AGRONOMY SCIENCES RESEARCH SUMMARY

IOWA EDITION - 2014

Introduction

According to USDA projections, U.S. farmers produced almost 14 billion bushels of corn in 2013, the largest corn crop in history. The average yield of this year's crop, 160.4 bu/acre, was exceeded only in 2009. The soybean crop was estimated at 3.25 billion bushels, which was higher only twice previously.

These results were achieved due to abundant spring rainfall that replenished soil moisture reserves throughout the Midwest and was then followed by generally favorable summer conditions in most states. However, some major production areas experienced progressively worsening drought stress during grain fill, which resulted in reduced yields. The hardest hit areas included most of Iowa and northern Missouri and parts of southern Minnesota, western Wisconsin and central Illinois.

Insufficient summer rainfall and other adverse weather conditions are the most serious risks faced by growers. For this reason, DuPont Pioneer researchers are developing hybrids and varieties that perform better under drought stress than historical seed products. Pioneer® brand Optimum® AQUAmax® corn hybrids are prime examples of these efforts, but other crops are benefitting as well.

In addition to adverse weather, grain price fluctuations also present a risk to the profitability of farming operations. To help reduce this exposure, DuPont Pioneer conducts studies each year designed to improve crop management practices. Results of these studies are made available to customers in multiple formats, including this Agronomy Sciences Research Summary. Growers can use this information to help optimize production decisions in their farming operations for increased yields and profits.

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AGRONOMY SCIENCES

RESEARCH UPDATE

Corn Yield Response to Row Spacing in Southwestern Iowa

2010-2013

Objectives

- Evaluate corn yield response to row spacing in the Missouri Valley of western Iowa.
- Determine if performance in narrow rows differs among hybrids and plant populations.

Study Description

Locations: 9 farms in the Missouri Valley of western Iowa
Years: 2010-2013
Plot Layout: 8-row field-length strips
Factors: Row Spacing: 20-inch and 30-inch
Population: 36,000 and 42,000 plants/acre
Pioneer® Hybrids/Brands[1]:
33M16 (HX1, LL, RR2)   33W88$_{\text{AM1}}$™ (AM1, LL, RR2)
P1162$_{\text{AMX}}$™ (AMX, LL, RR2)   P1480$_{\text{HR}}$ (HX1, LL, RR2)

- Hybrids/brands were selected to represent a range in leaf architecture, foliar health and drought tolerance.
- All plots were planted using commercially available 20- and 30-inch row planters.

Results

- Across all locations and years, average corn yield was 11 bu/acre greater in 20-inch rows than 30-inch rows (Figure 1).
- Yield response to narrow rows varied greatly among years, with the greatest response observed in 2011.
- The four hybrids/brands included in this study responded similarly to row spacing (Figure 2).
- Yield response to row spacing was similar between plant populations (Figure 3).

Conclusions

- The average yield advantage observed in this study with 20-inch rows was greater than has been generally reported in Iowa.
- The unusually large yield response to narrow rows could be associated with higher solar radiation in southwest Iowa relative to the rest of the state.
- This research indicates that adopting narrower row spacing could potentially increase corn yields on some farms.
- Narrow row spacing involves many management aspects that should be considered before adopting.

Figure 1. Average yield advantage of 20-inch rows compared to 30-inch rows over four years.

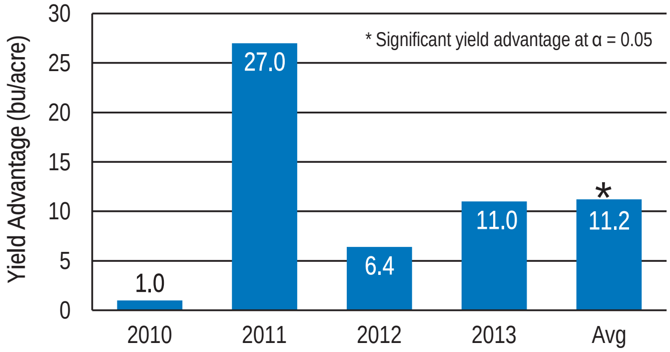


Figure 2. Average yield response of hybrids/brands to 20-inch rows.

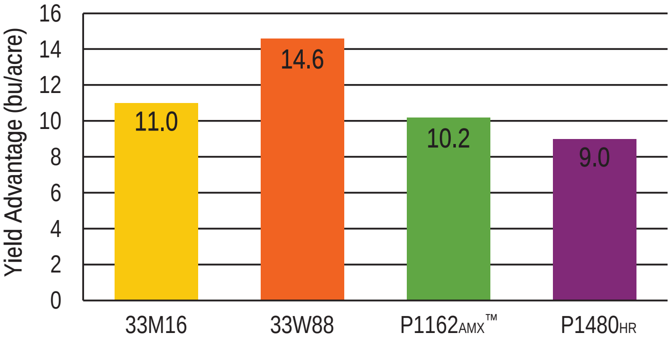
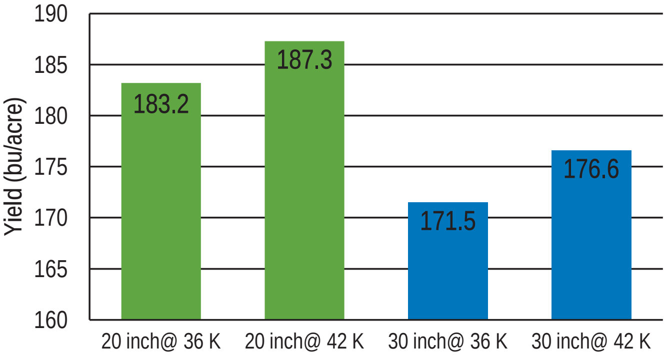


Figure 3. Effect of row spacing and plant population on corn yield.



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[1] All Pioneer products are hybrids unless designated with AM1, AM, AMRW, AMX and AMXT, in which case they are brands.

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 1 and Herculex RW genes. LL - Contains the LibertyLink® gene for resistance to Liberty® herbicide. 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. AM1 - Contains the 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 refuge must be planted with Optimum AcreMax Xtra products. 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. Herculex® Insect Protection technology by Dow AgroSciences and Pioneer Hi-Bred. Herculex® and the HX logo are registered trademarks of Dow AgroSciences LLC. YieldGard®, the YieldGard Corn Borer design and Roundup Ready® are registered trademarks used under license from Monsanto Company. Liberty®, LibertyLink® and the Water Droplet Design are trademarks of Bayer. PIONEER® brand products are provided subject to the terms and conditions of purchase which are part of the labeling and purchase documents. 2013 data are based on average of all comparisons made in nine locations through November 15, 2013. Multi-year and multi-location is a better predictor of future performance. Do not use these or any other data from a limited number of trials as a significant factor in product selection. Product responses are variable and subject to a variety of environmental, disease, and pest pressures. Individual results may vary.

AGRONOMY SCIENCES

RESEARCH UPDATE

Do Hybrids Respond Differently to Row Spacing?

2011-2013

Objectives

- Farmers that have adopted narrower row spacing in corn emphasize that hybrids respond differently to narrower row spacing.
- In this research, we screened 11 hybrids with known differences in plant height, leaf uprightness, drought tolerance, disease susceptibility and stalk strength.
- The goal of this research was to help farmers in narrower row spacing systems select the best genetics for their operations.

Study Description

Years:	2011-2013
Location:	1 in Missouri
Replications:	5
Factors:	
Row Spacing:	15 and 30 inch
Plant Population:	30 and 36 thousand plants/acre

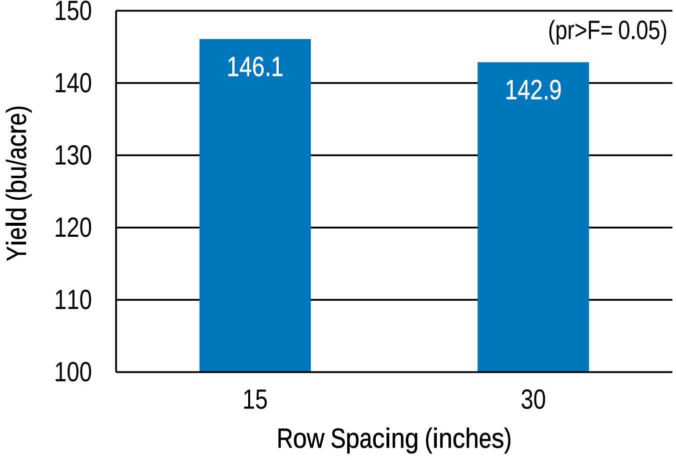
Hybrids: 11 Pioneer® brand corn hybrids selected to represent a range in leaf uprightness, plant health, disease and drought tolerance.

Pioneer® Brand Corn Hybrids	
Hybrid Characteristics	Hybrid/Brand[1]
Expected to respond to narrow row spacing. Erect leaves and relatively higher ear placement.	33T57 (HX1, LL, RR2)
	P0636AM™ (AM, LL, RR2)
	P1498AM™ (AM, LL, RR2)
Not expected to respond to narrow row spacing. Horizontal leaves and lower ear placement.	P0621HR (HX1, LL, RR2)
	P1151AM™ (AM, LL, RR2)
	P1324HR (HX1, LL, RR2)
Horizontal leaves and relatively high ear placement.	P0461HR (HX1, LL, RR2)
	P1018AM™ (AM, LL, RR2)
	P1420HR (HX1, LL, RR2)
Erect leaves and lower ear placement.	P1360HR (HX1, LL, RR2)
	P1395AM™ (AM, LL, RR2)

Results

- When averaged across years and hybrids, there was a small but statistically significant advantage to 15-inch vs 30-inch row spacing (Figure 1).
- Corn yield was not significantly affected by plant population in this study (data not shown).
- In two of three years, drought stress significantly limited yield potential. Narrow row management decisions should not be based solely on the results of this study.

Figure 1. Effect of row width on corn yield



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

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[1] All Pioneer products are hybrids unless designated with AM1, AM, AMRW, AMX and AMXT, in which case they are brands.

2013 data are based on average of all comparisons made in one location through November 21, 2013. Multi-year and multi-location is a better predictor of future performance. Do not use these or any other data from a limited number of trials as a significant factor in product selection. Product responses are variable and subject to a variety of environmental, disease, and pest pressures. Individual results may vary.

Results

- In this study, hybrids responded differently to narrower row spacing (Figure 2). The narrow row advantage for Pioneer® hybrids P1324HR, 33T57 and P1018HR was positive ranging from 7 to 17 bushels (significant at $p<0.15$).
- Based on plant structure, P1324HR was not expected to respond to narrower row spacing. In field experience with this hybrid, it is known to tolerate higher plant density and early season moisture stress. This tolerance to early season moisture stress could explain the observed yield response to narrow rows with this hybrid.
- The hybrid with the most erect leaves in this study, Pioneer® hybrid P1360HR, did not respond to narrow row spacing. Having poorer drought tolerance and lower ear placement could explain this lack of response.
- A key observation in this study was that some hybrids tended to change their leaf angle in response to narrower rows. For example, leaves in Pioneer® P1395AM™ and P1018AM™ brand corn tended to be more upright in 15-inch rows (Figure 3).

Figure 2. Yield advantage of various hybrids in 15- vs 30-inch row spacings.

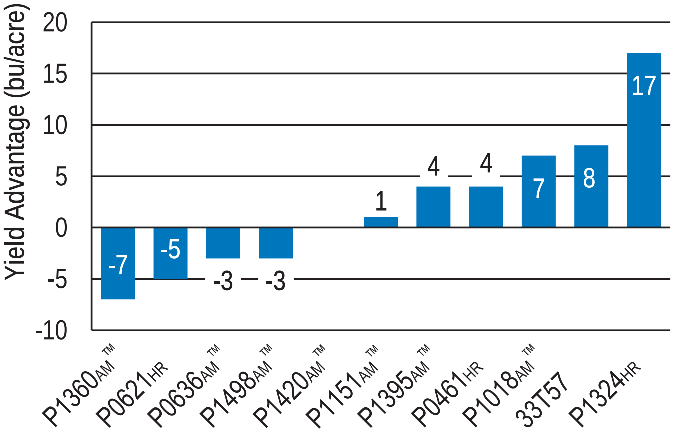


Figure 3. Some genetics changed their leaf angle in response to narrower row spacing. Left: P1018AM™ in 15-inch rows. Right: P1018AM™ in 30-inch rows.

Hybrid Suggestions for Narrow Row Corn

1. Start with hybrids most adapted to your area. Hybrids that do well in 30-inch rows will likely perform equally well in narrower rows.
2. Consider hybrids with tolerance to higher plant density. In the example of P1324HR, there seemed to be a relationship in tolerance to high plant density in 30-inch rows with performance in narrow rows.
3. Consider hybrids with better foliar health and stalk strength. While not observed in this study, disease pressure in can be greater with narrower rows due to the more humid canopy.
4. Test several hybrids to optimize genetics in your system. The observation that some genetics change their leaf angle in response to narrow row spacing makes it difficult to predict hybrid responses.

Planting Depth Effects on Corn

Early corn planting recommendations in most Corn Belt areas are to plant 1.5 to 2 inches deep to ensure adequate moisture uptake and seed-to-soil contact. Deeper planting may be recommended as the season progresses and soils become warmer and drier. Planting shallower than 1.5 inches is almost never recommended at any planting date or in any soil type.

Growers who plant at depths less than 1.5 inches expect that seed will emerge more rapidly due to warmer soil temperatures closer to the surface. This is an important consideration, as corn growers across the Corn Belt are planting earlier to complete planting before yield potential begins to decrease after the first week of May. Particularly in soils that crust, speed of emergence is critical to establish plant stands before heavy rainfalls "seal" the soil surface.

When corn is planted 1.5 to 2 inches deep, the nodal roots develop about 0.75 inches below the soil surface. However at planting depths less than 1 inch, the nodal roots develop at or just below the soil surface (Figure 1). Such excessively shallow planting can cause slow, uneven emergence due to soil moisture variation; and rootless corn ("floppy corn syndrome") later in the season when hot, dry weather inhibits nodal root development (Figure 2).

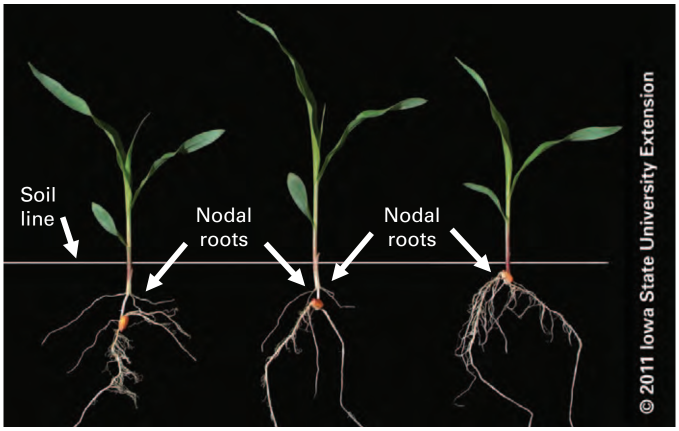


Figure 1. Planting depth (2.5" on left to 0.5" on right) determines the placement of nodal roots, which are developing too near the soil surface in shallow-planted corn plant at right.

Study Justification and Objectives

Well-documented effects of shallow planting on root development has led to the assumption that planting depth may play a role in managing the drought susceptibility of a hybrid. According to some agronomists, shallow plantings increase stress and result in less developed roots, smaller stalk diameters, smaller ears and reduced yields. However, data substantiating such claims are limited.

Although previous research has generally documented faster emergence rates with shallower planting depths, the comparisons have often included deeper planting depths than the recommended ranges, and results are highly influenced by temperature and rainfall in the given season. Recent studies comparing planting depths that are within the depth ranges commonly used by growers are limited, and none have attempted to compare hybrid differences between planting depths.

Figure 2. Rootless corn syndrome caused by shallow planting and dry soils conditions.

DuPont Pioneer has worked to introduce hybrids with improved drought tolerance to provide more yield stability on variable and droughty soils. Hybrids with higher levels of drought tolerance may provide improved yield stability in shallow-planted situations while also providing improved performance at normal planting depths, though this has not been documented. Improving our understanding of newer hybrid responses to planting depth across planting dates and over different soil types may help improve our understanding of hybrid management and positioning. Incorporation of differing planting dates and soil types will allow a more robust analysis of the impact of temperature, soil water holding capacity and crusting potential over the course of the study.

The objectives of this research study were:

- to evaluate the effect of planting depth on stand establishment of Pioneer® brand corn products
- to evaluate the grain yield response of corn products with different drought tolerance ratings to varying planting depths
- to assess if planting depth effects varied across growing environments that differed by soil type and planting date.

Study Description

Locations - This study was conducted by Dr. Peter Thomison in conjunction with the 2011 Ohio State University Ohio Corn Performance Test (OCPT) and established at 10 locations (Hebron, Washington Court House, S. Charleston, Greensville, Van Wert, Hoytville, Upper Sandusky, Bucyrus, Wooster and Beloit).

Plot Design - The experiment was replicated three times in a randomized complete block arranged in split-plot layout. The main plot was planting depth and subplot was hybrid. Plot size was 4 30-inch rows 25 feet in length. Force® 3G soil insecticide was applied in a T-band to all plots.

Hybrids and Planting Depth Treatments - Three Pioneer® brand corn products, Pioneer® P0965AM1™ brand corn (AM1, LL, RR2, 108 CRM), Pioneer® P0891AM1™ brand corn (AM1, LL, RR2, 109 CRM) and Pioneer® hybrid 35H42 (HX1, LL, RR2, 107 CRM) were planted at three planting depths (0.5, 1.5, and 2.5 to 3 inches). The drought scores for the three products were 8, 7 and 6, respectively. The Pioneer drought rating scale is from 1 to 9 (9 = best).

