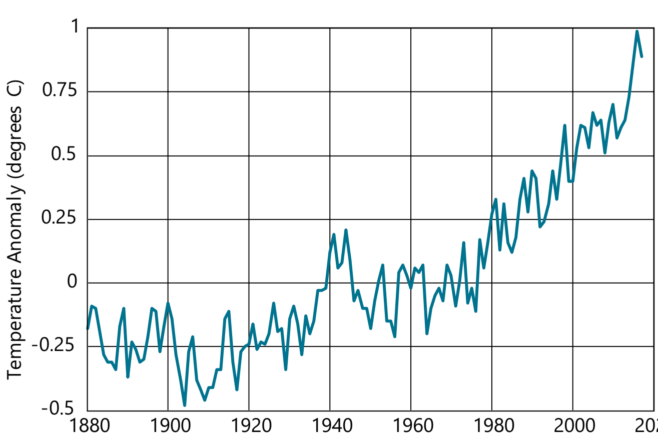
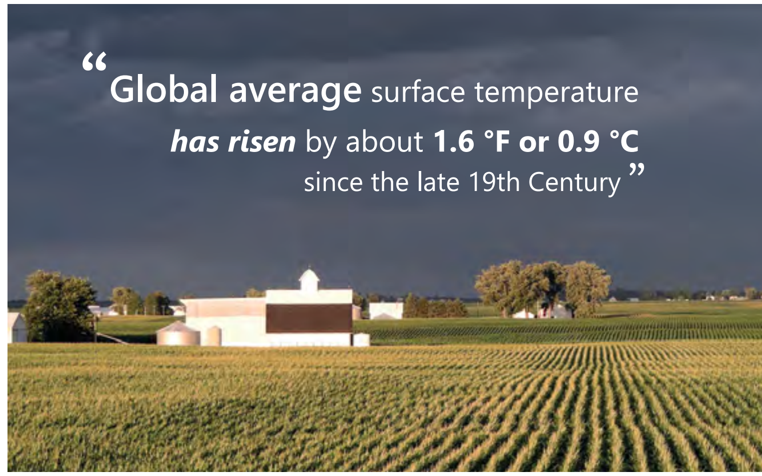


Figure 1. Annual global land and ocean temperature anomaly (deviation from 20th century average), 1880-2018 (NOAA NCEI, 2019).



Average global temperatures are increasing, but this does not mean that warmer temperatures manifest uniformly over the entire earth all of the time. Earth's climate system is complex and dynamic. The effects of altering one parameter of the system can produce different effects in different regions due to other interacting factors. Some of these associated climatological effects may have a greater direct impact on human populations and activities than the underlying rise in temperatures. For example, changes in water distribution (e.g., atmospheric humidity, sea levels, and precipitation patterns) may be a much more immediate concern for populations near bodies of water or industries dependent upon water, such as agriculture.

The following section provides an overview of some of the observed and projected climate trends relevant to agriculture summarized in the Fourth National Climate Assessment (NCA4), focusing specifically on the Midwestern U.S. (Angel et al., 2018). NCA4 provides a comprehensive overview of current climate science and potential implications for many industries and segments of society, including agriculture. The complete report, including summaries for other regions of the U.S., is available at www.globalchange.gov/nca4.

OBSERVED AND PROJECTED CLIMATE TRENDS

Temperature

One might expect the most reliable outcome of global warming to be hotter maximum temperatures during the summer, but this has not been the case in the Midwest. Annual average temperatures have increased, but this has been primarily due to higher maximum temperatures in the winter. Maximum summer temperatures have not increased in the Midwest as they have in most other regions of the country (Table 1) (Angel et al., 2018). Daily minimum temperatures have increased across all seasons, however. The 2018 growing season was the hottest on record for the continental U.S., primarily because of high nighttime temperatures.

Research indicates that one of the reasons maximum temperatures during the summer have not increased in the Midwest is because of greater precipitation in the spring and early summer as well as subsequent high levels of evapotranspiration of water from agricultural crops (Alter et al., 2017). As agricultural productivity in the region has increased, so has the amount of water transpired from growing crops into the atmosphere. This causes humidity to rise, which

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tends to reduce daytime maximum temperatures, increase nighttime temperatures, and increase precipitation. This same phenomenon has been observed in other areas of the world where intensive agricultural production has been associated with a suppression of extreme temperatures in the region (Mueller et al., 2017).

Table 1. Observed regional changes in annual average temperature from 1901-1960 to 1986-2016. Estimates are derived from the nClimDiv dataset (Vose et al., 2017).

Region	Change in Annual Temperatures	
	Maximum	*Minimum*
Northeast	+1.16 °F	+1.70 °F
Southeast	+0.16 °F	+0.76 °F
Midwest	+0.77 °F	+1.75 °F
Great Plains North	+1.66 °F	+1.72 °F
Great Plains South	+0.56 °F	+0.96 °F
Southwest	+1.61 °F	+1.61 °F
Northwest	+1.52 °F	+1.56 °F

Although the Midwest has thus far not experienced higher maximum temperatures during the summer months, higher night temperatures have the potential to be detrimental. Research has shown that above-average night temperatures during reproductive growth can reduce corn yield both through reduced kernel number and kernel weight due to accelerated phenological development as well as increased rates of cellular respiration (Lutt et al., 2016).

Precipitation

One of the most significant climate trends that has been observed for the Midwestern U.S. over the past few decades has been increased rainfall, particularly in the April to June time frame (Figure 2) (Angel et al., 2018; Feng et al., 2016).

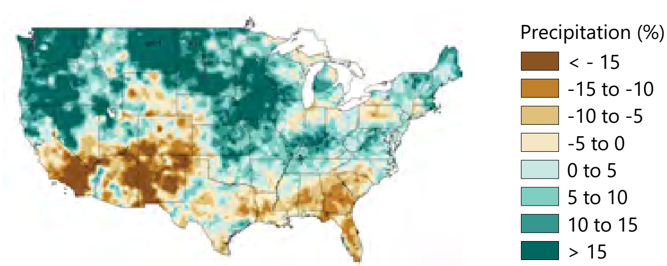

Figure 2. Change in spring precipitation from 1986-2015 compared to 1901-1960 (Easterling et al., 2017).

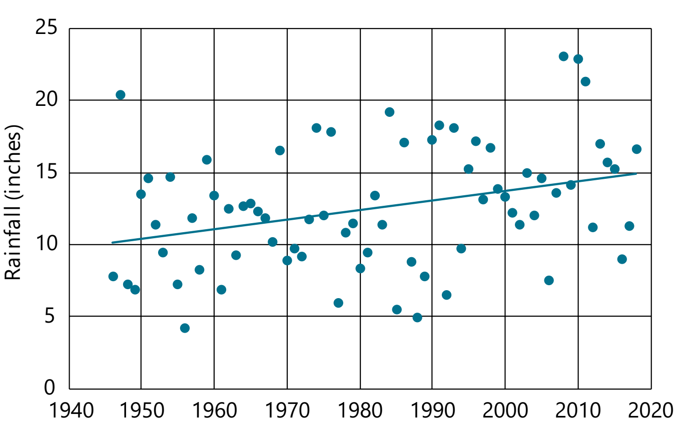

Figure 3. Annual cumulative rainfall in April, May, and June at the Des Moines International Airport, Des Moines, IA (NOAA NCEI, 2019).

In general, warmer air is able to hold more moisture, increasing the amount of water available to fall as precipitation. In Des Moines, IA, for example, total rainfall between April and June has increased nearly 50% from an average of around 10 inches in 1950 to 15 inches in 2018 (Figure 3).

Rainfall overall has also tended to be concentrated into more intense rainfall events with the frequency of heavy rainfall events doubling in the Midwest over the past century (Hayhoe et al., 2009). A shift toward a greater percentage of total precipitation falling in very heavy rainfall events has occurred in many parts of the Continental U.S. with the greatest change occurring in the Northeast. These trends are larger than natural variations for the Northeast, Midwest, Southeast, and Great Plains (Walsh et al., 2014) (Figure 4).

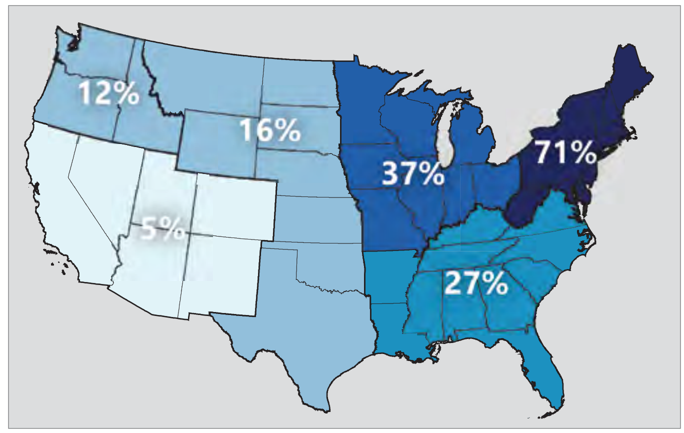

Figure 4. Percent increase in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958-2012 for each region of the Continental U.S. (Walsh et al., 2014, updated from Karl et al., 2009).

One of the reasons for the shift toward more intense rainfall events in the Midwest is the effect that warmer temperatures have on storm systems called *mesoscale convective systems* (MCSs). Mesoscale convective systems are complexes of thunderstorms that can spread over an entire state and last more than 12 hours. They are typically most active at night and extend into the morning hours. These types of systems have historically accounted for 30 to 70% of the total warm-season precipitation in the Central U.S. (Fritsch et al., 1986). Research shows that warmer spring temperatures are causing these storms to be more frequent, more intense, and longer-lasting in the Central U.S. (Feng et al., 2016).

Nearly all of the Midwestern U.S. has experienced a significant increase in rainfall from mesoscale convective systems over the past 40 years (Feng et al., 2016). In the Midwest, these systems are produced by a low-level jet stream, called the *Great Plains low-level jet*, that transports heat and moisture from over the Gulf of Mexico north and east. Higher temperatures over the Southern Great Plains tend to strengthen this jet stream and increase the amount of moisture evaporated from the Gulf of Mexico that is transported inland, which leads to stronger and more frequent storms (Figure 5).

Rainfall during the April to June time frame provides the benefit of charging the soil profile early in the season, which can help mitigate the effect of dry spells later in the summer on growing crops. However, excessive rainfall during this time can also cause delays in field work due to saturated or flooded soils. Intense rainfall events can also erode soils that may have little or no protection at this time of the season.

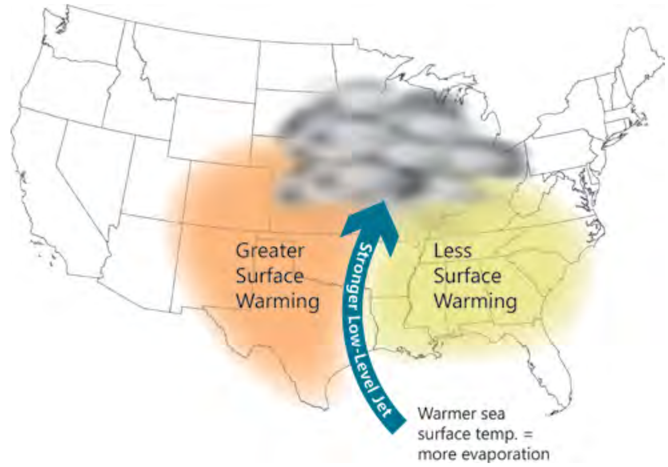

Figure 5. Warmer sea surface temperatures in the Gulf of Mexico increase water evaporation into the atmosphere. Surface warming over the Southern Great Plains increases the pressure gradient across the Central U.S., which strengthens the Great Plains low-level jet, increasing the amount of moisture carried up to the Midwest that falls as precipitation.

Projected changes in precipitation over the next century vary greatly across different regions of the U.S. Significant increases in winter and spring precipitation are projected for the Midwest and Northern Great Plains. Changes in summer and fall precipitation are not expected to exceed the range of natural variability. Studies project that the trend toward more frequent and intense heavy precipitation events will continue in the future (Easterling et al., 2017).

Drought

The frequency of widespread droughts in the Midwest has decreased in the latter half of the 20th century (Mishra and Cherkauer, 2010). Climate scientists are uncertain how the severity, frequency, and duration of droughts will change in the future. Season-long droughts, such as those experienced in 1988 and 2012, are not necessarily expected to increase in frequency. Rather, projections suggest a more frequent pattern of excess moisture in the spring given the changes in precipitation trends, followed by a lack of moisture in the summer due to higher temperatures and evapotranspiration (Angel et al., 2018).

Frost-Free Season

The length of the frost-free season (the length of time between the last spring frost and the first fall frost) has gradually increased throughout the entire continental U.S. since the 1980s. Compared to the 1901 to 1960 time period, the frost free season was 9 to 10 days longer on average in the Midwest and Great Plains during 1991 to 2012 (Walsh et al., 2014) (Figure 6). The length of the frost-free season is projected to continue to increase in the Midwest by up to 20 days by mid-century and possibly a month by late-century (Angel et al., 2018).

> "The length of the frost-free season has gradually increased throughout the entire continental U.S. since the 1980s"

A longer frost-free season means a longer period for plant growth and productivity each year, which, by itself, can generally be considered positive for agricultural production, particularly in northern areas where productivity is greatly constrained by the length of the growing season. Adaptation to this trend

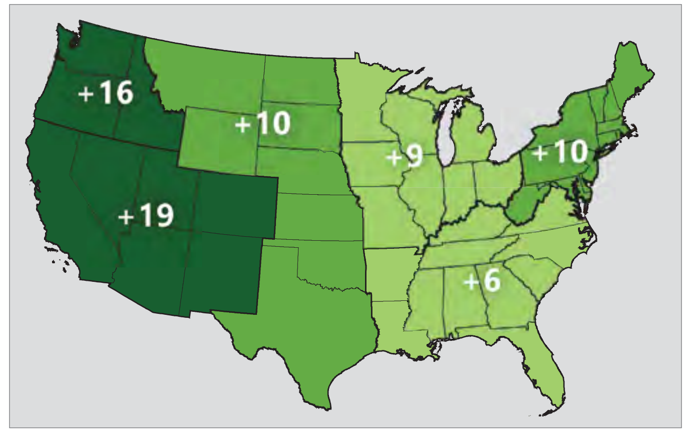

Figure 6. The frost-free season length, defined as the period between the last occurrence of 32 °F in the spring and the first occurrence of 32 °F in the fall, has increased in each U.S. region during 1991-2012 relative to 1901-1960 (NOAA NCDC / CICS-NC, 2019).

is already apparent with the expansion of corn production in the Northern Great Plains and western Canada. It is important to remember, though, that it is not just crops experiencing a longer growing season but weeds, insects, and diseases. The Southern areas of the Midwest will experience fewer frosts as the freeze zone moves north, which has implications for pests and pathogens.

Polar Vortex Disruption

Winter temperatures in the Midwest and Great Plains have generally increased and are projected to continue to do so. However, one of the more counterintuitive manifestations of increasing global temperatures may be the potential to produce extreme cold snaps, such as the one experienced in the Midwest and Northern Great Plains in late January of 2019. The cold air over the Arctic is generally separated from the warmer mid-latitude air by the jet stream – a river of wind that flows from west to east over North America. Over the past century, the Arctic has warmed at a much faster rate than the rest of the earth, which has decreased the temperature differential between the Arctic and North America. As the difference in temperature decreases, so does the difference in atmospheric pressure, which causes the jet stream winds to weaken. As the jet stream weakens, extremely cold high-altitude Arctic air has the potential to plunge south into the U.S. (Figure 7). The potential for cold snaps like this to increase in frequency in the future is undetermined and currently an active area of research.

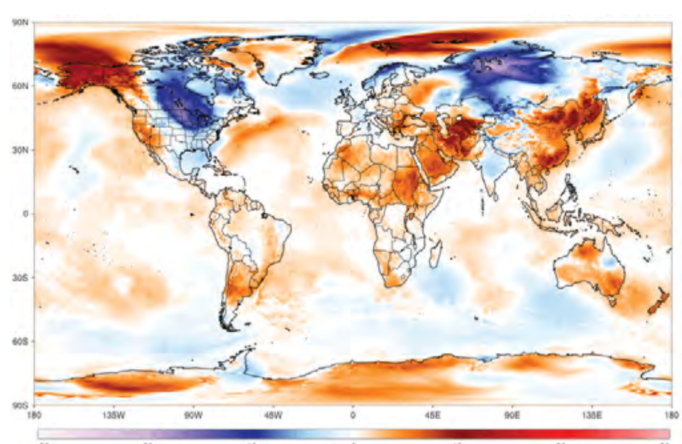

Figure 7. Average near-surface temperature anomaly for January 28-30, 2019, showing an area of extreme cold over North America (Climate Reanalyzer, Climate Change Institute, University of Maine. Data from NOAA Global Forecast System model).

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CROP MANAGEMENT IMPLICATIONS

Crop Yield

When considering the possible implications of climate change for agricultural productivity in the U.S., one must first consider two indisputable facts: 1) significant shifts in climate are already occurring, and 2) U.S. average corn and soybean yields have continued to go up. This would suggest one of three possibilities: 1) climate change experienced thus far has required little, if any, adaptation to maintain yield trends; 2) adaptation is being implemented and has been successful; or 3) yields have been reduced by climate change, but these losses have been more than offset by gains from better genetics and management.

To some extent, adaptation by crop producers to changing climatic conditions has been and will continue to be automatic – by continually optimizing crop selection, hybrid/variety selection, and agronomic management for maximum yields, adaptation happens without anyone necessarily thinking about it. As current climate trends continue to intensify in the future, however, adaptation may become more important to specifically plan towards. It will be very important to protect soils and crops against a more volatile climate with a higher frequency of extreme events. In the near-term, the greatest need for active adaptation will likely not be associated with rising temperatures and longer growing seasons so much as with more abundant and intense rainfall. Specific adaptive practices will vary by geography, crop, and operation.

Unrelenting rainfall caused widespread delays in spring tillage and planting in 2019. The continuing trend toward more spring rainfall will be a major challenge for crop production in the Midwestern U.S.

Field Work Suitability

One of the greatest risks to crop yield associated with climate change will likely be the inability to conduct field operations, particularly planting, in a timely manner. The continuing trend toward more precipitation in the spring with a greater proportion concentrated into intense rainfall events will result in fewer days suitable for field work. Adequate field drainage will be increasingly important to help move water out of fields as well as shorten the time between heavy rains and suitability of soils for fieldwork. Machinery and labor resources may also need to be increased to allow more fieldwork to be done within smaller windows of time in which conditions are favorable.

Soil Conservation and Health

The trend toward greater precipitation and more intense rainfall events will place a greater importance on good soil conservation practices to protect against erosion. Protecting the soil will be especially important during the fallow periods of late winter and spring when precipitation is forecast to increase the most. Shorter and warmer winters mean a greater proportion of total precipitation will fall as rain rather than snow, which will increase the risk of erosion and flooding from heavy rains in late winter and early spring.

Managing soil compaction will be important as farmers may be increasingly compelled to conduct field operations when soil conditions are wetter than optimal in part or all of the field. The dramatic increase in the weight of many farm machines over the past few decades coupled with wetter soils means the risk of deep and persistent soil compaction will be greater than ever before (Jeschke, 2018). Management practices that help build soil organic matter and structure will help make the soil more resilient to compaction, increase water-holding capacity, and allow excess water to drain more quickly, all of which will be increasingly important with the greater frequency of growing seasons that are too wet early and too dry late.

Increased soil conservation measures will be necessary to protect against more frequent and intense precipitation in the late winter and spring.

Disease, Insect, and Weed Management

Some of the most noticeable impacts of climate change on crop production may not be to the crop itself but to associated weeds, diseases, and insects. The geographic distribution of pest species is heavily influenced by climate, so as climate changes, pest distribution and activity will also change. In general, the Midwestern states are likely to face more challenges from pests traditionally associated with southern states due to rising temperatures and shorter winters. Two examples that fit this expected pattern for which changes have already been observed are southern rust of corn (*Puccinia polysora*) and Palmer amaranth (*Amaranthus palmeri* (S.) Wats.), both of which have become a greater problem in the Midwest in the past decade (Jeschke et al., 2017; Kistner and Hatfield, 2018). Pests, such as corn earworm (*Heliothis zea*), that do not currently overwinter in the Midwest are expected to increase in prevalence as the southern boundary of the seasonal freeze zone moves north.

Weed management will likely become more challenging with rising temperatures and atmospheric CO_2. Research has shown that weed species tend to respond more to elevated CO_2 than crop species, making them more competitive with growing crops (Ziska, 2004). Higher temperatures give a competitive advantage to weed species with the C4 photosynthetic pathway, such as waterhemp (*Amaranthus tuberculatus*), Palmer amaranth, and Johnsongrass (*Sorghum halepense).* Weed management programs that include multiple modes of action and sequential treatments will be critical for effective weed control.

Climate change effects on corn disease severity is projected to be mixed with differing effects on individual pathogens (Juroszek and von Tiedemann, 2013). Plant pathogens are highly responsive to humidity, precipitation, and temperature. Pathogens will generally be favored by increased humidity and frequency of rainfall, but a greater frequency of dry conditions during pollination and grain fill could limit the spread of foliar disease in the crop canopy during the most critical period for yield. Wetter conditions during the fall, such as those experienced in 2018, may increase the severity of diseases that affect grain quality and harvestability.

Insect pests of crops are likely to increase in the Midwest. Research has shown that temperature is the single most important factor driving insect ecology, epidemiology, generations per growing season, and distribution (Coakley et al., 1999), so warmer temperatures and longer frost-free periods will generally be favorable to insects. Greater insect pressure could put increased stress on the effectiveness of insect protection technologies and treatments, making the use of integrated management strategies with multiple tactics and modes of action more important.

Fertility Management

Increased frequency and intensity of rainfall early in the growing season may impact nitrogen management in corn by increasing the risk of nitrogen loss. In such situations, nitrate may be lost from the soil either by leaching or denitrification, depending primarily on soil characteristics. Coarse-textured soils allow water and nitrates to move readily downward through the soil profile. When this leaching places nitrate below the root zone, it is of no use to the plant and essentially lost. Fine-textured soils, on the other hand, have capillary pores that hold water tightly, restricting its downward movement. In this situation, saturated soils and anaerobic conditions may result in nitrate being lost to the atmosphere through denitrification.

The use of nitrification inhibitors can help reduce the risk of nitrogen loss from the soil by slowing the conversion of ammonium to nitrate, thus prolonging the period of time that nitrogen is in the immobile ammonium form. Applying nitrogen in-season can help protect against nitrogen loss by timing application more closely to plant uptake. However, uptake of late-season nitrogen can be limited if conditions turn dry during the summer.

In addition to nitrogen, the availability of other nutrients that are mobile in soil water can be affected by frequent early season rains. Sulfur and boron are both highly mobile in their plant-available forms and subject to loss through leaching. Sulfur deficiencies are most common on sandy or other low organic soils because of their reduced ability to supply sulfur and losses due to leaching. In recent years, however, deficiencies have become more prevalent across a variety of soil types, likely due to increased crop removal and reduced atmospheric deposition. Boron can also become deficient in areas where the nutrient is readily leached and is not replenished through organic matter decomposition.

CONCLUSIONS

Midwest farmers will need to adapt and protect their farms from increased precipitation in the winter and spring and more intense storms, which will lead to a greater frequency of saturated soils and flooding. This will have implications for field operations, soil conservation practices, and fertility management. Warmer temperatures and longer frost-free seasons may alter the crop rotations used or hybrid/variety maturities selected. Weed and insect pressure varies yearly and is expected to worsen overall with more diligent management necessary.

Corteva Agriscience offers a range of tools and tactics to help growers adapt their crop production systems to changing conditions and new challenges:

1. **Crop breeding** efforts in key geographies coupled with extensive local testing ensures that new hybrids and varieties *have the characteristics necessary* to ***thrive*** in the environments in which they are grown.

2. **Extensive research** on pest management tools, seed treatments, and crop management helps farmers ***protect yield potential*** in the face of environmental stresses and *shifting pest spectrums*.

3. **Crop management research** and insights provided by Pioneer agronomists helps farmers *optimize management practices* and ***stay ahead*** of emerging issues.

4. **Granular tools and analytics** allow farmers to *monitor crop conditions*, proactively identify issues, and ***efficiently allocate inputs***.

5. And finally, Corteva Agriscience **support** for numerous university research studies helps develop solutions tailored to **address unique challenges** in *specific geographies*.

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Variability in Crop Yields in 2019

Matt Essick, M.S., *Agronomy Manager*

OVERVIEW

2019: Another Challenging Year in Crop Production

- Yield is determined by the interaction of the environment, management practices, and genetics of the seed (Figure 1).
- Understanding the effects of the environment the crop is grown in, management of the field, and their interactions with crop genetics can help explain some of the variability within fields.
- Environmental factors include soil type, drainage, sunlight, rainfall, and temperature.
- Management factors can include planting date, tillage practices, fertility programs, weed management, disease management, and a host of other practices.

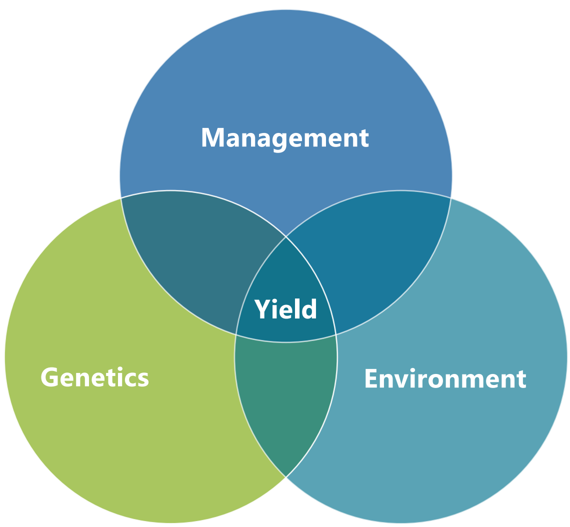

Figure 1. Yield is determined by the interaction of genetics, environment, and management practices.

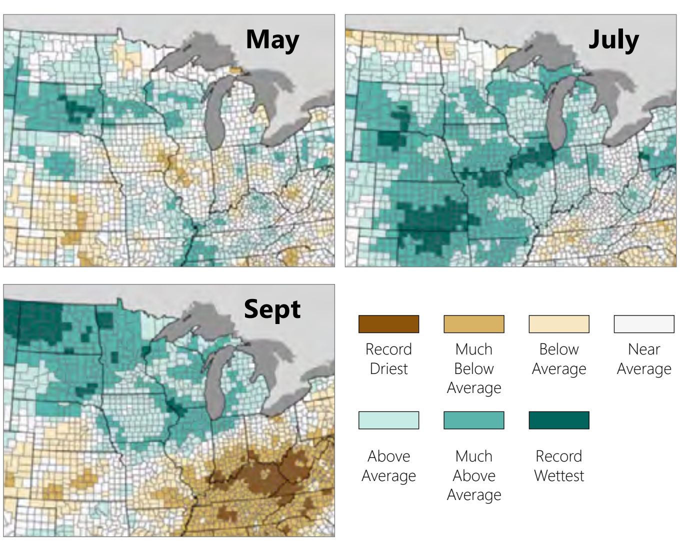

Figure 2. County level precipitation ranks (1895-2019) showing areas of above average and record high precipitation in several states during May, July, and September of 2019 (NOAA NCEI 2019).

2019 WEATHER

- Wet conditions in April and May led to delayed planting and planting into less than ideal soil conditions in many areas (Figure 2).
- Planting was delayed across much of the corn-growing areas in the United States, resulting in the slowest planting progress on record for the U.S. (Figure 3).
- Soils became saturated again in July and September, leading to nutrient losses and reduced plant health (Figure 2).
- Temperatures were near average for much of the growing season and generally above average in September (Figure 4).

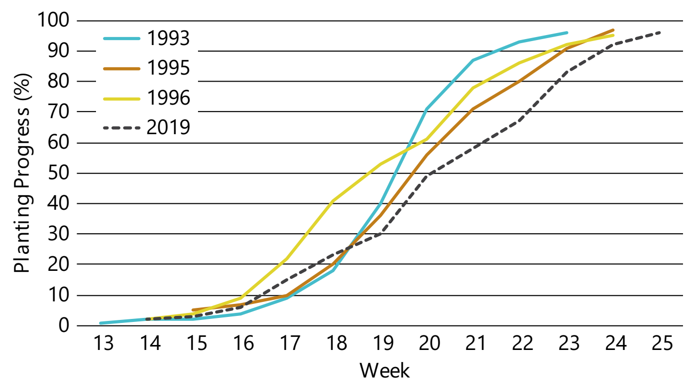

Figure 3. Weekly U.S. corn planting progress for 2019 compared to other historically late planting seasons (USDA-NASS, 2019).

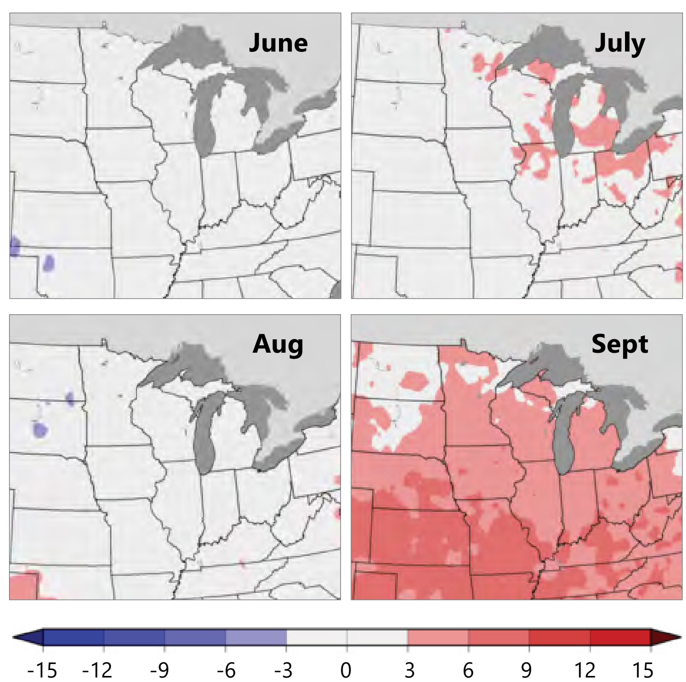

Figure 4. Mean temperature departure from average (1895-2019) during June, July, August, and September of 2019 (NOAA NCEI 2019).

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EFFECTS OF WET SOILS ON CROP YIELDS

- Field conditions at planting were often highly variable in 2019, leading to differences in emergence and root development
- Wet soils at planting can lead to reduced, delayed, or uneven emergence; sidewall compaction; and reduced yield performance.
- Saturated soils reduce oxygen levels in soils, slowing root growth and creating a favorable environment for disease.
- Saturated soils also reduce biological activity in the soil and increase loss of key nutrients, such as nitrogen.
- Soils with better drainage experience shorter durations of these conditions, resulting in higher yield potential.

Figure 5. Wet soils at planting causing slower emergence and swollen mesocotyl.

SUNLIGHT INFLUENCE ON YIELD

- Solar radiation is critical to providing plants the needed energy to conduct photosynthesis and fuel plant growth.
- The most critical period for photosynthesis in crop production is during the reproductive growth stages. Many fields in Minnesota, the Dakotas, and Wisconsin received below-average solar radiation during this time frame in 2019 (Figure 4).

OTHER INFLUENCES ON YIELD

- Soil type is a major environmental factor when it comes to water-holding capacity and drainage.
- In wet years, soils with poor internal drainage are difficult to manage.
- Fall of 2018 was historically wet in many areas, so crop growth in 2019 could have been affected by compaction created during last year's harvest.
- Plants with slower emergence or reduced root growth due to soil compaction are often smaller and capture less sunlight as well as other critical resources for yield.
- Wet conditions also prevented fall tillage in many areas in 2018, creating residue management challenges. Residue that is not properly managed can reduce stand establishment, restrict root growth, and tie up nutrients.
- Diseases, such as northern corn leaf blight and tar spot, can lead to higher yield variability across fields.

Variable plant size due to wet soil conditions at planting.

MANAGEMENT INFLUENCES

- Planting later into May and early June reduces total photosynthesis over the growing season and pushes grain-fill periods later. Fields that enter reproductive growth later can be more susceptible to foliar disease, drought, and other stresses.
- Fields that emerge more uniformly have a greater chance of producing higher yields.
- Soil fertility levels are extremely important in years where soils are either too wet or too dry as root growth and soil microbial activity are reduced under wet and dry conditions.
- In-season applications of nitrogen in wet years can help improve yields.

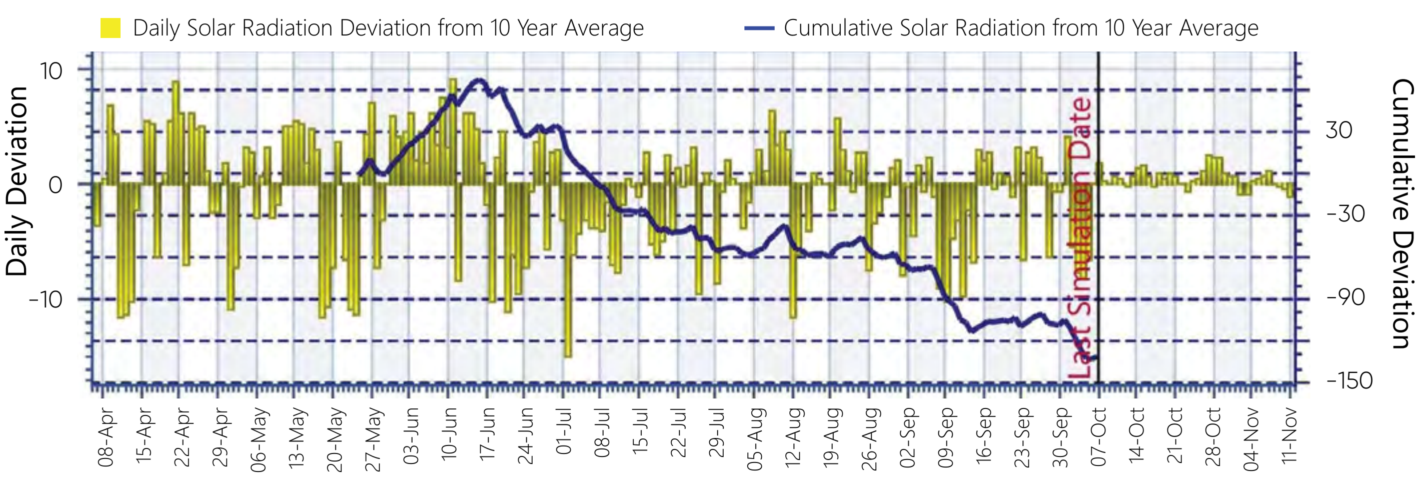

Figure 6. Chart indicating below-average solar radiation during much of August and September for Blue Earth County, MN.

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Managing 2019 Prevented Plant Acres for the 2020 Growing Season

Matt Essick, M.S., *Agronomy Manager,* ***Adam Gaspar, Ph.D.,*** *Integrated Field Sciences,* ***Clyde Tiffany,*** *Field Agronomist, and* ***Mark Jeschke, Ph.D.,*** *Agronomy Manager*

UNPRECEDENTED PREVENTED PLANTING IN 2019

- Extremely wet conditions in the spring of 2019 led to challenging planting conditions across much of the Midwestern U.S.
- The number of prevented plant acres reported in 2019 was the highest since the USDA began releasing this report in 2007 (USDA 2019).
- Over 19 million acres went unplanted in 2019, including over 11 million acres of corn and 4 million acres of soybeans.
    - » South Dakota had the most prevented plant acres, totaling nearly 4 million.
    - » Illinois, Minnesota, Missouri, and Ohio all had over 1 million prevented plant acres.

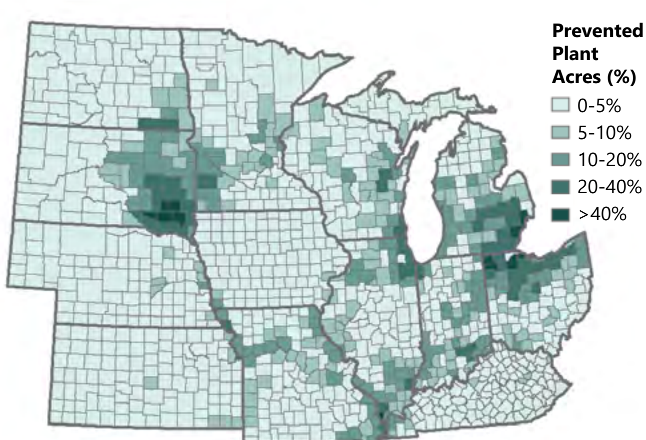

Figure 1. Percent of acres reported to FSA as prevented plant acres by county in several Midwestern states as of August 1, 2019.

MANAGEMENT OF PREVENTED PLANT ACRES IN 2020

- Management of prevented plant acres in 2019 varied from field to field. Fields may have been seeded to a cover crop or forage; managed for weed control mechanically and/or chemically; left untouched; or a combination of these (Figure 2).
- Prevented plant acres may require additional management in 2020 to address unique challenges associated with fallowing or planting to a cover crop in 2019.

Figure 2. Field with a large fallow area due to flooding in 2019.

Proactive management will be required to prevent fallow syndrome in this area if the field is rotated into corn in 2020.

FALLOW SYNDROME IN CORN

- Corn planted in fields in which no crop was grown the previous season can have reduced early season growth (Figure 3) and lower yields, a condition known as fallow syndrome (Wiersma and Carter, 2013).
- Fallow syndrome is associated with a reduction in symbiotic fungi called vesicular arbuscular mycorrhizae (VAM) in the soil.
    - » VAM are key beneficial fungi that support plant growth, especially in corn, through improved P nutrition and soil P cycling (Vivekanandan and Fixen, 1991).
    - » Soil without actively growing roots of a host species can experience a significant reduction in VAM populations.
    - » Grass cover crops like cereal rye and oats are hosts to VAM and help maintain populations, while Brassica cover crops (turnips and radishes) are not.
    - » Reduced populations of VAM are associated with fallow syndrome in corn; soybeans are not as susceptible.
- Placing a chelated zinc and phosphorus fertilizer directly in the seed furrow as a pop-up fertilizer has been shown to minimize yield loss from fallow syndrome (Stahl et al., 2018).

Figure 3. Corteva Agriscience field demonstration site in which plots that were fallow the prior season have a visible reduction in early season corn growth relative to adjacent plots planted to soybeans the prior season.

NODULATION IN SOYBEANS

- Nitrogen fixation in soybean is carried out by *Bradyrhizobium japonicum* bacteria that colonize the roots.
- While rhizobia can persist in the soil for many years, saturated soils can reduce the number of rhizobia present in the soil.
- Possibly more detrimental to soil rhizobia population survival are the excessively high soil temperatures (>100 °F) that can occur in barren fields (Figure 4) (Munevar and Wollum, II, 1981).
- The potential reduction in soil rhizobia may lead to reduced nodulation, and an inoculant on soybean seeds may be beneficial in 2020.

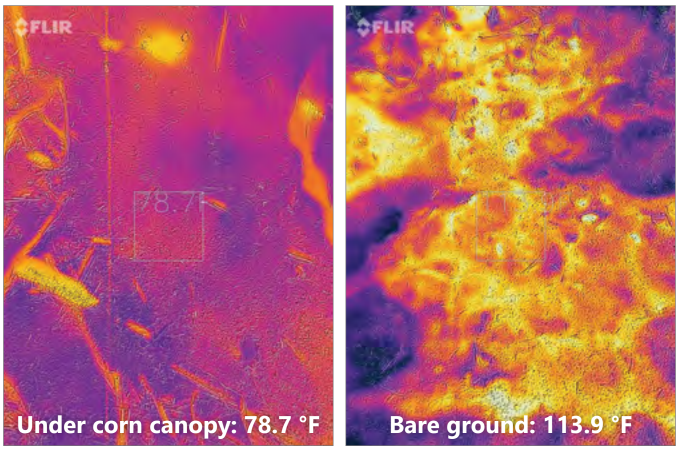

Figure 4. Thermal imagery showing the effect of ground cover on soil surface temperature. Soil temperature at mid-day under a corn crop canopy was 78.7 °F, compared to 113.9 °F for an adjacent area of bare ground under full sunlight. Imagery taken August 2, 2019, 11:23 AM, Johnston, IA.

WEED MANAGEMENT IN 2020

- **Understand any crop rotational restriction from any 2019 applied herbicides.**
- **In some 2019 prevented plant fields, weed control was difficult due to excessive precipitation through the summer, leading to the potential for weed management concerns in 2020. Furthermore, perennial cover crops that overwinter will need to be managed in 2020.**
- **Managing weeds in both corn and soybeans in 2020 will require a multi-faceted approach of chemical, cultural, and mechanical, when appropriate.**
- **Effective use of burn-down herbicides in fields that will be no-till or strip-till will be important to ensure that the crops have minimal competition from weeds early in their growth stages.**
- **Residual pre-plant or pre-emergence herbicides need to be included in weed management plans for 2020 to reduce the number of weeds exposed to post-emergence herbicide applications, which is a key resistance management practice.**
- **Timely in-season applications of herbicides with effective modes of action and layered residual activity will help prevent yield loss from late-season weed competition.**

Figure 5. Prevented plant field in 2019. Herbicide was applied, but larger weeds were not completely killed and will likely still produce viable seed, increasing the weed seedbank for the 2020 season.

SOIL CHEMICAL AND PHYSICAL PROPERTIES

- Some 2019 field operations likely took place under less than ideal soil conditions. Appropriate fall tillage may be beneficial to shatter compaction layers, especially at lower latitudes. However, if limited plant residue was produced in 2019, tillage passes should be kept to a minimum to reduce the potential for wind and water erosion in addition to soil crusting in the spring of 2020.
- Any 2019 spring-applied N or S will have left the soil profile by 2020 unless a cover crop was seeded early in the season. Nitrogen may be managed differentially between fields with and without a 2019 cover crop.
- Grass cover crops will have tied up some of the residual soil N, while legume like hairy vetch would have been a good source of N fixation.

Figure 6. Prevented plant field seeded to a grass cover crop in 2019.

OTHER MANAGEMENT CONSIDERATIONS

- Cover crops can potentially host insect pest species that may damage the subsequent crop, so additional attention to insect management may be required.
- Insect pests that can potentially be associated with cover crops include green cloverworm, Japanese beetle, bean leaf beetle, stink bugs, true armyworm, black cutworm, seed corn maggot, and wireworms (McMechan, 2018).
- Cover crops can also influence certain non-insect pests. For example, legume cover crops can serve as a host for soybean cyst nematodes, while grass cover crops do not.

Soil Temperature and Corn Emergence

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

SUMMARY

- Corn is a warm season crop. Germination and emergence are optimal when soil temperatures are approximately 85 to 90 °F. Cold conditions following planting impose significant stress on corn emergence and seedling health.
- Corn seed is particularly susceptible to cold stress during imbibition. Planting just before a stress event, such as a cold rain or snow, can result in a reduced stand.
- 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.
- Pioneer® brand corn products are rated for stress-emergence to help farmers manage early season risk. Choosing hybrids with higher stress-emergence scores can help reduce genetic vulnerability to stand loss due to cold soil temperatures.
- Pioneer brand corn products include an industry leading seed-applied technology portfolio designed to help farmers establish healthy, uniform crops and maximize productivity.

"***Successful corn emergence*** is a combination of three key factors – **environment, genetics *and* seed quality.**"

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INTRODUCTION

Successful corn emergence is a combination of three key factors – environment, genetics, and seed quality (Figure 1). 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. Pioneer® brand corn products are selected to provide the best genetics for consistent performance across a wide range of environments, and seed production practices are optimized for maximum quality. However, even with the best genetics and highest seed quality, environmental factors can still influence stand establishment. A combination of field- and lab-based research on the effects of stressful conditions on corn germination and emergence provides valuable insights, which can help farmers make informed decisions and better manage their field operations to maximize stands.

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

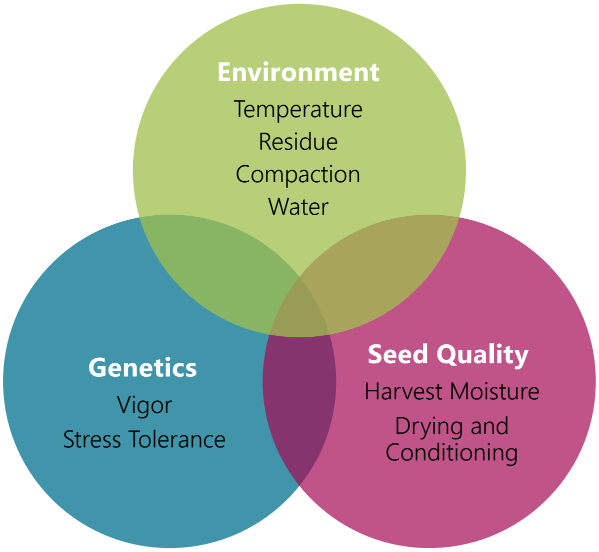


Figure 1. Some critical environmental, genetic, and seed-quality factors that affect stand establishment.

OPTIMAL TEMPERATURE FOR EARLY CORN GROWTH

Corn is a warm-season crop and grows best under warm conditions. In North America, early season planting typically puts substantial stress on corn seedlings, especially if planting is followed by cold, wet weather. As planting has shifted earlier, the potential for cold soil at planting and cold, wet weather after planting has increased. In fact, it is not unusual for early planted corn to remain in cold, saturated soil for two to three weeks or longer before emerging.

To illustrate the effects of temperature on corn growth, three 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. 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 2). It is generally recommended that farmers

plant when soil temperatures are at or above 50 °F. Farmers can expect much slower emergence and growth at the cool soil temperatures that are typical during corn planting in much of the U.S. and Canada.

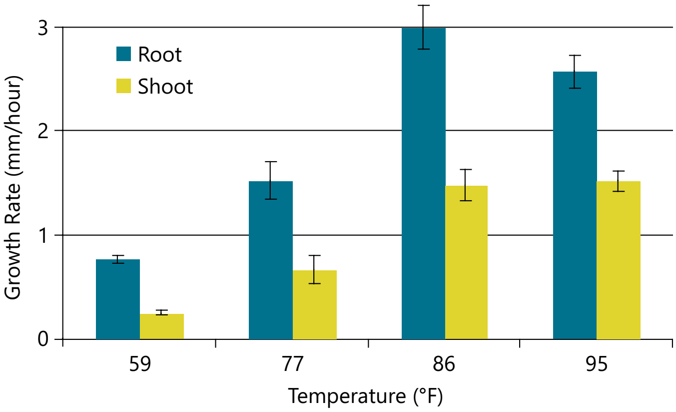


Figure 2. Average early root and shoot growth rates for 3 hybrids under 4 soil temperatures ranging from 59 to 95 °F.

Spring soil temperatures can vary greatly year to year. Soil temperatures at planting in combination with near- to moderate-term weather trends have profound effects on the probability of establishing optimal stands and achieving maximum yields. Researchers recorded average soil temperatures at planting depth at several stress-emergence research locations in 2018 (Figure 3).

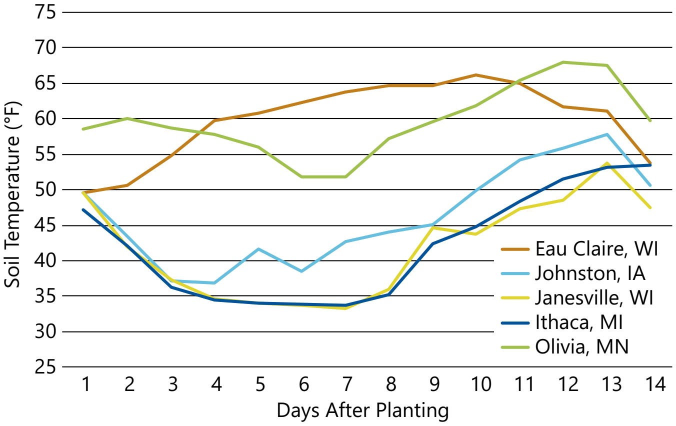


Figure 3. Average late-April soil temperatures recorded at 2-inch depth at several stress-emergence testing locations.

At 3 research locations, soil temperature dropped well-below 50 °F for a week or more after planting. Figure 4 illustrates the general relationship between soil temperature and stand establishment observed at these locations in 2018.

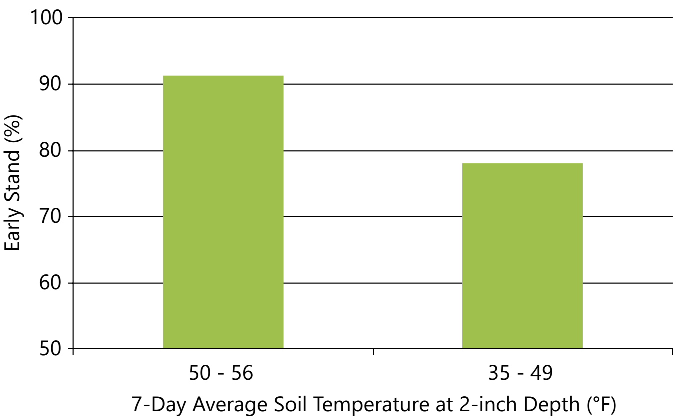


Figure 4. Relationship of soil temperature at planting depth (7-day average after planting) to final stand at stress-emergence research locations, 2018.

GENETIC DIFFERENTIATION FOR EMERGENCE IN COLD SOILS

Pioneer® brand corn products are rated for stress-emergence to help farmers manage early season risk. Choosing hybrids with higher stress-emergence scores can help reduce genetic vulnerability to stand loss due to cold soil temperatures. To generate stress-emergence ratings, hybrids are tested over multiple years and environments, beginning several years before commercialization. The goal is to generate data from many different types of early season stress before assigning ratings.

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

Hybrids are tested in several early planted field sites, including no-till and continuous-corn locations. Testing sites are located in Minnesota, Wisconsin, Iowa, South Dakota, North Dakota, and Michigan and are chosen to reflect the various seedbed as well as environmental conditions likely to be experienced by farmers. For example, some eastern sites are characterized by extended cold, wet conditions that often persist into late spring and early summer, while northern and Midwestern sites are more likely to provide extreme day/night temperature fluctuations. These testing sites with their diverse and unique conditions provide a more thorough understanding of hybrid responses to early season stress. A typical testing site is characterized by large amounts of residue, cold soil (below 50 °F) at planting followed by cold rain or snow and emergence usually requiring two to three weeks.

"Choosing hybrids with higher stress-emergence scores can help reduce genetic vulnerability to stand loss due to cold soil temperatures."

Pioneer brand corn products are also tested in lab assays that simulate stressful field conditions. These tests, which have been validated by multi-year field trials, provide consistent and reproducible test conditions coupled with the flexibility of year-round testing. These lab assays are used to support hybrid advancement decisions and also to support breeding efforts to improve early season stress tolerance through maker-assisted selection.

In 2018, a wide range of stress-emergence conditions and soil temperatures were observed in stress-emergence field plots. To demonstrate how stress-emergence ratings relate to stand establishment in the field, hybrids were grouped by "low stress-emergence" – those with a stress-emergence rating of 4 and "high stress-emergence" – those with a stress-emergence rating of 6.

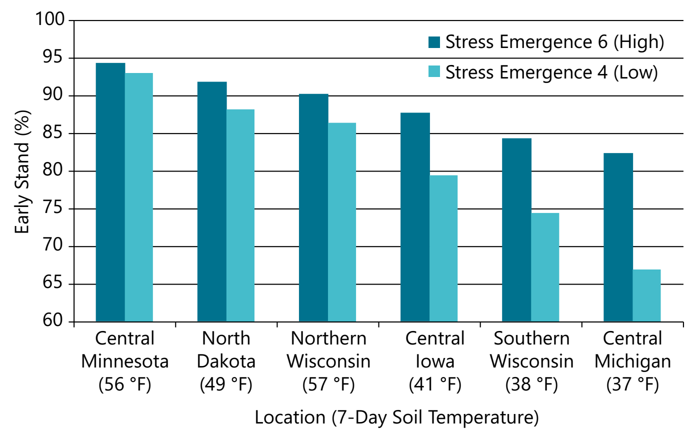


Figure 5. Average stand establishment for high and low stress-emergence score hybrids in six stress-emergence locations in 2018. Locations are sorted from least stressful (left) to most stressful (right) based on average early stand.

The trials included 199 low stress-emergence hybrids and 159 high stress-emergence hybrids. Early stand counts for all hybrids within each group were averaged at each location. As stress level increased, both the low stress-emergence and high stress-emergence hybrids experienced stand reduction. However, the hybrids with a stress-emergence score of 6 were able to maintain higher stands as compared to those with a low stress-emergence score (Figure 5).

TIMING OF COLD STRESS IMPACTS GERMINATION

Early planting often exposes seeds to hydration with cold water, which can cause direct physical damage. When the dry seed imbibes cold water as a result of a cold rain or melting snow, imbibitional chilling injury may result. The cell membranes of the seed lack fluidity at low temperatures, and under these conditions, the hydration process can result in rupture of the membranes. Cell contents then leak through this rupture and provide a food source for invading pathogens. Cold water can similarly affect seedling structures as they begin to emerge. The degree of damage ranges from seed death to abnormalities, such as corkscrews or fused coleoptiles (Figure 6).

Figure 6. Abnormal mesocotyl and coleoptile development due to cold stress in an early planted Illinois field.

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

To help understand the importance of the timing of cold stress, 2 hybrids with stress-emergence 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 7).

Both hybrids showed significant stand loss when the cold stress was imposed immediately (0 hours). However, the hybrid with a higher stress-emergence score had a higher percent germination than the hybrid with a low stress-emergence 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.

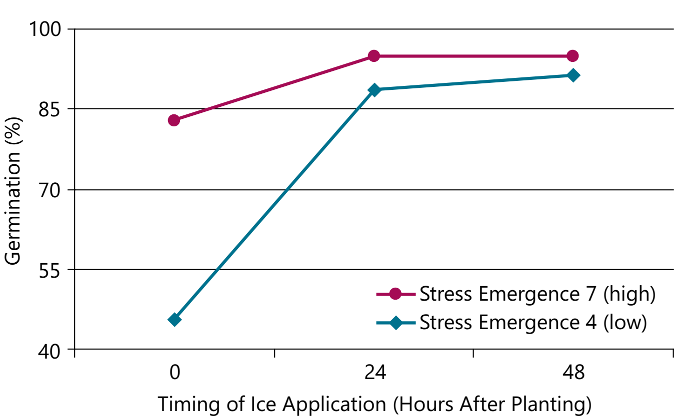


Figure 7. Germination of 2 hybrids with stress-emergence scores of 7 (above average) and 4 (below average) following imbibitional chilling induced by melting ice. Ice was applied immediately after planting (0 hours), after 24 hours, or 48 hours of pre-germination in warm conditions.

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 seed are able 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 min to determine water uptake (Figure 8).

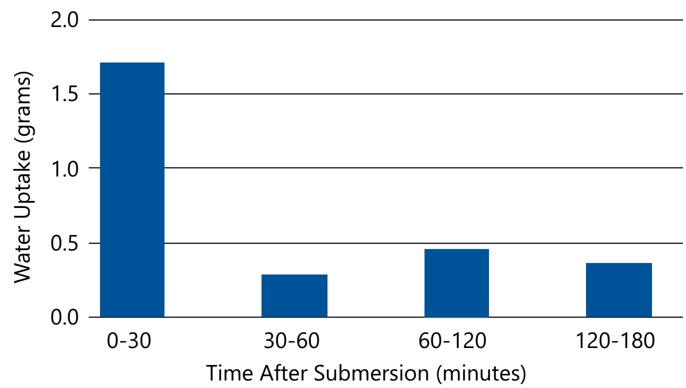
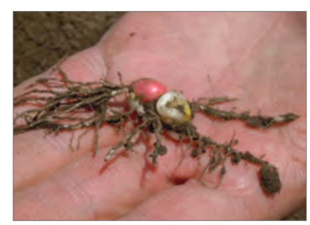


Figure 8. Amount of water uptake by corn seed during the first 3 hours after submersion in 50 °F water.



Seedling injury caused by temperature fluctuations.

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

Farmers 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 water-holding capacity than heavier soils. As such, they tend to experience wider temperature fluctuations, especially on clear nights with cold air temperatures.

In 2015, soil temperatures were recorded at a 2-inch depth at a research 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 as low as 38 °F, and on some days, the soil temperature difference between 6 AM and 6 PM was over 20 °F (Figure 8). An average of 16% stand loss was observed at this location, suggesting that day-night temperature fluctuation after planting can cause added stress to germinating corn. Farmers should be aware of expected night temperatures when choosing a planting date.

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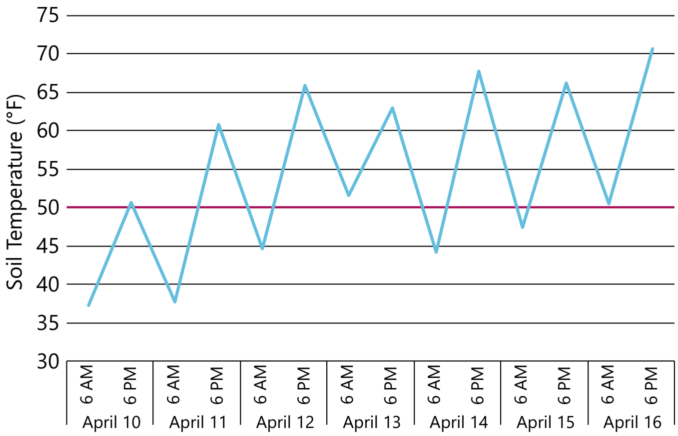

Figure 9. Soils temperatures at 6:00 AM and 6:00 PM for seven days after planting in a stress-emergence field location near Eau Claire, WI, in 2015.

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 125 soil GDUs are needed after planting for corn emergence. From April 1 to April 30, soils under low residue were able to accumulate 99 soil GDUs. During the same time frame, neighboring soils under heavy residue accumulated only 28 soil GDUs.

In mid-April 2019, a 15-degree midday temperature difference was noted in the same field between soil under low residue and soil ~20 yards away under soybean residue (Figure 10). Using a row cleaner to clear residue off the row in high-residue fields allows for warmer daytime soil temperatures and faster GDU accumulation.

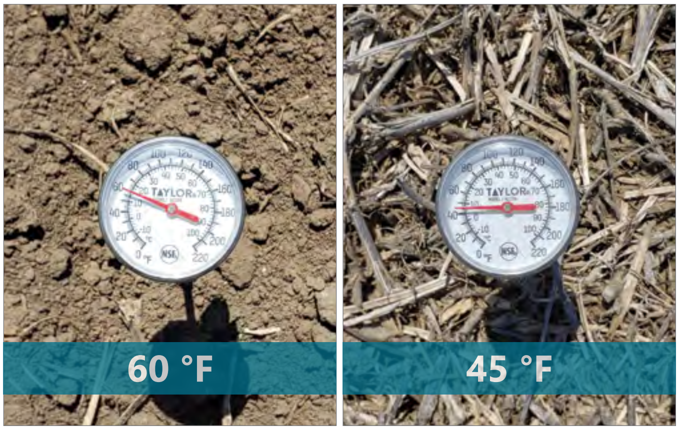

Figure 10. A 15-degree temperature difference was observed midday on April 15, 2019, in a central Iowa field between soil under no residue and soil under heavy residue.

SEEDLING DISEASE AND STRESS-EMERGENCE

Stress-emergence is an agronomic trait intended to reflect genetic variability for tolerance to abiotic stress in the early season. It is not a rating for disease resistance. Early season stress can promote seedling disease if certain conditions are met, including inoculum presence and prolonged cool, wet conditions. Injury to emerging seedlings will also promote seedling disease. Injury can be caused by chilling, such as imbibitional damage, or by feeding of insects, such as seedcorn maggots, white grubs, and wireworms.

In environments with heavy inoculum pressure, disease progression is often in a race with seedling growth. Conditions that promote rapid soil warming will generally favor seedling growth and reduce disease incidence. On the other hand, extended cool, wet conditions will generally favor disease progression.

Many soil pathogens, including some Pythium species, are most active at temperatures in the 40s and 50s (°F). Low temperatures, such as these, can injure emerging seedlings and facilitate infection. Low temperatures also impede stand establishment and increase the window of vulnerability to infection. Fungicide seed treatments generally provide good efficacy against target organisms for 10 to 14 days after planting. However, protection will be diminished if emergence and stand establishment are delayed beyond this period.

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. For more information on seed treatment options for Pioneer® brand corn products, contact your local Pioneer sales professional or visit 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 row cleaners to allow soils to warm up faster.**
- **In the Northern Corn Belt, 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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Diagnosing Emergence Issues Using a Square-Bottom Spade

Gary Brinkman, CCA, CPAg, *Field Agronomist*

DIG TO THE BOTTOM OF EMERGENCE ISSUES

- The square-bottom spade is a useful agronomic tool that can help get a better picture of emergence issues below ground.
- The square-bottom spade helps to visually see emergence issues that would be difficult to reveal with a trowel digging from the top down.

OPENING UP THE SEED FURROW WITH A SQUARE-BOTTOM SPADE

1. Place the spade about 4 to 6 in from the row, and insert it to a depth of about 8 to 10 in.

2. Place your other hand on the opposite side of the seed row, and hold it in place while you pry with the spade.

3. The seed furrow seam should open with relative ease.

   Getting the soil to break cleanly at the seed furrow slot does not work every time. It works best when the soil is moist and/or has a higher clay content.

4. This technique helps preserve the structure of soil around the seedling and can reveal the presence of side-wall compaction.

   This plant has restricted root growth due to side-wall compaction. The roots are also showing some seedling diseases. This combination of factors has slowed the growth of this emerging seedling.

1

2

3

4

DIAGNOSIS OF EARLY EMERGENCE ISSUES

- In this example, the radicle was damaged by seedling diseases but note new growth on both the radicle and seminal roots. There are signs of sidewall compaction.

- Leafing out underground due to soil crusting.

- This seedling shows root decay issues. The soil color indicated that this soil is not very well drained.

- Opening up the seed furrow with a square-bottom spade reveals exactly how deep the seed was planted.
- This seed shows considerable seed rot. The field had some drainage issues. It also looks like the embryo may have some insect feeding, most likely seed corn maggot.

- In this example, the grower noted uneven growth in this area of the field. Opening up the seed furrow revealed the insect culprit – white grub, active right next to the roots.

- About every 30 to 40 feet in this field, there were 2 consecutive plants in the row that were slow to emerge or did not emerge at all.
- In general, plant uniformity was good, but there were enough skips to cause concern.
- Soil conditions for these seedlings were good with no sign of side-wall compaction. However, the roots were not in good shape — notice the dark discoloration of the radicle root on the stunted plants.
- The two plants on the left were side by side in the field and looked like potential runts. This is a very common occurrence where disease and/or insect issues usually impact two to three plants together.
- The field was planted April 18th and was visited on May 31st. The seeds had been in the ground for over 30 days, far beyond the life of the fungicide.
- The plant on the right had a robust radicle and seminal roots as was typical of most of the plants that had more timely emergence.
- This picture clearly shows the importance of the radicle and seminal roots in achieving uniform emergence. If anything happens to the radicle, the plant is set back, may lose the emergence race, and become a runt.
- Using a spade to open the seed furrow helped reveal the emergence issues taking place belowground.

