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On the cover: Jesse Deardorff (left), a recent Iowa State University (ISU) graduate, and Chad Krull, an ISU senior in agricultural studies, inspect soybean plants at the Ag 450 Farm. The farm is used as a classroom for a capstone class that offers students hands-on experiences in farm management. Photo by Barb McBreen, ISU College of Agriculture and Life Sciences.

American Society of Agronomy


Crops & Soils magazine
Securing the future of **Agronomy** with public–private partnerships

By Madeline Fisher  
Associate Editor–Magazines  
mfisher@sciencesocieties.org

With all of the challenges facing agronomy these days, from declining public investment in agriculture to increasing demand for food and other resources on fewer acres with fewer qualified college graduates, there is great need for everybody in the ag community to work together. Many are calling for more “public–private partnerships,” in which businesses and universities work together to train students, assist farmers, or do applied research.
Like many CCAs in Iowa, Amy Asmus looks to Iowa State University (ISU) for the continuing education credits she needs to stay certified. But Asmus, currently vice chair of the International CCA Board, also maintains much deeper ties to her alma mater in Ames.

She has served on several boards for ISU’s College of Agriculture and Life Sciences, including an advisory board to the vice president of extension and outreach. She talks regularly with people in the agronomy department about everything from ideas for research projects to ways to revamp extension. And last year, she and her husband, Harlan, helped establish the department’s “Into the Field” initiative, which seeks to better prepare agronomy students for careers at agribusinesses, such as the couple’s own company, Asmus Farm Supply.

In short, Asmus recognizes the value of the “public–private partnership,” in which businesses and universities work together to train students, assist farmers, or do applied research. Faced with declining funding at both the federal and state levels, ISU and other land grant universities have looked increasingly to companies to help them sustain research, education, and extension programs. Now, a growing number of agribusiness people are calling for industry to embrace these collaborations more fully, as well.

Partnerships between public and private organizations can be tricky to navigate, and both sides have been reluctant at times to collaborate. But for Asmus, today’s farming challenges are simply too great for universities and agribusinesses to continue operating as they have traditionally: “moving toward the same goals along parallel lines,” she says. The emergence of glyphosate-resistant weeds, for example, is a game-changing development that will only be managed through the combined ingenuity and efforts of many, many people. “And it’s not just weed resistance and chemical programs. It’s the same with everything,” Asmus says. “So it’s time to get outside our comfort zone and work together to solve problems.”

Harold Reetz, a long-time Illinois CCA who today runs a consulting business, Reetz Agronomics, sees the same need. That’s why he spearheads
an American Society of Agronomy special interest community that fosters cooperation between academia and industry with his good friend and colleague, University of Minnesota agronomy professor Vernon Cardwell. Cash-strapped academic programs obviously have much to gain from strengthening their ties to industry and tapping private money. But companies shouldn’t forget how they rely on universities for continuing education, Reetz says, not to mention the new agronomy students who eventually fill company positions. Already there’s a shortage of qualified graduates, making the need to join forces all the more urgent. And Reetz thinks there are many more areas of common ground.

“Hopefully we’re all in this to make improvements in our agricultural industry,” he says, including how the community is using scientific information, preparing future crop advisers, and most importantly, he adds, “making decisions on the farm.”

Getting undergraduates into the field

What happens on the farm is the ultimate concern, but one trend that worries both Reetz and Asmus is how fewer and fewer undergraduates today have ever actually worked on one. In the past, most students who studied agronomy in college already had loads of practical experience, since they were, for the most part, farm kids. But many of today’s agronomy students have grown up in cities or suburbs instead, and though they may be plenty smart, their lack of hands-on skill can be a liability for the ag retailers, co-ops, and other businesses that eventually hire them.

This is why Asmus and her husband made their gift to the ISU agronomy department last year to jump-start “Into the Field.” The premise of this public–private partnership program, Asmus says, is to integrate the core agronomic knowledge students learn in college with experiences that expose them to farming and the challenges ag professionals face. This doesn’t mean taking students on an occasional field trip, however. What “Into the Field” aims to offer are meaningful experiences that inform students about emerging agricultural issues, such as new diseases, advanced technology, or herbicide-resistant weeds.

“From the time students start as freshman to the time they’re seniors, agronomy is moving at light-speed in the real-world,” Asmus says. “So how do we keep them up-to-date, so that they’re up-to-date when they graduate? Plus, how do we keep their professors up-to-date so that what they’re teaching is in line with the latest developments in agriculture?”

Another way to think about the program is that it seeks to give agronomy students the same practical training in diagnosis, problem-solving, and treatment that medical students undergo before they become full-fledged doctors, says ISU agronomy department chair Kendall Lamkey. Medical students aren’t allowed to practice medicine until they’ve worked under skilled physicians in a residency, he explains. And yet most agronomy graduates go to work on something equally important—food production—without anything approaching the same training.

“That’s why I like ‘Into the Field’,” Lamkey says, “because it’s an opportunity for us to figure out how to get our students what I would call some ‘clinical’ experience during their time as undergraduates.”

The vision is to weave this experience throughout the entire agronomy curriculum, which
means it will take several years of curriculum development for the program to reach its full potential, he adds. Meanwhile, several short-term goals can be tackled straightaway. This summer, for instance, he hopes to engage agronomy professors who do a lot of undergraduate teaching in two- to four-week sabbaticals at agribusinesses, like Asmus Farm Supply. The idea is to give professors a chance to see what goes on at these companies, hear about current issues, and interact with industry agronomists because sometimes, Lamkey says, “faculty members get disconnected from what’s going on in the real world.”

Along similar lines, his department wants to give students a better grasp of this world by improving and formalizing the department’s internship program. Although well intentioned, agribusinesses sometimes aren’t certain how best to mentor and interact with undergraduates, Lamkey says. So he and his colleagues plan to work with several employers and interns this summer to set expectations up front on both sides, and then monitor the internships to make sure they’re meeting those expectations.

Internships don’t just benefit students, Reetz adds. They also strengthen the entire agricultural community by getting companies and academic departments talking and may help to attract today’s new breed of student to ag careers in the first place. “We’re probably missing out on a lot of really sharp people who could add to our profession if they just knew about it,” Reetz says. “They’d be excited about it. But they don’t know the opportunities are there.”

Besides, undergraduates don’t just have a lot to learn; they have things to teach, as well, Asmus says. Young people have superior skills with smartphones and other high-tech gadgets, for example, and they’re often brimming with ideas on how to use technology to help farmers. Working with college students also gives agribusiness people a chance “to understand these kids: what they’re thinking, where they’ve coming from,” she adds, “because they’re not the traditional agronomy students we’ve had in the past.”

