Iron deficiency chlorosis in soybeans
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Feature

Iron deficiency chlorosis in soybeans is caused by the inability of the plant to utilize iron in the soil. Without enough iron, chlorophyll production is hampered and the plant will suffer and possibly die, with obvious effects on crop yield. This article discusses some of the causes of iron deficiency chlorosis as well as management strategies and recommendations.

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Iron deficiency chlorosis in soybeans is caused by the inability of the plant to utilize iron in the soil. Without enough iron, chlorophyll production is hampered and the plant will suffer and possibly die, with obvious effects on crop yield. This article discusses some of the causes of iron deficiency chlorosis as well as management strategies and recommendations.

By John Morgan
*Crops & Soils* magazine contributing writer

The problem of iron deficiency in crops seems pretty straightforward: there is an absence of enough iron to grow a healthy plant. But it isn’t that simple. In the case of iron deficiency chlorosis, or IDC, it’s not the availability of iron but the ability for the plant to take up that iron that’s the problem, according to Dan Kaiser, an extension nutrient management specialist at the University of Minnesota, who recently presented a webinar on the topic for the Plant Management Network.

“One of the things to note with IDC in soybeans is that it is not caused by iron deficiency in the soil,” Kaiser said. “This is different from other deficiencies like phosphorus or potassium. With iron, there is plenty in the soil. Iron deficiency chlorosis is caused by the inability of the plant to utilize the iron that’s in the soil.”

To understand IDC better, it is helpful to look at the role of iron in plant development. First of all, iron is a micronutrient, and thus while it is essential, uptake is relatively smaller than its macronutrient cousins, which plants require in relatively higher concentrations. Yet, without enough iron, chlorophyll production is hampered and the plant will suffer and possibly die, with obvious effects on crop yield.

IDC symptoms are known to be interveinal in their presentation, and so the yellowing occurs between the veins of the leaves, while the veins themselves remain green. The extent of the problem varies depending on the field and the year; plants can even tolerate some degree of yellow-
ing, but if symptoms persist, losses can result.

“In general, when we look at specific areas within a field, small pockets to maybe larger areas of the field will be affected in some areas of the state while whole fields may be affected in others. It really depends on where you are at and what types of soils are present in fields,” Kaiser noted.

Thankfully, research has revealed some answers as to what accounts for this variability, and Kaiser and his colleagues who work on IDC throughout the Midwest offer several solutions for counteracting the problem.

Uncovering the causes of IDC

In his research, Kaiser has examined the prairie pothole region of Minnesota. These areas are dotted with small pockets that can remain wet for long periods of time. The reason why IDC occurs more commonly in these areas goes back to how the soils were formed.

“What can happen in these areas is some differentiation between where IDC will and will not occur. In general, this is related to water movement within the soil and also the climatic conditions of where those soils are in relation to how the soils were formed,” Kaiser explained.

Picture a pothole area in a field. Water moves to these areas carrying solutes that collect over time. As water sits in the pothole basin, the edges of these areas may remain dry. As water evaporates from the soil, surface solutes can travel with the water out of the pothole area and collect on the rims. This is why the rims of the pothole areas can have more severe IDC present as solutes have collected over time.

“When we look at areas specifically in fields, we look at zones that are high in pH. These are typically zones that have pH levels of 7.4 or higher,” Kaiser said. “When we talk about soils of the western Corn Belt and the Great Plains, we have high amounts of pedogenic carbonates, or carbonates that were deposited in the parent material of the soil itself.”

While all of this is important, the climate where the soils formed probably has had the bigger impact on where IDC occurs. “In cases where we see many of our IDC-affected soils, the level of evapotranspiration exceeds the amount of water that is leached through the soil,” Kaiser explained. “This prevents solutes from leaching, keeping salts or carbonates in the upper surface of the soil. In many cases when you dig into the soil, a carbonate layer can be seen at a shallow depth of many soils where IDC is present.”

Chemistry of nutrient uptake in soybeans

In order to understand the proposed management techniques for IDC, it is important to consider three aspects of nutrient uptake in soybeans: bicarbonates in the soil and their relationship to plants, the important distinction of how Strategy 1 plants take up iron, and, finally, the relationship between nitrogen and IDC.

“What it boils down to when we look at this problem is an increase
in concentration of bicarbonates within the soil,” Kaiser said. “Typically soils are tested in this region for calcium carbonate equivalent, but this does not necessarily equate back to the bicarbonate content in the soil. In addition, many growers will get a soil test back for soluble salts, which is a measure of the electrical conductivity of the soil. While many field areas with IDC may exhibit high salt contents, soybeans themselves are not sensitive to many of the salt concentrations that we typically see in many soils. Therefore, it is not clear whether salts are a cause of the problem or are more of an indicator of where saturated soil conditions may persist in a field. In the case of a direct soil test for IDC, it isn’t really a viable option at this point since there is not a single factor that causes the problem. So we have to look at other factors within the field or look at other environmental factors to gain a better understanding when IDC may be more severe on a year-to-year basis.”

Kaiser notes that this means looking at other related factors such as soil moisture and soil temperature in order to make conclusions about whether an area is high in bicarbonates. And when it comes to IDC, bicarbonates are the key, particularly with regard to Strategy 1 plants such as soybeans.

“Strategy 1 plants such as soybean, blueberries, and azaleas must convert iron into an available form in order to allow for uptake. This is accomplished via the release of acids, which make the iron soluble, as well as reductants, or electrons, which reduce the iron present into a form that the plant can use. Strategy 1 plants can significantly differ in what types of pH they adequately grow in. Soybeans can grow in soils with pH levels near neutral or slightly alkaline better than a plant such as blueberries, which survive in very acid soils. When it comes to iron, most soils contain iron oxide or hydroxides. The problem is that in soils with adequate aeration, the form that iron will be in is Fe³⁺, which is not soluble and the plant cannot take it up. Strategy 1 plants rely on the release of acids and reductants to increase the availability and solubility of Fe in the soil. This is what happens when Fe³⁺ is converted to Fe²⁺.”

So the crux of the IDC problem is truly due to an overabundance of bicarbonate in the soil and not a dearth of iron, and research shows that this most commonly occurs in soils that are saturated or where a lot of carbonates reside thanks to the soil’s parent material or a lack of aeration that will trap carbon dioxide in the soil profile. This is important because bicarbonate levels in the soil are proportional to the amount of carbon dioxide. Carbon dioxide is produced through microbial respiration.

One interesting phenomenon related to IDC is the mysterious green wheel tracks (see above). What is found in early spring are green diagonal lines extending though chlorotic areas that exist where the wheels drove during the final tillage pass before planting. Researchers wondered for years what might be causing these tracks.

To understand what was happening, they took both plant and soil samples and examined levels of nitrates, salts and carbonates, potassium, and phosphorus. The only noticeable issue was that the areas within the wheel tracks had lower soil nitrate than the areas outside of them. Several theories have been offered, and there remains some debate regarding the issue, Kaiser acknowledged. But one theory has emerged that the compaction due to the tractor traffic could be causing...
denitrification, which would then lower the nitrate that would be available for uptake by the plant.

“While we know that soybeans with the rhizobium bacteria will produce their own nitrogen, if there is nitrate within the soil, typically soybeans will take that nitrate up and will do that before they actively start colonizing with rhizobium and producing their own nitrogen,” Kaiser said. “Plants want to remain neutral. So if they take in an anion, which would include nitrate, they need to let an anion out of the root. They need to exchange one for the other. One of the thoughts about why IDC might worsen because of nitrate is that as [the plants] start to take in nitrate, they’ll let out bicarbonate, and over time, we’ll see an increase in bicarbonate around the roots due to that nitrate uptake. So, in effect, soybeans can be making things worse for themselves around the roots where maintaining an adequate supply of iron is critical.”

The issue gets even more complicated when researchers turn their attention to leaves. Knowing that the plant has to convert nitrate to ammonium, they looked at this conversion in plants with high nitrate levels in their leaves.

“One of the things that is suggested by soil chemists during this conversion is that we see acids and reductants that are needed to convert Fe³⁺ to Fe²⁺ being used to convert nitrate over to ammonia, which the plant can use. What can happen is that iron can accumulate in the leaves and not be utilized. This is the reason that when sampling upper trifoliate leaves from soybeans with IDC, you can see very high levels of iron—the plant has taken it up but cannot utilize it,” Kaiser explained.

Management strategy recommendations

Despite the myriad of problems for soybean plants leading to IDC, many management strategies exist. The number one solution for IDC is to first seek out a proven IDC-resistant seed variety and to do your homework when deciding which one is best because, experts warn, not all IDC-resistant varieties are created equal.

“Number one on the list has always been: planting a tolerant variety. When we look at our current recommendations, it still is what we recommend producers to do in case all else fails,” Kaiser stressed.

Next on this list—due to the nitrogen/IDC relationship—is simply to strive to minimize nitrate carryover from year to year. Yet, these may not be enough, and other treatments may need to be considered as well.

Because of the nature of IDC, a logical concept might be to counteract the problem by managing the soil itself. But Kaiser explained that while oftentimes nutrient deficiencies can be thwarted via a broadcast fertilizer, it simply won’t work in this instance.

“Sometimes we get questions on managing the soil itself and on changing the soil’s chemical properties. And in terms of the feasibility, we know that it isn’t cost effective to try to change—especially to lower soil pH—because a lot of these soils typically are buffered to a point where you can’t really effectively lower the pH enough to be able to lessen the problem. So we start looking at it in terms of managing with some sort of iron fertilizer to try to deal with the problem. Can we use an iron broadcast fertilizer? We know that it isn’t really feasible because, again, we know the problem is caused by an inability of the plant...
to take up iron and not the fact that there is no iron in the soil.”

Kaiser said that foliar sprays, a traditional approach, can be successful, but it is not easy to predict where a positive response may occur, and multiple applications may be needed to correct the problem.

“Most of the past research has shown that we typically need to know where the problem will occur and apply a foliar before the problem occurs to be successful with a foliar. A better approach would be to apply iron chelates with the planter. One approach we have had success with is an application of a 6% EDDHA iron chelate directly on the seed at planting. Unlike other liquid fertilizer sources, the application of EDDHA Fe products alone have not been found in our research to reduce seedling emergence.”

Traditionally, the ortho-para form was most commonly used and is seen to be relatively ineffective compared with the ortho-ortho form, which is found in high concentrations for the 6% EDDHA chelates. While there are multiple sources for the EDDHA chelates, it is important to note that the amount in the ortho-ortho form can vary by supplier. This may affect the rate applied, but Kaiser normally suggests applying 1 to 3 lb of these products per acre depending on the potential severity of IDC in an area of the field.