- A small water bottle can be a useful tool to wash off the roots in order to examine them more closely.

SUMMARY

- Take advantage of the natural soil seam created by the planter's double-disc openers to help reveal emergence issues.
- Learn the technique of opening this soil seam with a square-bottom spade.
    - » Place the square-bottom spade four to six inches from the row.
    - » Insert the spade well below the seed depth, around 8 to 10 in deep.
- Pry open this soil seam, and invite the grower to observe what is happening below ground.
- Remember that the health of the radicle and seminal roots is the primary driver for uniform emergence.
    - » These roots start the plant's race to the soil surface and will determine which plants become winners or losers.
    - » An insect bite, root decay, or side-wall compaction can set these important roots at a growth disadvantage, which can turn these plants into runts.

Water Retention and Nutrient Availability in Soil: Drainage and Compaction

Stephen D. Strachan, Ph.D., *Research Scientist,*
and **Mark Jeschke, Ph.D.,** *Agronomy 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).

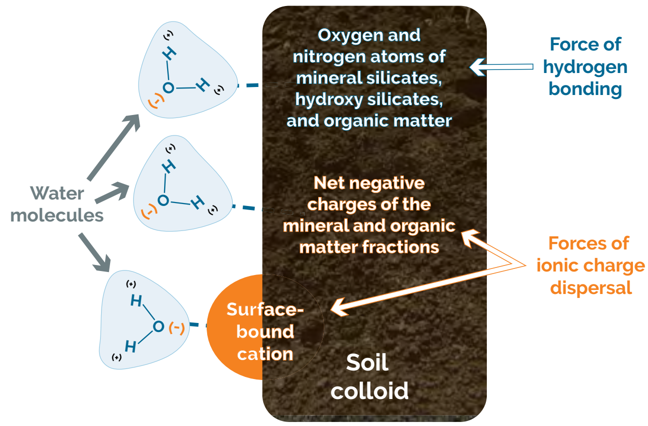

Figure 2. A combination of forces resulting from hydrogen bonding and ionic charge dispersal hold the first ring of water molecules very tightly to soil. Corn roots cannot easily extract these water molecules from soil.

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

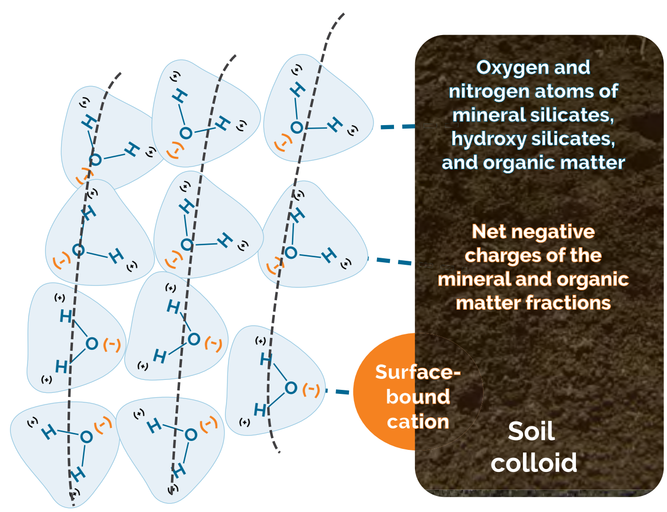

Figure 3. Multiple rings of water molecules form around each soil colloid. As each ring of water forms farther from the soil colloid, forces pulling water molecules toward the soil colloid diminish. Rings of water farthest removed from soil colloids are more available for plant uptake.

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 reality 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).

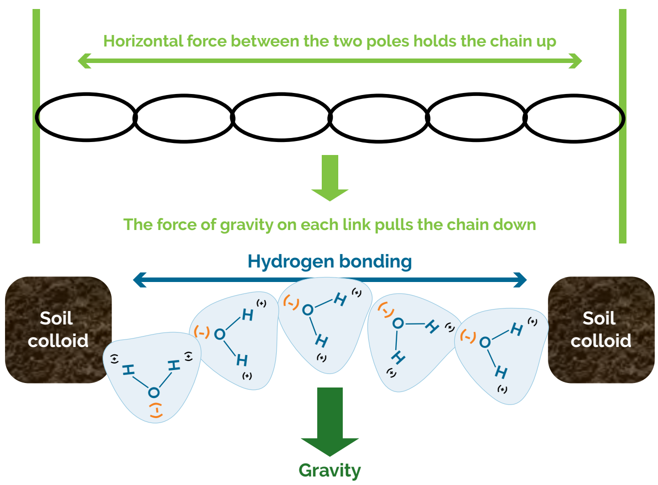

Figure 4. Water molecules behave like links in a chain.

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).

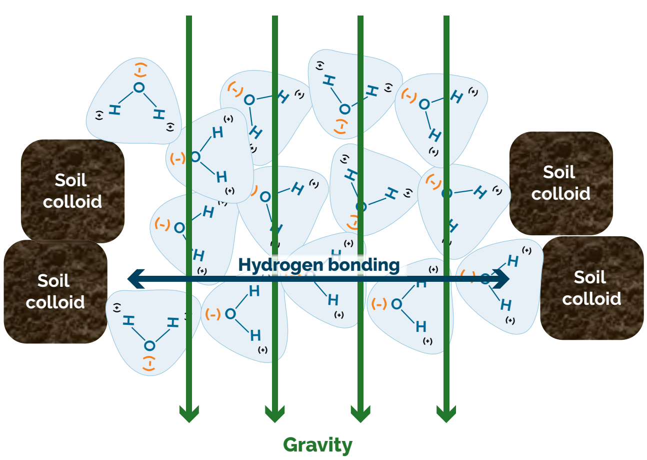

Figure 5. Multiple forces are pulling on all water molecules in the soil profile.

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.

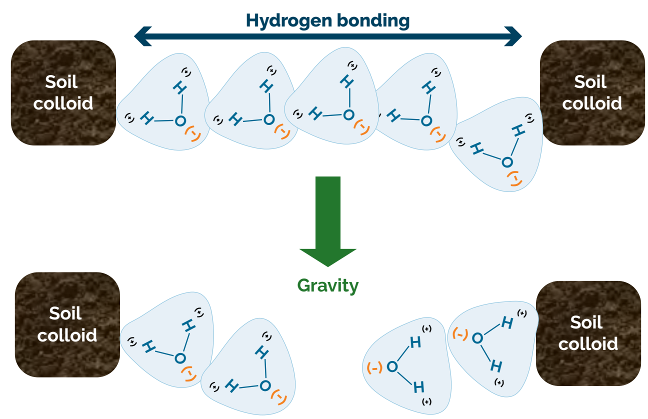

Figure 6. For soil pores with larger openings at their base, the force of gravity is stronger, and water drains from the center of the pore.

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 is an excellent model to show how soil pores retain water (Figure 7).

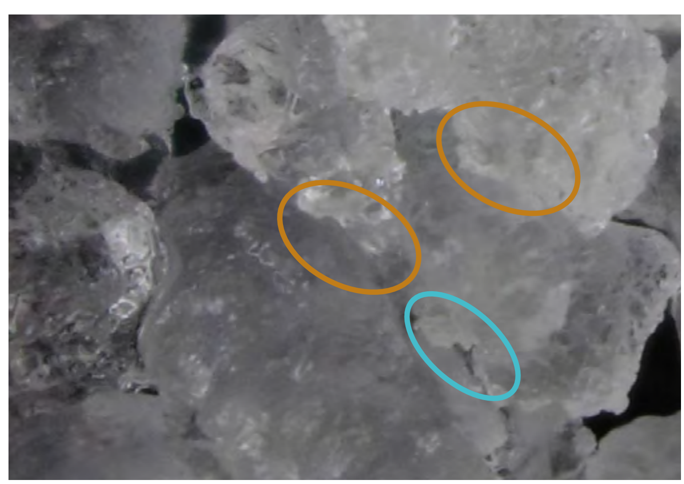

Figure 7. Model of liquid water in crushed ice illustrating how soil pores retain water. Micropores (orange ovals) are full with water while macropores (blue oval) retain water only along edges of solid surfaces.

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).

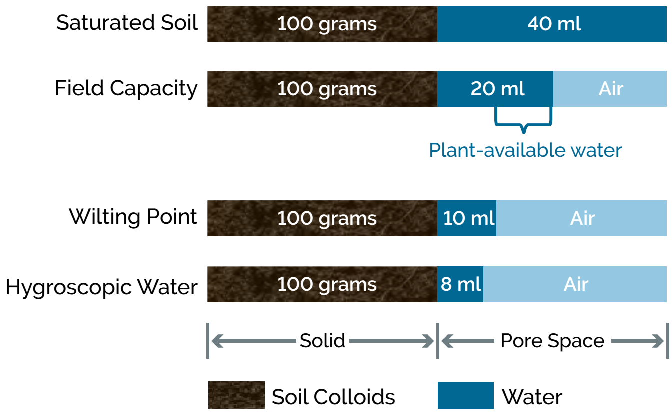

Figure 8. Volumes of water and air associated with soil pores in 100 g of a well-granulated silt loam soil.

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 emergence 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 and other forms of drainage to drain saturated or nearly saturated soils more quickly as well as 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, 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 than 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.

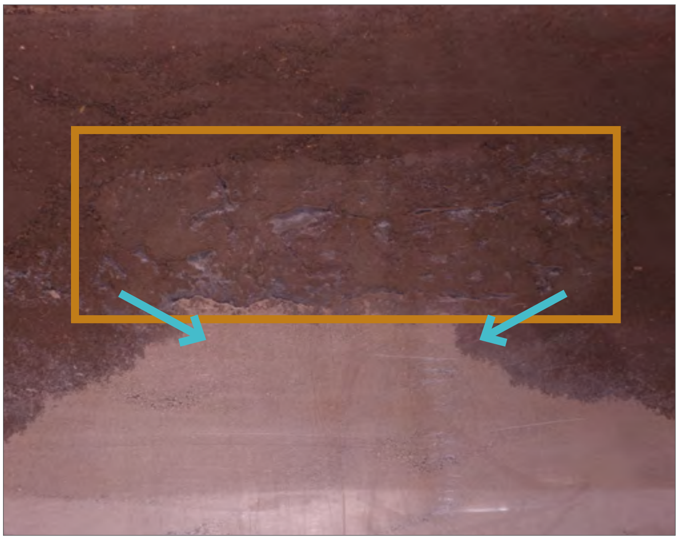

Figure 9. Water as it drains through the soil profile is limited by a zone of highly compacted soil (outlined by the orange box). Water drains through less compacted soil more quickly and eventually begins to move below the zone of high compaction (blue arrows).

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 are 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 are 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.

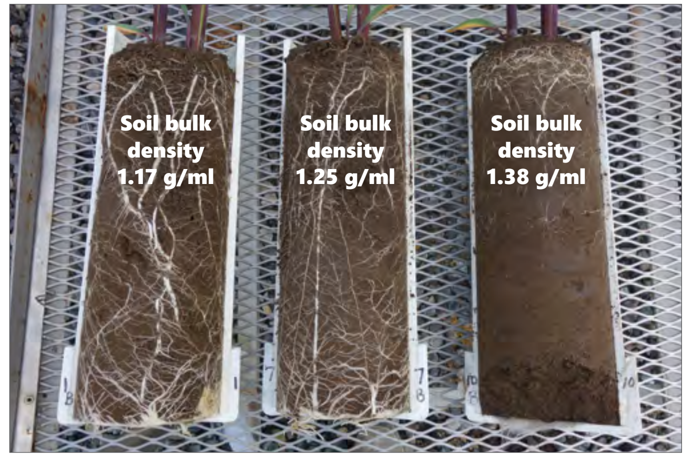

Figure 10. Root growth of corn plants (V5 growth stage) growing in soil compacted to different bulk densities before corn seeds are planted. Roots were washed, and dry weights were recorded for each soil treatment. Root dry weights are 2.47 g, 1.77 g, and 1.43 g for the 1.17 g/ml, 1.25 g/ml, and 1.38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

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

POLLINATION SUCCESS IS CRITICAL TO FINAL YIELD

- The number of kernels set is largely determined near the time of pollination.
- Yield losses due to reduced kernel set at pollination cannot be fully regained.

Kernel set requires the successful completion of several plant processes.

- Production of viable pollen by the tassel
- Interception of pollen by receptive silks
- Fertilization
- Embryo and endosperm development

POLLINATION

- Pollen shed, or anthesis, is controlled by a combination of genetic and environmental factors.
- Once pollen grains have matured inside corn anthers, these anthers begin to dry, or dehisce.
- Anthers typically shed pollen around mid-morning as anthers dry in the heat and sunlight.

- As anthers dehisce, they split apart to allow pollen grains to fall into the open air.
- Pollen grains are viable for only a few minutes after they are shed until they desiccate.
- A tassel normally sheds pollen for about five days.
- Pollen shed in a field can last up to two weeks.

SILK EMERGENCE

- Each silk that emerges from an ear shoot connects to a single ovule, or potential kernel.
- A silk must be pollinated for the ovule to develop into a kernel.

- Silk emergence proceeds from the base to the tip of the ear over the course of four to eight days.
- Silks will continue to elongate for up to 10 days after emergence or until they are pollinated.
- Silk receptivity decreases over time following emergence due to the senescence of silk tissue.

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STRESS AT POLLINATION CAN REDUCE YIELD

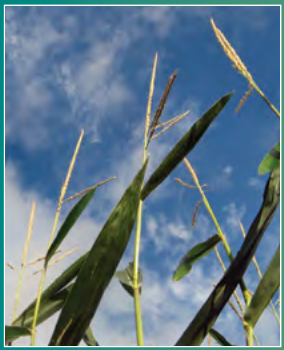
- Stress susceptible period extends from one week prior to silking to approximately two weeks after silking.
- Yield losses during this period result from reduction in kernel number and are, therefore, irreversible.

DROUGHT EFFECTS ON SILK GROWTH

- Reduction in kernel number may result from asynchrony of pollen shed and silking.
- Silk elongation requires high water potential; drought stress can delay silking and increase the anthesis-silking interval (ASI); the time between the start of pollen shed and silk emergence.
- Silks that emerge after most of the pollen is shed may not be pollinated.
- Moderate silk delay can cause poorly filled ear tips, whereas more severe stress can result in ears that are nearly or completely barren.

HEAT EFFECTS ON POLLEN SHED

- The location of the tassel exposes it to high radiation and potential temperature extremes.
- Extreme heat stress (over 100 °F) can reduce pollen production and viability.
- Severe losses in pollen production or viability are necessary to affect kernel set, which would require an extended period of extremely high temperatures.



KERNEL ABORTION

- Drought stress can prevent pollination as well as cause successfully pollinated kernels to abort.
- Drought stress causes kernel abortion by reducing photosynthesis and carbohydrate availability following pollination.

Aborted kernels will appear white and shriveled. The yellow embryo may also be visible.

SILK CLIPPING

- Insects, such as corn rootworm beetles and Japanese beetles, can interfere with pollination by clipping silks.
- Clipped silks can still elongate and receive pollen; however, continuous intense insect activity can result in reduced seed set.

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Corn Maturity and Dry Down

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

MOISTURE LOSS DURING GRAIN FILL

- Kernels lose moisture through the grain-filling period due to a combination of evaporative water loss and accumulation of kernel dry matter.
- Corn plants channel photosynthate into the kernels during the grain-fill period, increasing kernel dry weight.

Table 1. Days following silking to reach corn reproductive growth stages and approximate grain moisture (Abendroth et al., 2011).

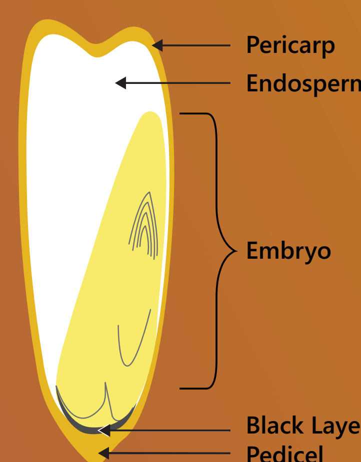
Growth Stage	Days After Silking	Approx. Moisture
Blister Stage (R2)	10-12	85%
Milk Stage (R3)	18-20	80%
Dough Stage (R4)	24-26	70%
Dent Stage (R5)	31-33	60%
Maturity (R6)	64-66	35%

PHYSIOLOGICAL MATURITY AND BLACK LAYER

- Physiological maturity is the point at which the hard starch layer reaches the base of the kernel and kernel dry matter accumulation is complete.
- Kernel moisture at physiological maturity is typically around 35% but can vary due to differences in hybrid characteristics and environmental conditions.
- Following physiological maturity, an abscission layer, known as the black layer, will form at the base of the kernel.
- Within the ear, the black layer usually forms first in the tip kernels with progression a few days later to the large kernels at the base.

BLACK LAYER FORMATION

- In early seed development, a black layer forms in a region of cells several layers thick between the endosperm base of the kernel and the vascular area of the pedicel.
- Near physiological maturity, these cells compress into a dense layer, which appears visibly black.
- Concurrently, the cells at the base of the endosperm also become crushed. These are specialized vascular cells, which absorb and transfer nutrients to the kernel, plus sucrose and other sugars produced by the plant in photosynthesis.
- This stops their capability for movement of sugars and nutrients from within the plant into the kernel.



Stage R5
Beginning Dent
Grain Moist.**~50-55%**
~400 GDUs remaining to maturity
Yield loss from killing frost at this stage: 35-40%

Stage R5.25
1/4 Milk Line
Grain Moist.**~45-50%**
~300 GDUs remaining to maturity
Yield loss from killing frost at this stage: 25-30%

Stage R5.5
1/2 Milk Line
Grain Moist.**~40-45%**
~200 GDUs remaining to maturity
Yield loss from killing frost at this stage: 12-15%

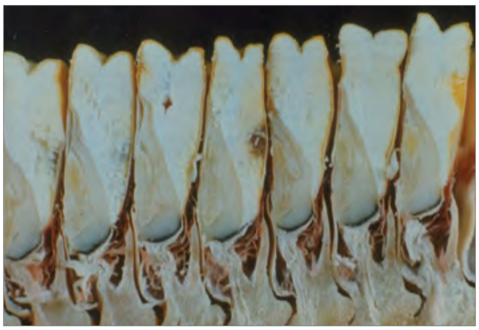
Stage R5.75
3/4 Milk Line
Grain Moist.**~35-40%**
~100 GDUs remaining to maturity
Yield loss from killing frost at this stage: 5-6%

Stage R6
Physiological Maturity
Grain Moist.**~30-35%**
0 GDUs remaining to maturity
Yield loss from killing frost at this stage: 0%





- Black layer is often used as a visual indicator of physiological maturity, and the two are often considered synonymous. However, but this is not actually the case.
  - » Black layer formation is triggered when sucrose translocation to the developing kernel stops.
  - » This cessation of sucrose flow can be due to the physiological maturity of the kernel but can also be the result of other factors, causing a sharp drop in plant photosynthesis, such as foliar disease, hail, frost, or prolonged cold temperatures.
  - » Black layer formation triggered by environmental stress can occur before physiological maturity, effectively shutting down grain fill prematurely.



Cross section of kernels following physiological maturity. The black abscission layer is visible at the tip of the kernels.

DRY DOWN FOLLOWING MATURITY

- Kernel drying that occurs following black layer is entirely due to evaporative moisture loss.
- Corn dry-down rate is tightly linked to daily growing degree unit (GDU) accumulation.
  - » In general, drying corn from 30% down to 25% moisture requires about 30 GDUs per point.
  - » Drying from 25% to 20% requires about 45 GDUs per point (Lauer, 2016).
- GDU accumulation and dry-down rates are greatest during the earlier, warmer part of the harvest season and decline as the weather gets colder (Table 2 and 3).
- By November, GDU accumulation rates are low enough that little further drying will typically occur.

Table 2. Average daily GDU accumulation during early-, mid-, and late-September and October for several Midwestern locations (1981-2010 average, Midwest Regional Climate Center).

	September			October		
	1-10	11-20	21-30	1-10	11-20	21-31
Lincoln, NE	20	17	14	11	8	7
Indianapolis, IN	20	16	13	11	8	6
Bloomington, IL	20	17	13	12	8	6
Ames, IA	18	14	12	10	7	5
Mankato, MN	17	13	10	8	6	4
Madison, WI	16	14	11	9	6	4
Brookings, SD	15	12	9	7	5	3

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Table 3. Average daily corn dry-down rate for different stages of the harvest season (Hicks, 2004).

Harvest Season Stage	Points of Moisture per Day
Sept. 15 – Sept. 25	¾ to 1
Sept. 26 – Oct. 5	½ to ¾
Oct. 6 – Oct. 15	¼ to ½
Oct. 16 – Oct. 31	0 to ⅓
Nov. 1 and later	~0

Timing of Physiological Maturity

- Corn that matures earlier will dry down faster due to more favorable drying conditions early in the harvest season.
- Later-maturing corn has fewer warm days to aid in drying and will dry down at a slower rate.

Weather Conditions Following Maturity

- Daily GDU accumulation and dry down can vary widely during the harvest season.
- Corn may dry one point of moisture per day or more under favorable conditions.
- Conversely, corn may not dry at all on a cool, rainy day.

Hybrid Characteristics Affecting Dry Down

- **Husk Leaf Coverage**: The more insulated the ear is, the longer it will take to dry down. Leaf number, thickness, and tightness all affect dry-down rate.
- **Husk Leaf Senescence**: The sooner these leaves die, the faster the grain will dry down.
- **Ear Angle**: Upright ears are more prone to capture moisture in the husks, which slows dry down.
- **Kernel Pericarp Characteristics**: Thinner or more permeable pericarp layers are associated with a faster dry-down rate.

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“Nematodes that affect corn ***are difficult to detect*** due to their small size, and the symptoms they cause often resemble symptoms of common stress factors, such as ***drought*** or ***nutrient deficiencies.***”

Nematode Biology and Management in Corn

Mark Jeschke, Ph.D., *Agronomy Manager,*
and ***Ron Sabatka, M.S.,*** *Seed Applied Technologies Marketing Manager*

SUMMARY

- Nematodes are often overlooked as a pest in corn due to their small size and non-distinctive damage symptoms, but they can cause significant yield loss by damaging corn roots.
- Nematodes may be becoming a greater threat to corn due to changing production practices.
- Visual symptoms of nematode damage are usually apparent in “hot spots” in the field. Plants may appear to be moisture-stressed, stunted, and chlorotic.
- Many different nematode species can cause yield loss in corn. Damage in a field can be caused by a single species or by several.
- The only way to confirm that symptoms are being caused by nematodes and not some other stress factor is by submitting a sample of soil and root tissue for testing.
- Lumialza™ nematicide seed treatment is a new biological treatment available with Pioneer® brand corn products that has activity against all seven primary corn nematode species.

NEMATODES: AN OVERLOOKED PEST OF CORN

Nematodes are a well-known pest of soybeans but are frequently overlooked as a cause of yield loss in corn. Nematodes that affect corn are difficult to detect due to their small size, and the symptoms they cause often resemble symptoms of common stress factors, such as drought or nutrient deficiencies. Today, however, there is a growing realization that nematodes can and do economically affect corn.

Over 50 species of nematodes are known to feed on corn in the U.S., several of which can cause significant economic damage. Corn nematodes are commonly thought of as a pest specific to sandy soils, such as in Kansas, Nebraska, and the coastal plains of North and South Carolina. While this is true of some species, other species can exist in a range of soil conditions. No field is immune to the potential for nematode damage. Nematodes normally do not kill plants but act as parasites on the host plant. If plant death did occur, nematodes would be more obvious and of more concern to growers. Instead, these microscopic roundworms often increase without being detected. This trait has earned them the reputation of "silent yield robbers" of corn.

A lesion nematode, one of the more ubiquitous nematode pests of corn.

IS NEMATODE DAMAGE IN CORN BECOMING MORE COMMON?

The capability of nematodes to damage corn has been known since the 1950s; however, recent trends in farming practices may be increasing nematode numbers as well as their economic importance as corn pests. Reduced tillage is known to favor some nematode species as is corn following corn. It is also likely that reduced use of carbamate and organophosphate insecticides for rootworm control in corn has caused an increase in nematode populations. These rootworm insecticides also have activity against nematodes, whereas newer alternatives, such as pyrethroid insecticides and transgenic rootworm-protected corn, do not.

Additionally, our ability to sample and diagnose nematode damage has improved. Symptoms that may have previously been attributed to some other stress factor are now correctly being traced to nematodes.

NEMATODE BIOLOGY

Nematodes are the most abundant multicellular organisms on earth and are ubiquitous across a wide range of ecosystems. Nearly 20,000 species have been described, although the biology of most species is poorly understood. Most species are microscopic, typically ranging from 0.25 to 3.0 mm in length, although some species are much larger.

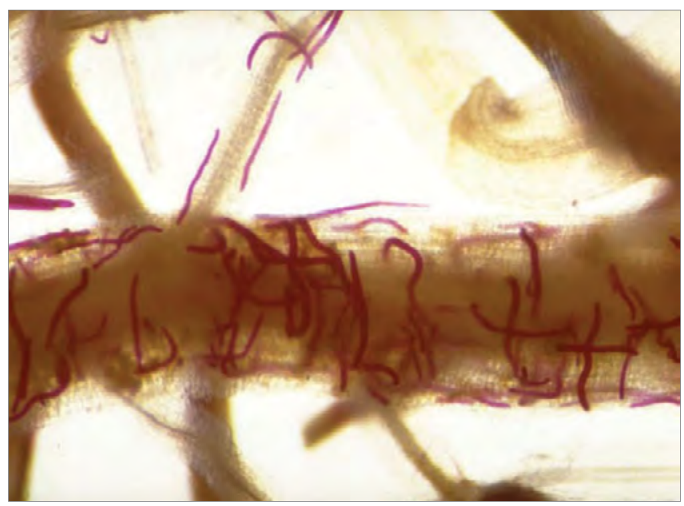
Nematode Life Cycle

The life cycle of corn nematodes is similar to other nematodes; juveniles hatch from eggs and pass through multiple larval stages to the adult stage. During each larval stage, a molt happens where the cuticle is shed and the nematode increases in size. Both juvenile and adult nematodes feed on the roots of the host plant. The length of time required to complete a life cycle varies widely among species, from several days up to a year. The most common corn nematodes complete their life cycle from egg to adult within about 30 days. Nematodes typically travel no more than 1to 2 meters during their life cycle.

Nematodes are notable in that juveniles hatch in a "unisex" form, and their sex is determined later in life. Those that become males move through the soil and probably do not contribute to plant damage, according to the scientific literature. In some species, males are rare and not required for reproduction or are absent entirely. Those that become female nematodes feed and reproduce additional nematodes as the life cycle begins anew. The eggs that females produce are the overwintering structure for these organisms.

Crop Damage

Plant parasitic nematodes are typically soil-borne and feed on plant roots. Nematodes use a stylet to pierce the corn root and extract nutrients. However, nutrient loss is only one of the negative effects of nematode feeding. Tissue damage at the feeding site can provide easy entry into the root system for commonly associated root pathogens. Nematode populations increase as their food source, corn roots, develops. Corn nematodes prefer feeding on new succulent cell tissue where cells are dividing; however, all root area is susceptible to damage. Nematode damage can occur throughout the growing season; however, corn is most vulnerable during early-season crop establishment.



Lance nematodes feeding on a root. Photo courtesy of Greg Tylka, Iowa State University.

Corn Nematode Feeding Habits

Nematode species vary in their feeding behavior, but all feeding types can have a significant effect on corn yield.

Ectoparasites: Nematodes live in the soil and feed on the surface of root tissue by inserting the stylet into cells within reach. Examples include sting, needle, dagger, and stubby-root nematodes.

Endoparasites: Nematodes that fully penetrate root tissue and feed within. Endoparasitic nematodes can be subdivided into migratory and sedentary endoparasites. Migratory endoparasites remain mobile, feeding as they move through the plant tissue. They spend most of their life cycle in the plant tissue but can also be found in the soil. Sedentary endoparasites enter the plant tissue and develop a permanent feeding site. Examples of endoparasitic nematodes include root-knot, lance, and lesion nematodes.

Semi-Endoparasites: Nematodes partially enter plant tissue, leaving the rear part of their bodies projecting into the soil. Examples include reniform nematodes.

VISUAL SYMPTOMS IN CORN

Nematodes frequently remain undetected as a cause of plant injury. Their small size makes them virtually invisible, and the damage they cause is often overlooked or mistaken for some other plant stress factor. However, if nematode numbers have increased to the point that they are causing economic damage, visual symptoms are usually apparent in "hot spots" in the field. These visual symptoms are similar to those often associated with soil compaction. Plants may appear to be moisture-stressed; stunted and chlorotic; or exhibit less extreme signs of generally poor plant growth. These symptoms are often mistaken for another problem, such as low fertility, weather stress, or insect or disease pressure.

Most often these symptoms do not appear over a very wide portion of the field. No specific patterns are usually identifiable with nematode damage; although, as the problem grows, it often moves in the direction of field tillage. This is due to the physical movement of the nematodes with soil in tillage operations.

Root symptoms may vary, as may above ground symptoms. Root pruning is usually evident as well as proliferation of fibrous roots; thickening or swelling of the smaller roots; and mild to severe discoloration. Soil may stick to the roots due to the oozing of damaged cell contents.

PRIMARY CORN NEMATODE SPECIES

Nematodes are similar to weeds and insect pests of corn in that there are many species of nematodes with different biological characteristics that are capable of reducing corn yield. Different soil environments will favor different nematode species.

It is difficult to establish widely applicable economic thresholds for nematode populations given their tendency for patchy distribution and other stress factors that can influence yield reduction. Economic thresholds established by universities can vary greatly from state to state. Scientists at Corteva Agriscience have developed high population indicators for major corn nematode species as a relative measure of low, medium, or high population levels. The foundation of these indicators is university and nematologist thresholds plus yield results from Corteva research trials. The purpose of the high population indicator is to simplify characterization of nematode population levels while taking into account varying thresholds across states.

Corteva Agriscience research has focused on seven economically important nematode species in corn. These seven species are considered economically important based on a combination of prevalence and crop injury potential.

Sting Nematodes (*Belonolaimus spp.*)

Sting nematodes are found in the sandy plains of the Atlantic and Gulf coast states as well as sandy areas in Midwestern states including Kansas and Nebraska. They are ectoparasites that feed on the outside of roots without attaching to or penetrating the root tissue. Sting nematode eggs hatch in approximately 5 days and reach full adult stage in 18 to 28 days. They migrate downward through the soil profile as roots develop, soil temperature rises, and moisture declines.

Damage Potential	Very damaging
Prevalence	Rare in Corn Belt, common in coastal and plains states
Soil Type	Sandy
High Population Indicator	1 per 100 cm^3 of soil

Feeding occurs at the tips as well as along the sides of the roots and can result in girdling plus death of the root. Sting nematodes inject a highly toxic substance into the root tissue before feeding. Injured areas will appear blackened and sunken. Sting nematodes are very large (approx. 3 mm) and are restricted to soils with at least 70% sand. They can be very damaging, particularly when stubby-root nematodes are also present. Severe corn yield losses above 50% have been reported. Sting nematodes have a wide host range, including soybean and cotton; thus, crop rotation alone will not provide effective management.

Needle Nematodes (*Longidorus* spp.)

Needle nematodes are the most devastating type of corn nematode in the Midwest but are usually confined to sand and loamy sand soils due to their large size. Needle nematodes are relatively large at 3 to 8 mm long, and the greater pore space in sandy soil is necessary to accommodate their size. Yield reduction can be severe, exceeding 60% in the most extreme cases. Corn roots will appear stubby due to pruning of the finer roots, and the above ground portion of the plant will appear stunted with symptoms resembling drought stress. Needle nematodes migrate downward as roots develop, soil temperature rises, and moisture declines. Needle nematodes feed primarily on grass species, so rotation to soybeans or another non-grass crop can be an effective management tool.

Damage Potential	Very damaging
Prevalence	Occasional
Soil Type	Sand and loamy sand, occasionally in finer soils
High Population Indicator	1 per 100 cm^3 of soil

Lance Nematodes (*Hoplolaimus* spp.)

Lance nematodes are also very potentially damaging. Like needle nematodes they are relatively large (approx. 1.5 mm), making sandy soil their most suitable habitat. They are not limited to sandy soil, however, and can be found in a wide range of soil types. Lance nematodes have a wide host range, which can limit the effectiveness of crop rotation as a means of control. At least four *Hoplolaimus* species are known to affect corn. *H. galeatus* is prevalent throughout the U.S. and is the most common lance nematode in Midwestern corn fields.

Damage Potential	Moderate
Prevalence	Occasional
Soil Type	Many soil types, varies by species
High Population Indicator	50 per 100 cm^3 of soil

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H. columbus, commonly known as Columbia lance nematode, is common in southern states where it can also be a damaging pest in soybean and cotton.

H. galeatus can exist in a range of soil types, whereas *H. columbus* is much more limited to sandy soil. Lance nematodes are initially ectoparasitic but can partially or completely penetrate the root tissue. Lance nematodes cause stunting in corn early in the season, which results in spindly plants with reduced yield at harvest.

Corn root system showing severe feeding damage from lance nematodes. Root exudate from severe feeding will cause soil to stick to the roots, as seen here. Photo courtesy of Jim Lafrenz.

Stubby-Root Nematodes (*Paratrichodorus minor*)

Damage Potential	Moderate
Prevalence	Common
Soil Type	Many types
High Population Indicator	50 per 100 cm^3 of soil

Stubby-root nematodes are common in corn in the U.S. across a wide range of soil types. Stubby-root nematodes are ectoparasites that feed on the root tips resulting in short, stubby roots, which can resemble herbicide damage. Affected plants will be stunted and yellow and may show magnesium deficiency. Corn is the preferred host of stubby-root nematodes; however, they have a wide host range including many other crop species, such as cotton, soybean, and sunflower.

Root-Knot Nematodes (*Meloidogyne* spp.)

Damage Potential	Damaging when populations are high
Prevalence	Common
Soil Type	Many types
High Population Indicator	50 per 100 cm^3 of soil

Root-knot nematodes are sedentary endoparasites that spend the majority of their life cycle inside the root tissue. There they form small galls on the roots. Multiple species of root-knot nematodes affect varying ranges of host crops throughout North America, so effective management requires knowledge of the specific species present. Of the four most common species, corn is a host for three. Root-knot nematodes generally have a wide host range, which limits the effectiveness of crop rotation as a means of control. Alfalfa and oats are non-host crops that may be rotated with corn to reduce populations; however, soybeans are a host crop and can be damaged even more than corn, particularly in the Southern U.S. The southern root-knot nematode (*M. incognita*) is a serious pest of cotton, and rotation with corn can increase the chances of cotton yield loss. Research has shown resistance in certain corn inbreds and hybrids; however, most current hybrids are not resistant to root-knot nematodes.

Dagger Nematodes (*Xiphinema* spp.)

Damage Potential	Moderate
Prevalence	Occasional
Soil Type	Many types
High Population Indicator	50 per 100 cm^3 of soil

Dagger nematodes are another relatively large type of nematode, making them favored by, but not limited to, sandy soil. Dagger nematodes have a wide host range and are important pests in many other crops, most notably grapes and other fruits. One species, *X. americanum*, is known to have a very long life cycle. This species reproduces once per year and can live four to five years in undisturbed soil with favorable conditions. Crop rotation is not an effective means of control for dagger nematodes; however, tillage may disrupt their life cycle and help reduce population numbers. Feeding on corn roots by dagger nematodes can cause stunting and chlorosis. In addition to causing root damage, Dagger nematodes can transfer viral mosaic and wilting diseases.

Lesion Nematodes (*Pratylenchus* spp.)

Damage Potential	Moderate
Prevalence	Very common
Soil Type	All types
High Population Indicator	50 per 100 cm^3 of soil

Although not the most damaging type of nematode, lesion nematodes are considered to be the most important genus to Midwestern corn production due to their prevalence. Lesion nematodes are widespread, and population densities of 10,000 nematodes/cm^3 of soil are not uncommon. This genus is found in a wide range of soil types. There are six species in this genus that are known to feed on corn. Lesion nematodes are migratory endoparasites that alternately feed and move within the root tissue. Symptoms include severe root pruning, resulting in stunting, chlorosis, and discoloration. Crop rotation has been shown to be effective at reducing lesion nematode numbers.

OTHER IMPORTANT NEMATODE SPECIES

Spiral and Stunt Nematodes (*Heliocotylenchus* spp. and *Tylenchorhynchus* spp.)

Spiral and stunt nematodes are very wide-spread in the Midwestern U.S. Three species of spiral nematode are known parasites of corn. Unlike many nematodes, they favor heavier soils rather than sand. Spiral nematodes are named for their characteristic spiral body shape when inactive. Stunt nematodes also tend to favor heavier soils. Both species are ectoparasitic and can cause damage to corn when populations are large or in conjunction with other nematode species; however, yield loss in corn is rare. Other host species include soybean, clover, and turfgrass.

Ring, Sheath, and Pin Nematodes (*Criconemoides* spp., *Hemicycliophora* spp., and *Paratylenchus* spp.)

Ring, sheath, and pin nematodes are all sedentary ectoparasites that tend to feed at a single site on the surface of the root tissue. Ring and sheath nematodes are rare in cultivated crops

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and more commonly parasitize perennial plants in undisturbed soil. Ring nematodes tend to favor sandy soil, whereas pin nematodes are very small and prefer finer-textured soil.

Corn Cyst Nematode (*Heterodera zeae*)

The biology of the corn cyst nematode is similar to that of the soybean cyst nematode. Its first discovery in North America was in Maryland in 1981. Fields known to be infested in Maryland and Virginia were quarantined from 1981 until 1996. It is known to have a higher optimal temperature than the soybean cyst nematode, which may limit the suitability of fields in the Corn Belt as a host environment. A new corn cyst nematode species, now known as the goose-grass cyst nematode, was found in Tennessee in 2006. Research conducted so far has confirmed that this species is different from *H. zeae* and shown that corn is a favorable host, whereas dicot species, such as soybean, are not. Whether this species will spread as an economically significant pest of corn is unknown.

Soybean Cyst Nematode (*Heterodera glycines*)

The soybean cyst nematode undoubtedly is the most widely known nematode species in the Corn Belt. Although many nematode species can damage soybean, soybean cyst nematode is by far the most important. Soybean cyst nematode does not pose a threat to corn.

Reniform Nematode (*Rotylenchulus reniformis*)

The reniform nematode is a serious pest of cotton in the Southern U.S. Soybean is also susceptible to reniform nematodes; however, corn is not.

NEMATODE POPULATION SURVEY

In 2018, Corteva Agriscience researchers conducted a survey of corn nematode populations across 10 Corn Belt states (Figure 1). Nematode populations were sampled at 67 locations planted to corn in 2018. At each location, samples were collected from 3 to 5 different evaluation zones within the field to evaluate uniformity of nematode pressure across the field. A total of 238 evaluation zone samples were collected across the 67 locations. Samples were taken when corn was between the V3 and V6 growth stage. Each location included a field-length nematicide seed treatment strip trial to measure yield loss associated with nematode damage. Trials included a strip planted to a Pioneer® brand corn product treated with a fungicide and insecticide seed treatment plus Lumialza™ nematicide seed treatment and an adjacent strip without the nematicide seed treatment.

All locations and zones had corn nematode populations present at some level. Dagger and lesion nematodes were the most common species in the survey, both appearing at over 50% of locations (Figure 2). Sting nematodes were not found at any of the locations as no locations sampled had soils sufficiently sandy (>70%) to support sting nematode populations.

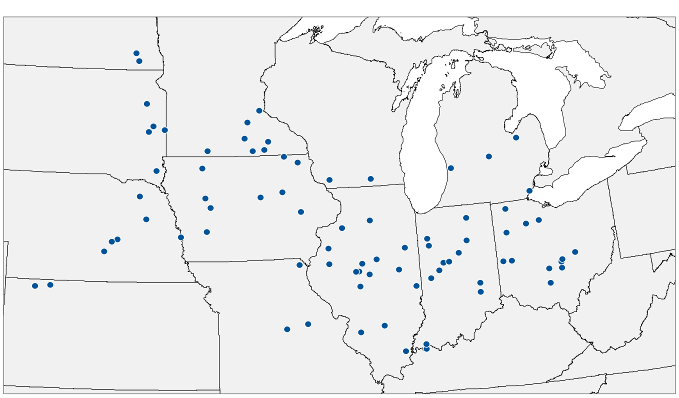

Figure 1. Corn nematode sampling locations in the 2018 Corteva Agriscience survey.

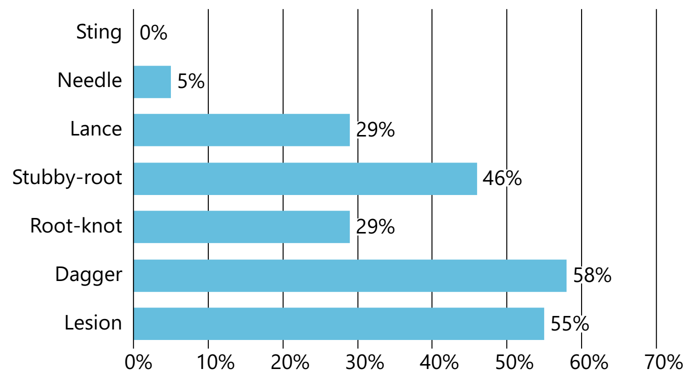

Figure 2. Frequency of detection of 7 corn nematode species at 67 survey locations in 2018.

Nearly half of the sample locations had one or more zones with moderate to high populations of at least one nematode species (Figure 3). High population in this survey was defined as exceeding the high population indicator level and moderate pressure was defined as greater than 50% of the high population indicator level. Of the 238 evaluation zones, 35% had moderate to high nematode populations, showing that nematode pressure is often uneven across a field.

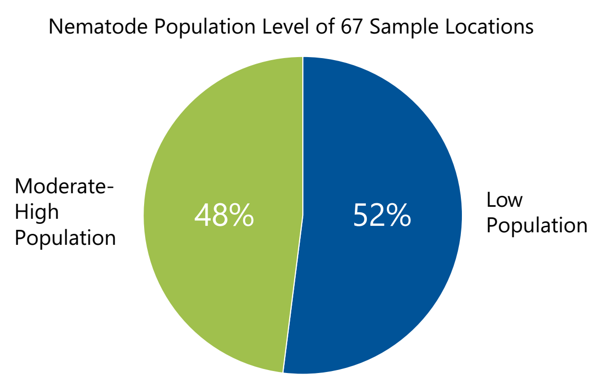

Figure 3. Proportion of locations sampled in 2018 with low nematode populations and moderate to high populations.

Yield loss associated with nematode damage was measured by comparing corn yield with and without nematicide seed treatment within evaluation zones. In zones with moderate to high populations of at least one nematode species, yield in the non-treated strip was reduced by an average of 6.7 bu/acre, compared to a reduction of 3.7 bu/acre in low population zones (Figure 4).

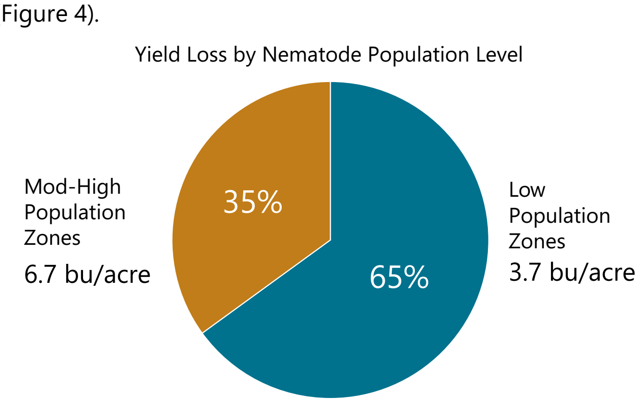

Figure 4. Corn yield loss in evaluation zones with moderate to high nematode population levels and low population levels.

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In 2019, Pioneer agronomists conducted a survey of corn nematode populations in the Western Corn Belt. Nematode populations were sampled at 233 locations planted to corn in 2019 when corn was between the V3 and V6 growth stage.

Nearly all locations (230 out of 233) had corn nematode populations present at some level (Table 1). High population levels of one or more nematode species were detected at 67 locations (29% of total), and another 65 locations (28% of total) had moderate nematode populations.

Table 1. Corn nematode population levels at 233 survey locations in 6 Western Corn Belt states in 2019.

State	Nematode Population Level			
	High	Mod.	Low	None
Colorado	5	1	1	
Iowa	17	33	55	1
Kansas	27	9	8	
Missouri	2	7	12	1
Nebraska	15	15	21	1
New Mexico	1		1	
Total	**67**	**65**	**98**	**3**

Population levels of 13 different corn nematode species were measured in the 2019 survey. The most common species was spiral nematode, which was found at 85% of locations, followed by dagger (46%), stunt (40%), and lesion (38%) (Figure 5). The most damaging nematode species, sting and needle, were found in 5% and 1% of locations, respectively.

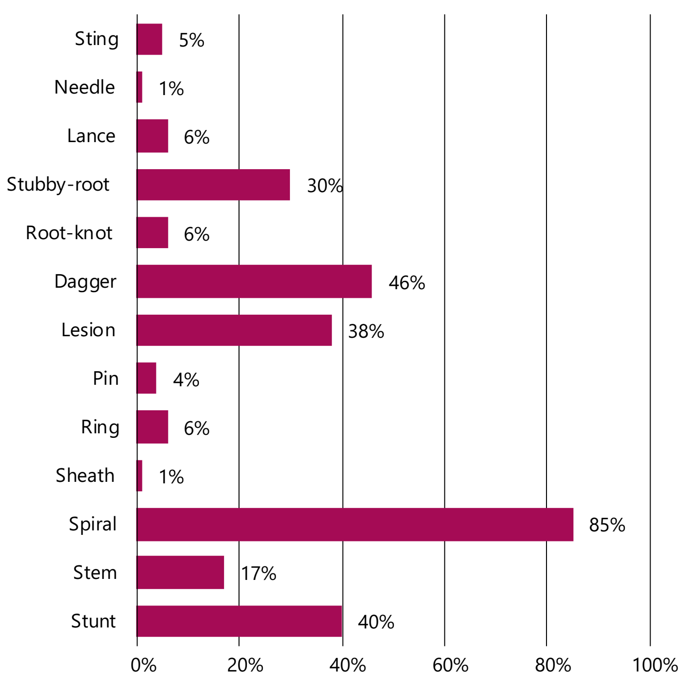

Figure 5. Frequency of detection of 13 corn nematode species at 233 survey locations in the Western Corn Belt in 2019.

NEMATODE SAMPLING

Nematodes should be sampled when populations are likely to be the highest. Healthy plant tissue is vital to nematode survival, so samples should be taken in fields where corn crop is actively growing and the nematodes have hatched and begun feeding.

Optimal timing for nematode sampling can vary based on soil characteristics. In sandy soils, samples should be taken early in the growing season when the corn is around the V3 to V6 growth stage. The most damaging nematodes in sandy soils, sting and needle nematodes, are both known to migrate deeper in the soil profile during the growing season. Samples taken later in the season may underestimate population levels if the nematodes have moved below sampling depth. Fields with finer-textured soils can be sampled throughout the growing season or after harvest.

Samples can be taken during early vegetative growth when areas of suspected nematode damage are visible. When sampling an area of potential nematode injury, samples should be taken from:

1. the affected area to send to the nematode lab
2. an unaffected area to send to the nematode lab
3. the affected area for standard soil nutrient testing
4. an unaffected area for standard soil nutrient testing

A great deal of soil is not needed for a nematode sample. Specific recommendations from your local lab should be followed, but keep these ideas in mind:

- Digging affected plants with a spade and including some soil with the roots is often suggested.
- Only a cup or two of soil is needed for analysis, and this is best taken from within the row of the growing crop.
- Clearly label all samples.
- Overnight or same-day delivery is best for sample transfer to the nematode-testing laboratory.

CONTROL MEASURES

Nematodes are one problem that will not go away if ignored. If damaging levels of corn nematodes are found, implementing control measures, such as rotation, sanitation or use of nematicides, should be considered.

Crop Rotation

Rotation to non-host crops can be an economical method of controlling species of plant parasitic nematodes that have a limited host range. Most of the major species of corn nematodes, however, have a wide host range and are unlikely to be affected by crop rotation. Exceptions include needle nematodes, which are limited to grass species, making rotation to soybeans a useful management tool. More diverse rotations, including alfalfa or oats, can help reduce populations of root-knot nematodes. For rotation to be an effective management tool, eliminating alternate hosts during the non-corn growing seasons is important. Weeds may serve as alternate hosts for some nematode species, so effective weed management is important in rotated crops. Farmers are encouraged to check with local university extension sources for a list of local alternate host crops and weeds.

"For rotation to be an effective management tool, eliminating alternate hosts during the non-corn growing season is important."

Nematicide Seed Treatments

Pioneer® brand corn products are available with two seed treatment options for nematode control.

Lumialza™ nematicide seed treatment is a new biological product that contains the active ingredient *Bacillus amyloliquefaciens* – Strain PTA-4838 – and has activity against all seven primary corn nematode species. Lumialza™ nematicide seed treatment colonizes the roots, forming a bio-barrier that protects roots from nematode attack. It also produces materials that cause juvenile nematode paralysis. Two key benefits of Lumialza™ nematicide seed treatment are the area and duration of protection it provides. The zone of protection encompasses the entire area of root growth, including between the rows and deeper in the soil profile, in contrast to hard chemistries which create a zone of protection around the placement of material, that may be 3 to 6 inches around the seed. Research has shown that nematode protection lasts for more than 80 days in the upper, middle, and lower root zones.

Poncho® 1250 + VOTiVO® insecticide provides broad spectrum control of corn soil insects plus the added protection of Poncho/VOTiVO insecticide for corn nematodes. Poncho/VOTiVO insecticide contains a unique strain of bacteria that lives and grows with young corn roots, creating a living barrier that helps protect corn seedlings and roots against nematodes.

Sanitation

Because nematodes cannot be eradicated once they are established in a field, prevention is a critical management strategy. Common-sense sanitation procedures can prevent movement of nematodes from known areas to uninfested fields or field areas. Equipment should be cleaned with high pressure water or steam to remove soil particles before moving to an uninfested area. Field operations should be conducted last in infested areas, if possible.

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"The **2018 contest** had the **second-highest number** of entries ***exceeding 300 bu/acre at 151***"

Managing Corn for Greater Yield

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

SUMMARY

- Improved hybrids and production practices are helping corn growers increase yields. Over the past 20 years, U.S. yields have increased by an average of 2.1 bu/acre/year.
- The National Corn Growers Association (NCGA) National Corn Yield Contest provides a benchmark for yields that are attainable when conditions and management are optimized.
- The 2018 contest had 151 entries that exceeded 300 bu/acre, down from the record high of 224 entries set in 2017.
- Selecting the right hybrid can affect yield by over 30 bu/acre, making this decision among the most critical of all controllable factors.
- 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.
- 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.
- 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.

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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 2.1 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 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.

2018 NCGA National Corn Yield Contest

Results of the 2018 NCGA National Corn Yield Contest represented somewhat of a regression toward the mean following the record-breaking results of 2017. The 2018 contest had the second-highest number of entries, exceeding 300 bu/acre at 151, but this was down considerably from the high-water mark of 224 set in 2017 (Table 1). Most Corn Belt states saw a decline in 300 bu/acre entries; Illinois, Indiana, Iowa, Kentucky, and Missouri were all down considerably from 2017. Nebraska was an exception to this trend with a second consecutive year of remarkable yield results. This may be attributable to the fact that the high-yield Nebraska entries were all irrigated, whereas the states that experienced a decline have a much higher proportion of non-irrigated entries. The Pacific Northwest also had a good year with Washington, Oregon, and Idaho all posting record-high numbers of 300 bu/acre entries.

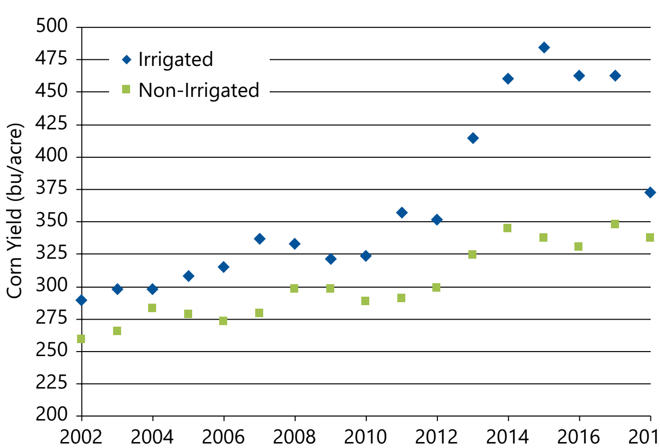

Figure 1. Average corn grain yield of NCGA National Corn Yield Contest national winners in irrigated and non-irrigated classes, 2002-2018.

The top yield overall in the 2018 contest was 477.6877 bu/acre, which is especially remarkable given that it was achieved in Michigan with a relatively short CRM hybrid (Pioneer® brand P0574AM™ (AM, LL, RR2)) compared to previous contest winners. However, yields among all national contest winners were down in 2018. The average yield of non-irrigated class national winners was down slightly from an all-time high in 2017 (Figure 1). The average yield of irrigated class winners was down considerably compared to results from the past five years.

A noteworthy result of the 2018 yield contest was the high yields achieved with early CRM hybrids. The first time an entry exceeded 300 bu/acre with a <100 CRM hybrid was in 2016. A total of five entries with 98-99 CRM hybrids topped 300 bu/acre in 2018. Pioneer® brand P9840AMXT™ (AMXT, LL, RR2) and P9998AM™ (AM, LL, RR2) were the top performers in this CRM range, accounting for four of the five 300 bu/acre entries.

> "A total of five entries with 98-99 CRM hybrids topped 300 bu/acre in 2018"

Table 1. Number of NCGA National Corn Yield Contest entries over 300 bu/acre by state, 2013-2018

State	2013	2014	2015	2016	2017	2018
	number of entries					
AL	0	2	2	1	3	3
AR	2	4	1	1	2	1
CA	3	1	0	2	0	3
CO	1	2	3	2	4	1
DE	0	6	3	2	0	0
FL	2	2	3	0	0	0
GA	5	6	7	4	7	0
IA	2	2	5	7	16	8
ID	0	3	1	1	0	8
IL	3	11	9	5	25	18
IN	7	4	3	1	26	17
KS	4	7	4	1	2	3
KY	1	4	1	0	17	4
MA	0	1	2	1	1	2
MD	1	9	5	4	4	2
MI	2	1	4	1	7	1
MN	0	0	0	0	1	0
MO	4	16	2	1	12	4
NC	0	1	0	1	0	1
NE	5	5	7	1	41	39
NJ	0	4	7	0	1	1
NM	1	1	0	2	2	0
NY	1	0	1	0	4	0
OH	6	0	0	0	1	2
OK	1	1	2	3	2	2
OR	0	1	1	1	3	4
PA	0	2	3	0	0	0
SC	0	8	3	5	9	0
SD	0	1	0	0	2	0
TN	1	12	0	3	9	2
TX	7	10	6	4	3	7
UT	1	2	6	3	7	6
VA	3	4	4	3	5	2
WA	0	0	2	2	2	9
WI	0	0	1	1	6	1
WV	7	3	0	2	0	0
Total	**70**	**136**	**101**	**66**	**224**	**151**

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The average yields among national winners tend to be skewed by a small number of very high yields, particularly in the irrigated classes. Therefore, as a yield performance benchmark, it can be more useful to look at a larger set of contest entries. Table 2 shows the median yield of the top 100 yielding entries in the irrigated and non-irrigated classes. Median yields of top entries in both the irrigated and non-irrigated classes exceeded 300 bu/acre for the second year in a row, which is about 75% greater than the current U.S. average. Median yield of non-irrigated entries in 2018 was down from 2017, while median yield of irrigated entries stayed about the same.

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

Year	Non-Irrigated	Irrigated	U.S. Average
	bu/acre		
2013	293	299	158
2014	299	306	171
2015	292	288	168
2016	283	294	175
2017	312	317	177
2018	300	315	179
Average	**297**	**303**	**171**

The top national yields in the NCGA contest tend to grab the headlines, but studying a larger group of high-performing entries can provide more insight on management practices that can be applied to improve yields in normal corn production. This article summarizes basic management practices employed in NCGA National Corn Yield Contest entries that exceeded 300 bu/acre over the past five years and discusses how these practices can contribute to higher yield potential for all corn growers.

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 as well as yield.
- Traits that provide resistance to major insects, such as corn borer, corn rootworm, black cutworm, and western bean cutworm. Insect pests reduce yield by decreasing stands, disrupting plant functions, feeding on kernels, and increasing lodging as well as dropped ears.
- Good standability to minimize harvest losses.

Pioneer® brand products were used in 7 national-winning entries (Table 3) as well as 189 state-level winning entries – more than any other seed brand. State-level winners included a total of 67 different Pioneer® brand products from 42 different hybrid families ranging from 72 to 120 CRM.

The brands of seed corn used in the highest-yielding contest entries in 2013 through 2018 are shown in Figure 2. Pioneer® brand products were used in more entries exceeding 350 bu/acre and 400 bu/acre than any other individual seed brand and more entries exceeding 300 bu/acre than all other seed brands combined.

Table 3. 2018 NCGA National Corn Yield Contest national winners using Pioneer® brand products.

Entrant Name / Category	State	Hybrid/ Brand[2]	Yield (bu/acre)
John Ruff AA NT/ST Non-Irrigated	IA	**P1366AM™** (AM, LL, RR2)	**333.09**
Nolan Mills NT/ST Irrigated	OR	**P1366AM™** (AM, LL, RR2)	**360.34**
Roger Danz NT/ST Irrigated	WA	**P0801AM™** (AM, LL, RR2)	**354.29**
Dean Harris NT/ST Irrigated	OR	**P0801AM™** (AM, LL, RR2)	**343.28**
Don Stall Irrigated	MI	**P0574AM™** (AM, LL, RR2)	**477.69**
Mike Moyle Irrigated	ID	**P1105AM™** (AM, LL, RR2)	**351.19**
Tommy & Valerie Cartrite Irrigated	TX	**P1828AM™** (AM, LL, RR2)	**350.63**

"Pioneer® brand products were used in **7 national winning entires,** *as well as* **189 state-level winning entries** – more than ***any other seed brand***"

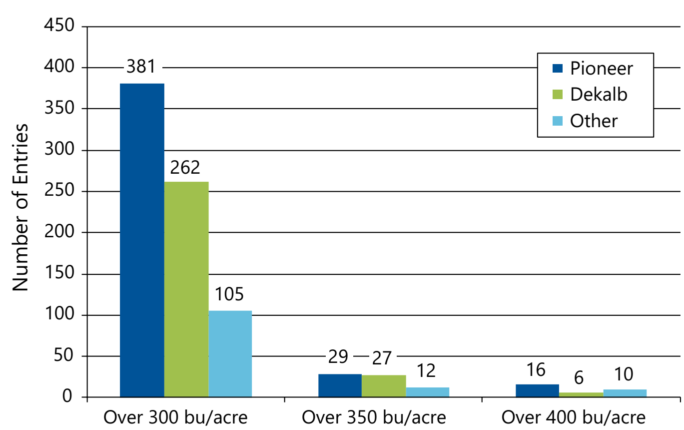

Figure 2. Seed brand planted in National Corn Yield Contest entries exceeding 300, 350, and 400 bu/acre, 2013-2018.

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.

> "Although population is important in establishing the yield potential of a corn crop, it is just one of many factors that determine final yield."

Harvest populations in irrigated and non-irrigated national corn yield contest entries over 300 bu/acre from 2013 through 2018 are shown in Figure 3. The average harvest population of irrigated entries (37,200 plants/acre) was slightly greater than that of non-irrigated entries (36,500 plants/acre) over five 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 is important in establishing the yield potential of a corn crop, it is just one of many factors that determine final yield.

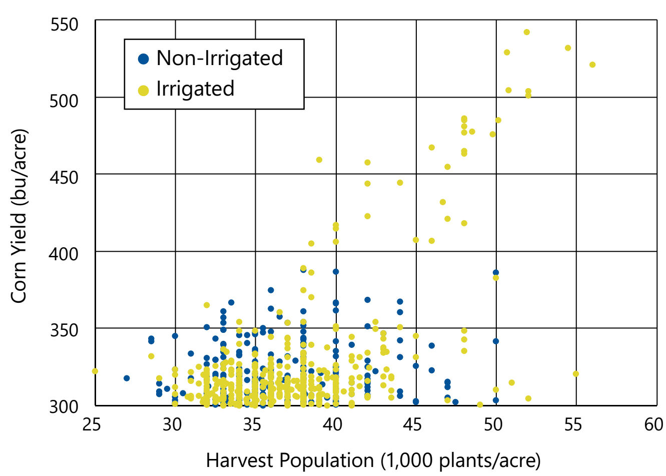

Figure 3. Harvest populations and corn yield of irrigated and non-irrigated NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2018.

Harvest population and yield per plant data over a larger yield range (150-350 bu/acre), which encompasses most of the entries in the contest, show tremendous variation in the relative contribution of yield components to final yield (Figure 4). For example, entries yielding between 250 and 300 bu/acre ranged from harvest populations below 25,000 plants/acre with yield per plant over 0.60 lbs/plant to harvest populations over 45,000 plants/acre with plant yield less than 0.35 lbs/plant. However, average values for harvest population and yield per plant both increase for each successively higher yield range. These results suggest that greater plant density and greater yield per plant are both critical to driving higher yields.

Optimizing plant population is important for maximizing profitability. The Pioneer Planting Rate Estimator, available on www.pioneer.com and as a free mobile app, allows users to generate estimated economically optimum seeding rates for Pioneer® brand corn products based on data from Pioneer research trials.

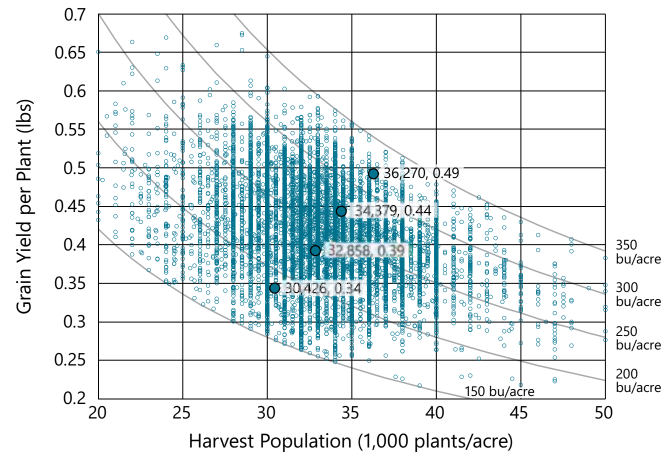

Figure 4. Harvest population and yield per plant for NCGA National Corn Yield Contest entries between 150 and 350 bu/acre, 2013-2018. Large dots indicate average values for harvest population and yield/plant for each yield range.