**New extension model focuses on CCAs**

Alongside this shift in the student body, the farming community has been witnessing another dramatic change: the loss of ag extension personnel. Before 1980, for example, each of Iowa’s 99 counties had an extension agent who worked with local growers to solve problems, while today just 10 to 12 ISU extension agronomists serve the entire state. “With 12 field agronomists trying to cover 23 million acres of row crops, plus forages and pasture, we just
couldn’t serve every grower the way we needed to,” says ISU Extension field agronomist Clarke McGrath. Not surprisingly, then, farmers have been looking elsewhere for help. In a survey conducted by ISU in 2004, for instance, more than 90% of the 400 Iowa corn and soybean growers who were polled identified crop consultants and agronomists at agribusinesses as their primary advisers.

At the same time, more than 80% of the 100 CCAs who were also surveyed named ISU Extension as their chief information source, and with these findings in mind, ISU established a new extension model based on the public–private partnership: the Corn and Soybean Initiative (CSI). Rather than working mainly with farmers like before, ISU Extension agronomists would “focus on trying to serve our farmers better by serving their service providers [the CCAs] better,” says McGrath, a former industry CCA himself. To do this, the CSI first reached out to agribusinesses across Iowa with which it wanted deeper ties—eventually some 400 in all. As CSI program manager, McGrath then drew on his own experience in ag retail to coach extension field agronomists on building stronger relationships with the CCAs at these companies.

“As a retailer, I had on speed dial the top 10 people I could rely on if I had questions, needed help with troubleshooting, wanted someone to come speak at a meeting, and so on,” McGrath says. “So, I laid down the challenge to our field agronomists to get on the speed dial lists of the agribusiness people in their areas.”

One of those people was Asmus, who also helped shape the CSI from the beginning. Some of her crop adviser colleagues tend to downplay the importance of maintaining strong ties to university personnel, she says, whether through the CSI or in other ways. But for her, these relationships provide her company and its clients with an invaluable source of unbiased, scientific information. “As a certified crop adviser, I have to weigh the information that’s out there because there is so much information,” she says. “And I believe that the university data has credibility to it. When data comes from a university, it’s more useful to me.”

Iowa CCA Rachel Halbach, a young agronomist at North Central Cooperative in Clarion, IA, thinks the CSI has also been useful to her career. New to the area when she started her job two years ago, Halbach says that her CSI extension contact, John Holmes, helped show her the ropes: conferring with her about local issues and introducing her to area growers, many of whom he’s worked with for years. “He has great relationships with many of our key customers,” Halbach says, “and so I was able to build relationships much more easily, I feel, than if I had just been out on my own.”

Another important aspect of the CSI, she adds, is the joint research projects it encourages among growers, ISU, and partner businesses. To identify areas of common interest, company and university personnel first talk together about applied problems of regional importance, such as questions on fertilizers or fungicide use. Once an issue emerges that appears practical to study, the university then provides research protocols to follow, CCAs find growers who want to host trials on their farms, and the CSI and businesses split the research costs.

In the past, ISU has sometimes been criticized for being behind or out of touch in its applied research programs, and the new approach has
definitely helped the university boost the relevance of these efforts, McGrath says. But the advantages also extend to the private side. Halbach adds. When field trials take place on actual farms, “growers aren’t just reading in a newsletter or hearing me tell them that they need to apply something or not apply something. They can see it for themselves,” she explains. “I think that not only gives them confidence in us, but it also gives them the power to make a decision based on first-hand knowledge.”

Plus, collaborating with ISU lends additional credibility to company studies and findings, McGrath adds.

For all its success, however, the CSI hasn’t been without its challenges. “This is a work in progress, because trying to bring a business model to a land grant university is ground-breaking,” McGrath says. “We’ve had some pushback, and we’ve had to learn along the way.”

Some extension professors and field staff, for example, still prefer to work directly with farmers, rather than focusing their time on serving CCAs. The CSI is also in transition: It will be re-launching in the future under a different name and with a renewed emphasis on applied, on-farm research.

Whatever shape the program takes in the future, Halbach believes the value of the partnership will endure. “We work well together,” she says, “and I think the relationship will continue no matter what the changes are to the CSI.”

Working together for the good of agriculture

These relationships not only must continue, but also grow, Reetz says because like Asmus, he believes many of today’s agricultural challenges can’t be met through anything other than teamwork. Take non-point sources of nutrient pollution. It’s obviously in the interest of everyone in the agricultural community to curb nitrogen and phosphorus runoff from farms. But equally obvious is how it takes nearly everyone in the community to make real progress here.

In two large projects in Illinois, for example, Reetz is coordinating the efforts of farmers, the USDA-ARS, conservation groups, state agencies, agribusinesses, and others to reduce nutrient discharges across two watersheds: the Indian Creek watershed and the Upper Salt Fork watershed. It isn’t easy. Organizations sometimes squabble over how project dollars are distributed, he notes. Growers in the same watershed are also competing for land, water, and other resources, he says, “so you have to really work on showing them how sharing information and working together is going to help.”

At the same time, farmers used to share labor and machinery all the time to harvest hay or shell corn in the days before everyone had their own equipment. Plus, at the Potash and Phosphate Institute (now the International Plant Nutrition Institute) where Reetz spent most of his career, he and his colleagues helped companies and universities cooperate on initiatives all the time. “That’s kind of the role we played: Providing that bridge between the academic and commercial world,” he says.

Cooperation is nothing new, in other words; people just need to get in the habit again of working together for mutual gain. “[Companies] need us and we need them,” Lamkey says, and now “Into the Field” is offering one more example of how the two sides can benefit one other. “There are a lot of things we can do down the road,” Reetz agrees, “if we just work on it.”
The equipment industry in agriculture has taken a huge jump towards precision agriculture, which is a broad term covering many aspects and areas. The focus for us as professionals is to be able to utilize as many aspects of this technology as we can and turn it into agronomical solutions.

Every agronomic recommendation or solution we come up with is touched by some sort of equipment. Think of your growers and producers. Fertility, seeding, tillage, herbicides, fungicides, and harvesting are all done through iron—a huge investment and cost to all growers. So if we understand the potential and limitations of this type of equipment and what we can do with it, we can then use precision agriculture and turn it into precision agronomic applications. Here’s how:

The blueprint

To first understand this daunting world of equipment, we have to be understood. We have to be able to make sound decisions based on sound information that can be applied through technologically advanced equipment. You have to be speaking the same language. This is the geo-referenced GPS language. Geo-referenced soil sampling is called grid sampling, and it gives us the ability to paint an accurate picture of information that prescription applications are based off of. Grid sampling takes GPS-plotted soil-sampling points in a field using assigned grid sizes—1 to 5 ac—and multiple soil plugs across that grid to give us an average representative of that location. In Fig. 1, we have a 105-ac farm. When grid-sampled, we get around 45 sampled grids. Since grid sampling is GPS-correlated soil sampling, each point has a latitude and longitude, and we can return to that location from year to year. Your grower’s equipment can find that location too, and so here is the magic…we can tell that piece of equipment to do anything we want at that location.