Seeding Rate, Measurements - Seeding rate was 34,000 seeds/acre. Measurements during the growing season included early stand, late emergers ("runts"), stalk diameter, final stand, ear weight, "nubbins", grain yield, stalk and root lodging, and test weight. Weather data were recorded at each site.

Applied Questions

How did planting depth affect corn yields?

2011 - Grain yields, averaged across locations and hybrids, were 13% and 15% greater for the 1.5- and 3-inch planting depths, respectively, than the 0.5-inch planting depth (Figure 3).

- At 8 of the 10 sites, yields of the 3-inch planting depth treatment exceeded those of the 0.5-inch planting depth treatment (data not shown).
- At 5 of the 10 sites, yields of the 1.5- and 3-inch treatments were similar; the 1.5-inch treatment out-yielded the 3-inch treatment at 1 site (data not shown).

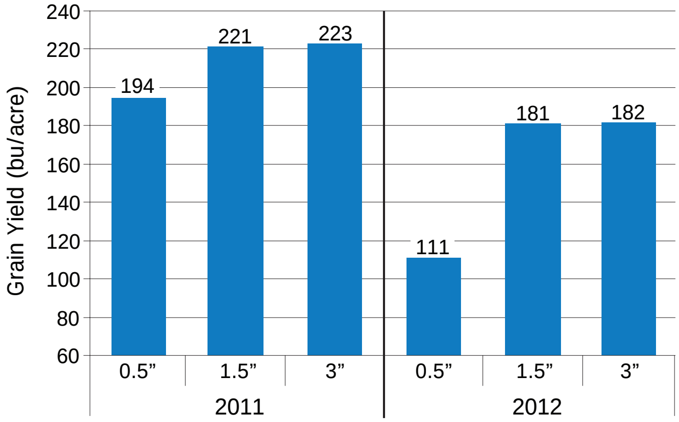


Figure 3. Corn yield response to planting depth in 2011 and 2012.

2012 - Grain yields averaged across locations and hybrids were 40% greater for the 1.5- and 3-inch planting depths than the 0.5-inch planting depth (Figure 3).

- At 9 of the 10 sites, yields of the 1.5-inch and 3-inch planting depth treatments were greater than those of the 0.5-inch planting depth (data not shown).
- At 6 of the 10 sites, yields of the 1.5-inch and 3-inch treatments were similar (data not shown).

Did planting depth affect stand establishment, and was this associated with yield effects?

2011 - The lower yield of the shallow planting treatment in Figure 3 was associated with a reduced final stand – 27,200 plants/acre for the 0.5-inch depth vs. 34,200 and 34,000 for the 1.5-inch and 3-inch planting depths, respectively (Figure 4).

- The lower yield was also associated with many more “runts” – 28% for the 0.5-in. depth vs. 5% and 4% for the 1.5-inch and 3-inch depths, respectively (data not shown).

2012 - The lower yield of the shallow planting treatment was associated with a lower final stand – 19,500 plants/acre for the 0.5-inch depth vs. 32,000 and 30,900 plants/acre for the 1.5-inch and 3-inch planting depths, respectively (Figure 4).

- The lower yield was also associated with many more “runts” – 31% for the 0.5-inch depth vs. 6% and 3% for the 1.5-inch and 3-inch planting depths, respectively.

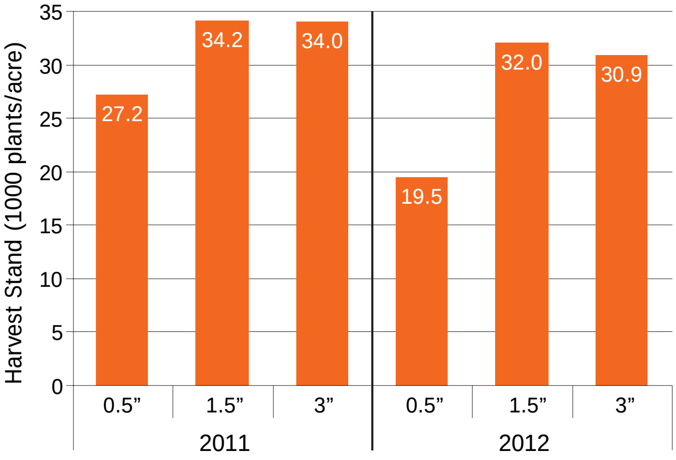


Figure 4. Harvest stand response to planting depth in 2011 and 2012.

Did corn products differ in their yield response to planting depth?

Although differences in yield were evident among hybrids, the three hybrids exhibited similar yield responses to varying planting depth (Figure 5).

- Averaged across locations, the yield of P0965AM1™ exceeded that of the other 2 hybrids by about 11 to 15 bu/acre at each planting depth.

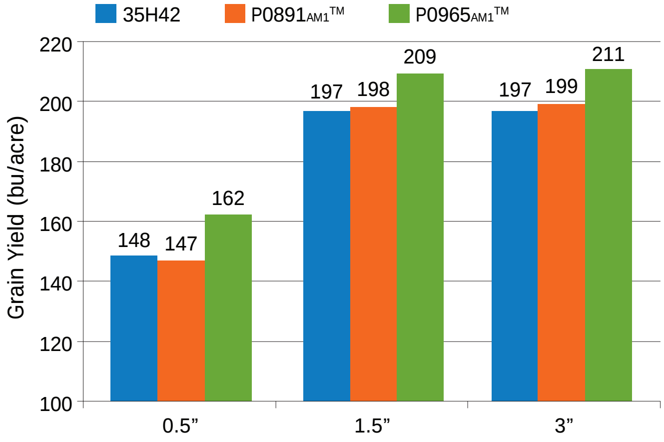


Figure 5. Corn product yield response to planting depth in 2011 - 2012.

Did differences in hybrid drought tolerance ratings affect yield response to planting depth?

Drought tolerance rating effects could not be separated from hybrid genetic effects in this study. However, similar to the prior question, there was no evidence that differences in hybrid drought tolerance ratings among the hybrids affected response to planting depth (Figure 5).

- P0965AM1™, the hybrid with the highest drought tolerance score, was consistently higher yielding than the other two hybrids at all planting depths.

Do not use these or any other data from a limited number of trials as a significant factor in product selection. Product responses are variable and subject to a variety of environmental, disease, and pest pressures. Individual results may vary.

AGRONOMY SCIENCES

RESEARCH UPDATE

On-Farm Plant Population Responses

2012-2013

Objectives

- DuPont Pioneer is committed to helping farmers get the most out of their seed investment.
- Over the past two years, DuPont Pioneer field agronomists have conducted a series of studies to evaluate new hybrids and how they respond to plant population, additional management and soil types.
- The results demonstrate ways farmers can optimize their seed investment.

Study Description

Locations:	511 on-farm locations over two years
Hybrids:	4 per location, 62 total
Populations:	30, 34, 38 and 42 thousand plants/acre
Soil Types:	Trials were planted across productive as well as less productive areas to better understand how hybrids, population and management interact with local soil types.
Plot Size:	One header width of the farmer's harvester by the length of the field.

Results

- The 2012 and 2013 growing seasons were not favorable for corn production in Iowa. Mild to extreme moisture stress during silking and grain fill reduced yield potential.
- Corn yield response to plant population differed among locations depending upon their yield level.
- For example, yield was greatest at 30k plants/acre for farms yielding 140-180 bu/acre, while a population of 38k plants/acre produced the greatest yield among farms yielding over 220 bu/acre (Figures 2-4).
- Results demonstrated how hybrids can respond differently to plant population (Figure 5).
- The potential for lodging can be a concern at higher populations. DuPont Pioneer agronomists may recommend a population lower than that needed to maximize yield in order to mitigate the risk of lodging.

Summary

- Thanks to our farmer cooperators, we have gained a tremendous wealth of knowledge on the effects of plant population and soil type on performance of new hybrids.
- Consult with your Pioneer sales professional regarding how our new hybrids respond to soils, population and management in your unique area.

Figure 1. Corn plant population research locations in 2012 and 2013.

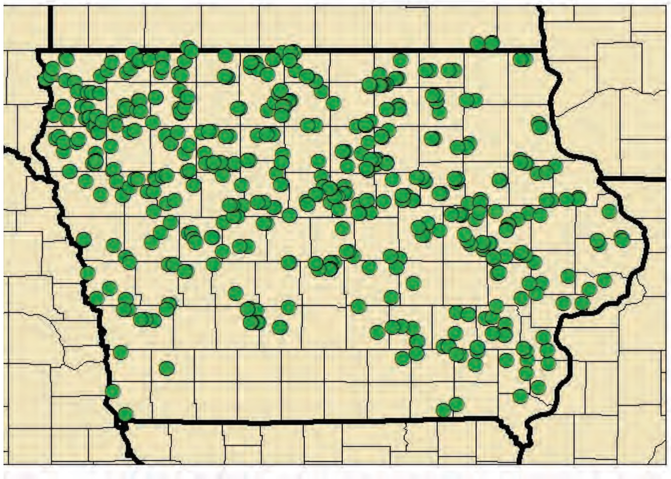
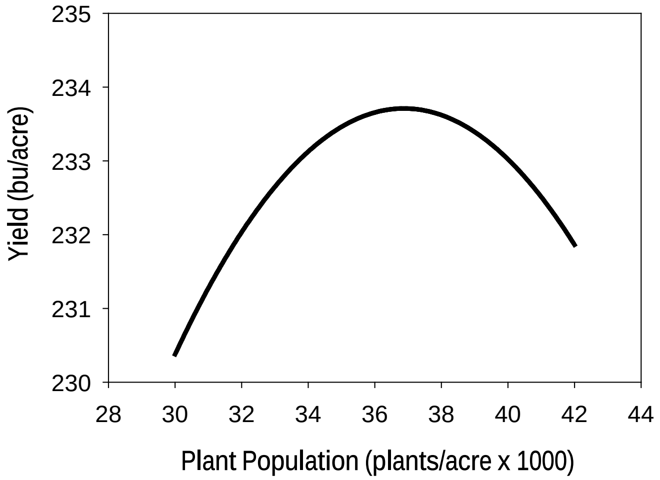


Figure 2. Yield response to plant populations in environments yielding greater than 220 bu/acre. n=47 locations of Iowa on-farm research.



Results

Figure 3. Yield response to plant populations in environments yielding between 180-220 bu/acre. n=215 locations of Iowa on-farm research.

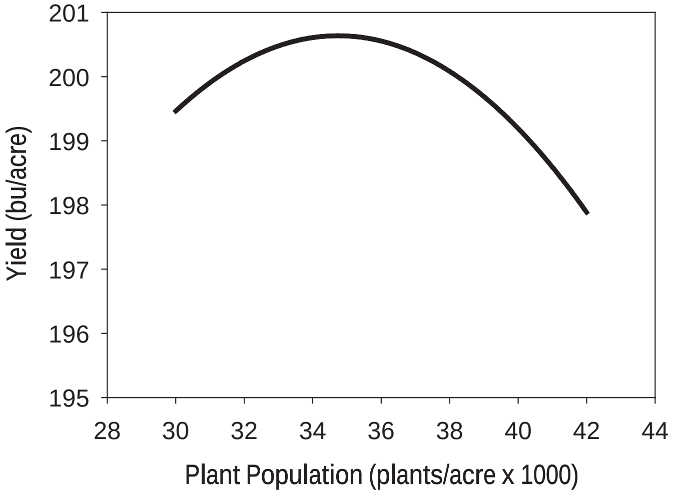


Figure 4. Yield response to plant populations in environments yielding between 140-180 bu/acre. n=157 locations of Iowa on-farm research.

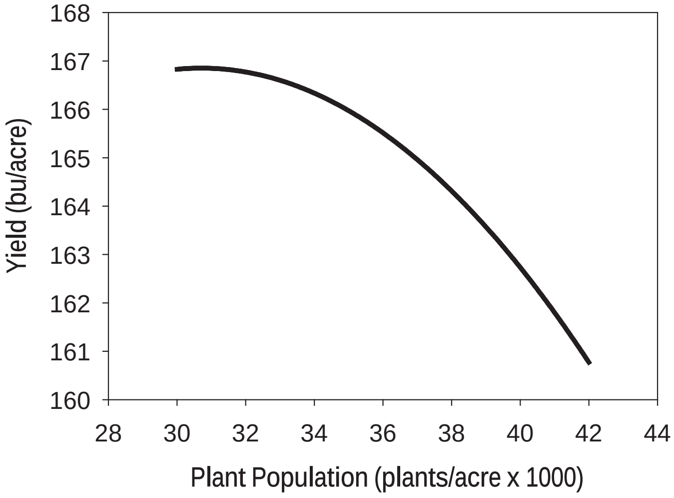


Figure 5. Hybrids can respond differently to plant population. Yield of Pioneer® P1365AMX™ brand corn (AMX, LL, RR2) had a greater than average response to plant population.

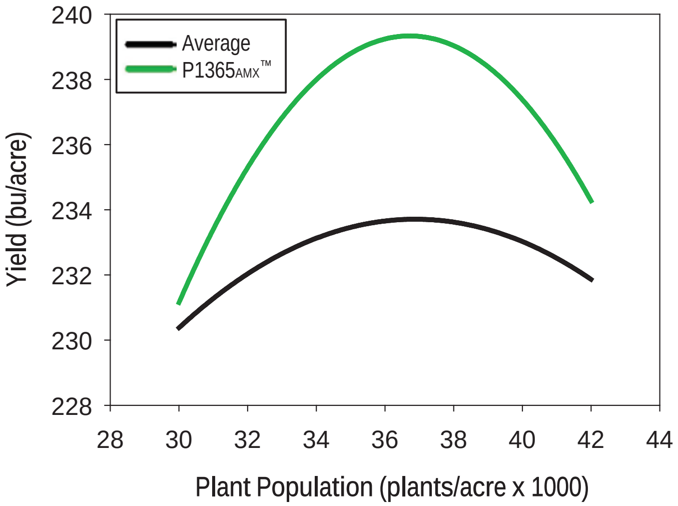
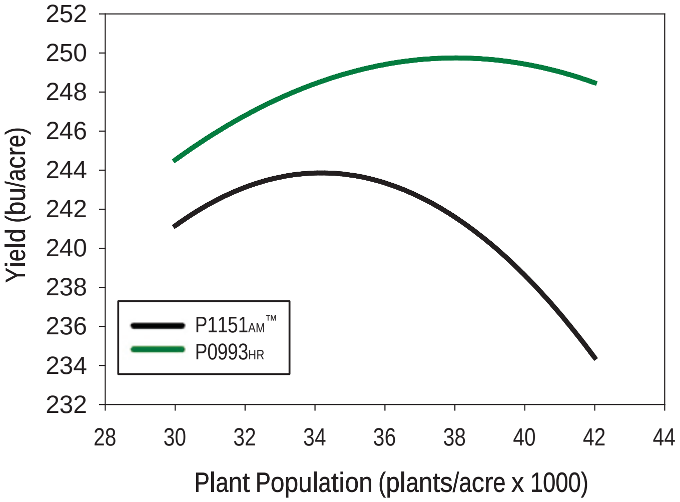


Figure 6. Yield of Pioneer® hybrid P0993HR (HX1, LL, RR2) was maximized at 38k plants/acre and at 34k plants/acre for Pioneer® P1151AM™ brand corn (AM, LL, RR2).



AM - Optimum® AcreMax® Insect Protection system with YGCB, HX1, LL, RR2. Contains a single-bag integrated refuge solution for above-ground insects. In EPA-designated cotton growing counties, a 20% separate refuge must be planted with Optimum AcreMax products. AMX - Optimum® AcreMax® Xtra Insect Protection system with YGCB, HXX, LL, RR2. Contains a single-bag integrated refuge solution for above- and below-ground insects. In EPA-designated cotton growing counties, a 20% separate refuge must be planted with Optimum AcreMax Xtra products. 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. 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. LL - Contains the LibertyLink® gene for resistance to Liberty® herbicide. HXX - Herculex® XTRA contains the Herculex I and Herculex RW genes. 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. YieldGard®, the YieldGard Corn Borer design and Roundup Ready® are registered trademarks used under license from Monsanto Company. Herculex® Insect Protection technology by Dow AgroSciences and Pioneer Hi-Bred. Herculex® and the HX logo are registered trademarks of Dow AgroSciences LLC. Liberty®, LibertyLink® and the Water Droplet Design are trademarks of Bayer.

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Corn Stalk Quality

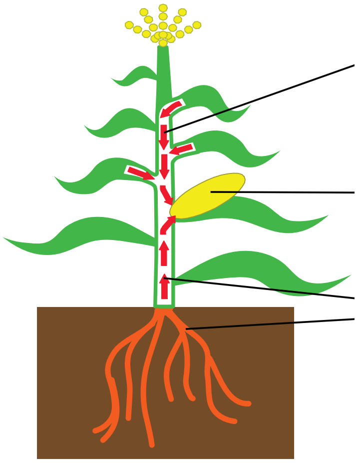
Many different stresses to corn plants can lower stalk quality, with the result that stalk problems occur in some fields each year throughout North America. Drought stress, reduced sunlight, insect and disease pressure, and hail damage are stresses that can result in poor stalk quality. Even good growing conditions can lead to stalk problems when followed by a less favorable environment. Cropping history, soil fertility, hybrid genetics and micro-environment effects can heighten the problem in certain fields. Growers should monitor their fields as harvest approaches to identify stalk quality problems, and if necessary, prepare to harvest before field losses occur.