Row Width

The vast majority of corn acres in the U.S. are currently planted in 30-inch rows, accounting for over 85% of corn production. A majority of 300 bu/acre contest entries over the past five years have been planted in 30-inch rows (Figure 5). This proportion has increased in recent years, reaching a high of 90% in 2017 as wider row configurations (most commonly 36-inch or 38-inch) have declined in frequency and narrower row configurations (15-inch, 20-inch, 22-inch or 30-inch twin) have largely remained steady with a slight decline in 2017.

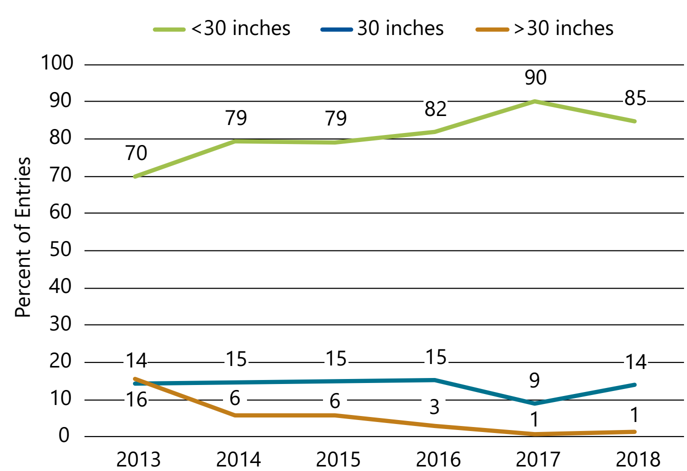

Figure 5. Row width used in NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2018.

Row spacings narrower than the current standard of 30 inches have been a source of continuing interest as a way to achieve greater yields, particularly with continually increasing seeding rates. However, research has generally not shown a consistent yield benefit to narrower rows outside of the Northern Corn Belt (Jeschke, 2018).

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 June 4, although mid-April to early-May planting dates were most common for locations in the Central Corn Belt (Figure 6).

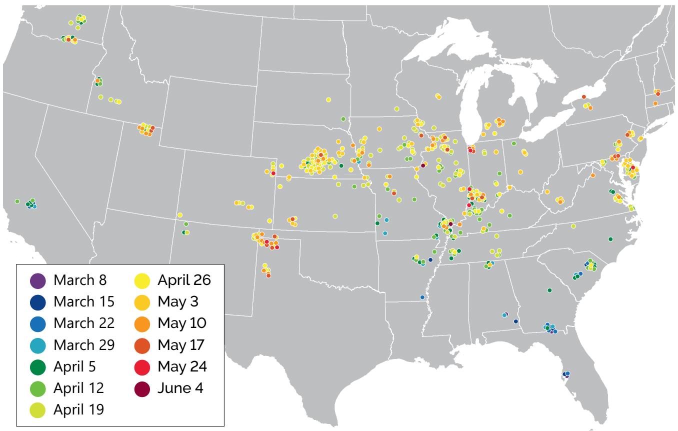

Figure 6. Planting date grouped by week of NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2018.

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 (67%) were planted to a crop other than corn the previous growing season (Figure 7).

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

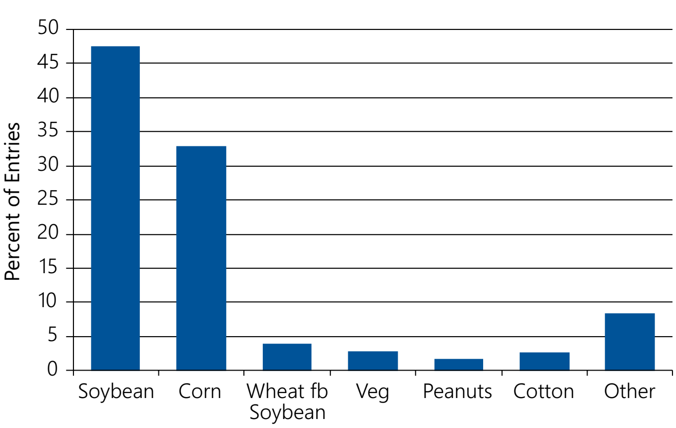

Figure 7. Previous crop in NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2018.

TILLAGE

Three of the six classes in the NCGA National Corn Yield Contest specify no-till or strip-till practices; however, nearly 60% of the contest entries over 300 bu/acre employed conventional, minimum, or mulch tillage (Figure 8). Tillage practices used in high-yield contest entries have stayed relatively consistent over the past several years.

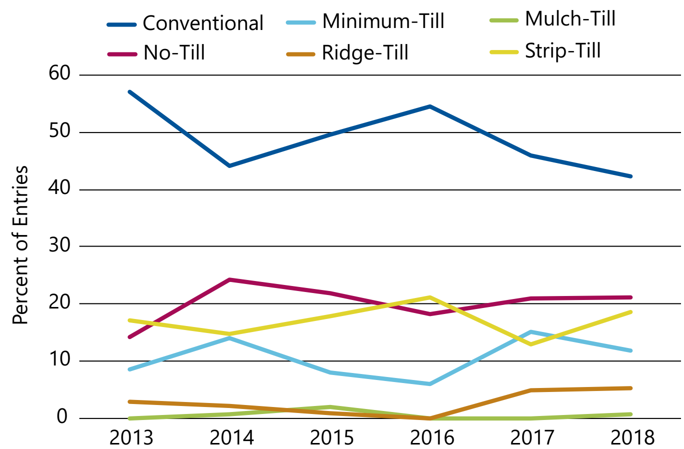

Figure 8. Tillage practices in NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2018.

SOIL FERTILITY

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

Nitrogen

Corn grain removes approximately 0.67 lbs of nitrogen per bushel harvested, and stover production requires about 0.45 lbs of nitrogen for each bushel of grain produced (IPNI, 2014). This means that the total N needed for a 300 bu/acre corn crop is around 336 lbs/acre. Only a portion of this amount needs to be supplied by N fertilizer; N is also supplied by the soil through mineralization of soil organic matter. On highly productive soils, N mineralization will often supply the majority of N needed by the crop. Credits can be taken for previous legume crop, manure application, and N in irrigation water. Nitrogen application rates of entries exceeding 300 bu/acre are shown in Figure 9.

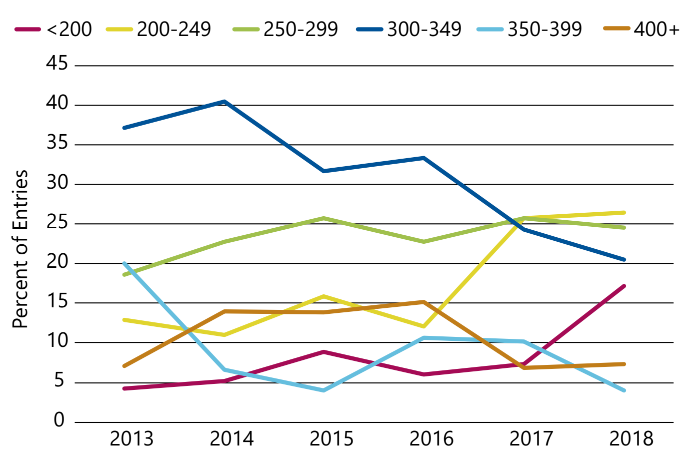

Figure 9. Nitrogen rates (total lbs/acre N applied) of NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2018.

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The N application rates of 300 bu/acre entries varied greatly, but a majority were in the range of 200 to 300 lbs/acre. Some entries with lower N rates were supplemented with N from manure application. Total N rates in high-yielding contest entries have declined over the last several years. In 2013, 64% of entries used N rates greater than 300 lbs/acre, compared to only 32% in 2018. As corn yield increases, more N is removed from the soil; however, N application rates do not necessarily need to increase to support high yields. Climatic conditions that favor high yield will also tend to increase the amount of N a corn crop obtains from the soil through increased mineralization of organic N and improved root growth.

> "Over 80% of 300 bu/acre entries included some form of in-season nitrogen application, either sidedressed or applied with irrigation."

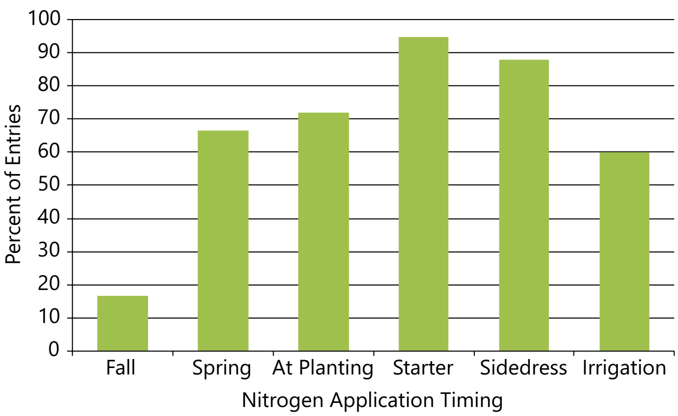

Figure 10. Nitrogen fertilizer application timing of NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2018.

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.

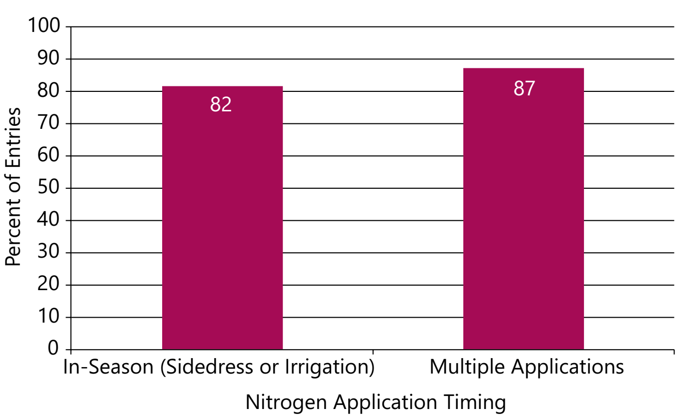

Figure 11. Nitrogen management programs of NCGA National Corn Yield Contest entries exceeding 300 bu/acre that included in-season application(s) and multiple application timings, 2013-2018.

Timing of N fertilizer applications in 300 bu/acre entries is shown in Figure 10. Very few included fall-applied N. Many applied N before or at planting. Over 80% of 300 bu/acre entries included some form of in-season nitrogen application, either sidedressed or applied with irrigation (Figure 11). Nearly 90% included multiple applications.

MICRONUTRIENTS

Micronutrients were applied on approximately half of the 300 bu/acre entries (Figure 12). The nutrients most commonly applied were sulfur (S) and zinc (Zn) with some entries including boron (B), magnesium (Mg), manganese (Mn), or copper (Cu).

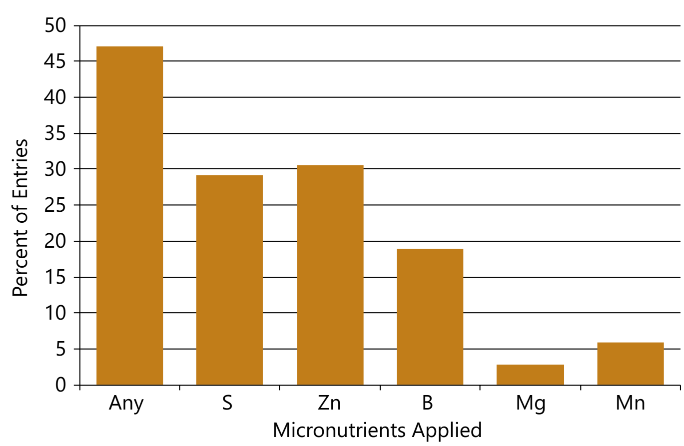

Figure 12. Micronutrients applied in NCGA National Corn Yield Contest entries exceeding 300 bu/acre, 2013-2018.

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.

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Pests of Late-Planted Corn

Madeline Henrickson, *Agronomy Intern*

INTRODUCTION

- Unfavorable weather during spring months can delay corn planting or make replanting necessary if germination and emergence are poor.
- When corn planting is delayed, the growth and development of the crop is also delayed. This can make the crop more vulnerable to yield loss from diseases and insects since they can affect the crop at earlier stages of development relative to grain fill.
- Diligent scouting is especially important in late-planted corn to watch for potential issues and determine if a treatment is economically justified.
- This article provides a brief overview of select insects and diseases that can pose a greater risk to late-planted corn.

INSECTS

Corn Rootworm (CRW)

- Larvae feeding duration lasts from late May to late July.
- CRW larvae initially feed on root hairs and outer root tissue before burrowing deeper into the root.
- Corn often suffers physiological stress as a result of feeding due to the hindrance of water and nutrient uptake.

CRW larvae feeding on corn root. Photo courtesy of Jim Kalisch

- Late-planted corn is at an increased risk of silk clipping due to presence of more rootworm beetles during pollination.
- Late-planted fields have the potential to become a trap crop for egg laying when they are surrounded by earlier-planted fields, increasing the risk of larvae infestation the following year.

Corn Earworm (CEW)

- Warm and humid nights are favorable for CEW.
- Migrates north as conditions become suitable
- Adults lay eggs on silks, and larvae will feed down the ear.
- Larvae can be found in the whorl and foliage on younger plants.

CEW feeding in a straight line down the ear. Corn earworms are cannibalistic so there is typically only one found per infested ear.

European Corn Borer (ECB)

- First generation ECB attacks corn starting in early June and can last until late July to early August.
- First generation larvae cause damage to the leaf surface and bore into the midrib before making their way to the stem.
- Second and third generations feed on the ear and also bore into the stalk.
- Yield loss potential from ECB damage varies by corn growth stage (Table 1).
- If no Bt traits are being utilized, first and second generation ECB can be controlled with insecticide as part of a scouting and integrated pest management program.

Table 1. Yield losses caused by ECB for various corn stages, based on physiological stresses and not stalk breakage or ear dropping (Krupke et al. 2010).

Plant Stage	Percent Yield Loss - # Borers/Plant		
	1	2	3
Early Whorl	5.5	8.2	10.0
Late Whorl	4.4	6.6	8.1
Pre-Tassel	6.6	9.9	12.1
Pollen Shedding	4.4	6.6	8.1

ECB larva tunneled into corn stalk.

Fall Armyworm (FAW)

- Late stage larvae can defoliate vegetative-stage corn, particularly in areas with grassy weeds.
- Fields with reduced tillage are at a higher risk than tilled ones.
- This pest is typically considered more of a southern pest when compared to the Corn Belt.

FAW feeding on vegetative tissue.

DISEASES

Southern Rust

- Fungal disease caused by *Puccinia polysora* pathogen
- Favored by high humidity and temperatures in the 80s and 90s (°F)
- More frequent in the South but may also spread into the Midwest by wind-blown spores, usually in late summer
- Spreads very rapidly when conditions favor development. New infections may occur every seven days. Epidemics may occur over large areas, so fields may be damaged very quickly.

Corn leaf infected with southern rust. Note round to oval pustules, light brown to orange in color.

Northern Corn Leaf Blight (NCLB)

- Fungal disease caused by *Exserohilum turcicum*, which overwinters in corn debris
- Infection occurs when free water is present for 6 to 18 hours and temperatures are 65 to 80 °F (18 to 20 °C).
- Spores spread by rain splash or are carried on air currents.
- Infection can occur during any growth stage, but plants are most susceptible after pollination.
- Fungicides are available to manage this pathogen, if necessary.

NCLB lesions on corn leaf.

Close up of NCLB lesion.

Stalk Rots

- Depletion of nitrogen due to leaching makes stalks more prone to rotting.
- Specific rots are weather dependent.

Stalk depicting both anthracnose and Gibberella stalk rot.

Gray Leaf Spot (GLS)

- Fungal disease caused by *Cercospora zeae-maydis* pathogen
- GLS builds up in corn residue over time.
- Favored by warm temperatures and high humidity
- Disease often spreads rapidly with favorable weather during late summer and early fall (during the grain-fill period of corn development)

Southern Corn Leaf Blight (SCLB)

- Fungal disease caused by *Cochliobolus heterostrophus* (also known as *Bipolaris maydis*)
- Development is favored by warm (70 to 85 °F), moist weather and free water on the leaf.
- Thrives in warm-temperate or subtropical corn-growing environments, including the Southeastern U.S.
- Spores are windblown or splashed by water to new crop leaves where they germinate and infect the plant.

GLS lesions (rectangular shape).

SCLB lesions (irregular shape).

Tar Spot

- Caused by the fungus *Phyllachora maydis* in the U.S.
- Dark fungal, fruiting spots, associated with the name, can inhibit photosynthesis.
- Pathogen favors cool temperatures (60 to 70 °F or 16 to 20 °C), a high relative humidity (75% or more), cloudy days, and/or 7+ hours of dew at night.
- Research is ongoing to determine the best management practices for this disease.

Tar spot of corn leaf.

Close up of tar spot on corn leaf.

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Estimating CRW Populations with Sticky Traps in Northern Illinois

Crystal Dau, *Field Agronomist*

OBJECTIVES

- Quantify the western and northern corn rootworm beetle populations across northern Illinois with Pherocon® AM/NB sticky traps
- Understand how modern management practices influence corn rootworm population levels
- Identify best management practices for growers to make informed decisions for the following growing seasons

STUDY DESCRIPTION

Year: 2019

Locations: 210 field locations across northern Illinois

Sampling Methods:

- Sticky traps placed in fields starting at blister stage (R2)
- Sticky traps placed per field: 6
- Northern and western corn rootworm beetles were counted every seven days and average counts per trap were recorded.
- Trapping continued for five consecutive weeks by Pioneer Sales Professionals and Agronomists.
- Trapping was conducted in fields managed in the following rotations:
  - » Continuous corn fields
  - » Corn following soybean fields
  - » Soybean following corn fields

Planting Dates Assessed:

- Northern Illinois experienced very challenging planting conditions in 2019, so fields included in the study were planted over a much greater range of dates than normal.
- Location planting dates were spread across April, May, and June.

Foliar Insecticide Treatment:

- 28 locations included a foliar insecticide treatment.
- Treatments were made with an aerial fungicide applicator and were made at blister stage (R2).
- Proper safety and reentry interval protocol was followed by individuals collecting beetle counts.

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

RESULTS

- Corn rootworm populations were characterized at four different levels for each sampling location:
  - » Zero = no beetles collected
  - » Low = <21 beetles/week
  - » Moderate = traps averaged 21 to 50 beetles/week
  - » High = traps averaged >50 beetles/week
- Peak corn rootworm beetle population levels observed at sampled fields across testing period (Figure 2):
  - » 6.7% of fields had zero adults collected
  - » 80% of fields had low populations
  - » 10% of fields had moderate populations
  - » 3.3% of fields had high populations

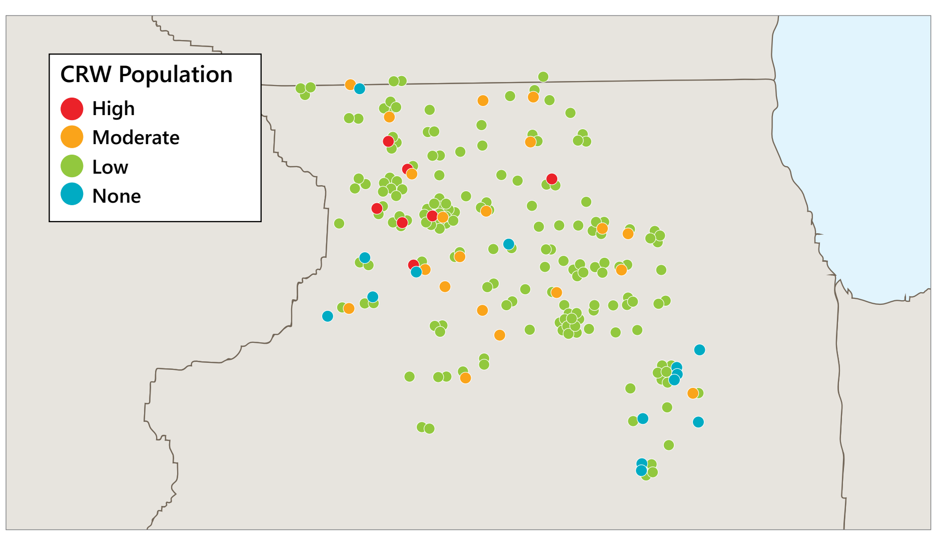

Figure 2. Peak population levels observed at corn rootworm beetle trapping locations in 2019.

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RESULTS (CONTINUED)

- Western corn rootworm and northern corn rootworm species compositions varied at locations depending on population levels (Figure 3).
  - » High population locations largely consisted of western corn rootworms at an average of 85%.
  - » Moderate population locations had a more even mix of species with western corn rootworm averaging 60% and northern corn rootworm averaging 40%.

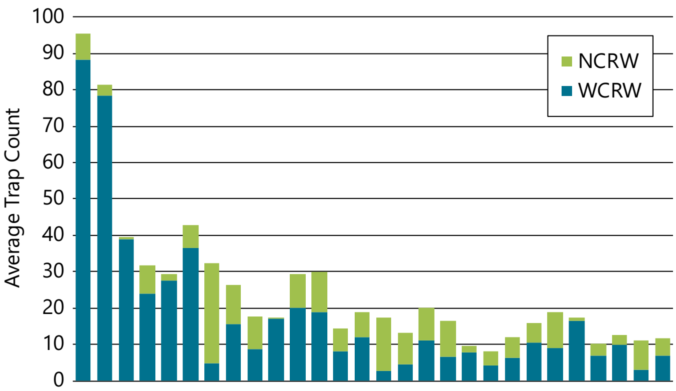

Figure 3. Species compositions for high and moderate population locations across northern Illinois in 2019.

- Planting date influenced the dates of peak trap count timing (Table 1).
  - » Corn rootworm populations peaked a week later in June-planted locations than in those planted in April or May.
  - » Across all moderate- and high-population locations, the average date of peak corn rootworm beetle populations was August 22, 2019.

Table 1. Among the untreated locations, peak population counts had different timings with each planting window in 2019.

Planting Date Month	Number of Locations	Average Peak Count Date	Average Peak Count
April	57	8/23/2019	15
May	37	8/23/2019	11
June	44	8/30/2019	8

- Crop rotation affected CRW pressure levels (Table 2).
  - » 100% of the high-pressure locations and 85% of the moderate-pressure locations were planted to corn following corn.
  - » All corn following soybean locations except one had low or zero corn rootworm populations.

Table 2. Distribution of pressure levels based on crop rotation.

Crop Rotation	High	Moderate	Low	None
Continuous Corn	7	17	73	2
Corn Following Soybeans	0	1	65	7
Soybeans Following Corn	0	1	27	5

ACTION THRESHOLDS

If traps average **<21 beetles** per week:

- **Low** rootworm populations are anticipated next year
- Select a control option for each field:
  - » Rotate acres to another crop
  - » Plant a corn rootworm Bt corn product
  - » Plant a non-Bt rootworm product with Poncho® 1250/VOTiVO® insecticide treatment
  - » Plant non-Bt rootworm product with soil insecticide for larvae

If traps average **21 to 50 beetles** per week:

- **Moderate** rootworm populations are anticipated next year
- Select a control option for each field:
  - » Rotate acres to another crop
  - » Plant a corn rootworm Bt corn product
  - » Apply a soil insecticide at planting for larvae

If traps average **>50 beetles** per week:

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

MANAGEMENT CONSIDERATIONS

- Studies have shown that the Herculex® RW (HXRW) trait remains an effective tool for corn rootworm management, but Pioneer and university research suggests that continuous, uninterrupted use of the same corn rootworm Bt technology can lead to reduced product efficacy against these insects.
- To maintain efficacy of Bt corn rootworm products, it is essential to develop a rootworm management plan that:
  - » Breaks the cycle
  - » Manages populations
  - » Protects the Bt trait
- Please contact your Pioneer sales professional or local extension professionals to assist you in developing field-specific best management practices for your operation.

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Harvest Timing Effect on Corn Yield

Steve Leusink, *Field Agronomist, and* **Mark Jeschke, Ph.D.,** *Agronomy Manager*

BACKGROUND AND RATIONALE

- When harvest is delayed due to weather or other factors, it is not uncommon to observe lower yields in the portion of the field harvested later than the portion harvested earlier.
- There are a number of possible reasons why yield may decline with later harvest, including ear drop, stalk lodging, insect feeding, ear rots, and greater harvest loss.
- Dry matter loss resulting from kernel respiration during grain dry down has also been hypothesized as an explanation for lower yields with later harvest dates, although recent research has failed to detect significant loss in kernel dry matter following physiological maturity.
- Lower grain moisture at harvest can result in greater shelling at the header; however; there is very little recent research to indicate how much this may contribute to lower yields with later harvest dates.

OBJECTIVES

- On-farm trials were conducted in 2018 to document any yield difference when harvesting corn at high moisture (>25%) versus low moisture (less than 20%).
- A subset of locations were sampled to determine the proportion of observed differences in yield attributable to pre-harvest loss (ear drop) and harvest loss (header + separating loss).

STUDY DESCRIPTION

- Trials were conducted at 14 locations in northern Iowa and eastern Nebraska.
- Fields were selected based upon grower convenience for harvesting at two different timings.
- A total of 8 different corn hybrids were used across trial locations, ranging from 101 to 118 CRM.
- Caution was used to prevent as much stalk lodging as possible by leaving extra rows on either side of the harvested strips.
- Targeted moisture ranges at harvest were >25% and <20% (referred to as "early harvest" and "late harvest" in the results).
- One round of corn was harvested at each harvest timing and yield measured by weigh wagon.
- Pre-harvest and harvest loss were measured at 6 of 14 locations.
  - » Pre-harvest loss (ear drop) was sampled by counting the number of ears on the ground prior to harvesting in $^1/_{100}$ of an acre (or 174 feet of row in a 30" row spacing).
  - » Harvest Loss (header and separating loss) was sampled by counting kernels on the ground (two random locations) after the combine passed in two or three 10 ft² areas across the header width (Figure 1).

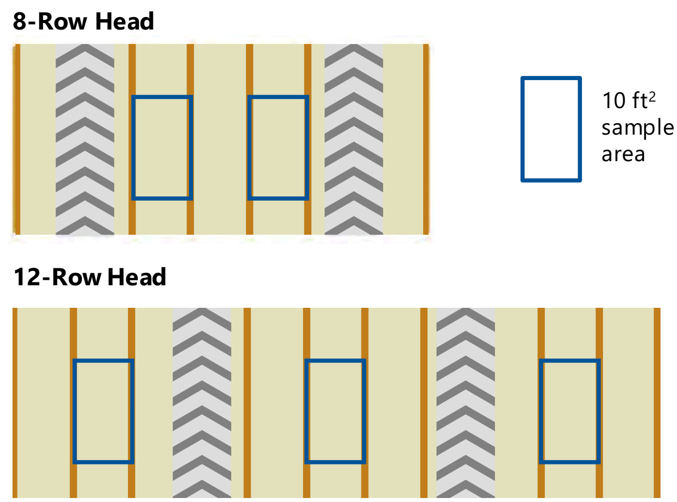

Figure 1. Sampling area layouts for measuring harvest loss.

RESULTS

- Due to the rapid dry down of grain experienced across much of the Midwest in 2018, grain moistures at early harvest timings were generally below the target range (Table 1).
- Extended periods of rainy weather resulted in long delays between early and late harvest at some locations (Table 1).

Table 1. Harvest date, grain moisture, and yield for early and late harvest timings at each trial location.

	Harvest Date		Grain Moisture		Yield	
Loc	Early	Late	Early	Late	Early	Late
			—— % ——		— *bu/acre* —	
1	Oct 16	Nov 2	23.0	15.9	238.7	216.2
2	Sept 25	Oct 25	21.1	15.1	269.5	248.4
3	Sept 17	Sept 26	23.1	17.9	231.1	210.2
4	Oct 15	Nov 1	25.0	17.0	235.3	222.2
5	Sept 20	Sept 28	19.9	18.0	232.1	221.4
6	Oct 2	Oct 24	21.6	16.4	290.5	280.3
7	Oct 18	Oct 31	24.0	18.5	275.5	266.0
8	Sept 25	Oct 17	20.4	19.2	271.2	264.7
9	Sept 20	Sept 28	20.1	18.0	243.7	238.4
10	Sept 26	Nov 8	21.8	17.4	266.0	261.9
11	Sept 20	Sept 28	19.7	17.5	213.1	210.4
12	Sept 26	Nov 8	21.1	17.4	269.3	268.2
13	Sept 20	Oct 25	19.6	14.0	260.4	261.2
14	Sept 26	Nov 8	21.4	17.4	266.0	268.0

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- Yield differences between early and late harvest varied widely across locations, from a decrease of 22.6 bu/acre to an increase of 2 bu/acre with later harvest. On average, yield was 8.9 bu/acre lower with later harvest (Table 2).
- Difference in grain moisture between the two harvest timings also varied widely across locations, from 1.2 to 8.0 percentage points (Table 2).
- Differences in yield between harvest timings showed no correlation with the number of days between early and late harvest or differences in grain moisture (Table 2). In fact, the three locations where yields differed by less than 1% between harvest timings all had greater than a month between the early and late harvest.
- Differences in yield between harvest timings also did not appear to correspond to hybrid or geography (data not shown).

Table 2. Number of days between early and late harvest and differences in yield and moisture between harvest timings

	Difference Between Early and Late Harvest		
Loc	Days	Yield (bu/acre)	Moisture (%)
1	17	22.6	7.1
2	30	21.1	6.0
3	9	20.9	5.2
4	17	13.2	8.0
5	8	10.7	1.9
6	22	10.2	5.2
7	13	9.5	5.5
8	22	6.5	1.2
9	8	5.3	2.1
10	43	4.1	4.4
11	8	2.7	2.2
12	43	1.1	3.7
13	35	-0.8	5.6
14	43	-2.0	4.0
Average	**22.7**	**8.9**	**4.4**

Harvest Loss

- At the 6 locations where harvest loss was measured, loss was generally low, averaging 0.62 bu/acre with early harvest and 1.55 bu/acre with late harvest (Table 3).
- Pre-harvest loss due to ear drop was negligible at all locations (data not shown).
- Harvest loss tended to increase with lower grain moisture across locations and harvest timings (Figure 2).
- Measured harvest loss only partially accounted for the differences in yield between harvest timings observed at some locations (Figure 3).
- However, there was a correlation between the difference in yield with both harvest timings and harvest loss; locations with lower yields at the later harvest timing also tended to have more harvest loss.

Table 3. Yield, harvest loss, and the differences in both for early and late harvest timings at locations where harvest loss was measured.

	Yield		Harvest Loss		Difference	
Loc	Early	Late	Early	Late	Yield	Loss
	— bu/acre —					
1	238.7	216.2	0.8	2.5	22.6	1.7
4	235.3	222.2	0.5	1.7	13.2	1.2
7	275.5	266.0	0.5	1.3	9.5	0.8
10	266.0	261.9	0.71	1.2	4.1	0.49
12	269.3	268.2	0.56	1.4	1.1	0.84
14	266.0	268.0	0.63	1.2	-2.0	0.57

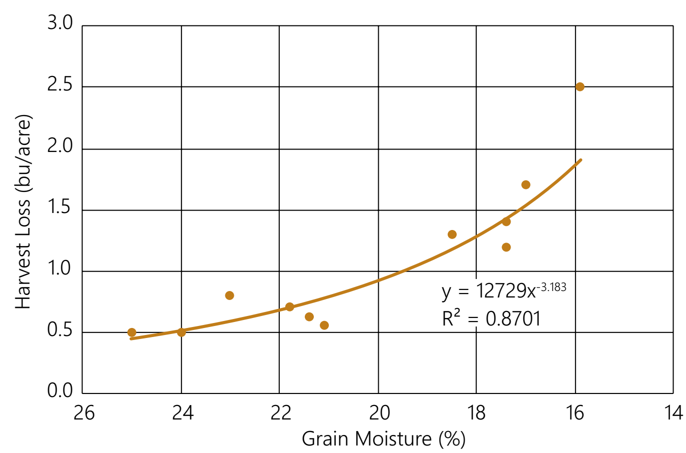

Figure 2. Grain moisture effect on harvest loss.

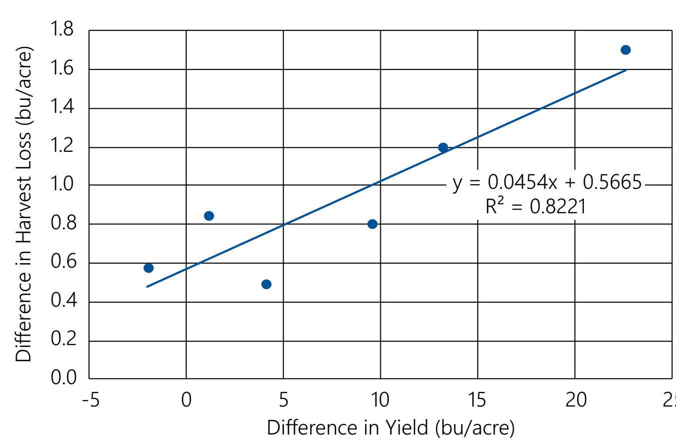

Figure 3. Relationship between difference in yield with early and late harvest as well as harvest loss.

CONCLUSIONS

- Results of this study showed that corn yield tended to decline with later harvest on average. However, it is not clear why and results varied widely among locations.
- Greater harvest loss only partially accounted for lower yields.
- The lack of correlation with grain dry down or length of harvest delay tends not to support the hypothesis that reduced yields are due to dry matter loss from kernel respiration.

"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"

Corn Seeding Rate Considerations

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

SUMMARY

- Improvement of corn hybrid genetics for superior stress tolerance has allowed hybrids to be planted at higher plant populations and produce greater yields.
- Over the past 30 years, average corn seeding rates used by corn growers in North America have increased by about 275 seeds/acre per year while U.S. average yields have increased by about 2 bu/acre per year.
- Each year Pioneer evaluates corn plant population responses in research trials that span the Corn Belt of North America. Pioneer researchers target representative environments based on maturity zone, expected yield (high or low), specific stresses, and other unique location characteristics.
- Farmers can use the multi-year and multi-location results to identify the best potential planting rates specific to their hybrid, location, and management practices.
- The economic optimum seeding rate (the point at which profitability is maximized) will always be a bit less than the seeding rate at which yield is maximized.
- In challenging emergence environments, farmers may need to increase rates. See seeding rate tips in this article or contact your local Pioneer sales professional for help.

HIGHER DENSITY DRIVES HIGHER YIELDS

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.

The continual increase in optimum plant density throughout the hybrid corn era has been well-documented by research. An analysis of Pioneer plant population data from the past 30 years has shown that this trend continues up to the present day (Ciampitti, 2018a). Additionally, this analysis showed that the range of the agronomic optimum plant density increased over time from the 1987 to 1991 period to the 2012 to 2016 period (Figure 1). This finding shows that modern hybrids not only need more plants to attain maximum yields but also that the stability of modern hybrids has increased relative to older hybrids.

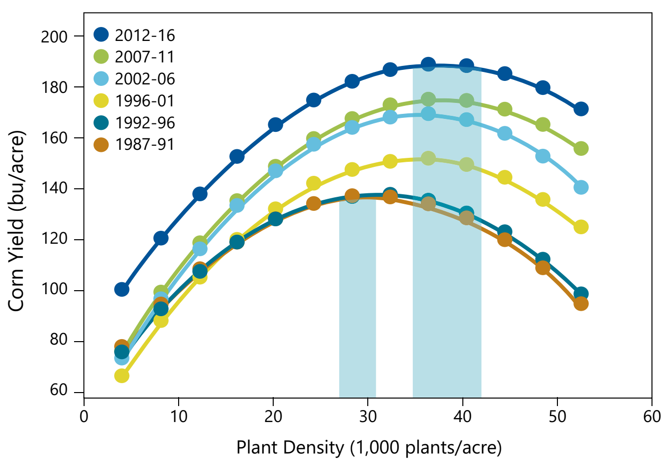

Figure 1. Agronomic optimum plant density (averaged over all Pioneer® brand hybrids) over six 5-year time periods from 1987-2016. Shaded bars show the increase in agronomic optimum plant density range from the earliest time period in the study to the most recent.

PLANT POPULATION TRENDS

Farmers have taken advantage of the higher stress tolerance of modern hybrids by pushing plant populations higher. The linear increase in average plant populations used by corn growers in North America tracks closely with the linear increase in average corn yields over the same time period. Since 1986, average corn seeding rates used by growers in North America have increased by about 275 seeds/acre per year while U.S. average yields have increased by over 2 bu/acre per year (Figure 2).

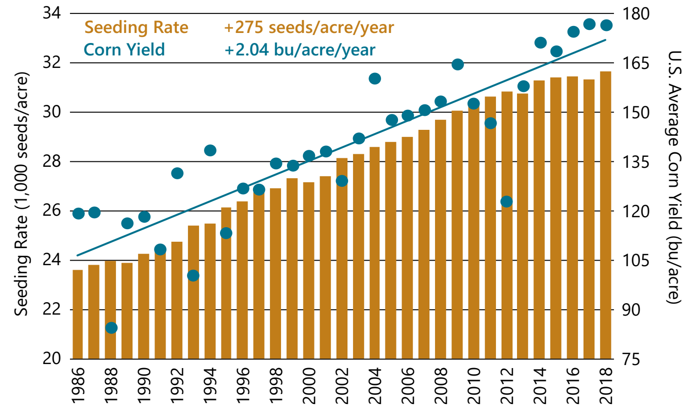

Figure 2. Average corn seeding rates reported by growers in North America (Pioneer Survey, 2018) and average U.S. corn yields (USDA NASS).

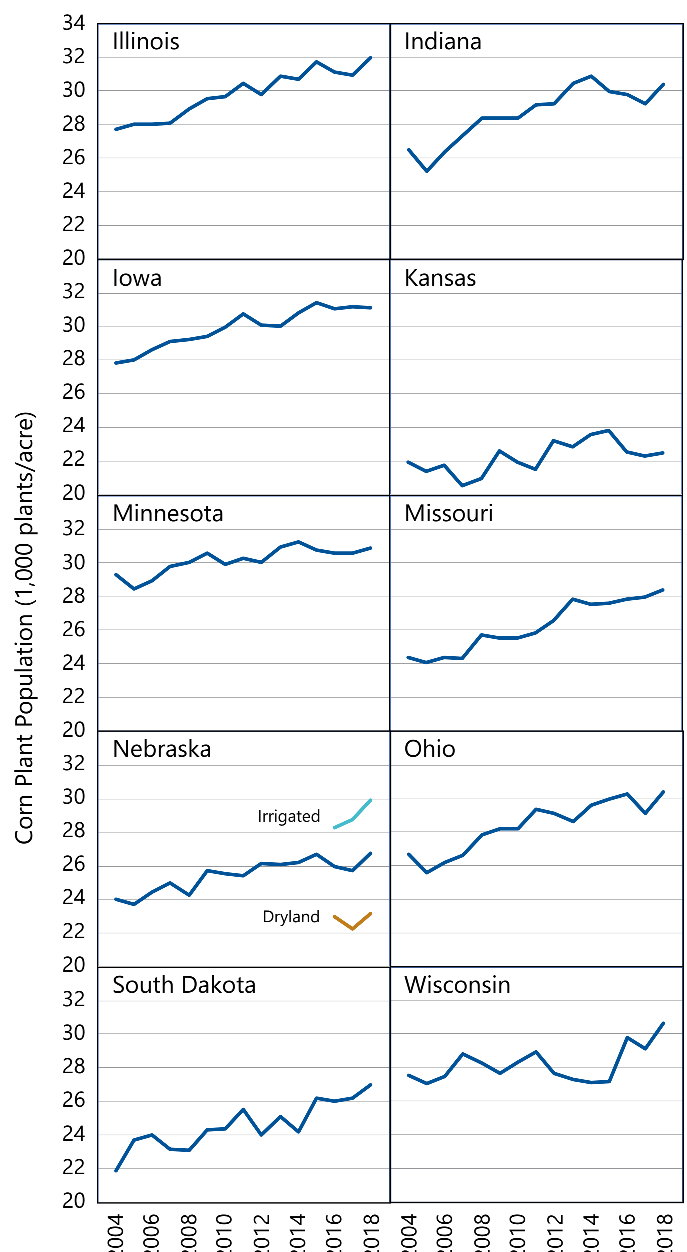

Figure 3. Average corn plant populations for major corn-producing states, 2004-2018 (USDA NASS).

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Corn plant populations vary by geography due to differences in growing environments and productivity levels, but populations have generally trended upward over time. The 10 corn-producing states for which the USDA collects corn plant population data have all had positive linear trends over the past 15 years (Figure 3). Wisconsin and Kansas had the smallest increases over this time period, with an average gain of around 125 plants/acre/year, while Indiana, Illinois, Missouri, and Ohio had the largest increases at over 300 plants/acre/year.

PIONEER PLANT POPULATION RESEARCH

Pioneer has been conducting plant population studies with corn hybrids for over three decades. Research studies have been conducted at over 320 locations throughout the U.S. and Canada in the last 6 years (Figure 4). Pioneer researchers target representative environments based on maturity zone, expected yield (high or low), specific stresses, and other unique location characteristics. Over the past several years, Pioneer has also conducted plant population research focused specifically on lower-yielding water-limited environments (Figure 5).

> “Pioneer has been conducting plant population studies with corn hybrids for over three decades.”

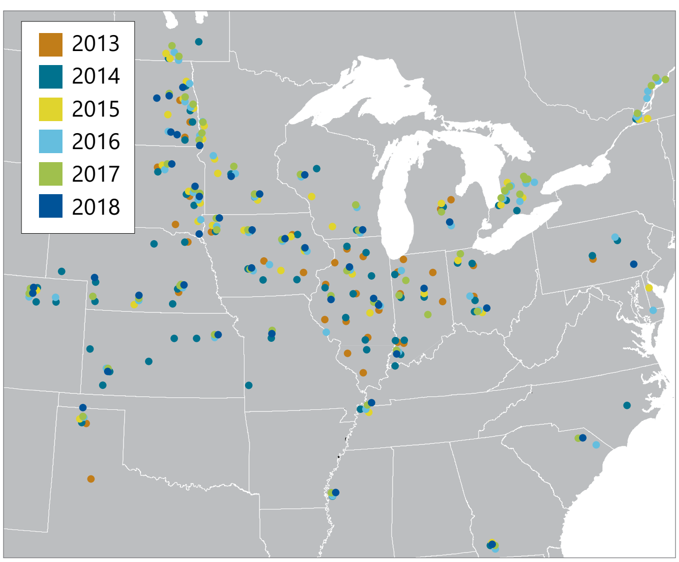

Figure 4. Pioneer plant population test locations in North America, 2013-2018.

Additionally, hundreds of on-farm Pioneer agronomy seeding rate trials are conducted each year comparing multiple corn products at up to four seeding rates at each location. These trials have considerable value for local observation, evaluation, and refinement of plant population agronomic response. Farmers can use the multi-year and multi-location results to identify the best potential planting rates specific to their hybrid, location, and management practices.

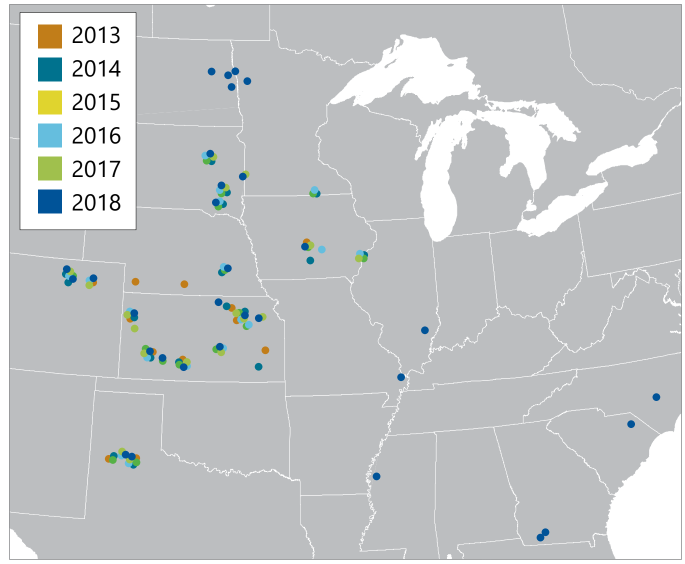

Figure 5. Pioneer water-limited plant population research locations in North America, 2013-2018.

Field Productivity Level

In general, corn hybrid response to plant population follows a quadratic response model in which yield increases with greater plant population up to an optimum point, beyond which yield declines. Pioneer research has shown that yield response to plant population depends on the yield environment. An analysis of 15 years of plant population response data showed that in low-yielding environments (below 100 bu/acre), maximum yield was attained at a plant population level of 24,000 plants/acre. In very high yield environments (above 200 bu/acre), yield response to plant population continued to increase even at 40,000 plants/acre (Figure 6).

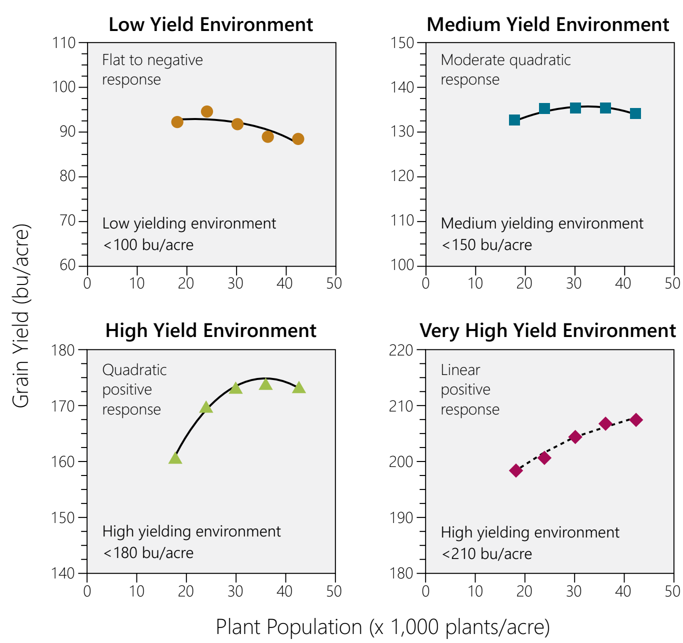

Figure 6. Corn hybrid response to plant population under 4 yield environments: a) low yielding <100 bu/acre; b) medium yielding 100-150 bu/acre; c) high yielding 150-180 bu/acre; and d) very high yielding 190-210 bu/acre (Ciampitti, 2018b).

Economic Optimum Seeding Rate

As yields increase with each increment of higher seeding rate, a point is reached where the yield benefit from the next addition of seed no longer exceeds the cost of the seed. That point is the optimum economic seeding rate. By definition, it is the seeding rate that generates the most income when seed cost and grain price are factored in. The economic optimum seeding rate will always be less than the seeding rate at which yield is maximized.

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

Results from recent Pioneer plant population research show that the economic optimum seeding rate increased from approximately 30,000 seeds/acre at the 150 bu/acre yield level to around 37,000 seeds/acre at the 240 bu/acre yield level (Figure 7).

At water-limited locations where yield levels were lower, economic optimum seeding rate varied 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 (Figure 8).

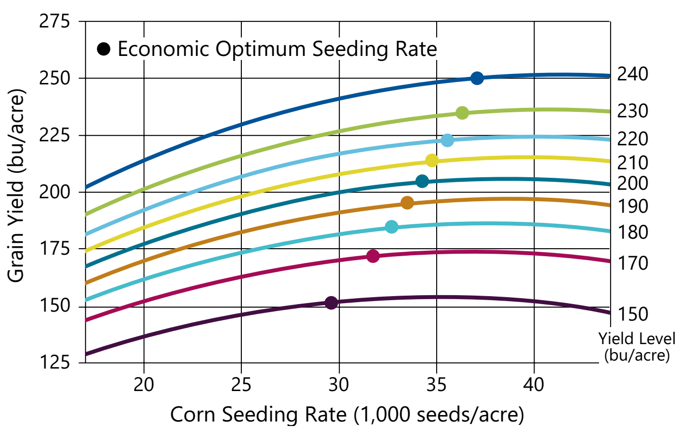

Figure 7. Corn yield response to population and optimum economic seeding rate by location yield level, 7-yr average.

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.

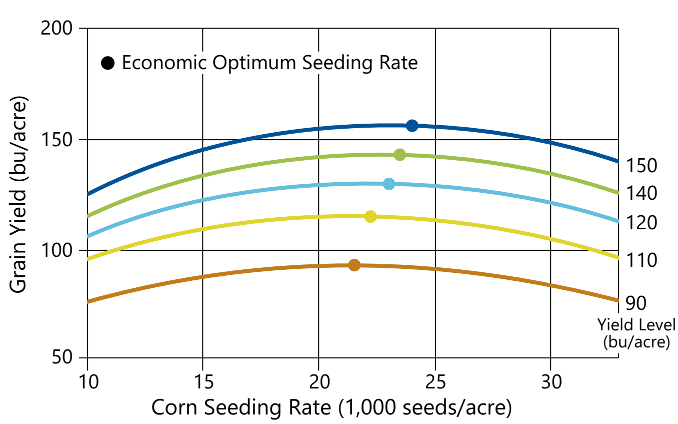

Figure 8. Corn yield response to population and optimum economic seeding rate by location yield level at water-limited sites, 7-yr average.

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.

Hybrid Maturity

Research has generally shown a higher optimum plant population for shorter comparative relative maturity (CRM) hybrids. Some researchers theorize that the disadvantages of smaller stature and lower leaf area index of early maturity hybrids are alleviated by higher populations. Increasing leaf area index may be required for highest yields in northern areas with limited light availability during late ear-fill stages.

An analysis of 15 years of Pioneer plant population research data showed that corn yield was generally lower and optimum population was greater with hybrids of shorter CRM. Long (106 to 115 CRM) and very long (>115 CRM) maturity hybrids generally reached their maximum yield within a very narrow plant population range of 34,000 to 35,000 plants/acre. On the opposite CRM range, very early to medium (<78 CRM to 105 CRM) maturity hybrids typically achieved maximum yield at plant populations ranging from 36,000 to 39,000 plants/acre.

PIONEER PLANTING RATE ESTIMATOR

The Pioneer Planting Rate Estimator, available on www.pioneer.com, allows users to generate estimated optimum seeding rates for Pioneer® brand corn products based on data from Pioneer research trials (Figure 9). The Planting Rate Estimator, which is aligned with the guidelines provided in Granular Agronomy VRS, provides flexibility in customizing the graph display based on grain prices and seed costs.

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. 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. Farmers should use the Planting Rate Estimator as an initial guide and work with their Pioneer sales professional for refinements based on local observations and on-farm trials.

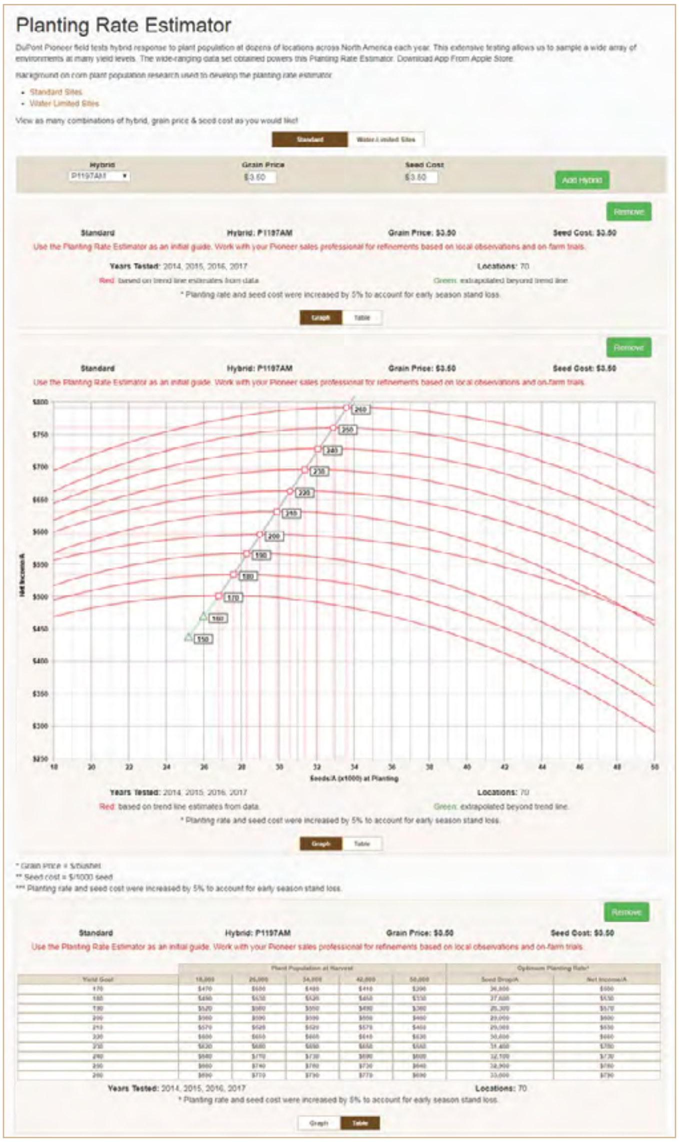

Figure 9. Pioneer Planting Rate Estimator user display.

SEEDING RATE TIPS

Challenging growing environments may reduce corn plant populations below optimum levels. These conditions can occur when planting into no-till, high-residue seedbeds, or cloddy or compacted soils. Soil-borne diseases and soil insects can also diminish stands. All of these factors can interact to challenge stand establishment, and effects are magnified when planting early into cold, wet soils. Therefore, consider the following points when choosing your seeding rate:

- In general, plan to drop 5% more seeds than the target population to account for germination or seedling losses.
- Boost target seeding rates by an additional 5% for extreme or challenging environments, such as those described in the paragraph above.
- In areas with perennial drought stress, seeding rate targets are lower. Base your seeding rate on the specific hybrid population response at the historical yield level of the field.
- Consult your Pioneer sales professional for optimum economic seeding rates of each Pioneer® brand hybrid, hybrid placement tips, and other helpful management suggestions.

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Corn Plant Population Research

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

PIONEER PLANT POPULATION RESEARCH

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

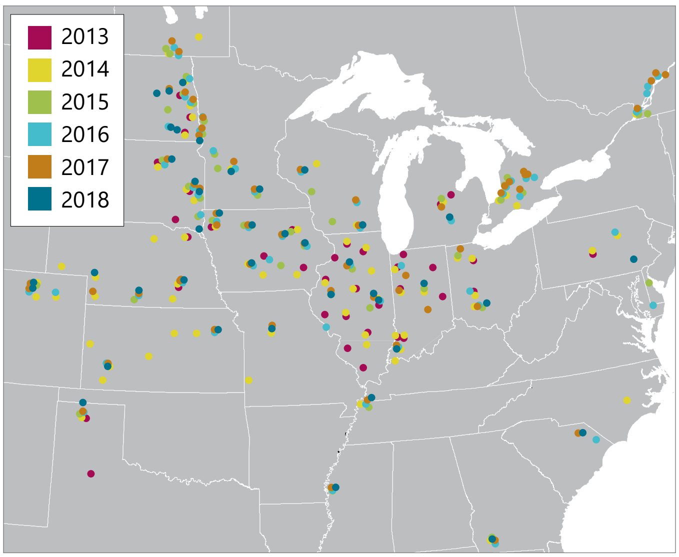

Figure 1. Pioneer plant population test locations in North America.

- 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 agronomy seeding rate trials are conducted each year comparing multiple corn products at up to four seeding rates at each location. These trials have considerable value for local observation, evaluation and refinement of plant population agronomic response (Figure 2).
- 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.

Figure 2. Pioneer on-farm seeding rate trial prior to harvest (Iowa, 2017).

Optimum Seeding Rate by Yield Level

- Like previous Pioneer studies, recent multi-year trials across the U.S. and Canada show that corn hybrid response 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.

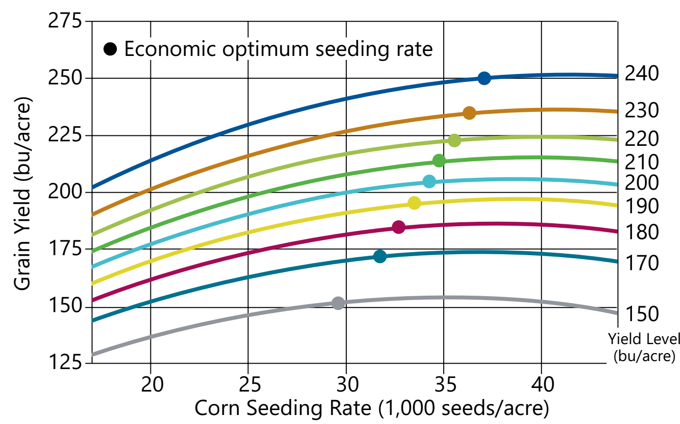

Figure 3. Corn yield response to population and optimum economic seeding rate by location yield level (7-yr average of all hybrids tested).

Averaged across all hybrids tested. Economic optimums based on a corn rain price of $3.50/bu and a seed cost of $3.00 per 1,000 seeds; assumes 5% 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).

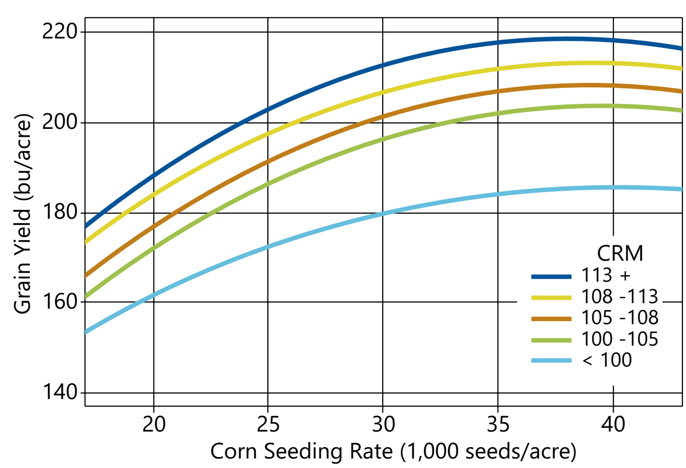

Figure 4. Yield response to plant population for corn hybrids from five maturity (CRM) ranges (7-yr average of all hybrids tested).

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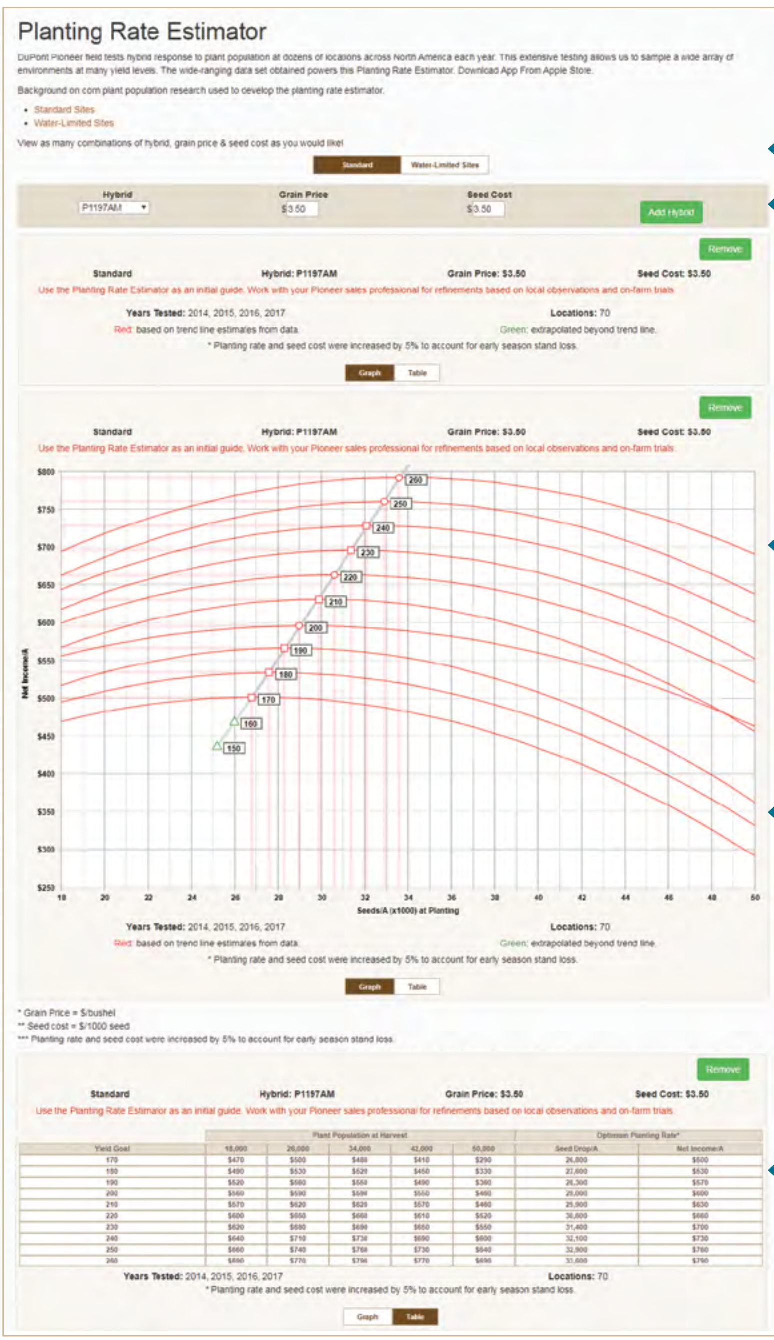
PLANTING RATE ESTIMATOR

The 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 trials.

Planting Rate Estimator Features

- The Planting Rate Estimator, which is aligned with the guidelines provided in Granular Agronomy VRS, provides flexibility in customizing the graph display based on grain prices and seed costs.
- 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.
- 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.



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

To provide a wider range in yield levels for variable rate seeding (VRS) the seeding rate optimum response trend line is now extrapolated to lower yield levels -- that is, extended beyond the regression trend response based on data to yield levels as much as 40 bu/acre lower, but not lower than 150 bu/acre. This extrapolation is indicated with the change from gray to green in the trend line.

Net income/acre data can also be displayed in tabular form. Years of testing and number of testing locations for the selected hybrid are shown below.

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Corn Plant Population Research
Water-Limited Sites

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

PIONEER PLANT POPULATION RESEARCH

- 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).

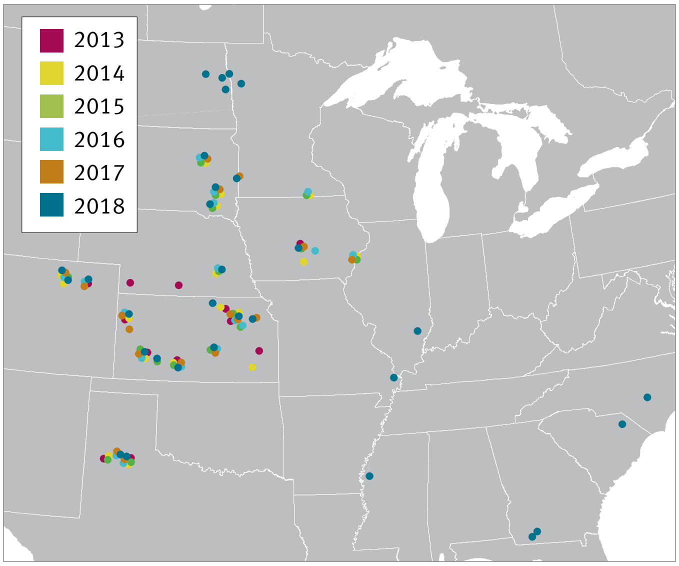

Figure 1. Pioneer plant population water-limited test locations in North America, 2013-2018.