“The biggest difference we see between the ortho-ortho versus the ortho-para is when we start looking at the linkages, especially around the iron molecule itself, is that it’s a more complete linkage around the molecule,” Kaiser said. “So what this does effectively is it protects the iron longer; it keeps it in a more available, highly soluble form longer than the older ortho-para form. A lot of the older research was done with the ortho-para, but the ortho-ortho form has been around a number of years as well. The ortho-ortho chelate form was simply too expensive to manufacture to be used in soybean production until recently when new manufacturing processes were developed.”

Kaiser stresses that the use of the ortho-ortho form, particularly in the heavily chlorotic fields, has been very useful and really rather noteworthy. “The ortho-ortho form has been found to provide more available iron. And this has been one of the biggest success stories in terms of managing IDC with these particular products.”

Other management options include planting a cover crop such as oats, which will assist in lowering nitrates and, potentially, for decreasing soil moisture. But the oats will need to be killed at a very specific time (no taller than 10 inches), which can be challenging in the case of wet years. If left for too long, the companion crop may decrease yields. Increasing seeding rates has also been explored but is least understood, and so it barely makes the list of recommendations at this point.

And so while the story of IDC is one wrought with varied causes related to plant–soil interactions that can vary from year to year, field to field, and even within a single field, many strategies exist that are supported by research and which offer effective management.

This article was developed from a webcast produced by the Plant Management Network (PMN). PMN provides content for researchers, crop management professionals, consultants, growers, educators, and students to make better plant management decisions and recommendations. For more information, visit www.plantmanagementnetwork.org.
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In 2008–2010, researchers evaluated the benefits of managing canola more intensively with foliar application of boron alone, and in combination with fungicides and insecticides, on yield and seed quality. In 2011, foliar boron was evaluated alone.

**Methods**

A total of 28 trials were conducted over three years on 11, 8, and 9 farm sites in 2010, 2009, and 2008, respectively. In each year, two of the sites were located in northern Ontario. Each site included two replications of foliar treatments of boron, fungicide + boron, and fungicide + boron + insecticide applied at the 10–30% flower stage. Fungicide and insecticide were applied at recommended labeled rates. Boron was applied with the other products at rate of 0.3 lb/ac (actual). Soil samples were collected prior to planting to measure soil boron. Plant tissue analysis was completed by collecting the uppermost open leaf at the beginning of flowering. The flowering stage of canola was noted prior to fungicide application. In 2011, 10 farm cooperators applied foliar boron at 0.3 lb/ac (actual) at early flowering. At three of the locations, foliar boron was evaluated at two timings: rosette stage, flowering, or rosette plus flowering.

<table>
<thead>
<tr>
<th>Table 1. 2011 Canola foliar boron trial.</th>
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<tr>
<th>Location</th>
<th>Check</th>
<th>Early</th>
<th>Early + Flowering</th>
<th>Flowering</th>
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<td>Average</td>
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† Early application was made at the rosette stage. Flowering state was 20–30% open flowers (fungicide timing) in general.

**Boron results**

Later-than-normal planting followed by hot, dry conditions during flowering and pod fill depressed 2011 canola yields. Results from nine sites that were harvested are presented in Table 1. Boron applied at flowering did not significantly improve yield over the check. A summary of all trials conducted from 2008–2011 showed that, on average, boron improved yield by 67 lb/ac (marginal) or 3% over the check (Fig. 1, next page). Yields were improved the most in 2010 (5%). In the 33 replicated trials from 2008–2011, boron increased yields in 73% of the trials and economic returns 36% of the time. In the three trial locations in 2011 that included early boron application and early plus flowering application, there was no increase in yield over the check.

**Mixed response to fungicide**

There was a visual difference in sclerotinia infection between the
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Foliar boron, fungicide trial

[continued from p. 12]

check treatments and those receiving fungicide. Growers sometimes commented that fungicide-treated plots were easier to combine with noticeable differences in stem infection. The visual differences in sclerotinia infection did not translate into a consistent improvement in yields or returns from fungicide application, but most sites had lush growth, and canola yields were excellent (Fig. 2). On average over the three years, fungicide application improved yield 67% of time and returns only 15% (canola price of $430/ton and fungicide cost of $24/ac + application). Application timing was generally at the 20–30% flower stage but varied between 5–60% flower. The results of this study do not clearly indicate if or when a protectant fungicide should be applied. Research trials indicate the optimum fungicide timing is at early flowering (20–30% flowers open). Sclerotinia infection is very site specific and difficult to forecast and manage, with weather, variety, soil moisture, spray timing, and coverage all being important factors.

Response to insecticide

Insect pressure from cabbage seedpod weevil and tarnished plant and lygus bugs was low through the three years of trial. Insecticide application did not improve yields or returns. Growers need to rely on scouting and established threshold for these insects in deciding on the need for insecticide application. To minimize the risk of killing bees, insecticide application should only be made during late evening when bees are not foraging.

Summary

In the trials conducted from 2008–2011, foliar boron applied at flowering improved yields marginally by 3% on average but rarely resulted in an increase in return. Further analysis of the data is required to determine if the results are significant. It is interesting to note that the greatest yield improvement occurred in 2010, a year with higher temperatures at flowering than in 2008 and 2009 when temperatures were cooler than normal. In 2011, conditions were cooler than 2010 but extremely dry. This would support research conducted by Dr. Hugh Earl, University of Guelph, with foliar boron applied at flowering. In Dr. Earl’s growth room studies, boron applied to canola that was under heat stress improved retention of pods on the main raceme.

The results from these field trials (73% wins) indicate that for growers who intend to apply a fungicide at flowering, applying boron at the same time is relatively inexpensive (with the cost of boron at $5/ac and application at 0.3 lb/ac) and would likely result in breakeven or a small increase in return. A positive response is more likely under conditions of heat stress (above 82°F) for a sustained period during flowering. Unfortunately, soil tests for boron are unreliable in predicting the need for boron.
Dr. Dave Franzen was recently recognized at the North Dakota CCA's ninth annual meeting as the 2011 North Dakota CCA of the Year.

Franzen became a CCA in Illinois during 1992–1993 and has been a North Dakota CCA since 1995. He provided leadership as a member of the North Dakota CCA board for six years, which included serving as board chair for two years. He was also a Midwest representative to the ICCA board for two years.

Franzen's career involves 35 years of crop-advising experience, including 18 years as an agronomist for an independent retail ag supply chain in east-central Illinois, assisting growers in the management of about 40,000 ac of corn and soybean. Since 1994, he has worked as North Dakota State University (NDSU) Extension Service soil specialist, providing soil management information for about 20 million acres of crops grown each year, including wheat, barley, corn, soybean, sunflower, flax, canola, dry bean, sugar beets, and alternative crops.

He established the NDSU Soil and Water Workshop in 1996 and has been a member of NDSU/University of Minnesota Advanced Crop Advisers Workshop planning committee since 1996. He also coordinates the crop production update seminars at the Northern Ag Expo. He has authored numerous NDSU Extension soils publications, and his research interests include site-specific agriculture, soil fertility, non-conventional soil amendments and additives, and soil–pest relationships.

The North Dakota CCA of the Year award is presented each year to an outstanding crop adviser who has made an impact on agriculture through leadership, professionalism, and education.
Golden Opportunity Scholars Institute Celebrates 5th Anniversary

The 2011 International Annual Meetings of the American Society of Agronomy, Crop Science Society of America and Soil Science Society of America marked the 5th Anniversary of the Golden Opportunity (GO) Scholars Institute. This program matches undergraduates with scientist-mentors during the annual meetings to encourage talented students to enter agronomy, crop and soil sciences, cultivate networks and succeed in their careers.

There are 72 GO Scholar Alumni and the current awardees number 21 in total. For more information on how to get involved with the program please visit:

www.goldenopportunityscholars.org

Celebrating 5 Years
Strong showing at India CCA examination

By Saveen Randhawa, India CCA Program Manager; saveen@isapindia.org

The fourth open India CCA exam was held successfully at different locations across India with 132 agribusiness professionals from leading companies participating in the exam. There was an appreciable hike of 45% in the participation with 132 candidates participating compared with 90 in the previous exam. Since the launch of the CCA program in India in 2010, more and more agribusiness professionals from top-notch companies are getting themselves certified to remain up to date on the latest in agriculture and be ahead of the rest.

Many companies have started using the CCA program as a performance evaluation tool for the promotion of their employees and deciding their incentive level. In the case of talent acquisition, the companies are looking for new CCAs as their prospective employees, which makes the CCA program a highly effective industry-recognized certification for young professionals who want to get their career off to a great start. New companies participating in the CCA program include: Nuziveedu Seeds Limited, Excel Crop Care, Euro Fruits, Coromandel Retail, and Syngenta.

Apart from agribusiness companies, a lot of universities providing specialized courses in agriculture extension have shown interest in the CCA program and are getting it incorporated in their course curriculum.

For more information about the program, visit www.certifiedcropadviser.org or contact me at Saveen@isapindia.org.
The complete soils profession depends on three balanced and sturdy legs (academic, government, and applied practice). These legs are equally important to the viability of a complete profession. Each leg or sector has to be mutually respected, equally represented, supported, and promoted if a profession is to survive, grow, and prosper. Professionally, soil science is at a critical crossroads. Does it continue as a diverse set of independent specialties, or does it organize to represent the true complete profession?

Much like a three-legged stool, professional status depends upon three very stable legs. What are the basic legs to support a healthy, recognized, respected, and complete profession? A starting point is to consider other recognized and respected professions such as medicine, engineering, law, etc. All of these professions have three interdependent and common components that stand out in order to attain a complete professional status:

1. Specialized knowledge through academia, education, and research.
2. Governmental bodies through extension, standards, policies, and laws.
3. Professional applied practice of knowledge through a set of standards, ethics, and certification or licensing.

These are the three primary legs of a recognized or complete profession. If one leg of the stool or profession is weak, the other two legs are equally unstable.

How does soil science compare with other recognized and established professions? Historically, soil science had been reasonably strong as to academic and governmental applications, while its applied practice has fluctuated depending upon professional will, professional boundaries, and structure of professional organizations. These forces are external and internal to the soil science profession.

When one of the three professional legs is weakened or strengthened, the other two legs are directly affected. The soil science profession is presently experiencing such times and circumstances through reduced enrollments, staff, workloads, budgets, and demand for services. Meanwhile, established or complete professions have not been as impacted. The soils profession needs to reflect and consider where it has been, where it is now, and where it
The soils profession needs to reflect and consider where it has been, where it is now, and where it is going—and act accordingly and quickly.

Professional will

Soil science was founded in the agronomic applications. These principles are the basis for many environmental and land use policies within the applied practice of soil science. Currently, most prospective students are drawn to soil science for the environmental and land use applications, not agronomic applications. The demand for soil science knowledge and application has greatly expanded, but our academia, governmental, and professional organizations have been slow or resistant to respond to this change. Why?