The science

We can then get our lab analysis of all 45 samples and make our prescriptions. So what prescriptions can we make with this sort of information? Well the fertility prescriptions are simple enough. We can make them up based on a simple deficiency or sufficiency approach; or even base saturation percentage. The foundation nutrients we can do this with are phosphorus, potassium, magnesium, and lime for pH neutralizing.

Fig. 2 is the potassium application prescription map for the same field shown Fig. 1. This shows the total amount of 0–0–62 K,O to apply, which is the blueprint to be

Fig. 1. Grid sampling of this 105-ac farm results in around 45 sampled grids, which can be precisely managed.
uploaded into the application equipment. The equipment applicator has a GPS system that knows where it is in that field at all times. Once its location corresponds with the GPS sample point, the machine’s controller knows how much we told it to apply. So as the machine drives throughout the field, the rate changes based on each point recommendation that we uploaded into the controller of the applicator. So we see this field has several different rates. The low application areas (in green) showed high soil test results in potassium, and hence they need a low amount of K2O application. The yellow is a medium test level, and the orange is low testing.

Now traditionally this field might have received just a straight rate of 150 lb of total 0–0–62. Just take a look and compare how many areas in that field we would have been overapplying and underapplying. There would have been 37.5 ac in this farm that would have been an over-application and 57.5 ac would have been an underapplication, leaving approximately 10 ac where we were right! This is where the agronomy starts to meet technology.

### Management zones

Well it’s pretty clear not every field has perfect 2.5-ac variability. So we can assume that after the initial investment of grid sampling is over, we can look to group certain grids showing the same CEC, soil types, and fertility together (see Fig. 3). These groupings are called management zones, and they have different prescriptions of fertility, seed population, and even yield goal relative to their potential. Some fields might have less than two zones, and some might have as many as eight. But with technology and GPS precision, we can farm each of these zones all at the same time, but equipment will change on the move to those zones.

### Equipment agronomic potential

Forgive the pun, but if you’re a little rusty on the capabilities of modern farm equipment, here is a quick rundown. Firstly with the streamlining and accuracy of GPS technology and with the equipment company’s ability to include this technology in every purchase a grower makes, most equipment has some sort of precision component.

Autosteer gives the tractor/combine the ability to work a field in a geo-referenced plan, meaning the operator’s screen knows that it’s pulling a 30-ft seeding unit. It can then make accurate, even swaths throughout the field, giving your grower more time to think about questions to call you with. Once the machine reaches the boundary of the field, it automatically switches off the seed when it comes to an area it already planted. This is referred to as swath control. This is environmentally a great thing when...
North American growers have been practicing precision agriculture for decades, and one look at the average farm shows why. Fields are dozens to hundreds of acres in size, making it wise to tailor crop inputs to the natural variability in soil properties and other growth conditions that exists at large scales.

But how about in India, where the typical farm is just 5 ac or less? Does enough variability exist in small fields to warrant precision farming there, as well? That’s the question now being addressed in the southern Indian state of Karnataka, where a state government grant ($220,000 in U.S. dollars) is supporting a new Precision Agriculture Project at Karnataka’s three agricultural universities. The project’s lead institution is the University of Agriculture Sciences (UAS), Raichur, in northeastern Karnataka, and its coordinator is M.B. Patil, a UAS plant pathologist.

In 2010, Patil traveled to Colorado State University in Fort Collins to learn about precision farming in the laboratory of Raj Khosla, a CPSS, soil science professor, and precision agriculture expert. Khosla, in turn, has a grant from the Indian government’s Department of Science and Technology to help UAS build its capacity to teach, study, and disseminate the practice. He has also conducted more than a dozen precision agriculture workshops across India during the last five years.

Under Khosla’s guidance, Patil and a team of scientists and local farmers are now conducting grid-sampling of conditions such as soil fertility, plant nutrient status, and crop health on area farms for the first time. Once they’ve mapped these parameters within fields, they’ll attempt to correlate the variability they see in these measurements with variability in crop yields.

Already they’re documenting significant differences in soil properties and crop characteristics across fields of just 2.5 to 5 ac in size, and in some cases, the scale of variability is similar to what researchers observe in large fields of Colorado, Khosla says. Although much more work remains, the findings make him and Patil hopeful that variable-rate fertilizer
application and other techniques can one day increase yields of northeastern Karnataka’s three major crops: rice, pigeon pea, and cotton.

Making progress on a pressing need

Precision agricultural techniques and concepts are urgently needed in India and other developing countries, Khosla says. Many nations struggle with low, stagnating, and declining crop yields—despite being heavy consumers of water, nitrogen, and other inputs. China and India are currently the world’s largest users of fertilizers, and developing nations as a whole consume 60 to 70% of global fertilizer supplies. Meanwhile, global nitrogen use efficiency hovers around 40%, suggesting that precision farming has a lot of potential to optimize inputs and boost yields in India and elsewhere.

Yet, until recently, most farmers in developing countries weren’t able to measure properties like plant nitrogen status, soil moisture, or electrical conductivity at all—much less map these parameters in fine detail within fields. Instead, they’ve made choices about where and when to spread fertilizers or seed based on differences in soils and plant growth that they can see by eye, as well as their historical knowledge of the land.

Now that precision farming tools and data are becoming available, however, the project’s participating farmers couldn’t be more enthusiastic about them, Patil says. After one local farmer used GPS to map the location of his farm, he asked his son to put the farm’s coordinates into Google Earth on a laptop. “They were so happy,” Patil says. “It was the first time they understood the location of their farm on the Google Earth image.”

Another farmer is so excited about the variability being revealed by grid sampling that he’s making a book of every 50 by 50 meter (150 by 150 ft) grid on his farm, including the nearly 50 observations that have been taken in each during the growing season.

During his time in Colorado, Patil learned that involving farmers from the start is critical to taking precision agriculture from research plots to actual farms because these early experiences build their confidence in the technology and begin showing them that farming can be done in a precise way. The project is already working with nearly 50 local farmers and has enrolled roughly 100 ac each of pigeon pea, cotton, and rice in its grid-based studies of soil properties.

Project scientists are also in the process of acquiring satellite imagery of all the project’s cropping areas. Once the images are in hand, the researchers will compare them against the actual crop growth on the ground to see

India CCA program showcased at International Conference on Women in Agriculture

By Saveen Randhawa, Program Manager-India CCA Program

On Mar. 13–15, 2012, the India CCA program had the opportunity to promote the value of certification at the International Conference on Women in Agriculture organized by the Indian Council of Agricultural Research (ICAR) and the Asia-Pacific Association of Agricultural research Institutions in Delhi. A lot of interest was shown in the CCA program by Krishi Vigyan Kendras (KVKs), ICAR, the Indian Agricultural Research Institute (IARI), NGOs, the Department of Agriculture, and international delegates. At this conference, the India CCA team got an opportunity to interact with important people in the agricultural sector such as Dr. Ayyappan (ICAR’s director general), Dr. Kokate (ICAR’s deputy director general for extension), and Dr. Arvind Kumar (ICAR’s deputy director general for education). We also had visitors from organizations like CIMMYT, ICRISAT, IFPRI, CARE, NDDB, and Monsanto at our booth. The goal was to increase the participation of women extension workers in the India CCA program.