Photosynthesis and Carbohydrate Translocation

Through photosynthesis, leaves of corn plant capture sunlight and carbon dioxide (CO_2) to produce sugars (photosynthates), which are directed to the actively growing organs of the plant. Early in plant development, sugars move to the roots, where they are converted to structural carbohydrates and proteins. As plants continue to grow, sugars are directed to the stalk for temporary storage.

Following pollination, kernel development places a great demand on the plant for carbohydrates. When the demands of the developing kernels exceed the supply produced by the leaves, stalk and root storage reserves are tapped.

Environmental stresses, such as drought and low available sunlight, decrease photosynthate production and force plants to extract even more stalk carbohydrates, which preserves grain fill rates at the expense of the stalk. Disease lesions, insect feeding and hail damage also limit photosynthate production by reducing the functional leaf area of the plant.



Stalk Rot / Plant Stress

Stressed plants make less sugar. Stresses include disease, drought, lack of sunlight, high plant density, etc.

Developing ears take priority. Amount of sugars required depends on kernel number (yield potential).

Root and stalk tissue have lower priority. Under stress, these tissues receive less sugar and weaken. Stalk rot fungi infect and initiate disease.

To reduce stalk rot, reduce stress.

As carbohydrates stored in the roots and stalk are mobilized to the ear, these structures begin to decline and soon lose their resistance to soil-borne pathogens. High temperatures increase the rate at which the fungi invade and colonize the plant. Though pathogens play a key role in stalk rot development, it is primarily the inability of the plant to provide sufficient photosynthates to the developing ear that initiates the process.

Stalk Rots Often Begin as Root Rots

Root rot beginning in the basal stalk region.

Stalk-rotting fungi inhabit the soil in the root zone of corn plants, surviving on discarded cells and nutrients excreted by the roots. They are prevented from invading the roots and stalk by metabolites produced in the plant. Though unable to overcome healthy living tissue, these opportunistic fungi rapidly invade weakened and dying roots as the plant redirects carbohydrates from the roots to kernels. After the roots are colonized, the infection spreads to the stalk (Dodd, 1983).

As vascular tissues in the plant become plugged by fungal mycelial growth, water supply to the plant becomes restricted. Wilting and premature death of the plant eventually follows. External discoloration of the lower stalk becomes evident as deterioration of the inner stalk tissue progresses. The structural integrity of the stalk is diminished by this decay, and the plant is susceptible to lodging. Storms and high winds provide the forces needed to topple the weakened stalks.

The Growing Environment

Almost any stress applied to the plant will reduce photosynthesis and resultant sugar production in the leaves.

Drought Stress - The decrease in photosynthetic rates due to drought stress has been well documented in research studies. Water relations within the plant and CO_2 and O_2 exchange are directly affected. In addition, if leaf rolling occurs during drought, the effective leaf surface for collection of sunlight is reduced.

In research studies that withheld water from plants beginning at the mid-grain-fill stage, photosynthesis was eventually shut down (Westgate and Boyer, 1985). Subsequent grain development depended entirely on stalk carbohydrate reserves.

Reduced Sunlight - Photosynthesis is most efficient in full sunlight. Studies show that the rate of photosynthesis increases directly with intensity of sunlight. In fact, photosynthesis rates are reduced more than 50% on an overcast day compared to a day with bright sunshine (Moss et. al., 1960). Prolonged cloudy conditions during ear fill often result in severely depleted stalk reserves.

Reduction of Leaf Area - Any reduction in leaf area will limit total photosynthesis. Leaf area may be reduced due to hail, frost, disease lesions, insect feeding or mechanical injury. Whenever functional leaf area is reduced prior to completion of ear fill, stalks will be weakened.

Early Favorable Conditions Followed by Stress - If favorable conditions exist when the number of kernels per ear is being established (V10 to V17), the eventual demand for photosynthates will be large. Each potential kernel represents an additional requirement for translocatable sugars from the plant. If stress conditions develop during ear fill that render the plant unable to produce enough sugars, stalks will suffer.

Research has demonstrated that the number of kernels per ear on stalk-rotted plants is often greater than that of adjacent healthy plants (Table 1). The additional demand for carbohydrates by larger ears often results in greater depletion of the stalk, leading to eventual stalk rot.

Table 1. Comparison of kernel numbers between plants with rotted stalks and adjacent plants with healthy stalks.*

Year	No. of Hybrids Tested	No. of Plant Pairs	Rotted Stalks	Adjacent Healthy Stalks	Diff.
			No. of Kernels / Plant		
Year 1	40	112	562	495	67**
Year 2	30	65	648	587	61**

* From Dodd, 1980. ** Significant at the .001 prob. level.

Soil Fertility

Research studies have documented that soil fertility has a profound effect on stalk quality. Most notable are studies which show that a combination of high nitrogen and low potassium can severely reduce stalk quality. Researchers suggest that yearly applications of N and K (actual N, K as K_2O) should be approximately at the ratio of 1 to 1 for favorable balance in the corn plant and to reduce the risk of stalk rots and stalk breakage.

High nitrogen (N) is associated with greater kernel number, which increases the demand for carbohydrates to the ear. Higher N also aids the movement of these carbohydrates out of the stalk and into the ear by increasing the rate of translocation within the plant.

The role of potassium (K) in preventing premature plant death has long been established. Potassium functions in the building of leaf and stalk tissue, as well as regulating water movement within the plant. Increases in K have been associated with increased photosynthetic rate.

Hybrid Differences / Foliar Fungicide Applications

Carbohydrate Partitioning - Some hybrids naturally partition more carbohydrates to the stalk. Though useful in a poor stalk quality year, that trait may limit yield potential in a more normal environment. As hybrids are developed, researchers must be careful to select those with highest harvestable yield potential across many years and environments. Too much emphasis on stalk quality alone could result in lower yield potential most years. Many carefully selected hybrids with very good stalk quality may appear inadequate during a one-year-in-ten stalk-lodging event.

Leaf Disease Resistance - Hybrids prone to leaf diseases may lose significant leaf area, weakening the stalks. For this reason, foliar fungicide applications may reduce stalk lodging in years with high levels of fungal leaf diseases. DuPont Pioneer rates its hybrids for resistance to major leaf diseases to aid customers in their decisions about fungicide applications.

Stalk Rot Resistance - Susceptibility to specific stalk rot pathogens also increases the stalk-lodging risk. Pioneer provides hybrid ratings for resistance to major stalk rots.

Other Effects

Micro-Environments - Oftentimes, even small differences between fields or between areas in the same field can determine whether corn stands or lodges. Differences in soil fertility, soil moisture, plant-to-plant spacing, insect feeding or wind gusts can push plants past the lodging threshold. These effects are difficult to predict; however, scouting in the fall can identify problem fields, and early harvest can reduce field losses.

Plant Population - Multi-year research studies show that stalk lodging is increased only slightly at higher plant populations. For example, a summary of DuPont Pioneer research from 35 high-lodging environments from 2004 to 2007 showed that percent stalk lodging increased only about 1% for each 2,000 plant/acre population increase.

Reducing Harvest Losses Due to Stalk Lodging

Careful scouting and harvesting fields according to crop condition can help prevent field losses due to low stalk quality. Corn loss potential should be weighed just as heavily as grain moisture in deciding which fields to harvest first. Scouting fields approximately two to three weeks prior to the expected harvest date can identify fields with weak stalks predisposed to lodging. Fields with high lodging potential should be slated for early harvest.

Collapsed corn stalk.

Weak stalks can be detected by pinching the stalk at the first or second elongated internode above the ground. If the stalk collapses, advanced stages of stalk rot are indicated. Another technique is to push the plant sideways 15 to 20 inches at ear level. If the stalk crimps near the base or fails to return to the vertical position, stalk rot is indicated. Check 20 plants in five areas of the field. If more than 10 to 15% of the stalks are rotted, that field should be considered for early harvest.

DuPont Pioneer Research Emphasizes Stalk Quality

DuPont Pioneer corn breeders and plant pathologists use aggressive techniques to weed out hybrids with poor stalk quality, including manual and mechanical push tests that mimic the forces of wind on corn plants. In addition, plants are inoculated with stalk rot organisms where appropriate to help ensure that susceptible genotypes do not escape detection. Plant pathologists monitor disease incidence and assist breeders in their efforts to inoculate, screen and characterize products. Research trials conducted by corn breeders are designed to measure product performance for all important traits across a wide range of growing conditions.

Pioneer IMPACT™ plots further test product performance, including characterization of stalk quality, thus determining proper placement of new product releases. Pioneer uses information from both breeder and IMPACT plots to develop stalk lodging ratings for all its hybrids to aid customers in selecting appropriate hybrids for their fields.

Yield-Limiting Factors in Continuous Corn Production

Numerous studies have documented yield reductions when corn follows corn rather than soybeans, even when all yield-limiting factors appear to have been adequately addressed. Better understanding of factors that limit continuous corn (CC) yield can help improve management of this production system.

A recent study in east-central Illinois compared CC and corn following soybean (CS) yields over a six-year period (Gentry et al., 2013). With the exception of N fertilizer rates, which were varied as part of the study, high-yield management practices were applied uniformly to both CC and CS systems – this included the use of soil-applied insecticides for rootworm control. In general agreement with previous research (Erickson, 2008), the Illinois study reported a significant yield penalty and generally higher N fertilizer requirement for CC compared to CS (Table 1). On average over six years, CC yielded 25 bu/acre less than CS and required 10 lbs/acre more N fertilizer to achieve optimum (but lower than CS) yields.

Table 1. Agronomic optimum N fertilizer rate and yield of continuous corn (CC) and corn following soybean (CS) in a six-year study in east-central Illinois (Gentry et al., 2013).

Year	Agronomic Optimum N Rate (lbs/acre)		Yield at Agronomic Optimum N (bu/acre)		CC Yield Penalty (bu/acre)
	CC	CS	CC	CS	
2005	99	85	108	127	19
2006	225	195	213	222	9
2007	194	219	190	213	23
2008	250	200	169	197	27
2009	200	200	165	197	32
2010	200	200	130	171	41
Avg	**194**	**183**	**163**	**188**	**25**

The authors of the study used their field data to develop a regression model that identified the most important combination of factors contributing to reduced yields in the CC system. Of 11 potential yield-limiting factors that were evaluated, 2 factors were identified that, when taken together, explained more than 97% of the difference between CC and CS yields: soil N supply and CC history of the field (Table 2).

Nitrogen Supply

Nitrogen supply was by far the most important factor explaining the difference between CC and CS yields. Overall, the ability of soil to supply N explained 85% of the CC yield penalty (Table 2). Soils with higher N mineralization capacity supported higher CC yields, as was evidenced by a negative relationship between unfertilized (0-N) corn yield and the CC yield penalty (Figure 1). Soil N mineralization is reduced in CC systems due to the slower rate at which corn residues break down and release N relative to soybean residues. Soils also tend to warm more slowly in the spring when the previous crop was corn, which reduces activity of soil bacteria responsible for N mineralization. The fact that the CC yield penalty was smallest where relatively high corn yields were achieved, even in the absence of N fertilizer, shows that soils with high intrinsic N supply capacity are generally best suited for CC.

Table 2. Factors identified as explaining the yield penalty for continuous corn (CC) compared to corn rotated annually with soybean (CS) in a six-year Illinois study (Gentry et al., 2013).

Yield Limiting Factor	Effect / Explanation
Soil N Supply	**Effect:** The CC yield penalty decreased as the ability of the soil to supply N increased. **Explanation:** Because N mineralization is reduced in CC compared to CS, soils with high N supply capacity are generally best suited for CC.
CC History	**Effect:** The CC yield penalty increased as years in CC increased. **Explanation:** Accumulation of corn residues in CC reduces N mineralization, soil temperature and soil moisture; and increases disease and insect pressure. These negative effects intensify over time.

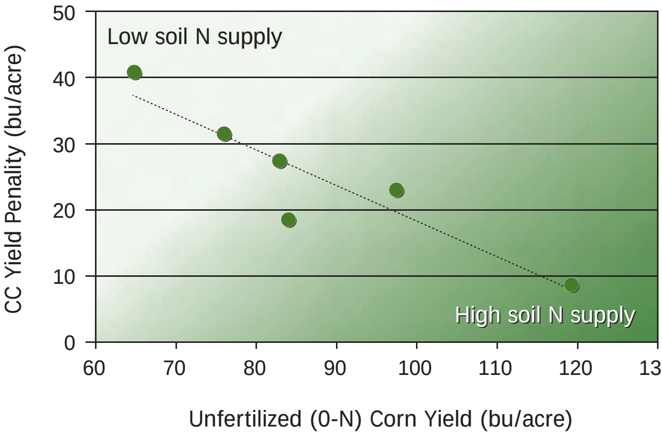


Figure 1. Relationship between unfertilized CC yield and the CC yield penalty. Adapted from Gentry et al., 2013.

CC History

Continuous corn production.

CC history was identified as the second most critical component of the CC yield penalty. Soil N supply and CC history together explained 97% of the difference between CC and CS yields. While many growers report that their CC yields approach CS yields over time, this study found that the CC yield penalty increased with years in CC (Figure 2). While producers typically alter management as they gain experience with CC, management remained relatively constant over time in the Illinois study. Therefore, CC history in this study likely reflects the underlying effects of excessive corn residues accumulating in and on the soil over time in the CC system. Corn residues exert negative effects on nutrient cycling, early-season soil temperature and moisture, and increased disease pressure for subsequent corn crops.

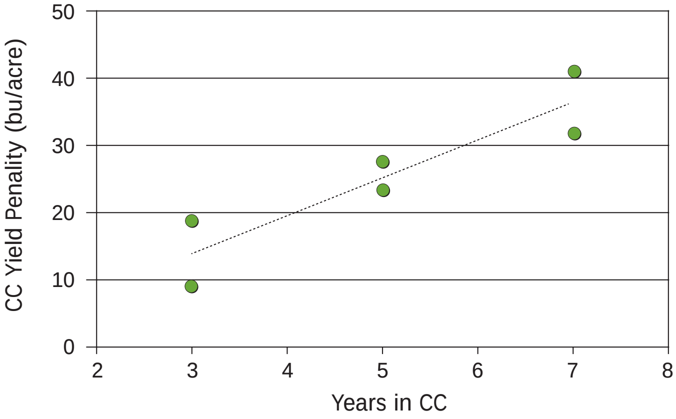


Figure 2. Relationship between years in CC and the CC yield penalty. Adapted from Gentry et al., 2013.

Managing Factors that Limit Continuous Corn Yield

There are numerous management factors that must be taken into consideration in order to maximize CC yields, including hybrid selection, tillage, soil fertility, and weed and insect control practices (Butzen, 2012). The following review focuses on just those factors that relate directly to the findings of Gentry et al. (2013) described in this article.

Field Selection - University research and grower experience both indicate that CC yield losses are minimized in highly productive and low stress environments (Porter et al., 1997). This understanding is consistent with Gentry et al.'s (2013) findings that soil N supply capacity was the most important factor explaining the CC yield penalty. The ability of soil to serve as a source of N for crop growth is directly related to its organic matter content. Soils with high organic matter, in turn, generally have high water-holding capacity. Positioning CC on these soils (or having access to irrigation) is critical for maximizing yields in this system.

Hybrid selection is a critical decision in any production system, but is particularly important for CC where high residue levels often cause additional management challenges. To assist in selecting hybrids for CC, Pioneer sales professionals can provide hybrid ratings for high residue suitability, disease resistance, and stalk and root strength. They can also recommend products with appropriate insect resistance traits and refuge options, as well as the best seed treatments.

Residue Management - Interference from past years' corn residues was a key factor identified by Gentry et al. (2013) as contributing to the CC yield penalty. Growers can take several actions to manage residues for improved CC performance.

Partial residue removal can be very effective in managing excessive residue in high-yield CC environments. DuPont Pioneer on-farm research in Iowa indicated that removing half the previous year's corn stover improved CC yield by an average of six bu/acre. Removing excess residue was found to increase CC yields through improved stand establishment and reduced nitrogen immobilization. Removing excess corn residues can provide many of the benefits associated with rotation with soybean. Additional details are available on the potential agronomic benefits of residue removal in CC systems (see Heggenstaller, 2012a). Residue removal is particularly advantageous in no-till CC systems, where residues are not incorporated into the soil (Heggenstaller, 2012b).

Baling corn stover for cellulosic ethanol production.

Tillage is a key residue management practice in most CC systems. Sizing and incorporating residues into soil are the first steps in getting them to begin to break down in advance of establishing the next crop. Full-width chisel plowing and strip-tillage in the fall are generally the best suited tillage practices for CC systems.

Fall nitrogen applications can help to accelerate the rate at which residues break down in environments where temperature and moisture are not limiting.

Limited rotation with soybean can be an effective way to maintain high yields in systems where corn is frequently grown consecutively for two or more years. Research conducted by DuPont Pioneer and the University of Illinois found a 5% yield penalty for second-year corn in a corn-corn-soybean rotation vs. corn grown the first year after soybean. This compared to a 17% penalty for corn grown continuously (Doerge, 2007).

References

Butzen, S. 2012. Best management practices for corn-after-corn production. Crop Insights. Vol. 22, no. 6. DuPont Pioneer, Johnston, IA.

Doerge, T. 2007. A new look at corn and soybean rotation options. Crop Insights Vol. 17. No. 2. DuPont Pioneer, Johnston, IA.

Erickson, B. 2008. Corn-soybean rotation literature summary. Department of Agricultural Economics. Purdue University. West Lafayette, IN.

Heggenstaller, A. 2012a. Corn production following partial stover harvest. Research Update. DuPont Pioneer Agronomy Sciences, Johnston, IA.

Heggenstaller, A. 2012b. Residue management: partial stover harvest increases no-till continuous corn yield. Crop Insights Vol. 22, no. 6. DuPont Pioneer, Johnston, IA.