Many have wanted soil science to remain solely within agronomic applications, strict research, or governmental extension services. Others did not want to enter the realm of environmental issues, policy making, politics, regulatory confrontations, or land development applications. It is natural to stay within the comfort of our surroundings, funding, or specialties, but when it is detrimental to the profession as a whole, we have to get out of our comfort zone.

Meanwhile, soil science and core geoscience programs have been further diluted through the establishment of broad environmental schools, governmental departments, or other professional organizations. These environmental schools, programs, and competing organizations evolved to answer public demand for additional soils or land knowledge, information, and applications. Many of the answers and principles already lay within the soil sciences—we just need to stand up, confront, and address the questions. Some soil science institutions are beginning to adapt to this challenge while others are being slowly defunded or abolished.

Our professional organizations have slowly begun to recognize these concerns, but efficient constructive actions are needed now to ebb the outgoing flood tide. These professional problems and challenges have all been previously well documented in the articles listed in the “Additional Readings” section at the end of this article. The question is whether our professional soil science organizations will continue to just “plan the work,” or does it have the professional will to collectively and constructively “work the plan” at the academic, governmental, and professional practice levels?

Professional boundaries

External competing boundaries are a part of any viable and dynamic profession. The soil science profession is no different: Where do geology and hydrology end or begin? Soil engineering and materials applications? Wetland sciences? Soft vs. hard engineering applications? Surveying or soil surveying? External competitive boundary issues can be identified and addressed directly through levels of education, competence, licensing / certification, and professional responsibility or liability for works.

Internal professional boundaries are more difficult to control and can severely harm the complete profession in the long term. This
occurs when one leg of a profession competes to the detriment of the other two supportive legs. For example, if the soil sciences are largely conveyed to the public through extension or governmental services, public perception is that the service or information has minimal value because it costs nothing, and there is no direct liability or responsibility for the information generated. When budgets are tight, these programs are more subject to cuts because the public puts little value on them.

The complete profession with a robust professional practice sector will also have strong academic/research/government sectors with subsequently better pay, benefits, and job security (e.g., medicine, accounting, law, engineering, etc.). What is the public’s normal contact with these recognized and complete professions? Is normal contact with governmental staff, researchers, academic professors, or with applied professional practitioners?

The three legs of the complete profession (government, academia, and practice) have to conduct their proper roles within their respective sectors. Otherwise they become internal competition to one another and a detriment to the profession as a whole. A healthy balance between the three professional legs of support is paramount for the complete profession to be viable.

Professional structure

The mission, goals, and structure of organizations representing the complete profession are important as to what and how professional objectives are accomplished. When looking at established and complete professional organizations, there is balance among academic, governmental, and applied practice sectors. This can be seen in reviewing such professional organizations as the American Medical Association, the American Dental Association, the American Society of Civil Engineers, American Engineering Association, and American Bar Association. These organizations are structured to present, promote, and market the professional services they provide to benefit society. Are major soil science professional organizations structured in a similar fashion?

The Soil Science Society of America (SSSA) is the largest and best positioned professional organization to represent the soil sciences. Historically, SSSA's structure consisted of 11 divisions that essentially represent separate academic or government-
The Conservation Professional Training Program is introducing a new national initiative to train a group of conservation professionals to provide the services associated with Conservation Reserve Program (CRP) planning, implementation, and management. A team led by the University of Wisconsin Extension and comprised of national university Extension staff, Natural Resources Conservation Service (NRCS) and Farm Service Agency (FSA) staff, and representatives from NRCS partner agencies and organizations has collaborated to develop and deliver the trainings and make them accessible, convenient, and consistent across all states. The new initiative is called the Conservation Reserve Program Readiness Initiative. It is funded by the USDA-NRCS.

In the coming years, thousands of CRP contracts will be up for renewal, creating a demand for qualified CRP conservation planners. When combined with decreased internal capacity at NRCS due to baby boomer retirement, the demand for planners will be even higher. Recognizing these concerns, the NRCS has sponsored the CRP Readiness Initiative to build a qualified, experienced group of conservation professionals to provide the services associated with the Conservation Reserve Program. Trained CRP consultants will work directly with landowners and their local NRCS offices to carry out these functions. Independent conservation professionals, registered technical service providers, members of conservation organizations, and employees of agencies with formal connections to NRCS are encouraged to participate.

Participants in the CRP Readiness Initiative will have the opportunity to attend a FREE two-day training workshop, work directly with a project mentor, participate in online forums and webinars, and sign up for supplemental training courses as needed. Free core training workshops are being held the first week of March through the end of May 2012. During the summer of 2012, the training curriculum will be transitioned to an online format, which will be available for a course fee. Some of the topics to be covered during the core workshops include: understanding the landowner’s objectives, developing a CRP plan according to national and state guidelines, and CRP best practices for conservation.

Members of the American Society of Agronomy, Crop Science Society of America (CSSA), and the Soil Science Society of America (SSSA) are uniquely suited to CRP work based on their expertise in agronomy, cropland management, and the soil sciences. Since many of the practices in CRP are directly related to these disciplines, attendees with ASA, CSSA, and SSSA affiliations will be valuable contributors to the training process.

The Conservation Professional Training Program is an initiative of the University of Wisconsin Extension and offers a broad suite of online and in-person workshops, webinars, and forums on conservation practices and natural resource management. The CRP Readiness Initiative is one example of the integrated educational experiences offered by the program.

Please visit http://conservation-training.uwex.edu/crpworkshops for a project overview and to sign up for a free regional workshop in your area. Contact Project Manager Karen Bassler, University of Wisconsin Extension, with additional questions (608-261-1092, karen.bassler@ces.uwex.edu).
Band vs. broadcast: understanding the issue

The band vs. broadcast application issue can be simplified to two basic questions: (1) Which is better: band- or broadcast-applied fertilizer? And (2) if I band, how much less fertilizer can I apply? This article addresses these questions by discussing the key factors that affect crop response to fertilizer and some common relationships between band and broadcast.

In order to understand how banding fertilizer compares with broadcasting it, it’s important to review the key factors that affect crop response to fertilizer: soil test levels, soil fixation or “tie-up” capacity, degree of soil incorporation or volume of soil fertilized, soil moisture, and temperature conditions.

Soil test levels and fixation

On average, banding is two to three times more efficiently used by the crop than broadcasting when soils test low. As the soil test levels increase, banding and broadcasting are equal. The exceptions would be situations where soil is cold and wet, early crop growth sets yield potential (e.g., corn), soil has high fixation, or reduced tillage and stratification occur. In such situations, banding would be expected to be superior to broadcasting, even at high soil test levels.

Soil reacts with fertilizer, making it less available for crop uptake, which is sometimes called fixation or “tie-up.” In an effort to reduce soil reactions with the fertilizer, the concept of banding fertilizer to minimize soil contact makes sense. Common soil reactions that reduce plant nutrient availability are listed below:

- Nitrogen and sulfur—soil bacteria tie-up (immobilization) nitrogen and sulfur when breaking down residue.
- Phosphorus—aluminum and iron in acid soil and calcium in alkaline soil converts soluble phosphorus fertilizer to insoluble minerals.
- Potassium—soil clay traps potassium between clay layers.
- Zinc—soil clay traps, adsorbs, and holds zinc.
- Copper—soil organic matter bonds and holds copper.
- Iron and manganese—soil pH converts these fertilizers into insoluble minerals.
- Boron—soil organic matter and clay trap and hold boron.
- Chloride—soil reactions that reduce chloride availability are unknown.
In some soils, fixation reactions are so prominent that it is impossible to raise the soil test levels. In such situations, fertilizer is applied to meet the crop demands on a yearly basis with no attempt to apply extra to build up soil test levels. In such situations, banding is the most efficient way to apply fertilizer to soils with high fixation.

**Degree of soil incorporation or volume of soil fertilized**

Increasingly more growers are adopting reduced-tillage systems. However, broadcast application remains the primary method of applying the phosphorus and potassium fertilizers. This can result in stratification of immobile nutrients. Immobile nutrients that are concentrated in the upper 2 inches of soil can be unavailable if the soil dries out. Positional unavailability could also result with mobile nutrients such as nitrogen if drought conditions persist after broadcast applications. Band application ensures nutrients are placed where roots are most concentrated and active.

The volume of soil fertilized influences the degree of root contact with the fertilized soil. If we assume that a broadcast moldboard plow application fertilizes 100% of the soil, a band application at a 30-inch spacing fertilizes only about 1% of the soil volume. A 1% band may contain approximately 4% of the root system, still leaving 96% of the root system unaffected by the applied fertilizer. From strictly a root contact standpoint, this is not desirable. It becomes even more of a concern when 96% of the soil tests extremely low. For example, the soil supplies 50 to 85% of the plant nutrients in a given year. At best, 15 to 50% of the fertilizer applied in a given year will be taken up by the crop. Total root uptake of a 180-bu corn crop is about 100 lb of P$_2$O$_5$ during the growing season. If 50 lb of P$_2$O$_5$/ac was applied, only about 20 lb of P$_2$O$_5$ of the 50 lb applied would be taken up by the crop, assuming 40% fertilizer efficiency. Where did the crop get the other 80 lb of P$_2$O$_5$ needed to produce 180-bu corn? The corn crop depended on the soil to supply the 80 lb of P$_2$O$_5$.

University research conducted at Nebraska demonstrated broadcast to be superior to band at extremely low soil test levels of 1.5 ppm (Olsen). Corn yielded 121 bu/ac with broadcast (incorporated) and 89 bu/ac with band (2 by 2 inches). This illustrates the important role of the unfertilized soil in supplying plant nutrients. At extremely low soil test levels, it’s physically impossible to pack enough roots into the band to supply the crop’s entire nutritional needs; therefore, a combination of broadcast- and band-applied fertilizer provides more opportunity for more roots to actively take up nutrients. Normally, soil test levels are not extremely low, and band is more efficient than broadcast.

**Soil moisture and temperature**

Nutrients move to the root via soil moisture. Therefore, it is essential to avoid placing fertilizer in the soil where it could potentially dry out. This can be a problem for both broadcast in reduced tillage and band (2 by 2 inches) placement when the top 3 to 4 inches of the soil dry out. In normal years, residue in reduced-tillage systems tends to maintain moist soil conditions in the 2 to 3 inches of soil. The best soil fertility program would be one where the entire soil profile (top 6–8 inches) is well fertilized as insurance against drought-induced deficiencies.

Soil temperature directly affects the amount of root growth to explore and take up soil nutrients. Root growth and nutrient uptake doubles as soil temperatures increase from 55 to 73°F. Young plants growing in cold soils have...
limited root systems to hunt for fertilizer and often exhibit nutrient deficiencies. In these situations, band is more effective than broadcast in meeting early crop growth nutritional needs. Reduced tillage results in more surface residue and colder soil temperatures. Research has shown even on high-testing soils, applying small amounts of fertilizer as starter will increase yields on reduced tillage. This undoubtedly is attributed to the colder soil conditions experienced with reduced tillage.