- 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

- Plant population research 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.

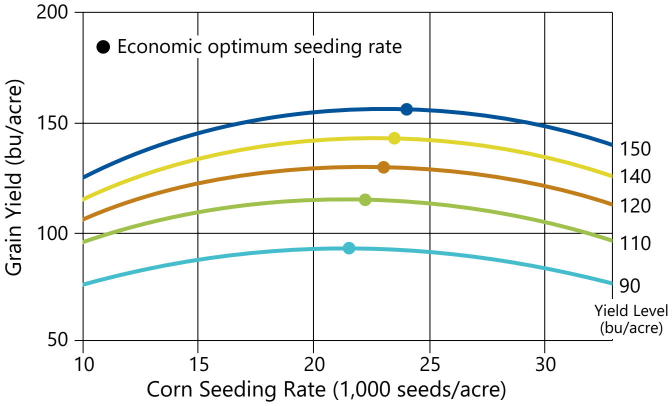

Figure 2. Corn yield response to population and optimum economic seeding rate by location yield level at water-limited sites, 7-yr average.

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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PLANTING RATE ESTIMATOR

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- The yield levels available for display will vary among hybrids based on the available research data.
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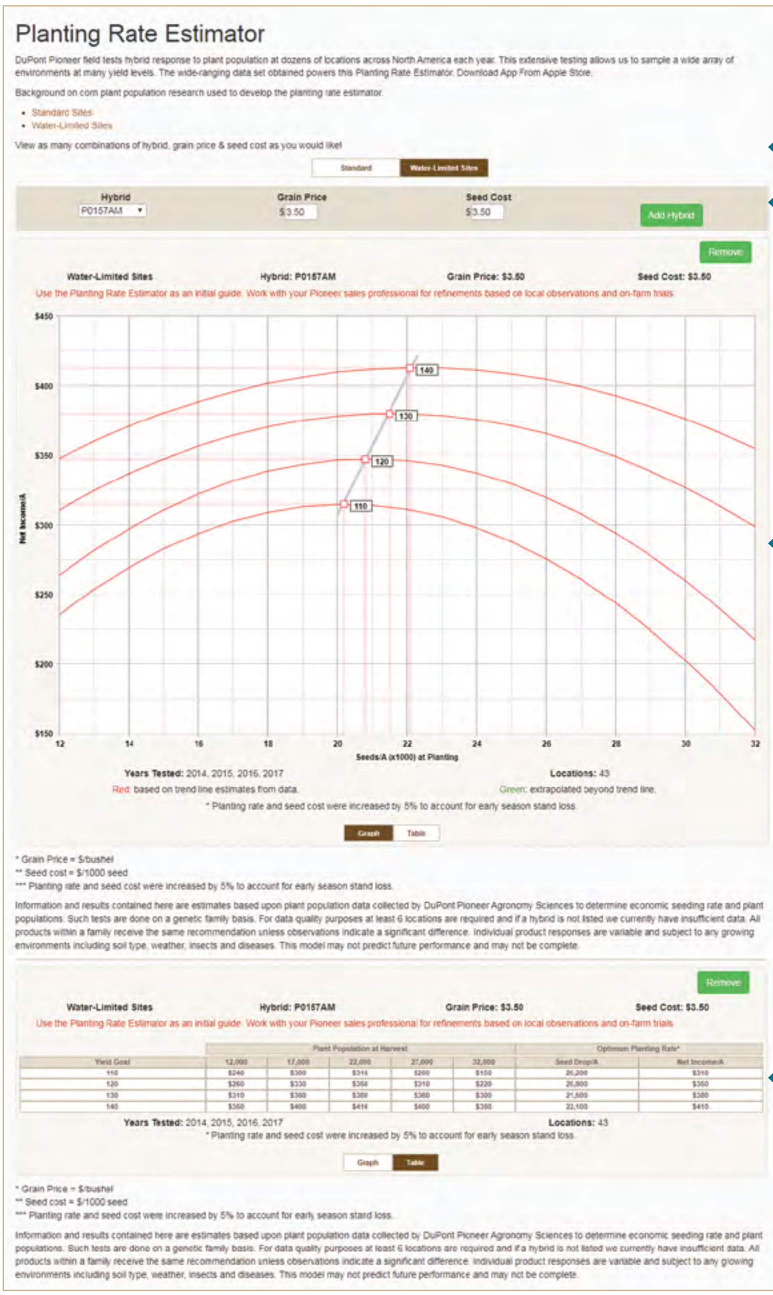

View plant population responses from either standard or water-limited research sites.

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

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

Net income/acre data can also be displayed in tabular form. Years of testing and number of testing locations for the selected hybrid are shown below.

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Planting Timing Effect on Corn Yield in the Central Corn Belt

Ryan Van Roekel, Ph.D., *Field Agronomist,* ***Nate LeVan,*** *Field Agronomist,*
and ***Mark Jeschke, Ph.D.,*** *Agronomy Manager*

PLANTING DATE EFFECT ON CORN YIELD

- Timely planting of full-season hybrids generally provides the best opportunity to maximize yields by allowing the corn crop to make use of the entire growing season.
- Delayed planting situations due to wet or cold weather invariably raise the question of how much yield is being lost.
- Corn yields from Pioneer on-farm trials provide an opportunity to look at the range of potential yield effects of delayed planting and how these trends vary from year to year.
- Thousands of these trials are planted each year over a range of planting dates that are generally reflective of the range of planting dates for the overall corn crop.
- Corn planting-date research generally shows an optimum window for maximum yield potential (typically mid-April to mid-May depending on latitude) after which yields decline.
- A survey of average yields in a large number of on-farm trials does not necessarily show the optimum planting-date window but can give a sense of the rate of yield decline observed.
- For simplicity, a linear regression was used to estimate the daily yield effect associated with planting date.

PLANTING DATE YIELD TRENDS IN PIONEER TRIALS

- Average yields from over 28,000 Pioneer on-farm trials conducted in Iowa, Illinois, and Indiana from 2011 to 2018 were compiled to look at yield trends associated with planting date.

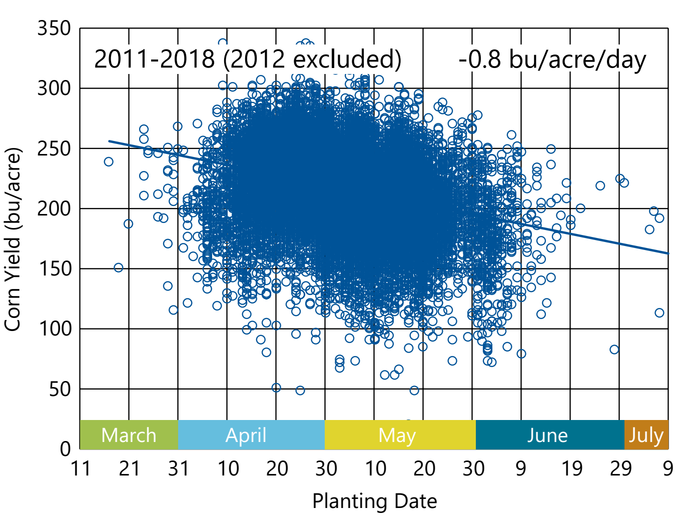

Figure 1. Planting date effect on average yield of Pioneer on-farm trial locations in Iowa, Illinois, and Indiana from 2011-2018, excluding 2012.

- Each yield value is an average of multiple hybrid entries at the location with comparative relative maturities (CRM) suited to the geography.
- Over 7 years of trials (2011 to 2018 with 2012 excluded), yield declined by 0.8 bu/acre/day of planting delay (Figure 1).
- However, there was not a strong correlation (R^2=0.0913) between planting date and corn yield, represented by the wide range in yield at any given planting date, which is indicative of the numerous other factors that can influence final yield.

Year to Year Differences

- Yield trends associated with planting date were variable when looking at yields from individual years (Figures 2 to 9).
- Results for 2012 were highly anomalous compared to all other years due to the widespread hot and dry conditions experienced that year.
  - » Planting was much earlier than normal due to exceptionally warm temperatures in March and April, and drought sharply reduced yield at many locations.
  - » Yield actually increased with later planting in 2012.
  - » Drought stress and rainfall timing relative to growth stage overrode any advantage to earlier planting.
- In the other years, rate of yield decline ranged from 0.2 to 1.2 bu/acre/day (Table 1).
  - » The largest rates of yield decline with later planting were observed in 2014 and 2018 with yield declining by an average of more than 1 bu/acre/day.
  - » The lowest rate of decline was observed in 2017, with only a 0.2 bu/acre/day decline.

Table 1. Number of Pioneer on-farm trial locations in Iowa, Illinois, and Indiana from 2011-2018 and rate of yield decline with delayed planting.

Year	Locations	Yield Decline
		bu/acre/day
2011	5,277	-0.6
2012	4,519	+0.8
2013	4,286	-0.5
2014	3,930	-1.1
2015	2,993	-0.4
2016	3,030	-0.7
2017	2,513	-0.2
2018	2,314	-1.2

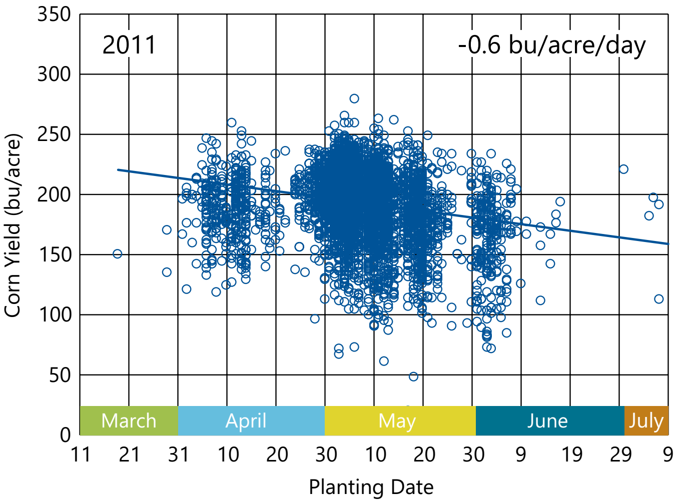

Figure 2. Planting date effect on average yield of Pioneer on-farm trial locations in Iowa, Illinois, and Indiana in 2011.

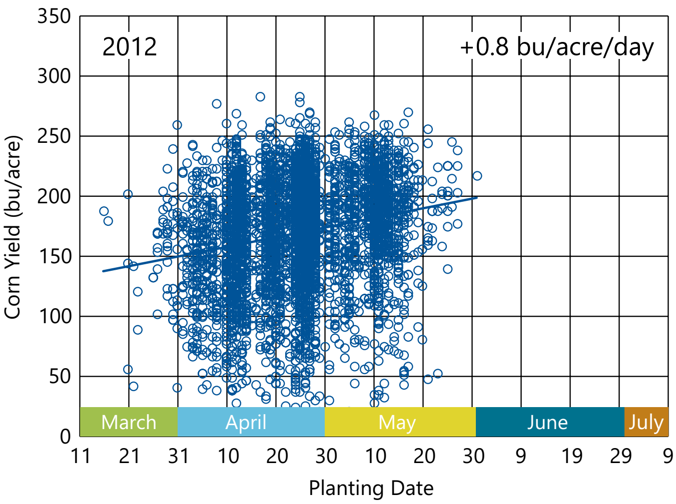

Figure 3. Planting date effect on average yield of Pioneer on-farm trial locations in Iowa, Illinois, and Indiana in 2012.

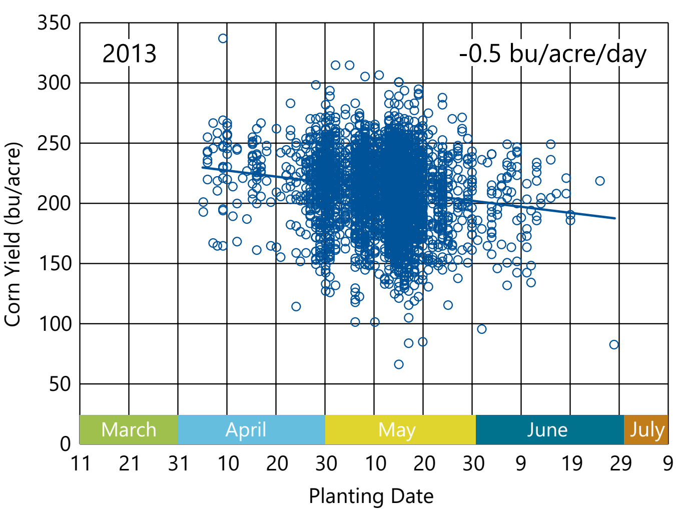

Figure 4. Planting date effect on average yield of Pioneer on-farm trial locations in Iowa, Illinois, and Indiana in 2013.

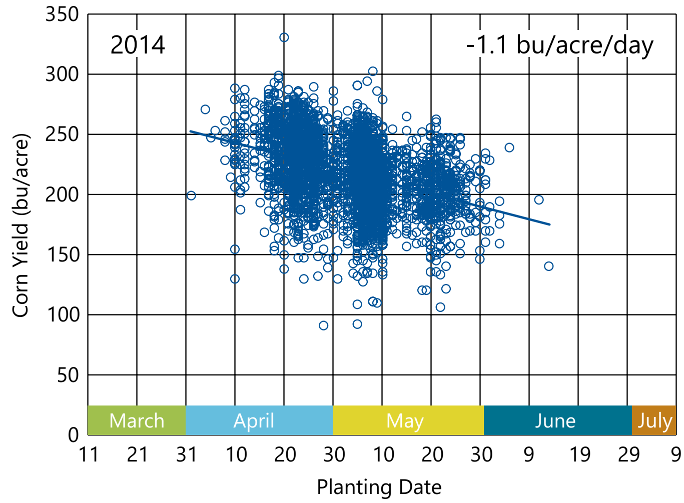

Figure 5. Planting date effect on average yield of Pioneer on-farm trial locations in Iowa, Illinois, and Indiana in 2014.

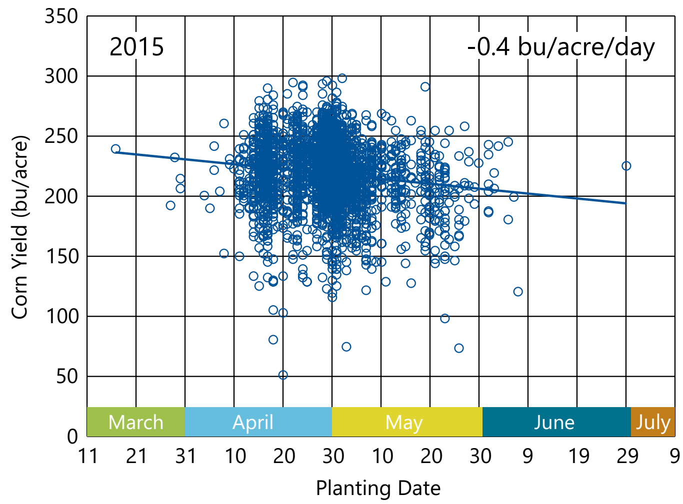

Figure 6. Planting date effect on average yield of Pioneer on-farm trial locations in Iowa, Illinois, and Indiana in 2015.

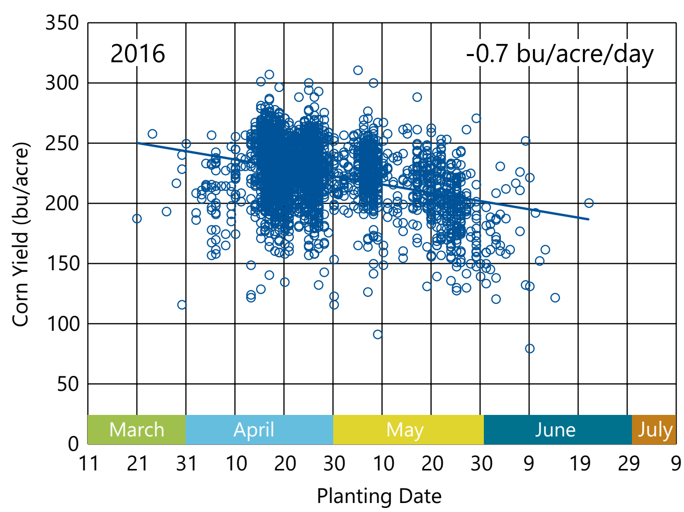

Figure 7. Planting date effect on average yield of Pioneer on-farm trial locations in Iowa, Illinois, and Indiana in 2016.

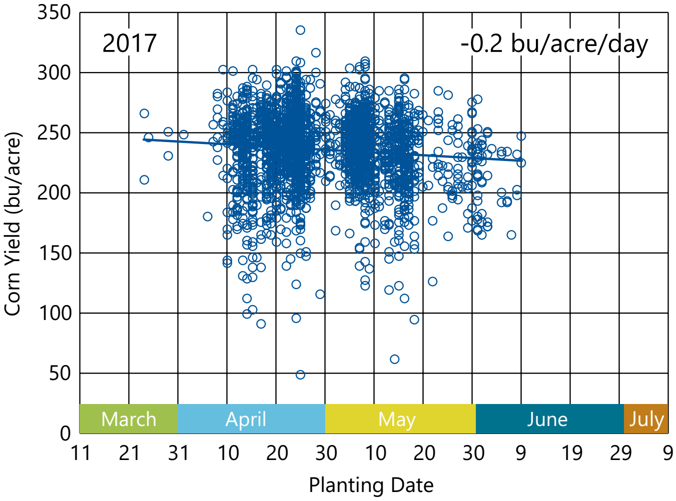

Figure 8. Planting date effect on average yield of Pioneer on-farm trial locations in Iowa, Illinois, and Indiana in 2017.

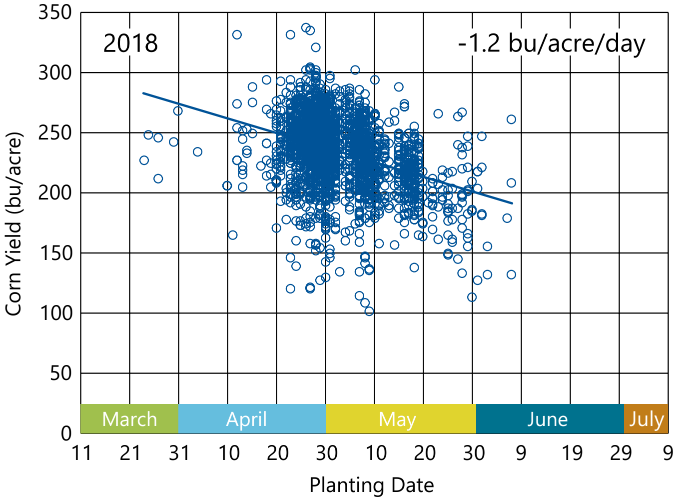

Figure 9. Planting date effect on average yield of Pioneer on-farm trial locations in Iowa, Illinois, and Indiana in 2018.

LOCAL TRENDS MAY DIFFER

- Pioneer on-farm research trials have also shown that yield trends associated with planting date can vary by geography due to local differences in growing conditions and weather during the season.
- Genetic differences may also add some variability due to the hybrids selected for use in local genetic product knowledge plots. For any given year, the timing of flowering, grain fill, and dry-down can greatly affect final plot yield outcome as well as its interaction with planting date.
- For example, comparison of yield trends in a subset of this dataset focusing only in North Central Iowa showed that the local yield effects did not necessarily follow the broader trends (Table 2).

Table 2. Yield trends by planting date of Pioneer on-farm trial locations in North Central Iowa compared to averages across Iowa, Illinois, and Indiana in 2016, 2017, and 2018.

Year	North Central Iowa Locations	Yield Decline	
		North Central Iowa	IA, IL, IN
		—— bu/acre/day ——	
2016	328	-0.2	-0.7
2017	262	-1.2	-0.2
2018	211	-1.7	-1.2

CONCLUSIONS

- Timely planting is generally favorable for achieving maximum corn yields but is just one factor out of many that influence final yield.
- Pioneer on-farm trials from 2011 to 2018 (2012 excluded) showed that yield declined by an average of 0.8 bu/acre/day with delayed planting.
- However, results also showed that yield trends can vary from year to year and by geography and that in some cases, there may be very little yield penalty associated with later planting.
- Most historic university studies show a dramatic yield decline associated with very late planting dates. This dataset did not have the same results but also did not have very many planting dates extending into June in most years. A quadratic or linear-plateau regression may also provide a better fit in some cases, which would also suggest steeper yield declines as the season progresses.
- During the planting season, no one knows what conditions the rest of the growing season will bring or how much yield may or may not be reduced due to later planting.
- In both early and late-planting situations, planting into unfavorable conditions may end up costing more yield than waiting until conditions are more suitable for planting. It is always important to have patience and wait until the field is fit for planting.

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Corn Hybrid Growth and Yield Response to Row Spacing in Ohio

Alex Lindsey, Ph.D., *and* **Peter Thomison, Ph.D,** *Department of Horticulture and Crop Science, Ohio State University, and* **Kirk Reese, M.S.,** *Former Agronomy Manager*

BACKGROUND AND RATIONALE

- Corn grain yield response to narrow rows (<30 inches, <76 cm) has been inconsistent in both university and Pioneer research. Responses have been slightly more positive in northern Corn Belt environments, averaging about 2.7 to 2.8% compared to central Corn Belt environments where responses have been negligible (Jeschke, 2018).
- Despite the lack of consistent yield benefit, interest in narrow-row corn continues in the popular press (Swoboda, 2013) and among corn growers. Factors driving interest may include:
  - Silage production where yield improvements with narrow rows have been fairly well-documented
  - Lower yielding environments where leaf area development could be limited by drought stress during the vegetative stages of growth
- Despite research that has often shown a lack of hybrid differences in response to narrow rows, there is still some perception that hybrids respond differently.
- Benefits from narrow rows would need to offset higher costs for planters and corn heads; higher starter fertilizer cost; and greater risk of damage during postemergence herbicide applications to be economically viable.

OBJECTIVES

- Research was conducted by Dr. Peter Thomison and Dr. Alex Lindsey at Ohio State University as a part of the Pioneer Crop Management Research Awards (CMRA) program to evaluate:
  - Yield response of four Pioneer® brand corn products (two early maturity and two late maturity) to row spacing in two environments with low and high yield potential.
  - The impact of row spacing on dry matter yield, harvest index, and yield components of Pioneer brand corn products.

STUDY DESCRIPTION

- **Years:** 2016-2018
- **Locations:**
  - South Charleston OSU Research Farm (high yield potential)
  - Hoytville OSU Research Farm (lower yield potential)
- **Planting Dates:**
  - 2016: South Charleston – May 24, Hoytville – May 20
  - 2017: South Charleston – June 2, Hoytville – May 26
  - 2018: South Charleston – May 9, Hoytville – May 11
- **Plant Population:**
  - South Charleston – 40,000 plants/acre (2016), 42,000 plants/acre (2017, 2018)
  - Hoytville – 36,000 plants/acre (2016-2018)
- **Experimental Design:** Split-plot randomized complete block design with four replications
- **Row Spacing (Whole-Plot Factor):**
  - 15 inches (38 cm)
  - 30 inches (76 cm)
- **Hybrid/Brand[2] (Subplot factor):**
  - Early Maturity: P0506AM™ (AM, LL, RR2), P0604AM™ (AM, LL, RR2)
  - Late Maturity: P1197AM™ (AM, LL, RR2), P1443AM™ (AM, LL, RR2)

RESULTS

2016

- Corn yield differed among hybrids but not row spacings at South Charleston, and a significant row spacing by hybrid interaction was observed (P = 0.019) at Hoytville (Table 1).
  - Grain yield was significantly lower (P<0.001) for Pioneer® P0604AM™ brand corn (162.5 bu/acre) compared to all other hybrids (228.6 to 236.6 bu/acre) at South Charleston.
  - At Hoytville, yield was greater in 15-inch rows for Pioneer® P1197AM™ brand corn, similar across row spacings for Pioneer® P0604AM™ and P1443AM™ brand corn, and greater in 30-inch rows for Pioneer® P0506AM™ brand corn (Table 1).
  - Yields at the Hoytville location were unusually low and likely impacted by the weather (wet spring followed by a very dry June and July) and nitrogen management regime (broadcast pre-plant unincorporated).

Table 1. Grain yield of each hybrid at Hoytville at each row spacing in 2016. Letters denote differences within a location.

Row Spacing	Hybrid/Brand[2]	Yield
		bu/acre
15-Inch	P0506AM™	72.2 g
	P0604AM™	124.4 c
	P1197AM™	154.3 a
	P1443AM™	108.8 de
30-Inch	P0506AM™	88.2 f
	P0604AM™	119.0 cd
	P1197AM™	139.5 b
	P1443AM™	95.1 ef

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- Plant height and ear height were not influenced by row spacing at either location, but both increased with greater hybrid CRM.
  - » Total dry biomass was affected by hybrid and row spacing at South Charleston but not at Hoytville.
  - » Total dry biomass was greater by 13% in 15-inch rows compared to 30-inch rows at South Charleston.
- Pioneer® P1197AM™ brand corn produced greater biomass than Pioneer® P0506AM and P0604AM™ brand corn. Pioneer® P1443AM™ brand corn produced similar biomass to the other hybrids.
- A significant row spacing by hybrid interaction of magnitude was present for stalk lodging at South Charleston.
  - » Stalk lodging was greater for all hybrids in 30-inch rows (4 to 82%) compared to 15-inch rows (2 to 56%), and lodging of P0604AM™ was greater than other hybrids, regardless of row spacing.
  - » Stalk lodging was not observed at Hoytville.
- Harvest index was similar for all hybrids at each location (South Charleston: 0.57 to 0.58; Hoytville: 0.50 to 0.53).
- Hybrid differences were observed for ear yield components at each location, but few consistent trends were observed. P0604AM™ consistently had lower kernel weights than the other hybrids (Table 2).

Table 2. Kernel numbers and weights at South Charleston and Hoytville in 2016. Letters denote differences within a location.

Location	Hybrid/ Brand[2]	Kernels per Ear	Yield *g/300 kernels*
South Charleston	P0506AM™	460	72.2 g
	P0604AM™	520	124.4 c
	P1197AM™	531	154.3 a
	P1443AM™	509	108.8 de
P-Value		0.094	0.003
Hoytville	P0506AM™	351 ab	88.2 f
	P0604AM™	387 a	119.0 cd
	P1197AM™	404 a	139.5 b
	P1443AM™	315 b	95.1 ef
P-Value		0.032	0.003

2017

- There was no significant effect of row spacing or row spacing by hybrid interaction on yield at either location in 2017 (Table 3).
  - » Corn yield was lower (P<0.02) for P0604AM™ compared to other hybrids at both locations.
- Plant height and ear height were not influenced by row spacing at either location, but across row spacings, both heights were greatest for P1443AM™ and least for P0604AM™.
- Total biomass was unaffected by row spacing, and no differences were recorded by hybrid aside from P0506AM™ producing less biomass than the other hybrids at Hoytville.
- Harvest index was similar for all hybrids at each location (South Charleston: 0.54 to 0.57; Hoytville: 0.56 to 0.58).
- Hybrid differences were observed for ear yield components at each location but were not consistent between locations and were dissimilar to results from 2016 (Table 4).

Table 3. Corn yield by hybrid and row spacing at each location in 2017. Letters denote differences within a location.

Row Spacing	Hybrid/ Brand[2]	Hoytville	South Charleston
		bu/acre	
15-Inch	P0506AM™	201.1 a	205.6 a
	P0604AM™	180.1 b	169.1 b
	P1197AM™	195.7 a	191.6 a
	P1443AM™	186.5 a	193.0 a
30-Inch	P0506AM™	183.2 a	210.5 a
	P0604AM™	170.2 b	174.3 b
	P1197AM™	182.1 a	203.9 a
	P1443AM™	193.8 a	195.5 a

Table 4. Kernel numbers and weights at South Charleston and Hoytville in 2017. Letters denote differences within a location.

Location	Hybrid/ Brand[2]	Kernels per Ear	Yield *g/300 kernels*
South Charleston	P0506AM™	476	82.3 a
	P0604AM™	433	68.0 c
	P1197AM™	424	74.0 bc
	P1443AM™	454	76.3 ab
P-Value		0.350	0.003
Hoytville	P0506AM™	461 c	82.2 b
	P0604AM™	505 bc	80.8 b
	P1197AM™	533 b	90.6 a
	P1443AM™	596 a	80.5 b
P-Value		0.001	0.027

2018

- There was no significant effect of row spacing or row spacing by hybrid interaction on yield at either location in 2018 (Table 5).
  - » Corn yield was lower (P<0.02) for P0604AM™ compared to other hybrids at both locations.

Table 5. Corn yield by hybrid and row spacing at each location in 2018. Letters denote differences within a location.

Row Spacing	Hybrid/ Brand[2]	Hoytville	South Charleston
		bu/acre	
15-inch	P0506AM™	228.7 a	270.0 a
	P0604AM™	215.8 b	267.1 b
	P1197AM™	230.9 a	301.2 a
	P1443AM™	230.9 a	281.5 a
30-inch	P0506AM™	223.4 a	272.8 a
	P0604AM™	212.6 b	261.4 b
	P1197AM™	225.2 a	282.3 a
	P1443AM™	213.5 a	275.0 a

- Plant height was not influenced by row spacing at either location, but across row spacings, plant height was greatest for P1443AM™.
- Ear height was greater in 15-in rows compared to 30-in rows at Hoytville (50.3 inches vs. 46.3 inches, respectively) but was unaffected in South Charleston.
- Harvest index was similar for all hybrids at each location (South Charleston: 0.56 to 0.57; Hoytville: 0.56 to 0.58).

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- Total dry biomass per plant was also unaffected by row spacing with differences in hybrids evident at each location. In general, total biomass per plant increased with greater CRM.
- Stalk lodging was less than 2.5% for all plots.
- Hybrid differences were observed for ear yield components at each location (Table 6) but differed from results from 2016 and 2017. Pioneer® P0604AM™ brand corn had more kernels per ear, but the lower kernel weight may have contributed to the lower yield noted in Table 5.

Table 6. Kernel numbers and weights at South Charleston and Hoytville in 2018. Letters denote differences within a location.

Location	Hybrid/ Brand[2]	Kernels per Ear	Yield *g/300 kernels*
South Charleston	P0506AM™	410 c	101.0 a
	P0604AM™	507 a	85.8 b
	P1197AM™	450 bc	102.6 a
	P1443AM™	470 ab	103.3 a
P-Value		0.013	<0.001
Hoytville	P0506AM™	473 b	109.5 a
	P0604AM™	560 a	92.5 b
	P1197AM™	516 ab	105.7 a
	P1443AM™	557 a	108.0 a
P-Value		0.006	<0.001

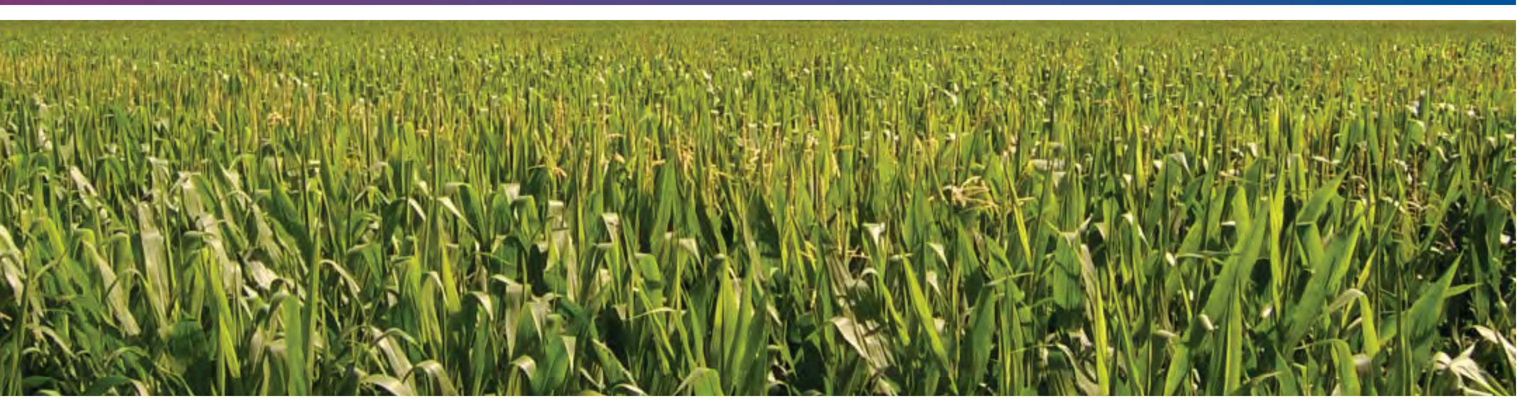
Table 7. Summary of significant main effects (hybrid, row spacing) and interactions (hybrid x row spacing) at South Charleston and Hoytville, 2016-2018.

	2016			2017			2018		
Variable	Hyb	RS	HxR	Hyb	RS	HxR	Hyb	RS	HxR
Yield	S		H	SH			SH		
Plant Height	SH			SH			SH		
Ear Height	SH			SH				H	
Biomass	S	S		H			SH		
Harvest Index									
Stalk Lodging			S						
Kernels/Ear	H			H			SH		
Kernel Weight	SH			SH			SH		

S = Significant effect at South Charleston
H = Significant effect at Hoytville
Hyb = Hybrid
RS = Row spacing
HxR = Hybrid x row spacing interaction

SUMMARY

- In most instances, row spacing had a limited effect on measured parameters. Plant height, harvest index, kernels per ear, and kernel weight were not influenced by row spacing at either location in any of the three years of the study (Table 7).
- Out of six total site-years, there was a significant hybrid by row spacing interaction in only one, and no significant row spacing effect in the other five site-years (Table 7).
- In the one site-year with a significant hybrid by row spacing interaction, one hybrid yielded more in 15-inch row, one yielded more in 30-inch rows, and the other two showed no difference.
- These results are similar to those observed in previous row spacing studies, which have generally found that hybrid performance differences by row spacing tend to be small and inconsistent.
- P0604AM™ tended to have lower kernel weight and yield than the other hybrids in the study.
- Plant height tended to increase with greater hybrid CRM with Pioneer® P1443AM™ brand corn usually being the tallest.
- Kernels/ear and kernel weight frequently differed among hybrids, but most of these differences were inconsistent across locations and years.



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Corn Growth and Yield Response to Row Spacing and Population in Ohio

Alex Lindsey, Ph.D., *and* ***Peter Thomison, Ph.D,*** *Department of Horticulture and Crop Science, Ohio State University, and* ***Kirk Reese, M.S.,*** *Former Agronomy Manager*

BACKGROUND AND RATIONALE

- Corn grain yield response to narrow rows (<30 inches, <76 cm) has been inconsistent in both university and Pioneer research. Responses have been slightly more positive in northern Corn Belt environments, averaging about 2.7 to 2.8% compared to central Corn Belt environments where responses have been negligible (Jeschke, 2018).
- Despite the lack of consistent yield benefit, interest in narrow-row corn continues in the popular press (Swoboda, 2013) and among corn growers. Factors driving interest may include:
  - » Silage production where yield improvements with narrow rows have been fairly well-documented.
  - » Lower yielding environments where leaf area development could be limited by drought stress during the vegetative stages of growth
- There is also a perception that higher plant populations are necessary to maximize the benefit of narrow rows.
- Benefits from narrow rows would need to offset higher costs for planters and corn heads; higher starter fertilizer cost; and greater risk of damage during postemergence herbicide applications to be economically viable.

OBJECTIVES

- Research was conducted by Dr. Peter Thomison and Dr. Alex Lindsey at Ohio State University as a part of the Pioneer Crop Management Research Awards (CMRA) program to evaluate:
  - » Corn population response in narrow (15 inch) and standard (30 inch) rows in low and high yield potential environments.
  - » The impact of row spacing on dry matter yield, harvest index, and yield components of corn at multiple plant populations.
  - » The potential for narrow rows to decrease the impact of lodging at higher plant populations.

STUDY DESCRIPTION

- **Years:** 2016-2018
- **Locations:**
  - » South Charleston OSU Research Farm (high yield potential)
  - » Hoytville OSU Research Farm (lower yield potential)
- **Planting Dates:**
  - » 2016: South Charleston – May 24, Hoytville – May 20
  - » 2017: South Charleston – June 2, Hoytville – May 18
  - » 2018: South Charleston – May 9, Hoytville – May 9
- **Hybrid/Brand[2]:** P0506AM™ (AM, LL, RR2)
- **Experimental Design:** Split-plot randomized complete block design with six replications
- **Row Spacing (Whole-Plot Factor):**
  - » 15 inches (38 cm)
  - » 30 inches (76 cm)
- **Population (Subplot Factor):**
  - » 35,000 plants/acre
  - » 40,000 plants/acre
  - » 45,000 plants/acre

RESULTS

2016

- There was a significant interaction of row spacing and population on yield at South Charleston (P<0.001; Figure 1).
- Yield was maximized at 40,000 plants/acre in 30-inch rows but at 45,000 plants/acre in 15-inch rows.
- Maximum yield was similar regardless of row spacing (~250 bu/acre).
- Neither population nor row spacing significantly affected yield at Hoytville (P=0.125; Figure 1).

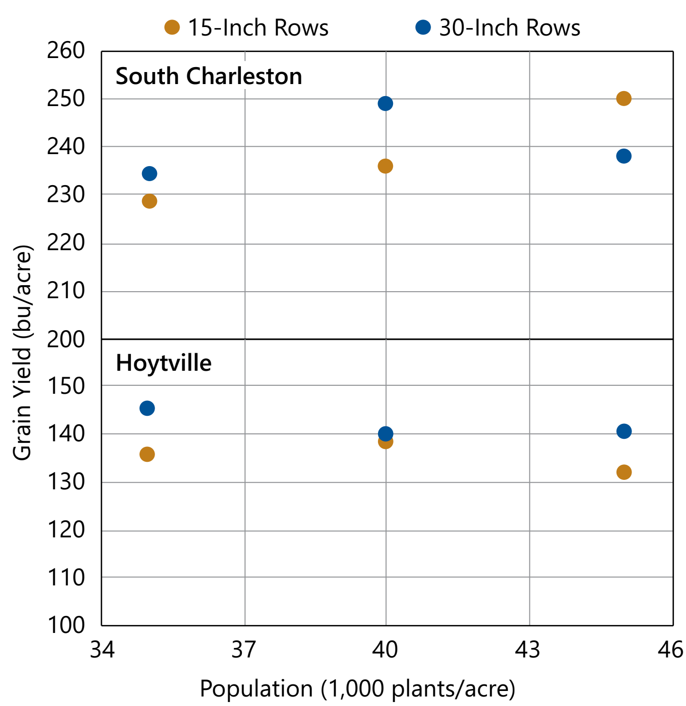

Figure 1. Corn yield response to population and row spacing in 2016.

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   - At Hoytville, grain yield ranged from 132 to 145 bu/acre and may have been limited by N availability due to application method and weather (wet spring, dry June and July).
- Plant height and total biomass were not influenced by row spacing at either site but decreased with increasing population.
- Ear heights were consistent regardless of site, row spacing, and population.
- Stalk lodging was not evident at Hoytville and was less than 2% at South Charleston for all treatments.
- Harvest index for all treatments was similar regardless of site, row spacing, and population (South Charleston: 0.54; Hoytville: 0.50 to 0.52).
- Row spacing did not influence kernel number per ear at either site, but increasing population decreased kernels per ear at both sites by 13-16%.
- A row spacing by population interaction was evident for kernel weight at South Charleston, but no significant effects were observed at Hoytville (Table 1).

Table 1. Kernel weight at South Charleston and Hoytville at each row spacing and population in 2016. Letters denote differences within a location.

Row Spacing	Population	South Charleston	Hoytville
	plants/acre	*— g/300 kernels —*	
15-Inch	35,000	96.3 a	96.0
	40,000	98.9 a	95.8
	45,000	87.3 b	94.7
30-Inch	35,000	98.4 a	99.1
	40,000	90.1 b	95.3
	45,000	90.5 b	97.0

2017

- There was a significant population effect on yield at South Charleston in 2017 but no row spacing effect (P<0.017; Figure 2).
   - Yield was maximized at 40,000 plants/acre.
   - Maximum yields were similar regardless of row spacing (~215 bu/acre).
- No significant population or row spacing effects on yield were evident at Hoytville (P=0.125; Figure 2).
- Plant biomass was unaffected by population and row spacing with average values of 9.3 to 9.8 ton/acre at Hoytville and 9.8 to 10.1 ton/acre at South Charleston.
- Plant height did not change with treatments at either site.
- Ear heights were unaffected by row spacing and decreased slightly with increasing population only at South Charleston (48.3 to 46.2 inches as population increased).
- Harvest index for all treatments was similar regardless of site, row spacing, and population (South Charleston: 0.55 to 0.57; Hoytville: 0.57 to 0.58).
- Row spacing did not influence kernel number per ear at either site, but increasing population decreased kernels per ear at both sites by ~15%.
- A row spacing by population interaction was evident for kernel weight at South Charleston, but no significant effects were observed at Hoytville (Table 2).

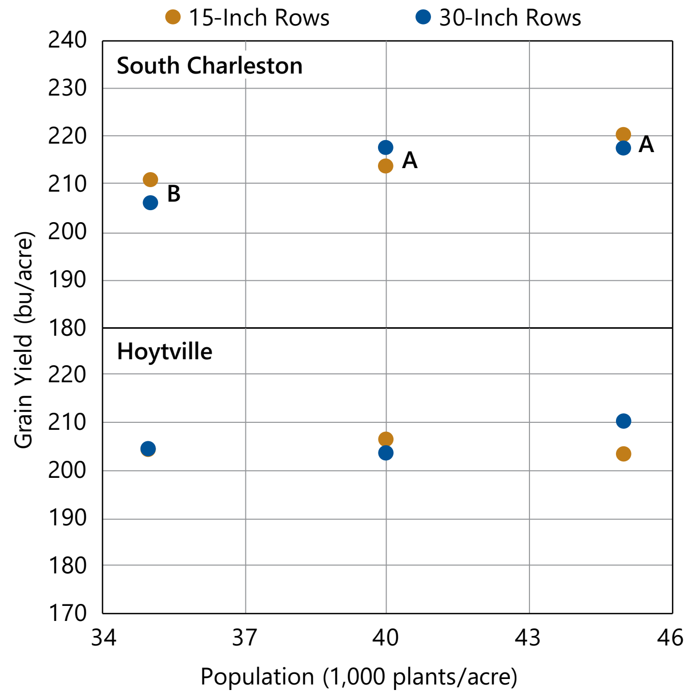


Figure 2. Corn yield response to population and row spacing in 2017.

Table 2. Kernel weight at South Charleston and Hoytville at each row spacing and population in 2017. Letters denote differences within a location.

Row Spacing	Population	South Charleston	Hoytville
	plants/acre	*— g/300 kernels —*	
15-Inch	35,000	90.2 a	90.2
	40,000	82.9 bc	83.6
	45,000	79.4 c	82.3
30-Inch	35,000	84.9 b	87.6
	40,000	84.2 b	87.2
	45,000	80.8 bc	85.5

2018

- There was a significant population effect on yield at South Charleston in 2018 but no row spacing effect (P=0.087; Figure 3).
   - Yield was maximized at 45,000 plants/acre, but yield at 40,000 plants/acre was similar statistically.
- Corn yield was significantly influenced by both population (P=0.007) and row spacing (P=0.024) at Hoytville in 2018.
   - Corn yield was optimized in each row spacing at 40,000 plants/acre.
   - Yields in 15-in rows averaged 4.8 bu/acre more than yield in 30-in rows across all populations.
- Plant biomass was not influenced by row spacing but decreased with increasing populations at both sites.
- Plant height did not change with treatments at either site.
- Ear height was greater in 15-inch rows at Hoytville (50.8 inches vs. 47.5 inches) but was not affected at South Charleston.
- Harvest index for all treatments was similar regardless of site, row spacing, or population (South Charleston: 0.56 to 0.58; Hoytville: 0.55 to 0.59).

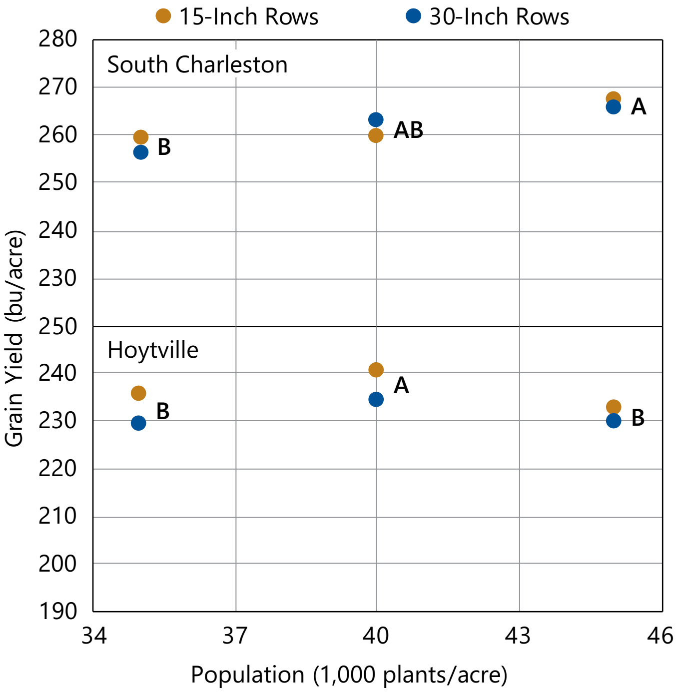


Figure 3. Corn yield response to population and row spacing in 2018.

- Row spacing did not influence kernel number per ear at either site, but increasing population decreased kernels per ear by 10 to 40%.
- Kernel weight decreased with higher population at Hoytville but was not affected by population or row spacing at South Charleston (Table 3).

Table 3. Kernel weight at South Charleston and Hoytville at each population in 2018. Letters denote differences within a location.

Population	South Charleston	Hoytville
plants/acre	*— g/300 kernels —*	
35,000	106.7	112.3 a
40,000	104.1	106.9 b
45,000	101.9	106.1 b

SUMMARY

- In most instances, row spacing had a limited effect on measured parameters.
- Out of six total site-years, yield was significantly affected by row spacing in one site-year and by population by row spacing interaction in one site-year with no significant row spacing effect in four site-years (Table 4).
- Population and row spacing had no effect on harvest index or stalk lodging in this study.
- The most consistent effect was of population on kernel number per ear, in which kernel number significantly declined with higher population in all site-years.
- Results of this study are not indicative of a consistent advantage of 15-inch rows over 30-inch rows or that narrower rows necessarily require higher populations to maximize yield.

Table 4. Summary of significant main effects (population, row spacing) and interactions (population x row spacing) at South Charleston and Hoytville, 2016-2018.

	2016			2017			2018		
Variable	Hyb	RS	HxR	Hyb	RS	HxR	Hyb	RS	HxR
Yield			**S**	**S**			**SH**	**H**	
Plant Height	**SH**								
Ear Height				**S**				**H**	
Biomass	**SH**						**SH**		
Harvest Index									
Stalk Lodging									
Kernels/Ear	**SH**			**SH**			**SH**		
Kernel Weight			**S**				**H**		

S = Significant effect at South Charleston
H = Significant effect at Hoytville

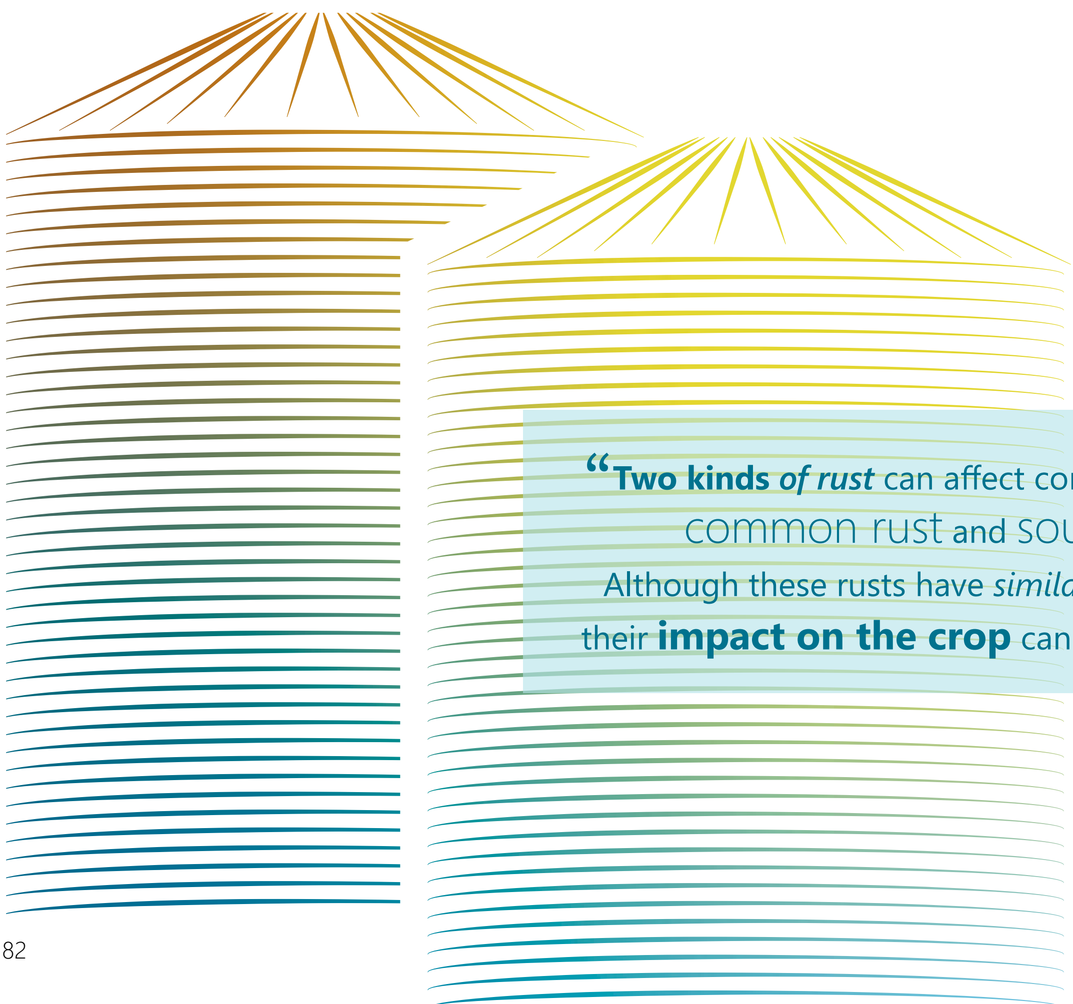
Hyb = Hybrid
RS = Row spacing
HxR = Hybrid x row spacing interaction

Common and Southern Rust in Corn

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

SUMMARY

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



"**Two kinds *of rust*** can affect corn in North America – common rust and southern rust. Although these rusts have *similar life cycles* on corn, their **impact on the crop** can be *very different.*"

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.

COMMON RUST DISEASE CYCLE

(Puccina Sorghi)

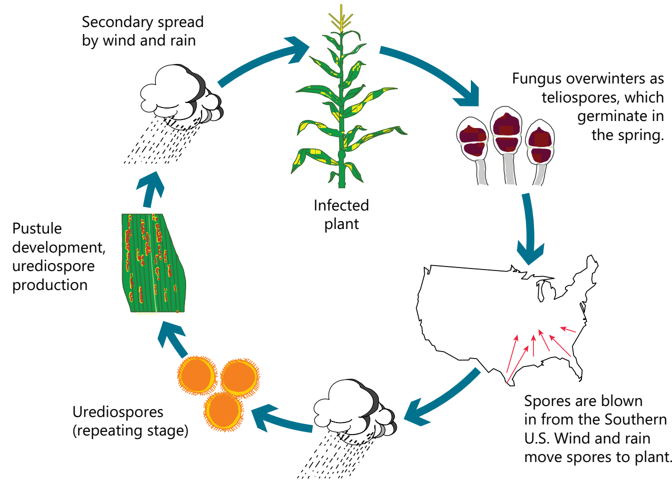


Figure 2. Common rust disease cycle.

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.

> "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."

Figure 3. Common rust pustules on a corn leaf.

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).

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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.

"Southern rust (also known as Polysora rust) is favored by high relative humidity and high temperatures."

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)

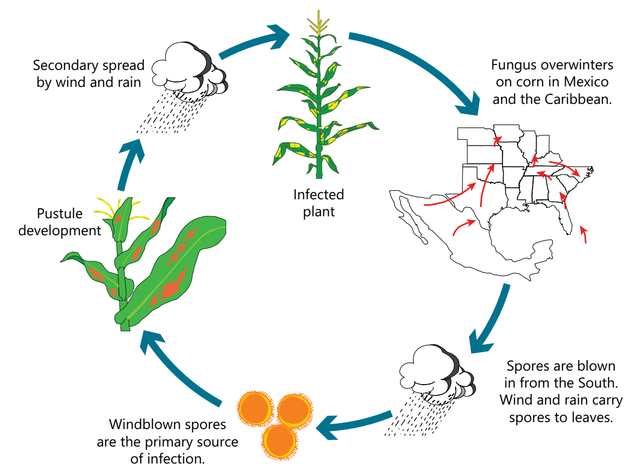

Figure 4. Southern rust disease cycle.

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 6), while those of common rust have an elongated, jagged appearance.

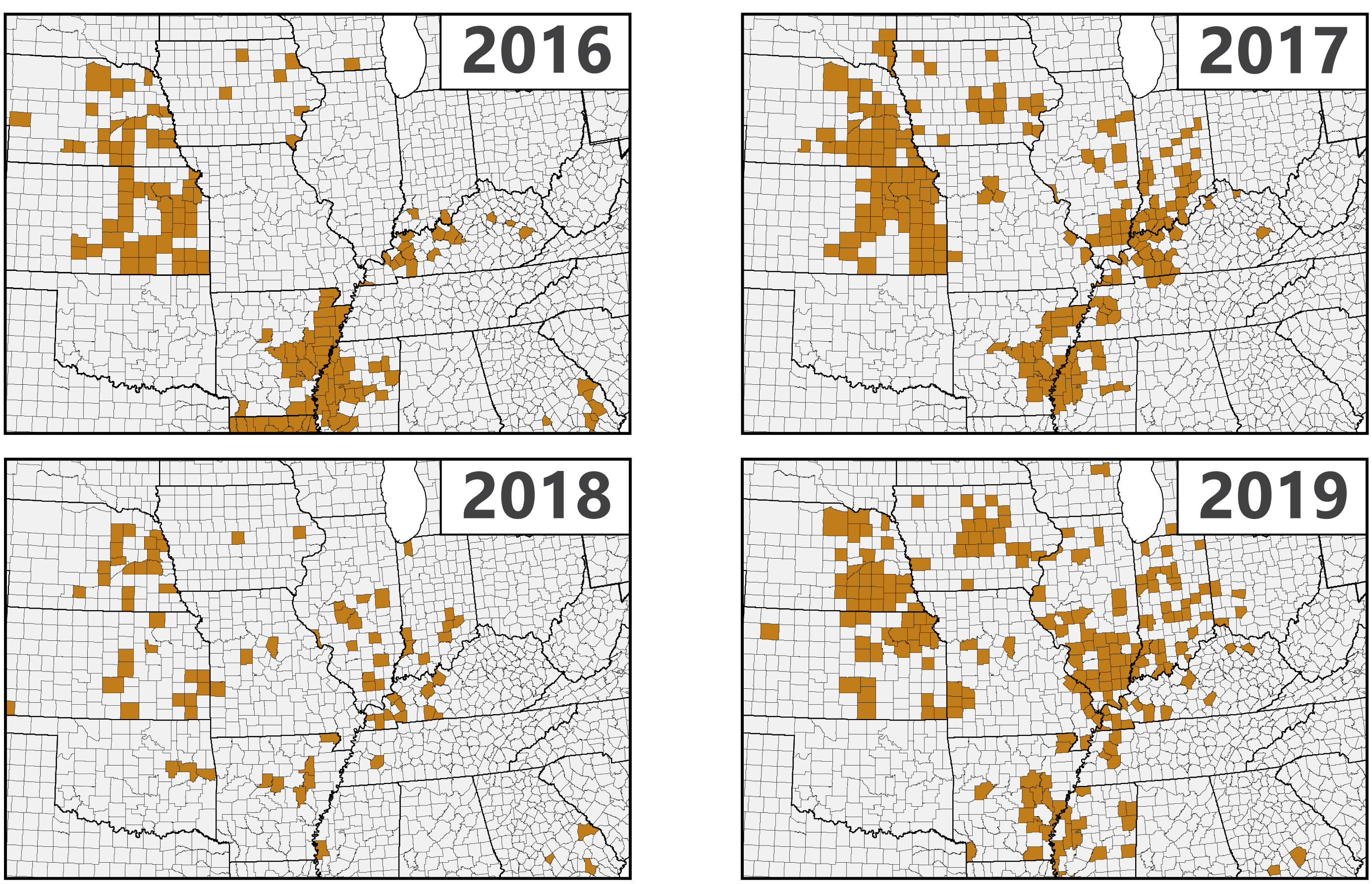

Figure 5. Confirmed detections of southern rust in corn through the first week of September during the 2016 to 2019 growing seasons.
Source: http://www.ipipe.org.

Figure 6. Southern rust pustules on a corn leaf.

Photo courtesy of Eric Alinger, Field Agronomist

Expanded Range of Southern Rust in Recent Years

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

Table 1. Distinguishing characteristics of common 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). 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).

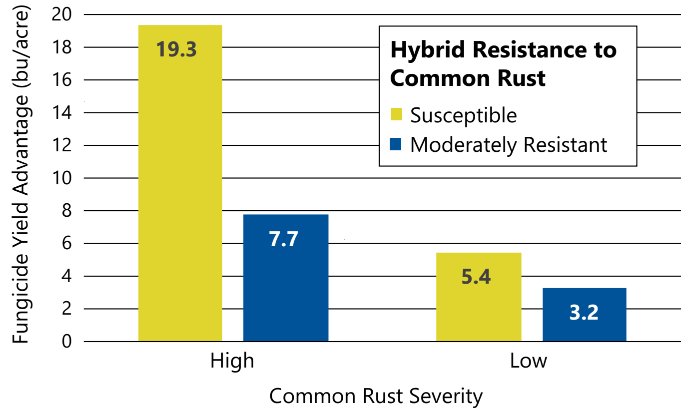

Figure 7. Average fungicide yield response of hybrids with low resistance (3 on a 1-9 scale) and moderate resistance (4-6) to common rust in Pioneer research trials in 2009.

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 Pioneer research location in Illinois in 2009.

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

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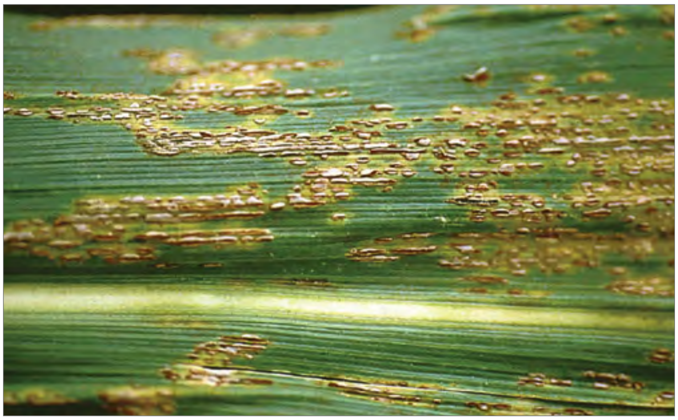

Figure 10. Typical symptoms of common rust (top) and southern rust (bottom) on corn leaf.

"Southern rust is generally more damaging to corn than common rust due to its ability to rapidly develop and spread under favorable conditions."

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

SCOUTING AND TREATMENT GUIDELINES

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

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

FUNGICIDE APPLICATION

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

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

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

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

Getting the application on early enough and achieving good coverage of the upper leaf canopy are essential for control of rust with fungicides. For aerial applications, a minimum of five gallons/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
- 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 (Figure 11). If lodging occurs, harvest losses may result.

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

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.

SILAGE FROM RUST-INFECTED CORN

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

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

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

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

Goss's Wilt Management in Corn

Steve Butzen, M.S., *Agronomy Consultant,* ***Madeline Henrickson,*** *Agronomy Intern, and* ***Mark Jeschke, Ph.D.,*** *Agronomy Manager*

SUMMARY

- Goss's wilt, a bacterial disease of corn historically confined to the Great Plains, has now spread to several states in the Midwest.
- The Goss's wilt pathogen enters the corn plant through wounds from rain, wind, and hail. It has a systemic wilt phase as well as a more common and damaging leaf blight phase.
- Goss's wilt's impact on the crop generally depends on the amount of leaf area lost during the grain-fill period. Yield losses up to 50% have been reported.
- No rescue measures are available to control Goss's wilt as fungicides are ineffective against bacterial diseases.
- Farmer can reduce the risk of yield loss from Goss's wilt by using resistant hybrids as well as reducing corn residue through crop rotation and tillage.
- Pioneer® brand hybrids with good to excellent resistance to Goss's wilt are available in a wide range of maturities suitable to at-risk areas.

"*The sudden spread of* Goss's wilt *across* primary corn-growing states places it among the major corn diseases capable of causing ***leaf loss***, ***lower stalk quality***, and ***reduced yields*** in corn."

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INTRODUCTION

Goss's wilt (*Clavibacter michiganensis* subsp. *nebraskensis*) is a bacterial disease that may cause systemic infection and wilting of corn plants as well as severe leaf blighting. The leaf blight phase is generally more prevalent and more damaging to the corn crop.

The leaf blight phase of Goss's wilt can cause significant loss of functional leaf area in corn fields.

Until recently, significant Goss's wilt damage was largely confined to corn fields in Nebraska and parts of Colorado, Kansas, and South Dakota. In the last decade, however, significant damage has been reported in Iowa, Missouri, Illinois, Indiana, Minnesota, North Dakota, Wisconsin, and even western Canada (Figure 1). Higher levels of corn residue from corn-after-corn production and reduced tillage are likely contributing factors in the spread of this disease. The increased prevalence of intense summer storms throughout much of the Midwest and Great Plains may also play a role. Wounds in plant tissue caused by hail, wind, and rainstorms can create an entry point for bacteria.

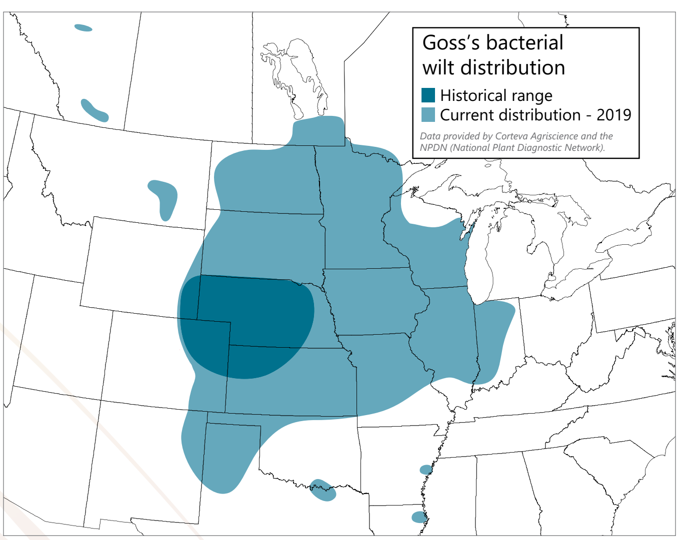

Figure 1. Historical and current distribution of Goss's wilt in North America.