Gentry, F., M.L. Ruffo, and F.E. Below. 2013. Identifying factors controlling the continuous corn yield penalty. Agron J 105:295-303.

Porter, P.M., J.G. Lauer, W.E. Lueschen, J.H. Ford, T.R. Hoverstad, E.S.Oplinger, and R.K. Crookston. 1997. Environment affects the corn and soybean rotation effect. Agron J 89:441–448.

Managing Winter Cover Crops in Corn and Soybean Cropping Systems

In recent years, interest in adding cover crops to corn and soybean cropping systems has increased as their potential benefits have become more widely recognized. Most of these benefits are realized over time as their ongoing use improves soil quality and function (Table 1). Thus, cover crops are best viewed as a long-term investment in soil productivity.

Table 1. Potential benefits of cover crops.

Potential Benefit	Description
Retain Soil Nutrients	Cover crops scavenge soil nutrients as they grow and ultimately release them for following crops to use. This reduces the potential for nutrient losses, especially N.
Prevent Soil Erosion	Cover crops help hold soil in place, reduce crusting and protect against erosion due to wind and rain.
Build Soil Organic Matter	Cover crop biomass contributes to soil organic matter, which helps to improve soil structure, water infiltration, and water-holding and nutrient-supply capacity.
Break Soil Compaction	Cover crop roots can act as “living plows”, breaking-up compacted soil layers. Cover crop shoots can also help protect the soil from the impact of heavy rains.
Add Nitrogen (N)	Leguminous cover crops fix N as they grow. This N mineralizes after the cover crop is terminated and becomes available for use by future crops.
Conserve Soil Moisture	Cover crop residues increase water infiltration and limit soil evaporation. This helps to reduce moisture stress during drought conditions.
Suppress Weeds	Cover crops shade the soil, which can reduce weed germination and growth. Some cover crops also have an allelopathic effect on weeds.
Provide Additional Forage	In some areas, it may be possible to graze, hay or chop cover crops before terminating in the spring.

Cover Crop Selection - Grasses, Legumes, Brassicas

Grasses, including winter cereals such as rye, wheat, barley and triticale, are the most widely used cover crops in corn and soybean cropping systems. Winter cereals are typically planted in late summer through late fall and produce a small to moderate amount of root and above-ground biomass before going dormant in the winter. Vigorous growth resumes in early spring, and large amounts of biomass are produced by mid to late spring. Some growers prefer non-winter-hardy cereals like oats, which establish rapidly in the fall but winterkill and leave behind little residue to manage in the spring. Annual ryegrass is another option if spring residue levels are a concern.

Legumes are valued as cover crops primarily for their ability to fix nitrogen (N). Common legumes include hairy vetch, field pea, lentil, crimson clover, red clover and berseem clover. Legumes can be seeded in early summer through early fall but in many regions must be planted earlier than cereals to survive the winter. The amount of N added by legumes varies among species but is directly proportional to the amount of biomass produced. For this reason, spring management of legume cover crops can involve a trade-off between early corn planting and waiting for more biomass and N production by the legume.

Cereal rye cover crop.

Field pea cover crop.

Brassica cover crops have grown in popularity recently due to their ability to provide many of the same benefits as grasses but with residues that break down more rapidly in the spring. Certain brassicas are also becoming well known for their ability to produce a large taproot that is effective at breaking soil compaction. Common brassicas include canola, mustards, forage radish and turnip. Like most legumes, brassicas must be planted earlier than cereals in order to successfully establish and provide maximum benefits. Many brassica cover crops winterkill in locations with sub-freezing temperatures, which helps accelerate residue decomposition in the spring.

Pure Stands vs. Mixtures

Mixtures of cover crops are often superior to a single species. Grass-legume mixtures combine the benefits of both – quick soil cover and N scavenging by grasses and N additions by legumes. Disadvantages of mixtures can include increased seed cost and more complicated management.

Rye and crimson clover mix.

Cover Crop Establishment

Establishment is one of the primary management challenges associated with the use of winter cover crops in corn and soybean cropping systems. The best method for seeding winter cover crops depends largely on the time of seeding, but type of cover crop and farming operation considerations are also important. The most common methods and equipment for seeding into corn and soybeans are described below. With all equipment, consult the owner’s manual, equipment dealer and cover crop seed dealer for specific equipment settings and seeding rate recommendations, especially when seeding mixtures.

Grain drills are a reliable method for seeding cover crops after grain crop harvest. Many grain drills include legume and fertilizer boxes that facilitate planting mixtures.

Broadcast seeding followed by shallow incorporation or rolling are often used after grain crop harvest. Cover crop seed can be broadcasted using an air seeder or mixed with fall fertilizer and applied with a floater. Check seed distribution to help ensure even stands. Increase seeding rates for broadcast vs. drill seeding, though this varies by species.

Row-crop planters can be an efficient method for seeding cover crops but require additional attachments for the smaller seeds. Seeding rates can be reduced by up to 50% for a row crop planter compared to a drill due to superior seed-to-soil contact, depth control and seed spacing. Special seed plates (e.g., grain sorghum plates) and brushes are often required if the row-crop planter is set up for larger corn and soybean seeds.

Aerial or high-clearance seeding equipment is required to seed cover crops into standing crops. Aerial seeding using an aircraft modified with a seed disperser has gained popularity in recent years because it can cost-effectively seed many acres in a timely manner. Some growers have converted high-clearance spraying and detasseling equipment into cover crop seeders. Aerial and high-clearance methods require higher seeding rates compared to other establishment methods; in some cases, 50% more seed is recommended relative to drilling.

Manure slurry seeding involves mixing cover crop seed with liquid manure and applying it in the fall. Moisture and nutrients in manure promote rapid cover crop growth, which in turn prevents loss of manure N. This method is generally best suited for grasses, which are well adapted for establishing quickly and scavenging manure nutrients in the fall.

Cover Crop Termination

Terminating cover crops is usually accomplished by winterkilling, tilling, mowing or herbicides. Each method has advantages and limitations. For example, winter-killing is only applicable to certain cover crops. Similarly, while tilling legumes can help increase N availability, it is less desirable for grasses that produce much greater quantities of low-N biomass. Due to simplicity and efficacy, many growers prefer to terminate cover crops using herbicides. Consider the following when terminating cover crops with herbicides:

- For best control, spray the cover crop before it begins reproductive growth.
- Avoid spraying translocated herbicides on cloudy or cold days, which slow or stop cover crop growth and uptake.
- In most areas of the Corn Belt, it is recommended that spraying occur two to three weeks prior to grain crop planting.
- Consult herbicide labels for information on efficacy and plant-back restrictions.

Cover Crop Effects on Corn and Soybean Yields

A review of 37 cover crop trials conducted in the U.S. and Canada revealed broad trends regarding the impacts of cover crops on corn yield (Figure 1). Generally, legume cover crops and grass-legume mixtures are more likely to have a positive effect on corn yield than grasses alone. While not universal, this likely holds true across a range of locations and management scenarios. Grass residues break down more slowly in the spring and are more likely to interfere with early corn growth than legume residues, which break down rapidly. Legumes also add N so are more likely to have a direct, positive effect on corn growth and yield.

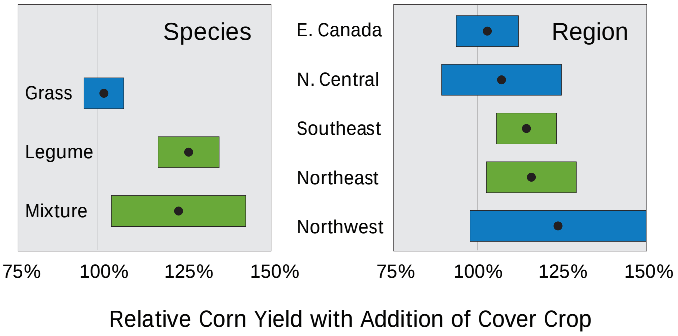


Figure 1. Corn yield response to winter cover crop based on cover crop species and region. Black points indicate average yield response, and bars represent yield response range. Results are adapted from Miguez and Bollero (2005).

Regional differences in corn yield response to cover crops highlight the importance of soil and climatic factors. Cover crops are more likely to have a positive effect on corn yield in southern and eastern locations than in the North. This is likely a result of more mild spring conditions in the South and East, which reduce the risk of delayed cover crop termination and interference with early corn growth. Lower soil organic matter levels in these areas can also be improved by cover crops.

The effects on yield of specific cover crops often vary by location and differ between corn and soybeans. For example, a four-year, on-farm study in Iowa demonstrated that a cereal rye cover crop was more likely to benefit soybeans than corn in this region (Figure 2).

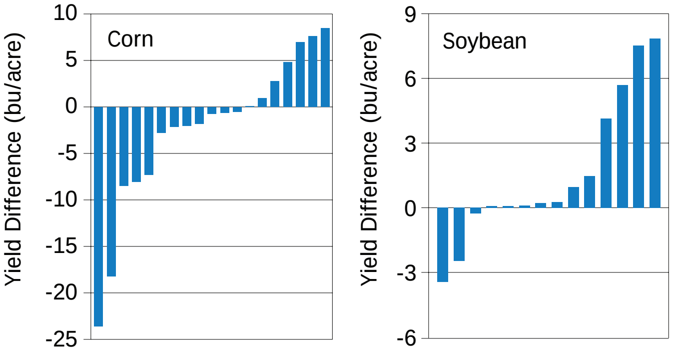


Figure 2. Corn and soybean yield response to a cereal rye cover crop in a four-year, on-farm trial in Iowa. Each bar represents the cover crop yield effect at one location in a single year. Results are adapted from Carlson, 2013.

Conclusions / References

For best results, cover crops must be managed intensely. Begin by identifying a management goal such as increasing soil organic matter or improving spring weed suppression. Start out by testing a cover crop on a single field, and expand as you gain management experience.

Carlson, S. 2013. Winter rye cover crop effect on grain crop yields: Year 4. Practical Farmers of Iowa. Ames, IA.

Miguez, F.E. and G.A. Bollero. 2005. Review of corn yield response under winter cover cropping systems using meta-analytic methods. *Crop Science.* 45:2318-2329.

High Yield Production Practices for Soybeans

Achieving top soybean yields requires intensive management. All critical aspects of soybean production must be considered, including variety selection, planting practices, seed treatments, soil fertility, fungicide/insecticide applications (when needed), crop rotation and timely weed control.

Variety Selection for Top Yields

Matching soybean varieties to the specific requirements of individual fields is a core practice for maximizing yield. Geographic location alone can impact maturity, drought stress potential and pest pressure. Soil type, drainage and soil condition (e.g., compaction) affect stand establishment and moisture stress. Soil pH can result in iron deficiency chlorosis in some varieties. Field history of soybean cyst nematode (SCN), Phytophthora, white mold, sudden death syndrome and other diseases determine resistance traits needed in the variety. Previous crop can heighten or moderate expected disease pressure and thus impact variety selection.

In addition to appropriate disease and SCN resistance for the growing environment, all varieties considered should have high yield potential, good standability and ability to withstand environmental stresses. Your local Pioneer sales professional can help you select the best soybean varieties for each field, with proven yield performance across multiple environments.

Newest Varieties - Soybean breeders at DuPont Pioneer make yield gains and agronomic improvements every year using new genetic tools such as the Accelerated Yield Technology (AYT™) system and marker-assisted selection. Sampling top new varieties each year and ramping these up to substantial acreages quickly can have a significant impact on overall farm yields.

Planting Practices

Row Width - A review of soybean row-spacing studies published within the past decade generally confirms previous results comparing row widths (Figure 1). In 5 studies, drilled narrow rows outyielded 30-inch rows by an average of 4.1 bu/acre. Six studies that compared 30- and 15-inch rows found similar results, with 15-inch rows holding a 3.6 bu/acre yield advantage. Yields were similar between 15-inch and drilled narrow rows. For that reason, many growers wanting better uniformity of planting depth and seed placement, or in areas where white mold is common, have chosen 15-inch rows.

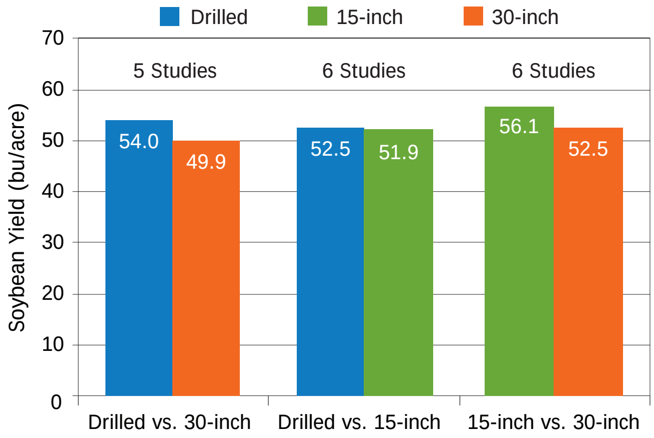


Figure 1. Average yield results from 7 soybean row spacing studies published during the last 10 years.

Planting Date - Soybean planting is trending earlier, particularly in operations with a planter dedicated to soybeans. DuPont Pioneer and university studies have shown that planting soybeans in the last half of April or first part of May often increases grain yield. Early planting extends reproductive growth by initiating flowering earlier. This allows the crop to accumulate more nodes, increasing the potential for greater pod and seed number. In addition, recent studies indicate that full-season varieties respond better to early planting than short-season varieties.

Full-season soybean variety.

Seed Treatments - Because of earlier planting and higher levels of crop residue on fields, soils are generally colder and wetter at planting, and seedling diseases have increased as a result. Consequently, more growers are seeing an advantage for fungicide seed treatments. Pioneer Premium Seed Treatment choices include next-generation fungicides with multiple modes of action that provide enhanced protection against a broad spectrum of early-season diseases including Rhizoctonia, Fusarium and Pythium. Adding an insecticide to the treatment reduces insect feeding that provides an entry port for disease infection. Pioneer Premium Seed Treatment options also include a rhizobia inoculant/extender and a biological component that help increase nodulation and enhance nutrient availability and uptake by the plant.

Soil Fertility

Phosphorus (P) / Potassium (K) - Some soybean producers depend on residual corn fertility to supply nutrients to their soybean crop. When soils are routinely maintained at high or very high levels of P and K, this may be a safe strategy, but when P and K are low, yield reductions are likely. A 60 bu/acre soybean crop removes, in the grain, about 48 lbs P_2O_5 and 84 lbs K_2O from the soil. This is 33% less P but 55% more K than a 200 bu/acre corn crop removes in the grain. Soil testing can determine if field levels are adequate to supply these or other required amounts.

Soil pH - Many chemical and biological processes in the soil are affected by pH, and maintaining pH in the proper range will maximize the efficiency of other crop inputs and decrease the risk of yield losses. Soybeans thrive in the pH range of 6.0 to 6.8 (in mineral soils). Liming acid soils or utilizing varieties with good iron deficiency chlorosis scores on high pH soils will help prevent yield reductions.

Nitrogen (N) - Soybeans are high in protein and therefore in N, removing 3.5 to 4.0 lbs from the soil for each bushel of grain produced. This compares to less than one lb of N removed per bushel of corn grain produced. However, soybeans supply most of their own N needs by N fixation, and additional N is supplied by soil mineralization.

An N "budget" developed from a summary of over 100 research studies shows that soil and fixed N are generally sufficient to supply N needs at yields up to 60 bu/acre (Salvagiotti et al., 2008). As yields increase to 80 bu/acre and higher, an N deficit may result. This deficit grows at yields of 80 to 100 bu/acre, raising the possibility of a need for N fertilizer or manure to supplement natural sources. However, research studies have not shown consistent yield increases from N applications; rather, they have more often demonstrated that N fixation may be inhibited in the presence of elevated levels of soil nitrate (NO_3). Thus, much more research is needed regarding the yield benefit and cost-effectiveness of N applications to high yielding soybeans.

Foliar Fertilizer and Banding - In studies conducted in Iowa, foliar feeding increased yields only 15 to 20% of the time; however, it may be useful when soil nutrients are inadequately supplied, such as production on sandy soils or high-yielding irrigated fields. Studies in Iowa and Minnesota with banding fertilizer close to the row have not shown benefit; rather, stands were reduced and yields were not improved.

Foliar Fungicide/Insecticide Application

Between 2007 and 2011, DuPont Pioneer researchers conducted 148 trials comparing yield of untreated soybeans to those treated with a foliar fungicide and 52 trials that included an insecticide in the treatment. Trials were located in 11 states and 2 Canadian provinces. Across these trials, the average yield response to a foliar fungicide application was 2.5 bu/acre, with a positive response in 82% of the trials (Figure 2). When an insecticide was included, the average response increased to 5.3 bu/acre, and a positive yield response was observed in 94% of the trials.

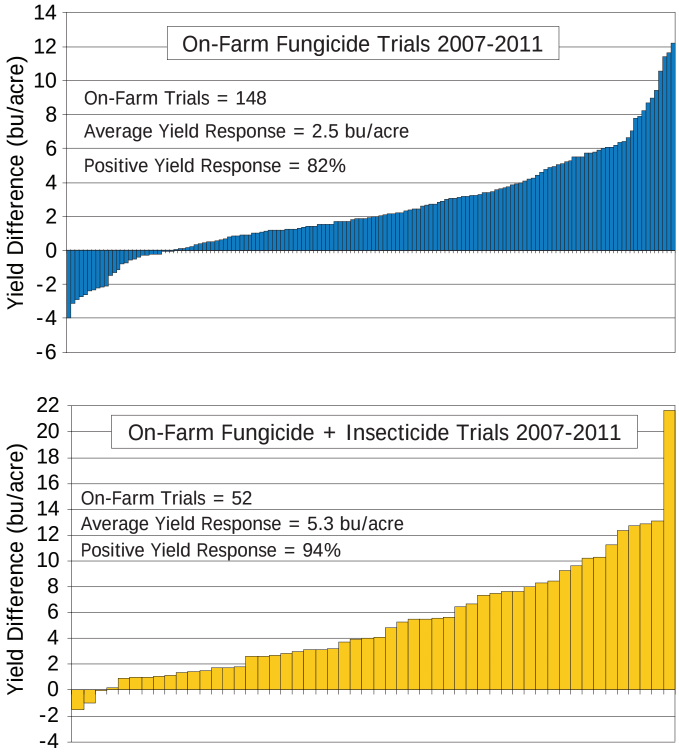


Figure 2. Average soybean yield response to foliar fungicide (top) and fungicide + insecticide (bottom) across DuPont Pioneer on-farm trials conducted from 2007 to 2011.