Crop response to band-applied fertilizer is expected to be more significant for cool-season crops such as cereal crops than warm-season crops such as soybeans. Corn is a warm-season crop, but early growth can be under stressful cold conditions. During this early growth, grain yield potential is determined, and yield loss can occur if nutrient stresses are not corrected.

Common relationships between band and broadcast

The four most common scenarios between band and broadcast are discussed below:

**Situation A: band equals broadcast (Fig. 1)**

This situation has most commonly been observed when soil test levels are relatively high and a limited amount of fixation occurs. Thorough incorporation of broadcast-applied fertilizer results in good root contact and increases the probability of the fertilizer being located in moist soil. Warm-season crops such as soybeans and, to a lesser extent, corn are more likely to exhibit this type of relationship due, in part, to warmer growing conditions.

**Situation B: band is better than broadcast up to some application rates (Fig. 2)**

Band exceeds broadcast at low rates, but both methods of application eventually reach the same maximum yield at high enough application rates. Response B has been reported in numerous studies and is likely the expectation of most agronomists. The factors normally associated with this response are low soil test levels, high-fixing soils, and cold, wet soil conditions.

**Situation C: band is better than broadcast regardless of application rate (Fig. 3)**

Broadcast never attains band yield. At least three different sets of circumstances can lead to Response C. The first situation is cold, wet soil leading to an accelerated early growth response to band-applied fertilizer when this accelerated early growth rate is critical in achieving a growing season’s full potential. The second situation could be low soil test value, minimal incorporation of broadcast fertilizer applications, and relatively dry surface soil conditions. The third condition could be soils with extremely high fixation capacities. The fixation is so great that the fertilizer has to be concentrated in an isolated band to minimize soil fixation reactions.

Soil properties associated with extremely high phosphorus fixation are high clay, high calcium carbonate, high aluminum, or iron oxide content. Fixation reactions are often extremely high when soils are deficient in manganese and iron. It is impossible to apply enough manganese and iron to raise the soil test levels; therefore, annual banding is the only option for manganese and iron. In contrast, copper and zinc soil tests can often be raised, so band or broadcast are both viable options. Banding is the best economical method for
nutrients where building up soil test levels is not the goal or is impossible because of fixation.

**Situation D: Broadcast is greater than band up to some application rates (Fig. 4)**

Broadcast is more efficient than band (reverse of Situation B). This response usually surprises both the reader and the scientist conducting the experiment. It shouldn’t: it is quite understandable when considering the factors influencing crop response. Response D is most likely on low-fixing soils with heavy residue cover and a warm, moist soil surface such as in no-till systems in humid environments or for irrigated no-till.

Under these conditions, root density is frequently highest at the soil surface, where broadcast P is located. Band treatments may be less effective because of insufficient root contact. In colder environments and/or crops where early growth is critical, a combination of broadcast and band placement will likely give best results.

**Rate**

The discussion of band versus broadcast is usually due to an effort to reduce fertilizer application rates and cost. Research results similar to Response B produce recommendations that are frequently made for P and K application rates being reduced if the fertilizer is band-applied rather than broadcast. On the average, band P and K application rates can be reduced 50% compared with broadcast.

Micronutrient band application rates are 10 to 20% of suggested broadcast rates. For mobile nutrients such as nitrogen and sulfur, band application rates can be reduced 10 to 20% of broadcast. However, application rates can be cut in half for only a short-term period without reducing yields. For example, 180-bu corn will remove about 840 lb of P\(_2\)O\(_5\) from the soil over a 10-year period.

Proponents of band application would say you only have to put on 420 lb of P\(_2\)O\(_5\) over the next 10 years. Obviously, soil test levels will decrease as the crop removes more P\(_2\)O\(_5\) than is applied; therefore, band application is a short-term solution for a financially distressed situation. Long-term, the pounds of crop nutrients removed eventually have to be applied to prevent depleting the soil and lowering soil test levels.

**Conclusion**

There are exceptions to nearly every placement rule in the book. Generally, band applications will perform equal to or better than broadcast applications. Broadcast application situations that outperform band will occur infrequently under normal conditions. In colder environments and/or crops where early growth is critical (e.g., corn), a combination of broadcast and band placement will likely give the best results. This especially makes sense when one considers 84 lb P\(_2\)O\(_5\) are required to maintain soil tests levels for a 180-bu corn crop.

Band application of 84 lb P\(_2\)O\(_5\) is impractical; therefore, a combination approach of 24 lb P\(_2\)O\(_5\) band and 60 lb P\(_2\)O\(_5\) broadcast makes the most agronomic sense. Application rates cannot be reduced on a long-term basis. You have to apply what is being removed to prevent lowering soil test levels.
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How well do farmers implement nutrient management plans?

By Chris Zimmerman, contributing writer for Crops & Soils magazine

Nutrient management plans (NMPs) are implemented to supply plants with ideal amounts of nutrients, minimize runoff pollutants, and maintain or improve the soil condition. As we continue to understand the effects farming practices have on the environment, NMPs present farmers with a set of conservation practices designed to reduce harmful pollutants while obtaining optimal crop yields.

Many U.S. Animal Feeding Operations (AFOs) produce excess N and P compared with the nutrient requirements of their cropland, and more regulations are being implemented to help reduce the pollution. In 1998, in response to President Clinton’s Clean Water Action Plan, the USDA and USEPA developed a Unified National Strategy to minimize the effects of AFOs on water quality and public health.

Today, each state has a different set of guidelines for NMPs, most of which involve farmers developing field-by-field records of nutrient applications. Currently, only Delaware and Maryland have nutrient management laws requiring all farmers to implement NMPs.

A new study published in the March–April 2012 Agronomy Journal evaluates how effectively four dairy farms implemented their own NMPs from 1999 to 2005. The researchers, from the University of Connecticut and the USDA, compared the farmers’ reported practices with the recommended manure and fertilizer management plans and evaluated whether manure and fertilizer management had significant effects on the nutrient status of soil and corn tissue tests.

The majority of the cropland of the four farms selected for this study was used for corn silage, with substantial acreage also used for grass hay. The farmers’ priority for management and nutrient tests was corn, so only corn fields were used in this study. Each of the soils at the four farms had sandy loam to loam texture, a slope of 0 to 8%, organic matter content of 3 to 6%, and were moderately well to well drained.

The NMPs of each farm consisted of two parts: a baseline year and the implementation years. In the baseline year, the research team collected information about each farm’s nutrient management. The factors considered included the number of livestock, cropland acreage, nutrient status of the cropland, manure production, manure management, and fertilizer management.

The farmers kept field-by-field records about manure and fertilizer applications but made no changes to the management of their nutrients. The information collected in the baseline year was used to develop field-by-field recommendations for manure and fertilizer management to be applied in the subsequent implementation years. The recommendations were based primarily on soil tests.

The rate of manure recommended was based on the amount of P needed by the crop, which researchers estimated from soil test results. If the farm had excess manure after fulfilling the crop’s P needs, recommendations were made to apply manure at a rate equal to the amount of P expected to be removed by the crop. If the farm still had manure left over, it was to be applied to fields to meet the N requirement for the crop to fields that had a low potential to export P to water bodies. Chemical fertilizer recommendations were made after all manure was allocated.

Soil samples were routinely collected by farmers or crop advisers and analyzed at the University of Connecticut Soil Testing Laboratory. Samples were taken from the surface 30-cm layer from most of the fields in late spring when the corn was 15 to 30 cm tall. The samples underwent pre-sidedress nitrogen tests (PSNTs), which indicate how much nitrogen is available in the soil.

Cornstalk samples were also collected for corn stalk nitrate tests (CSNTs), which provide a retrospective assessment of a season’s nitrogen management. Farmers collected 15 cornstalk samples from each field during the period ranging from one week prior to harvest through one day after harvest.

During the implementation years, farmers were provided the results of the PSNT test and the recommended N sidedress. However, the percentage of times the farmers actually ap-
plied the recommended N rate when the sidedress N recommendation was greater than zero was low, ranging from 6 to 24%.

The percentage of times the farmers applied the recommended N rate ranged from 79 to 90% when the recommended rate was zero. This data implies that farmers were not likely to follow recommendations derived from PSNT tests when the recommendation was to apply N. This behavior is supported by scientific reports showing that PSNT tests are most reliable when the N recommendation is zero.

The farmers applied fertilizer P at the recommended rate in the NMPs in the majority of the fields. In most years, more than 50% of the fields received a recommendation of zero fertilizer P, and farmers tended to follow that recommendation. Across the four farms, the overapplication of P occurred in less than 3% of the field-by-year combinations. This data shows that farmers were willing to adopt P fertilizer recommendations provided in their NMPs.

Only a small percentage of the fields, ranging from 3 to 37%, received the recommended amount of manure N and P. Variability in the amount of residual N available from previous manure applications caused great variance in the PSNT and CSNT tests, indicating that several years of data are needed before these tests can be used to accurately evaluate the performance of a NMP.

The four farmers in this study seemed confident that fertilizer recommendations were appropriate when based on soil tests, especially recommendations for fertilizer P. However, there was no significant change in soil test P values, probably due to the large spatial variation of P in the fields.

The results from this study showed no decreasing trend in the concentrations of nitrate in the PSNT and CSNT tests. The large variation in the amounts of manure and fertilizer applied by the farmers may be responsible for this lack of improvement.

Only a small percentage of fields received the recommended amount of manure application, and no significant decrease in the amount of manure overapplication compared with the recommended amount was found in this study.

Documenting improvements in N and P management after the implementation of an NMP proved to be a difficult task for the researchers of this study, due to both biological and management factors, such as non-uniform manure spreading and annual variations in weather, especially rainfall.

Overall, the researchers say that manure and fertilizer management on dairy farms could be improved by using a longer timeframe than the three- to five-year plans typically used by NMPs. Management plans implemented using a process of adaptive management for N, which provides more detailed, continuous evaluations about the N status of corn fields, have also been shown to improve N management.

As of January 2012, the Certified Professional Agronomist (CPAg) Program is now part of the International Certified Crop Adviser (CCA) Program infrastructure. While both programs were run by the American Society of Agronomy (ASA) and focused on the agronomy profession, they were independent of each other prior to this year. This integration will allow for one seamless agronomy certification process with CCA being the base certification and CPAg an optional specialty. There were no changes to the CCA process or continuing education.

To become a CPAg, individuals must already be a CCA in good standing or become one first. Then they should complete the CPAg application by documenting additional experience, references, resume, and degree course work and transcripts if they did not include it in their CCA application. There are no additional exams. The local CCA boards will also review the CPAg applications.