[continued on p. 18]
Nitrogen (N) is the most limiting nutrient for crop production in humid temperate soils because crops require N more than any other element to achieve target yield. However, N use efficiency of most crops ranges from 20 to 60% with an average value of 50%. Nitrogenous fertilizer use efficiency seldom reaches 50% of the applied N, and in many circumstances, 80% of the N fertilizer is lost from the rhizosphere. Improving fertilizer use efficiency and minimizing the adverse impacts of N losses on the environment is critical for sustainable agriculture production systems. Denitrification loss of N in the form of N₂O gas is one of the major pathways to loss of applied fertilizer N. Moreover, N₂O as a greenhouse gas has a global warming potential that is 310 times higher than carbon dioxide, and agricultural soil management is responsible for more than two-thirds of N₂O emission in the U.S.

Denitrification is the biochemical reduction process during which N oxides, nitrate (NO₃⁻) and nitrite (NO₂⁻), are reduced sequentially through nitric oxide (NO) and nitrous oxide (N₂O) to release di-nitrogen gas (N₂) (Fig. 1). The denitrification process is mediated by the denitrifiers group of soil microorganisms. Denitrifiers are mainly heterotrophic bacteria, but some archaea and fungi are also reported to be capable of denitrifying. The activity of denitrifiers depends on (i) organic carbon (C) supply from crop residues, (ii) soil O₂ concentration/water-filled pore space, (iii) soil physicochemical properties, and (iv) soil management.

Organic carbon supply and crop residues

Denitrifiers depend on labile carbon compounds as electron donors for their metabolism. The quantity of organic compounds such as soil organic matter, root exudates, and manure and their relative position in the soil profile in relation to soil NO₃⁻ largely control the denitrification rate. However, under N-limited conditions such as after application of residues with a large C:N ratio, the denitrification rate is reduced due to immobilization of N, and simultaneous addition of N fertilizer with residue accelerates the N loss through denitrification. Quality or C:N ratio of the specific residue controls the decomposition rate and hence the C supply to denitrifiers. Moreover, the depth of residue incorporation is important, and subsoil incorporation has a greater positive effect on the denitrification rate than surface placement. In C-limited systems like arid soil, root exudates and root surface cells are critical in denitrification. Nitrate is leached into lower soil horizons, but the availability of C limits the denitrification in the subsoil.
Moreover, most denitrifiers live at the surface (0–2 inches), and numbers decline exponentially between 6 and 12 inches deep.

**Soil oxygen level and water-filled pore space**

Soil moisture controls the denitrification process through (i) maintaining soil microbial activity, (ii) reducing the oxygen supply level to microsites by filling pore space, (iii) transporting substrates to and away from the reaction site, and (iv) releasing C substrates through drying and rewetting phases. The oxygen level is critical for the synthesis and the activity of enzymes. Water-filled pore space is a better way to interpret the denitrification than moisture content, particularly when comparing among different soil textures. A water-filled pore space of 60% is the critical point for the optimum denitrification rate, and above 80%, most of the denitrification end products are dominated by N₂.

**Soil physicochemical environment**

**Soil pH:** Most denitrifying organisms thrive best in between pH 6 and 8, and the process is slightly favored by alkaline pH. Acidic pH reduces the availability of molybdenum, which is responsible for the synthesis of NO₃⁻ reductase, a molybdo-protein enzyme.

**Soil texture:** Soil texture controls the denitrification process through physical variations in water-filled pore space, aggregation, water infiltration rate affecting aeration, water holding/absorption capacity, and micro-environment. The direct relation between texture and denitrification is the water-filled pore space. However, the prediction of denitrification rate becomes complex due to interactions between different soil texture types and variability in soils’ inherent capacity to supply NO₃⁻ and metabolize organic residues.

**Soil temperature:** Like any other soil biological process, the denitrification rate is increasing with soil temperature from 59 to 95°F, but a rapid decrease is observed below 41°F and above 113°F.

**Soil management**

Among soil management practices, the release of N₂O is directly related to the amount of N added to soil in the form of fertilizer or any other means such as manure and crop residues (Fig. 1). Some portion of the added N always ends up in the formation of N₂O. Crops with a high N requirement like corn are subjected to have higher denitrification N loss potential than crops with a lower N requirement.

Management of fertilizer N input with the application of the right source at the right rate, time, and place can reduce N₂O emission. Use of at least 75% of N in the NH₄⁺ form will reduce the formation of N₂O from NO₃⁻ and/or the use of fertilizer additives to slow down the N release rate such as N inhibitors. Application of nitrification inhibitors with nitrogenous fertilizers reduces the nitrate loss through denitrification under sandy and poorly drained soils. Nitrapyrin, acetylenic, and phosphoramides are three common compounds used as nitrification inhibitors. Nitrapyrin is commercially available under the trade name of N-serve and Instinct, and the application rate varies from 0.5 to 1 lb/ac. Two weeks after application, nitrapyrin is generally degraded depending on soil type, organic matter content, and particularly soil temperature.

Application of N fertilizer should be based on the soil tests of pre-application soil N level and recommended dose of N. Additional reduction in the N application rate is also suggested if the crop follows a leguminous crop in the rotation. Precision N management to reduce the loss includes considering the spatial variability of N distribution at the landscape level. The fertilizer N use efficiency will be maximized when the application of fertilizer coincides with high plant N requirement. Required fertilizer N should be judiciously divided in between pre-planting application and post-emergence application at the growth stage with maximum N requirement. Surface broadcast application of N fertilizer is prone to loss, and deep placement at a soil depth below 4 inches is effective in some soil types.

Soil compaction and soil with poor drainage favor the denitrification process. In some cases, no-tillage practice under poorly drained soils may increase the denitrification rate during rainfall. The possible reason is attributed to higher water content in no-till soils within the mulch layer at the surface compared with tilled soil. No-tillage also results in the development of compaction zone under wheel track areas. Denitrifier populations are also higher at the surface of no-till soil than plowed soil. The rate of denitrification depends on the intensity of tillage, and the maximum loss of nitrogen through denitrification under no-tillage happens immediately after rainfall. Installation of subsurface-tile drainage may have the potential to reduce the excess moisture and keep soil at field capacity level. Conservation tillage can be followed in conjunction with water management practices such as tile drainage to reduce the chance of N₂O loss.