Fungal diseases that can be managed with foliar fungicides include anthracnose, Septoria brown spot, Cercospora leaf blight, frogeye leaf spot, pod and stem blight, and soybean rust. The most common insects with potential to lower soybean yield include soybean aphids, bean leaf beetles and a variety of stink bugs (green, brown, red-shouldered, red-banded and brown marmorated). Scout to determine if insect levels exceed economic thresholds, and use established integrated pest management (IPM) practices.

Crop Rotation

Crop rotation is important in all crops to break disease and insect cycles and increase yield. Diseases such as soybean cyst nematode, white mold, brown stem rot and sudden death syndrome survive in the soil or in crop residue and readily attack a successive soybean crop. Most soybean diseases survive more than one or two years in the soil, so rotation does not eliminate the problem. However, time away from soybeans diminishes the amount of disease inoculum available to infect the next crop, and thereby lessens its severity.

Rotation studies in MN and WI showed that soybeans in a corn/soybean rotation yielded 8% more than continuous soybeans. These studies were conducted in good growing environments where moisture was not severely limiting. Soybeans following 5 years of continuous corn yielded 15 to 17% more than continuous soybeans.

Soybeans planted after corn.

Other Practices for Increasing Soybean Yields

Tillage has long been used to bury crop residue, prepare a seedbed and control weeds. Current planting equipment and herbicides now allow growers to achieve excellent soybean stand establishment and weed control with little or no tillage. Research has shown that soybean yields are similar across conventional, minimum till and no-till. For this reason, growers can choose a tillage system that makes sense economically, environmentally and logistically, and focus on optimizing other management practices within that tillage system.

Weed Control - If weeds compete with soybeans for moisture, light and nutrients during the critical development period from the second trifoliate stage to beginning flowering, yield may be reduced even if weeds are ultimately controlled. The development of more and more weed populations resistant to glyphosate makes the use of other herbicide modes of action an important component of a weed management system. Use of a pre-emergence herbicide followed by glyphosate allows for multiple active ingredients to be applied, while also controlling weeds earlier than glyphosate-only programs.

Reference

Salvagiotti, F., K.G. Cassman, J.E. Specht, D.T. Walters, A. Weiss, and A. Doberman. 2008. Nitrogen uptake, fixation, and response to fertilizer N in soybeans: A review. Field Crops Res. 108:1-13.

Corn Rootworm Management

Corn rootworm (CRW) is the primary pest of corn in the major corn-growing areas of North America, causing more than one billion dollars in damage annually in control costs and yield reductions. Pioneer® brand Optimum® AcreMax® 1 (AM1), Optimum® AcreMax® Xtra (AMX) and Optimum® AcreMax® XTreme (AMXT) insect protection products with integrated refuge allow growers to reduce refuge requirements with a single product. These products deliver flexibility and convenience for insect refuge management by providing one mode of action for corn rootworm protection (Herculex® RW trait) in AM1 and AMX products and two modes of action for corn rootworm protection (Herculex® RW and Agrisure® RW traits) in AMXT products.

Left: Western corn rootworm adult on corn silks.
Right: Corn rootworm larva feeding on corn roots.

Study Description

On-Farm Trials

On-farm strip trials were conducted at 95 midwestern locations in 2013 to evaluate the efficacy and grain yield performance of AM1, AMX and AMXT products with and without the use of soil-applied insecticide. Trials were placed primarily in corn-on-corn fields in areas with a history of moderate to severe corn rootworm feeding.

Corn rootworm efficacy was measured by digging and washing 10 roots from each entry. All roots were assigned a CRW node injury scale (NIS) rating using the Iowa State 0-3 Node Injury Scale. Efficacy ratings reported here include both traited and non-traited plants within the 10 plants evaluated for integrated refuge entries. Corn rootworm pressure at each location was assessed by sampling roots from a check area with no CRW protection (no CRW trait, no insecticide).

Results reported here are combined for AM1 and AMX products, which have the same CRW protection trait and percent integrated refuge component. Entries were not identical across all on-farm trials; consequently, summary charts and tables shown here reflect data from the subset of locations at which the products and treatments were included.

Small-Plot Trials

Small-plot trials were conducted in 2012 and 2013 to evaluate the efficacy and grain yield performance of AMX and AMXT products under varying levels of corn rootworm feeding pressure.

Replicated trials were conducted at 12 locations in 2012 and at 9 locations in 2013. Eight hybrid platforms were evaluated in each year of testing, and trial locations extended from central Nebraska to central Indiana each year.

CRW efficacy was measured by digging and washing 10 consecutive plants from row 1 of each integrated refuge treatment and 5 consecutive plants in each base treatment. All roots were assigned a CRWNIS rating using the Iowa State 0-3 NIS scale. Efficacy ratings reported here include both traited and non-traited plants within the 10 plants evaluated for integrated refuge entries.

Results

Among 95 on-farm trial locations in 2013, high CRW pressure (defined as >1.5 on the Iowa State 0-3 NIS) was observed in 12 locations (Figure 1). Corn rootworm feeding was very intense at several of these locations. Four trials had CRW injury ratings between 2.0 and 2.5 (very high) in the unprotected check, and three had CRW injury greater than 2.5 (severe).

Corn rootworm feeding pressure was generally higher in 2012 small-plot testing locations compared to 2013. In 2012, 3 of 12 locations experienced high corn rootworm pressure (defined for these experiments as > 1.75 on the Iowa State 0-3 NIS), and 3 others experienced moderate feeding pressure (between 0.75 and 1.75 on the Iowa State 0-3 node injury scale). Conversely, in 2013, only three of nine testing locations had moderate feeding pressure, and none experienced high feeding pressure.

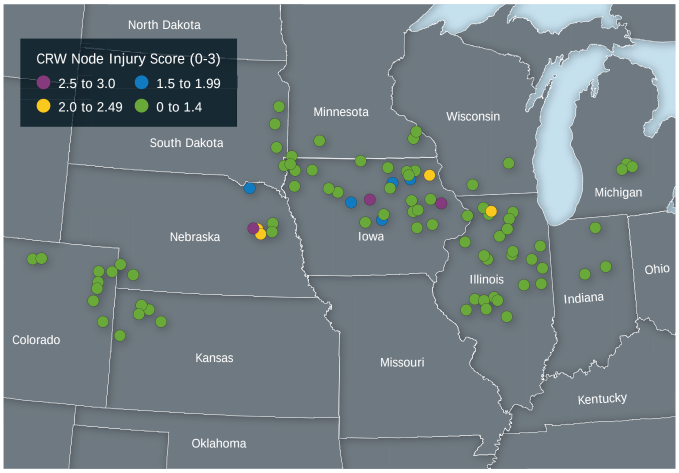


Figure 1. Corn rootworm pressure at on-farm strip trial locations in 2013.

Performance of AM1 and AMX products was very consistent in 2013 on-farm trials, even under intense CRW pressure (Figure 2). Average CRW injury was significantly reduced relative to the unprotected check at all levels of CRW pressure. Average CRW injury in AM1 and AMX products was only 0.52 among the three locations with pressure greater than 2.5 in the check, indicating that these products continue to provide a high degree of protection under severe CRW pressure.

Small-plot trials evaluated performance of both AMX and AMXT products. Across three locations with high CRW pressure in 2012, average CRW feeding was 0.22 on AMX products and 0.13 on AMXT products compared to 2.02 in the unprotected check (Figure 3). Nearly identical results were observed in 2013

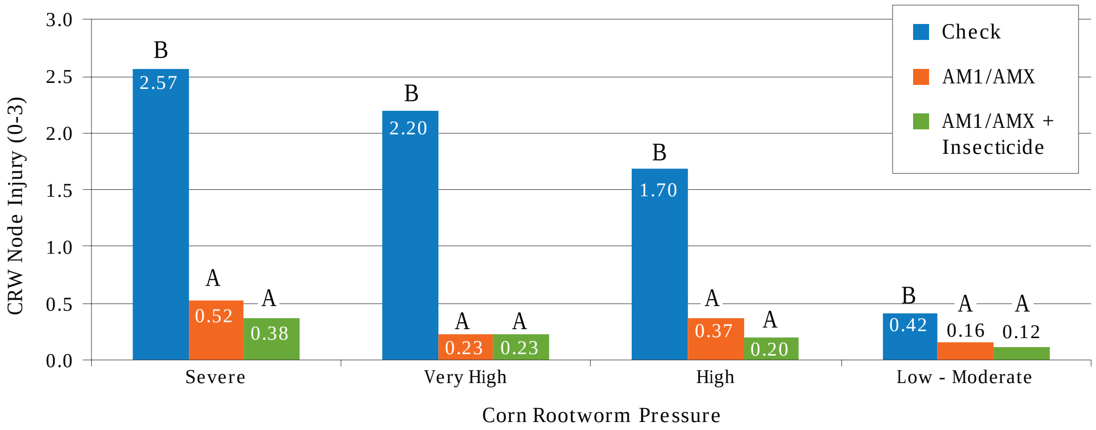


Figure 2. Corn rootworm injury (NIS scores) observed with AM1/AMX products, AM1/AMX products + soil-applied insecticide and no CRW protection (check) in on-farm trials with low to moderate (n=10), high (n=4), very high (n=4) or severe (n=3) CRW pressure.

Averages designated with the same letter within a CRW pressure grouping were not significantly different at α = 0.05.

on-farm trials that included both AMX and AMXT products. Average CRW feeding was 0.29 on AMX products and 0.08 on AMXT products compared to 2.06 in the unprotected check.

In both cases, CRW feeding was slightly lower on AMXT products than AMX products, although not to a statistically significant degree. Corn rootworm protection would be expected to be slightly greater with AMXT products due to the combined effects of trait efficacy (dual mode vs. single mode) and a lower percentage of refuge plants (5% vs. 10%).

The addition of a soil insecticide to AMX and AM1 products tended to result in a slight reduction in CRW feeding, although the effect was not statistically significant even under severe CRW pressure (Figure 2).

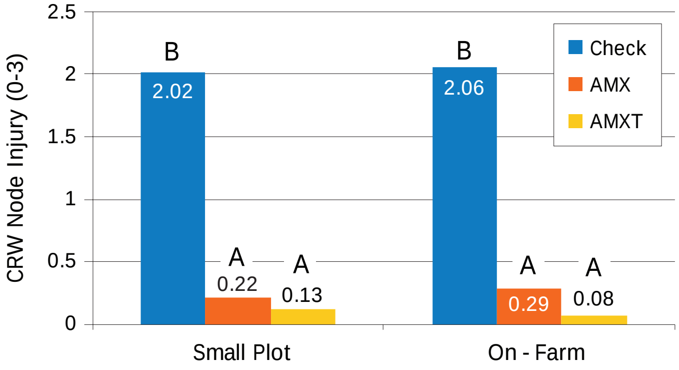


Figure 3. Average corn rootworm injury (NIS scores) observed with AMX products, AMXT products and no CRW protection in three small-plot trials in 2012 and six on-farm trials in 2013 with high CRW pressure.

Averages designated with the same letter within a trial type were not significantly different at α = 0.05.

Corn yield tended to be slightly greater with the addition of a soil insecticide, with increases ranging from 2.9 to 3.8 bu/acre at locations with high, very high or severe CRW pressure (Figure 4). A slight increase in average yield was also observed with a soil insecticide application among sites with low to moderate CRW pressure, suggesting that yield improvements may be partially due to the control of insect pests other than corn rootworm.

Comparison of CRW feeding and yield performance between AM1/AMX products and non-CRW protected corn with an insecticide demonstrated the superior CRW protection provided by the Optimum® AcreMax® family of products (Table 1).

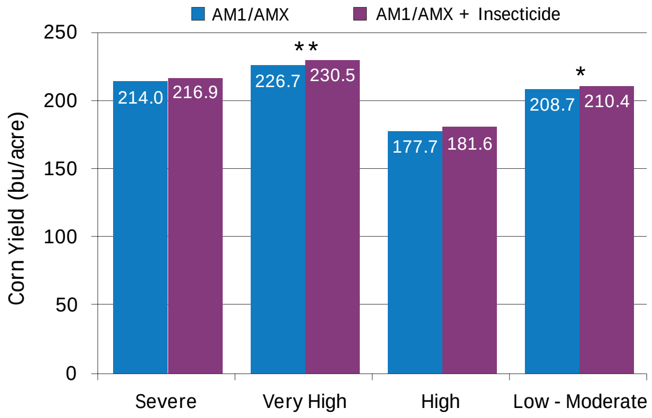


Figure 4. Average yield of AM1/AMX products without and with a soil-applied insecticide in on-farm trials with low-moderate, high, very high and severe CRW pressure.

** significantly different at α = 0.10. ** significantly different at α = 0.05.*

Table 1. Corn rootworm injury and corn yield of AM1/AMX products, non-CRW corn with a soil-applied insecticide, and an unprotected check across seven on-farm trials with high CRW pressure in 2013.

	CRWNIS	Yield
AM1/AMX	0.45 A	210 A
Insecticide	1.01 B	191 B
Check	2.14 C	181 B

Averages designated with the same letter were not significantly different at α = 0.05.

Soil-applied insecticides significantly reduced CRW feeding relative to an unprotected check; however, AM1/AMX products performed significantly better than the soil-applied insecticide, both in terms of CRW feeding and corn yield.

Results of DuPont Pioneer on-farm and small-plot research trials showed that the Optimum® AcreMax® family of products with Herculex® RW trait provided excellent protection against CRW, even when pressure was severe. AM1 and AMX products provided significantly better CRW protection and greater yield than a soil-applied insecticide under high CRW pressure. Addition of a soil-applied insecticide to AM1 and AMX products did not significantly improve CRW protection but did result in slightly higher corn yield, likely due, at least in part, to control of insect pests other than CRW.

AGRONOMY SCIENCES

RESEARCH UPDATE

DUPONT

PIONEER

Effect of Plant Population on Corn Yield Response to Fungicides

2013

Objectives

- Over the past two years, DuPont Pioneer field agronomists have conducted a series of studies to evaluate the value of foliar fungicides in corn planted at higher populations.
- The theory was that denser canopies at high populations would tend be more prone to foliar disease due to reduced light and air movement through the canopy, which could results in stalk lodging and yield loss.

Study Description

Locations:	60 Iowa on-farm locations over two years
Hybrids:	Results are pooled across 47 hybrids.
Populations:	30, 34, 38 and 42 thousand plants/acre
Treatments:	Untreated, Treated

- Fungicide strips were applied perpendicular to hybrid and plant population strips at each location. Treatment widths varied but were a minimum of 250 ft.

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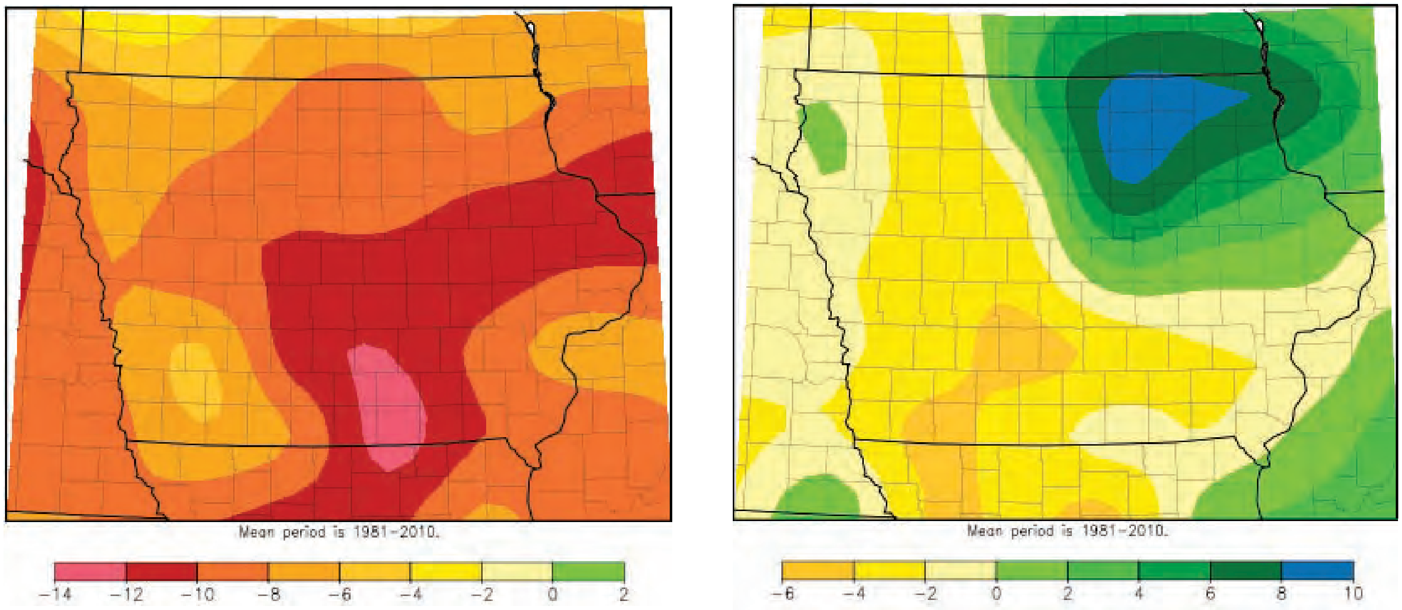
Results

- Weather patterns for the years of this study ranged from extreme to moderate drought over most of the study area (Figures 1 & 2).
- Averaged across locations, the yield response to fungicide treatment was greater in corn following corn compared to corn following soybeans (Figure 3).
- In higher yielding fields, yield response to fungicide treatment was greater at higher plant populations (Figure 4).
- In lower yielding fields, corn yields were typically greater with fungicide treatment by yield response did not differ as greatly across populations (Figures 5 & 6).