The CPAg continuing education requirements have changed. There is now a total CEU minimum of 50 per two-year cycle. The same four CCA technical categories of nutrient management, soil and water management, integrated pest management, and crop management now apply for CPAg. In addition, there are three new categories in which they can earn CEUs—professional development, professional service, and professional study—which incorporate the previous CPAg categories of community service, author educational materials, and self-directed study. Though CPAg’s are required to earn 10 more CEUs on a two-year cycle than CCAs, they have more categories to choose from, allowing for more flexibility. Each CPAg was sent two letters explaining the specific changes, but

Certified Professional Soil Scientists (CPSS) and Classifiers (CPSC) have new logos, and therefore new stamps and embossers are available for purchase. Keep in mind that it is always best, and at times required, that you sign and stamp your work as a professional.

Stamps/embossers are to be ordered through Fox Valley Stamp (Menasha, WI) and can be personalized with your name and certification number. Once you order with the company, it will verify with SSSA that your certification is up to date to fill the request.

You can order by phone (920-725-2683) or email (office@foxfstamp.com). Indicate whether you would like the SSSA, CPSS, or CPSC stamp or embosser. The rubber stamp will cost $25.50, and the embosser costs $36.50. All will have additional shipping, tax, and handling charges applied.
to learn more, you can go to the website (www.agronomy.org/certifications/cpags) or contact your certification representative at ASA.

CCA marketing and promotions website

Last fall, the CCA Program launched a marketing and promotions campaign centered around the theme: “CCA—that’s sound advice.” A website was developed as part of the campaign, That’sSoundAdvice.com, to brand and promote the certification to individuals, farmers, and employers so they learn the benefits. It is also designed to provide promotional tools for local boards and individual CCAs. Check out the web pages and start using the promotional materials now by visiting That’sSoundAdvice.com. Let us know what you think while you are there, so we can add the content that you want and make improvements. Check out page 32 for more information.

CCA–Mexico

In the last issue of Crops & Soils magazine, I provided an update on the development of the CCA–Mexico Program. Dr. Bruce Erickson, ASA’s agronomic education manager, and I spent several days in Toluca, Mexico meeting with the newly formed exam committee and board. Toluca is about an hour drive west of Mexico City. I do need to make a correction to a statement I wrote about Mexico City. It is not in the state of Mexico like I thought it was. My Mexican friends corrected me on this when I met with them. Mexico City is the capital of Mexico and is in a federal district similar to Washington, DC for the US. I am sorry about the mistake.

The CCA–Mexico Program will be ready to pilot-test its exam in May with a small group of agronomists. This will provide some base statistical data to do an evaluation and any minor editing before it is offered publicly in August. The exam performance objectives are in their final editing mode and will be posted to the website soon. The performance objectives for Mexico are about 90% the same as those for the U.S. and Canada, leading us to believe that we could develop a North American exam.

The Mexico team is very excited about having the CCA Program as part of their employee development. Our Program Manager in India, Saveen Randhawa, is doing a great job communicating with and explaining the program to those in the agriculture community. The potential in India for the CCA Program is amazing considering the sheer number of people in the profession and the growing demand for increasing food production.

CCA–India

In February, we conducted the annual review of the CCA–India exam and met with the board. The program in India has reached 220 CCAs and continues to grow. The focus of the board was on continuing education and how to make it more available to the CCAs. The good news is that there are educational programs being developed and delivered by the university-based faculty, but they might not be very well known by the agribusiness communities. That will change this year as more communications with CCAs will focus on available continuing education and how the CEU requirements work.

We visited with a group of farmers while in India who were very interested in the CCA Program for their advisors but also for themselves. They asked if they could get certified, so we talked about the requirements as well as the “advising other farmers” feature where they would then advise their fellow farmers in the village. A typical Indian farm in this village is about 5 ac—one for vegetable production, another for a wheat–rice rotation for home use, and the other three for a cash crop. I had an Indian friend contrast it with the U.S. He said in the U.S. you have a 1,000 ac and one farmer, but in India, they have a 1,000 farmers on that same parcel. So if you’re a CCA in the U.S. who thinks keeping up with your customer list is a challenge, just imagine being in India! The village is the center point for business and social activities. The farmers meet daily to share information and commonly work together. This group was very progressive in adopting new practices, crop rotations, and technologies, so the CCA Program made sense to them and also fit their pattern of information flow.

We also met with agribusinesses that are adopting the CCA Program as part of their employee development. Our Program Manager in India, Saveen Randhawa, is doing a great job communicating with and explaining the program to those in the agriculture community. The potential in India for the CCA Program is amazing considering the sheer number of people in the profession and the growing demand for increasing food production.

International CCA Program

The International CCA board recently designated a task force with the objective of evaluating whether or not the CCA Program should pursue ANSI ISO accreditation. This would essentially be certification for the program itself. The task force recommendation was to take a deliberative and slow approach to evaluating all of the functional areas of the program against industry standards. Where discrepancies exist, the appropriate committee would determine the best course of action with recommendations to the CCA–International Council. It will not happen fast, and once the program review is complete, then a determination will be made on whether to complete the ANSI ISO application. The primary objective will be to focus on continuous self-improvement for the program and ultimately increasing value for the CCAs and those they serve, the farmer.
You might be in a unique position to help improve global food production, feed more people, and save lives. How? By writing articles for *Crops & Soils* magazine.

For many years, *Crops & Soils* magazine has been a trusted source of solid research-based agronomic information for our practicing professionals. It reaches more than 14,000 CCAs, CPAg’s, and CPSS/C’s and more than 1,500 students. But, the number of farmers they influence could easily be 10 times that number. The magazine currently reaches professionals in the USA, Canada, and India. Soon it will also be going to Mexico, Argentina, and other parts of Central and South America. The potential reach and impact is enormous.

We are looking for agronomy, soil science, and crop science professionals who would be interested in writing production-agriculture-focused articles about their research, latest developments, experiences, and practical tips that certified professionals would want to know and/or would help them assist their clientele—farmers. Our goal is to include at least one Extension-type report for each major region each issue (published six times/year). We’re looking for at least one person from each major region to serve on the editorial board as a “contributing board member.” Currently, we are most in need of contributions from the Western U.S., Southern U.S., Northeast U.S., Canada West, and India.

The regional contributor would coordinate one article from his/her region each issue (either write the article, get a colleague to write an article, or re-purpose content from an existing publication). Articles don’t have to be long and can be re-purposed from reports/articles that have already been written as part of your work.

I know we are asking a lot. Writing articles takes time and effort, but you will impact thousands of professionals who will share what they know to tens of thousands of farmers who in return put the science into action on the farm. If you are a CPAg or CPSS, you can report CEUs for writing educational articles. It counts as professional service for a CPAg and as education/author education materials for a CPSS. The amount of time preparing the article equals the number of CEUs that should be reported. Extension educators: this might give you another outreach opportunity for your extension publications. We find the writing style of Extension publications meets the needs of the *Crops & Soils* magazine audiences.

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- Notley, Kayla, Dunmore, AB (CCA-PP)
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- Kreway, Lyndsay, Ituna, SK (CCA-PP)
- Saworski, Kelvin, Moose Jaw, SK (CCA-PP)
- Tedford, Jenn, Strasbourg, SK (CCA-PP)

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- Holtman, Garry, Visalia, CA (CCA-CA)
- Kratt, Jerel, Bakersfield, CA (CCA-CA)
- Mulder, Seth, Sacramento, CA (APAg)
- Tillman, Stephanie, Chico, CA (CPAg)
- Uceda, Luis, Guadalupe, CA (CCA-CA)

**Delaware**
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**Florida**
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**Georgia**
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**Iowa**
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- Borglum, Jamie, Waverly, IA (CCA-IA)
- Brunsman, Ross, Dyersville, IA (CCA-IA)
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- Hunsley, Thomas, Morton, IL (CCA-RET)
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Jarvis, Jeffrey, Brodhead, WI (CCA-WI)

Soil science at a crossroads

[continued from p. 20]


Efficient cover crop management has been shown to increase organic matter, reduce erosion, control moisture, and provide N to agricultural systems. Inputs such as manures and commercially available materials can be difficult to manage because they often have low available N contents and can provide P and micronutrients in excess of crop needs. The use of legume cover crops to fix atmospheric N\(_2\) through biological nitrogen fixation (BNF) is an established and highly beneficial farming practice. Estimates of the N contribution from legume cover crops vary widely.

Many organic farmers incorporate green manures into the soil two or three weeks before planting. Emphasis on reducing tillage has stimulated an interest in alternative cover crop management systems and implements. The roller-crimper is a tractor-mounted implement with a water-filled rolling drum that terminates a cover crop by crimping the stems while leaving the root system and soil undisturbed. The effectiveness of roll-kill is related to the growth stage of the cover crop, and termination for optimal kill, defined as the date when cover crops could be successfully terminated by the roller-crimper, corresponds to the active flowering period. In many regions of the United States, it has proven difficult to match the peak production of winter annual cover crop species with the preferred planting dates for spring cash crops.

For optimum yield, corn in North Carolina is usually planted before early April to avoid overlap of drought-sensitive growth stages with a historical dry period at the end of June. This early planting date falls before most winter annual cover crops’ point of peak biomass and N accumulation and, because cover crops are often incorporated two to three weeks before planting, could result in a significant loss of potential N delivery to the system. A recent study in Pennsylvania found that peak N production of hairy vetch occurred two weeks after the optimum corn planting time, resulting in a potentially significant loss of cover crop N.

New, underutilized, and early flowering cultivars of winter annual legumes could reach maturity early enough in the season to complement the North Carolina production schedule. The southern-adapted hairy vetch cultivars AU Merit and AU Early Cover reach 50% flowering 15 days earlier than other hairy vetch cultivars or common vetch, and crimson clover cultivars AU Sunrise and AU Robin flower earlier than the traditionally used cultivars Tibbee or Dixie. Biological N fixation of less commonly used species may be important for delivering new N to organic systems; however, few studies have examined the BNF potential of legume candidate species that are appropriate for the roller system, especially regarding their performance in the southeastern United States where cover crop growth may be increased by favorable climatic conditions found in this region.

In a new study published in *Agronomy Journal*, researchers hypothesized that high total N derived from the atmo-

**Abbreviations:** BNF, biological nitrogen fixation; Ndfa, nitrogen derived from the atmosphere.
sphere (Ndfa) and total N in cover crops that are sensitive to termination by the roller-crimper will be associated with high grain yields in a succeeding corn crop. This hypothesis was tested by (i) measuring the biomass production and total N accumulation at three potential kill dates, (ii) determining the percentage of Ndfa at the optimal kill date, and (iii) identifying roller-crimper-compatible legume species for North Carolina organic corn production systems.