The sudden spread of Goss's wilt across primary corn-growing states places it among the major corn diseases capable of causing leaf loss, lower stalk quality, and reduced yields in corn. Yield losses up to 50% have been reported (Harveson, 2011). Consequently, farmers should learn to recognize and manage this disease to help protect future corn yields and profits. This article discusses development, symptoms, and management of Goss's wilt of corn.

DISEASE DEVELOPMENT

Goss's wilt overwinters in infected corn residue and that of other host plants, including green foxtail, barnyardgrass, and shattercane. Bacteria are transferred from infected residue to growing plants via rain splash, although Goss's wilt can also survive in irrigation water during the growing season. Once on the plant, bacteria invade plant tissue through wounds caused by hail, heavy rain, wind, or mechanical damage (Figure 2). Plants may be infected at any stage of development. Wet weather and high relative humidity favor development of Goss's wilt. Leaf wetness is required for infection to occur, and the bacteria spread most readily in humid weather. However, disease has also been documented spreading during hot and dry conditions.

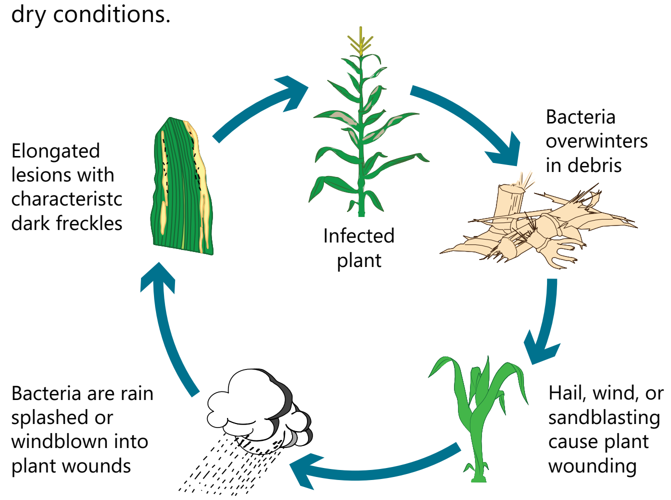

Figure 2. Disease cycle of Goss's wilt in corn.

DISEASE SYMPTOMS

Early leaf symptoms are oblong or elongated lesions of water-soaked, grayish-green tissue that progress to long, dead streaks with wavy, irregular margins (Figure 3). These streaks extend along the leaf veins (Figure 4), which is characteristic of a bacterial infection. One of the most distinctive symptoms of Goss's wilt is dark spots resembling freckles that develop within the streaks. A sticky exudate will form in the streaks, which dries to form a glistening residue within the lesion (Figure 4).

Figure 3. Early Goss's wilt symptoms progressing to long, dead streaks on the leaf.

Figure 4. Characteristic symptoms of Goss's wilt: lesions extend along leaf veins (left); exudate dries leaving a shiny residue on the leaf (right).

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As lesions enlarge and coalesce, they form large areas of necrotic tissue on the leaves, and eventually, entire leaves may wilt and dry up (Figure 5).

Figure 5. Goss's wilt lesions may expand to eventually encompass the entire corn leaf.

Distinguishing Goss's Wilt from Stewart's Wilt

Goss's wilt symptoms can be confused with those of another bacterial disease, Stewart's wilt. Table 1 lists important distinctions between these two diseases.

Table 1. Comparison of Goss's wilt and Stewart's wilt.
Adapted from Jackson et al., 2007.

Symptoms	Goss's Wilt	Stewart's Wilt
Pathogen	*Clavibacter michiganensis* subsp. *nebraskensis*	*Pantoea stewartii*
Infection of Corn	Plant injury	Flea beetle feeding
Long Irregular Lesions	Yes	Yes
Leaf Freckle Symptoms	Yes	No
Varnish-Like Exudate	Yes	No
Crown Cavity Symptoms	No	Yes
Vascular Discoloration	Orange	Yellow

Laboratory tests can easily distinguish the two diseases from one another, but careful field examination can distinguish them as well. One of the primary clues lies in the cause of plant infection. Development of Goss's wilt is most common after a hailstorm or sandblasting, whereas Stewart's wilt is vectored by flea beetles, so epidemics occur when populations are high. Stewart's wilt is accompanied by obvious flea beetle feeding scars on leaves (Figure 6).

Figure 6. Adult corn flea beetles on a corn leaf. Adults feed by scraping long grooves into the upper leaf surface, causing leaf tip die back. Flea beetles vector Stewart's wilt disease.

Figure 7. Stewart's bacterial wilt on corn leaves as shown by elongated brown lesions.

Distinguishing Goss's Wilt from Bacterial Stalk Rot

Figure 8. Corn stalk cross section showing discolored vascular tissue due to Goss's wilt infection. *Photo courtesy of T. Jackson, Univ. of Nebraska-Lincoln.*

Plants may also be infected systemically by Goss's wilt, especially in the seedling stage. These plants have discolored vascular tissue with a slimy bacterial exudate in the stalk (Figure 8). Plants are commonly stunted, and wilt, and die as if drought stressed. Bacterial stalk rot is a different disease caused by multiple species in the genus Erwinia. It often occurs in the same field as Goss's wilt, and can sometimes be confused with systemic Goss's infection. Bacterial rot can affect the plant at any node and can spread to additional nodes after infection. The initial symptoms of bacterial stalk rot are leaf sheath and stalk discoloration at a single node. Stalk splitting will reveal soft, slimy rot and internal discoloration. A foul odor is associated with advanced stages of bacterial stalk rot. Infection usually results in the collapse of the top portion of the plant and the loss of any yield potential for individually infected plants. Bacterial stalk rot is most commonly associated with irrigation using contaminated surface water from ponds, lakes, or slow-moving streams.

CROP IMPACTS OF GOSS'S WILT

Goss's wilt may reduce corn plant stands and vigor; stalk and grain quality; and yield. During the systemic infection phase, Goss's wilt may reduce plant stands and weaken surviving plants, both of which are associated with reduced yield. However, in most cases, yield loss is mainly due to the leaf blight phase of the disease when reduction in green leaf area and premature death of plants may occur (Figure 9).

Timing of leaf blight infection has a critical role in Goss's wilt yield reductions. Early infections lead to the greatest yield loss, whereas late infections often have little yield influence. Yield reductions of 50% have been documented when susceptible hybrids were infected early in the growing season. Other agronomic issues, such as stalk lodging, may result from fields that have leaf area loss from Goss's wilt. This can result in further reductions in yield if harvest losses occur and reductions in grain quality if ears contact the ground.

Figure 9. Field showing severe symptoms of Goss's wilt: loss of most green leaf area and premature death of some plants.

Figure 11. Aerial photograph of a field in Nebraska with high Goss's wilt pressure. Note differences in hybrid resistance as indicated by brown vs. green coloration.

DISEASE MANAGEMENT

No rescue measures are available to control Goss's wilt, so preventing or avoiding infection is crucial. In fields where the disease is already present, growers can minimize damage by reducing corn residue and using resistant hybrids.

Prevention/Avoidance

Goss's wilt may be transmitted from field to field by equipment and weather that moves infected residue. Harvest and tillage equipment, balers, and wind can all transfer infected residue and soil to previously uninfected fields. To help avoid spreading the pathogen in this way, harvest and till infected fields last plus clean equipment of crop residue.

Reducing Corn Residue and Alternate Hosts

Crop rotation and tillage, when practical, can be used to reduce the amount of corn residue remaining on the soil surface. This makes the environment less favorable for bacteria survival. Crop rotation to a non-host crop, such as soybeans, dry beans, or alfalfa, allows for an additional year of corn residue decomposition between corn crops. Deep tillage is especially effective at incorporating and burying infected residue. Although these practices reduce disease occurrence, they do not prevent it altogether. Goss's wilt has been reported to occur on fields that are first-year corn and in fields that were plowed.

> "No rescue measures are available to control Goss's wilt, so ***preventing or avoiding infection is* crucial.**"

Grassy weeds that are alternate hosts for the bacteria should also be controlled to help minimize disease inoculum. Susceptible grasses include green foxtail, barnyardgrass, and shattercane.

Resistant Hybrids

Because useful levels of resistance to Goss's wilt have been identified in certain parent lines and hybrids, hybrid resistance is the primary method for management of this disease. Pioneer® brand hybrids are rated for resistance relative to known susceptible and resistant hybrids using a 1 to 9 rating system (1 = susceptible, 9 = highly resistant). These scores are made available to customers to aid in selection of hybrids with appropriate levels of resistance for each field. Your local Pioneer sales professional can assist in identifying hybrids with Goss's wilt resistance and other traits needed for optimum production potential on your fields.

Corteva Agriscience researchers screen commercial and potential new hybrids for resistance to Goss's wilt at sites with reliable annual disease pressure (Figure 10). In addition to screening under naturally occurring infections, researchers also inoculate parent lines and hybrids with Goss's wilt bacteria plus evaluate for disease symptoms. On-farm strip trials provide an additional resource for data collection if the disease occurs.

Figure 10. Aerial photograph of Pioneer IMPACT™ hybrid advancement plot with high Goss's wilt pressure. Note differences in hybrid resistance as indicated by brown vs. green coloration.

Fungicides NOT Effective

Goss's wilt is caused by a bacterium, not a fungus. That is why foliar fungicides commonly used to control corn leaf diseases resulting from fungal pathogens are NOT effective against the Goss's wilt pathogen. No chemical control measures are currently available with proven efficacy against this disease.

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Tar Spot in Corn in the Midwestern U.S.

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

SUMMARY

- Tar spot *(Phyllachora maydis)* is a relatively new disease of corn in the U.S., first appearing in Illinois and Indiana in 2015 and subsequently spreading to neighboring states.
- In 2018, tar spot established itself as an economic concern for corn production in the Midwest, with severe outbreaks affecting corn yield reported in several states.
- Tar spot gets its name from the fungal fruiting bodies it produces on corn leaves that look like spots of tar, developing black oval or circular lesions on the corn leaf.
- Tar spot is favored by cool temperatures (60to 70 °F, 16 to 20 °C), high relative humidity (>75%), frequent cloudy days, and 7+ hours of dew at night.
- Tar spot can rapidly spread through the corn canopy under favorable conditions, causing premature leaf senescence.
- Commercial corn hybrids vary widely in their susceptibility to tar spot. Hybrid selection should be a primary consideration in managing for tar spot.
- Fungicide treatments have shown some effectiveness in reducing tar spot symptoms; however, specific management recommendations for fungicides are still being developed.

"**Tar spot** in corn is caused by the fungus ***Phyllachora maydis,*** which was first observed in high valleys in Mexico."

INTRODUCTION

Tar spot is a foliar disease of corn that has recently emerged as an economic concern for corn production in the Midwestern U.S. It is not a new disease, having been first identified in 1904 in high valleys in Mexico. Historically, tar spot's range was limited to high elevations in cool, humid areas in Latin America, but it has now spread to South American tropics and parts of North America. It first appeared in the U.S. in 2015. During the first few years of its presence in the U.S., tar spot appeared to be a minor cosmetic disease that was not likely to affect corn yield. However, widespread outbreaks of severe tar spot in multiple states in 2018 proved that it has the potential to cause a significant economic impact.

With its very limited history in the U.S., much remains to be learned about the long-term economic importance of this disease and best management practices. This article discusses tar spot's appearance and spread in the U.S.; the epidemiology of the tar spot pathogen; identification and symptoms of the disease; and management considerations.

TAR SPOT OCCURRENCE IN THE U.S.

Tar spot in corn is caused by the fungus *Phyllachora maydis*, which was first observed in high valleys in Mexico. Historically, *P. maydis* was not typically associated with yield loss unless a second pathogen, *Monographella maydis*, was also present, the combination of which is referred to as tar spot complex. In Mexico, the complex of *P. maydis* and *M. maydis* has been associated with yield losses of up to 30% (Hock et al., 1995). In some cases, a third pathogen, *Coniothyrium phyllachorae*, has been associated with the complex. Only *P. maydis* is known to be present in the United States but it has proven capable of causing significant yield losses even without the presence of the second pathogen.

The first confirmations of tar spot in the U.S. were in Illinois and Indiana in 2015 (Bissonnette, 2015; Ruhl et al., 2016). It has subsequently spread to Michigan, Wisconsin, Iowa, Ohio, and Minnesota. Its presence was also confirmed in Florida in 2016 (Miller, 2016). Tar spot reappeared in 2016 and 2017 but remained a relatively minor cosmetic disease of little concern.

> "**Growers** in areas ***severely impacted by tar spot*** anecdotally reported yield reductions of **30-50%** *compared to 2016 and 2017 yield levels.*"

2018 Outbreak

In 2018, tar spot established itself as an economic concern for corn production in the Midwest, with severe outbreaks reported in Illinois, Indiana, Wisconsin, Iowa, Ohio, and Michigan. Significant corn yield losses associated with tar spot were reported in some areas. University corn hybrid trials conducted in 2018 suggested potential yield losses of up to 39 bu/acre under the most severe infestations (Telenko et al., 2019). Growers in areas severely impacted by tar spot anecdotally reported yield reductions of 30 to 50% compared to 2016 and 2017 yield levels. Yield losses specifically attributable to tar spot were often difficult to determine, however, because of the presence of other corn diseases due to conditions generally favorable for disease development. Instances of greatest tar spot severity in 2018 were largely concentrated in northern Illinois and southern Wisconsin where other foliar diseases and stalk rots were also prevalent.

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

2019 Observations

In 2019, tar spot severity was generally lower across much of the Corn Belt and appeared later and more slowly compared to 2018, although severe infestations were still observed at some locations. There is no clear explanation for why tar spot severity was lower in 2019 in areas where it was severe in 2018. Less favorable conditions for disease development during the latter part of the growing season in 2019 may have played a role. Reduced winter survival may have been a factor as well. Winter temperatures in some tar spot-affected areas oscillated between warm periods and extreme cold, which may have affected fungal dormancy and survival (Kleczewski, 2019).

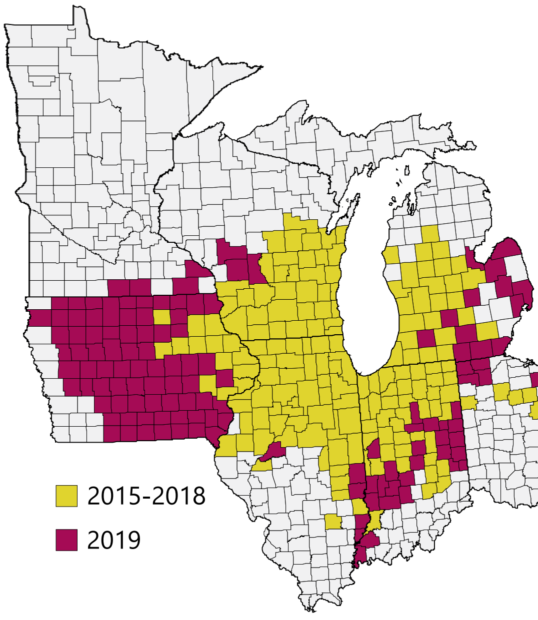

Figure 1. Counties with confirmed incidence of tar spot prior to 2019 and new confirmations during 2019 (as of 10-21-19) showing the expanding range of disease incidence (Corn ipmPIPE, 2019; Pioneer agronomist observations).

Despite the generally lower disease severity, tar spot continued to expand its geographic range in 2019. In Iowa, tar spot presence was limited to around a dozen eastern counties in 2018 but expanded to cover most of the state in 2019 (Figure 1). Tar spot was confirmed in Minnesota for the first time in September of 2019 (Malvick, 2019). Tar spot spread to the south and east as well with new confirmations in parts of Indiana, Ohio, and Michigan. Tar spot has likely spread into northeast Missouri as well.

IDENTIFICATION AND SYMPTOMS

Tar spot is the physical manifestation of fungal fruiting bodies, the ascomata, developing on the leaf. The ascomata look like spots of tar, developing black oval or circular lesions on the corn leaf (Figure 2). The texture of the leaf becomes bumpy and uneven when the fruiting bodies are present. These black structures can densely cover the leaf and may resemble the pustules of rust fungi (Figure 2 and 3). Tar spot spreads from the lowest leaves to the upper leaves, leaf sheaths, and eventually the husks of the developing ears (Bajet et al., 1994).

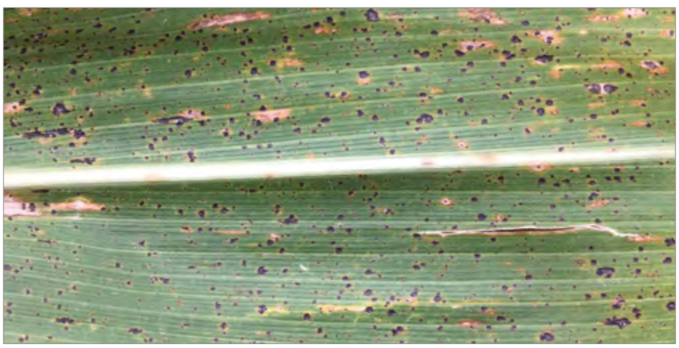

Figure 2. A corn leaf with tar spot symptoms.

Figure 3. Corn leaf under magnification showing dense coverage with tar spot ascomata.

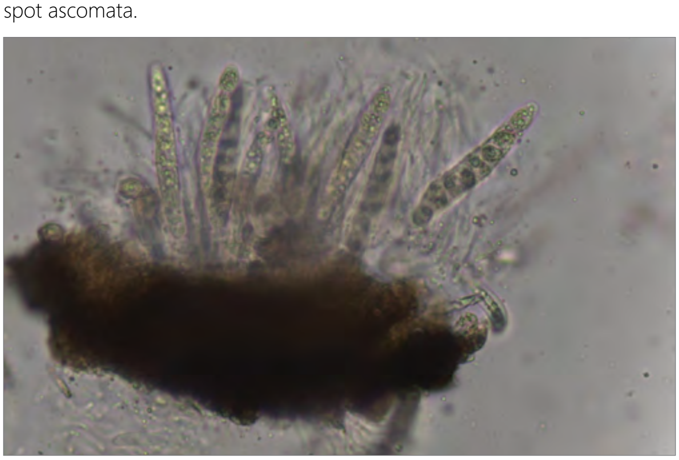

Figure 4. Microscopic view of fungal spores of *P. maydis*.

Under a microscope, *P. maydis* spores can be distinguished by the presence of eight ascospores inside an elongated ascus, resembling a pod containing eight seeds (Figure 4).

Tar Spot Look-A-Likes

Common rust (*Puccinia sorghi*) and southern rust (*Puccinia polysora*) can both be mistaken for tar spot, particularly late in the growing season when pustules on the leaves produce black teliospores (Figure 5a). Rust pustules can be distinguished from tar spot ascomata by their jagged edges caused by the spores breaking through the epidermis of the leaf (Figure 5b). Rust spores can be scraped off the leaf surface with a fingernail, while tar spot cannot. Saprophytic fungi growing on senesced leaf tissue can also be mistaken for tar spot.

Figure 5a. Southern rust in the teliospore stage late in the season, which can resemble tar spot.

Figure 5b. Corn leaf with common rust spores showing jagged edges around the pustules.

Figure 6. Corn leaf with tar spot symptoms.

TAR SPOT ARRIVAL IN THE U.S.

Numerous reports have speculated that *P. maydis* spores may have been carried to the U.S. via air currents associated with a hurricane in 2015, the same mechanism believed to have brought Asian soybean rust (*Phakopsora pachyrhizi*) to the U.S. several years earlier. However, Mottaleb et al. (2018) believe that this scenario is unlikely and that it is more plausible that spores were brought into the U.S. by movement of people and/or plant material. Ascospores of *P. maydis* are not especially aerodynamic and are not evolved to facilitate spread over extremely long distances by air.

Tar spot was observed in corn in Mexico for over a century prior to its arrival in the U.S., during which time numerous hurricanes occurred that could have carried spores into the U.S.

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Chalkley (2010) notes that *P. Maydis* occurs in cooler areas at higher elevations in Mexico, which – coupled with its lack of alternate hosts – would limit its ability to spread across climatic zones dissimilar to its native range. Chalkley also notes the possibility of transporting spores via fresh or dry plant material and that the disease is not known to be seedborne. The risk of importation of the second pathogen of tar spot complex, *M. maydis*, into the U.S. via people and/or materials is believed to be high (Mottaleb et al., 2018).

TAR SPOT EPIDEMIOLOGY

Much is still being learned about the epidemiology of tar spot, even in its native regions and especially in the U.S. *P. maydis* is part of a large genus of fungal species that cause disease in numerous other species; however, *P. maydis* is the only *Phyllachora* species known to infect corn, and it appears to *only* infect corn (Chalkley, 2010).

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

So far, *M. maydis* has not been detected in the U.S. "Fish-eye" lesions, consistent in appearance with those caused by tar spot complex in Mexico, were observed in many Midwestern fields in 2018 and 2019 (Figure 7) (Smith, 2018; personal observation). *M. maydis* was not detected in association with fish-eye symptoms in any of these cases. The cause of the fish-eye symptoms and why they showed up in some fields but not others remains undetermined. Currently, fish-eye symptoms in U.S. corn are believed to be a result of interactions among the host, pathogen, and environment.

Figure 7. Tar spot lesions with necrotic halos resembling the "fish-eye" lesions characteristic of the two-pathogen tar spot complex in Mexico. Fish-eye lesions have been observed in many Midwestern fields even though the second pathogen of the complex has not been detected. *Photo courtesy of Karen Zuver, Field Agronomist.*

MANAGEMENT CONSIDERATIONS

Yield Impact

2018 was the first time that corn yield reductions associated with tar spot were documented in the U.S. University corn hybrid trials conducted in 2018 suggested potential yield losses of up to 39 bu/acre under heavy infestations (Telenko et al., 2019). Pioneer on-farm research trials, along with grower reports, showed yield losses of up to 50% under the most extreme infestations during the 2018 growing season.

Differences in Hybrid Response

Observations in hybrid trials in 2018 showed that hybrids differ in susceptibility to tar spot (Kleczewski and Smith, 2018). Tar spot affects yield by reducing the photosynthetic capacity of leaves and causing rapid premature leaf senescence. Longer maturity hybrids for a given location have been shown to have a greater risk of yield loss from tar spot than shorter maturity hybrids (Telenko et al., 2019). Pioneer agronomists and sales professionals continue to collect data on disease symptoms and hybrid performance in locations where tar spot is present to assist growers with hybrid management. Pioneer hybrid trials have shown differences in canopy staygreen among Pioneer® brand corn products* and competitor products under tar spot disease pressure (Figure 8). Genetic resistance to tar spot should be the number one consideration when seeking to manage this disease as it appears to have a greater impact on symptoms and yield loss than either cultural or chemical management practices.

Severe tar spot infestations have been associated with reduced stalk quality (Figure 9). If foliar symptoms are present, stalk quality should be monitored carefully to determine harvest timing.

1	P0688AM™ (AM, LL, RR2)	12	DKC 55-53 RIB
2	P0075AM™ (AM, LL, RR2)	13	P0720Q™(Q, LL, RR2)
3	DKC 51-40 RIB	14	DKC 55-85 RIB
4	DKC 52-35 RIB	15	P0825AM™ (AM, LL, RR2)
5	P0306Q™(Q, LL, RR2)	16	DKC 56-45 RIB
6	DKC 52-68 RIB	17	P0977AM™ (AM, LL, RR2)
7	P0506AM™ (AM, LL, RR2)	18	DKC 58-34 RIB
8	DKC 53-27 RIB	19	P0963AM™ (AM, LL, RR2)
9	P0574AM™ (AM, LL, RR2)	20	DKC 59-82 RIB
10	DKC 54-64 RIB	21	P1077AM™ (AM, LL, RR2)
11	P0688AM™ (AM, LL, RR2)		

Figure 8. Pioneer on-farm trial with high tar spot pressure in Ottawa County, Michigan, showing differences in canopy staygreen among hybrids (September 27, 2019).

Figure 9. Field with severe tar spot infection and extensive stalk lodging in Wisconsin in 2018. *Photo courtesy of Scott Rowntree, Field Agronomist.*

Fungicide Treatments

Research in Mexico on tar spot complex has shown that fungicide treatments can be effective against tar spot (Bajet et al., 1994). Specific management recommendations for the use of fungicides in managing tar spot in the Midwestern U.S. are still in development as more research is done. A limited number of university trials conducted in 2018 in locations where tar spot was present provided evidence that fungicides can reduce tar spot symptoms and potentially help protect yield. However, initial work also suggests that tar spot may be challenging to control with a single fungicide application due to its rapid reinfection cycle, particularly in irrigated corn. DuPont™ Aproach® and Aproach® Prima fungicides have both received FIFRA 2(ee) recommendations for control/ suppression of tar spot of corn.

Agronomic Practices

The pathogen that causes tar spot overwinters in corn residue, but to what extent the amount of residue on the soil surface in a field affects disease severity the following year is unknown. Spores are known to disperse up to 800 ft, so rotation or tillage practices that reduce corn residue in a field may be negated by spores moving in from neighboring fields. Observations so far suggest that rotation and tillage probably have little effect on tar spot severity.

Duration of leaf surface wetness appears to be a key factor in the development and spread of tar spot. Farmers with irrigated corn in areas affected by tar spot have experimented with irrigating at night to reduce the duration of leaf wetness, although the potential effectiveness of this practice to reduce tar spot has not yet been determined.

Yield potential of a field appears to be positively correlated with tar spot risk with high productivity, high nitrogen fertility fields seeming to experience the greatest disease severity in affected areas. Research on *P. maydis* in Latin America has also suggested a correlation between high nitrogen application rates and tar spot severity (Kleczewski et al., 2019).

Mycotoxins

There is no evidence at this point that tar spot causes ear rot or produces harmful mycotoxins (Kleczewski, 2018).

HOW FAR WILL TAR SPOT SPREAD?

Mottaleb et al. (2018) used climate modeling based on long-term temperature and rainfall data to predict areas at risk of tar spot infection based on the similarity of climate to the current area of infestation. Model results indicated that the areas beyond the current range of infestation at highest risk for spread of tar spot were central Iowa and northwest Ohio. Observations in 2019 were consistent with model predictions, with further spread of tar spot in counties in northwestern Ohio and a dramatic expansion of tar spot across Iowa. Results indicated the potential for further expansion to the north and south but primarily to the east and west, including New York, Pennsylvania, Ohio, Missouri, Nebraska, South Dakota, eastern Kansas, and southern Minnesota.

Tar spot has not been detected in Canada yet, but given the spread of tar spot into eastern Michigan in 2019, pathologists expect that it will show up in southern Ontario in the near future.

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Bacterial Stalk Rot in Corn

Madeline Henrickson, *Agronomy Intern*

DISEASE FACTS

- Bacterial stalk rot can be caused by multiple bacteria, depending on environmental conditions and geographic location. Some causative bacteria species include:
    - » *Erwinia chrysanthemi pv. Zeae*
    - » *Erwinia carotovora*
    - » *Erwinia dissolvens*
- Bacterial stalk rot can occur in a wide range of crops, including corn, sunflower, sugarbeet, potato, onion, and tomato.
- These bacteria utilize pectinases to break up pectin, an important component in maintaining cell structural integrity.
- Bacteria can live epiphytically on the leaf surface without causing disease.
- Once plant injury occurs or bacteria numbers become high enough, then infection can take place.

DISEASE SYMPTOMS

- Initially there will be a discoloration of a leaf sheath or node, typically beginning at the base of the plant closer to the soil line.
- Plant tissue will become soft as it is degraded.
- Pith begins to visibly rot as bacteria are transported in the vascular system.
- As tissue rots, there is the presence of a pungent odor that is typically compared to the smell of silage.
- Bacterial rots can be distinguished from fungal rots due to the lack of fungal structures like spores and mycelium.
- Infection can also be initiated by plant wounding and spread from points of injury.
- Weakened plants may be more prone to lodging.

Decaying corn stalk due to bacterial infection.

Photo courtesy of Naeem Gill, Area Agronomy Manager - Pakistan

MANAGEMENT CONSIDERATIONS

Environment

- High relative humidity and warm temperatures favor disease.
- Leaf or stalk injury from hail, insects, or mechanical injury can facilitate infection.
- Irrigation with contaminated surface water is the most common source of infection.
    - » Phytopathogenic bacteria can be found in water that is sourced from ponds, lakes, or slow-moving streams.
    - » This, paired with the damage caused by center pivot movement, has the potential to inoculate a field.

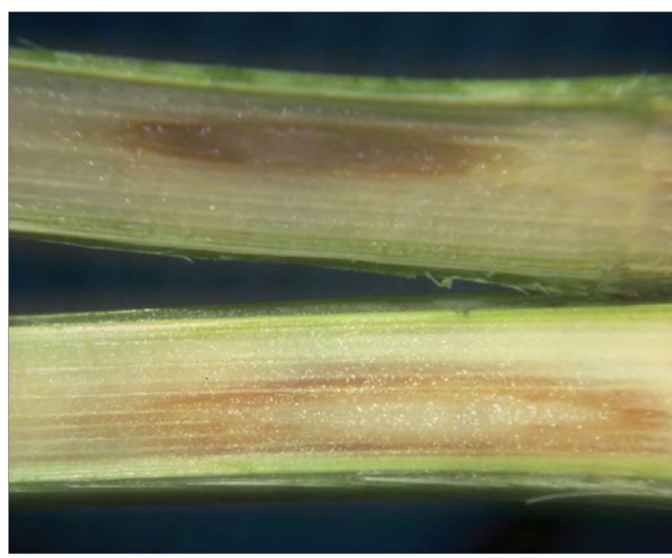
Pathogen

- Bacteria can survive and over-winter on residue.
- Burying plant material with till-age can potentially decrease inoculum.

Host

- Differences in hybrid resistance have been observed but are generally not well-characterized due to the infrequency of bacterial stalk rot occurrence.

Bacterial infection showing symptoms on leaf tissue (above) and pith tissue (below).



Treatment

- Because this stalk rot is caused by bacteria and not a fungal pathogen, no rescue treatments are available to combat it.

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Common Corn Ear Rots

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).

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

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)

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.

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Less Common Corn Ear Rots

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

PENICILLIUM EAR ROT (MYCOTOXINS MAY OCCUR)

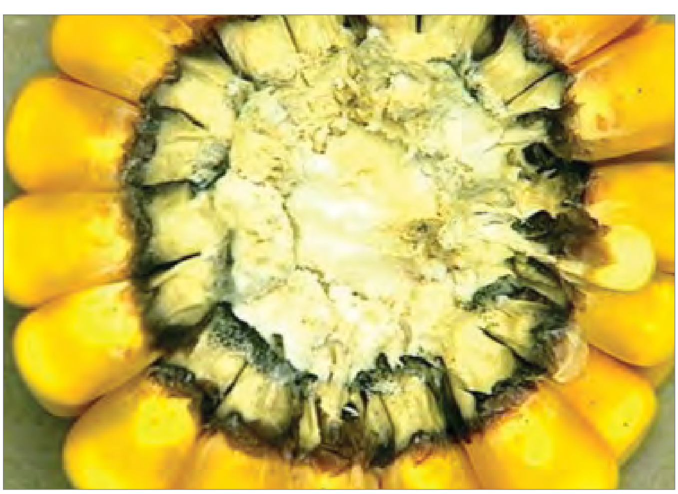
- Blue-green fungal growth on and between kernels usually near the ear tip is characteristic of this disease.
- Fungal disease of ears often associated with damage from insects or other physical injury
- Infected kernels may become bleached or streaked.
- Common and damaging fungus of stored grain; can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

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.

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.



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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Gray Leaf Spot of Corn

Madeline Henrickson, *Agronomy Intern*

PATHOGEN FACTS

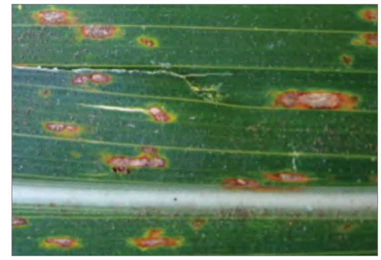
- Gray leaf spot (GLS) is a common fungal disease in the United States caused by the pathogen *Cercospora zeae-maydis* in corn.
- Disease development is favored by warm temperatures (80 °F or 27 °C) and high humidity (relative humidity of 90% or higher for 12 hours or more).
- *Cercospora zeae-maydis* overwinters in corn residue, allowing inoculum to build up from year to year in fields.
- Cropping systems with reduced- or no-till and/or continuous corn are at higher risk for gray leaf spot outbreaks.
- Conducive weather conditions encourage the rapid spread of disease near the end of summer and early fall when corn plants allocate more resources to grainfill.

Cercospora zeae-maydis spore

IDENTIFICATION

Early Symptoms

- Gray leaf spot lesions begin as small, necrotic pinpoints with chlorotic halos; these are more visible when leaves are backlit.
- Coloration of initial lesions can range from tan to brown before sporulation begins.
- Because early lesions are ambiguous, they are easily confused with other foliar diseases, such as anthracnose leaf blight, eyespot, or common rust.



GLS lesions begin as small, necrotic spots with chlorotic halos.

As GLS develops, lesions become blockier in appearance and more gray in coloration.

GRAY LEAF SPOT LIFE CYCLE

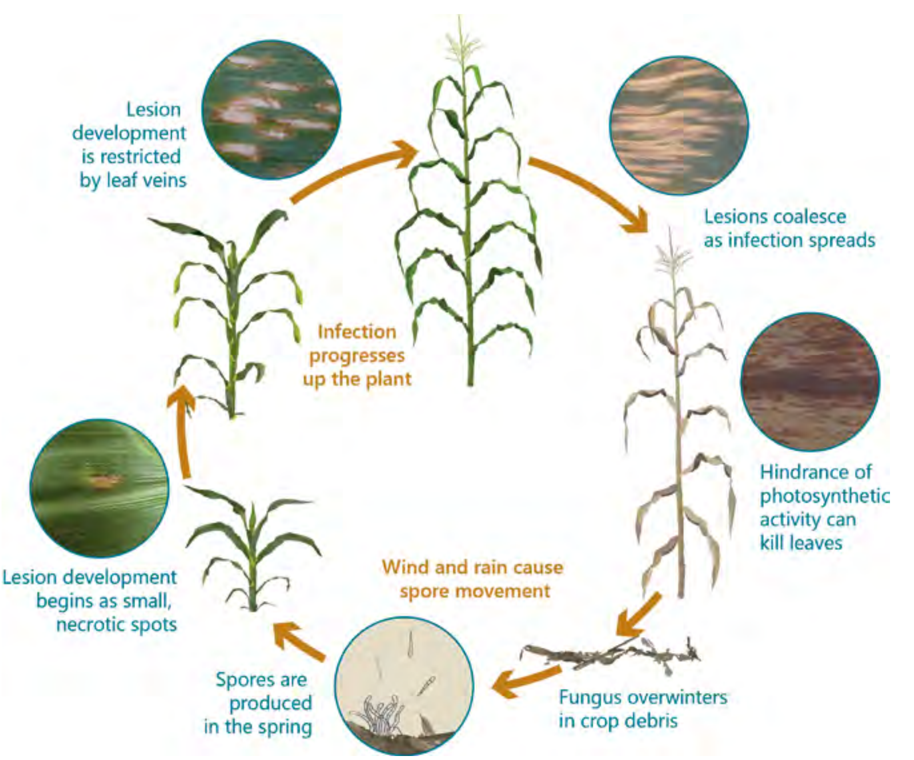


Figure 1. Life cycle of gray leaf spot, *Cercospora zeae-maydis*, in corn. Spores and lesions are enlarged to show detail.

Later Symptoms

- As infection progresses, lesions begin to take on a more distinct shape.
- Lesion expansion is limited by parallel leaf veins, resulting in the blocky shaped "spots."
- As sporulation commences, the lesions take on a more gray coloration.
- Entire leaves can be killed when weather conditions are favorable, and rapid disease progression causes lesions to merge.

As GLS progresses, lesions will coalesce and form larger necrotic areas.

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CROP DAMAGE

- Gray leaf spot lesions on corn leaves hinder photosynthetic activity, reducing carbohydrates allocated towards grain fill.
- The extent to which gray leaf spot damages crop yields can be estimated based on the extent to which leaves are infected relative to grainfill (Table 1).
- Damage can be more severe when developing lesions progress past the ear leaf around pollination time.
- Because a decrease in functioning leaf area limits photosynthates dedicated towards grainfill, the plant might mobilize more carbohydrates from the stalk to fill kernels.
- This can result in a higher risk of stalk lodging and stalk rots due to a loss of structural integrity.

Smaller kernels and a lower test weight can be the result of reduced carbohydrate contributions from photosynthetic activity.

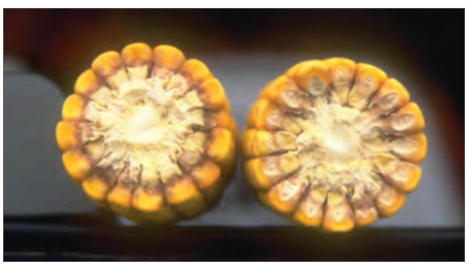

Table 1. Estimated yield loss based off of percent of tissue infected by gray leaf spot (Lipps, 1998).

Percent Leaf Area Affected at R5 (Early Dent Stage)	Approximate Yield Loss
5% or less	0 – 2%
6 – 25%	2 – 10%
25 – 75%	5 – 20%
75 – 100 %	15 – 50%

MANAGEMENT CONSIDERATIONS

Cultural Practices

- *Cercospora zeae-maydis* overwinters in corn debris, so production practices, such as tillage and crop rotation, that reduce the amount corn residue on the surface will decrease the amount of primary inoculum.
- Crop rotation away from corn can reduce disease pressure, but multiple years may be necessary in no-till scenarios.

Hybrid Resistance

- Planting hybrids with a high level of genetic resistance can help reduce the risk of yield loss due to gray leaf spot infection.
- Pioneer® brand hybrids and parent lines are improved through a screening process in areas with a high incidence of GLS and specialized "disease nurseries."
- Customers can see the effectiveness of hybrid resistance based off of a score (ranging from 1 to 9) that is assigned to Pioneer® brand products.
- Susceptible hybrids are more likely to benefit from a foliar fungicide application, but resistant varieties may benefit as well under high gray leaf spot pressure (Figure 2).

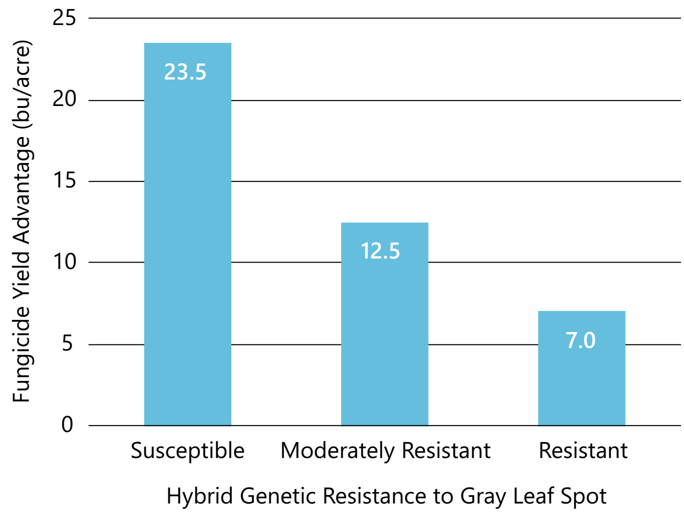

Figure 2. Average yield increase of hybrids with varying levels of resistance to GLS due to a foliar fungicide application in a 3-year University of Tennessee/Pioneer research study with very high GLS pressure.

Fungicides

- During the growing season, foliar fungicides can be used to manage gray leaf spot outbreaks.
- Farmers must consider the cost of the application and market value of their corn before determining if fungicides will be an economical solution to GLS.
- When selecting a fungicide, it is important to keep in mind the efficacy of the available products (Table 2).

Table 2. Fungicide efficacy for control of gray leaf spot. (Wise, 2019).

Fungicide	Active Ingredients	GLS Efficacy
DuPont™ Aproach® Prima	picoxystrobin + cyproconazole	Excellent
Headline®	pyraclostrobin	Excellent
Headline® AMP	pyraclostrobin + metconazole	Excellent
Priaxor®	pyraclostrobin + fluxapyroxad	Very Good
Quilt® Xcel	propiconazole + azoxystrobin	Excellent
Stratego® YLD	prothioconazole + trifloxystrobin	Excellent

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Northern Corn Leaf Blight

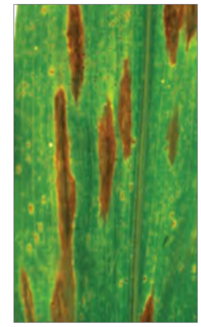
Madeline Henrickson, *Agronomy Intern*

PATHOGEN FACTS

- Northern corn leaf blight (NCLB) is a foliar disease caused by the fungus *Exserohilum turcicum*.
- Disease development is favored by moderate temperatures (64 to 81 °F) and extended periods of leaf wetness (6 to 18 hours).
- Heavy dew, overcast days, or humid field margins near tree lines can create an environment conducive for disease.
- *Exserohilum turcicum* overwinters in corn residue, allowing inoculum to build up from year to year.
- Cropping systems with reduced or no-till and/or continuous corn are at higher risk of northern corn leaf blight outbreaks.

Spores from *Exserohilum turcicum. Photo courtesy of Jennifer Chaky.*

IDENTIFICATION



- Infections generally begin on lower leaves and progress up the plant, but infections may begin in the upper plant canopy when spore loads are high.
- Spores progress up the plant by wind or rain splash and may be carried long distances by the wind.
- With optimum conditions, lesions can form 7 to 12 days after infection.
- Lesions are unrestricted by leaf veins, beginning as elliptical and becoming long, narrow, and "cigar shaped."
- Coloration of lesions starts as tan or gray-green and takes on a darker shade as *Exserohilum turcicum* sporulates.
- Spore coloration ranges from olive green to black and can be visible with a hand lens. Lesions are often described as appearing "dirty."
- Lesions can coalesce to form large areas of necrotic leaf tissue, making leaves appear gray/burned.
- New lesions can produce spores in as little as one week, allowing northern corn leaf blight to spread much faster than many other corn leaf diseases.

NORTHERN CORN LEAF BLIGHT LIFE CYCLE

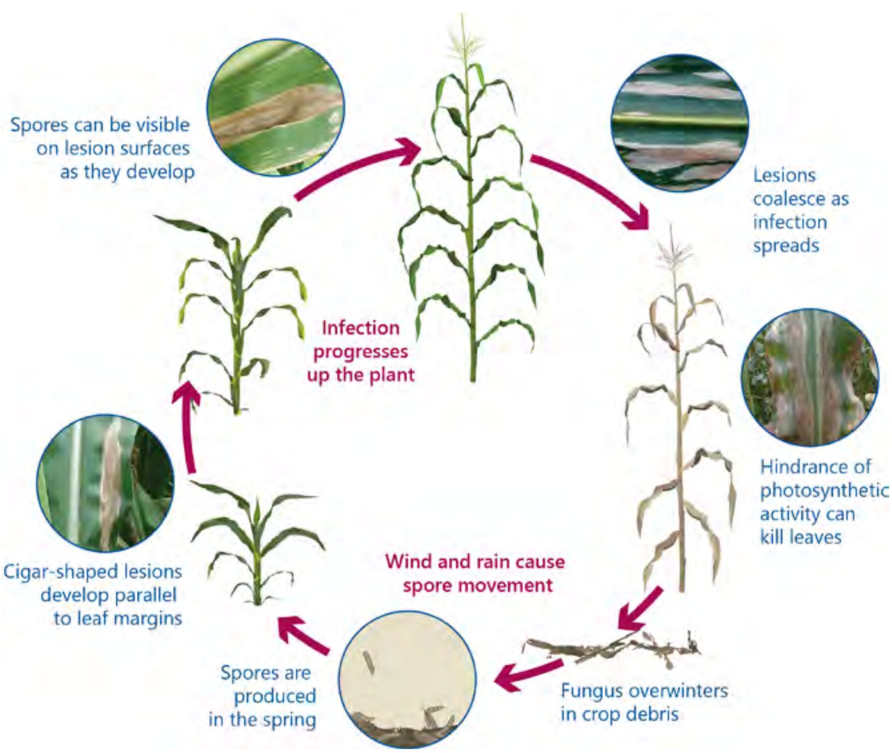


Figure 1. Life cycle of northern corn leaf blight, *Exserohilum turcicum*, in corn. Spores and lesions are enlarged to show detail.

CROP DAMAGE

- Lesions on corn leaves hinder photosynthetic activity, reducing the amount of carbohydrates allocated towards grainfill.
- If lesions progress to the ear leaf or higher two weeks before or after tasseling and pollination, yield loss can occur.
- Yield losses are most severe when northern corn leaf blight infects corn plants early and progresses to the upper plant leaves by pollination or early ear fill.
- Yield losses up to 30% have been reported.
- Because a decrease in functioning leaf area limits photosynthates dedicated towards grainfill, the plant may mobilize more carbohydrates from the stalk to fill kernels, which can make plants more susceptible to stalk rots and lodging.

MANAGEMENT CONSIDERATIONS

Cultural Practices

- *Exserohilum turcicum* overwinters in corn debris, so production practices, such as tillage and crop rotation, that reduce the amount of corn residue on the surface will decrease the amount of primary inoculum.
- However, reducing corn residue does not protect against spore showers carried into a field on wind currents.

Hybrid Resistance

- Planting hybrids with a high level of genetic resistance can help reduce the risk of yield loss due to northern corn leaf blight.
- Pioneer® brand hybrids and parent lines are improved through a screening process in areas with a high incidence of northern corn leaf blight and specialized "disease nurseries".
- Pioneer brand hybrids are rated for northern corn leaf blight resistance. Most hybrids are rated from 3 to 7 on the Pioneer 1 to 9 scale, where 9 indicates highly resistant.
- Susceptible hybrids are more likely to benefit from a foliar fungicide application.
- Two types of resistance are available in hybrids (Table 1).

Corn leaf of showing a mixed reaction to NCLB. The Ht1 hybrid shows resistance to Race 0 (yellow lesions in the center and in the left side of the leaf) and susceptibility to race 1 (the susceptible lesion on the right side of the leaf).

Table 1. Comparison between multigenetic and single Ht resistance.

Multigenic Resistance	Single Gene "Ht" Resistance
Non-race specific	Race specific
More stable over time	May be overcome in time
Reduces number of lesions on a leaf	Delays spore production, limits sporulation

Fungicides

- Several foliar fungicides are labeled for control of northern corn leaf blight (Table 2).
- Northern corn leaf blight may not always be controlled as completely as some other diseases. This is due to the more rapid life cycle, which may be as short as one week under favorable conditions.
- Because northern corn leaf blight sporulates so rapidly, it is more difficult to time a single fungicide application.
- Weather conditions anticipated during ear fill are a primary factor for disease development and often have the most impact (along with hybrid disease rating) on the profitability of fungicide applications.

Table 2. Fungicide efficacy for northern corn leaf blight (Wise, 2019).

Fungicide	Active Ingredients	NCLB Efficacy
DuPont™ Aproach®	picoxystrobin	Very good
DuPont™ Aproach® Prima	picoxystrobin + cyproconazole	Very Good
Headline®	pyraclostrobin	Very Good
Headline® AMP	pyraclostrobin + metconazole	Very Good
Quadris®	azoxystrobin	Good
Quilt® Xcel	propiconazole + azoxystrobin	Very Good
Stratego® YLD	prothioconazole + trifloxystrobin	Very Good
Trivapro®	benzovindiflypyr + azoxystrobin + propiconazole	Very Good

Corn leaves with large northern corn leaf blight lesions. Note how the coloration varies from gray-green to tan.

> "Plant diseases **vary in the mechanisms** that they use to ***infect plants,*** and plant species have evolved a **wide range of defenses** to protect them ***from pathogens.*** "

Plant Physiology in Response to Pathogen Attack

Madeline Henrickson, *Agronomy Intern*

SUMMARY

- Genetic resistance of crop cultivars to plant diseases is an important tool to protect crop yield and quality.
- Plant pathogens can differ in their infection tactics – they can feed off living plant tissue; kill tissue of the host plant and feed off of the components of the dead tissue; or both.
- Plants can utilize several strategies to defend themselves against pathogens, including defenses that are always present and defenses that can be activated in response to pathogens.
- Resistance can be expressed genetically as traits that are either qualitative (involving one mechanism) or quantitative (involving many mechanisms).
- The challenge for improvement of crop varieties is determining how quantitative resistance genes apply to a specific pathogen.

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INTRODUCTION

Plant pathogens are one of the most important threats to crop production globally. Potential yield losses from pathogens are estimated at around 16 percent on average (Oerke, 2005); however, severe infections can wipe out, contaminate, or decrease the quality of agricultural products. Genetic resistance to diseases in crop cultivars has played a key role in the battle against fungi, bacteria, and viruses – providing an important line of defense for protecting crop yield and quality from crop diseases. Plant diseases vary in the mechanisms that they use to infect plants, and plant species have evolved a wide range of defenses to protect them from pathogens. Plant breeders work to incorporate these natural defense mechanisms into crop cultivars, making them more resistant to common crop diseases.

This article reviews some of the physiology behind plant resistance to pathogens – how pathogens attack plants, how plants defend themselves, and how pathogens are able to sometimes overcome these plant defenses. The ongoing evolutionary arms race between plants and pathogens demonstrates the complexity of evolutionary biology as well as how these molecular battles can directly impact our crop production and food supply.

Corn field severely infected by northern corn leaf blight.

TYPES OF PATHOGENS

Pathogens are divided into three general categories according to mechanisms they employ to colonize and feed off of plants:

Biotrophs feed on living host tissue. Biotrophic pathogens establish specialized biochemical connections with the host plant during infection. These communications suppress the plants defense and increase the quantity of nutrients being sent to the infection site. Examples of biotrophic pathogens in corn include common rust (*Puccinia sorghi*), southern rust (*Puccinia polysora*), tar spot (*Phyllachora maydis*), and Physoderma brown spot (*Physoderma maydis*).

Necrotrophs kill host tissue and feed off of the dead tissue. They accomplish this by quickly overwhelming the plant with toxic compounds and tissue-degrading enzymes before the host plant is able to react and initiate defenses. Examples of necrotrophic pathogens in corn include gray leaf spot (*Cercospora zeae-maydis*) and southern leaf blight (*Cochliobolus heterostrophus*).

Hemibiotrophs utilize components of both strategies. They begin as biotrophic during initial infection and become necrotrophic as colonization progresses. Examples of hemibiotrophic pathogens in corn include northern corn leaf blight (*Exserohilum turcicum*) and anthracnose (*Colletotrichum graminicola*).

Southern rust establishes a biotrophic relationship with corn (left), whereas gray leaf spot uses a necrotrophic approach (right).

TYPES OF DEFENSE

Plant species have evolved a wide range of different mechanisms to protect themselves from invading pathogens that can be classified into two general categories:

Constitutive defense is a form of continuous defense that the plant is able to utilize without expending additional energy. Constitutive defense includes barriers like cell walls, waxy cuticles, and bark that deter pathogens from invading the plant.

Inducible defenses are turned on after the pathogen is detected by the plant. Plants can produce toxic chemicals, deploy pathogen-degrading enzymes, or destroy infected plant cells. Inducible defenses remain latent because they require energy and nutrients to activate and maintain.

REQUIREMENTS FOR INFECTION

For disease to occur, three things must be present: a susceptible host plant, a pathogen, and an environment favorable for infection. For many common crop diseases that are able to overwinter in crop residue, the pathogen is always present at some level in fields, making environmental conditions during the growing season the key determinant for infection. Diseases vary in the specific conditions that are optimal for the pathogens to commence infection.

Some pathogens like many necrotrophs can infect a large range of plants. If a plant species can be infected by a pathogen, then it falls into the host range. If disease occurs during infection, then that is considered a compatible response (Figure 1). However, not all species within the host range for a pathogen are susceptible. When a pathogen tries to infect a host and little to no disease results, it is characterized as an incompatible response. The range of effectiveness of incompatible response, in order from high to low, includes: immunity (no disease symptoms), highly resistant (some minor disease symptoms), and highly susceptible (substantial disease symptoms).

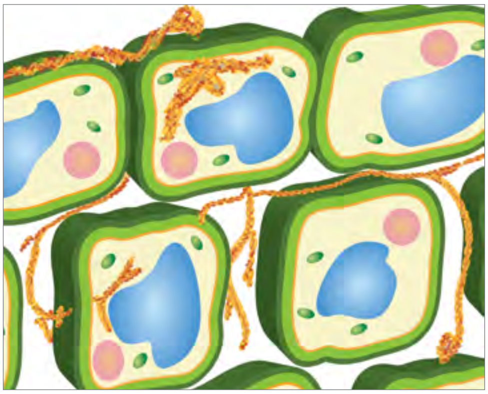

Figure 1. A representation of a plant and a biotrophic pathogen displaying a compatible response.

PLANT DETECTION AND RESPONSE TO PATHOGENS

Plants have a multifaceted approach for detecting and defending against pathogens. Initial responses are less intensive and use fewer resources. If the situation becomes more severe, then plant defenses can ramp up to counter the threat. Basal resistance, also termed *inducible* or *innate immunity*, is the first line of defense against pathogen attack.

When the plant detects the pathogen, it is recognizing microbe-associated molecular patterns (MAMPs). MAMPs can include common components of microbe cell walls, specific proteins, and lipopolysaccharides. Non-pathogens can also trigger basal resistance because their makeup can be detected as a potential threat. However, some pathogens can suppress basal resistance, requiring the plant to resort to more extreme measures of defense.

Hypersensitive response is when the plant deliberately terminates infected cells for the safety of the entire system (Figure 2). It cuts off the pathogen's access to water and nutrients, removing resources that are necessary for survival and limiting the spread of infection in the plant. This is a more specific response after the recognition of a pathogen effector molecule. Effector molecules selectively bind to proteins and regulate biological activity. They can increase or decrease enzyme activity; gene expression; or cell signaling. In other words, the plant can detect when a foreign molecule is trying to control how a cell is operating.

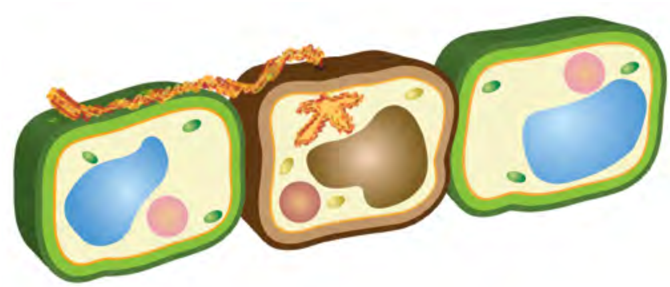

Figure 2. Representation of hypersensitive response in plants, in which infected cells are teminated by the plant to limit the spread of infection.

Once hypersensitive response is triggered and threat of infection is certain, the plant can amplify defenses against a broad range of pathogens for an extended period. This is called systematic acquired resistance (SAR). The ability for the plant to react to new threats is elevated as resources are prepared and mobilized. These resources include chemical compounds, proteins, and enzymes.

For virus protection, some plants can recognize foreign molecules and digest them, so they are no longer a threat. This process is called RNA silencing. In some cases, plants can retain a template, much like an immune system, to discover future threats faster. Soybean plants able to resist soybean mosaic virus and soybean dwarf virus have been developed using transgene-induced RNA silencing. Resistance to these viruses was achieved by transforming plants with genes or gene segments derived from viruses, creating what is referred to as pathogen-derived resistance (Kasai et al., 2013). It has been suggested that methods like this might be useful when looking for resistance in non-viral pathogens as well.

STRUCTURAL DEFENSES

The Cell

The cell passively dissuades many potential organisms from establishing, inhabiting, and infecting the plant. Cell walls are thick and can quickly activate chemical defenses at the detection of pathogens (Figure 3). Primary cell walls provide structural support with cellulose. Microfibrils are fibers made of cellulose that allow the cell to be flexible. Hemicellulose is made of cross-linking glycans, which provide extra strength to the cell. Pectins act as a glue that keeps neighboring cells together while regulating water content. The combination of these components fortifies the cell. When an element is removed, the stability of the overall structure is compromised, allowing pathogen invasion.

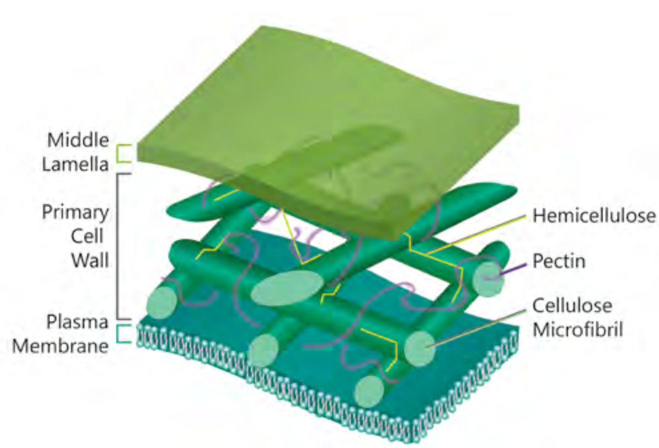

Figure 3. Close-up illustration of the cell wall, showing the key components that maintain structural integrity.

Induced Modifications

Upon detection of pathogens, proteins along the cell wall prepare to protect the cell by inducing defenses. Reactive oxygen species are released to damage as much of the pathogen as possible. A reactive oxygen species, or ROS, has unpaired electrons. This, coupled with the high electronegativity of oxygen, causes these free radicals to take electrons from whatever is closest. Essentially, electrons are pulled from cell walls, degrading the pathogen. The oxidative burst also encourages cross linkage between plant cell wall polymers as electrons are removed. This drastic step in cell defense signals to other components of the plant that there has been a pathogen attack.

The plant can also synthesize callose in the membrane between the cell wall and the area adjacent to the pathogen. This is called papillae and can either slow down or halt pathogen development (Figure 4). The success of induced modifications depends greatly on the speed at which they are activated.

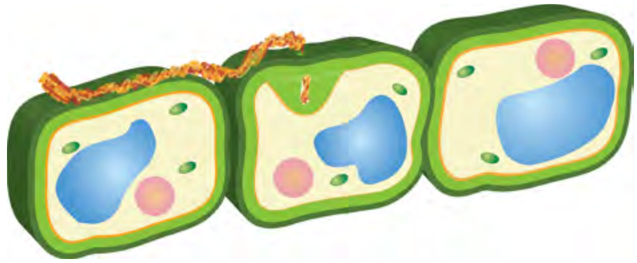

Figure 4. Papillae growth in response to initial infection. Callose tissue prevents the hyphae from spreading and infecting the plant.

Tissues and Modifications

Solitary cells can accomplish great feats in plant defense while utilizing individual cell attributes; however, a network of cooperative cells can build larger structures and signal to one another when coordinated action needs to be taken on a greater scale. The goal of modified tissues is to make the plant surface inhospitable for epiphytic pathogen growth. The waxy cuticle of many plant leaves repels water, reducing the potential for moisture to collect and persist on leaves where it can provide a favorable environment for fungal spore germination. Guard cells, which allow gas exchange on plant surfaces, close when in the presence of MAMPs. Trichomes are hairs found on plants that provide a physical and chemical barrier to the plants. Glandular trichomes secrete repellent oils.

CHEMICAL DEFENSE

Chemicals involved in defense are called secondary metabolites because they are not necessary for the everyday functionality of the plant. These are typically classified as either phytoalexins or phytoanticipins. Phytoalexins are synthesized in response to pathogen attack, and phytoanticipins are preformed inhibitors (Freeman and Beattie, 2008). There are many compounds that can be used in either a preformed or induced mechanism for plant defense.

Terpenoids

Terpenoids, or terpenes, are the largest class of secondary metabolites. Different types of terpenoids are defined by how many isoprene units they contain. Isoprene is a volatile gas emitted by some plants during photosynthesis. Plants that produce isoprene are more well-suited to enduring rapid heat stress and are more tolerant to their own reactive oxygen species that they produce (Gould, 2004). A small alteration in the number of isoprene units and their structure can result in a great variation in the defense compounds.

Monoterpenoids are highly volatile compounds that can carry some antibacterial and antifungal activity. Many people are familiar with essential oils and spices, which are comprised of monoterpenoids. Triterpenoids are similar in structures to hormones and sterols. When multiple triterpenoids accumulate, they create saponins, which are incredibly important in plant defense. Saponins are glycosylated triterpenoids; they create a soap-like substance that disrupts the membranes of invading pathogens. A study conducted on oats demonstrated that mutants deficient in avenacin saponins were susceptible to pathogen invasion via *Gaeumannomyces graminis* var. *tritici* (Papadopoulou et al., 1999). This pathogen causes the disease take-all in wheat and barley, but oats are typically resistant to it.

Phenolics are another large class of secondary metabolites involved in plant defense against pathogens. They are found in many different tissues throughout the plant and play a key role in plant defense. Flavonoids are a large subclass of phenolics that can be further divided into subgroups depending on their structure. Anthocyanins are the compounds responsible for bright colors in plant tissue and provide a multifaceted defense approach. They help the plant protect itself from UV damage by scavenging free radicals like reactive oxygen (Gould, 2004). Phytoalexins are isoflavonoids with antibiotic and antifungal properties. These are typically pathogen-specific and disrupt pathogen metabolism or cellular structure. Tannins are a class of polyphenolic molecules with a diverse range of biochemical functions, including protection against pathogens. Tannins are stored in vacuoles and released when cells are damaged to protect the plant. Tannins are commonly found in roots tissues to protect plants from soil-borne pathogens. Furanocoumarins are a class of protective compounds common in citrus plants to defend against pathogens and herbivorous insects. Furanocoumarins are activated by UV light and have the potential to be highly toxic. They integrate into the DNA, which can cause rapid cell death.

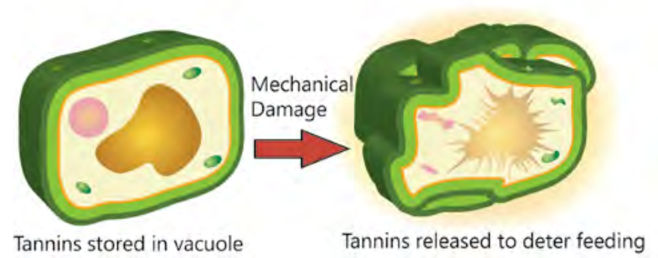

Figure 5. Depiction of how tannins are stored and deployed in plants after cell destruction.

Alkaloids

This class of nitrogen compounds includes some of the most well-known chemicals associated with plant defense, such as caffeine and nicotine, which provide protection against pathogens, insects, and herbivores. These substances can cause significant alterations to the physiology of organisms, which can be deadly.