Conclusions

- Results of these studies tend to support the hypothesis that foliar fungicides would provide a greater yield benefit at greater plant populations in high-yield environments.
- However, previous crop was a more important factor affecting yield response to foliar fungicide treatment.
- Corn diseases pressure during the years of this study was modest to light. Fungicide would be expected to have a greater value in years with significant disease pressure.

Figures 1 & 2. Seasonal rainfall was below historical norms for the time period of this study. Left: 2012, Right: 2013.



Source: Midwest Regional Climate Center

Figure 3. Yield advantage for fungicide was greater in corn following corn compared to corn following soybeans. (n=60 Iowa locations over 2 years)

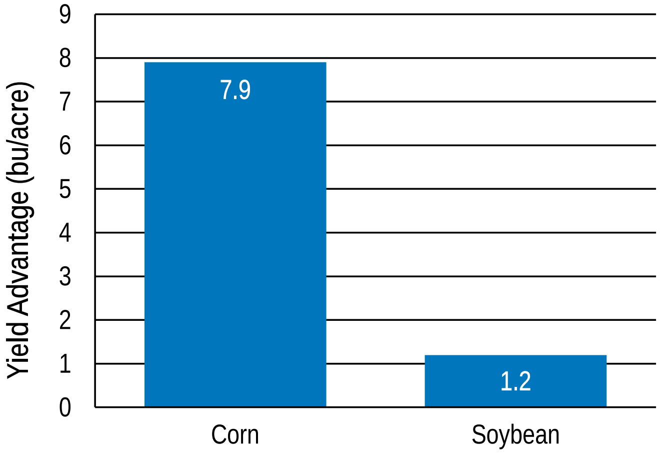


Figure 4. Corn yield response to population and fungicide treatment in environments yielding greater than 200 bu/acre. n=21 locations, 2 years and 39 hybrids.

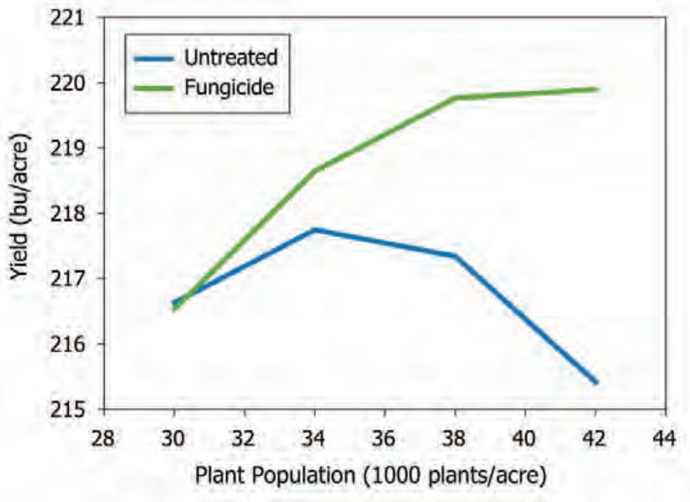


Figure 5. Corn yield response to population and fungicide treatment in environments yielding less than 150 bu/acre. n=9 environments, 2 years and 23 hybrids.

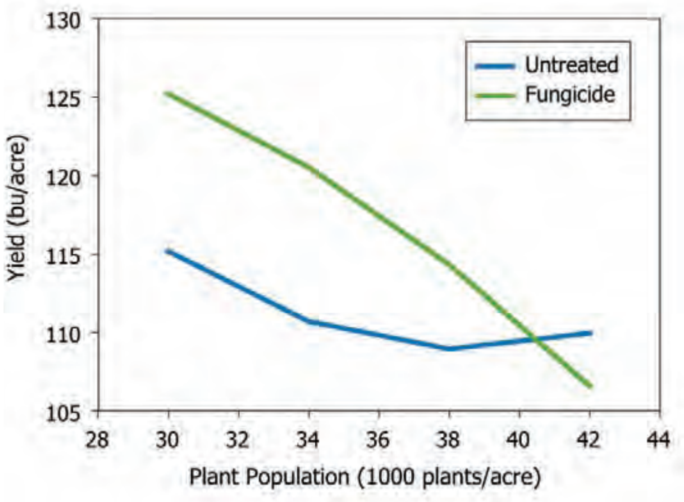
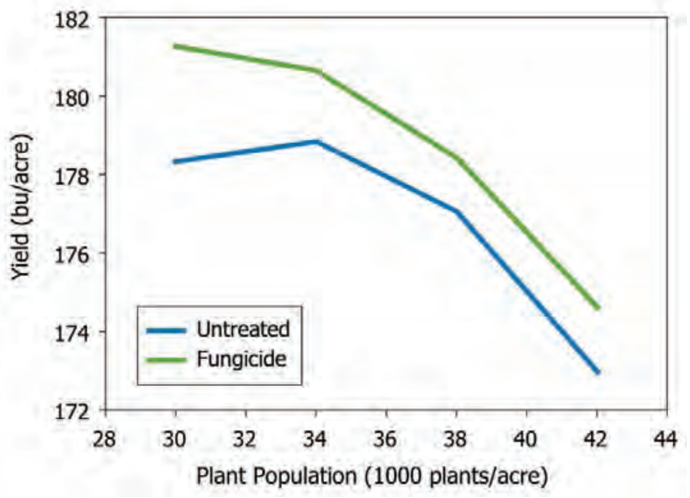


Figure 6. Corn yield response to population and fungicide treatment in environments yielding between 150 and 200 bu/acre. n=30 environments, 2 years and 43 hybrids.



White Mold of Soybean

White mold is a fungal disease that can attack hundreds of plant species. Also known as Sclerotinia stem rot, it has become an annual threat to soybeans in northern growing areas throughout North America. When wet, cool conditions prevail during flowering, the disease can be found in central states as well. When severe infestations occur, primarily due to sustained wet weather conditions, losses may be substantial. The spread of white mold in recent years is likely due to cultural practices that have accelerated canopy development, including earlier planting and narrow row spacings.

Disease Description and Life Cycle

Sclerotia on stem.

White mold persists in soybean fields over time by production of survival structures called sclerotia. These dark, irregularly shaped bodies about ½-inch long are formed within the white, cottony growth both inside and outside the stem during the fall. These sclerotia contain food reserves and function much like seeds, surviving for years in the soil and eventually germinating, producing millions of spores beneath the soybean canopy.

White mold spores are not able to invade plants directly but must colonize dead plant tissue before moving into the plant. Senescing flowers provide a ready source of dead tissue for preliminary colonization. From these flowers in the branch axils or stuck to developing pods, the fungus spreads to healthy tissue. Stem lesions develop and may eventually be overgrown with white mold. The disease can then spread directly from plant to plant by contact with this moldy tissue. Sclerotia are formed within the moldy growth and inside the stem to complete the disease cycle.

Wet, cool conditions are required throughout the white mold disease cycle, including germination of the sclerotia in the soil, spore release, infection of soybean flowers by spores and spread of white mold from plant to plant. As the disease progresses, tissue rots and sclerotia form inside the stem, often leading to rapid wilting and death of the entire plant.

Management of White Mold[1]

White mold is often a disease of high yield potential soybeans, but abandoning high yield management practices to control the disease may be counter-productive. Rather, a systems approach that includes avoiding disease spread, selecting tolerant varieties, adjusting cropping systems, and applying specific fungicides or herbicides can reduce soybean damage during white mold outbreak years.

Disease Avoidance - White mold spreads either by movement of spores or sclerotia from field to field. There is little known about stopping the spread of spores. Sclerotia move from field to field in harvest equipment or in contaminated seed. Harvest equipment should be thoroughly cleaned when moving from infected to non-infected fields. Harvesting infected fields last provides additional safety. DuPont Pioneer avoids growing seed beans in fields with a history of white mold. Seed is also thoroughly cleaned and inspected to ensure that it is disease-free. Seed cleaning with a gravity table or centrifugal tower is essential to remove sclerotia. Fungicide seed treatments can help ensure that no disease is transmitted by mycelia present on seed.

White Mold Development: Long-Term Risk Factors

The North Central Plant Health Initiative has developed the following list of risk factors for white mold:[a]

Field/Cropping History - Pathogen level will gradually increase if:

- Other host crops are grown in rotation with soybean.
- Only 1- to 2-year intervals occur between soybean crops.
- White mold susceptible varieties are grown.

Weed Management Systems - Inoculum will increase if control of broadleaf weeds is ineffective. Some herbicides used in rotation systems may be suppressive to white mold.

Topography of Field - Pockets of poor air drainage, tree lines and other natural barriers that impede air movement will create a favorable micro-environment for white mold development.

Pathogen Introduction:

- Contaminated and infected seed
- Movement of infested soil with equipment
- Wind-borne spores from apothecia in areas outside fields

[a] Adapted from: North Central Soybean Research Program, Plant Health Initiative. http://www.planthealth.info/whitemold_basics.htm

Variety Selection - At this time, there is no complete genetic resistance to white mold – all varieties can develop white mold symptoms under severe infestations. But varieties do differ, and DuPont Pioneer researchers assign each Pioneer® brand soybean variety a 1 to 9 rating based on these differences. These scores reflect varietal differences in the rate at which the infection develops and the extent of damage it causes. Growers can use this rating to help choose the best variety for their field (higher scores indicate more tolerance). However, because there is no complete genetic resistance available at this time, white mold may sometimes occur even with above-average tolerance scores. Your local Pioneer sales professional can suggest white mold tolerant varieties with a complete package of traits needed for top soybean production in your area.

Pioneer researchers have targeted improvement of varieties for white mold tolerance as a key research objective. To accomplish this goal, soybean breeders use new lab and field techniques as well as conventional selection in white mold environments. These scientists also continue to screen novel, exotic and alternative germplasm sources with native tolerance to white mold. Future possibilities include transgenic approaches – transferring resistance genes from other crops or organisms into soybeans.

Cropping Systems

Tillage - Sclerotia germinate from the top two inches of soil. Below that depth, they can remain dormant for up to 10 years. Because of its longevity in the soil, it is difficult to devise a strategy to control white mold with tillage. Deep tillage buries sclerotia from the soil surface but may also bring prior sclerotia into their zone of germination. If the disease is new to a field and a severe outbreak has occurred, a deep tillage followed by no-till or shallow tillage for many years may be beneficial. Research studies have shown that no-till is generally superior to other tillage systems in limiting white mold development.

Rotation - Rotation with a non-host crop is an effective means of reducing disease pressure in a field. Non-host crops include corn, sorghum and small grains. Susceptible crops to avoid in a rotation include alfalfa, clover, sunflower, canola, edible beans, potato and others. Depending on soybean tolerance, field history and other factors, more than one year away from soybeans may be required. Because sclerotia survive for up to 10 years in the soil, rotation is only a partial solution.

Chemical Application[2]

DuPont™ Aproach® - In research trials conducted by Ohio State University, Michigan State University and the University of Illinois in 2009 to 2011, Aproach® fungicide reduced white mold severity and increased yield by 7.2 bu/acre (Wessel and Butzen, 2013). The Aproach fungicide label specifies to make an initial preventative application at 100% bloom (one flower blooming on all plants) and follow with a second application 7 to 10 days later at full bloom. A second application is most important if cool, wet environmental conditions conducive to disease development persist throughout flowering. Apply Aproach in a minimum volume of 10 gal/acre. Penetration of spray droplets into the lower canopy is critical to achieve optimum efficacy. Ensure spray volume and spray pressure are optimized to achieve thorough coverage.

Topsin® M is another foliar fungicide labeled for white mold control in soybeans, but results have been inconsistent. Proper timing of application and penetration of the fungicide through the soybean canopy to the flowers are critical for success. Drop nozzles may be helpful to ensure spray coverage of flowers on the lower half of the plant.

Cobra® and Phoenix® - Some studies have shown reduced white mold incidence and increased soybean yield from an application of Cobra® at the R1 growth stage. The active ingredient of Cobra and Phoenix®, lactofen, is a herbicide for post-emergence weed control in soybeans that often causes moderate levels of leaf necrosis. Although the reduction in leaf area from this necrosis is likely a contributing factor in white mold control with lactofen, yield loss may result in the absence of disease. Producers should use caution if considering widespread use of this herbicide, especially on moderately resistant varieties when environmental conditions do not favor disease.

Production Practices

- It is well-established that many current practices that increase soybean yields also increase white mold. Whether growers should abandon their yield-enhancing practices to help control white mold is debatable. In areas with lower white mold levels or drier climate, production practices that increase yield but also increase white mold levels may still be highest yielding. However, in areas with higher white mold levels and a cool, wet climate, some change in production practices may be necessary to limit early, dense canopy development.

Row Width - A review of soybean row-spacing studies published within the past 10 years generally confirms previous results comparing 30-inch rows and drilled narrow rows. In 5 studies, drilled soybeans outyielded 30-inch row soybeans by an average of 4.1 bu/acre. Six studies that compared 30-inch rows and 15-inch rows found that 15-inch rows increased yield by 3.6 bu/acre. Yields were similar between 15-inch row and drilled narrow-row soybeans in these studies.

A 6-year research study in Wisconsin measured yield and white mold incidence in 7-inch (drilled) vs. 30-inch rows (Grau, 2001). Though white mold mortality was much higher in drilled beans, the yields were nevertheless equal or higher for drilled vs. 30-inch rows when averaged across years.

These results suggest that narrow-row planting systems should not necessarily be abandoned simply to help control white mold. In fact, narrow-row systems generally increase yields each year, and white mold does not develop every year. However, because research studies have shown that 15-inch rows often yield as well as 7-inch rows, many growers in white mold areas have chosen the 15-inch row width.

Planting Date - Later planted soybeans are generally shorter and less branched and therefore, later to canopy closure. Some planting date studies show that later planting results in less incidence of white mold. However, yields are generally reduced when planting is delayed past mid-May in northern states. The trade off between less yield reduction due to white mold but more yield reduction due to late planting may not be favorable, especially in years of low disease pressure.

Plant Population - Soybean yields generally increase with increased plant population within a range. Studies have demonstrated higher white mold incidence with higher plant population, but yields were not reduced. However, part of the expected increase from higher seeding rates was likely offset by losses from the disease. In fields with high risk of white mold, seeding rates should be sufficient for uniform stand establishment but should not be aggressively high. Actual rates will vary depending on planting date, seedbed conditions, row width and seed quality.

Weed Control - White mold has over 400 plant hosts, including many broadleaf weeds. Host weeds that are also common weed species throughout soybean growing areas include lambsquarters, ragweed, pigweed and velvetleaf. In addition to acting as host to the disease, weeds can also increase canopy density, which favors disease spread.

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[1] Many factors including weather influence white mold levels and crop damage from year to year. Your results may vary.

[2] This article is not intended as a substitute for the product label for the products referenced herein. Product labels for the above products contain important precautions, directions for use and product warranty and liability limitations that must be read before using the product. Always read and follow all label directions and precautions for use when using any pesticide. Mention of a product in this article does not imply an endorsement.

Corn Responses to Crop Rotation and Reduced Nitrogen Environments

Beginning in 2006, DuPont Pioneer has conducted an annual study to evaluate the response of corn in limited nitrogen (N) environments. This study is unique in that each treatment is positioned on precisely the same field area each year. This allows researchers to learn how corn responds to each N level over multiple years of production. In addition, after many years of no added N, the "0-N" treatment represents a truly N-deficient environment. This is particularly important when characterizing hybrids for their efficiency of N use, as differences are inherently small and year-to-year variability in residual soil N can mask genetic differences.

Pioneer is developing corn hybrids with improved nitrogen use efficiency (NUE) to help lower N input costs for its customers. N fertilizer is a major input adding significantly to the cost of producing corn, making development of NUE hybrids an important goal for researchers. Specifically, Pioneer goals are to develop hybrids that equal today's yields but utilize less N and/or to develop hybrids that yield significantly more with the same N rates used today. The information from these comparisons provides a better understanding of N utilization. This enables researchers to set up experiments to properly evaluate NUE among different corn genetics.

Research Objectives

- Understand how farmers' crops and fields may react the first few years after reducing N rates.
- Determine how many years are required for reductions in N rate to result in lower corn yields.
- Determine how well scientists can measure corn hybrid response to relatively small increments of applied N.
- Determine the difference in response of current commercial corn hybrids to reduced N fertilizer rates as affected by crop rotation.

Study Description

The reduced N evaluation has been conducted over multiple years (2006 to 2013) at each of four DuPont Pioneer research stations located in major Corn Belt states (Table 1).

Table 1. Reduced nitrogen study environments.

Location	Years
Johnston, IA	2006 – 2013
Windfall, IN	2007 – 2013[a]
Champaign, IL	2007 – 2013
York, NE	2008 – 2013

[a] The 2012 Windfall plot was abandoned due to extreme drought.