The study was conducted at two sites in 2009: the Tidewater Research Station in Plymouth, NC on a Portsmouth soil (a fine loamy over sandy or sandy-skeletal, mixed, semiactive, thermic Typic Umbraquult) and the Piedmont Research Center in Salisbury, NC on a Lloyd soil (a fine, kaolinitic, thermic Rhodic Kanhapludult). In 2009–2010, the study was conducted at the Caswell Research Farm in Kinston, NC on a Pocalla loamy sand (a loamy, siliceous, subactive, thermic Arenic Plinthic Paleustalf) and again at the Piedmont Research Center in Salisbury, NC on a Mecklenburg loam (a fine, mixed, active, thermic Ultic Hapludalf). For details on the test design, see the original article in *Agronomy Journal* (cited below).

The natural abundance method calculates the Ndfa percentage based on three values: the proportion of 15N from a non-fixing reference plant grown in the same field and under the same conditions as the legume and assumed to access the same soil N pool, the field-grown legume, and the isotopic fractionation value of shoot tissue from the same species grown entirely dependent on BNF. The Ndfa percentage is then calculated.

**Results**

Within species, comparisons were made for all cultivars of hairy vetch, crimson clover, and Austrian winter pea; however, no consistent differences among specific cultivars were observed across all site-years. For hairy vetch, AU Merit produced significantly more biomass and N than the other cultivars at the Caswell site in 2010. This could be attributed to a lack of rainfall in early spring when the early cultivars AU Early Cover and Early Cover–Winter Hardy were maturing; beginning in May, this site began receiving modest irrigation, which may have benefited the later-maturing AU Merit. Across all species, hairy vetch had among the highest total N contents overall, resulting from its high biomass and low C/N ratio (Fig. 1) relative to the other cover crops.

Corn grain yields for all cover crop and planting date treatments are reported in Table 1 (next page). Nitrogen response curves varied widely, with a significant interaction with the cover crop termination (corn planting) date at Tidewater in 2009 and Caswell in 2010, probably as a result of water stress.

Cover crop treatment and the cover crop × termination date interaction had significant effects on the corn yield for all site-years ($P < 0.001$; Table 1). In 2009, hairy vetch treatments were among the highest yielding for corn grain at the late termination date. The lowest yield was seen at Piedmont in 2009 for the early termination date of berseem clover. Of all cover crops tested, hairy vetch treatments were the most consistent in producing high corn grain yields. Between-species contrasts indicated that the hairy vetch treatments produced more grain than crimson clover for all site-years except Tidewater ($P < 0.05$), with a significant interaction with termination date for all site-years except Piedmont in 2010 (Table 1). Corn planted in hairy vetch cultivars yielded more grain than in common vetch in 2009 ($P < 0.01$), but this difference was nonsignificant in 2010. The hairy vetch bicultures, AU Early Cover + Wrens Abruzzi and AU Merit + Wrens Abruzzi, had higher grain yields in 2010 at both Caswell and Piedmont than the hairy vetch monocultures AU Early Cover, AU Merit, Early Cover–Winter Hardy, and Purple Prosperity ($P < 0.05$).

**Fig. 1.** Carbon/nitrogen ratios of winter annual cover crops grown in North Carolina in 2009 and 2010. Crops were harvested in late April (mid termination) and mid-May (late termination). Cover crops included hairy vetch cultivars AU Early Cover (AUE), AU Merit (AUM), and Purple Prosperity (PRO); common vetch (VET); Austrian winter pea cv. Whistler (WHI) and unstated cultivar (PEA); crimson clover cultivars AU Robin (AUR), AU Sunrise (AUS), Dixie (DIX), and Tibbee (TIB); Balansa clover cv. Frontier (FRO); berseem clover cv. Bigbee (BIG); subterranean clover cv. Denmark (DEN); and bicultures rye plus AUE (MXE), rye plus AUM (MXM), and rye plus Austrian winter pea (MXP).
Table 1. Grain yields of corn planted into roll-killed cover crop residues at four locations in North Carolina. In 2009, corn was planted on April 16, April 29, and May 13 at Tidewater for early, mid, and late, respectively, and on April 23, May 8, and May 21 at Piedmont for early, mid, and late, respectively. In 2010, corn was planted on April 23 and May 6 at Caswell for mid and late, respectively, and on April 28 and May 28 at Piedmont for mid and late, respectively. Corn planting was preceded by cover crop roll-kill operations on the same day. Reported yields are least squared means.

<table>
<thead>
<tr>
<th>Treatment†</th>
<th>Grain yield</th>
<th>Tidewater 2009</th>
<th>Piedmont 2009</th>
<th>Caswell 2010</th>
<th>Piedmont 2010</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Early</td>
<td>Mid</td>
<td>Late</td>
<td>Early</td>
<td>Mid</td>
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<tr>
<td>N fertilized, lb/ac</td>
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<td>2.8</td>
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<td>50</td>
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<td>100</td>
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<td>5.2</td>
<td>3.9</td>
<td>4.3</td>
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<td>3.5</td>
<td>4.6</td>
<td>3.7</td>
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<td>Hairy vetch</td>
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<td>PRO</td>
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<td>0</td>
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<tr>
<td>Balansa, berseem, and subterranean clovers</td>
<td>FRO</td>
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<td>–</td>
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<td></td>
<td>BIG</td>
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<td></td>
<td>DEN</td>
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<td>2.5</td>
<td>2.0</td>
<td>1.1</td>
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<tr>
<td>Austrian winter pea</td>
<td>PEA</td>
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<tr>
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</table>

† AUE, AU Early Cover; AUM, AU Merit; EAR, Early Cover–Winter Hardy; PRO, Purple Prosperity; VET, unstated cultivar; AUR, AU Robin; AUS, AU Sunrise; DIX, Dixie; TIB, Tibbee; FRO, Frontier; BIG, Bigbee; DEN, Denmark; PEA, unstated cultivar; WHI, Whis-tler; MXE, AU Early Cover + Wrens Abruzzi; MXM, AU Merit + Wrens Abruzzi; MXP, unstated cultivar + Wrens Abruzzi.

‡ Missing data are a result of corn not being planted in treatment combinations at particular site-years.
other cultivars at Tidewater ($P < 0.05$), with a cultivar × termination date interaction being significant at Piedmont in 2009 ($P < 0.05$), indicating that AU Early Cover treatments had greater yields at earlier termination dates. In 2010, AU Early Cover grain yields were not significantly greater than other hairy vetch cultivars, although AU Merit had greater yields at Caswell at the late termination date. Within-species comparisons of Austrian winter pea and crimson clover were nonsignificant. Apart from late-terminated hairy vetch, most cover crop treatments resulted in lower yields than the highest-yielding N-fertilized control treatments. In 2009, corn yields from late-terminated hairy vetch treatments were equal to or greater than the highest-yielding late-planted, N-fertilized corn.

Discussion

The roller-crimper is a popular new tool being evaluated for cover crop termination in organic corn production. This study sought to identify cover crop species compatible with the roller-crimper system in North Carolina using defined criteria of high biomass and N production, susceptibility to termination by the roller-crimper in mid-April, and high grain yield from corn planted into roll-killed mulch. None of the cover crops tested fulfilled all criteria. Earlier-flowering crimson clover, while susceptible to termination in April, failed to produce adequate corn yields. Hairy and common vetch matured late and thus could not be killed in time to achieve the desired corn planting for this region, although corn yields from late cover crop plantings were surprisingly high at some site-years.

This study suggests that the agronomics of a roller-crimper-based organic no-till system are substantially different from either a conventional management or tillage system. In particular, cover crop species selection, the degree of cover crop biomass and total N produced, and successful termination of the cover crop to avoid competition with corn growth appear to be the most important factors affecting corn yields.

All species derived a majority of their tissue N from BNF, with most having more than 70% of the N derived from N$_2$ fixation. Research on hairy vetch has shown that peak N$_2$ fixation occurs between late April and early May. This study supports the idea that roll-killing vetch during this peak N period may result in both successful termination of legume cover crops and greater input of fixed N to the agroecosystem. The high proportion of N derived from BNF in legume tissues was consistent with previous findings for other forage and cover crop legumes.

In the conventionally managed, N-fertilized control plots, corn grain yield rarely responded to N applications greater than 100 lb N/ac, suggesting that N was not the limiting factor beyond this threshold. Two probable causes for yield reductions at high N rates were weed competition and water stress. Despite herbicide application at planting, increased weed populations were often observed.
in the highest N rate plots, suggesting that excess N led to increased weed competition.

The roller-crimper failed to kill all hairy vetch cultivars, common vetch, berseem clover, and Austrian winter pea at the early roll date in 2009. Even after attempted termination at these dates, cover crops continued to show vigorous growth and competition with the corn, resulting in severely decreased corn grain yields that were lower \((P < 0.05)\) than the 0 N control plot yields. Table 1 shows that as termination dates progressed later in the season, corn yields from hairy vetch treatments increased and yields from corn planted into all hairy vetch cultivars (AU Early Cover, AU Merit, and Early Cover–Winter Hardy) at the late planting date in 2009 were comparable to the controls.

In 2010, the corn yields were greater following biculture mulches than following the individual legume stands \((P < 0.05)\). An additional reason for the yield increase could be related to the mulch weed suppression ability. Research on rolled rye cover crops in soybean production has shown reduced weed populations under rolled rye leading to an increase in soybean yields.

### Conclusions

From the data and observations collected in this study, it is clear that the ecology and agronomics of a no-till organic system in North Carolina are distinctly different from either a conventional no-till system or a more traditional organic system. The researchers hypothesized that cover crop treatments producing high amounts of biomass and acquiring significant N through BNF would be predictive of high corn grain yields. This was true for some cover crop \(\times\) termination date combinations. In addition, corn yields from many cover crop treatments were less than or equal to those of the 0 N controls, regardless of termination date or biomass. This suggests that in a roller-crimper system, the choice of cover crop species, followed by biomass production, are the most important factors determining the success of the succeeding crop. While some data suggest that early maturing cultivars of hairy vetch result in increased yield over later-maturing cultivars, overall the cover crop treatments that resulted in higher corn yields required a later termination date than is traditionally used in this state, suggesting that producers who wish to use a roller-crimper system for organic corn production will have to adjust planting schedules to accommodate this late termination.

Cover crop biomass also appears to have an important effect on controlling weed populations as well as providing adequate N to the corn crop, but additional information on how rolled biomass and cover crop species affect weed interactions, soil N dynamics, and soil–water relations is needed. Before it can be recommended to farmers, there is still much to be investigated about the roller-crimper system. In the immediate future, however, farmers choosing to use a roller-crimper as a legume cover crop termination and N delivery tool should choose cover crops with low C/N ratios, such as hairy vetch, that are known to produce high amounts of biomass. Further studies investigating the potential pest management and drought risks that producers may face by shifting planting dates later in the season, and how these risks compare with those in a fertilized, conventionally managed, or more traditional organic system, are necessary before this system could be recommended for adoption.