PROTEINS AND ENZYMES

Proteins and enzymes are complex structures when compared to chemicals used in plant defense. Therefore, they are only synthesized after pathogen infections. Pathogenesis-related proteins, often called PR proteins, can be acidic or basic and incorporate varying antifungal properties. In addition, PR proteins also aid the plant when it encounters abiotic stresses. There are numerous PR proteins that have been classified, but there is still much to discover (Table 1).

Defensins are a family of PR proteins that can inhibit the growth and functionality of bacteria and fungi by disrupting ion balance. This is accomplished by constraining ion channels or by creating new pores in membranes. Digestive enzyme inhibitors release a protein that inhibits starch digestion. Alpha-amylase inhibitors inhibit protein synthesis, which is incredibly toxic, even to humans. Protease inhibitors interfere with digestion. After herbivory commences, plants can move protease inhibitors to distal areas of the plant, protecting the unharmed areas. Hydrolytic enzymes can degrade the cell walls of pathogens. Chitinases destroy chitin, which composes the cell wall of true fungi. Glucanases degrade glucans, which are what protect oomycetes (water molds). Lysosomes can damage bacterial cell walls.

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Table 1. Known families of pathogenesis-related proteins and their properties (Devi et al., 2017; Moosa et al., 2017).

Family	Protein Activity	Targeted Pathogen Site
PR- 1	Antifungal	Active against oomycetes
PR- 2	1,3 ß-glucanases	Cell wall glucan of fungi
PR- 3	Chitinases	Cell wall chitin of fungi
PR- 4	Chitinase type I, II	Active against oomycetes
PR- 5	Thaumatin	
PR- 6	Proteinase inhibitor	Active on nematodes and insects
PR- 7	Endoproteinase	Microbial cell wall dissolution
PR- 8	Endochitinase with lysozyme activity	Cell wall chitin of fungi and mucopeptide cell wall of bacteria
PR- 9	Peroxidase	Strengthening of plant cell wall
PR- 10	Ribonuclease-like proteins (RLP)	
PR- 11	Endochitinase	Cell wall chitin of fungi
PR- 12	Defensin	Antifungal and antibacterial activity
PR- 13	Thionin	Antifungal and antibacterial activity
PR- 14	Lipid-transfer proteins	Antifungal and antibacterial activity
PR- 15	Oxalate oxidase	Produce H_2O_2 that inhibits microbes and also stimulates host defense
PR- 16	Oxalate oxidase-like with super dismutase activity	Produce H_2O_2
PR- 17	Antiviral and antifungal	

QUALITATIVE VS. QUANTITATIVE RESISTANCE

An understanding of disease resistance must be coupled with an understanding of genetics. There are two ways in which resistance can be expressed in plant genomes, qualitative and quantitative. Qualitative resistance yields phenotypes that follow basic Mendelian genetics and can be viewed as dominant or recessive. Quantitative resistance, on the other hand, is the product of many traits and aspects of a plant. Disease resistance can be expressed both ways.

For example, wheat displays both quantitative and qualitative resistance against powdery mildew. A study on durum wheat demonstrated that it has 60 genes associated with disease resistance. The researchers found that in environments with low disease pressure, qualitative traits are enough to defend the plant. However, when more disease is present, resistance genes are expressed in a quantitative manner (Marone, 2013). The efficacy of qualitative resistance traits is often short-lived because of the rapid adaptability of pathogens to single traits. An article published by the American Society of Plant Biologists puts it this way, "[in nature] quantitative resistance genes are responding to the blend of pathogens in a specific environment rather than a single predominant pathogen" (Corwin and Kliebenstein, 2017).

The challenge for improvement of crop varieties is determining how quantitative resistance genes apply to a specific pathogen. This has been the subject of extensive investigation, especially for important agronomic crops. The results from these studies are not necessarily straightforward. For example, analysis of corn mechanisms of resistance to Fusarium verticillioides, found that numerous chemical compounds, enzymes, and proteins were utilized. Structural enhancement was accomplished through the lignification of tissues. Defense responses also included the biosynthesis of many secondary metabolites, such as shikimate, phenylpropanoid, flavonoid, terpenoid, and diterpenoid (Wang et al., 2016).

PATHOGEN RESISTANCE

Although plants can utilize a range of techniques to defend themselves, some pathogens are still able to create a compatible response and cause infection. They accomplish this with many different strategies that specialize in combating plant defense. Some pathogens can either metabolize or detoxify reactive oxygen species produced by the plant. To slow the accumulation of PR proteins, the pathogen will release fewer elicitor proteins. Some pathogens can exclude chitin from the cell walls of their infection apparatus, causing the surveillance system of the plant to misperceive the pathogen.

Pathogens can also release elicitors that compete with the host receptors that bind to and identify chitin, once again concealing the pathogen. Strong, lignified cell walls can be degraded by some pathogens when they produce a higher concentration of pectolytic enzymes. The rapid degradation of pectin decreases structural integrity and leads to failure of plant defense. In a similar way, pathogens can use stronger hydrolytic enzymes like esterases to split esters that results in the degradation of plant cells.

In other words, even if the plant is doing everything right, it can still fall victim to infection by a pathogen. As plants evolve more successful defenses, they increase the selection pressure on the pathogens. Therefore, the few pathogens that have the tools necessary to overcome plant defenses persist and multiply. The cycle begins anew as plants develop additional methods to counteract this. These interactions are known as boom and bust cycles (Figure 6).

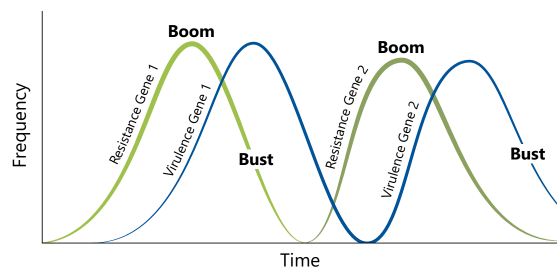

Figure 6. Generalized boom and bust cycle whereas resistance genes are plant alleles and virulence genes are pathogen alleles.

CONCLUSIONS

When it comes to defending themselves, plants have many tools at their disposal. Preformed defenses deter many pathogens, insects, and even larger vertebrates from damaging the plant. They can contain highly perceptive surveillance systems that are able to detect pathogens even before infection takes place. Induced defenses can be deployed to shut down the progression of infection before it can affect the whole system. However, pathogens have their own means to survive by preventing, stalling, or overpowering plant defenses. Evolution has armored both plants and pathogens with competing structures, enzymes, and communication systems. When plant breeders are evaluating potential gene pools to incorporate into crop hybrids and varieties, they are assessing a multifaceted approach to overcoming disease. No single mechanism of plant defense can be relied upon exclusively. Instead, a utilization of the plant's diverse defense capabilities is more likely to achieve success. Breeders work to understand and incorporate these attributes into crop cultivars, making them more resistant to common crop diseases.

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Late Nitrogen Application Effects on Grain Filling in Corn

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RATIONALE AND OBJECTIVES

- Yield improvement in corn over the past few decades has been accompanied by an increase in plant nitrogen (N) uptake with modern hybrids absorbing more N during reproductive stages while delaying N remobilization to the grain for later in the growing season.
- To evaluate the effect of late-season N applications in distinct corn genotypes, grain yield as well as grain filling parameters were evaluated in field experiments under different N regimes using recent and historical Pioneer® brand corn hybrids.
- Experiments were conducted in two environments, one irrigated and one non-irrigated.

STUDY DESCRIPTION

- **Year:** 2017
- **Location:** Ashland Bottoms Research Farm, Manhattan, KS (Soil pH = 5.9, soil organic matter = 1.34%, 50 ppm of phosphorus (Mehlich), and 158 ppm of potassium)
- **Environments:** Non-Irrigated, Irrigated
- **Planting Date:** May 5
- **Plot Size:** 10 x 70 ft
- **Experimental Design:** Split-plot
- **Hybrid/Brand²:**

	Year	CRM	GDU Silk	GDU Mat.
» 3394	1991	111	1,442	2,760
» P1151AM™ (AM, LL, RR2)	2011	111	1,320	2,580
» P1197AM™ (AM, LL, RR2)	2014	111	1,400	2,730

- **Nitrogen Application Timings (Sub-Plot Factor):**
  - » 0 N (non-fertilized check)
  - » Planting + V6 + R1
  - » Planting + V6 + 2 weeks after R1
- **Data Collected:**
  - » Yield (combine harvest)
  - » Yield components (kernel number, kernel weight)
  - » Grain filling was measured beginning at the R2 growth stage, collecting one ear per plot every 3 to 4 days. Ten kernels from the central portion of the ear were sampled to track changes in kernel dry weight and water volume during the entire period.
  - » Total aboveground biomass
  - » Leaf area index (LAI, Plant Canopy Analyzer LAI 2200)

Table 1. Nitrogen rates applied at each application timing in the non-irrigated and irrigated experiments.

Environment	Planting	V6	R1 or 2 Weeks After R1	Total N Applied
	lbs/acre			
Non-Irrigated	50	50	22	**122**
Irrigated	50	100	44	**194**

Table 2. Monthly values for daily solar radiation, temperature, and total precipitation for the 2017 growing seasons.

	May	Jun	Jul	Aug	Sep
Solar Radiation (MJ m^{-2} day^{-1})	25.2	27.3	26.5	23.0	18.5
Mean Temperature (°F)	65.8	75.4	80.4	72.1	72.0
Precipitation (in)	3.74	2.82	1.33	6.09	0.81

RESULTS

- Kernel number and kernel weight were both positively correlated with final grain yield (R^2 = 0.58 and R^2=0.43, respectively) for all hybrid and treatment combinations.
- Total aboveground biomass and leaf area index were measured at the R1 and R3 growth stages to determine correlation with final yield. No differences among nitrogen treatments were detected.
- Table 3 summarizes average yields and yield components for fertilizer N rate levels (N) and corn hybrids (H).

Corn Yield

- Yield significantly differed among hybrids ($P \leq 0.05$) with a positive trend between the year of release of the hybrid and yields, from 176.8 bu/acre for Pioneer® hybrid 3394 (1991) to 205.5 bu/acre for Pioneer® P1197AM™ brand corn (2014) average across N treatments (Figure 1).
- As expected, fertilized treatments differed from the zero N treatment (with a more prominent effect under irrigated conditions).
- There was no significant difference in average yield between the two N treatments (Figure 1).

Yield Components

- Significant differences among N treatments and hybrids were found for kernel number ($P \leq 0.001$ and $P \leq 0.05$, respectively) and among N treatments for kernel weight ($P \leq 0.001$) (Table 3).

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Table 3. Analysis of variance and means for yield (15.5% moisture), kernel number, kernel weight, grain filling rate, and grain filling duration for three nitrogen (N) levels and three hybrids.

Factor	Yield	Kernel Number	Kernel Weight	Grain Filling Rate	Grain Filling Duration
	bu/acre	*kernels/m²*	*mg/kernel*	*mg/°C day/kernel*	*°C days*
No Nitrogen	119.5 b	2927 b	217 b	0.31 b	1146 b
N at R1	234.2 a	4017 a	273 a	0.33 a	1219 a
N 2 weeks after R1	223.0 a	4195 a	279 a	0.34 a	1207 ab
3394	176.8 b	3285 b	254	0.34	1158 b
P1151AM™	194.4 ab	4021 a	251	0.32	1181 ab
P1197AM™	205.5 a	3833 ab	263	0.32	1232 a
Sources of Variation					
Hybrid	*	*	ns	+	*
N Treatment	***	***	***	**	*
Hybrid x N	ns	ns	*	**	ns

+ Significant at P ≤ 0.1; * significant at P ≤ 0.05; ** significant at P ≤ 0.01; *** significant at P ≤ 0.001, ns: non-significant.

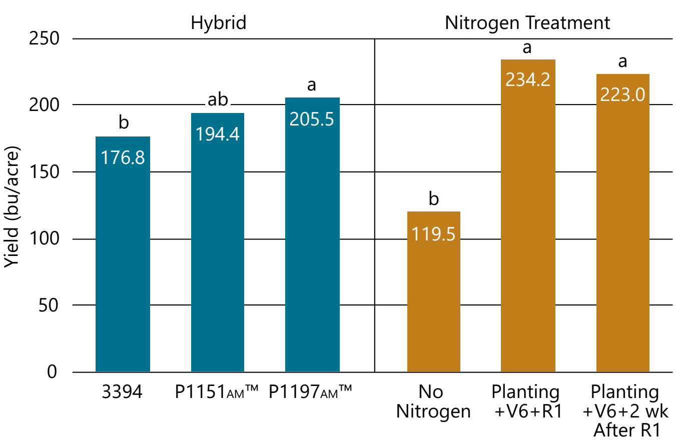
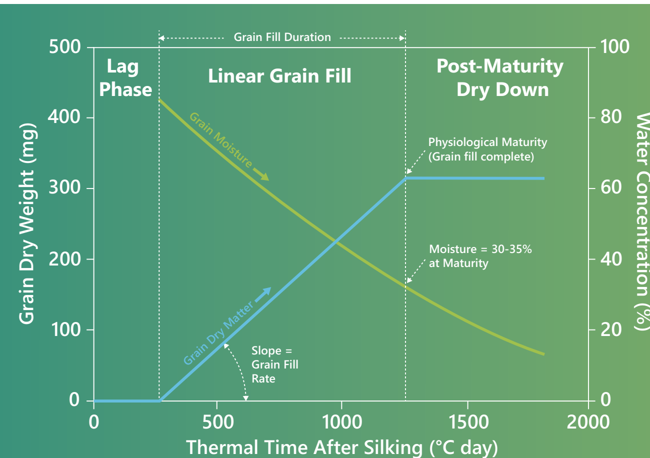


Figure 1. Hybrid and nitrogen treatment effects on corn yield.

- Kernel weight did not differ among hybrids (Table 3), indicating that differences in yield were primarily driven by the number of kernels per ear defined around silking.
- Kernel number and kernel weight were both affected by the absence of N fertilization (Table 3), suggesting that kernel weight reductions could have a considerable effect on yields, particularly in N-deficient environments.

Grain Filling Duration and Rate

- Grain filling dynamics were evaluated in terms of duration of the grain filling period and rate of dry matter accumulation using a bi-linear model. Grain-filling period was considered as divided by two phases: a lag phase and a linear grain-filling phase. (A generalized version of the bi-linear grain filling model is shown in Figure 2.)
- Grain fill duration was longer for Pioneer® P1197AM™ brand corn than Pioneer® hybrid 3394, and nitrogen fertilization extended grain fill duration relative to the zero N treatment (Figure 3).
- There were no differences in duration of lag phase across N treatments nor hybrids, indicating that variations in grain fill duration were primary driven by changes in linear grain fill.



Lag Phase: A period of active cell division when potential kernel size is defined. Extends from silking (R1) through the start of rapid kernel dry matter accumulation following R2.

Linear Grain Fill: Period of rapid dry matter accumulation from R3 to R6. Grain moisture declines throughout this phase.

Post-Maturity Dry Down: Grain dry matter has reached its maximum; grain moisture continues to decline.

Figure 2. Bi-linear model of corn grain fill showing changes in grain dry matter and grain moisture by thermal time.

- The effect of N fertilization in grain fill rate was dissimilar among hybrids, reflecting a significant genotype and environment interaction response (Hybrid x N, Table 3, P<0.05).
- The progression of grain dry-matter accumulation, grain water content, and grain percent -water concentration for each hybrid and N treatment combination is shown in Figure 4.
- N treatment effects on grain filling rate differed slightly for Pioneer® P1151AM™ brand corn vs. P1197AM™ and 3394, although changes were minor and not statistically significant.
  - » Lack of N fertilization appeared to reduce grain filling rate for 3394 and P1197AM™ but not for P1151AM™ (indicated by the lesser slope of the green lines relative to the red and blue lines in Figure 4A and 4C).

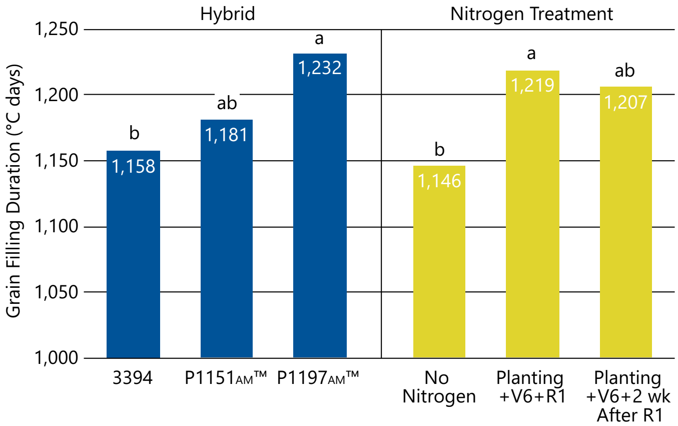


Figure 3. Hybrid and nitrogen treatment effects on grain fill duration.

- The significant reduction in grain dry weight associated with lack of N fertilization (Table 3) is illustrated in Figure 4A-4C by the gap between the green line as well as the red and blue lines following physiological maturity (the flat part of the model).
- Differences in grain weight between N treatments and zero N were related to changes in both grain fill duration and grain fill rate (Table 3, Figure 4).
- All N conditions evaluated in this study reached final grain weight (black layer formation) at a similar moisture content of around 35%, indicating that the model of grain filling on a water concentration basis was not affected by changes in the rate or timing of N fertilization.

CONCLUSIONS

- A positive trend was found between hybrid year of release and yield with the newest hybrid (P1197AM™) yielding the most, as would be expected due to genetic gain in yield over time.
- Lack of N fertilization significantly reduced corn grain yield by negatively affecting both grain number and grain weight.
- N fertilization significantly increased grain filling duration and grain filling rate; however, no differences in grain filling parameters were observed between the two N treatments.
- No significant differences were found between final N application at silking or two weeks after silking for any of the analyzed parameters in this study.
- Further studies are still needed in order to unravel reproductive N uptake dynamics and partitioning to better understand N impact during the grain filling process in corn.

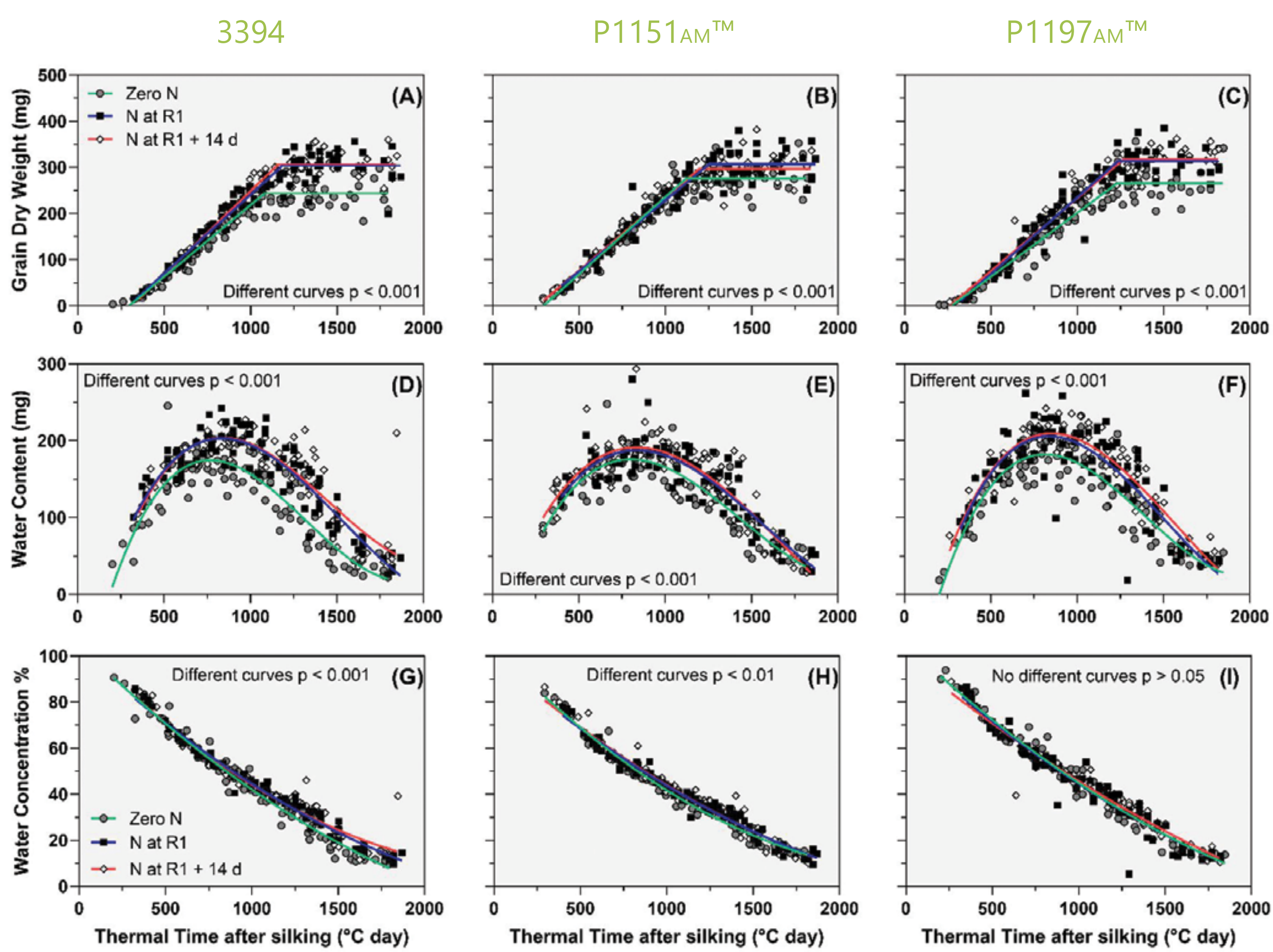


Figure 4. Progression of grain dry weight in mg (A to C), water content in mg (D to F), and water concentration in % (G to I) on a thermal-time basis from silking to harvest moisture for Pioneer® hybrid 3394, P1151AM™, and P1197AM™ brand corn.

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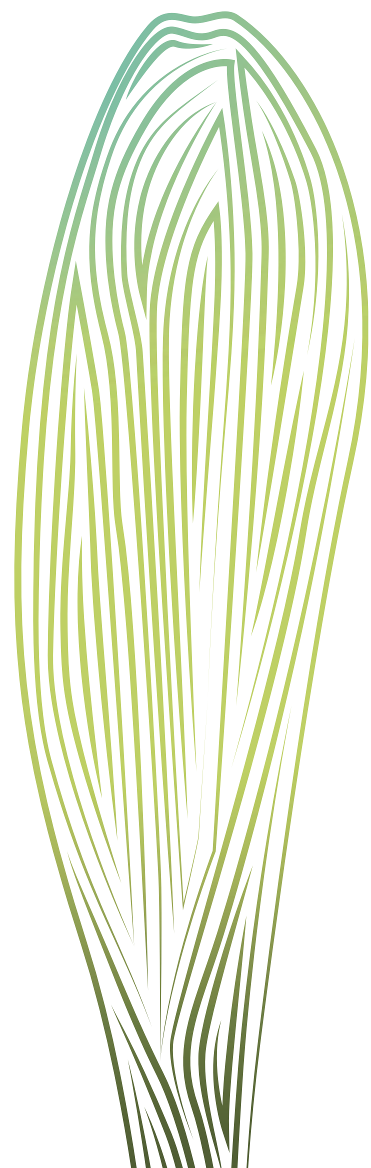
Environmental Fates, Nutrient Demands, and Efficient Nitrogen Fertility Programs to Maximize Corn Grain Yield

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

SUMMARY

- Nitrogen (N) fertilizer is one of the most expensive and essential costs in corn production.
- Multiple species of microorganisms consume N, and different soil constituents store N – only a portion of applied N is taken up by corn plants.
- Corn roots extract essentially all N as ammonium N or nitrate N from soil to meet the corn plant's entire nutritional demand.
- Corn plants are efficient in converting ammonium N and nitrate N to grain yield. Corn grain yield correlates best with the amount of N and not the type of N applied.
- Corn needs an ample supply of N throughout its life cycle with the greatest N demand between V6 to R1 and the second greatest N demand between R2 to R5.
- Efficiency of nitrogen fertility improves as nitrogen is metered to meet corn nutrient demand. The most efficient and cost-effective nitrogen management program provides some N to support corn germination as well as early growth and provides the majority of N at about V5 and later to complete vegetative and corn ear development.



INTRODUCTION

Nitrogen fertilizer is one of the most expensive and essential costs associated with corn grain and dry matter production (Plastina, 2019). Root uptake of nitrogen, in either the ammonium or nitrate form, supports the entire demand for plant growth and grain yield. Nitrogen fertilizer, after it is applied to the soil, can be taken up by the corn plant; incorporated into soil organic matter; consumed by microorganisms; immobilized by soil colloids; vaporized into the atmosphere; denitrified and lost as nitrogen gas; or leached from the corn root zone (Tisdale and Nelson, 1975). The corn producer's goal is to apply the proper amount of nitrogen at the proper time in the proper manner so that the corn plant uses the highest percentage of this nitrogen fertilizer for grain and dry matter yield. Maximum efficiency is desired because reduced nitrogen uptake by the corn plant often reduces yield.

This article addresses the different types of nitrogen fertilizers, the different fates of nitrogen in soil, and management factors to maximize nitrogen uptake by the corn plant.

TYPES OF NITROGEN FERTILIZERS

The most common synthetic nitrogen (N) fertilizers contain nitrogen as an ammonium salt (NH_4^+), ammonia (NH_3), urea (H_2NCONH_2), or as nitrate salt (NO_3^-) (Butzen, 2013; Mengel, 1986). Fertilizer manufacturers create different products by mixing and formulating the different forms of nitrogen in appropriate ratios to create the desired products with specific physical properties. The corn producer decides which product is best adapted to his or her operation. For example, anhydrous ammonia (NH_3) is often the most economical form of nitrogen fertilizer per unit of N but requires careful handling to ensure applicator safety. Aqueous solutions of nitrogen fertilizers are often more expensive for each unit of N but are safer for the applicator and can serve as a carrier to apply crop protection products. Granular formulations of nitrogen fertilizer, such as urea (H_2NCONH_2) or diammonium phosphate [DAP – $(NH_4)_2HPO_4$], can be used by corn producers who desire a dry fertilizer.

Organic forms of nitrogen fertilizer, such as manure, compost, and incorporated legumes, also contain nitrogen as ammonium salt, ammonia, urea, or nitrate salt. However, the vast majority of nitrogen is incorporated into amino acids, amino sugars, proteins, and other complex nitrogen-containing compounds. Organic forms of nitrogen fertilizer release the ammonium and nitrate forms of nitrogen very quickly into the soil and continue to slowly release more nitrogen into the soil as complex organic molecules degrade. Corn roots extract only the ammonium (NH_4^+) and nitrate (NO_3^-) forms of nitrogen from soil. Nitrogen in the more complex molecules of organic fertilizers must, therefore, mineralize to the ammonium ion or the nitrate ion before this nitrogen is available to the corn plant.

FATE OF NITROGEN IN THE SOIL

Soil microorganisms create very nearly all of the nitrogen-containing compounds in soil from just NH_4^+ and NO_3^- ions. The N cycle is a very complex process. Figure 1 illustrates the major pathways and fates of N in the soil environment.

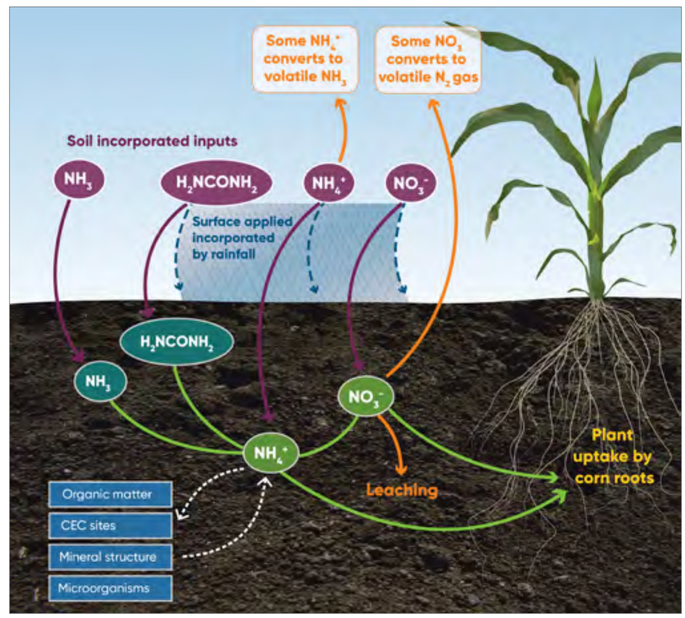


Figure 1. Environmental fates and pathways of different forms of synthetic nitrogen fertilizer.

Corn producers must properly incorporate anhydrous ammonia. Ammonia is a gas at atmospheric pressure and at temperatures typical for ammonia application. When injected into the soil, each ammonia molecule (NH_3) immediately reacts with a hydrogen ion (H^+) to form the positively charged ammonium ion (NH_4^+). Ammonium cations are retained in soil by adhering to cation exchange sites on soil colloids.

Urea can be surface-applied or incorporated into soil. In both environments, urease enzymes subsequently convert the N in urea (H_2NCONH_2) to the ammonium ion (NH_4^+). When surface-applied, rainfall incorporates fertilizers containing water-soluble urea and ammonium ion salts into the soil. While remaining on the soil surface, the ammonium ion (NH_4^+) can lose its positively-charged hydrogen ion (H^+) to convert to ammonia (NH_3). This ammonia escapes as a gas into the atmosphere and is no longer available for corn fertility.

The risk of ammonia loss from surface-applied fertilizers containing urea and ammonium salts is greatest when these fertilizers are applied in warm environments to dry soils. Up to approximately 6% of the applied nitrogen can be lost due to ammonia volatility for each day there is insufficient rainfall or irrigation water to incorporate surface-applied N fertilizer into the soil (Tisdale and Nelson, 1975). When these N fertilizers are surface-applied in cooler environments to soils with greater moisture content, N loss from ammonia volatility decreases to as little as 0 to 1% of the applied N for each day there is insufficient rainfall or irrigation water to incorporate the N fertilizer.

Nitrogen fertilizers containing the nitrate anion (NO_3^-) can be surface-applied or incorporated into the soil. The major concern for nitrate-containing fertilizers is too much rain or irrigation water. Nitrate ions move with water. If there is too much water, nitrate ions can be lost with surface run-off or leached downward through the soil profile below the root zone of the corn plant. When soil is water-saturated, the soil environment can become anaerobic. Under anaerobic, soil-saturated conditions, nitrate denitrifies to N_2O and eventually to N_2 gas, and escapes into the atmosphere. Any nitrogen lost as N_2 gas has no fertility value to the corn plant.

Ammonium and nitrate ions are incorporated into and released from soil constituents, such as soil mineral structures, organic matter, and living microorganisms. In addition, ammonium ions also reversibly adhere to soil cation exchange sites. For each of these soil-bound fates, ammonium and nitrate establish equilibria between mineralized nitrogen (nitrogen existing as either ammonium or nitrate ions) and nitrogen incorporated into more complex nitrogen-containing structures. The vast majority of nitrogen resides in the different soil fractions. Equilibrium dynamics for these soil pathways occur rapidly. Research studies show that only a fraction of the fertilizer N applied to support corn yield is directly incorporated into the corn plant. Much of this fertilizer N is incorporated into the different soil constituents to be released later as ammonium or nitrate at some future time.

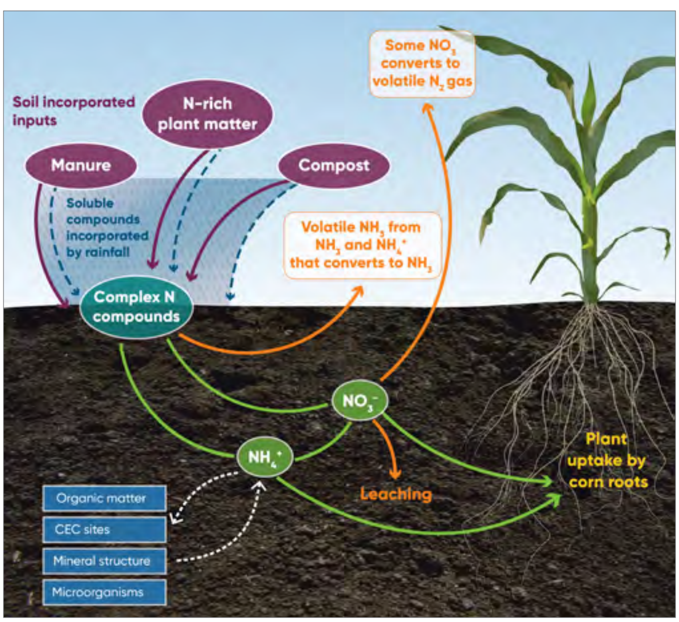


Figure 2. Environmental fates and pathways of different forms of organic nitrogen fertilizer.

Organic nitrogen fertilizers, such as manure, compost, or nitrogen-rich plant residues, can be surface-applied or incorporated into soil (Figure 2). When surface-applied, rainfall or irrigation water incorporates water-soluble nitrogen compounds into the soil profile. Small portions of complex molecules may incorporate directly into soil organic matter. However, the vast majority of complex molecules (amino acids, amino sugars, urea, and other nitrogen-containing organic compounds) degrade to ammonium or nitrate nitrogen. Once in the ammonium or nitrate form, nitrogen originating from organic and synthetic fertilizers undergoes the same biochemical reactions, leading toward the same environmental fates.

NITROGEN UPTAKE IN CORN

Essentially all nitrogen enters the corn plant via corn roots. Corn extracts only ammonium and nitrate forms of nitrogen from soil. The corn plant requires different quantities of nitrogen at different phases of its life cycle (Figure 3). The corn plant consumes approximately 5% of its total nitrogen demand between seed emergence and V6 (Richie et al., 1997).

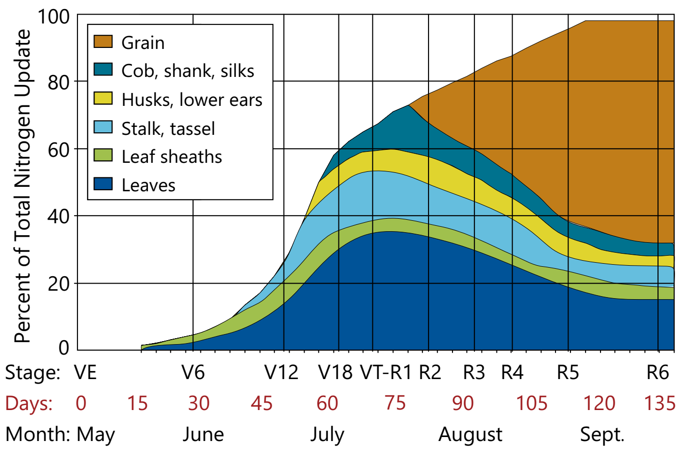


Figure 3. Nitrogen uptake and partitioning by corn. Adapted from Richie et al., 1997.

Nitrogen supply must meet or exceed nitrogen demand at the V6 and subsequent growth stages because the corn plant is determining the number of kernel rows around the ear at about V6 (Strachan, 2016). Fertility stress at this growth stage has the potential to reduce kernel rows around the ear, thus increasing the risk of limited kernel production and reduced grain yield. The corn plant acquires 20% of its total nitrogen demand between the V6 and V12 stages. Nitrogen at this growth stage supports vegetative growth and early ear development. Nitrogen consumption increases dramatically between V12 and R1. The corn plant acquires approximately 35% of its total nitrogen demand during this 3 to 4 week interval. Nitrogen at this growth stage supports completion of vegetative growth; the preparation of the ear, cob, and ovules for pollination; and establishes a reserve supply of N in the stalk and leaves to feed the maturing ear after pollination and during grain fill.

Inadequate supplies of N during V12 to V18 result in fertility stress that can reduce grain yield via two ways. First, maximum ear length and the total number of ovules (potential kernels) that can successfully receive pollen are restricted. The total number of kernels a corn plant produces accounts for approximately 85% of the grain yield (Otegui et al., 1995). Any stress that limits kernel production has a high risk of reducing grain yield. Second, during grain fill (R2 to R5) the corn plant extracts nitrogen reserves from the stalk and leaves to feed the developing kernels. Limited reserves of N in the stalk and leaves reduce the supply of N to the maturing kernels, thus reducing total kernel number or kernel weight resulting in additional risk of reduced grain yield.

The corn plant acquires the remaining 40% of its total nitrogen demand during the approximately 60 days between R1 and physiological maturity (R6). During grain fill, nitrogen supports the total number of kernels that grow to maturity and supports the increase in individual kernel weights. Approximately 15% of total grain yield is determined by kernel weight – heavier kernels result in more bushels per acre at harvest.

During R1 to R5, corn roots cannot extract sufficient amounts of N from the soil to meet kernel demand. The corn plant, therefore, remobilizes reserve N from the stalk and leaves and transfers this N to the kernels to support kernel growth. Fertility stress from inadequate amounts of N at this growth phase results in late-term kernel abortion (reduced kernel counts), smaller harvestable kernels (reduced kernel weight), and poor stalk strength, increasing the risk for lodging at maturity.

The corn plant efficiently converts both ammonium N and nitrate N into grain yield. Maximum grain yield occurs when corn roots extract 50% ammonium ions and 50% nitrate ions from soil (Midwest Labs, 2016; Shortemeyer et al., 1993). This 1:1 ratio of ammonium to nitrate optimizes the pH of corn roots and the surrounding soil rhizosphere and supports increased uptake of other essential nutrients (Blair et al., 1970). Phosphorus (HPO_4^{2-} and $H_2PO_4^-$) and sulfur (SO_4^{2-}) uptake is associated with ammonium ion uptake, and calcium (Ca^{++}) and magnesium (Mg^{++}) uptake is associated with nitrate ion uptake.

The corn plant can still meet this 1:1 demand of ammonium to nitrate if corn producers provide all or almost all nitrogen fertilizer in the ammonia or ammonium form because under warm, aerobic conditions suitable for rapid corn grown, Nitrosomonas and other microorganisms rapidly convert ammonium N to nitrate N in the soil profile. The most critical factor to consider is that grain yield correlates best with the total amount of fertilizer N applied and not with the form (NH_4^+ or NO_3^-) of N applied. Ample N must be available during all phases of corn growth to achieve maximum yield.

ENVIRONMENTS ASSOCIATED WITH LOSS OF N FERTILITY

Nitrogen can do many things in the soil environment. Your job as a corn producer is to get as much nitrogen fertilizer as you can into corn roots (the green arrows in Figures 1 and 2). One way to illustrate different methods of success is to present different programs of nitrogen fertility and to show the associated risks and benefits of each program.

Nitrogen Management Scenarios

Scenario A. A corn producer applies nitrogen as ammonia or ammonium in the fall or early spring, subsequent weather is warm and ideal for corn growth early in the growing season, and then soils become saturated due to an extended period of heavy rainfall.

There is nothing wrong with applying nitrogen fertilizer as ammonia or in the ammonium form as long as the soil cation exchange capacity and soil texture are capable of retaining this N. These two forms of nitrogen are stored in soil by binding to the cation exchange sites in the soil profile. As long as soil temperatures are cool or frozen, ammonium nitrogen remains in soil and is available for corn uptake for an extended period of time. A primary benefit of fall or early spring application to the corn producer is the opportunity to spread out his or her work load. However, the disadvantage of this practice is there is ample opportunity for nitrogen to be consumed through pathways other than crop uptake. Nitrosomonas bacteria become active as soon as the soil temperature warms up and become very active when soil temperatures approach 80° F. During the warm, early growing season, Nitrosomonas bacteria are converting ammonium N to nitrate N as rapidly as they can. During anaerobic soil conditions, such as those caused by a period of heavy rainfall, other micro-organisms, such as Nitrobacter, convert this nitrate N to nitrogen gas (N_2) as rapidly as they can. Nitrogen as N_2 gas has no fertility value to corn. With excessive rainfall, nitrate N can leave the field via surface run-off or through drain tiles, or it can be leached below the corn root zone. Corn producers may include a nitrogen stabilizer when they apply their ammonia or ammonium form of N fertilizer. A nitrogen stabilizer acts as an insurance policy by inhibiting the conversion of the soil-stable ammonium N to the more mobile nitrate N (Butzen, 2013).

Scenario B. A corn producer applies all ammonium N in one application to a sandier soil with a low cation exchange capacity.

The benefit of this program is the time savings in applying all fertilizer N in one trip. However, soils with low cation exchange capacity (CEC) do not have the capacity to hold all of the fertilizer N plus other essential cation nutrients in the root zone. Essential cations are ammonium (NH_4^+), potassium (K^+), calcium (Ca^{++}), magnesium (Mg^{++}), copper (Cu^{++}), iron (Fe^{++} and Fe^{+++}), manganese (Mn^{++}), and zinc (Zn^{++}). Some fertilizer N is, therefore, lost due to leaching below the corn root zone, thus increasing the risk for reduced corn grain yield. For fertilizers applied as anhydrous ammonia or as ammonium N, approximately 0.53 cation exchange capacity (CEC) sites per acre-furrow-slice are required to retain 150 pounds of actual N (182 pounds of ammonia or 193 pounds of ammonium N). One acre-furrow-slice is a surface acre of soil that is approximately six inches deep and weighs about two million pounds (Foth and Turk, 1972). From soil test analysis, 1 CEC = 1 meq per 100 grams of soil.

Scenario C. A corn producer side-dresses all fertilizer N into a corn field that also contains substantial corn stalk residues.

The benefit of this program is that the N is applied close to the period of maximum uptake by corn plants. However, a portion of this applied N will be consumed as residual corn stalks are degraded and is not available to support growth of corn plants currently growing. Corn stalks residing on the soil surface and remaining intact are not the immediate problem. Corn stalks that are in direct contact with the soil surface or that are buried within the soil are the immediate problem because soil microbes have ample opportunity to degrade these corn stalks. Corn

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stalks have a carbon:nitrogen ratio of about 60:1. Nitrogen from some other source (the added N fertilizer) must be supplied for proper microbiological activity. Organic materials that have a carbon:nitrogen ratio of about 20:1 to 30:1 contain sufficient N to support degradation of residues. Organic materials such as green legume residue and manure, contain carbon:nitrogen ratios of about 12:1 to 25:1 and, therefore, supply added N to the soil profile as these biological materials degrade. There is one rule that applies to all resources required for corn production, and this rule applies particularly to fertilizer nitrogen – if corn and soil microbes must compete for the same limited resource, the microbes will win.

Best-Case Scenario

The best-case scenario is to apply sufficient fertilizer N just before the corn plant demands this N during the entire corn growth cycle. From a practical perspective, this requires at least two nitrogen applications. This application program consists of some N applied just before planting in the spring or late in the fall if the weather is cool and will remain cool until corn planting time. A low amount of N applied in the fall is a good practice if planting corn on corn and there is a lot of corn stalk residue that will be degrading either before or during the growing season for the new corn crop. This nitrogen supports residue degradation, corn emergence, and early corn growth. A substantial portion of the N is applied as a side-dress after the corn has emerged. This N supports corn growth during the middle and later vegetative growth stages; provides additional N to be stored in the corn stalk and leaves for later mobilization; and supports early ear development and pollination. The third application of N should be applied sometime shortly after pollination. This N supports later grain fill by increasing the total number of harvestable kernels (reduces tip die-back) and increases individual kernel weight. Corn producers who irrigate can apply this final application of N through the irrigator. Corn producers who do not irrigate must apply this final application with a high-clearance sprayer or must apply sufficient N during the side-dress application to carry the corn plant through physiological maturity.

The benefits of this application program are: (1) corn plants have the best opportunity to extract the nitrogen fertilizer the corn producer applies, and (2) rates of fertilizer N in the later application timings can be adjusted based on crop needs. However, the disadvantage of this program is that it requires a lot of time and management at a time when many tasks are necessary and when inclement weather can interfere with field operations.

Presently, there are conflicting reports regarding the added value of the post-pollination nitrogen application. Researchers at Purdue University (Eastern Corn Belt) have shown that corn grain yield was the same when N was applied as: (1) a single treatment of 200 pounds per acre at V5, (2) a split treatment with 50 pounds of N applied at V5 and 150 pounds applied at R1, and (3) as a split treatment with 150 pounds of N applied at V5 and 50 pounds applied at R1 (Mueller and Vyn, 2017). In this study, a single side-dress treatment at V5 maximized corn grain yield. However, the researchers did comment that an R1 application timing may improve grain yield if corn was growing under environmental conditions in which the opportunity for nitrogen loss is a concern. These environments include sandier soils, fields that are frequently water-logged, fields that are fertilized via irrigation, and fields where the majority of the fertilizer N was applied during the previous fall or very early spring before the current crop of corn was planted.

Alternatively, researchers in the High Plains saw an average increase of 31 bushels per acre of corn grain yield when fields were fertilized with nitrogen at R1 to R2 (French et al., 2015). All of these fields were irrigated, and supplemental nitrogen was applied through irrigation water, so these test results are consistent with comments presented by Mueller and Vyn (2017). Researchers for the High Plains studies also addressed the improved efficiency of nitrogen fertilizer when applied in multiple applications. Their baseline efficiency was 1.3 pounds of N is required to produce one bushel of corn per acre when nitrogen fertilizer is applied as a single pre-plant broadcast application. This management program requires 260 pounds of N to support a corn grain yield of 200 bushels per acre. In their studies, the efficiency of N increased to 0.9 pounds of N to produce one bushel of corn per acre when the nitrogen fertilizer was metered over multiple timings that include a pre-plant NPK band, starter N at planting, side-dress N at V6, and fertigation at R2 (brown silk). This multiple-application management program requires 180 pounds of N to support a corn grain yield of 200 bushels per acre. This 80-pound reduction of N at an estimated cost of $0.38 per pound of N (Plastina, 2019) reduces nitrogen fertilizer costs by approximately $30 per acre.

SUMMARY

As a corn producer, your job is to maximize profit per acre. Typically, profits are highest when corn grain yields are highest. Nitrogen fertilizer is an essential nutrient that is one of the larger expenses in corn grain production. Nitrogen can do so many things in the soil environment because many different systems and organisms demand the ammonium and nitrate forms of nitrogen. An excellent nitrogen management program creates the greatest opportunities for corn roots to extract ammonium nitrogen and nitrate nitrogen from the soil.

The best nitrogen management programs are those programs that supply the nitrogen fertilizer just before the corn plants demand this nitrogen fertilizer. Corn has the greatest nitrogen demand during V6 to R1 but also has substantial nitrogen demand during grain fill (R2 to R5). Some soils and environments allow for all of the nitrogen to be applied as one application. However, for many if not most soils and environments, the best nitrogen management program includes multiple applications of nitrogen fertilizer that are metered according to corn plant demands. Time and resources required for this higher-management nitrogen fertility program must be balanced against other items, tasks, and weather conditions that must be addressed for successful corn production.

"The **BCSR** method *focuses solely* on maintaining cations at specific ratios, *without consideration* of important variables like **soil type, soil test values, crop**, and **yield potential**."

Base Saturation and Cation Exchange Capacity

Adam Gaspar, Ph.D., *Integrated Field Sciences*

SUMMARY

- Build and maintain; sufficiency level; and base cation saturation ratio (BCSR) have been the three driving philosophies driving soil fertility recommendation throughout the U.S. concerning positively charged nutrients.
- Base saturation is the sum of base cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+) held onto the soil exchange sites divided by the total cation exchange capacity (CEC) and expressed as a percentage.
- Advocates of the BCSR maintain that there is an approximate ratio of basic cations that must occupy the soil CEC or plant growth will be limited.
- The amount of Ca^{2+}, Mg^{2+}, K^+ in the soil can vary considerably depending upon the given soil's CEC and actual base saturation.
- No "ideal" ratio or range of ratios exists to improve crop production, and the BCSR methodology can lead to expensive, non-consistent fertility recommendations.
- Growers should use the build and maintain or sufficiency approach to direct their fertility management as these methodologies have been intensively tested, calibrated, and consider probability of a response.

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INTRODUCTION

Since the 1950s, there have been three philosophies driving soil fertility recommendation throughout the U.S. concerning certain base cations (Ca^{2+}, Mg^{2+}, K^+). They include build and maintain; sufficiency level; and base cation saturation ratio (BCSR). The theory of an "ideal" BCSR in the soil has been extensively discussed and used to a limited extent throughout the Midwest by some soil testing labs to guide fertility recommendations. This "ideal" soil was first suggested by researchers from New Jersey in the 1940s (Bear et al., 1945; Bear and Toth, 1948; Hunter, 1949; Prince et al., 1947) and further emphasized by William Albrecht, Professor from the University of Missouri. Their theory built upon work done by Loew and May (1901) ,which suggested that Ca and Mg should be in a 5:4 ratio for optimal plant growth. However, this theory has been a subject of great debate in terms of its utility for affecting crop yields and farmer profitability. Numerous studies have found flaws in the BCSR method and showed no proven yield increases, while a greater research base exists supporting the sufficiency and build and maintain approaches (Eckert and McLean, 1981; McLean et al., 1983). Yet, some consultants and ag retailers still use the BCSR method to guide fertility recommendations. All land-grant university fertility recommendations in the Midwest use a sufficiency or build and maintain approach. This article will discuss the theory behind the BCSR method, its applicability, if there is any value to it, and why state fertility recommendations do not endorse the BCSR method.

PHILOSOPHY BEHIND THE BCSR APPROACH

To understand the theory behind the BCSR method or specifically, the Ca:Mg ratio, one must understand cation exchange capacity (CEC). Cations are positively charged ions in the soil solution (Ca^{2+}, NH_4^+, Mg^{2+}, K^+, Na^+, etc.). CEC is defined as the total amount of cations, in milliequivalents (meq), held to soil components through an electrostatic attraction, which can be exchanged with cations in soil solution. A specific soil's CEC is dependent upon three main factors:

1. The amount of clay (soil texture)
2. Type of the clay
3. Amount of organic matter (OM)

For this reason, the CEC of a given soil can vary from 0 to 50 meq/100g soil. Soils with a low CEC typically have a high sand fraction and low OM content, whereas soils with a high CEC have a relatively high clay fraction and/or OM content (Figure 1).

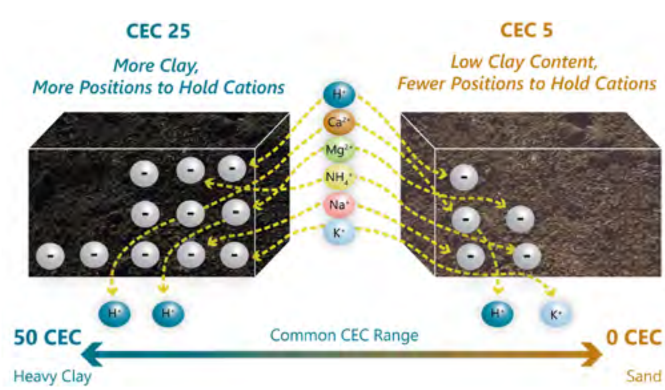

Figure 1. Depiction of the soil CEC. *Adapted from Spectrum Analytics Inc.*

Further knowledge of base saturation is critical to the BCSR method. Base saturation is the sum of base cations (Ca^{2+}, Mg^{2+}, K^+, and Na^+) held onto the soil exchange sites divided by the total CEC and expressed as a percentage. Base saturation can be described by Figure 2. For this reason, the amount of cations on the exchange sites will be limited as the soil pH decreases or becomes more acidic due to the increased amount of H^+ ions on exchange sites and in soil solution.

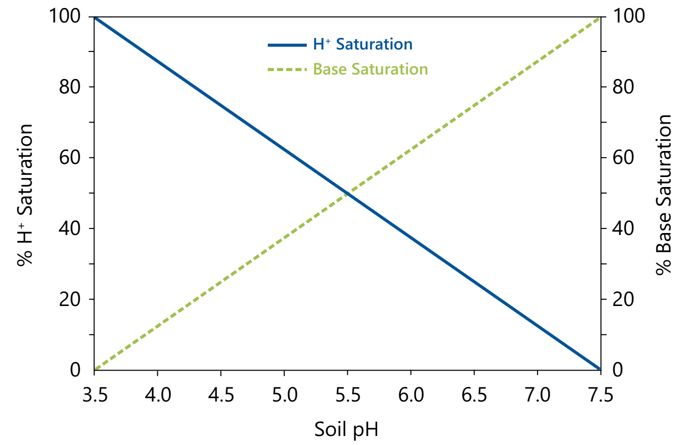

Figure 2. Relationship between base saturation and H^+ on the CEC across soil pH.

Base Cation Saturation Ratio

Advocates of the BCSR maintain that there is a ratio of basic cations (Ca^{2+}, Mg^{2+}, and K^+) that must occupy the soil cation exchange sites or plant growth will be limited. Bear et al. (1945) suggested that the base saturation of the cation exchange complex should be in specific amounts of 65% Ca^{2+}, 10% Mg^{2+}, 5% K^+, and 20% a combination of H^+, Na^+ and NH_4^+. This results in a base cation saturation ratios of 6.5:1 for Ca:Mg, 13:1 for Ca:K, and 2:1 for Mg:K, which is also expressed as 13:2:1 for Ca:Mg:K and has been termed the "ideal" ratio (Table 1). Furthermore, Bear and his colleagues mentioned that there is likely a range in the amount of Ca^{2+}, Mg^{2+}, and K^+ that can occupy exchange sites and still allow optimal crop growth. However, no such range was ever reported, and therefore, many soil testing labs took these values as absolute with no margin of error. Base saturation ranges were not reported until Graham (1959) did so and again by Baker and Amacher (1981). However, these ranges are completely based upon theory along with the work of Bear and his colleagues and not on actual field or laboratory experiments (Table 1).

Table 1. Previously reported base saturations and subsequent base cation saturation ratios (BCSR) for an "ideal" soil.

Nutrient	Bear et al. (1945)	Graham (1959)	Baker & Amacher (1981)
	Base Saturations (%)		
Ca	65	65 – 85	60 – 80
Mg	10	6 – 12	10 – 20
K	5	2 – 5	2 – 5
	Base Cation Saturation Ratios		
Ca:Mg	6.5:1	5.4:1 – 14.1:1	3.0:1 – 8.0:1
Ca:K	13:1	13.0:1 – 42.5:1	12.0:1 – 40.0:1
Mg:K	2:1	1.2:1 – 6.0:1	2.0:1 – 10.0:1

** Bear et al. (1945) is considered the "ideal" ratio.*

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The BCSR method focuses on keeping these three nutrients close to specific cationic ratios (Table 1) regardless of soil test values, soil type, crop, and yield potential. However, because the BCSR approach solely focuses on maintaining a specific ratio between Ca^{2+}, Mg^{2+}, and K^{+} (13:2:1), the amount of these nutrients in the soil can vary considerably depending upon the given soil's CEC (Table 2) and actual base saturation (Table 4).

Table 2. Comparison of 2 soils with the same base saturations but different CEC and their approximate levels of Calcium, Magnesium, and Potassium in the soil at the "ideal" ratio.

		CEC=40 meq/100g	CEC=5 meq/100g
Nutrient	Base Saturation	Estimated Soil Test Level	
	%	*ppm*	*ppm*
Ca	65	5,200	650
Mg	10	480	60
K	5	780	98
Na+H+etc.	20	--	--

For example, a soil with a CEC of 5 meq/100g soil will contain approximately 1,300 lb/acre Ca (650 ppm) compared to 10,400 lb/acre Ca (5,200 ppm) in a soil with a CEC of 40 meq/100g, both at the same base saturation of 65% Ca (Table 2). While, these levels of Ca are not detrimental to plant growth, reaching this Ca base saturation for a high CEC soil can require large and expensive fertilizer applications. For instance, if the Ca:Mg ratio is initially 5.5:1 (55% Ca and 10% Mg) and the soil CEC is 40 meq/100g, there is roughly 8,800 lb/acre Ca. Obviously, a soil with over 4 tons/acre Ca (4,000 ppm) is in excess supply, but the BCSR approach would recommend 3.6 tons/acre of gypsum to bring that soil to the "ideal" ratio of 6.5:1. At $40/ton of gypsum, this would cost approximately $144/acre on soil that is already excessively high for Ca (>1,000 ppm) as conveyed by the build and maintain approach (Table 3).

Another two soils with the same CEC, both at the "ideal" ratio, can have vastly different amounts of Ca, Mg, and K due to different base saturations of the cation exchange complex (Table 4). Displayed in Table 4 are two sandy soils with low CEC that are both at the "ideal" ratio; however, soil #2 with base saturations of 32.5% Ca, 5% Mg, and 2.5% K would contain less than optimal amounts of all three nutrients for crop production. The soil test levels would subsequently be 325 ppm Ca, 30 ppm Mg, and 49 ppm K (Table 3). All three nutrients would fall into the low-end of the low soil test category (Table 3) and, therefore, likely limit crop production even though the soil is at the "ideal" ratio. Furthermore, such a low saturation of the CEC with Ca, Mg, and K would likely lead to a pH well below 6.0 due to high saturation of H^{+} ions on the exchange sites (Figure 2). Current recommendations would suggest an application of agricultural or dolomitic lime to correct the pH. Besides raising the pH, the lime application would also move the BCSR away from the "ideal" ratio but actually improves crop production due to a more favorable pH.

RESEARCH ON THE BASE CATION SATURATION RATIO

Ratios in Wisconsin Soil

The growing environment and soil types vary considerably across Wisconsin. Schulte and Kelling (1985) quantified the Ca:Mg ratio of 17 common soil types throughout Wisconsin and found the ratio ranged from 8.1:1 to 1.0:1 (Table 5). Some of the silt loam soils like Antigo fell near 4:0.1 compared to soils with more clay, like Marathon with a ratio of 7.7:1.

Table 3. Wisconsin soil test categories for Calcium, Magnesium, and Potassium. *Adapted from Laboski and Peters (2012).*

Nutrient	Soil type	Very low	Low	Optimum	High	Very high
				Parts per million (ppm)		
Ca	Sandy	0 – 200	201 – 400	401 – 600	>600	--
	Loamy	0 – 300	301 – 600	601 – 1,000	>1,000	--
Mg	Sandy	0 – 25	26 – 50	51 – 250	>250	--
	Loamy	0 – 50	51 – 100	101 – 500	>500	--
K	Sandy	<45	45 – 65	66 – 90	91 - 130	>130
	Loamy	<70	70 – 100	101 – 130	131 - 160	161 - 190

Table 4. Comparison of two soils with the same CEC and "ideal" ratio of 13:2:1 of Ca:Mg:K but different percent base saturations and their approximate levels of Calcium, Magnesium, and Potassium.

Nutrient	Base Saturation	Estimated Soil Test Level	Base Saturation	Estimated Soil Test Level
	Soil #1		***Soil #2***	
	%	*ppm*	*%*	*ppm*
Ca	65	650	32.5	325
Mg	10	60	5	30
K	5	98	2.5	49
Na+H+etc.	20	--	60	--

** Both soils are at the "ideal" ratio.*

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Table 5. Ca:Mg ratio for various soil types throughout WI. *Adapted from Schulte and Kelling (1985).*

Soil	Ca:Mg Ratio	Soil	Ca:Mg Ratio	Soil	Ca:Mg Ratio
Antigo	4.0:1	Kewaunee	3.1:1	Pella	3.9:1
Almena	3.2:1	Marathon	7.7:1	Plainfield	6.1:1
Boone	1.0:1	Morley	4.0:1	Plano	3.3:1
Dubuque	4.0:1	Norden	8.1:1	Poygan	4.3:1
Gale	4.3:1	Onaway	6.7:1	Withe	3.5:1
Freer	3.7:1	Ontonagon	4.0:1		

Obviously, the Ca:Mg ratio will vary between soil types, but theory would suggest that the ratio should change after years of producing a crop and subsequently removing various amounts of exchangeable Ca and Mg. However, the effect of cropping was negligible and only decreased the ratio in the Boone loamy soil (Table 6). It was noted that this decrease was a result of reducing the exchangeable Ca (Schulte and Kelling, 1985).

Table 6. Effect of crop production on the Ca:Mg ratio in four WI soils. *Adapted from Schulte and Kelling (1985).*

Soil	Ca:Mg Ratio	
	Non-Cropped	Cropped
Plainfield sand	7:9:1 (850/108)†	8:7:1 (590/68)
Boone loamy sand	1:5:1 (75/50)	1:0:1 (50/50)
Gale silt loam	2:6:1 (540/206)	4:3:1 (2,040/472)
Ontonagon silt loam	3:9:1 (1,930/140)	4:2:1 (2,660/634)

†Actual pounds of exchangeable Ca/exchangeable Mg.

Effects of BCSR on Crop Production

Due to the popularity of BCSR fertility recommendations from some commercial soil testing labs, many studies were conducted in the 1970s and 1980s to test this methodology. The results from these studies have shown almost no evidence of a base cation saturation ratio effect on crop yields. In fact, the results from Bear et al. (1945) and Graham (1959) may be more attributed to the changes in soil pH when the base

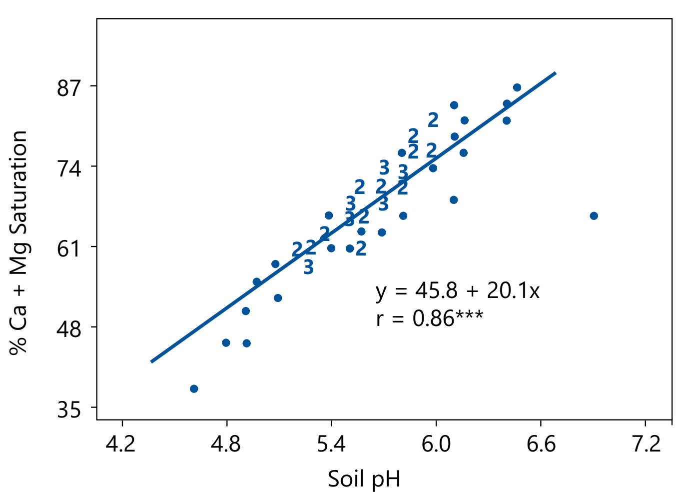

Figure 3. Soil pH and Ca+Mg relationship. *Adapted from Liebhardt (1981).*

"…the proposed "ideal" ratio corresponds with a pH slightly above 6.0, which is optimum for non-leguminous crops like corn."

saturation of Ca and Mg was adjusted to 65% and 10%, respectively, rather than the actual ratio. Liebhardt (1981) showed a direct relationship between soil pH and exchangeable Ca+Mg (Figure 3). Coincidently, the "ideal" ratio corresponds with a pH slightly above 6.0, which is optimum for growth of non-leguminous crops and may explain the increased plant growth reported by Bear et al. (1945), Bear and Toth (1948), Hunter (1949), and Prince et al. (1947). Furthermore, Liebhardt (1981) reported that there is a wide range of Ca:Mg ratios that will support corn and soybean production given K saturation is not limiting. This agrees with Key et al. (1962), who reported no effect of the Ca:Mg ratio across a CEC range of 3 to 27 meq/100g on corn and soybean yield given the ratio is not below 1.0:1, which is extremely rare in agricultural soils. Furthermore, a study in Ohio evaluated 18 different BCSR combinations over 4 years and their effect on corn and soybean grain yields (McLean et al., 1983). The results of this study identified no relationship between BCSR and grain yield, and no specific "ideal" ratio was found. Actually, there was a wide range of ratios that corresponded to the highest and lowest grain yields each year and are displayed in Table 7.