Emission of N₂O varies spatially and temporally and is hard to extrapolate. Research experiments based on the farm scale for multiple years of N₂O emission data will need to make a general consensus on the control of N₂O emission. Following precision N fertilizer management practices alone have the potential to reduce denitrification N loss to a great extent. However, we need to make the decision according to soil type, crop rotation, and weather pattern.
One of the most important soil amendments we buy regularly is lime. We add lime to the soil, from time to time to adjust the soil pH (an indexing method to express the relative level of soil acidity) and to add calcium and magnesium. We adjust the pH of the soil to make the soil acidity most hospitable for the plant roots of the species that we grow and manage it for optimum nutrient availability. Crop nutrients vary in their availability at different soil pH levels, and so we strive to maintain soil pH at the “sweet spot” so that we maximize available soil fertility. As well, some soil bacteria, necessary for the conversion of nitrogen in the air to plant-available forms, are sensitive to acid soils and prefer a soil pH between 6.0 and 7.0.

We frequently satisfy our perceived liming needs by telling the salesman to apply a ton of lime per acre, or we ask him to quote his price for a ton of lime and then compare his price (sometimes) to that of his competitor. When we make these rather arbitrary comparisons, we are assuming we know the characteristics and effectiveness of the products that we are comparing. Often, however, a ton of lime from one supplier is not the same as a ton of lime from another supplier. We need to be sure that we are comparing proverbial equals.

Like fertilizer, lime must have a label stating the chemical and physical characteristics of the product. These labels are available from the lime quarry or from the retail dealer. You should obtain a copy of the lime label from vendors that you use so that you can accurately determine how much lime is necessary and what available nutrients you are getting from a ton. By referring to the label, you can use vendors’ prices to accurately compare the liming and nutrient value of different products. Then, and only then, can you be sure that you are comparing products fairly. One liming product may cost more per ton but may be a more effective liming material, requiring less product per acre to obtain the same effect as a less expensive, but less effective, product.

Effective neutralizing value

Several characteristics are taken into account to determine the effective neutralizing value (ENV) of a liming material. They are total oxide content and fineness. In Maryland, both of these values should be listed on the...
lime label. Fineness is listed as the percentage of the product that passes through wire mesh screens of various sizes, such as 20, 60, or 100 wires per inch. Therefore, the ENV takes into account the total oxide content and the fineness in an equation to standardize the quality of a lime product so that different materials can be compared.

University of Maryland Extension’s Soil Fertility Management publication SFM-5 (http://anmp.umd.edu/files/SFM-5.pdf) has all of this information pertaining to calculating the ENV, as well as recommended application rate tables of total oxides necessary to adjust soil pH from the current value to a target value. These tables are specific to certain crops and locations throughout the state.

For example, if we are growing the typical corn–soybean–wheat rotation in an Eastern Shore field with a silt loam soil and the pH is 5.8, Table 2 from the SFM-5 publication tells us to apply 1,500 lb of total oxides per acre. Then we compare two lime products: Product A has a labeled ENV of 80, and thus we would recommend an application of 1,500/0.8, or 1,875 lb of this lime product per acre. Product B has an ENV of 70, and thus we would recommend an application of 1,500/0.7, or 2,142 lb of Product B per acre. Now let’s say that Product A has a price of $41/ton and Product B has a price of $38/ton. You can compare actual cost per acre to obtain the same liming effect. Using Product A will cost you $38.44/ac (1,875/2,000 × $41) while using Product B will cost you $40.70/ac (2,142/2,000 × $38). Now you can see that Product B, while less expensive by the ton, actually costs you more per acre than the “expensive” Product A to get the same liming effect. This $2/ac cost over several hundred acres adds up to a significant amount of money.

I know that this discussion may have been terribly confusing, and I have left out some minor points in writing it. But just remember not to judge limes until you know what you are comparing—they are not always the same. I encourage you to read the University of Maryland Extension publication SFM-5, written by Dr. Frank Coale, by visiting http://anmp.umd.edu/files/SFM-5.pdf. Please don’t hesitate to contact your local extension agent or me if you have questions.

Acknowledgements

I would like to thank Dr. Frank Coale, University of Maryland, for his help in editing this article.
Precision technology solutions
[continued from p. 11]

used with chemical application equipment for things like herbicide, fungicide, or growth regulators.

For about a decade now, harvest equipment like combines have had the ability to record yields throughout the field and create yield maps showing the range of low- and high-yielding areas. These are invaluable tools for us as professionals. These maps give us lots of data to target low-yielding areas and develop solutions for increasing their yield potential. Think of it as the answer to every management decision that you and your grower did that year.

Now moving into the future, we can make nutrient applications based on crop removal rates for things like potassium and phosphorus based on those exact yield maps. We simply apply higher amounts of nutrients to those areas that yield more and less to low-yielding areas. The challenge to this approach is that we still need some sort of soil sampling to find our exact soil needs. We also need multiple years of data to fine-tune those variable areas. These really start to solidify efficiency when we layer them on top of grid-sampled fertility maps. Combining these two pieces of precision agriculture together, we can target our fields into a zone-based approach.

Tying it all together

So as a whole, there are certain areas of precision agriculture that are specific to us. These precision agronomics are our future. When combined with our science-based recommendations and solutions, we can help our clients and growers make the most of their huge input costs and equipment purchases. This revolution of technology is not slowing down, nor is the need to maximize every acre we work with. Not every acre is the same, so why would we still treat them all that way when we have the tools to treat them all specifically with what they need? Environmentally, this all makes sense as well by limiting runoff and ground water pollution from overapplication.

The entire process of precision agronomic applications takes a multi-year approach to tie it all together. Equipment is ready, and most growers are ready to pull the trigger on most things mentioned throughout this article. Are we ready? Do we feel confident enough to climb into a $300,000 machine and upload a prescription? Can we show and train growers or operators how to utilize their equipment investment? We as CCAs, CPAg’s, agronomists, agrologists, and consultants will be the foundation for all of this technology-based application for the future. After all, every agronomic thing we do is touched by some sort of equipment...It is time to learn it!

Precision ag in India
[continued from p. 13]

“how the image tells the story” of what’s happening in the field, Patil says.

The next stage

Mapping variability is only the beginning, of course. The next step will be to apply fertilizers and other inputs according to location-specific conditions—a challenging proposition, Patil admits. Right now, the team adds fertilizers to the grids in study fields by hand, and many local farmers still spread fertilizers and harvest crops by hand, as well.

But mechanized paddy transplanters, small combine harvesters, and other machines are becoming much more common in Karnataka, Patil says. These technologies are still relatively expensive for Indian farmers, but the government offers subsidized loans to purchase farm machinery, and farmers also share the equipment willingly, just as they’ve shared labor in the past. When Patil explained to one farmer that a GPS unit cost 5 lakh rupees, or $10,000 U.S. dollars, for example, Patil thought the farmer would object to the price. “But immediately he said, ‘No, no, we’ll get it. We’ll share it among 10 farmers,’” Patil recalls. “‘We’ll get it if it is useful to us.’”

With Karnataka carved into so many tiny farms, cooperation will in fact be the key to success in precision farming, he adds. “A very wild ambition of this precision agriculture project is that in our fragmented farming community, the farmers will get together.” Already a precision farming cooperative is being planned for one regional crop, and other farmers outside the UAS project are expressing interest in precision farming practices, too.