This study examined the impact of roll-killing specific cover crop cultivars on a single season of corn but did not investigate how long-term use of a roller-crimper would affect an agroecosystem. Studies investigating how the long-term use of a roller-crimper in organic agriculture would affect soil C and N pools, soil structure and respiration, and other parameters known to be affected by no-till agriculture are also important for understanding how this system could be optimized.

March–April 2012
self-study quiz

Nitrogen delivery from legume cover crops in no-till organic corn production (no. SS 04804)

1. According to the article, inputs such as manures and some commercially available materials can be difficult to manage because

☐ a. they often have too much available N.
☐ b. estimates of their N contributions vary widely compared with legumes.
☐ c. they can provide P and micronutrients in excess of crop needs.
☐ d. of uneven incorporation.

2. The roller-crimper is a tractor-mounted implement with a water-filled rolling drum that terminates a cover crop by

☐ a. crimping the stems while leaving the root system and soil undisturbed.
☐ b. leaving the stems undisturbed while removing the roots and other debris.
☐ c. incorporating part of the cover crop into the soil.
☐ d. rolling the stems while crimping the root system and soil.

3. The effectiveness of roll-kill is related to the growth stage of the cover crop while termination for optimal kill corresponds to the

☐ a. emergence of the following crop.
☐ b. active flowering period.
☐ c. peak biomass period.
☐ d. appearance of buds.

4. A recent study in Pennsylvania found that peak N production of hairy vetch occurred two weeks after the optimum corn planting time, resulting in a potentially significant loss of cover crop N. What’s the solution?

☐ a. New, underutilized, and early flowering cultivars of winter annual legumes.
☐ b. Delayed planting of drought-tolerant corn varieties.
☐ c. Earlier planting of cold-tolerant vetch.
☐ d. Supplemental pre-emergence N applications.

5. In 2009, hairy vetch treatments were among the highest yielding for corn grain at the late termination dates. Where was the lowest yield seen?

☐ a. At Piedmont and Caswell in 2009 for the early termination date of crimson clover.
☐ b. At Piedmont in 2009 for the early termination date of hairy vetch.
☐ c. At Caswell in 2009 for the early termination date of hairy vetch.
☐ d. At Piedmont in 2009 for the early termination date of berseem clover.

6. The hairy vetch bicultures, AU Early Cover + Wrens Abruzzi and AU Merit + Wrens Abruzzi, had corn higher grain yields in 2010 at both Caswell and Piedmont than

☐ a. Wrens Abruzzi alone.
☐ b. a number of hairy vetch monocultures.
☐ c. the bicultures of common vetch and subterranean clover.
☐ d. berseem clover and Austrian winter pea.

This quiz is worth 1 CEU in Crop Management. A score of 70% or higher will earn CEU credit.

Directions

After carefully reading the article, answer each question by clearly marking an “X” in the box next to the best answer. Complete the self-study quiz registration form and evaluation form on the back of this page. Clip out this page, place in an envelope with a $20 check made out to the American Society of Agronomy (or provide your credit card information on the form), and mail to: ASA c/o CCA Self-Study Quiz, 5585 Guilford Road, Madison, WI 53711. Or you can save $5 by completing the quiz online at www.certifiedcropadviser.org/certifications/self-study.

Quiz continues next page
7. In 2010, the corn yields were greater following biculture mulches than following the individual legume stands. An additional reason for the yield increase could be related to
   □ a. higher amounts of N in the mulch.
   □ b. enhanced water-holding capacity.
   □ c. additional micronutrients.
   □ d. the mulch weed suppression ability.

8. Which cover crop species were compatible with the roller-crimper system in North Carolina according to the criteria set by the study authors?
   □ a. AU Early Cover.
   □ b. AU Merit.
   □ c. Purple Prosperity.
   □ d. None of the cover crops tested fulfilled all criteria.

9. In the immediate future, farmers choosing to use a roller-crimper as a legume cover crop termination and N delivery tool should choose cover crops with low C/N ratios, such as hairy vetch, that
   □ a. are known to produce high amounts of biomass.
   □ b. help suppress weeds by producing a dense cover.
   □ c. have a long growing season.
   □ d. are easiest to terminate with the roller-crimper.

10. According to the authors, what should further studies focus on before use of the roller-crimper on organic, no-till farming can be recommended?
    □ a. Long-term soil compaction of the roller-crimper.
    □ b. Pest management and drought risks.
    □ c. Effect of precision crimping soil N.
    □ d. Optimum corn planting densities following cover crops.
Seeding rate effects on soybean height, yield, and economic return

The increased seed cost for glyphosate-resistant soybean, when compared with conventional soybean cultivars, makes seeding rate an important decision in soybean production systems. High soybean yields are possible with a wide range of plant densities because plants can adjust to low population density by producing more branches per plant and by increasing the number of pods on both the main stem and branches.

Environmental conditions such as temperature and precipitation are important factors influencing soybean vegetation growth and yield. Due to the erratic precipitation during the growing season in the southeastern coastal region of the United States, soybean is frequently exposed to drought stress, which may result in yield reduction. Under drought-stressed conditions, grain yield may not increase with high seeding rates because of competition for limited soil moisture. Though mature plant height is usually not considered an important factor in determining grain yield, it is affected by environmental conditions. It has been observed that both plant height and grain yield increased with seeding rate only under high-yield environmental conditions. Therefore, a positive response of plant height to seeding rate may indicate a less stressed environmental condition.

There are five soybean maturity groups (IV through VIII) planted in this region. Soybean MG IV is part of the early soybean production system (April planted), MG V and VI are for the full-season production system (May planted), and MG VII and VIII are for the double-cropping production system (DCPS) (June planted). Lowering seeding rates for the short-season soybean MG IV and late-planted soybean MG VII and VIII may reduce the amount of vegetative growth and reduce yield because of the short growth period. Conversely, soybean cultivars in MG V and VI that are planted in the full-season soybean production system may be able to maintain yield at lower seeding rates because the long growing period allows branch development to achieve desired leaf area index and normalized difference vegetation index.

Materials and methods

A three-year experiment was conducted under nonirrigated conditions at the Clemson University Edisto Research and Education Center near Blackville, SC in the Southeastern Coastal Plain from 2007 to 2009. The field was in the rotation of corn and soybean production with a winter wheat cover crop before the experiment. During the experimental period, only soybean and the winter wheat cover crop were kept in the system.

Five soybean maturity groups (IV through VIII) were used in the study. For each MG, a separate experiment was conducted using a randomized complete block design with four blocks. Seeding rates were 55,060; 82,600; 110,121; 137,650; and 165,180 seeds/ac in 2007. An additional rate of 27,530 seeds/ac was included in 2008 and 2009 because soybean grain yield at the lowest seeding rate in 2007 did not differ from the yield at the recommended seeding rate for all maturity groups. Only one cultivar for each maturity group was studied in each year.

Abbreviations: DCPS, double-cropping production system; MG, maturity group.
A partial-budget analysis was used to evaluate economic return for the seeding rates. Gross revenue was the product of commodity price and grain yield. Partial economic return was the gross revenue minus the sum of seed cost and hauling and handling charges. Seed and grain sale prices and hauling and handling charges were obtained from the South Carolina Soybean Enterprise Budgets. Average seed cost and grain sale prices during 2007–2009, which were about $0.82/lb and $0.17/lb, respectively, were used for the partial-budget analysis. Hauling and handling charges were nearly $0.01/lb. Mean seed number per pound was generated from three random seed samples for each cultivar used in this study and was averaged across years for each soybean maturity group. Therefore, seed size was set at 2,955; 3,182; 3,410; 2,727; and 3,000 seeds/lb for cultivars in MG IV, V, VI, VII, and VIII, respectively. Other costs such as equipment and drying were assumed to be the same for the different seeding rates and thus had no effect on economic return.

Results and discussion

Plant height

For MG IV, plant height increased linearly with increasing seeding rate in 2007 and 2009, but not in 2008. Plant height of cultivars in MG V and VI responded linearly to seeding rate in all three years. The response of plant height to seeding rate for cultivars in MG VII and VIII was positive and linear in 2007 and 2008, but not in 2009. An increase in plant height with seeding rate due to intraplant competition was reported. For cultivars in MG IV in 2008 and MG VII and VIII in 2009, the nonresponse of plant height to seeding rate was probably due to drought stress during vegetative growth. Total precipitation during the period from planting to the R5 stage for MG IV was low in 2008 and only 55 and 42% of that in 2007 and 2009, respectively. Total precipitation during the vegetative stage (from planting to R1 stage) in 2009 was moderate among the three years for determinate soybean cultivars in MG VII and VIII; however, its distribution was uneven as the precipitation in the first month after planting was only 27 and 26% of the total for MG VII and VIII, respectively. The dry soil conditions after planting may have slowed plant growth.

Grain yield and precipitation conditions

For the soybean cultivars in MG IV, grain yield did not respond to seeding rate in 2007 and 2008 but increased linearly with increasing seeding rate in 2009. Precipitation distribution during the growing season in each year may explain most of the yield responses to increasing seeding rates found for soybean in MG IV. Total precipitation during the soybean growing season was more in 2009 than the other two years. Plants at a higher density should have experienced greater competition because of less available soil water in 2007 and 2008 compared with plants at a lower density. In addition, total precipitation during the seed-filling stage in 2007 and from planting to the R5 stage in 2008 was only 63 and 32% of the 30-year average, respectively. Though the precipitation during the period of R1 to R5 for the MG V soybean cultivar in 2009 was only 39% of the 30-year average, plants might have suffered less drought stress as 40% of the precipitation during vegetative stages (0 to R1) occurred one week before flowering. Thus, a positive yield response to seeding rate was only observed in 2009 when less drought stress may have occurred. This agrees with reports that drought stress during the growing season, especially during the pod-filling stage, can have a large effect on yield, and that grain yield may not respond to increasing seeding rate under dryland conditions.
Grain yield of soybean cultivars in MG V varied with seeding rate by a linear function in 2008 and quadratic function in 2009, while grain yield for soybean cultivars in MG VI did not respond to increasing seeding rates in all three years. Precipitation during the period of R1 to R7 was about 65 and 60% of the 30-year average for soybean cultivars in both MG V and VI in 2007 and 2009, respectively. The distribution of precipitation was uneven in 2009 during the vegetative period for MGs V and VI: about 80% of the precipitation occurred in the first 18-day period with only 20% occurring in the last 35-day period. The percentage of the total precipitation over the 30-year average during the seed-filling stages was 34, 100, and 20% for MG V and 32, 41, and 23% for MG VI in 2007, 2008, and 2009, respectively. This likely resulted in water stress for MG V in 2007 and 2009 and for MG VI in all three years. However, grain yield of MG V in 2009 still responded to increasing seeding rate. The different responses of MG V and VI to increasing seeding rate in 2009 may have been due to the differences in maturity and cultivar. The average grain yields of soybean cultivars in MG V and VI were in the order of 2008 > 2007 > 2009 (P ≤ 0.001). Grain yield in 2007 and 2009 was only 76 and 52% for MG V and 52 and 46% for MG VI, respectively, compared with the grain yield in 2008. Though the precipitation during the whole growing season in 2007 and 2009 was about 80 and 101% of that in 2008 for both maturity groups, total precipitation during the reproductive stages (R1–R7) in 2007 and 2009 was only 60 and 55%, which reflects the importance of timely distribution of precipitation on grain yield. The effect of seeding rate on grain yield for MG VII was significant in 2009, but insignificant in 2007.