Table 7. Range of BCSRs for the five highest and lowest yields for corn and soybeans. *Data from McLean et al. (1983), and table adapted from Rehm (1994).*

Ratio	Yield Level	Ranges in BCSR			
		Corn (1975)	Corn (1976)	Soybean (1977)	Soybean (1978)
Ca:Mg	Highest Five	5.7 – 26.8	5.7 – 14.3	5.7 – 14.0	5.7 – 26.8
Ca:Mg	Lowest Five	5.8 – 21.5	5.0 – 16.1	2.3 – 16.1	6.8 – 21.5
Mg:K	Highest Five	0.6 – 3.0	1.3 – 3.1	1.0 – 3.0	1.1 – 3.1
Mg:K	Lowest Five	1.1 – 2.1	0.7 – 2.1	0.7 – 3.6	0.7 – 2.1

Simson et al. (1979) also found no effect of the Ca:Mg ratio on corn grain yield and alfalfa dry matter production at four locations throughout Wisconsin where a ratio as low as 1.0:1 was tested. They went on to further suggest that a very wide range of Ca:Mg ratio would support alfalfa and corn production. The same conclusions were found to be true for the Mg:K ratio in an irrigated sandy soil in Nebraska where the BCSR of 10.3:2.5:1.0 was altered up and down by additions of Mg and K but maintained above critical soil test values for crop production (Rehm and Sorensen, 1985). Regardless of any Mg or K application, no effect on grain yield was observed.

The only plant effect observed when altering the soils BCSR was the relative concentration of Ca, Mg, and K in plant tissue. Rehm and Sorensen (1985) found the Mg concentration of the plant increased as Mg saturation of the CEC increased, but Mg plant tissue concentration actually decreased when K saturation of the CEC increased, which agrees with McLean and Carbonell (1972). Calcium concentrations in alfalfa and corn were also found to increase when the Ca saturation of the CEC increased (Simon et al., 1979). However, even though plant uptake of these various cations (Ca^{2+}, Mg^{2+}, and K^{+}) could be altered by changing the base saturation of the soil's CEC, no yield increases resulted.

BUILD AND MAINTAIN APPROACH

Unlike the BCSR, a build and maintain approach builds fertility levels to critical soil test levels by applying fertilizer over multiple years, avoiding a one-time excessively high application rate. Once the critical soil test level is reached based upon the crop rotation and soil type, fertilizer recommendations are then based upon maintenance (annual crop removal), not keeping a specific soil cationic ratio (Laboski and Peters, 2012; Macnack et al., 2013). This concept is best illustrated by Figure 4 where the relative fertilizer application decreases as the soil test level builds. In addition, the amount of fertilizer targeted at either crop removal or soil building proportionally changes across the soil test categories. For instance, between the Very Low and Optimum categories, a rate that meets crop removal is applied plus a certain amount of fertilizer targeted to build the soil. Within the Optimum soil test category, enough fertilizer is recommended to meet only crop removal. If the soil test level moves above the Optimum category, the fertilizer application includes a reduced rate for crop removal and nothing targeted at soil building. For example, when the soil tests in the High category, the recommendations is ½ of crop removal, and when in the Very High category, only ¼ of crop removal is recommended. This helps maintain profitability when the soil test level is above optimum because yield responses to fertilizer are not as large or frequent in these categories. In summary, the build and maintain approach directs producers to keep soil test levels – the amount of Ca, Mg, and K – within an optimum range (Table 4) and then continue to fertilize the crop, not the soil, to maximize profitability throughout their crop rotation (Figure 4).

Work with your Granular CSA to define the optimal soil test range for your farm and fertilizer to build or maintain levels within that range for each nutrient.

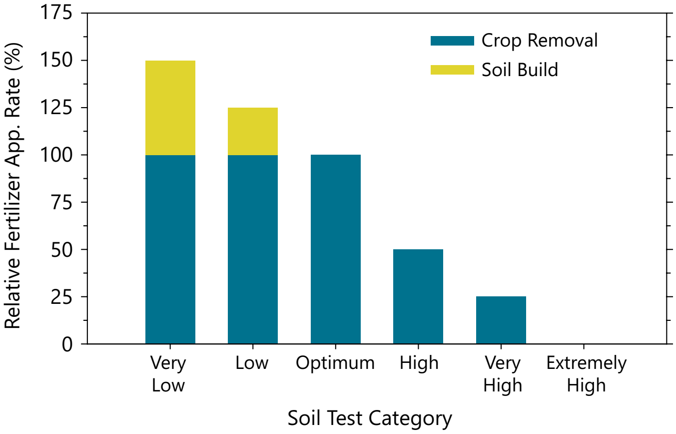

Figure 4. Theory behind a build and maintain fertility recommendation.

CONCLUSION

In summary, the BCSR approach to soil fertility was developed in the 1940s and is only based upon a handful of studies conducted in the eastern U.S. (Bear et al., 1945; Bear and Toth, 1948; Hunter, 1949; Prince et al., 1947). Unfortunately, it was incorporated into soil fertility recommendation at some soil testing labs during the 1950s and still persists with a few ag retailers throughout the country. Its methodology can lead to expensive, non-consistent recommendations that hold Ca, Mg, and K at very different levels due to a soil CEC and/or base saturation. In many cases, this can result in excessive fertilizer applications or nutrient deficiencies even though the "ideal" ratio is being held. There was considerable work done through the 1970s and 1980s to test the BCSR concept. The conclusion of all of these studies was that no "ideal" ratio or range of ratios existed to improve crop production and advised that these nutrients should be held in sufficient but not excessive levels instead of aiming for a specific ratio or base saturation (Key et al., 1962; McLean et al., 1983; Moser, 1933; Rehm and Sorensen, 1985; Simson et al., 1979).

In contrast, this article also summarizes the methodology behind the build and maintain soil fertility approach, which is backed by a larger research base with proven yield responses. In addition, this approach includes an economic aspect when creating fertility recommendations. The build and maintain or sufficiency approach is currently recommended by all universities throughout the Midwest and should be used instead of the BCSR approach by growers to employ environmentally and economically sustainable fertility programs.

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Corn Blotch Leafminer

Cody Daft, *Territory Manager, and* **Mark Jeschke, Ph.D.,** *Agronomy Manager*

SUMMARY

- The corn blotch leafminer is a sporadic pest of corn that rarely causes enough damage to affect yield.
- Larvae feed on the middle layer of leaf tissue, hollowing it out to create the characteristic blotches.
- Populations typically go through four or five generations per season, with later generations doing less damage because of the increased thickness and toughness of mature corn leaves.
- Insecticide treatments for corn blotch leafminer are not likely to be economically beneficial and may be harmful to beneficial species.

INTRODUCTION

The corn blotch leafminer, *Agromyza parvicornis*, is a native North American insect and is widely distributed throughout the United States, Canada, and Mexico. It is a minor and sporadic pest of corn, causing only minor cosmetic damage in most instances. In rare cases, outbreaks have resulted in more significant damage to corn crops. Abnormally high numbers and increased crop damage were observed in the Western Great Plains in 2010, with previous outbreaks documented in 2006 and 1995. Little research has been conducted on the biology, economic importance, and management of this pest, but inferences can be made from leafminers of other crops.

IDENTIFICATION AND LIFE CYCLE

Corn blotch leafminer has four to five generations per year in the Corn Belt. The adult emerges from an overwintering pupa in the spring to begin its life cycle. With normal temperatures, the leafminer completes its life cycle in about three weeks.

The adult corn blotch leafminer is a small, gray to black fly, about 6 mm (¼ inch) in length that looks very similar to an adult house fly. Adults feed on the leaf, and females lay eggs through the upper or lower leaf surface within five days of emerging from their overwintering stage. Each female can lay up to 100 or more eggs in its short lifespan.

The eggs are very small (0.5 mm in length) and appear translucent white. The fly larvae begin to tunnel or "mine" into the corn leaves between the upper and lower epidermis soon after they hatch. These larvae are yellow-green to white in color at the time of emergence and may become more yellow as they mature. Color is easily influenced by the green of the chlorophyll they ingest.

DAMAGE TO CORN

Larvae feed by scraping away and eating the middle layer of green leaf tissue, or mesophyll, with a pair of black mouthhooks. The void of plant cells between the leaf surfaces creates a transparent tunnel or mine where the pest can be found. This species feeds for a short time in a linear direction and then begins to feed radially, creating a "blotch" within the leaf. The total mine is usually confined within an area less than one inch long and a half inch wide. A related species, the serpentine leaf miner (found on other plant species), feeds in a long, winding, linear tunnel that may be several inches in length but only a couple of millimeters wide and does not create a blotch. Adult corn blotch leafminers feed by using their rasping-sponging mouthparts to scar the leaf tissue.

Corn leaf showing corn blotch leafminer tracks. The corn blotch leafminer larva makes a serpentine tunnel, or mine, between the upper and lower leaf surfaces.

The corn blotch leafminer's egg laying and subsequent mining are more common on lower leaves from early generations of the insect, but subsequent generations can be seen on upper leaves as well. With heavy infestations, the mines may overlap. The white of the light reflecting off the airspace within the leaves may be noted at a distance in areas of heavy infestation due to the accumulated mining activity.

As leaves age (at more mature plant growth stages), the increased thickness and toughness of the epidermis make them more resistant to egg laying. When oviposition does occur on mature leaves, larval feeding is usually only on one side of the leaf, producing the air pocket within the leaf but reducing the total amount of plant injury when compared to feeding on younger leaves.

Leaf with corn blotch leafminer adults and visible larval feeding damage (left). Larval feeding in linear and radial patterns (right). Photos courtesy of Clyde Tiffany, Field Agronomist.

POTENTIAL YIELD IMPACT

Corn blotch leafminer damage is rarely associated with economic loss, and very few studies on yield loss have been conducted with this pest. However, extensive tunneling by the corn blotch leafminer has the potential to kill leaves, create plant stress, and decrease photosynthesis due to reduction of photosynthetic leaf tissue. Damage and subsequent yield losses may be assessed as with any defoliating pest or weather condition.

Corn leaf with adult corn blotch leafminer feeding injury. Adults feed by using their rasping-sponging mouthparts to scar the leaf tissue.

A common tool for assessing yield loss associated with defoliation are tables used by hail adjusters, reproduced here (Table 1). These tables were developed to provide an estimate of yield loss associated with plant defoliation at various growth stages. The tables should be used only as a general guide because they are based on injury that affects the plant canopy randomly. Corn blotch leafminer damage may remain confined to the lower portion of the plant, which is less important to yield during the grain-fill period.

Table 1. Estimated corn yield loss due to defoliation at various growth stages.

Stage of Growth	Percent of Leaf Area Destroyed					
	10	20	40	60	80	100
8 Leaf	0	0	1	5	7	11
10 Leaf	0	0	4	8	11	16
12 Leaf	0	1	5	11	18	28
14 Leaf	0	2	8	17	28	44
18 Leaf	2	5	15	33	56	84
Tassel	3	7	21	42	68	100
Silk	3	7	20	39	65	97
Blister	2	5	16	30	50	73
Milk	1	3	12	24	41	59
Soft Dough	1	2	8	17	29	41
Dent	0	0	4	10	17	23
Mature	0	0	0	0	0	0

MANAGEMENT

Limited research has been conducted on agronomic systems and cultural practices associated with corn blotch leafminer activity and damage. Consequently, we do not have a good understanding of what role these factors play in leafminer population changes. Populations overwinter in the soil, so corn-following-corn fields may experience greater damage.

There are several species of parasitic wasps that provide a level of natural control by killing larvae within the leaf mines. The populations of these wasps are dynamic, and the level of control contributed by the wasps is not predictable. However, because of the sporadic nature of the pest, it is likely that weather or biological control agents and not crop management are the primary regulatory factors of insect population levels.

Leafminer larvae are protected by the leaf cuticle while feeding, making insecticide applications less effective at controlling them. To be most effective, insecticide applications would need to be targeted at the flies (adults) before the eggs are laid. Because of the unpredictability of economic injury and the difficulty as well as expense associated with frequent applications necessary to control flies, attempts at chemical control of this pest are not generally recommended. Insecticides may also have a negative impact on populations of parasitic wasps and predators that feed on corn blotch leafminer plus other insect pests.

As with many insects, feeding on young corn plants has been observed to be lower in fields in which seed was treated with a neonicotinoid insecticide seed treatment. Although differences in feeding have been noted, they have not necessarily been associated with differences in final yield. Corn blotch leafminer is not included on labels for these products.

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Asiatic Garden Beetle

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

PEST FACTS

Distribution

- Asiatic garden beetle (*Maladera castanea*) is a non-native species in North America that was introduced to the Northeast U.S. from Japan in the 1920s.
- Following its initial introduction, populations have spread westward through the Northeastern U.S. and parts of eastern Canada – as far as Kansas and Missouri – and southward – as far as Georgia and Alabama (Skelley, 2013).

Host Range

- Asiatic garden beetle has a wide host range – over 100 hosts are known, consisting primarily of perennial ornamentals.
- It has historically been a pest of ornamentals and turf grass but can also damage vegetables and row crops, including corn, soybeans, and wheat.
- Asiatic garden beetle is also known to feed on several common weed species, including marestail, giant ragweed, chickweed, purple deadnettle, pokeweed, and Virginia creeper (DiFonzo, 2018; Pekarcik, 2018).

Natural Enemies

- Although there are naturally occurring diseases and nematodes that affect Asiatic garden beetle, there are no major native enemies of this imported pest.

Figure 1. Asiatic garden beetle feeding may be scattered across a field, but the most severe damage is often concentrated in areas of intensive egg laying or better survival of larvae, commonly in sandy spots. Damage may be compounded by other factors affecting plant vigor.

PEST STATUS

- Asiatic garden beetle has historically been a sporadic pest of field crops.
- In recent years, however, it has become a more frequent pest of corn in Indiana, Michigan, and Ohio.

IDENTIFICATION

Larvae in the Soil

- Larvae are up to ½ inch long and can be identified most easily by the enlarged maxillary palps just behind the mouth parts. These are light-colored, fleshy appendages that appear to be in constant motion (Figure 2).
- Asiatic garden beetle larvae also have a characteristic anal slit and semi-circular raster pattern under the tail.

Adults in Soil or on Foliage

- Adults are scarab-shaped, tan- or cinnamon-brown-colored beetles with a slight iridescent sheen. They are slightly smaller than Japanese beetles (about ⁵⁄₁₆ to ⅜ inch in length).

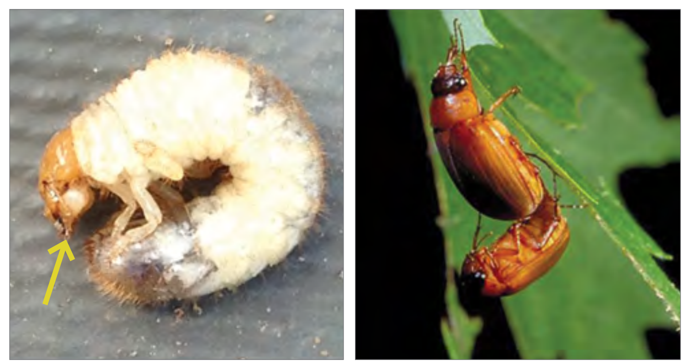

Figure 2. Asiatic garden beetle larva (left) with arrow indicating the enlarged maxillary palps and adults (right). *Beetle photo courtesy of David Shetlar, Ohio State University.*

INJURY SYMPTOMS AND IMPACT ON CROP

- Crop injury symptoms are primarily the result of larval root feeding. Symptoms closely resemble root feeding by other grub pests including annual and biennial white grubs and Japanese beetles in the spring.
- Larval feeding removes root hairs and may damage the mesocotyl between the seed and the main root system. This reduces early vigor until the affected plants can regrow an adequate root system.
- Root damage can cause stunting as well as discoloration of plants and can kill plants if severe enough. Stand losses of over 40% due to larval feeding have been observed (Pecarcik, 2018).
- Aboveground symptoms are often not visible until feeding has already been underway for several days.
- Heavy infestations are most common in sandy soils.
- Adult feeding is rarely a problem in row crops but may be noticeable on nearby vegetable or ornamental foliage as feeding on the leaves, especially at night and particularly around the leaf edges.

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Figure 3. Root damage on corn and soybean seedlings caused by Asiatic garden beetle feeding in Indiana, 2018. *Photos courtesy of Lance Shepherd, Field Agronomist*

RELATED OR OFTEN MISIDENTIFIED GRUBS

- Manure scarabs – generally smaller size, found associated with pastures or manure.
- Annual grubs, biennial grubs and Japanese beetle – generally above ½ inch in length with a different raster pattern and no maxillary palps. Asiatic garden beetle grubs are smaller and generally more active than these other common grubs.

Figure 4. Raster patterns of Asiatic garden beetle and other grubs common to field crops.

MANAGEMENT CONSIDERATIONS

Trapping

- Limited success of identifying elevated grub numbers prior to planting has been made with wireworm bait stations.
- Adult populations have also been monitored with immersion-type western bean cutworm traps.

Scouting

- Scouting for Asiatic garden beetle larvae prior to planting to identify fields at risk of damage provides the only real opportunity to protect the crop by including an insecticide at planting (MacKellar and DiFonzo, 2018).
  - » Prior to spring tillage, dig around any alternate weed hosts that are present in the field, such as marestail or giant ragweed, to look for larvae.
  - » Check freshly tilled soil during tillage operations for larvae, particularly if there are a lot of birds feeding in the tilled soil.
- Scout for Asiatic garden beetle larvae in corn by digging around plants in the field during the early vegetative growth stages to look for signs of root feeding or presence of larvae.
  - » Focus scouting on plants that appear to be suffering some sort of stress. Damaged plants often appear stunted and purplish.
  - » Asiatic garden beetle is most prevalent in fields with sandy soil, and damage often occurs in irregular patches.
  - » Root feeding ceases when larvae enter the pupal stage, typically around the end of May. Later-planted fields generally have a lower risk of root feeding damage.
- Asiatic garden beetle adults are active from June through September. They are nocturnal, attracted to outdoor lights, and feed on nearby foliage. Monitor these locations to get a sense of relative population levels in an area.

Winter Survival

- Soil disturbance may promote larval mortality and predation to a low degree; thus, no-till may be conducive to higher survival.
- Dry soils that promote desiccation are least conducive to winter survival.

Weed Management

- Asiatic garden beetles appear to have a preference for several common weed species, such as giant ragweed and marestail.
- Managing weed populations can help prevent them from acting as an attractant for egg-laying adults later in the growing season.
- Grubs feeding on weeds early in the season appear to continue feeding on the weeds even after a corn crop is established. Controlling these weeds with a herbicide application will force the feeding grubs to shift their feeding to the corn plants, which can cause a rapid escalation in damage to the corn crop.

Insecticides

- Data on insecticide efficacy for Asiatic garden beetle control in corn are limited. Insecticides labeled for corn rootworm control may provide suppression of Asiatic garden beetle. Check insecticide product labels for specific guidelines.
- Preliminary investigations suggest that high-rate insecticide seed treatments can provide protection against low to moderate feeding pressure, but further research is needed.
- Rescue treatments applied in a growing corn crop after damage has been detected are not likely to be effective.

*"**The gall midge family** includes numerous species that are **economically important pests** of agricultural crops, including **Hessian fly, wheat blossom midge,** and **sunflower midge.**"*

Gall Midge in Soybeans

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

SUMMARY

- Soybean gall midge is a new insect pest of soybeans first found in Nebraska in 2011 that has now spread to parts of Iowa, Missouri, South Dakota, and Minnesota.
- Gall midge injury in soybean is a result of larval feeding, which occurs near the base of the plant. Prolonged feeding can cause the stem to break, resulting in plant death.
- Injury is generally most severe at field edges, which suggests that populations are moving in from adjacent fields planted to soybeans the previous season.
- Yield loss reports have ranged from a 1 to 2 bu/acre to nearly total yield loss depending on how early injury occurs and the severity of the infestation in certain areas of a field.
- In 2019, populations of a second gall midge species that feeds specifically on white mold-infected plant tissue were found in soybeans in Minnesota.
- Management recommendations for soybean gall midge are still in the process of being developed. Research on soybean variety susceptibility as well as foliar insecticide and seed treatment efficacy is currently underway.

GALL MIDGE – A NEW PEST OF SOYBEAN

Soybean gall midge is a relatively new insect pest of soybean. Gall midge was first observed in soybeans in Nebraska in 2011. Initially, it appeared to be a relatively minor pest of soybeans, mostly confined to field margins and feeding on soybean plants that were already damaged or diseased. However, instances of greater infestation levels and damage to soybeans were observed beginning in 2018 with populations extending further into field interiors and feeding on otherwise healthy plants.

Very little was known up to this point about the biology of soybean gall midge, including exactly what species it was. Initial investigations identified gall midge observed in soybeans as belonging to the genus *Resseliella*, which included 15 species known to exist in the U.S., none of which were known to infest soybeans. Genetic and morphological analyses subsequently confirmed soybean gall midge to be a previously undescribed *Resseliella* species, now named *Resseliella maxima* (Gagne et al., 2019).

Figure 1. Gall midge larvae feeding in soybean stems in Iowa, August 3, 2018. *Photo courtesy of Jessie Alt, Corteva Agriscience Research Scientist.*

Soybean gall midge has now been confirmed in five states and has proven capable of causing significant crop damage as well as reductions in yield. There is still much to be learned about the biology and life cycle of this pest as well as effective management practices. The situation was further complicated in 2019 with the discovery of a second gall midge species affecting soybeans in parts of Minnesota.

FIELD OBSERVATIONS IN SOYBEANS

Gall midge damage in soybeans was first reported in Nebraska in 2011 in isolated cases mostly associated with damaged or diseased stems. Sporadic infestations were observed in subsequent years, but damage generally was not severe enough to impact yield. While remaining a relatively minor concern for soybean production, gall midge populations began to spread with feeding in soybeans first reported in South Dakota in 2015 and western Iowa in 2016.

> "There is still much to be learned about the biology and life cycle of this pest, as well as effective management practices."

Pioneer agronomists and scientists at the University of Nebraska, Iowa State University, and South Dakota State University all noted increased infestation in 2018 with infestations occurring earlier in the season and causing higher levels of damage to soybeans. Numerous infestations were observed in 2018 by Pioneer agronomists on otherwise healthy soybean plants, indicating that damaged or diseased tissue is not a necessary prerequisite for gall midge infestation. Economic levels of damage were observed again in 2019. The spread of soybean gall midge has continued with populations reported in Minnesota in 2018 and in Missouri in 2019 and expansion of affected areas in Nebraska, Iowa, and South Dakota (Figure 2).

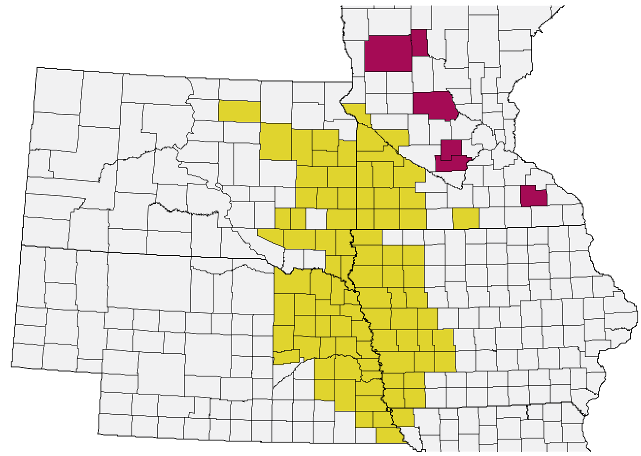

Figure 2. Counties with documented infestations of soybean gall midge and white mold gall midge (Koch et al., 2019; McMechan, 2019).

CHARACTERISTICS AND PLANT INJURY

Larvae are very small and start out white, turning bright red or orange as they mature (Figure 3). Adult midges are small (2 to 3 mm in length) and have long antennae and hairy wings (Figure 4). Gall midge injury in soybean is a result of larval feeding, which occurs near the base of the plant. Multiple larvae can infest a plant. Larvae feed inside the stem, causing swelling and abnormal growth (galls). Infested portions of the stem will appear swollen and brown (Figure 5 and 6). Discolorations of the stem often begin near the soil surface and can extend up to the unifoliate node. Prolonged feeding can cause the stem to break off, resulting in plant death.

Figure 3. Gall midge larvae feeding in a soybean stem at the soil surface in South Dakota, August 8, 2018. *Photo courtesy of Curt Hoffbeck, Field Agronomist.*

Figure 4. Gall midge adults. *Photos courtesy of Lauren Botine, Corteva Agriscience Agronomist.*

Figure 5. Galls on a soybean stem due to gall midge infestation (left). Stem girdling from prolonged feeding (right). *Photos courtesy of Jessie Alt, Corteva Agriscience Research Scientist.*

Figure 6. Galls on a soybean stem near the soil surface due to gall midge infestation in Nebraska, August 8, 2018. *Photo courtesy of Jessie Alt, Corteva Agriscience Research Scientist.*

GALL MIDGE SPECIES

Hessian fly *(Mayetiola destructtor)*, an agricultural pest in the *Cecidomyiidae* family. *Photo courtesy of Scott Bauer, USDA-ARS.*

- The term *midge* is used to refer to a broad group of small fly species, encompassing several taxonomic families. Gall midge refers to species of flies in the family Cecidomyiidae.
- Gall midges are characterized by larvae that feed inside plant tissue, resulting in abnormal plant growth (galls).
- Over 6,000 species of gall midge have been described worldwide, although the total number of species in existence is believed to be much larger. Over 1,100 species have been described in North America.
- The gall midge family includes numerous species that are economically important pests of agricultural crops, including Hessian fly *(Mayetiola destructor)*, wheat blossom midge *(Sitodiplosis mosellana)*, and sunflower midge *(Contarinia schulzi)*.
- Some species of gall midge are known to feed primarily on decaying organic matter, fungi, and molds; therefore, they tend to be attracted to damaged or diseased areas on plants.

INJURY PATTERNS IN SOYBEANS

Infestation can occur during vegetative and reproductive stages. Injury is generally most severe at field edges (Figure 7). Injury on field margins suggests fly movement from previous crop residue to new crop. Injury has also been observed next to CRP, and pastures, tree-lines, and groves. In severe cases, infestation can extend into the interior of the field.

Figure 7. Dead soybean plants due to gall midge injury along the edge of a soybean field in South Dakota, August 8, 2018. *Photo courtesy of Curt Hoffbeck, Field Agronomist.*

Depending on the severity of gall midge infestation, some soybean plants may wilt, die, or simply show signs of poor pod development and small seed size, especially in the upper ⅓ of the canopy on "healthy-appearing" green plants. Yield loss reports have ranged from a 1 to 2 bu/acre to nearly total yield loss depending on how early injury occurs and the severity of the infestation in certain areas of a field.

LIFE CYCLE

Soybean gall midge undergoes complete metamorphosis with egg, larva, pupa, and adult stages. It was believed that gall midge larvae probably overwintered in larval cocoons in the soil, similar to wheat midge *(Sitodiplosis mosellana)*. Researchers at North Dakota State University were able to confirm this using soil samples collected by Pioneer agronomists in Fall of 2018 from fields with high gall midge pressure (Figure 8).

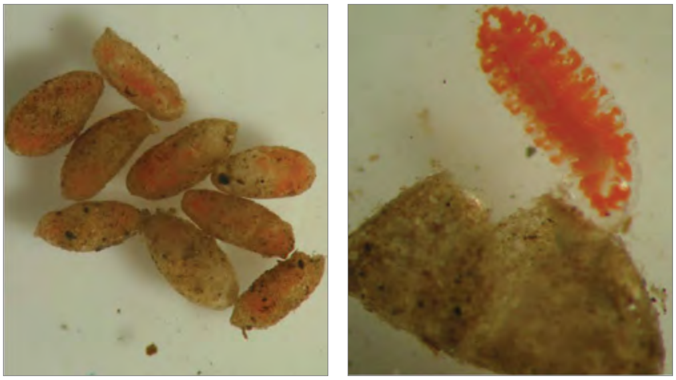

Figure 8. Soybean gall midge larval cocoons found in soil samples taken in a field with high soybean gall midge pressure (left). A soybean gall midge larvae extracted from a larval cocoon (right). *Photos courtesy of Kirk Anderson and Marion Harris, Dept. of Entomology North Dakota State University.*

Timing of adult emergence from the soil varies by geography with first adult emergence observed in mid-June in Nebraska and early July in Minnesota (Knodel, 2019). Adults have a long emergence window – overwintering generation adult emergence extended over a 17-day period in a Corteva Agriscience study in 2019 (Figure 9). Larval infestation of soybean plants was not observed prior of the V3 growth stage in 2019 studies. The current hypothesis is that at this stage of soybean growth, the stem diameter expands creating small fissures which allows the overwintering generation adults to deposit eggs into the stem. Prior to V3, the soybean stems do not have these fissures. Based on observations so far, soybean gall midge appears to go through two or three overlapping generations per year.

Figure 9. Trap set up following soybean planting to measure soybean gall midge adult emergence from the soil in 2019. *Photo courtesy of Lauren Botine, Corteva Agriscience Agronomist.*

A SECOND GALL MIDGE SPECIES IN SOYBEAN

In 2019, populations of a second gall midge species were observed in soybeans in Minnesota. These populations were identified as belonging to a different species in the gall midge family (Cecidomyiidae), *Karshomyia caulicola*, known to exist in North America and northern Europe (Koch et al., 2019). Observations of *Karshomyia caulicola* have been in fields infected with white mold and within the context of soybean management, it is now being referred to as white mold gall midge. *Karshomyia caulicola* is known to be a fungus feeder on other plant species and is likely to be feeding on white mold fungus in soybeans rather than the soybean plants. There is no evidence so far of white mold gall midge causing or spreading white mold infection.

It was determined that gall midge populations in southeast and central Minnesota previously thought to be soybean gall midge were actually white mold gall midge and that soybean gall midge was limited to the southwest corn of the state (Figure 2) (Koch et al., 2019). A population of white mold gall midge was also found in a field in northwest Wisconsin in 2019.

Larvae of white mold gall midge are very similar in appearance to those of soybean gall midge. Within the relatively limited geography in which both species of gall midge could potentially be present, the most effective way to distinguish between the two species is based on the timing and location of larval feeding. White mold gall midge feeding is specifically associated with the presence of white mold infection, so it has only been observed later in the season after flowering when infected tissue is present. White mold gall midge feeding can occur anywhere in the field where there are infected plants and anywhere on the plant where there is infected tissue.

MANAGEMENT CONSIDERATIONS

Management recommendations for soybean gall midge are still in the process of being developed. Preliminary investigations into foliar insecticide treatments have shown some promise for suppressing gall midge populations when applied at the time of pre- or early post-emergence herbicide applications to control egg-laying adults. However, these types of insecticide applications still need more thorough evaluation, and careful consideration is needed to avoid insect resistance issues with midge or other insects, and potential harm to beneficial insects.

The long emergence window of soybean gall midge adults poses a significant challenge for timing and effectiveness of insecticide application. Foliar treatments later in the season when larval feeding in the stems is already underway are not likely to be effective since the larvae are protected from exposure to the insecticide. More insecticide treatment timings, active ingredients, and rates need to be fully evaluated to determine what options are effective.

Cultural practices do not appear to have an effect on the extent or severity of infestation. Research on differences in soybean variety susceptibility to gall midge damage and insecticide seed treatment effects on gall midge is ongoing. Scouting recommendations for adult flies have not yet been developed. Scouting for adults will be challenging due to the small size of adult midges.

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Redbanded Stink Bug

Madeline Henrickson, *Agronomy Intern*

PEST FACTS

- The redbanded stink bug, *Piezodorus guildinii*, is an invasive species originating from the Caribbean Basin.
- It is more mobile than other stinkbugs and therefore, harder to control with pesticides.
- Five to eight generations may occur in one single growing season, typically having an overlap during July.
- Populations generally affect southern states more. Severity increases with warmer climates that are closer to the equator.
  - » Redbanded stink bugs (RBSB) are often deemed one of the most important hemipteran pests of soybeans in Brazil.

Adult redbanded stink bug. *Photo courtesy of Derek Scroggs, Product Agronomist.*

DAMAGE

- Adults and nymphs feed on soybean stems, leaves, and flowers but have shown an affinity for developing pods.
- Stink bugs insert their piercing-sucking mouthparts to extract sugars from the plant.
  - » Puncture wounds can be identified as small brown or black spots on plant tissues.
- When feeding is targeted at developing pods, there can be a great loss in yield due to:
  - » Reduction in seed size
  - » Flower and pod aborting
  - » Loss of quality
  - » Predisposition to infection via pathogens
- Feeding usually begins near field borders, especially around tree lines, but due to the mobility of this pest, infestations can pop up quickly in any area.
- Redbanded stink bugs are typically considered a late-season pest because they specifically target pod development.
- Increased mobility allows for this pest to move back into a field and re-infest after a pesticide application has been made.
  - » Because of this, it is recommended to scout fields once a week in areas that are known to contain this species.
- Economic thresholds differ by state, growth stage, and price of the affected commodity.

IDENTIFICATION

- It is important to correctly identify the redbanded stink bug to establish accurate population numbers for determining economic thresholds.
- Other stink bugs have the potential to cause similar damage. However, redbanded stink bugs are highly mobile; therefore infestations and crop damage can occur more quickly than with other species.

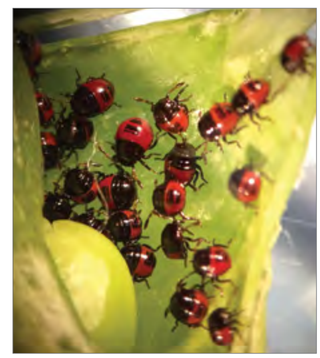
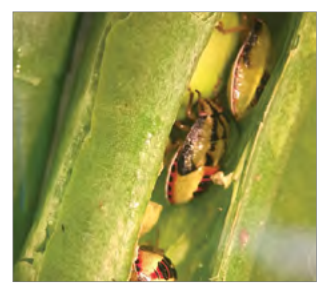
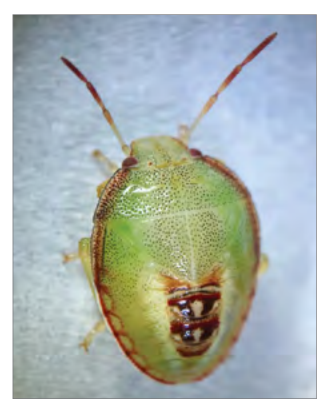
Redbanded stink bug eggs. *Photo courtesy of Brewer Blessitt, Agronomy Manager.*

Eggs

- Redbanded stink bug eggs are distinct from other stink bug eggs in appearance and orientation.
  - » They are darker in color and barrel-shaped.
  - » Eggs are typically laid in tight clusters or parallel rows on pods, stems, or the underside of leaves.

Nymphs

- Redbanded stink bug nymphs have thick stripes on the dorsal surface of their abdomen, but this is mainly centered in the middle and does not run all the way across the surface.
- Nymphs often remain gregarious, grouping together at feeding sites where plant tissues are softer and causing minimal harm. In the later instars, they begin to disperse and cause more damage.
- Younger instars have black heads and pronotums. Bodies are red in color with black bands in the center of the back.
- Later instars become green with green and black dorsal stripes on the abdomen.

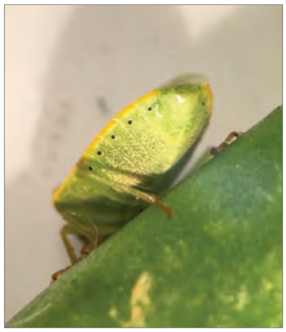





Redbanded stink bug nymphs. *Photos courtesy of Jennifer Carr, Univ. of Florida, Bugwood.org.*

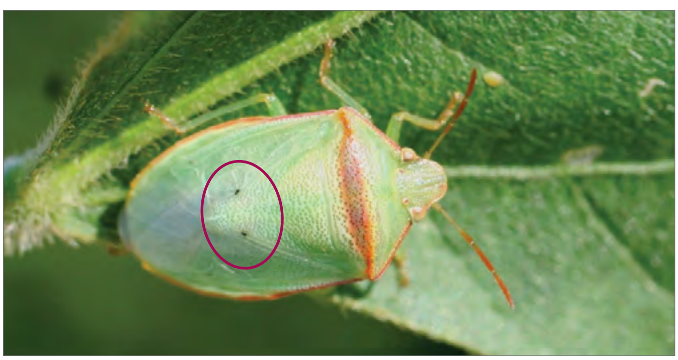
IDENTIFICATION (CONTINUED)

Adults

- The main identifying characteristic is a fixed abdominal spine on the underside of the abdomen.
  - » This is typically difficult to spot, especially in a field-scouting setting.
- They typically appear more slender than the green or southern green stink bugs.
- The red-shouldered stink bug has a flatter finish when compared to the redbanded stink bug.
- On adults, two small, black dots on the back of the redbanded stink bug can be a good identifying characteristic.
- Redbanded stink bugs are smaller in size than similar looking species (Figure 1).
  - » A general rule of thumb is that they are half the size of other stink bugs.



Redbanded stink bug adults. *Photos courtesy of Jennifer Carr, Univ. of Florida, Bugwood.org.*



Two black dots on the back of a RBSB highlighted with a red circle. *Photo courtesy of Russ Ottens, University of Georgia, Bugwood.org.*

Size Comparison of Stink Bugs

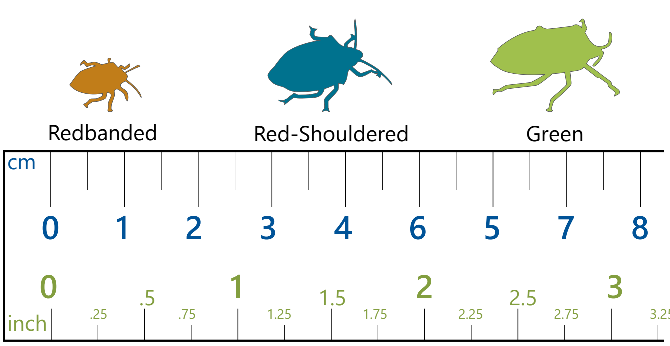


Figure 1. The size of adult stink bugs is an important differentiator in identification. Pictured above are the sizes of stink bugs to demonstrate the smaller size of the redbanded sink bug in comparison.

LOOK-A-LIKES

Red-Shouldered Stink Bug

- Easiest species of stink bug to misidentify as the redbanded stink bug.
- If a red band is present, it typically extends from one pointed shoulder to the other.
- The overlapping wings are darker than those of the redbanded stink bug.

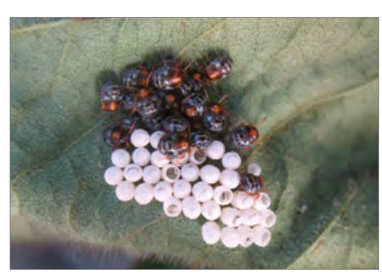
Red-shouldered stink bug. *Photo courtesy of Herb Pilcher, USDA ARS, Bugwood.org.*

Southern Green Stink Bug

- Red bands are often seen on antennae.
- Southern green stink bugs have a rounded abdominal spine.

Green Stink Bug

- Usually has solid green coloration
- Wing covers will rarely have small spots or marks.



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Thistle Caterpillar

Madeline Henrickson, *Agronomy Intern*

PEST FACTS

- Thistle caterpillar (*Vanessa cardui*), also known as the painted lady butterfly, is a sporadic pest of soybeans in the U.S.
- *Vanessa cardui* does not overwinter in the Corn Belt but migrates north from southern states and Mexico each year.
- Thistle caterpillar larvae have a wide host range that includes up to 300 plant species.
- Larvae feed on soybeans for two to six weeks before pupating, feeding preferentially on earlier planted soybeans.
- In most of the Northern Corn Belt, *Vanessa cardui* is bivoltine, meaning it has two generations per year.
- *Vanessa cardui* is predated on by ants, spiders, parasitic wasps, birds, and bats.

DAMAGE

- Characteristic webbing and leaf rolling indicate the presence of thistle caterpillar (Figures 1 and 2).
- Higher populations can be found near field borders because of closer proximity to plants with a high nectar content.
- Most feeding occurs in the final two larval instars.
- Larvae feed primarily on softer tissue in the upper canopy but can be found anywhere on the plant.
- The economic threshold for thistle caterpillar defoliation is 30% in vegetative soybeans and 20% in reproductive soybeans (Rice and Hodgson, 2017).

Figure 1. Thistle caterpillars feeding on the upper canopy.

Dark frass (droppings) inside of the webbing can be another indicator of this pest. In Figure 2, frass is seen to the left of the caterpillar.

Figure 2. Thistle caterpillar inside of unrolled soybean leaf.

IDENTIFICATION

Larvae

- **Coloration of larvae is incredibly variable, ranging from gray-brown (Figure 3) to creamy white (Figure 4).**
- **A yellow strip running down the back may be visible on some caterpillars but will not be present on every one.**
- **Branching spines along the body are easy to spot and characteristic of this species.**

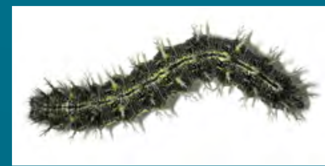

Figure 3. Darker-colored thistle caterpillar.

Figure 4. Lighter-colored thistle caterpillar.

Figure 5. Painted lady butterfly displaying forewings and hindwings.

Moths

- **Adults can vary in coloration but have a few distinguishing features.**
- **Forewings have a black patch and a white bar on the leading edge.**
- **Hindwings have a row of five small, black spots.**
- **Undersides of wings are mottled with brown, gray, and black, and have four eyespots (Figure 6).**

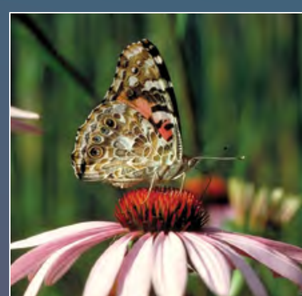

Figure 6. *(Left)* Painted lady butterfly displaying wing underside.

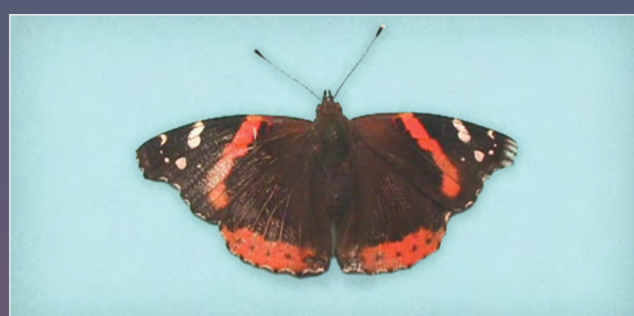

Figure 7. A painted lady butterfly with darker coloration. Note presence of identifying features.

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Three-cornered Alfalfa Hopper

Madeline Henrickson, *Agronomy Intern*

PEST FACTS

- Three-cornered alfalfa hopper, *Spissistilus festinus,* is part of the Membracidae, or tree hopper family.
- Both nymphs and adults have piercing-sucking mouthparts.
- It was first discovered and identified in 1831.
- Although it has a wide host range, it shows a preference for leguminous species and is an occasional pest of soybeans.
- *Spissistilus festinus* is established in the Southeastern and Mid-Southern U.S.
- Adults typically fly within or just above plant canopies.
- Some studies suggest that populations tend to be greater in no-till or reduced-tillage systems.

Spissistilus festinus female *(left)* and male *(right)*. Note red coloration on the pronotum.

IDENTIFICATION

- Both adults and nymphs are wedge-shaped and triangular when viewed from above.
- The "three corners" can be observed from the two points at each shoulder and one at the apex of the pronotum.
- Adult bodies are typically very small, 6 to 7 mm long.
- Coloration on mature adults ranges from green-brown to vibrant green.
- Nymphs have lighter-colored dorsal spines to deter predators.
- Females are distinguishable from males because they have an ovipositor that deposits eggs directly into plant material, whereas males have a red tint on the edges of their pronotum.

LIFE CYCLE

- Eggs are laid within plant tissue either singly or in small clusters.
- Feeding typically starts in other crop and non-crop species before progressing to soybeans.
    - » Examples include cotton, clovers, dock, wild geraniums, sunflowers, tomatoes, etc.
- As the season progresses, the pest beings to move towards soybeans.
- *Spissistilus festinus* can overwinter as eggs in plant tissue or as adults under cover.

DAMAGE

- *Spissistilus festinus* is a phloem feeder, meaning it sucks the sugary sap out of the plant.
- The removal of nutrients and sugars impedes growth of the plant.
- Feeding can occur sporadically on tissues or in a ring around the circumference of the stem.
- The series of lateral punctures can cause a girdle, preventing the plant from transporting nutrients.
- Girdles diminish structural integrity of the targeted stems and petioles, making them more susceptible to their environment.
- Weakened plants may snap and lodge; severity depends on population and growth stage.
- Wounds caused by feeding can also predispose the plant to pathogen attack.

Stem breakage and lodging due to circumferential feeding and girdling of the plant. Note the bulge where photosynthates have accumulated.

MANAGEMENT CONSIDERATIONS

- There is no universal economic threshold that has been developed for this pest.
- Some states recommend treatment after 50% or more of seedling plants are girdled during early infestation.
- During reproductive stages, a treatment threshold of one hopper per sweep (100 per 100 sweeps) is sometimes recommended.
- In Tennessee, treatment for hoppers is recommended when 10% or more of plants less than 10 to 12 inches tall are infested.
- Consult your local university recommendations for best management practices.

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Monitoring Soybean Cyst Nematode HG Types in the Eastern Corn Belt

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

BACKGROUND AND RATIONALE

- Soybean cyst nematode (SCN; *Heterodera glycines*) is a major yield-reducing pathogen of soybean production in North America. It has spread to practically all important soybean production areas of the U.S. and Canada and is reaching economic levels in more areas.
- SCN may decrease yields substantially without inducing obvious symptoms. Studies have shown that in SCN-infested fields, yields can be reduced by over 30 percent without visible aboveground symptoms.
- The most important management tactic for SCN during the years since its establishment as a yield-limiting pest in North America has been selection of soybean varieties with genetic resistance to SCN.
- Most resistant soybean varieties use the resistance source PI 88788. However, SCN types that can overcome PI 88788 resistance are becoming more widespread throughout the Eastern Corn Belt.
- SCN populations are genetically diverse and have historically been separated into races by their ability to reproduce on soybean tester lines. However, a newer classification system called the *HG type test* has been widely adopted. The term *SCN race* referred to individual nematodes, but *HG type* reflects the entire population found in a field.
- Results of the HG type test indicate on which resistance sources a population of SCN found in a field would still be able to feed and reproduce (Table 1). For example, an HG Type of 2 means the population can reproduce on PI 88788 soybean varieties while HG Type 1.2 can reproduce on both PI 88788 and Peking varieties. Type 0 is well controlled by all resistance sources, including PI 88788 (Tylka, 2006).

Table 1. Indicator lines for HG type classification of SCN.

	Indicator Line		Indicator Line
1	PI 548402 (Peking)	5	PI 209332
2	PI 88788	6	PI 89772
3	PI 90763	7	PI 548316
4	PI 437654 (Hartwig)		

OBJECTIVES

- In order to determine how to best steward the SCN resistance traits, Pioneer field agronomists sampled soybean fields across the Eastern Corn Belt in 2018 and 2019 to detect the presence and HG type of SCN populations.

STUDY DESCRIPTION

- In 2018, soil samples were taken from Pioneer soybean product knowledge plots across Illinois, Indiana, Ohio, and Michigan.
- Samples were submitted to the University of Illinois Plant Clinic for Mini HG tests. The Mini HG test uses the three tester lines that are available in commercial soybean varieties: PI 548402 (Peking), PI 88788, and PI 437654 (Hartwig or CystX). A female index (FI) is calculated by comparing reproduction on the resistant line to that of a susceptible cultivar, 'Lee.' A FI over five indicates resistance.
- In 2019, samples were collected again from the original geography plus from New York and Pennsylvania.

RESULTS - 2018

- 65% of samples were HG Type 2, indicating increased ability to reproduce on varieties with PI 88788 resistance (Table 2).
- 5% of samples were HG Type 1.2, indicating increased ability to reproduce on varieties using both PI 88788 and Peking resistance (Table 2).

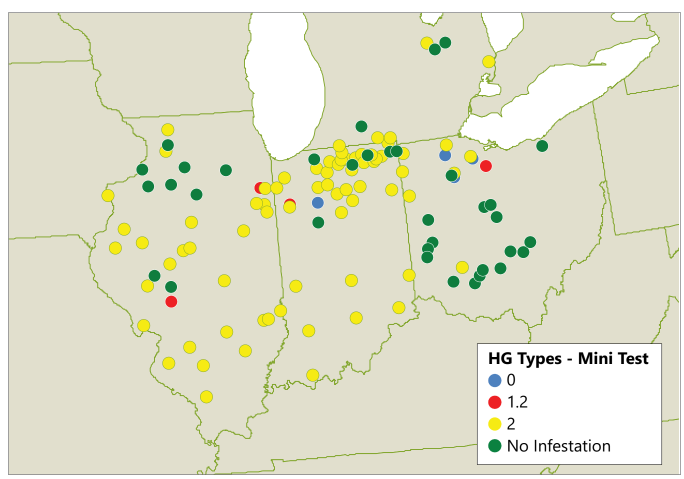

Figure 1. Distribution of HG types found in soybean plots in 2018.

Table 2. 2018 SCN survey HG type results.

SCN HG Type	Number of Locations
No Infestation	37
Type 0	5
Type 1.2	5
Type 2	86
Total	**133**

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PRELIMINARY RESULTS - 2019

- As of November 2019, egg counts had been completed for submitted samples.
- SCN infestations were found widely throughout the Eastern Corn Belt.
- SCN infestations were generally higher in Illinois, Indiana, and Michigan than in Ohio, Pennsylvania, and New York.
- Samples with more that 40 eggs per 100 cc of soil will be tested to determine HG Type with results expected in early 2020.

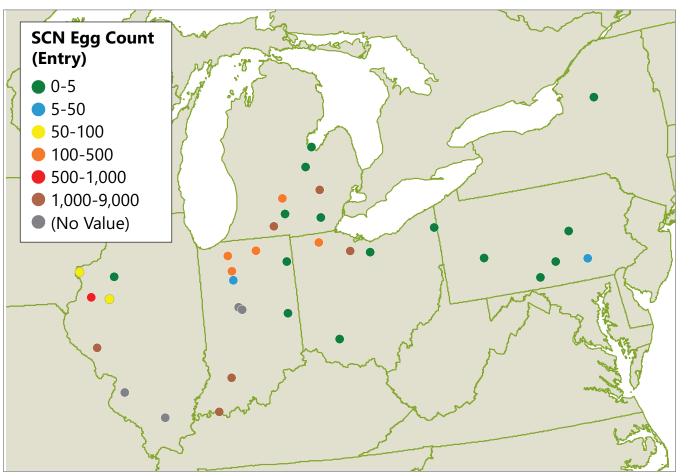

Figure 2. SCN egg counts by location in 2019.

CONCLUSIONS

- SCN populations capable of overcoming PI 88788 resistance are found in the Eastern Corn Belt.
- Although strong yields are still possible from soybean varieties using PI 88788 resistance, this trait needs to be stewarded in order to preserve it for future use.
- Fewer SCN populations can overcome Peking resistance, but there are some present in the Eastern Corn Belt. Stewardship of Peking resistance needs to start now.

What You Can Do:

- Test soybean fields for SCN.
- If no infestation is found, use good management practices, and rotate a combination of resistant or susceptible varieties in the field.

If SCN is Found:

- Rotate to non-host crops, such as corn.
- Consider using a nematode protectant seed treatment, such as ILeVO®.
  - » Nematicide seed treatments are intended to supplement current SCN management strategies, not replace them. Seed treatments should, therefore, be used in coordination with SCN-resistant varieties and rotation to non-host crops (Bissonnette and Tylka, 2017).
  - » The LumiGEN™ system offering includes ILeVO® fungicide/nematicide seed treatment, which has activity against SCN.
  - » A Pioneer study, including 193 on-farm trial locations, found an average yield response of 4.9 bu/acre in high SCN fields when ILeVO fungicide/nematicide seed treatment was added to the standard fungicide and insecticide seed treatment package (O'Bryan and Burnison, 2016).
- Control alternate weed hosts, such as henbit, purple deadnettle, field pennycress, shepherd's purse, small-flowered bittercress, and common chickweed.
- Rotate resistant varieties.
  - » If you have Type 0 SCN, change varieties in a field each soybean rotation.
  - » If you have Type 2 or Type 1.2 SCN, consider rotating to a Peking-source variety every other soybean rotation if agronomically appropriate Peking varieties are available.
  - » Twelve Pioneer® brand A-Series soybean varieties with Peking resistance are available for the Eastern Corn Belt for 2020.
  - » Variety and resistance source rotation is even more important in continuous soybean production.
- Consult your university soybean extension specialist for specific management recommendations for your state.

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Achieving 100 bu/acre Yields in Soybeans

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

INCREASING YIELDS IN SOYBEANS

- Improvements in genetics and management have driven substantial gains in soybean yields in the U.S. over the past 50 years, at a rate of 0.48 bu/acre/year (Figure 1).
- U.S. average soybean yields topped 50 bu/acre for the first time in 2016 and again in 2018.

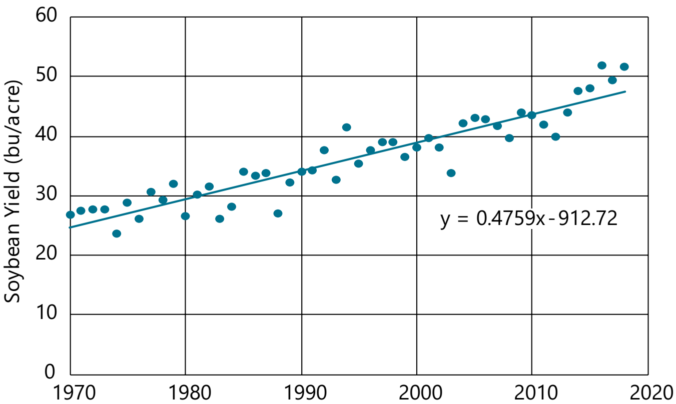

Figure 1. U.S. average soybean yields, 1970-2018 (USDA-NASS).

- 100 bu/acre has often served as a target yield level for farmers seeking to see how high they can push yields with optimized management and the newest genetics.
- Across all of the on-farm genetic and agronomic trials Pioneer conducts each year in the U.S. and Canada, it has not been unusual for a few entries each year to top 100 bu/acre.
- In 2018, however, the number of plots exceeding 100 bu/acre increased dramatically. The majority of these plots were planted to new Pioneer® brand A-Series soybean varieties (Figure 2).

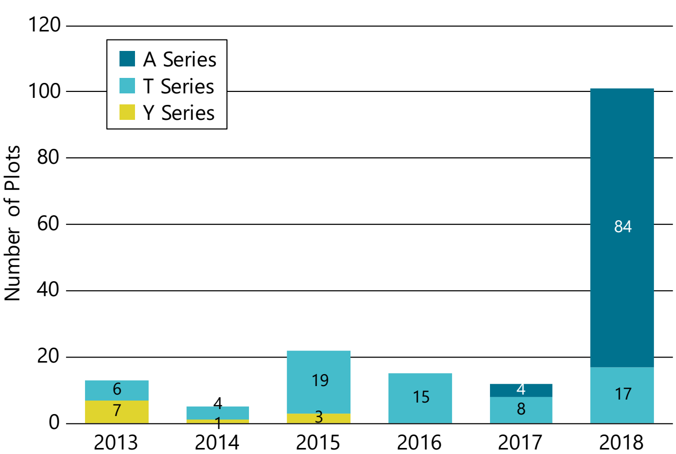

Figure 2. Series of Pioneer brand soybean varieties used in Pioneer on-farm trial entries exceeding 100 bu/acre, 2013-2018.

PIONEER ON-FARM TRIAL RESULTS

- A total of 101 on-farm soybean trial entries exceeded 100 bu/acre in 2018, 84 of which were planted to A-Series soybean varieties (Figure 2).
- 100 bu/acre was achieved with 35 different Pioneer brand varieties from maturity group 2.3 to 5.2 (Table 1).
- Yields over 100 bu/acre were achieved over a relatively wide geography from 2013 to 2018, including 17 U.S. states and 2 Canadian provinces.

Table 1. Pioneer brand soybean varieties used in 2018 Pioneer on-farm trial entries exceeding 100 bu/acre.

Variety/Brand[3]	Plots	Variety/Brand[3]	Plots
P23A15x (RR2X)	1	P37A69x (RR2X)	3
P24A80x (RR2X)	3	P37A78x (RR2X)	1
P25A54x (RR2X)	1	P37T51PR (Plenish, R)	1
P25A70R (R)	2	P38A98x (RR2X)	3
P26A61x (RR2X)	1	P38T42R (R)	1
P27A17x (RR2X)	1	P40A47x (RR2X)	11
P27T59R (R)	8	P40T84x (RR2X)	1
P28A94x (RR2X)	1	P42A52x (RR2X)	4
P28T71x (RR2X)	4	P42A96x (RR2X)	7
P29A25x (RR2X)	5	P44A72BX (BOLT, RR2X)	1
P31A22x (RR2X)	16	P44T63R (R)	1
P33A24x (RR2X)	5	P45A23x (RR2X)	1
P33A53x (RR2X)	3	P46A16R (R)	1
P33T72R (R)	1	P46A57BX (BOLT, RR2X)	1
P35A33x (RR2X)	1	P48A60x (RR2X)	4
P35A91BX (BOLT, RR2X)	2	P49A34x (RR2X)	1
P36A18x (RR2X)	2	P52A26R (R)	1
P37A27x (RR2X)	1		

PIONEER® BRAND SOYBEAN VARIETIES TOPPING 100 BU/ACRE IN ON-FARM TRIALS IN 2018 INCLUDED:

- 27 varieties with Roundup Ready 2 Xtend® Technology
- 8 varieties with glyphosate tolerance
- 3 varieties with BOLT® Technology
- 3 varieties with Peking SCN resistance source (P25A70R, P27A17x, P27T59R)
- 1 Pioneer® brand Plenish® high oleic soybean variety

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AGRONOMIC PRACTICES

- 100 bu/acre yields were achieved in a range of different environments and with a range of different agronomic practices.
- Analyses of management practices used in yield contest winners in other crops have produced similar findings (Jeschke, 2019), indicating that there is no single one-size-fits-all formula for achieving high-yield potential.

Previous Crop

- The vast majority of 100 bu/acre plots were planted to corn the prior season – 155 of 168 – while 9 were planted to soybeans and 4 to another crop (data not shown).

Tillage

- The most common tillage system used at locations with 100 bu/acre plots was conventional tillage, followed by no-till (Figure 3).

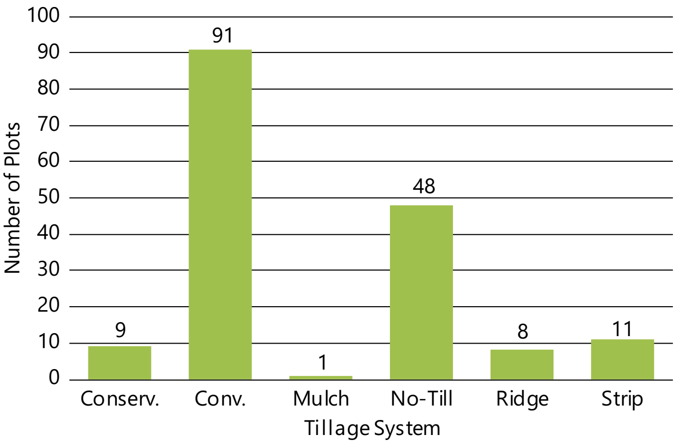

Figure 3. Tillage practices used in Pioneer on-farm trials with entries exceeding 100 bu/acre, 2013-2018.

Seeding Rate

- Seeding rates used in plots yielding above 100 bu/acre ranged from 110,000 seeds/acre to 200,000 seeds/acre, with an average of 157,000 seeds/acre (Figure 4).

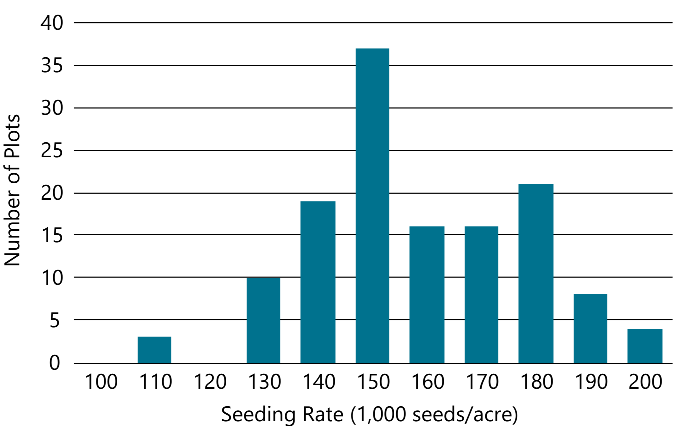

Figure 4. Seeding rate used in Pioneer on-farm trials with entries exceeding 100 bu/acre, 2013-2018.

- Average seeding rate was slightly higher among no-till locations (159,000 seeds/acre) than conventional-till locations (152,000 seeds/acre).
- Seeding rates differed among the 4 states with the most 100 bu/acre plots:
  - » The average seeding rate across Illinois and Indiana locations was 149,000 seeds/acre.
  - » The average seeding rate across Kansas and Nebraska locations was 170,000 seeds/acre.
- Seeding rates in Kansas and Nebraska are similar to those documented in a larger, multi-year survey of high-yield soybean production in these states, which found an average seeding rate of 174,000 seeds/acre (Propheter and Jeschke, 2017).

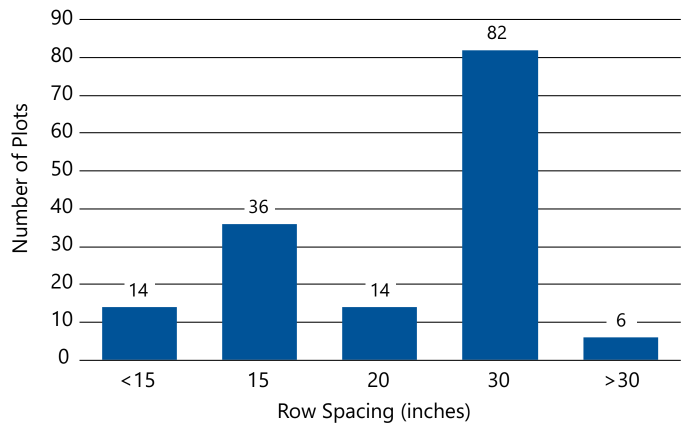

Figure 5. Row spacing used in Pioneer on-farm trials with entries exceeding 100 bu/acre, 2013-2018.

Row Spacing

- Over half of the 100 bu/acre plots were planted in 30-inch rows with most of the rest in 15-inch rows or other narrow row configurations and a few in rows wider than 30 inches (Figure 5).
- Geographic distribution of row-spacing practices roughly corresponded with findings of recent USDA surveys, with 30-inch rows most common from Illinois west and narrower rows more common from Indiana east (Jeschke and Lutt, 2016) (data not shown).