In the meantime, the UAS College of Agriculture launched a Precision Agriculture Research Laboratory last December, with Khosla in attendance. Equipped with the latest tools—including Trimble GPS units, ArcGIS, ERDAS imaging software, Skype radiometers, and handheld sensors like the Greenseeker—the lab will offer a course in precision farming and host a series of trainings this year for faculty, students, and extension agencies, in addition to doing research.

While this rapid progress is encouraging, however, Patil cautions that the project doesn’t want to expand too quickly. It’s better to take the time to do things right. “Already other countries have spent 20 to 30 years doing precision agriculture, but we’re in the infancy,” Patil says. “So we want to understand, convince ourselves first, of what exactly is happening in the field.”
Handheld data collector

CAS DataLoggers has teamed with Lascar Electronics to offer customers a new accessory for its popular handheld data collector and programmer: Lascar’s Handheld DataPad. The EL-DataPad Protective Boot is said to protect the device from scratches and light knocks, making it even more suited to remote data collection in the field. The Handheld DataPad lets users quickly and easily configure all their EasyLog (EL) USB datalogger units, download data, and view logging results on the spot. The device enables continuous monitoring with negligible breaks in collecting data; displays onsite data collection presentation in graph, legend, and summary format; and lets users reconfigure their dataloggers while still in the field.

The EL-DataPad Boot is a rubber casing that fits tightly around the EL-DataPad to guard it against everyday wear and tear. Users simply slip the black cover over the handheld collector. Strategically placed openings in the boot allow regular use of the handheld data collector with a Lascar datalogger and connection to the computer using its mini USB cable.

For more information, visit www.DataLoggerInc.com or call 800-956-4437.

Spray tip

TeeJet Technologies says that its new AI3070 spray tip provides thorough plant coverage with minimal spray drift. This spray tip utilizes a patent-pending design that provides two spray patterns at angles of 30º forward and 70º rearward. The company says that the leading pattern provides good penetration into the foliage while the trailing pattern provides thorough coverage of the upper crop.

[continued on p. 21]
Adversity is a theme all too common in the world of farming. Growers are constantly faced with difficult challenges and must adapt to harsh Mother Nature. The Inland Pacific Northwest area is no exception. Conditions are volatile, and growers must be agile and quick to act. CCA Larry Hector assists with these challenges on a daily basis, relying on his experience and expertise to guide his clients in the right direction.

Hector grew up in Eureka, WA, where his parents owned a dryland wheat farm. Being raised on a farm left an impression on Hector, who moved to San Luis Obispo, CA in 1966 to attend Cal Poly. The Washington native graduated in 1970 with a major in agricultural economics and a minor in soil science. After graduation, he returned to Washington and began working for K2H Farms, an irrigated farm developed in the late 1960s using water from the Snake River. Hector would eventually manage the farm for eight years before leaving the company in 1988 to begin working with the McGregor Company.

After nearly 25 years, Hector is still with the McGregor Company, serving as an account manager for growers in the Touchet and Wallula areas. “Basically, I go out in the field and make recommendations regarding soil fertility, crop rotations, and herbicide and pesticide application,” says Hector, who serves more than 40,000 diverse acres of land in southeastern Washington.

Unusual conditions are the usual in this region, where decisiveness and experience are necessary in effectively helping farmers manage their crops. “Some of the growersLarry serves raise wheat on lands as arid as 6 to 10 inches of annual rainfall,” says James Fitzgerald, executive director of the Far West Agribusiness Association (FWAA). “Timing, careful stewardship of scarce moisture, cautious expense management, and budgeting—Larry does it all.”

A high-end fieldsman

Fitzgerald first noticed Hector after he was selected by the Northwest Certified Crop Adviser Regional Board as the 2010 Northwest Regional CCA of the Year. “As part of that process, I was able to review his credentials and then meet Larry at the ceremony,” Fitzgerald says. “His mannerisms are exactly what you’d expect from a high-end fieldsman.”

Fitzgerald was so impressed with Hector that he recommended that the FWAA president appoint him to serve as the chair of the FWAA Washington Committee, which he did. The position involves leading a team that reviews, recommends, and contacts speakers and presenters for FWAA conferences. As a result of his preparation and efficiency, Fitzgerald says they had a record number of attendees at last December’s conference.

Hector’s professionalism and preparation extend from the office to the field. On average, he serves approximately 25,000 ac of dryland farms and 15,000 ac of irrigated farms annually. Juggling these diverse farming conditions is a difficult task, but Hector has shown he’s up to the challenge. He credits the CCA program for helping him become the crop adviser he is today.

After passing the national CCA exam in 1993, Hector became certified in 1994 by passing his state’s exam. He says he has seen the program constantly evolve since he joined nearly 20 years ago. “It’s taken on more of a professional tone. I think the standards have been improved since the beginning.”

Some of the program’s improvement can be credited to Hector himself, who served on the CCA National Committee for four years. “The exam questions have been refined and have really begun to test a person’s in-field knowledge, rather than just academic, book-type information,”

Correction: We wish to report an error on p. 25 of the March–April 2012 issue of Crops & Soils magazine. In the sentence, “On the average, band P and K application rates can be reduced 5% compared with broadcast,” “5%” should have read “50%.” We regret the error.
canopy and grain head. The AI3070 incorporates air induction technology to minimize spray drift while producing a large percentage of droplets in the medium to coarse category to maximize surface coverage.

The AI3070 was designed specifically for fungicide application in cereal crops. “The prevalence of Fusarium in wheat and other cereal crops makes this an ideal nozzle for small-grain producers,” states Tim Stuenkel, marketing manager at TeeJet Technologies. “The AI3070 is designed to maximize the efficacy of a grower’s fungicide application, which contributes to higher yields and a higher quality grain sample.”

The AI3070 comes in six VisiFlo color-coded sizes from –015 to –05 capacities. It is constructed of acetal (polymer) with a recommended operating range of 20–90 psi.

For more information, see www.teejet.com or call 630-665-5000.

Hector says. “I think the program feels like it's becoming self-regulated, and a lot of pride is taken in the standards associated with becoming a CCA.”

While Hector is happy with the direction of the CCA program, he says that inspiring youth to consider a career in agriculture has become an increasingly difficult challenge. “I think we’ve seen the young generation shy away from farming,” Hector says. “A lot of areas don’t have anyone coming up to take over what is the heritage of the land.”

Still, he says that many of the young farmers that do stick around to take over their family’s land are in tune with modern technology, bringing a real advantage to the future of agriculture.

After more than 30 years of crop advising experience, Hector has seen agriculture evolve through technological advancements and a better understanding of the environment. Yet some aspects of the industry have remained constant.

“If you’re going to be a CCA and work with growers, you must be ethical and honest,” he says. “Your word has to be worth something, and you better be able to stand behind it.”