For soybean cultivars in MG VII, total precipitation during the early and late reproductive stages (R1–R5 and R5–R7, respectively) in 2007 was 59 and 27%, respectively, of the 30-year average. The total precipitation for MG VIII cultivars during the early reproductive stages in 2009 and the late reproductive stages in 2007 were only 25 and 17%, respectively, of the 30-year average. These conditions might also have strengthened the competition for limited soil water as seeding rate increased. The total and timely distribution of precipitation in 2008 provided favorable growing conditions for MG VII and VIII soybean cultivars. Grain yield in 2008 increased with increasing seeding rate; however, yield reached a plateau at a seeding rate of 92,388 seeds/ac for MG VII and showed a slight decline at higher seed rates for MG VIII. This reduction in grain yield with such high seeding rates might have been due to limitations other than soil moisture; it has been suggested that interplant shading and competition for light were more severe.

### Economic return and optimum seeding rates

For MG IV cultivars in the early soybean production system, there was a negative linear relationship between seeding rate and partial economic return in 2008 and no significant relationship in 2007 and 2009. Across years and seeding rates, the average economic return in the three years for MG IV was only 56, 59, 57, and 60% of that for MG V, VI, VII, and VIII, respectively. It was suggested that the lower grain yield of MG IV was due to its shorter duration of vegetative stage compared with soybean cultivars in MG V to VIII under the same environmental conditions.

For soybean maturity groups in the full-season soybean production system, economic return responded to seeding rate by a quadratic function for MG V and a negative linear function for MG VI in 2009. In this study, economic return for MG V increased with increasing seeding rate when seeding rate was not greater than 93,360 seeds/ac in two out of three years (Table 1).

For soybean cultivars in MG V, the predicted seeding rate for maximum yield in 2009 was 153,840/acre, which was 40% greater than the predicted economically optimum seeding rate (Table 1). In this study, seeding rates of 84,453 to 102,267 seeds/ac produced an economic return within $1.01/ac of the maximum value for the MG V

### Table 1. Estimated maximum economic return, optimum seeding rate, and the range of seeding rate to achieve an economic return within $1.01/ac of the maximal value for three soybean cultivar and year combinations.

<table>
<thead>
<tr>
<th>MG</th>
<th>Year</th>
<th>Estimated maximum economic return</th>
<th>Seeding rates at maximum economic return</th>
<th>Seeding rates at maximum yield</th>
<th>Seeding rates within $1.01/ac maximum economic return</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$/ac</td>
<td>seeds/ac</td>
<td>$/ac</td>
<td>$/ac</td>
</tr>
<tr>
<td>V</td>
<td>2009</td>
<td>288</td>
<td>93,360</td>
<td>131,943</td>
<td>84,453–102,267</td>
</tr>
<tr>
<td>VII</td>
<td>2008</td>
<td>513</td>
<td>72,510</td>
<td>92,388</td>
<td>69,757–165,182</td>
</tr>
<tr>
<td>VIII</td>
<td>2008</td>
<td>542</td>
<td>325,900</td>
<td>163,158</td>
<td>124,858–138,947</td>
</tr>
</tbody>
</table>
cultivar in 2009 (Table 1). For MG VI cultivars, there was no clear indication of an optimum seeding rate in 2007 and 2008 as economic return did not differ with seeding rate. The economically optimum seeding rates for MG VI were about 50% of the recommended seeding rate, which is 110,121 seeds/acre for the region.

For MG VII and VIII cultivars in the DCPS, there were no valid response functions to describe the relationship between partial economic return and seeding rate in 2007 and 2009. In 2008, however, there was a quadratic-plateau and a quadratic response of economic return to seeding rate for MG VII and VIII, respectively. The predicted economically optimum seeding rate for MG VII in 2008 was 72,510 seeds/acre with a maximum economic return of $513/acre; and the rate of 69,757 seeds/acre or greater produced an economic return within $1.01/acre of the maximum (Table 1). This optimum seeding rate for maximum economic return was 20% greater than that for the maximum yield. For MG VII in 2007 and 2009, however, there was no difference of economic return among various seeding rates. Considering all these variations together, seeding rates of 69,757 to 165,182 seeds/acre for MG VII cultivars would achieve the optimum economic return.

For the soybean cultivar in MG VIII in 2008, the economically optimum seeding rate was 131,943 seeds/acre, which was 20% less than the seeding rate to maximize yield (Table 1). However, seeding rates of 124,858 to 138,582 seeds/acre produced economic returns within $1.01/acre of the maximum. In 2007 and 2009, there was no difference of economic return for MG VII among seeding rates. The mean economic return in 2007 and 2009 was less than that in 2008, which was probably related to the lower amount of precipitation in 2007 and 2009 (38 and 31% less than the 30-year average precipitation, respectively). High seeding rates for cultivars in MG VIII have been shown to improve the potential for attainment of a leaf area index of 3.5 to 4.0 within the shorter growing season for the DCPS, which ensures maximized light interception and crop biomass. High seeding rates may also provide compensation for seeds that do not attain good seed-to-soil contact due to the high level of small-grain residue that can be present in DCPS.

**Conclusions**

This study demonstrates the effects of seeding rate on mature plant height, yield, and economic return for soybean cultivars in MG IV, V, VI, VII, and VIII. Plant height increased linearly with increasing seeding rate for soybean cultivars in MG IV in 2007 and 2009, MG V and VI in all three years, and MG VII and VIII in 2007 and 2008. Grain yield increased linearly with increasing seeding rate for soybean cultivars in MG IV in 2009 and MG V in 2008. Grain yields for MG V, VII, and VIII were not affected by seeding rates when precipitation was about 30% lower than the 30-year average, likely because of greater competition for limited soil water at a higher population density. Economic return decreased linearly with increasing seeding rate for MG IV in 2008 and MG VI in 2009 and responded to seeding rate by quadratic functions for MG V in 2009 and VIII in 2008 and by a quadratic-plateau function for MG VII in 2008.

The results from this study indicate that optimum seeding rate could be reduced by 25 and 50% for MG V and VI, respectively; however, for MG VII and VIII cultivars, the optimum seeding rates could be increased by 3 to 12% and 12 to 21%, respectively, compared with the currently recommended seeding rate. For soybean cultivars in MG VII and VIII, which are for the DCPS, high seeding rates should facilitate rapid canopy cover and increase yield potential during a short growing season. Within a given MG, it is likely that cultivars may respond differently to seeding rate.

1. High soybean yields are possible with a wide range of plant densities because plants can adjust to low population density by
   - a. producing larger seeds in the pods.
   - b. reducing losses from falling pods.
   - c. producing more branches per plant and more pods.
   - d. reducing losses from stalk lodging.

2. In this study, grain yields for MG V, VII, and VIII were not affected by seeding rates when
   - a. precipitation was about 30% lower than the 30-year average.
   - b. precipitation was about 20% higher than the 20-year average.
   - c. seeding rates were about 30% higher than the 30-year average.
   - d. seeding rates were about 20% lower than the 20-year average.

3. Which of the following is true regarding the relationship between plant height and grain yield?
   - a. A positive response of grain yield to plant height may indicate a water-limited situation.
   - b. A negative response of grain yield to plant height may indicate a less stressed environmental condition.
   - c. Mature plant height is usually considered an important factor in determining grain yield.
   - d. Mature plant height is usually not considered an important factor in determining grain yield.

4. The authors suggest that the reduction in grain yield that they saw in 2008 with high seeding rates for MG VIII might have been due to
   - a. interplant shading and competition for light.
   - b. lack of adequate soil moisture.
   - c. poor seed-to-soil contact.
   - d. greater pest populations.

5. The article states that high seeding rates in the DCPS may also provide compensation for seeds that do not attain good seed-to-soil contact due to
   - a. the high level of small-grain residue.
   - b. lack of adequate soil moisture.
   - c. variable seeding depths.
   - d. heavy rainfall right after planting.

6. In this study, economic return for MG V
   - a. increased with increasing seeding rate when seeding rate was not greater than 93,360 seeds/ac in two out of three years.
   - b. decreased with increasing rate when seeding rate was not greater than 93,360 seeds/ac in two out of three years.
   - c. increased with decreasing seeding rate when seeding rate was not lower than 93,360 seeds/ac in two out of three years.
   - d. decreased with decreasing seeding rate when seeding rate was not lower than 93,360 seeds/ac in two out of three years.

7. For cultivars in MG IV in 2008 and MG VII and VIII in 2009, the nonresponse of plant height to seeding rate was probably due to
   - a. pest pressure during vegetative growth.
   - b. heat stress during reproductive growth.
   - c. drought stress during vegetative growth.
   - d. less-than-optimal temperatures during reproductive growth.
8. High seeding rates for cultivars in MG VIII have been shown to improve the potential for attainment of a leaf area index of
   - a. 0 to 2.5.
   - b. 3.5 to 4.0.
   - c. 4.0 to 4.5.
   - d. 5.0 to 6.5.

9. For soybean cultivars in MG VII and VIII, which are for the DCPS, high seeding rates should
   - a. increase yield potential during a long growing season.
   - b. decrease yield potential during a short growing season.
   - c. decrease yield potential during a long growing season.
   - d. increase yield potential during a short growing season.

10. According to the article, optimum seeding rate could be
    - a. reduced by 3 to 12% and 12 to 21% for MG V and VI, respectively; and increased by 25 and 50%, respectively, for MG VII and VIII.
    - b. reduced by 25 and 50% for MG V and VI, respectively; and increased by 3 to 12% and 12 to 21%, respectively, for MG VII and VIII.
    - c. increased by 25 and 50% for MG V and VI, respectively; and decreased by 3 to 12% and 12 to 21%, respectively, for MG VII and VIII.
    - d. increased by 25 and 50% for MG VII and VIII, respectively; and increased by 3 to 12% and 12 to 21%, respectively, for MG V and VI.

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