The N treatments were standardized to 5 rates – 0%, 50%, 70%, 100% and 130% of university economic optimum recommendations. This corresponded to applied N rates of 0, 100, 140, 200 and 260 lbs/acre for continuous corn, and 0, 75, 105, 150 and 195 lbs/acre for rotated corn. Nitrogen treatments were applied to corn in continuous production as well as corn in rotation with soybean on exactly the same plots from year to year.

The corn hybrid used at a given location varied from year to year and was typically a Pioneer® brand corn leader product for that particular geography. However, in 2012 and 2013, two Pioneer® hybrids [33D49 (HX1, LL, RR2) and P1498HR (HX1, LL, RR2) at Champaign, IL; Windfall, IN; and York, NE; Pioneer® 33D53AM-R™ brand corn (AM, RR2) and Pioneer® P1498AM-R™ brand corn (AM, RR2) at Johnston] were used at each study site to address the question of whether hybrids respond differently to crop rotation and varying N rates. All N was applied as dry urea surface-banded by hand [except at the York, NE, location where urea ammonium nitrate solution (28-0-0) was sidedressed] at approximately the V2 growth stage. All plots were eight rows wide, and the center four rows of each plot were harvested for grain yield.

Applied Questions

What is the long-term response of corn to varying N fertilizer rates and crop rotations?

The data shown in Figures 1 and 2 indicate that the response to varying N rates and crop rotations differed for the rain-fed eastern sites compared to the irrigated western location (NE).

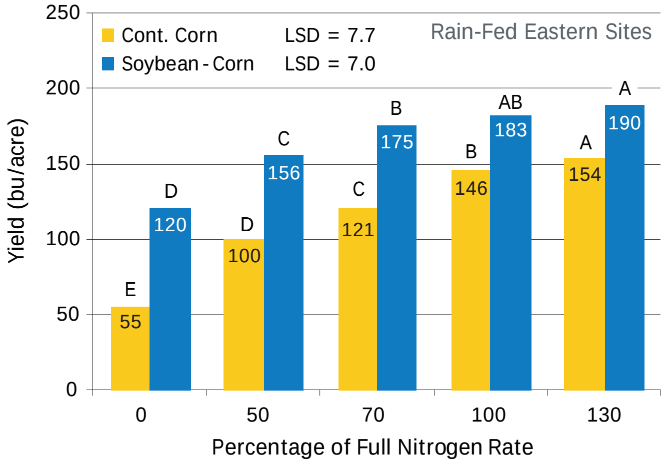


Figure 1. Influence of nitrogen rate on yield averaged over years and crop rotations for rain-fed eastern sites (IA, IN, IL).

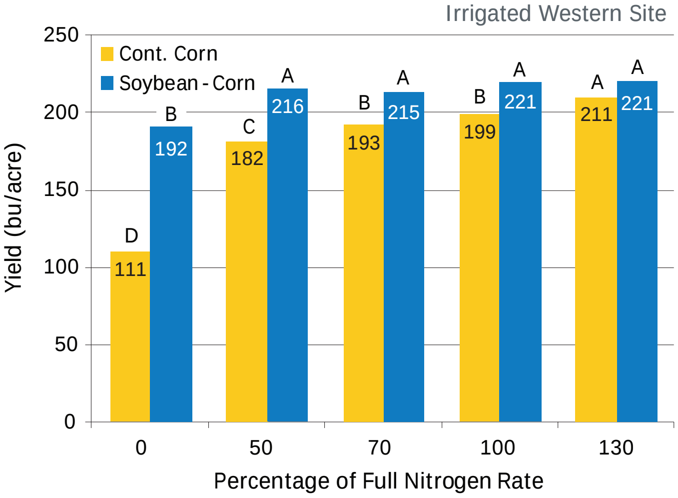


Figure 2. Influence of nitrogen rate on yield averaged over years and crop rotations for the irrigated western site (NE).

For example, average yield across all N rates at the eastern sites was 115 bu/acre for continuous corn vs. 165 bu/acre for corn in rotation, or a 44% yield advantage associated with the rotation treatment. Meanwhile at the irrigated site, the average yield for corn grown in rotation was 213 bu/acre vs. 179 bu/acre for continuous corn, an 18% yield advantage. Hence, the negative effect on yield for continuous corn observed under rain-fed conditions was less pronounced under irrigated conditions, suggesting that irrigation resolved some of the adverse effects associated with continuous corn.

As expected, corn yield increased with N rate in both continuous corn and corn rotated with soybean (Figures 1 and 2). However, reducing N rates resulted in much more substantial yield decreases for continuous corn than for rotated corn, especially for rain-fed eastern sites. For example, yield was reduced by 35% at the 50% N rate for continuous corn but only by 18% in rotation (Figure 1). At the irrigated site, reducing N by up to 50% produced much less dramatic effects on yield for either crop rotation (Figure 2).

These results demonstrate that as N was reduced, N stress occurred sooner (i.e., at a higher N rate) and with more yield impairment for continuous vs. rotated corn, especially for rain-fed vs. irrigated conditions. Similar results have been observed by numerous university researchers and can be attributed to reduced N mineralization and residual soil N associated with the higher residue levels for continuous corn (Figure 3, top) compared to corn grown after soybean (Figure 3, bottom).

Figure 3. Top: Continuous corn plot showing crop residue on surface.
Bottom: Corn-after-soybean plot showing little residue.

Do hybrids respond differently to nitrogen rates and crop rotations?

The design of this experiment serves to reduce available soil N in the sub-optimal N treatments over time. As a result, it allows comparisons of hybrids across a truly wide range of available soil N levels and moisture conditions. The results indicated that the two hybrids tested in 2012 and 2013 responded differently to varying soil N levels (Figures 4 and 5) at the rain-fed vs. irrigated locations. While the two hybrids responded similarly to N and crop rotation in the Eastern Corn Belt (Figure 4), they responded differently at the Western trial (Figure 5). Under irrigated conditions, P1498AM-R™ produced around 30 bu/acre more yield than 33D53AM-R™ when grown under continuous corn rotation and N rates greater than 200 lbs/acre.

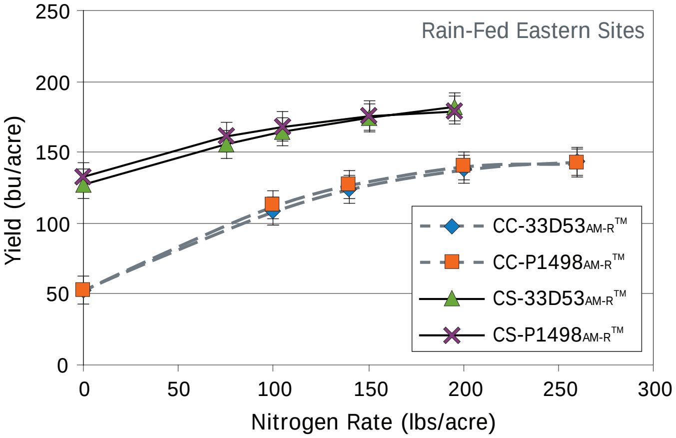


Figure 4. Response of two hybrids (33D53AM-R™ and P1498AM-R™) to increasing N rates under continuous corn (CC) and soybean-corn (CS) averaged for rain-fed eastern sites (IA, IN, IL) in 2012 and 2013.

(For Figures 4 above and 5 below, vertical bars on each data point are error bars. Where bars overlap, there are no statistical differences between hybrids or N rates.)

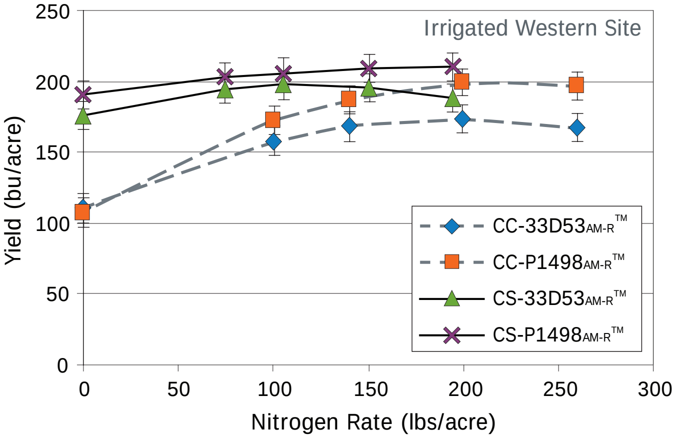


Figure 5. Response of two hybrids (33D53AM-R™ and P1498AM-R™) to increasing N rates under continuous corn (CC) and soybean-corn (CS) averaged for the irrigated western site (NE) in 2012 and 2013.

These results, though preliminary, are useful to DuPont Pioneer researchers in designing the proper field research procedures for evaluating NUE among different corn genetics.

Common Nitrogen Fertilizers and Stabilizers for Corn Production

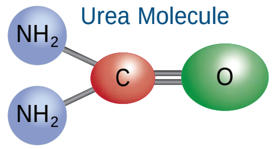
Nitrogen (N) fertilizer is a critical input in corn production, but it is subject to loss under wet field conditions. Losses may be moderate or severe, depending on the form of N fertilizer applied and the type of weather conditions that follow. Nitrogen stabilizers (also called "additives") are available to help reduce N losses from the soil. These products must be used with compatible N formulations to be effective. The most common forms of N fertilizer are shown in Table 1.

Table 1. Nitrogen fertilizers most commonly used for field crop production in North America.[1]

Fertilizer	Form	% N
Anhydrous ammonia	Gas, applied as liquid from pressurized tank	82%
Urea	Solid	46%
Urea-ammonium nitrate solutions	Liquid	28% - 32%

[1] These forms account for over 80% of N applied for corn production.

Anhydrous ammonia, NH_3, is the most basic form of N fertilizer. Ammonia, a gas at atmospheric pressure, must be compressed into a liquid for transport, storage and application. Consequently, it is applied from a pressurized tank and must be injected into the soil to prevent its escape into the air. When applied, ammonia reacts with soil water and changes to the ammonium form, NH_4^+. Most other common N fertilizers are derivatives of ammonia transformed by additional processing, which increases their cost. Due to its lower production costs, high N content that minimizes transportation costs, and relative stability in soils, anhydrous ammonia is the most widely used source of N fertilizer for corn production in N. America.



Urea is a solid fertilizer with relatively high N content (46%) that can be easily applied to many types of crops and turf. Its ease of handling, storage and transport; convenience of application by many types of equipment; and ability to blend with other solid fertilizers has made it the most widely used source of N fertilizer in the world.

Urea-ammonium nitrate (UAN) solutions are also popular nitrogen fertilizers. These solutions are made by dissolving urea and ammonium nitrate (NH_4NO_3) in water to create 28%, 30% or 32% N-containing solutions.

Other N-fertilizer choices include ammonium sulfate, calcium nitrate, ammonium nitrate and diammonium phosphate.

Nitrogen Fertilizers and Soil Reactions

Anhydrous ammonia is applied by injection six to eight inches below the soil surface to minimize escape of gaseous NH_3 into the air. NH_3 is a very hygroscopic compound and once in the soil, reacts quickly with water and changes to the ammonium (NH_4^+) form. As a positively charged ion, it reacts and binds with negatively charged soil constituents, including clay and organic matter. Thus, it is held on the soil exchange complex and is not subject to movement with water.

Soil Reactions - Over time, with soil temperatures that support biological activity, NH_4^+ ions are converted to the nitrate (NO_3^-) form by soil bacteria in the process of **nitrification**. Nitrification generally occurs at soil temperatures above 50° F and increases at higher temperatures. However, some limited activity occurs below 50° F as well. Ammonium is converted first to nitrite (NO_2^-) by the action of *Nitrosomonas* bacteria and then to nitrate by *Nitrobacter* and *Nitrosolobus* bacteria.

Only after the nitrification process has converted ammonium to negatively charged ions repelled by clay and organic matter in the soil complex, can ammonium N be lost from most soils by leaching or denitrification. Plants can take up N in both the ammonium and nitrate forms. Thus, if N can be held as ammonium until uptake by plants, it is at little risk of loss (except on sandy soils that cannot bind much ammonium.)

Urea readily dissolves in water, including soil water. Thus, it can be "incorporated" into the soil by sufficient rainfall or irrigation (½ inch is typically suggested). Otherwise, it should be incorporated by tillage to reduce losses.

Soil Reactions - Urea applied to the soil and not incorporated by water or tillage is subject to volatilization losses of N as urea undergoes hydrolysis to carbon dioxide and ammonia:

$$(NH_2)_2CO + H_2O \longrightarrow CO_2 + 2(NH_3)$$

Urea hydrolysis is catalyzed by urease, an enzyme produced by many bacteria and some plants, and thus, is ubiquitous in soils. The biological degradation of urea by urease that releases the N for plant use also makes it subject to volatilization (as NH_3, a gas) depending on whether the reaction occurs in the soil or on the soil surface. If within the soil, the ammonia quickly reacts with soil water to form NH_4^+, which is then bound to the soil. If it occurs at the soil surface, the gaseous ammonia can easily be lost into the air. If plant residue is abundant on the soil surface, it increases bacterial populations, concentration of urease, and volatilization losses of urea.

UAN solutions are mixtures of urea, ammonium nitrate and water in various proportions. All common UAN solutions (28%, 30% and 32%) are formulated to contain 50% of actual N as amide (from urea), 25% as ammonium (from ammonium nitrate) and 25% as nitrate (from ammonium nitrate).

Soil Reactions - The urea portion of UAN solutions reacts just as dry urea does (see previous section on urea). If applied on the surface, the amide-N in the solution may incur losses due to volatilization, but if UAN is incorporated by tillage or sufficient water, the NH_3 quickly reacts with soil water to form NH_4^+. This NH_4^+, as well as the NH_4^+ derived from ammonium nitrate in the solution, adheres to soil components at the application site and is not subject to immediate losses. Like N applied as anhydrous ammonia, this N will either be taken up by plants in the NH_4^+ form or converted to NO_3^- by soil bacteria.

The remaining 25% of N in UAN solutions is in the nitrate (NO_3^-) form. Because it is negatively charged, it will not adhere to clay and organic matter particles (which are also negatively charged) but rather, will exist as an anion in the soil solution. Because it moves with water, it is easily taken up by plant roots but is also subject to losses by leaching and denitrification. Leaching is defined as moving below the root zone of plants;

denitrification is loss of nitrate to the air as N_2 gas under anaerobic conditions (flooded or saturated soils).

Nitrogen Stabilizers / Additives

Nitrification inhibitors are compounds that slow the conversion of ammonium to nitrate, thus prolonging the period of time that nitrogen is in the "protected" form and reducing its loss from the soil. Several compounds have proven effective for this purpose, but only nitrapyrin and DCD (dicyandiamide) have current widespread use in North American agriculture.

Nitrapyrin, 2-chloro-6-(trichloromethyl) pyridine, works by inhibiting *Nitrosomonas* bacteria. Nitrapyrin has a bactericidal effect, actually killing part of the *Nitrosomonas* population in the soil. Thus, it is effective until the bacterial population recovers in the zone of application and diffusion. Its activity is very specific to *Nitrosomonas.* Nitrapyrin products for delaying nitrification of ammoniacal and urea fertilizers include N-Serve® 24 (launched in 1976) and Instinct® (launched in 2009).

Nitrapyrin added to anhydrous ammonia may reduce N losses, especially with fall-applied anhydrous. *Photo courtesy of Case-IH.*

DCD (dicyandiamide) - Products containing only DCD are generally used with N solutions and liquid manure. In the U.S., products that contain DCD include Guardian®-DF, Guardian®-DL 31-0-0, Guardian®-LP 15-0-0 and Agrotain® Plus.

When to Consider Nitrification Inhibitors - The highest value of nitrification inhibitors should be realized when NO_3^- losses are expected to be high from leaching or denitrification, including these conditions: tile-drained soils when leaching potential is high, wet or poorly drained soils, and fields with N applied in the fall. On the other hand, nitrification inhibitors are usually least valuable when NO_3^- losses are unlikely, for example, when N is applied sidedress, as crop demand is high at this time (Ruark, 2012).

Urease inhibitors are compounds that inhibit the action of the urease enzyme on urea and thus, delay urea hydrolysis. This allows some time for urea to be incorporated into the soil (e.g., by rainfall) where volatilization losses are unlikely when hydrolysis occurs. Only one product has been widely used in agriculture as a urease inhibitor. That product, N-butyl-thiophosphoric triamide or NBPT, is a structural analog of urea and as such, inhibits urease by blocking the active site of the enzyme. NBPT is the active ingredient in the Agrotain family of urease-inhibiting products.

Agrotain®, with the active ingredient NBPT, is an additive for use primarily with urea (applied to urea by the retailer) and secondarily with urea-ammonium nitrate solutions. **Agrotain® Ultra** is a more concentrated formulation of Agrotain.

Eventually, these products degrade, allowing urea hydrolysis to naturally occur. Once in the NH_4^+ form, N from urea is subject to denitrification to NO_3^-, a form that may be lost from the soil. Agrotain and Agrotain Ultra provide no activity against nitrifying bacteria.

Agrotain® Plus is an additive specifically for UAN solutions, according to the product label. Agrotain Plus contains both the urease inhibitor NBPT and the nitrification inhibitor DCD. Thus, it acts against both the volatilization and nitrification processes that lead to N losses from UAN solutions. However, it does not protect the portion of the solution originally in the nitrate form (i.e., the 25% of the N content of the solution derived from nitrate in ammonium nitrate).