New products
[continued from p. 19]

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P and K fertilization do not affect soybean storability

A pressing question for the seed industry today is whether fungicide-treated soybean seeds can maintain viability and vigor after being stored for a year. During storage in dealers’ warehouses and farmers’ storage sheds, treated seeds may be exposed to fluctuating temperature and relative humidity conditions that cause them to lose their germination potential and vigor.

In the past, returned, untreated soybean seed was quickly sold in the commodity market, but today, seed companies must pay a high cost for disposing treated soybean seed in an environmentally safe way. The need to do so has sparked renewed interest in finding ways to store treated soybean seed so that it remains viable until the next growing season. Farmers’ demand for fungicide-treated soybean seed grew from less than 8% treated soybeans in 1996 to more than 30% in 2008 (Munkvold, 2009), and the trend is expected to continue.

In the March–April 2012 issue of Agronomy Journal, researchers investigated the germination and vigor of soybean seeds produced by plants that were fertilized with different rates of phosphorus (P) and potassium (K) fertilizer and stored under optimum and stressful storage conditions. These two nutrients were chosen because P and K are vital for normal cell function in seeds.

The results demonstrate that after 13 months of storage, soybean seeds lost their germination and vigor even further. However, K fertilization did maintain good soybean seed germination and vigor for six months in stressful storage environments, while P did not.

In 2011, the U.S. soybean seed industry produced and conditioned more than 94 million soybean seed bags. This number already includes an additional 10% for distribution excess, seed returns, and replants. Consequently, the authors speculate that one or two million bags of treated soybean seed could be returned to seed companies for disposal. Prolonging the seed germination and vigor of soybean seed in storage could reduce the need to dispose of seed.

The findings from this research also are important to crop protection chemical companies because seed treatments are one of the fastest-growing segments of the crop protection market. According to MarketsandMarkets.com (2010), the predicted global seed treatment market for 2016 is $3.4 billion, an increase from $2.23 billion in 2010.

References

We have just launched a new CCA blog at www.certifiedcropadviser.wordpress.com. We know many CCAs use social media—Facebook, LinkedIn, Twitter, etc.—and we know CCAs are mobile and probably access the majority of their information through their smartphone. Currently, there are some websites for CCA boards or discussions, but nothing is interconnected very well. We hope to connect all of them and expand what is being offered. We want it to be dynamic and become a valuable resource for you.

The blog will feed all of the outlets and allow you to comment or have discussions with other CCAs. You won’t need to keep up on all of them—just your favorites. It will focus on CCA program information, agronomy, and other issues that may impact you as a CCA and/or your customers. We will try to stay away from things that are already being covered by other sources or can get too emotionally charged. It will be kept at the professional level with information that will help you in what you do every day as a CCA.

Now you have the opportunity to discuss agronomy issues with other CCAs from your county, state/province, country, and all around the world! Maybe the problem you are working on was already solved by a CCA in another part of the world or just down the street. The infrastructure we will be creating will allow that interaction to take place.

The blog will allow you to create your own small groups while remaining connected to the larger, international aspects of the program. You’ll be able to share information, comment on posts, solve problems, and gain new knowledge. Your responses will guide future program benefits and the development of educational programs that are important to you.

You can let me know what you think by going to www.certifiedcropadviser.wordpress.com.

CCA marketing

The new CCA marketing web pages are up and ready for your use at www.Thatssoundadvice.com. The information is customized based on the audience that is identified by the user—farmers, CCAs, and employers, and there are tools that CCAs can use to promote themselves to their clients and customers. So take a few minutes to see what is there and put it to use.

CPAg credentials

As of the beginning of this year, CPG is now a specialty certification as part of the International CCA program infrastructure. If you are a CCA with at least five years of experience and a minimum of a B.S. degree in agronomy or a very closely related field, you might want to investigate adding CPG to your credentials.

CCA app

Coming this fall, we will be releasing the CCA app that will allow you to report your CEUs via your smartphone. No more sign-in sheets (well not completely, we will still have sign-in sheets for those who do not have a smartphone) and waiting for the vendor to send it to ASA and then ASA to enter it into your account. Hopefully, it will streamline the reporting process. It will also eliminate the need for scanning your CCA card and the additional equipment at the site to record your attendance. The sign-in sheets will give you the option to scan the QR code with your phone or sign the sheet.

Check out the new CCA blog at www.certifiedcropadviser.wordpress.com
Newly certified

The following list includes newly certified individuals and those who have added additional certifications since the last issue of *Crops & Soils* magazine. This list is alphabetized by surname within each state/province.

**Canada**

**Alberta**
- Clark, Neil, East Coulee, AB (CCA-PP)
- Uchikura, Gary, Taber, AB (CCA-PP)
- Visser, Daniel, Neerlandia, AB (CCA-PP)

**Manitoba**
- Baron, Thomas, Carberry, MB (CCA-PP)
- Falk, Donald, Winkler, MB (CCA-PP)

**Prince Edward Island**
- Proctor, William, Charlottetown, PE (CCA-AP)

**United States**

**Alabama**
- Bishnoi, Udai, Normal, AL (CCA-RET, CPAg-RET)

**Arkansas**
- Kildow, Derek, Pocahontas, AR (CCA-AR)

**California**
- Aguilar, Luis, Santa Maria, CA (CCA-CA)
- Laux, Dennis, Porterville, CA (CCA-CA)
- Martin, Gerald, Fresno, CA (CCA-CA)
- Miller, Nathaniel, Philo, CA (CCA-CA)
- Morgan, Eric, Lockwood, CA (CCA-CA)
- Porter, Ashley, Madera, CA (CCA-CA)
- Robledo, J. Daniel, Napa, CA (CCA-CA)

**Florida**
- Yonce, Henry, Deland, FL (CCA-FL)

**Georgia**
- Smith, Kevin, Dublin, GA (CPSS)

**Iowa**
- Hennings, Jameson, Hartley, IA (CCA-IA)
- Lackore, Anthony, Renwick, IA (CCA-IA)
- Ness, Brent, Williamsburg, IA (CCA-IA)
- Schmitt, Gregory, Nora Springs, IA (CCA-IA)
- Tweet, Karen, Wellsburg, IA (CCA-IA)
- Wells, Nathan, Williamsburg, IA (CCA-IA)

**Illinois**
- Baer, Kerry, Pekin, IL (CCA-IL)
- Frazee, Robert, Henry, IL (CCA-RET, CPAg-RET)
- Hocking, Philip, Mount Carmel, IL (CCA-IL)
- Lower, Jonathon, Mount Carroll, IL (CCA-IL)
- Moritz, Justin, Herscher, IL (CCA-IL)
- Wassmann, Matthew, Princeton, IL (CCA-IL)
- Weller, Lawrence, Bloomington, IL (CCA-RET, CPAg-RET)
- Wyss, John, Bourbonnais, IL (CCA-IL)