Planting Date

- Recent research has shown the importance of early planting for maximizing soybean yields (Van Roekel, 2019). Most trial locations with 100 bu/acre plots were planted in the latter half of April through the first half of May (Figure 6).

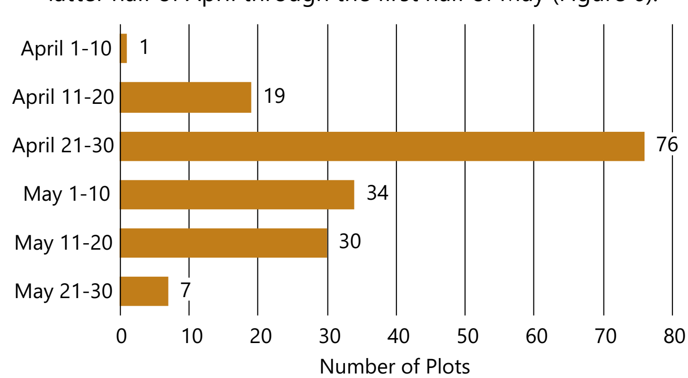

Figure 6. Planting date of Pioneer on-farm trials with entries exceeding 100 bu/acre, 2013-2018.

Other Practices

- Other management practices employed at locations with 100 bu/acre plots included foliar fungicides, foliar insecticides, and supplemental nitrogen applications.

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Management of Late-Planted Soybeans

Madeline Henrickson, *Agronomy Intern*

INTRODUCTION

- Continuous rain during spring months can saturate fields, causing severe delays in the timeliness of planting.
- As crop planting is postponed, the development of the crop is set back, making the management of some field pests crucial.
- Smaller crops are more vulnerable to pests, making scouting very important.
- This article will cover a brief overview of a selection of pests that might pose a risk to late-planted soybeans as well as management practices, when applicable.

Before using pesticides, consider the following:

- Percent of leaf area affected/damage inflicted
- Corn growth stage
- Cost of treatment
- Expected value of the crop

INSECTS

Defoliating Insects

- Insects that defoliate small and vulnerable plants may pose more of a threat in growing seasons with late planting.
  - » Defoliating can cause significant damage to plants that are already behind on vegetative growth (Figure 1).
- Bean leaf beetle pod feeding can also cause significant damage.
- If insects are present and feeding and defoliation exceeds 30% of the leaf surface area, treatment may be necessary (Hunt et al., 2016).
- Common pests that defoliate soybeans are bean leaf beetles, Japanese beetles, Mexican bean beetles, a variety of caterpillars, etc.

Figure 1. Bean leaf beetles feeding on soybean, can vector bean mottle virus.

Skeletonization of soybean leaf due to Japanese beetle feeding.

Soybean Aphid

- Aphids pose a threat to soybeans from May to August.
- Piercing-sucking mouthparts damage already stressed soybeans and can vector viruses.
- Females are parthenogenic, meaning they can reproduce without mating, causing infestations to progress rapidly.
- There are many beneficial organisms that are natural enemies to aphids and can suppress their numbers.
- The economic threshold for aphids is 250 per plant; monitoring their numbers is crucial to proper management.

Ladybird beetle predating on aphids.

Close up of soybean aphid.

Stink Bugs

- Found throughout the temperate and tropical areas of the world
- Stink bugs are most problematic when appearing in soybean fields during pod fill and maturation.
- Feeding may cause delayed maturity, green stem, and abnormal pods. Seeds fed upon may be shriveled, deformed, undersized, or aborted.
- Late-planted and late-maturing soybeans are at a particular risk.
- Fields with broadleaf weed growth, especially shepherd's purse, may be more susceptible; field margins can contain higher numbers.

Brown stink bug showing piercing-sucking mouthparths below head and between legs.

Soybean Podworm – Corn Earworm

- Corn earworm can also feed on soybean foliage and pods, and is referred to as soybean podworm on these occasions.
- Open canopies of late-planted crops can serve as egg-laying sites.
- If defoliation reaches 20% or more during pod fill or 5 to 10% of pods are damaged, then treatment is justified (Bailey, 2014).

Soybean podworm feeding on soybean.

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DISEASES

Rhizoctonia Root and Stem Rot

- *Rhizoctonia solani* is a soilborne fungus that infects the roots and stems of soybeans.
- Overwinters as survival structures called sclerotia.
- Symptoms of this disease are rusty brown, dry, sunken lesions on stems and roots near the soil line.
- Soybeans can also appear stunted, chlorotic, and wilted as a result of root decay.
- This pathogen is favored with high soil moisture and warm soil temperatures, 81 °F (27 °C).
    - Because of this, it is common in late-planted soybean fields.

Red discoloration at soil line due to Rhizoctonia solani.

Cankers in roots due to rhizoctonia root rot.

Close up of red discoloration due to Rhizoctonia solani.

Phytophthora Root and Stem Rot

- Caused by the soil borne fungus *Phytophthora sojae* (also known as *Phytophthora megasperma* f.sp. *glycinea*)
- Associated with wet soil conditions
    - Commonly occurs on heavy, poorly drained or compacted soils
    - May occur on any soil saturated for an extended period of time
- Displays seed rot, seedling blight, and root/stem rot phases

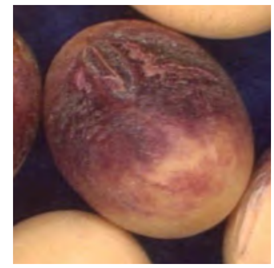
Phytophthora infected soybean on right, compared to a healthy soybean on the left. Note the dark brown lesion.

Soybean plants wilted due to Phytophthora rot.

Cercospora Leaf Blight and Seed Stain

- Caused by the fungal pathogen *Cercospora kikuchii*, which attacks both the leaves and the seeds of soybeans
- Favored by warm, wet conditions
- Disease is spread as spores are blown or splashed onto soybean plants from infected residue, weeds, or other soybean plants.
- Leaves will have a general bronzing to purpling discoloration.
- Seeds are infected through their attachment to the pod. Infected seeds may show a pink to pale or dark-purple discoloration.

Bronzing on leaves due to Cercospora.



Cercospora seed stain on soybean.

Frogeye Leaf Spot

- Frogeye leaf spot, *Cercospora sojina*, is most common in the mid-South, Mississippi Delta, and southeastern soybean growing areas.
- Disease development is favored by warm, humid conditions; frequent rains following disease onset can lead to serious epidemics.
- The center of lesions become light brown to light gray, and the border remains dark.

Frogeye leaf spot on soybean.

Viruses

- An increase in vector populations can increase the chance of viral infections in soybean fields.
    - Soybean mottle virus is vectored by bean leaf beetle.
    - Soybean mosaic virus is vectored by aphids.

Soybean leaf with symptoms of bean mottle virus.

Aphid feeding on soybean leaf.

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White Mold of Soybeans

Madeline Henrickson, *Agronomy Intern*

SCLEROTINIA FACTS

- White mold, also known as Sclerotinia stem rot, is caused by the fungus *Sclerotinia sclerotiorum*.
- Soybean is just one out of hundreds of known hosts for this soil-borne plant pathogen.
- White mold can infect soybeans across a wide geography with favorable climatic conditions for disease establishment, including several northern and near-northern states in the U.S. and Ontario as well as Quebec in Canada.
- Infection is favored by wet and cool conditions during flowering. Dense canopies with high moisture and temperatures ranging from 68 to 78 °F (20 to 25 °C) are conducive for disease development.

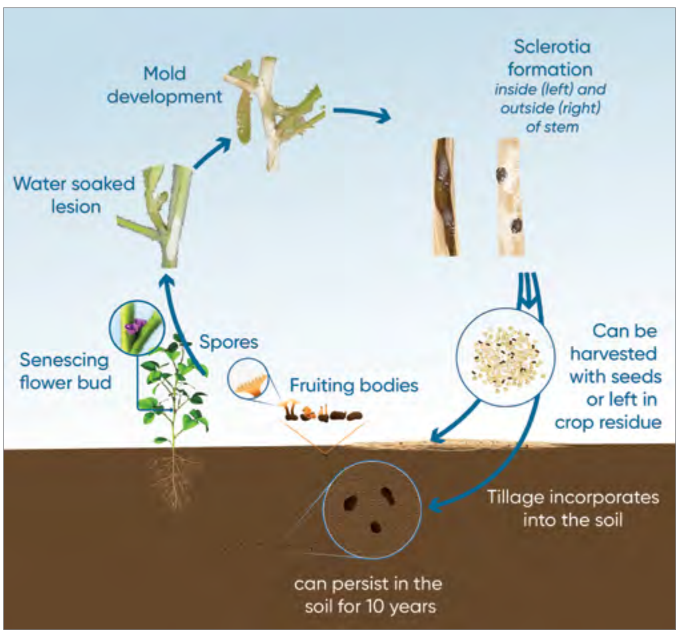

Figure 1. White mold life cycle in soybeans.

PATHOGEN LIFE CYCLE

- White mold can persist for years in soil via structures of hardened mycelial masses called sclerotia, which function like seeds.
- Apothecia germinate from the sclerotia and produce millions of spores that colonize dead plant tissue, particularly senescing soybean flowers.
- Infection can then spread via contact with this moldy material, which is favored in dense canopies with high moisture and minimal airflow.
- The next generation of sclerotia form outside of the plant, surrounded by the white mold on the infected plant, or internally within the soybean stem.

Figure 2. White mold development on soybean, formation of sclerotia.

IDENTIFICATION AND SYMPTOMOLOGY

- Infection begins with water-soaked lesions at infection sites.
- Cottony white, moldy masses form on stems (Figure 2).
- Sclerotia can develop both outside and inside the stem (Figures 3 and 4). Sclerotia appear as dark, irregularly shaped bodies ¼ to ¾ inches long, similar in appearance to seeds.
- Infection can lead to lodging due to weakened stems.

Figure 3. White mold sclerotia on outside of soybean stems among moldy tissue, appearance is more rounded.

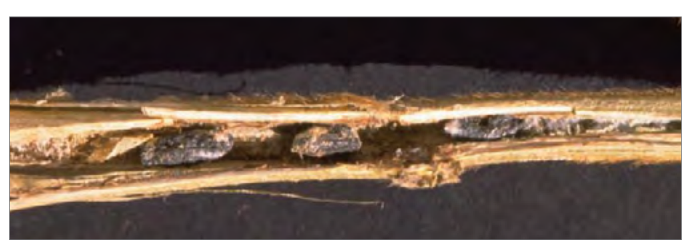

Figure 4. White mold sclerotia within soybean stems, appearance more cylindrical.

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MANAGEMENT CONSIDERATIONS

Variety Selection

- No variety is completely resistant to white mold, particularly under severe disease pressure, but differences in tolerance exist among varieties.
- Pioneer® brand soybean varieties are rated on a scale of 1 to 9 (9 = most tolerant) for genetic tolerance to white mold.
- Ratings are determined by analyzing data from multiple locations and evaluating infection development rate as well as the extent of damage caused by the pathogen.
- Selecting varieties with high tolerance ratings is a good management practice in locations that often encounter white mold. Consult your Pioneer sales professional for help selecting suitable varieties for your farm.

Production Practices

- **Early planting, narrow row width, and high plant populations encourage early canopy formation and white mold risk. These practices also tend to increase yield.**
- **Abandoning practices that increase yield most years to reduce white mold (which does not occur every year) may not be a favorable economic trade-off.**

Figure 5. High-density canopies with cool and moist conditions favor disease development.

Crop Rotation

- *Sclerotinia sclerotiorum* has a wide host range, including alfalfa, clover, sunflower, canola, edible beans, and more.
- Non-host crops that can be utilized in a rotation include corn, sorghum, and small grains.
- Because sclerotia persist in the soil for up to 10 years, rotation is only a partial solution for reducing disease pressure. More than one year away from soybeans may be required to see a benefit.

Weed Management

- Weeds are also alternate hosts for white mold in fields.
- Lambsquarters, ragweed, pigweed, and velvetleaf are some common weeds that can be infected by *Sclerotinia sclerotiorum*.

Figure 6. Soybeans that have lodged due to loss of structural integrity as a result of white mold infection.

Tillage

- Sclerotia germinate from the top 2 in of soil but can persist at lower depths for up to 10 years.
- Buried sclerotia can be resurfaced by tillage and germinate.
- If a severe outbreak has occurred in a field that is new to white mold, deep tillage followed by zero tillage in the subsequent season may help.

Fungicide Treatments

- Fields that are at high risk of white mold infestation may benefit from foliar treatments used in tandem with cultural practices that disfavor the pathogen.
- Products labeled for white mold control or suppression:
  - » **Synthetic fungicides:** DuPont™ Aproach® fungicide, Quadris® fungicide, Topguard® fungicide, Proline® fungicide, Domark® fungicide, Topsin® fungicide, and Endura® fungicide
  - » **Biological fungicide:** Contans® fungicide
- In 2017 on-farm trials, DuPont Aproach fungicide increased soybean yield by an average of 7 to 9 bu/acre with a single application and 13 bu/acre with sequential applications in fields with heavy white mold pressure (Wessel et al., 2017).
- Herbicides containing lactofen (Cobra® herbicide and Phoenix® herbicide) can also reduce white mold incidence.

Foliar Fungicide Application Timing

- **Applications must be made prior to infection because they have little activity on the established pathogen.**
- **Optimum application timing for fungicides for white mold control in soybeans is approximately the R1 growth stage when blooms are vulnerable to the initial infection and canopies are still open.**
- **Soybean susceptibility for white mold lasts as long as the crop is flowering, often 30 days or more, so a second application may be necessary if environmental conditions favorable to infection persist into mid-summer.**
- **Later fungicide applications have the potential for reduced canopy penetration, particularly in narrow-row soybeans, which can reduce their effectiveness.**
- **Always read and follow all label directions plus precautions for use when applying fungicides.**

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Diaporthe/Phomopsis Fungi Complex in Soybeans

Samantha Reicks, *Agronomy Intern*

FUNGI FACTS

- *Phomopsis (P. longicolla)* and *Diaporthe (D. phaseolorum var. sojae)* are fungi that function as a complex and infect soybeans.
- The fungi cause diseases to form in the plant, which can reduce yield. Some of these diseases include:
  - Pod and stem blight
  - Phomopsis seed decay
  - Stem canker
- Mature plants that are split longitudinally may show signs of zone lines on lower stems as seen in Figure 1. This was previously often mistaken for symptoms of charcoal rot.
- *Diaporthe/Phomopsis* can infect the plant at any time in the growing season but may not be visible until later in the growing season.
- This fungus complex and diseases associated with it can be found throughout most soybean-producing areas in North America.

Figure 1. Dark zone lines in the longitudinal section of the lower stem are an indicator of *Diaporthe* fungal infection.

CONDITIONS FAVORING INFECTION

Hosts of the Fungus

- *Diaporthe/Phompsis* fungi complex overwinters in soybean residue for several years after an infected crop was present. Repeatedly planting soybeans will increase the risk of a field being infected.
- Early season rainfall can splash spores onto the growing plant.
- Plants with infected pods will produce infected seeds. Chances for severe pod infection increase when the pod begins maturing, especially around R5 and R6. When the pods are infected, seeds are susceptible to seed decay.
- Several weeds, such as velvetleaf, morning glories, and pigweed, can host the *Diaporthe/Phomopsis* fungi complex and will not show symptoms.

Life Cycle

- The plants can be infected at any time in the growing season but are most often infected early in the season. When the leaves are wet for extended periods early in the growing season, the diseases are more likely to occur in the field.
- There is an increased chance of infection when the weather is warm and humid close to maturity.
- Wet weather that delays harvest will increase the chance and severity of seeds being infected. Rainfall during pod fill can also splash fungi spores from residue onto pods.
- High winds, hail, and other events that rip the plant tissue give the pathogen an entryway into the plant.
- Chance for infection decreases at R7 and when the seed moisture is below 19%.

POTENTIAL DISEASES

Pod and Stem Blight

- Leaves may have water-soaked margins that are grey in color and/or small black specks called pycnidia. The black dots may be more prevalent on leaves and petioles that have fallen on the ground. It is also possible that no symptoms are visible.
- Stems have parallel rows of pycnidia on mature plants (Figure 2). These black dots are often mistaken for anthracnose stem blight and charcoal rot, which have unorganized black specks on the stems (Figure 3 and 4).
- Pycnidia on pods will not be in organized rows and will begin to occur near the end of the reproductive stages, around R6 and R8.
- If the plant is infected, there is a possibility that all of the seeds that are produced are also infected. The seeds will produce seedlings with orange lesions on the cotyledon and red/brown mark on the hypocotyl. This looks similar to Phomopsis seed decay.

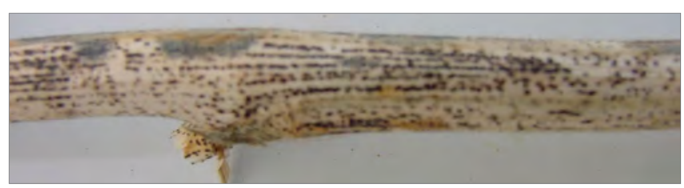

Figure 2. Soybean infected with pod and stem blight disease have black specks that are in linear rows.

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 as well as 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, and sudden death syndrome, as well as herbicide, frost, and lightning damage.
- If the taproot of the plant is split and the inside of the root displays a color that is not normal, the plant most likely has brown stem rot or sudden death syndrome, not stem canker.
- Stem canker is more likely to infect fields with high fertility and organic matter.

Figure 6. Stem canker in soybeans caused by the fungus *Diaporthe.*

MANAGEMENT PRACTICES

Before Planting

- Rotate from soybeans to corn or a non-legume that is not a host for the fungi complex. Alfalfa is a potential host for stem canker.
- Fertilize to maintain sufficient levels of potassium. Seed infection increases when potassium is deficient.
- Tillage will reduce the amount of residue on the surface and lower the chances of spores splashing on to future crops.
- *Diaporthe/Phomopsis* fungi complex is more likely to occur in soybeans that mature early. Planting soybeans with a late relative maturity will decrease the chance of humid conditions in the late stages of reproduction.

During the Growing Season

- Strive to achieve a full, even stand. Extensive branching due to gaps in the stand can result in lodged plants with broken branches. Broken branches give the fungi a means of entry into the plant.
- Fungicides can be used in fields that have low to moderate disease pressure and in areas that favor severe disease pressure.
  - To mitigate pod and stem blight, apply fungicides between R3 and R5.
  - The amount of disease may diminish in the field, but this does not necessarily mean that the yield will improve.
- Do not delay in harvesting the crop. The longer soybean seeds remain in the field after maturity, the greater the chances of the seeds being infected.

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Target Spot in Soybeans

Madeline Henrickson, *Agronomy Intern*

TARGET SPOT FACTS

- Target spot is caused by the fungus *Corynespora cassiicola.*
  - This is **not** *Bipolaris sorghicola*, which causes target spot of grain sorghum.
- The pathogen can overwinter in debris for up to two years.
- It is found in tropical and subtropical regions. In the U.S., it occurs in the Midsouth and southern states.
- *Corynespora cassiicola* has hundreds of alternate hosts, including cotton, tomato, cucumber, cowpea, and sesame.

Figure 1. Defoliation of soybeans due to target spot. *Photo courtesy of Brewer Blessitt.*

IDENTIFICATION AND SYMPTOMOLOGY

- Symptoms of target spot will appear in the lower canopy first as spores spread from residue, typically around canopy closure.
- The most distinctive characteristic of target spot is concentric lesions that form on leaves (Figures 2 and 3).
- Less distinct lesions will be reddish-brown with a chlorotic halo.
- Dark-brown specks to longer lesions can be found on stems, and minuscule, circular purple/black lesions with brown margins can be seen on pods.
- Plant defoliation can occur if disease severity is high enough.

CONDITIONS FAVORING DISEASE

- Humidity greater than 85% and warm temperatures are required for initial infection.
- Multiple consecutive days of rainfall increase disease incidence.
- Dense canopies, high soybean populations, and tight row spacing limit airflow, favoring disease development.
- Soybean monoculture, or rotation with cotton, allows the pathogen to persist in agricultural systems.

Figure 2. Soybean leaf demonstrating variability of lesion size and appearance, note yellow halos. *Photo courtesy of Brewer Blessitt.*

MANAGEMENT CONSIDERATIONS

- Historically, target spot rarely caused significant yield loss in soybeans; however, losses have been reported with greater frequency in recent years.
- Yield loss potential is highly dependent on the degree and timing of defoliation caused by target spot. In a defoliation study, yield loss of up to 10% occurred with 60% defoliation at R5 but only 5% if the same occurs at R6 (Faske, 2016).
- Yield losses due to target spot alone are often difficult to determine due to the presence of other pathogens.
- Rotation to non-host crops like corn, sorghum, grain, or rice can help reduce the inoculum load in a field.
- A fungicide treatment may be justified when weather conditions are highly favorable for disease development. Application timing is key to suppress disease development before it progresses up the canopy.

Figure 3. Variability of zonate "target" lesions. *Photo courtesy of Brewer Blessitt.*

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Septoria Brown Spot

Madeline Henrickson, *Agronomy Intern*

PATHOGEN FACTS

- Septoria brown spot is a foliar disease of soybeans caused by the fungal pathogen *Septoria glycines*.
- The first occurrence of *Septoria glycines* in the United States was documented in South Carolina in 1923.
- Today, Septoria brown spot is widely distributed across the country and is especially prevalent in agricultural systems in which soybeans are grown continuously.
- Although it is the most common foliar disease of soybean, Septoria rarely causes significant yield loss.
- *Septoria glycines* primarily infects legumes but can use velvetleaf as an alternate host.

IDENTIFICATION AND SYMPTOMOLOGY

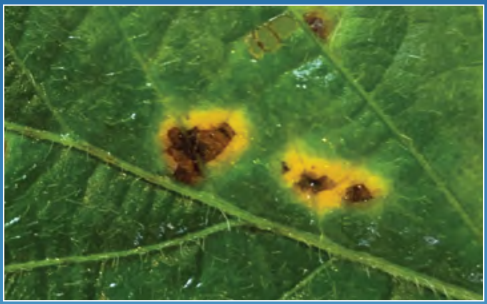
- Septoria brown spot overwinters on infected soybean residue and infects new seedlings around V2 after spores are splashed from the soil surface.
- Lesions appear as small brown flecks with indefinite margins, typically paired with chlorotic regions.
- Lesion coloration can range from rusty brown to brown with a purple hue.
- When lesions enlarge, they coalesce into irregularly-shaped brown areas.
- Infected leaves can become chlorotic and drop off the plant; this typically happens in the lower to mid-canopy.
- If rainfall is heavy and frequent later in the season, there is a potential that *Septoria glycines* can move to the upper canopy.
- Lesions are often confused with bacterial blight (see below).

CONDITIONS FAVORING DISEASE

- Warm temperatures (60 to 85 °F) and humid conditions promote conidia sporulation of *Septoria glycines*.
- Extended periods of leaf wetness are conducive for disease development.
- Conidia are spread throughout the canopy via wind or rain splash.
- Soybean monoculture, or rotation with other legumes, allows the pathogen to overwinter in crop debris.

MANAGEMENT CONSIDERATIONS

- Under severe disease pressure, yield losses up to 9% may occur.
- The potential effect on yield can be estimated by assessing the severity of infection during podfill, particularly at R6.
- There is no variety that is completely resistant to Septoria brown spot, but partial resistance does exist.
- Rotating to a non-host crop outside of leguminous species is effective at decreasing the inoculum in the field.
- Tillage can effectively bury crop debris and cause a rapid decay of the fungus.
- Foliar fungicides applied from R3 to R6 can slow the development of *Septoria glycines* through the middle to upper canopy during podfill.



Septoria brown spot lesion *(left)* compared to bacterial blight lesion *(right)*. Note how the necrotic center eventually falls out of the bacterial blight lesion.

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In-Field Starch Digestibility Variation, Implications on Silage

Dann Bolinger, M.S., *Dairy Specialist*

INTRODUCTION

Starch digestibility of corn grain, whether as pure grain or as a component of corn silage, receives substantial attention in the dairy and beef cattle industry. Rumen digestion is of particular interest and value as it has significant impact on rumen health, animal performance, and feed efficiency. Readily available laboratory methods to predict rumen starch digestion, in vitro starch digestion (%IVSD-7), and in situ starch digestibility (%ISSD-7) along with Kd rates, have empowered nutritionists to pursue desired starch digestion characteristics in corn-based feedstuffs.

Spanning six years, 2013 to 2018, a series of four small studies were conducted in Michigan and Ohio to increase understanding of relative influence of hybrid genetics on rumen digestion of starch as it leaves the field and the practical implications to feeding of cattle.

KERNEL TEST WEIGHT

Five hybrids of independently unique genetics were compared in 2013 across 15 growing environments. The five hybrids were selected based upon varying relative maturities for silage as well as varying test weight genetic characterizations and grown in strip trials. Grain from representative ears collected at silage harvest was analyzed for density (specific gravity, g/cc) and %IVSD-7 (Figure 1). Test weight as measured by kernel specific gravity was a very poor predictor (R^2=0.09) of rumen starch digestion (%IVSD-7). While hybrid was highly related to test weight (P<0.01), hybrid did not have a strong relationship with %IVSD-7 (P=0.10).

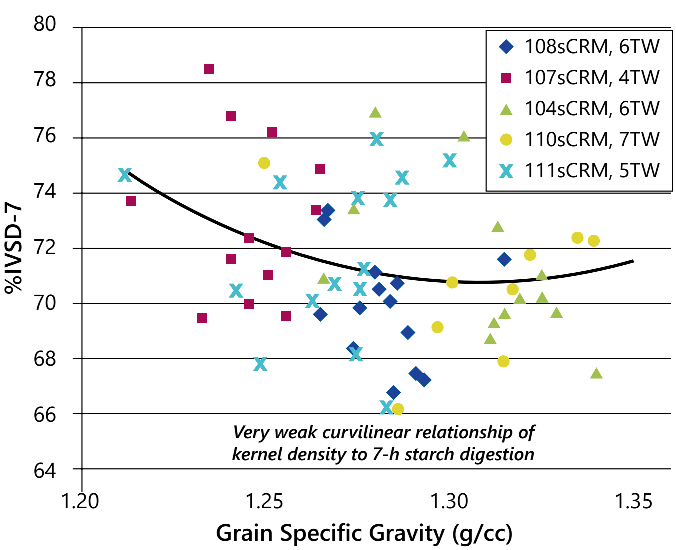

Figure 1. Five hybrids representing 104 to 111 silage corn relative maturity (sCRM) and 4 to 7 test weight (TW) characterization scores from 15 locations. Harvested at silage maturity. (Michigan, 2015)

GROWING ENVIRONMENT INFLUENCE, FIELDS AND GROWING SEASONS

The 2013 trial showed substantial variation of %IVSD-7 within each hybrid across locations. To look more closely at genetics and environment interaction, nine representative ear samples were collected from a single hybrid from seven locations during the 2015 and 2016 growing seasons (Figure 2). These samples were also taken the day of silage harvest (¼ to ½ milk line). Two locations (Ga, C) were repeated to the specific location within each field across both years. Three locations (Ga, Gb, Gc) were within 2.5 miles of each other. Two additional locations (Ia, Ib) were 1.2 miles apart.

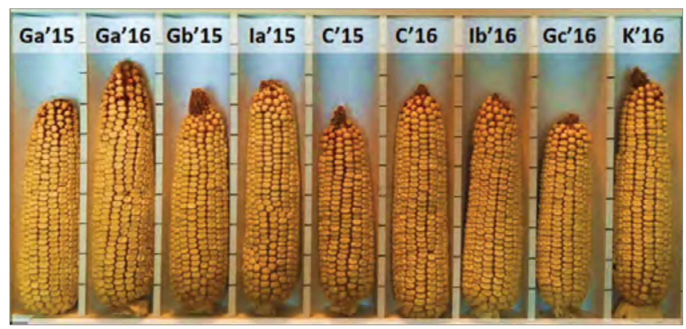

Figure 2. Same hybrid from 7 locations, 2 growing seasons. Ear samples collected at silage harvest (¼-½ milk line). Air dried on cob to 90% DM.

Starch digestibility within one hybrid ranged from 45.9 to 64.2 %ISSD-7 (Figure 3). Differences of as much as 10 points of %ISSD-7 occurred within relatively short distances between fields. A tendency was noted for individual locations to have relatively high or low %ISSD-7 consistently across growing seasons.

When samples of equal volume were processed for equal time in an electric coffee grinder, visual differences in particle size and texture particles post-grinding does not appear to be a reliable predictor of starch digestibility (Figure 4).

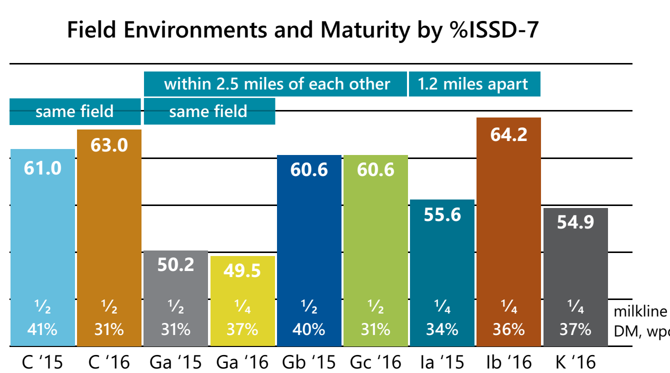

Figure 3. %ISSD-7 of grain from same hybrid, 7 locations, 2 growing seasons. Sampled at time of silage harvest. Air dried on the cob to 90% DM prior to hand shelling for lab analysis. (Michigan, 2015-16)

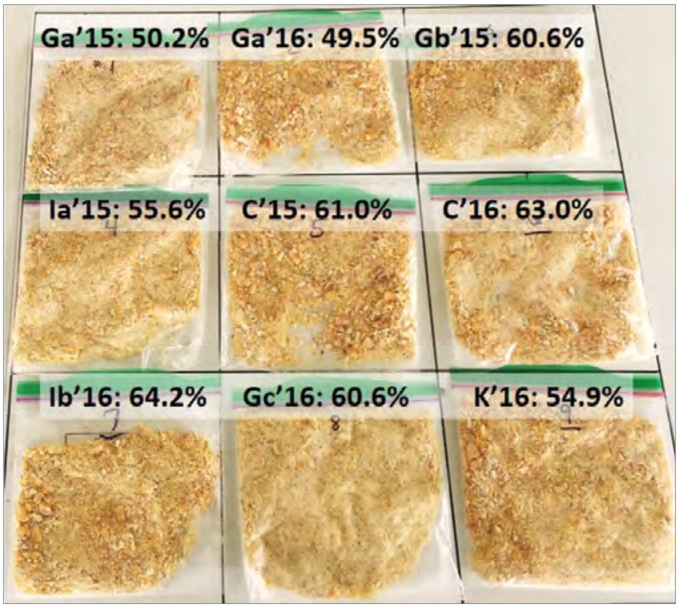

Figure 4. Ground samples of equal kernel volume and grind time with respective %ISSD-7.

MICRO-GROWING ENVIRONMENT INFLUENCE WITHIN A FIELD

Variability in rumen starch digestibility (%IVSD-7) was explored for a single hybrid that was planted and harvested the same day in the same field in 2016. Eight silage samples were collected from random loads in each of two large fields. The fields were within three miles of each other and consisted largely of same soil type (Hoytville silty clay, <1% slope), constituting 84% and 93%, respectively, of the 120- and 155-acre fields. Each entire field was planted to a single hybrid of unique genetics. Within each field, rumen starch digestibility spanned a seven or more point range in %IVSD-7 (Figure 5). Decreasing rumen starch digestibility as whole plant dry matter increased was a tendency that provides a partial explanation for the observed differences.

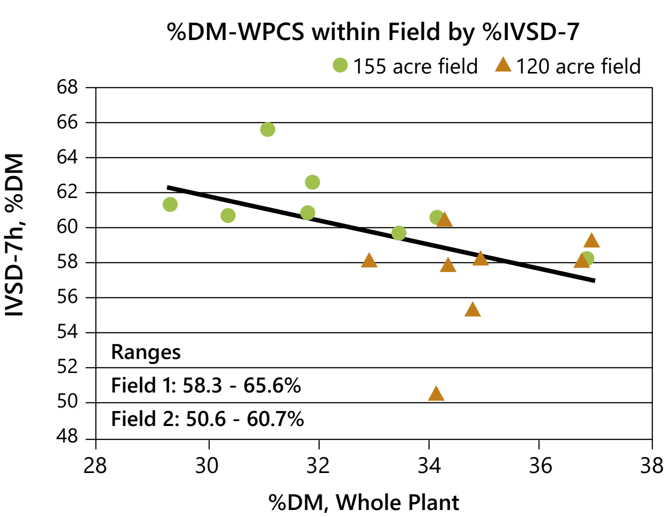

Figure 5. %IVSD-7 by % dry matter at silage harvest of 8 random loads, each of two neighboring fields. Highly uniform in soil type, slope, drainage, and management within and across fields (Ohio 2016).

INFLUENCE OF ENSILING ON RUMEN STARCH DIGESTIBILITY

Like most studies on this subject, the trials mentioned thus far represent non-fermented samples as they exited the field. It is a well-accepted management recommendation and practice in the industry to only feed chopped, whole corn plants as fermented silage. To evaluate the influence of fermentation on rumen starch digestibility variation in the field, 17 fresh samples from 3 farms during 2018 and 2019 growing seasons were split via the quartering method. Duplicate samples were inoculated and vacuum sealed. One was frozen fresh, while the other was fermented at room temperature (~72 °F) for 16 weeks, and then frozen.

While the fresh samples ranged from 49.2 to 78.4 %ISSD-7, rumen starch digestibility converged to a compressed range of 71.6 to 83.1 %ISSD-7 post-ensiling (Figure 6). Relative rankings also changed dramatically as many of the lowest pre-ensiled samples became among the highest post-ensiling. For example, the very lowest fresh sample measurement, 49.1 %ISSD-7, is the same sample with the very highest fermented measurement, 83.1 %ISSD-7.

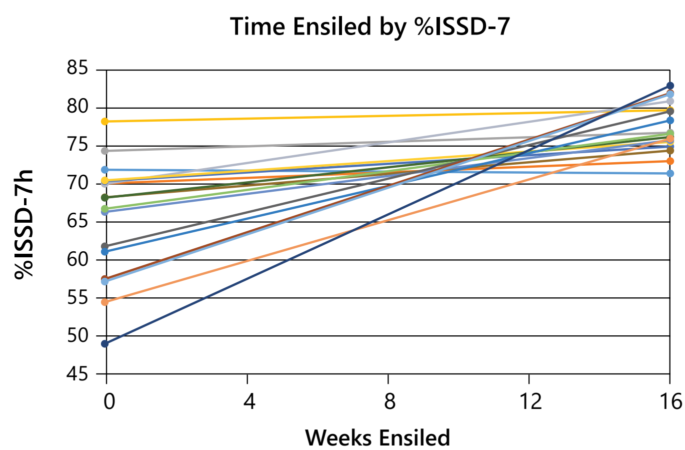

Figure 6. %ISSD-7 of 17 duplicated WPCS samples, fresh and fermented 16 weeks, from 3 trial locations (Michigan, 2017-18)

CONCLUSIONS

Among fresh samples of whole plant corn silage, variability in rumen starch digestibility, as measured by either %IVSD-7 or %ISSD-7, is great and largely unavoidable. Variability within a single hybrid is so great that comparing starch digestibility of two hybrids is of little practical value. Fermentation converges differences coming out of the field and dramatically changes the relative rankings of hybrids; therefore, rumen starch digestibility at silage harvest has minimal influence on animal feeding responses at feed out. Claims of hybrids with soft kernel texture or specialized traits influencing starch digestion are also subject to these observations in variability and fermentation as examples of these attributes were represented in this data. Starch digestion characteristics observed in fermented corn silage as well as snaplage and high moisture shelled corn by inference are subject to little or no influence from hybrid selection.

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2019 Survey of Fecal Starch in Michigan Feedlots

Dann Bolinger, M.S., *Dairy Specialist*

INTRODUCTION

Corn is the predominant source of energy in the beef cattle diets of Michigan feedlots. Starch typically represents 68 to 72% of corn grain dry matter and is the primary energy contributor. Reducing undigested starch excreted in manure may represent a significant opportunity to improve feed efficiency and farm profitability.

Several management factors influence the extent of starch digestion. Harvest percent dry matter (%DM), kernel particle size reduction (processing), and ensiling are the three most significant variables.

Measuring the amount of starch secreted in manure is an indicator of lost opportunity in feed energy. While target fecal starch levels are relatively consistent in the study of dairy nutrition, beef feedlots tend to have more variability in measured fecal starch. A portion of observed feedlot fecal starch variability can be attributed to varying levels of starch in the diet, while variability in corn grain %DM and processing represent the other primary driver.

METHODS

During the spring of 2019, a survey was conducted of Michigan beef feedlots to assess the status of starch digestion and identify opportunities to enhance feed efficiency. Fecal and total mixed ration (TMR) samples were collected from 10 feedlots, representing 10 finisher and 9 grower diets. Nine of 10 farms were feeding Holstein steers. Fecal starch was measured through Dairyland Laboratory. Manure samples were also washed over a strainer for visual assessment. TMR samples were processed through a Penn State particle separator. Starch sources were identified. Extent of corn grain processing was labeled as either extensive (+) or modest (-) based on the kernel processing cup for corn silage and visual appraisal for other corn grain sources.

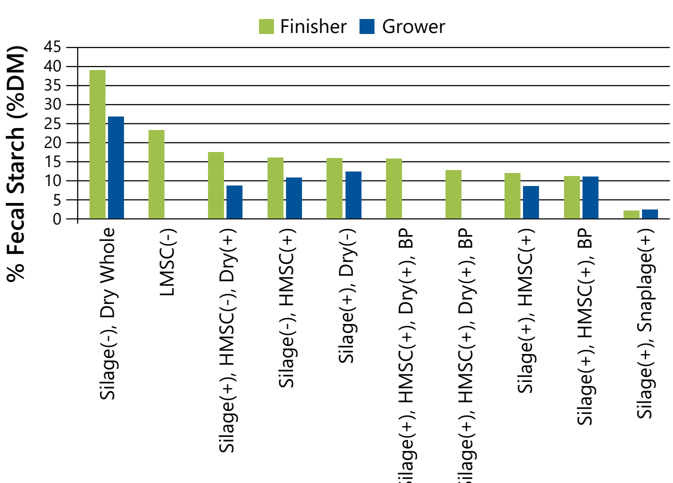

Figure 1. Fecal starch of finisher and grower diets from 10 Michigan feedlots. Starch sources in diet include: Corn silage, dry whole corn, dry cracked corn/screenings, low moisture shelled corn (LMSC), high moisture shelled corn (HMSC), snaplage, and by-products (BP). Relative processing (+/-).

RESULTS AND DISCUSSION

Fecal starch content was highly variable, ranging from 1.5% to 39.5% of fecal dry matter. Ranking finisher samples by fecal starch content (Figure 1) showed a relationship to moisture content and processing of corn sources in the diet. Grower diets tended to not follow the same pattern.

It was noticed that the Penn State particle separator typically captured whole and minimally processed corn kernels in the middle pan (<19mm, >8mm) (Figure 3). Very few particles resided in the top pan (>19mm). All but one farm's diets showed modest to low forage fiber content. The lone high-forage diet was excluded as an outlier in this particle-size analysis.

Finisher fecal starch tended to correlate most closely with percent as-fed in the middle pan of the particle separator (Figure 2). This suggests kernel particle size, i.e. processing, is strongly correlated to fecal starch content.

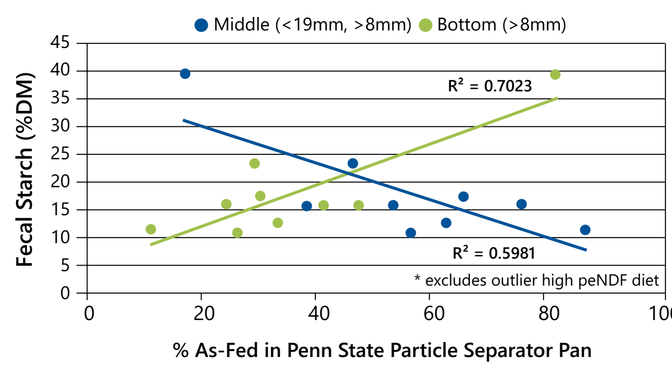

Figure 2. Feed trapped in middle pan was heavily influenced by presence of whole or modestly processed corn kernels.

CONCLUSIONS

Extent of starch digestion is highly variable between feedlots. TMR starch levels at estimated 40to 60% of dry matter contribute to much of the differences, while management of corn sources explain another large portion of the variability. As expected, increased dependency on high moisture, ensiled corn products and more extensive processing related to lower fecal starch levels. Washed manure samples (Figure 4) have some but limited value in evaluating fecal starch.

Opportunity may exist to increase feed efficiency through the more extensive processing of corn. Greater dependence on high moisture, ensiled sources of corn grain also enhances starch digestion. Maintaining rumen health and optimizing rate of gain should also be considered when enhancing rumen availability and digestion of starch.

Figure 3. Example Penn State particle separation analysis with many whole and modestly damaged kernels in the middle pan. Well-processed corn and other concentrates are in bottom pan. The manure sample associated with this TMR was 17.4% starch of total fecal DM.

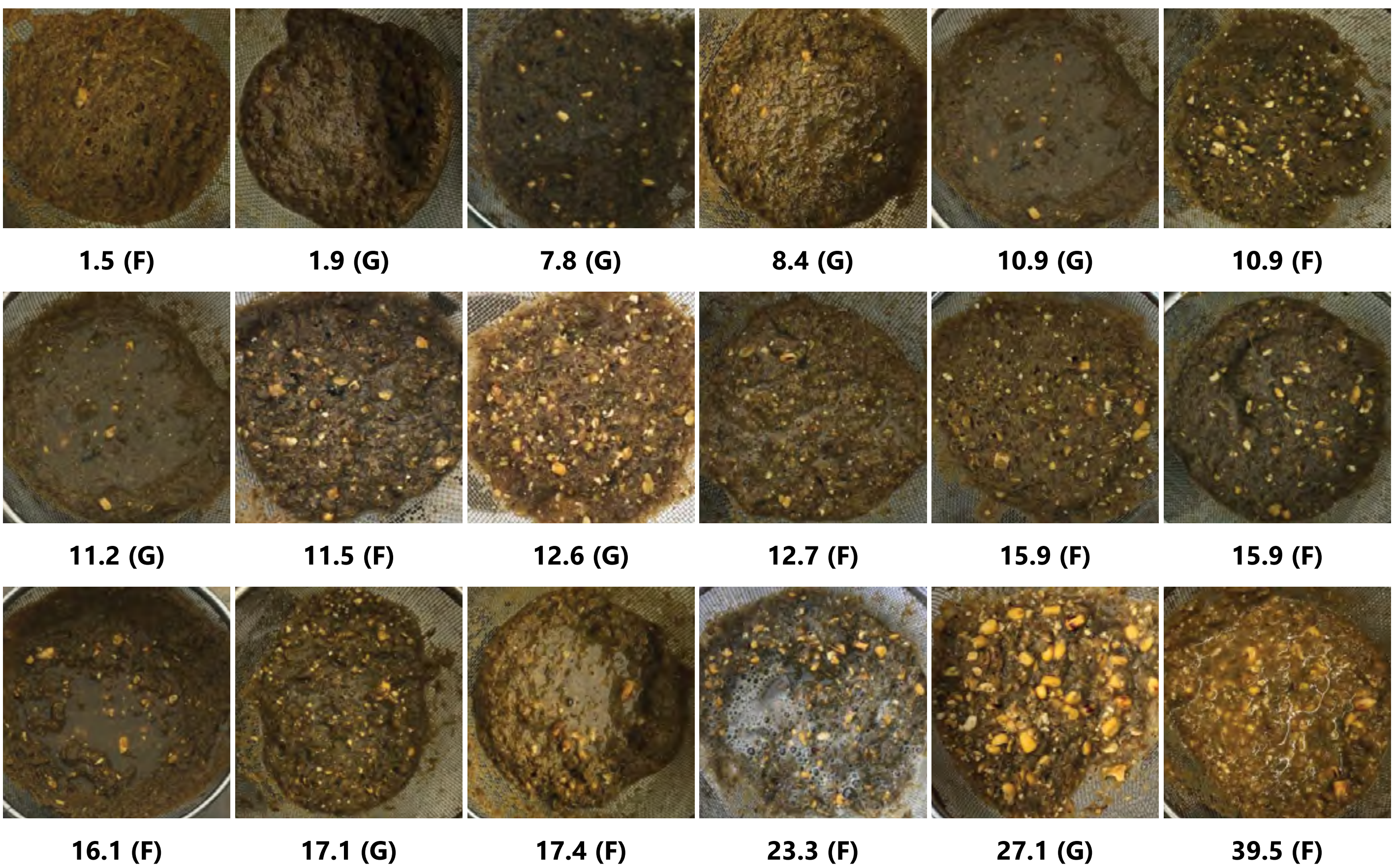

Figure 4. Washed manure samples and associated fecal starch (% total DM) representing finisher (F) and grower (G) diets.

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Sugarcane Aphid Tolerance and Management in Sorghum

Justin Gifford, Ph.D., *Research Scientist,* **Cleve Franks, Ph.D.,** *Research Scientist,* **Molly Ryan-Mahmutagic,** *Senior Research Associate,* **Dan Berning,** *Agronomy Manager, and* **Mark Jeschke, Ph.D.,** *Agronomy Manager*

Sugarcane aphids feed on the sap of plants and can cause ***severe yield losses*** in sorghum.

Best management practices include *removal of volunteer sorghum plants,* the use of *tolerant sorghum hybrids*, high quality **seed treatments**, good *grass weed management*, *scouting*, and the use of **insecticides,** if needed.

Knowing the *genetic tolerance* of sorghum hybrids to sugarcane aphid is only one tool for management of the pest. This knowledge along with *good field management* offers the ***best protection*** against sugarcane aphid.

SUGARCANE APHID FEEDING ON SORGHUM

- Sugarcane aphid (*Melanaphis sacchari*) is capable of causing significant damage and reductions to yield in sorghum.
- Overwintering populations that feed on volunteer sorghum plants can be a significant source of spring infestation.
- Populations can start to build during the early seedling stages if the crop is not protected by an effective seed treatment.
- Sugarcane aphids have piercing/sucking mouthparts, which enable them to feed on the sap of plant.
- As populations increase, sugarcane aphids remove nutrients from the plant that would have been used for plant growth and ultimately, yield.
- Plants will become stunted and leaves may become necrotic. Severe infestations produce large quantities of honeydew, which allows sooty mold to blacken the leaves and can cause harvest problems.
- The plant may have uneven and/or poor head development and emergence; poor grain set; increased stalk lodging; and harvest issues.
- Yield loss in sorghum can be severe, with cases of 100% loss reported.

ALTERNATE HOSTS

- Sugarcane aphids need living host plants to persist.
- In addition to sorghum, they can feed on shattercane (*Sorghum bicolor*), Johnsongrass (*Sorghum halapense*), and volunteer sorghum plants. Aphids also overwinter on these same plant species.
- In Mexico, the sugarcane aphid has been found colonizing barnyardgrass (*Echinochloa crus-galli*).

Sugarcane aphids: A winged adult, non-winged adults, and nymph.

SCOUTING FOR SUGARCANE APHID

- Scouting should begin a few weeks after sorghum emergence. Scout at least once per week until aphids are found; then, increase frequency to two field visits per week.
- In four or five areas within the field, inspect the underside of an upper leaf and a lower leaf for aphid presence. When populations begin to build, honeydew will be present on the top side of leaves.
- Take notes on the number of aphids present in each area. Several southern universities recommend an action threshold of 50 to 125 or more aphids per leaf on 25% or more of the plants.

Sooty mold resulting from heavy infestation of sugarcane aphid.

Infested sorghum leaf with all stages of aphids present.

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SUGARCANE APHID MANAGEMENT

Insecticides

- Several insecticides are labeled for use on sorghum in the U.S. For information on chemical control of sugarcane aphid (if needed), consult your local Corteva Agriscience representative.
- When applying insecticides by ground equipment, University of Arkansas recommends that insecticides be applied in 10 gallons of water per acre.
- Farmers 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.

Understanding Differences in Hybrid Tolerance

- Corteva Agriscience has developed a technique for screening sorghum lines for their ability to reduce the survival and reproduction of the sugarcane aphid.
- The bioassay facility screens germplasm for native tolerance to this important pest. Native tolerance is an important part of an integrated pest management (IPM) system.
- The goal of IPM is to keep the number of aphids per plant below the economic threshold level.
- The identification and introgression of tolerance is an important part of hybrid development in sorghum.
- Sorghum tolerant to the sugarcane aphid has been identified, and tolerant hybrids are currently under development.
- Sorghum entries are evaluated and scored for sugarcane aphid antixenosis (Table 1). These scores should be used as a management tool along with diligent scouting.

Table 1. Pioneer® brand sorghum hybrids with moderate to high sugarcane aphid tolerance.

Pioneer® Brand Hybrid	CRM*	Relative Maturity**	Sugarcane Aphid Tolerance***
86P20	103 (106)	64	6
86Y89	110 (115)	68	5
85G46	112 (114)	68	5
85P05	112 (118)	68	5
85P44	114 (119)	70	5
84P72	117 (120)	71	5
84P68	118 (117)	69	7
83P56	(120)	71	7
83G19	(125)	72	5
83P17	(125)	73	6
83P73	(125)	73	5

* CRM (COMPARATIVE RELATIVE MATURITY): Approximate length of time from emergence to physiological maturity, which will vary depending on planting date, environment, and growing conditions. ( ) = south & central TX and Delta.

** RM (RELATIVE MATURITY): Approximate length of time in days until flowering.

*** RATING: 9= Excellent; 1= Poor.

An Example of a Sorghum Hybrid:

A. Highly susceptible to sugarcane aphid feeding

B. Moderately susceptible to sugarcane aphid feeding

C. High level of tolerance to sugarcane aphid feeding

BEST MANAGEMENT PRACTICES

- Best management practices include removal of volunteer sorghum plants, the use of tolerant sorghum hybrids, high quality seed treatments, good grass weed management, scouting, and the use of insecticides, if needed. Here is a brief checklist:

1. Control volunteer sorghum to remove source of early infestation.
2. Plant a sorghum hybrid with aphid tolerance.
3. Use an effective insecticide seed treatment.
4. Plant early.
5. Scout fields early and weekly.
6. Apply an approved insecticide when the action threshold is reached. Avoid pyrethroid insecticides, which are harmful to beneficial insecticides and may cause aphid populations to rebound rapidly.
7. Consider using a harvest aid when sorghum nears maturity (25% grain moisture in the lower portion of the head) to kill and dry-down the crop.

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Wheat Management to Maximize Yield Potential

Brian Bunton, *Field Agronomist*

NEED ADEQUATE STANDS FOR TOP PRODUCTION

- Stand establishment is critical for achieving high yields and having good weed control. Seeding rates should consider the amount of seeds per acre rather than pounds of seed per acre. Rates from 1.2-1.8 million seeds per acre should be acceptable depending on tillage and planting date.
- Stand establishment of 27-35 plants/ft^2 with 3-5 tillers/plant is optimal. To maximize potential yield, there should be at least 40 heads/ft^2, with the optimum numbers between 60 and 80 heads/ft^2. Final stands of 15-18 plants/ft^2 or less are candidates for replanting to corn or soybeans.
- Rule of thumb for yield potential: 1.3-1.6 bu/acre per head/ft^2.

NITROGEN MANAGEMENT

- Wheat uses 1.1-1.5 pounds of nitrogen for each bushel of expected yield and utilizes 70-75% of the total nitrogen requirement between Feekes growth stages 6 and 10. The greatest amount of nitrogen should be available at that time.
- At 70+ tillers/ft^2, apply nitrogen at Feekes growth stage 4-5 (prior to jointing).
- 100-140 lbs/acre of nitrogen spring-applied is recommended.
  - High rates of nitrogen may cause lodging in certain varieties. Avoid overlaps in application.
  - If a high rate of nitrogen is planned, consider a split application of 40 lbs/acre before green-up and another 60 lbs/acre at Feekes growth stage 4-5 (prior to jointing).
- Do not delay nitrogen application on a marginal stand of wheat. If stands are thin and tiller counts are low, an early application of nitrogen can induce tillering and consequently increase the number of heads/ft^2. In this situation, a split application may help. Apply 60 lbs/acre of nitrogen for a first application (before green-up) and another 40 lbs/acre at Feekes growth stage 4-5 (before jointing).
- A split application of nitrogen is suggested and has shown positive yield results, especially on light or sandy soils.
- Nitrogen application rates may be reduced if fields have a history of manure application.
- If a stand is destroyed, credit 50-75% of applied nitrogen to a subsequent corn crop (depending on growth stage).
- **What Form of Nitrogen Should be Used?** The form of nitrogen is not as important as how accurately it is applied. Apply a uniform rate across the entire application width, and avoid application methods that may burn the leaves, which could reduce yield (such as 28% solution applied with herbicides). Common forms of nitrogen used include ammonium sulfate, urea, and 28% solution.

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

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

Source: Purdue University.

PEST MANAGEMENT

- **Insects:** Scouting is critical. If aphid populations exceed thresholds (10 per foot of row with early green-up and good conditions), a treatment should be applied to protect from barley yellow dwarf virus (BYDV).
- **Diseases:** A good crop with high yield potential and high wheat prices will increase the probability of an economic benefit to fungicide application. 100+ bu/acre wheat is thick and does not get a lot of air movement within the canopy— a perfect environment for disease if the weather also remains wet and provides a favorable environment for disease.
- Apply DuPont™ Aproach® fungicide at 3-4 fl oz/acre between tillering and jointing for early season disease control/suppression.
- For optimal yield and flag-leaf disease control, apply DuPont™ Aproach® Prima fungicide at 6.8 fl oz/acre at Feekes stage 9.
- **Weeds:** Start clean, stay clean! Keep fields clean early, and do not let weeds get too big. Use a burndown herbicide well before planting in no-till environments to eliminate weeds and volunteer corn. Use multiple tillage passes in a conventional tillage program if needed to start clean. The best weed control after seeding is a good stand of wheat.
- **Recommendation:** Quelex® herbicide with Arylex™ active. Apply 0.75 ounces of Quelex herbicide per acre to actively growing wheat from 2-leaf to flag leaf emergence stage. For best results, apply when weeds are actively growing in the 2- to 4-leaf stage or less than 4 inches tall. Be sure to read and follow all label directions.
- Do not apply a total of more than 0.75 oz of Quelex herbicide per acre per season. Consider the fall weed management program before proceeding with spring treatments.
- Consult your local Pioneer sales professional or Corteva Agriscience crop protection representative for local, specific recommendations.

Feekes Scale	
Stage	**Scale**
Tillering	1-5
Stem Extension	6-10
Heading	10.1-10.5
Flowering	10.5.1-10.5.4
Ripening	11.1-11.4

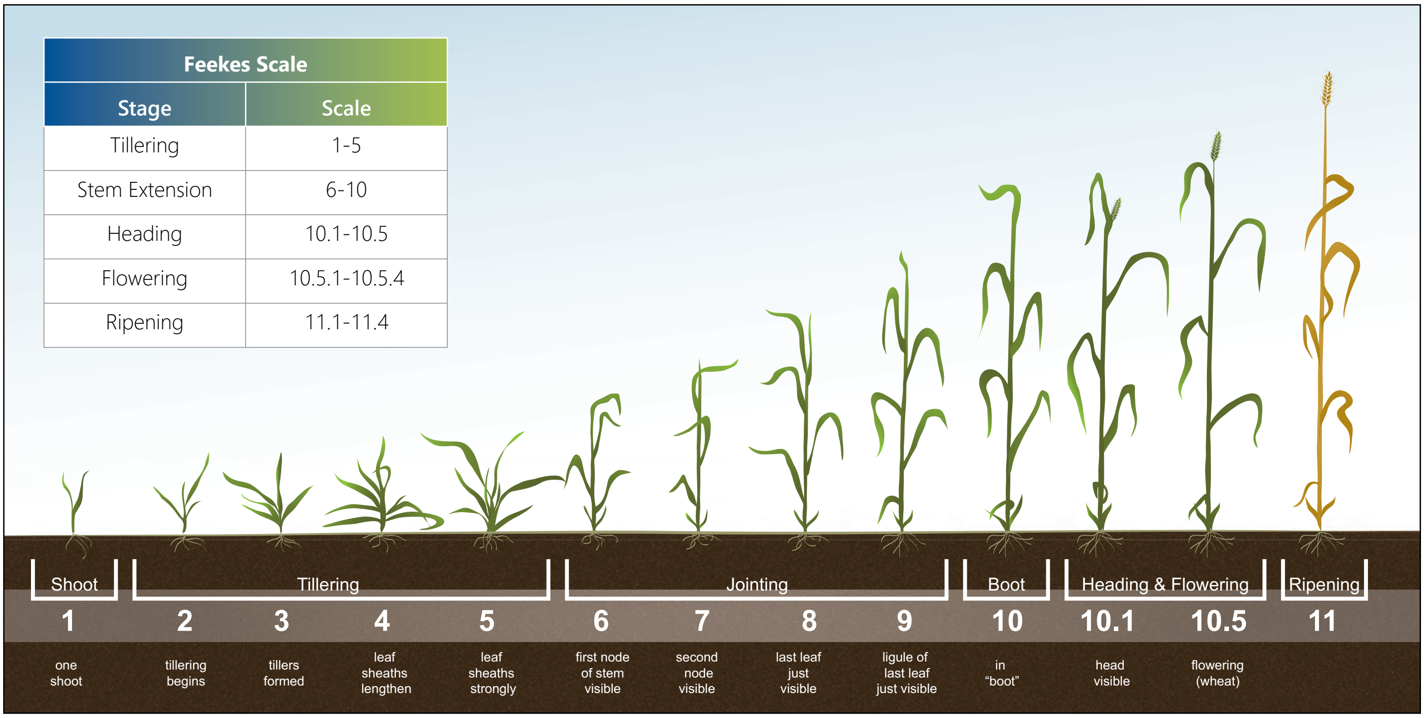

Photo courtesy of Purdue Extension.

Boot Stage

Feekes 10.0

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

Ripening Stage

Feekes 11.0

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

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FOOTNOTES AND ACKNOWLEDGMENTS

[1] Data Sources:

1. Cropland data layer is an annual raster-format land-use map created by the USDA NASS (https://www.nass.usda.gov/Research_and_Science/Cropland/Release/index.php), based on the Landsat 5 TM, Landsat 7 Enhanced Thematic Mapper (ETM+), the Indian Remote Sensing RESOURCESAT-1 (IRS-P6), Advanced Wide Field Sensors (AwiFS), Landsat TM/ETM+, and AWiFS imagery (the last two since 2010). Since 2008, the raster layers are released on a 30 m resolution and cover the continental U.S.

2. Historical state- and county-level corn yield information is available for downloading from the Internet in tabular form in USDA/NASS Quick Stats website (https://quickstats.nass.usda.gov/). This database is released as a point information in a county level (each point is a county/year yield record) without geographical information, such as latitude and longitude.

3. Enhanced vegetation index images were obtained from the MODIS /006/MOD13Q1 collection, which provides images with 250-meter resolution (each MOD13Q1 pixel contains the best possible observation during a 16-day period). All of the images from this collection were gathered between March 1 and November 10 and between May 1 and November 10 from 2008 to 2017, for corn and soybean respectively, in order to cover the entire growing season for these two crops.

4. Yearly, average temperature and growing degree units (GDU) were derived from the PRISM Daily Spatial Climate Dataset AN81d; this raster layer contains daily and monthly 4 km gridded climate datasets for the U.S., produced by the PRISM Climate Group at Oregon State University.

5. Vapor pressure deficit was assessed from the Gridded Surface Meteorological dataset that provides a ~4 km daily surface weather raster layers for the contiguous U.S. This dataset blends the high-resolution spatial data from PRISM with the high-temporal resolution data from the National Land Data Assimilation System (NLDAS).

6. Soil information (clay, available water content, organic matter content, and pH) was gathered from POLARIS, a map of soil series probabilities that has been produced for the contiguous U.S. at a 30-m spatial resolution and using machine learning algorithms to remap the Soil Survey Geographic (SSURGO) database.

[2]All Pioneer products are hybrids unless designated with AM1, AM, AMRW, AML, AMT, AMX, AMXT and Q, in which case they are brands.

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

Photos on pages 65, 115, and 116 courtesy of Deere and Co.

Photos on pages 57, 67, and 113 courtesy of CNH.

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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.

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.

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.

RW,HX1,LL,RR2 (Optimum® TRIsect®) - Contains the Herculex I gene for above-ground pests and the Agrisure® RW trait for resistance to corn rootworm.

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.

YGCB,HX1,LL,RR2 (Optimum® Intrasect®) - Contains the YieldGard® Corn Borer gene and Herculex® I gene for resistance to corn borer.

Qrome® products are approved for cultivation in the U.S. and Canada and have also received import approval in a number of importing countries. Pioneer continues to pursue additional import approvals for Qrome products in accordance with Excellence Through Stewardship Product Launch Guidance.

Plenish® high oleic soybeans have an enhanced oil profile and are produced and channeled under contract to specific grain markets. Growers should refer to the Pioneer Product Use Guide on www.pioneer.com/stewardship for more information.

Varieties with BOLT® technology provide excellent plant-back flexibility for soybeans following application of SU (sulfonylurea) herbicides such as DuPont™ LeadOff® or DuPont™ Basis® Blend as a component of a burndown program or for double-crop soybeans following SU herbicides such as DuPont™ Finesse® applied to wheat the previous fall.

Components of the LumiGEN™ system for soybeans are applied at a Corteva Agriscience™, Agriculture Division of DowDuPont production facility, or by an independent sales representative of Corteva Agriscience or its affiliates. Not all sales representatives offer treatment services, and costs and other charges may vary. See your sales repre-sentative for details. Seed applied technologies exclusive to Corteva Agriscience and its affiliates.

This product may not be registered for sale or use in all states. Contact your local Corteva retailer or representative for details and availability in your state.

Lumialza™ nematicide has not yet received regulatory approvals in any country outside the United States; approvals are pending.

The information presented here is not an offer for sale. This presentation is not intended as a substitute for the product label for the product(s) referenced herein. The information contained in this technical presentation is based on the latest to-date technical information available to DuPont, and DuPont reserves the right to update the information at any time.

TRADEMARKS (CONTINUED)

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.

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

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

Roundup Ready 2 Xtend®, YieldGard®, the YieldGard Corn Borer design and Roundup Ready® are registered trademarks used under license from Monsanto Company.

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

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

HXRW - The Herculex® RW insect protection trait contains proteins that provide enhanced resistance against western corn rootworm, northern corn rootworm and Mexican corn rootworm. Herculex® RW Rootworm Protection technology by Dow AgroSciences and Pioneer Hi-Bred.

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

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

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

Always follow stewardship practices in accordance with the Product Use Guide (PUG) or other product-specific stewardship requirements including grain marketing and pesticide label directions.

The foregoing is provided for informational use only. Please contact your Pioneer sales professional for information and suggestions specific to your operation. Product performance is variable and depends on many factors such as moisture and heat stress, soil type, management practices and environmental stress as well as disease and pest pressures. Individual results may vary.