When to Consider Urease Inhibitors - Urease inhibitors may be considered whenever urea-containing fertilizers are broadcast and not incorporated with tillage or irrigation. Research shows that N loss from surface-applied urea can be significant; loss is greatest with warm, windy weather and a moist soil surface. Urease activity increases as temperature increases; thus, hydrolysis is normally completed within 10 days at a temperature of 40° F and within 2 days at a temperature of 85° F. Hydrolysis is also highly correlated with the organic matter, total N and cation exchange capacity (CEC) of the soil and increases as any of these factors increase. Urease inhibitors help prevent volatilization, potentially for two weeks or more, thus increasing the chances that rainfall will incorporate urea before losses occur.

Performance of N Stabilizers

N stabilizers/additives have been widely tested over many years. Research results vary widely, from no advantage to yield increases of more than 20%. This is not surprising; when conditions favor N losses for a period and an N stabilizer has been applied (and is not yet degraded), a large benefit is predictable. On the other hand, in conditions not conducive to N losses, little advantage would be expected. Therefore, N stabilizers can be considered as "insurance" to help protect against N losses should conditions develop that favor losses.

Regional performance differences for N stabilizers are expected, as soil and climate factors vary greatly across regions of North America. Soils differ by texture, drainage, organic matter, pH, slope and other variables. Climate differs by temperature extremes and durations, rainfall amounts and patterns and other variables. Because of these geographical differences, making decisions about the value of N stabilizers in each farming operation is complex. In order to make the best decisions, research results that represent your field and climate should be examined, and local prices for N fertilizers and stabilizers should be used.

This decision should take into account all factors that influence the risk of N loss for a particular field. These include geographic location; topography; soil type; residue level; form of N fertilizer applied; timing of application relative to crop growth; expected rainfall, temperature and soil moisture levels; and other factors. Even so, N stabilizers will not be cost effective every year, especially when conditions are not conducive for N losses. However, N stabilizers can provide some insurance against the risk of N losses in many susceptible fields.

Nitrogen Fertilizer for Soybean?

Soybean has high protein content, which is rich in N, so its needs for N are high. Fortunately, N-fixation and uptake of residual and mineralized N from the soil are usually sufficient to supply most of the N needs of a soybean crop. However, some soil fertility recommendations are now suggesting that N fertilizer applications may be needed at very high soybean yield levels. This article discusses the N needs of today's higher yielding soybean crops, sources of N supply to the crop and whether N fertilizer applications may be needed for maximum soybean yields.

Nitrogen Demands of a Soybean Crop

Soybean is high in protein, so its needs for N are high.

When soybean is harvested, a large amount of N is removed from the field. This is because soybean grain has very high protein content (~40% or more on a dry weight basis), and protein contains about 16% N. For example, 60 bu of soybean contains ~210 lb N in the grain and ~80 lb N in the above-ground plant tissues, totaling ~290 lb N (Salvagiotti et al., 2008). This is more N than a high-yielding corn crop requires – 200 bu of corn contains about 270 lb N in the above-ground plant portion. The important question is: "How much of this can come from N fixation and how much can come from the soil?"

Sources of Nitrogen for a Soybean Crop

Unfertilized soybean receives its N from only two sources: N fixation and soil N (Figure 1). A recent review of scientific papers compared the N demand of high-yielding soybean to the capacity of soybean to fix N from the air and obtain it from the soil (Salvagiotti et al., 2008). Because N concentration in soybean seed is fairly constant, N plant uptake from fixation and soil sources increases proportionally to grain yield (Figure 1).

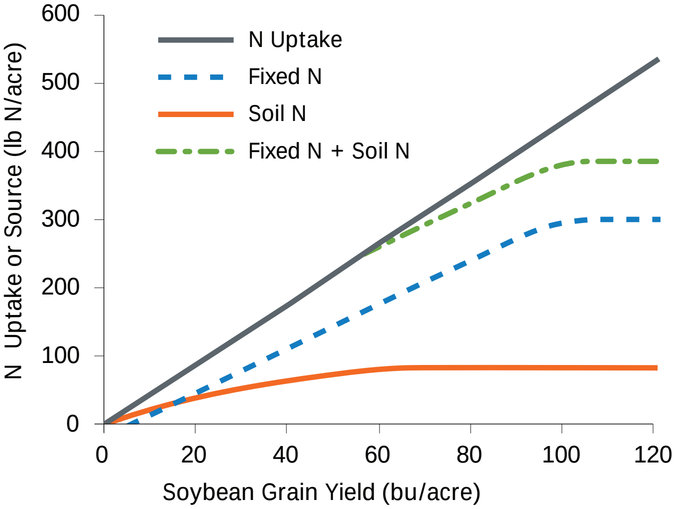


Figure 1. A generalized N budget for soybean. Adapted from Salvagiotti et al., 2008.

N-fixing nodules on soybean roots.

As Figure 1 indicates, average N fixed by soybean increases linearly with increasing yield, but only a portion of the total N requirement is met through N fixation (about 50 to 60% of the total N requirement at yields of 50 bu/acre or less). Based on the average of the 100+ studies represented in Figure 1, at a yield level of 60 bu/acre, fixed N provides about 180 lb of the 270 lb N uptake in soybean, or 65 to 70% of the total required N. For yields up to 60 bu/acre, the difference between total N uptake (i.e., plant requirement) and fixed N is usually provided by soil sources.

The N budget also illustrates that there may be a small N deficit for yields between 60 and 80 bu/acre, which means that yield could be restricted because of too little N. Realistically, conditions that are favorable for top soybean yields are usually conducive to high soil mineralization as well, so N would not always be limiting in this range. However, these studies clearly show that there are upper limits to the amount of N supplied by fixation (about 300 lb/acre) and soil sources (about 85 lb/acre). As yields increase above 80 bu/acre, it is clear that total N needs of the soybean crop will not be met by soil and fixation, and yield-limiting N shortfalls may occur without addition of N.

The Challenge of Applying N Fertilizer to Soybean

Recommendations vary regarding when, where and how N should be applied (if at all) in soybean production. Some indicate that soils with low organic matter, which mineralize less N, may potentially respond to N fertilizer. Others indicate that N fertilizer applied in the zone of N fixation (near the surface in the root zone) will inhibit N fixation, and the benefit of the additional N fertilizer is offset by less fixed N (see next page for more discussion of this). Regarding N timing, some say to apply N before flowering, while others indicate to apply during pod fill when the plant's demands for N are greatest.

In fact, there is neither clear proof from the scientific literature nor consistent anecdotal evidence to predict the conditions leading to a soybean response to fertilizer N. In addition, scientists have not yet been able to identify precisely when soybean will respond to N fertilizer and therefore, when to apply it. However, understanding more about a soybean plant's variable needs for N throughout its life cycle can provide some guidance for application timing. Nitrogen demand by soybean is illustrated in Figure 2.

Application at Early Reproductive Stages? At about 60 days after planting, or about the R4 growth stage, soybean begins to move N from the vegetative parts of the plant to the grain. This might suggest that the best time to apply additional N is prior to R4 (during the early reproductive growth stages) so that fertilizer N is readily available to the plant by R4. If this applied N could delay or minimize the shift of N from the vegetative parts to the seed, it may prolong the duration when the plant remains green and is moving carbohydrates to the seed and therefore, may increase overall grain yield.

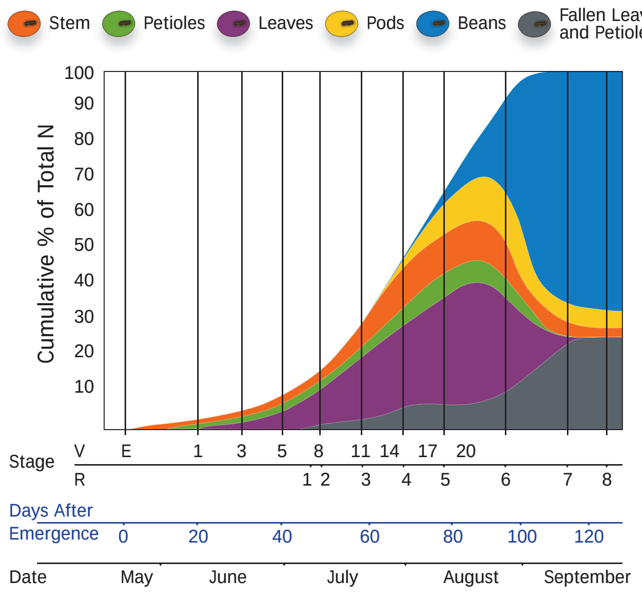


Figure 2. Nitrogen uptake of soybean by growth stage and date for various above-ground plant tissues. Adapted from Ritchie et al., 1982.

Although an N fertilizer application during early reproductive growth stages is during a period of great demand by soybean, it is not known if the N applied would be additive to the N fixed by the plant. Conversely, it could decrease N fixation by some amount, even up to the total quantity of N applied, thus resulting in a zero net gain in available N to soybean.

N Fixation Reduced by Soil Nitrate - Research on N fixation in the presence of soil nitrate is consistent: N fixation by soybean is inhibited in the presence of elevated levels of soil nitrate (NO_3^-). This means that when N fertilizer is applied, soybean simply fixes less N. From a physiological perspective, this makes sense because the process of initiating the symbiotic relationship with rhizobia is energy-demanding. If soybean can avoid the additional "expense" of fixing N by obtaining inorganic N already present in the soil, it will forego, or at least postpone, N fixation. Because all N fertilizers ultimately change to the nitrate form in the soil, this limitation applies to all N-containing fertilizers.

How might N fertilizer be applied to soybean without adversely affecting N fixation? An approach taken in a Nebraska study was to apply slow release N fertilizer (polymer coated) eight inches below the soil surface midway between the rows (Salvagiotti et al., 2009). The placement was intended to avoid or minimize the reduction of N fixation by putting the N fertilizer below the zone where most N fixation occurs. Results showed that this treatment was successful in not reducing the amount of N fixed by the soybean.

Conclusions

Research studies have not consistently identified the conditions for yield increases from supplemental N applications. However, the N budget shown in Figure 1, which was derived from a summary of over 100 research studies, may represent the best estimate of N supply from soil and N-fixation sources and resulting sufficiency or need in soybean production. The budget indicates that a yield-limiting N deficit may exist as yields increase above 60 to 80 bu/acre.

Nitrogen needs that are unmet by the combination of N mineralization by the soil and N fixation by the plant can be supplied by other sources, such as N fertilizer or manure. These supplemental N amounts to meet crop demands are shown below for various soybean yield levels.[1,2] These are based on the potential N deficit (difference between N supply and crop needs) shown in Figure 1 for soybean yields above 60 bu/acre.

Nitrogen Needs[1,2] of Soybean Based on N Budget Shown in Figure 1

50 to 60 bu/acre soybean yields - Additional N is likely not needed, except perhaps in soils with very low inherent N mineralization.[1,2]

60 to 80 bu/acre soybean yields - 0 to 30 lbs/acre additional N may be needed to reach this yield level.[1,2] In soils with high mineralization capability, N may be sufficient.

80 to 100 bu/acre soybean yields - 30 to 60 lbs/acre additional N may be needed to reach this yield level.[1,2]

100 bu/acre and higher soybean yields - More than 60 lbs/acre additional N may be needed to reach this yield level.[1,2]

[1] *These N needs are only approximations based on the N budget shown in Figure 1. Soybean fields are subject to a wide variety of environmental effects, including climatic, disease and insect pressures. Mineralization of N by soils and soybean N fixation is affected by soil moisture, temperature and other factors that vary within season and from season to season. Consequently, soybean needs for fertilizer sources of N are variable and difficult to predict. Individual results may vary.*

[2] *In soils with low mineralization capacity (soils with low organic matter), an additional 20 lbs N/acre may be needed.*

Even if soybean needs for supplemental N are identified, the question of cost-effectiveness of applications remains. That question will only be answered over time with broad-based research studies and side-by-side comparisons in growers' fields. With that in mind, the best approach to determine if supplemental N is required for your high-yielding soybean field may be to simply try a low rate of N in alternate strips on a few acres and adjust future trial rates based on year-to-year results.

Authored by John P. Schmidt, DuPont Pioneer Research Scientist, Soybean Production. Champaign, Illinois.

References

Ritchie, S.W., J.J. Hanway, and H.E. Thompson. 1982. How a soybean plant develops. Iowa State University Coop. Ext. Special Report no. 53. Ames, Iowa.

Salvagiotti, F., J.E. Specht, K.G. Cassman, D.T. Walters, A.Weiss, and A. Dobermann. 2009. Growth and nitrogen fixation in high-yielding soybean: Impact of nitrogen fertilization. Agron. J. 101:958-970.

Salvagiotti, F., K.G. Cassman, J.E. Specht, D.T. Walters, A. Weiss, and A. Doberman. 2008. Nitrogen uptake, fixation, and response to fertilizer N in soybeans: A review. Field Crops Res. 108:1-13.

AGRONOMY SCIENCES

RESEARCH UPDATE

Responses to Side-Dressed Nitrogen

2013

Objectives

- DuPont Pioneer is interested in helping customers get the most out of their nitrogen investment.
- In 2013, DuPont Pioneer field agronomists conducted a series of studies to understand the value of side-dressed or in-season nitrogen (N) applications.

Study Description

Locations:	30 on-farm locations
Hybrids:	Results are pooled across 48 hybrids
Populations:	30, 34, 38 and 42 thousand plants/acre

Treatments:

- Farmer standard N management
- Farmer standard plus 50-75 lbs/acre side-dress N application

At this high yielding location, side-dressed N seemed to reduce late season lodging. Left: Farmer standard. Right: Side-dress N.

Results & Conclusions

- Farms in Iowa received abnormally high rain fall in late April and early May. This created conditions favorable for loss of fall or preplant applied nitrogen.
- The yield advantage by locations is shown in Figure 1.
- Side-dress N modestly improved the response to plant population in environments yielding between 150 and 200 bu/acre (Figure 2).
- At locations yielding more than 200 bu/acre, side-dress N strips were at a higher yield level across populations.
- Extreme drought and heat from silking through grain fill most likely limited yield responses to side-dress N.
- Despite the unusually dry summer, this research demonstrates the value of side-dress and in-season N applications.

Figure 1. Yield advantage with the addition of a side-dress N application. n= 30 locations

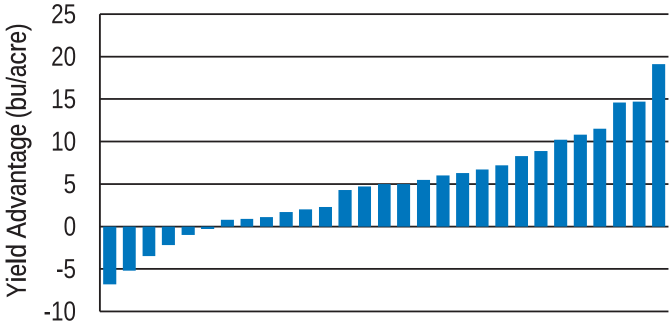


Figure 2. Corn yield response to population and side-dressed N at locations yielding between 150-200 bu/acre. n=11 locations and 17 hybrids.

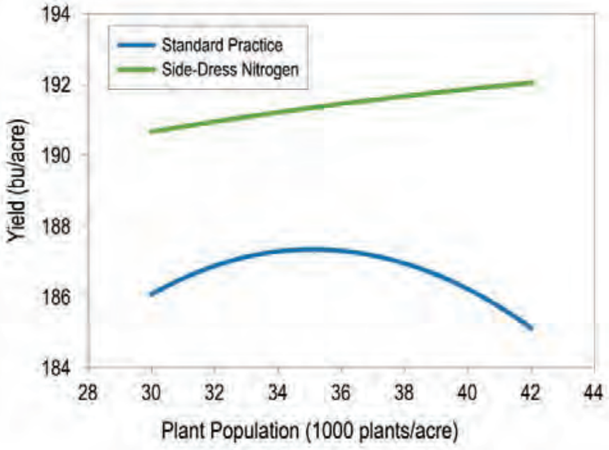
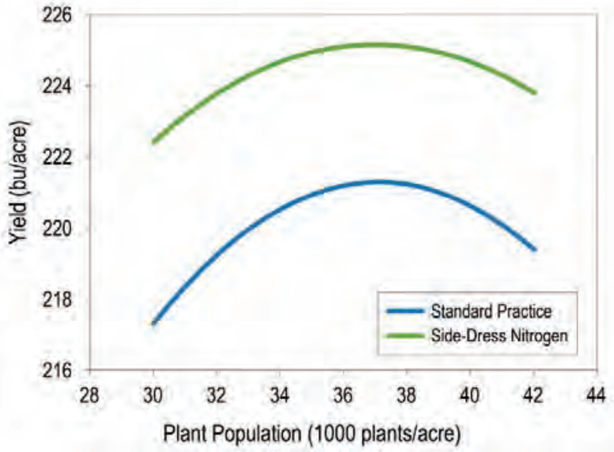


Figure 3. Corn response to population and side-dressed N at locations yielding greater than 200 bu/acre. n=16 locations and 28 hybrids.



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

AMXT - Optimum® AcreMax® XTreme contains a single-bag integrated refuge solution for above- and below-ground insects. The major component contains the Agrisure® RW technology, the YieldGard® Corn Borer gene, and the Herculex® XTRA genes.

AM-R - Optimum® AcreMax® Insect Protection system with YGCB, HX1, RR2. Contains a single-bag integrated refuge solution for above-ground insects. Do not spray with Liberty®. Not all seeds in the bag are tolerant to Liberty herbicide. In EPA-designated cotton growing counties, a 20% separate refuge must be planted with Optimum AcreMax products.

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

AM1 - Contains the 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.

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

LL - Contains the LibertyLink® gene for resistance to Liberty® herbicide. Liberty®, LibertyLink® and the Water Droplet Design are trademarks of Bayer.

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

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

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 - Contains the Herculex® RW insect protection trait contains proteins that provide enhanced resistance against western corn rootworm, northern corn rootworm and Mexican corn rootworm.

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