**Indiana**
- Sullivan, Raymond, Shelbyville, IN (CCA-RET, CPAg-RET)

**Kansas**
- Fenderson, Travis, Garden City, KS (CCA-IA)

**Montana**
- Pink, Trudy, Miles City, MT (CPSS)

**Nebraska**
- Oltmans, Craig, Holdrege, NE (CCA-NE)

**New York**
- Owens, Donald, East Aurora, NY (CPSS)
- Slezak, Joseph, Voorheesville, NY (CCA-NR)

**Oregon**
- Scoles, Philip, Portland, OR (CPSS)

**Pennsylvania**
- Russick, Max II, East Greenville, PA (CPSS)

**Tennessee**
- Dickerson, Phillip, Hartsville, TN (CPSS)
- Donoho, Michael, Hendersonville, TN (CPSS)

**Washington**
- Jansen, Nicole, Pasco, WA (CCA-NW)

**Wisconsin**
- Bernstein, Naomi, Marshall, WI (CCA-WI)
- Durward, Eric, Arlington, WI (CCA-WI)
- Evans, Scott, Marshfield, WI (CCA-WI)
- Nitzel, Dennis, Rhinelander, WI (CCA-RET)
- Ritter, Harold, Delavan, WI (CCA-RET)
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
Corn is the most valuable crop produced in the U.S., with a value of $67 billion. Soil conservation efforts by corn farmers have reduced soil losses over the past 20 years, with 21% of the U.S. corn under no-till production practices and an additional 18% being mulch-tilled. In these conservation tillage systems, retention of surface residues plays an important role in reducing soil erosion by physically protecting against soil particle detachment, increasing water infiltration rates, and reducing runoff rate and volume, whereas less intensive tillage systems reduce the occurrence of mechanical and physical soil movement and organic matter degradation.

Nearly 97% of corn in the U.S. is treated with herbicide annually, irrespective of the tillage system. Reduced-tillage corn production systems are particularly reliant on herbicides because mechanical weed control options are typically not available. Overreliance on herbicides can lead to the development of herbicide-resistant weed communities and contribute to non-point source contamination of surface and ground waters. New herbicide-resistant weed communities limit the efficacy of important herbicide modes of action, and non-point contamination of water resources can have negative impacts on aquatic ecosystems and human health and may draw further regulatory scrutiny to herbicides.

Glycine (e.g., glyphosate), photosystem II inhibitors (e.g. atrazine and simazine), and chloroacetamide (e.g., metolachlor and acetochlor) herbicides are among the most widely used in corn. Glyphosate initially served primarily as a non-selective “burndown” herbicide to control unwanted vegetation before planting, replacing the need for primary and secondary pre-plant tillage. With the development of glyphosate-resistant corn hybrids, the use of glyphosate has increased substantially in corn. Although the risk of chronic health hazards associated with glyphosate is considered to be quite low and it is not considered a major contaminant of water resources, heavy reliance on glyphosate has led to the development of resistant weed populations. In corn production systems, resistance evolution of Amaranthus and Ambrosia species is a concern.

The evolution of glyphosate-resistant weeds is likely to increase dependence on other herbicides, particularly in the photosystem II and chloroacetamide herbicide families. Weeds resistant to the photosystem II inhibitors are quite common in corn and other production systems, but resistance is relatively rare with the chloroacetamide herbicides (five species reported). Herbicides with both of these modes of action, however, are frequently detected in surface and ground water sources in agricultural regions of the U.S. although the cumulative risks associated with the photosystem II herbicides were found to be below the Food Quality Protection Act regulatory level of concern in a 2006 review. A re-evaluation of the health risk associated with these herbicides is currently under way. Valuable herbicide activities may be lost due to the evolution of resistant weeds and/or regulatory action, resulting in fewer weed control tools available for farmers.

Mechanical weed control implements designed to operate under high-residue conservation tillage conditions have been developed and are commercially available. However, limited objective information exists to support...
the use of these tools in no-till or reduced-tillage production systems. The implements of interest in this research include: (i) vertical coulters, (ii) rotary harrows, (iii) high-residue rotary hoes, and (iv) high-residue row cultivators. The vertical coulter is a relatively new implement used to size crop residues, aerate the soil, and increase soil temperatures in the upper soil surface before planting. The vertical coulter alone provides very little weed control but may increase the efficacy of other implements by providing a friable soil surface. The rotary harrow is a full-width tillage implement with numerous rigid tines arranged in a cylinder that rolls over the soil surface, evenly distributing crop residues and uprooting small weeds. A combination tool (e.g., Turbo-Till by Great Plains Manufacturing, Inc., Salina, KS), equipped with vertical coulters trailed by rotary harrow units, allows for a one-pass operation. The high-residue rotary hoe is a modified version of a standard rotary hoe designed for high-residue environments with greater clearance for residue flow due to increased distance between the front and rear wheels. The rotary hoe is a full-width blind cultivation tool that is used before or after crop emergence. Although there have been no results reported for high-residue rotary hoe performance in no-till corn to our knowledge, poor weed control performance was reported in no-till soybeans, and modest weed control performance was reported in no-till wheat. High-residue inter-row cultivators are also commercially available and are basically modified versions of a standard inter-row cultivator designed to handle high-residue and no-till conditions.

In a recent study published in Agronomy Journal, researchers set out to develop integrated weed and crop management strategies for conservation tillage corn that are less reliant on herbicides through the evaluation of individual and multiple mechanical implements in combination with select herbicide programs. Specifically, this study evaluated: (i) mechanical tools with and without herbicides on weed management and corn yields in high-residue corn; (ii) the impact of the mechanical implements on surface residue cover; and (iii) the economic outcome of these weed management options. Within these objectives, the researchers developed six hypotheses:

1. The combination of the vertical coulter/rotary harrow would provide weed control comparable to a burndown herbicide program.

2. Two to three passes of the rotary hoe would provide equivalent weed control to a broadcast soil-applied residual herbicide.

3. The inter-row cultivator would provide between-row weed control comparable to soil-applied or post-emergence herbicides.

4. Banded pre-emergence residual herbicides would improve weed control over the cultivator alone by providing in-row weed control.

<table>
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<th>Broadcast</th>
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<td>VC/RH + BDCST Pre</td>
<td>×</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>VC/RH + Hoe + Post</td>
<td></td>
<td></td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Burn down + Hoe + Cult</td>
<td>×</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>VC/RH + Hoe + Cult (Banded Pre)</td>
<td></td>
<td></td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>VC/RH + Cult (Banded Pre)</td>
<td></td>
<td></td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>VC/RH + Hoe + Cult</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>VC/RH + Cult</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Weedy check</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Herbicide applications were made to treatments indicated by an “X.”
‡ BDCST Pre = broadcast pre-emergence herbicide program; Cult = high-residue cultivator; VC/RH = vertical coulter/rotary harrow; Hoe = high-residue rotary hoe; Post= postemergence herbicide program; Banded = banded pre-emergence herbicide program.
5. Adequate (i.e. \( \geq 30\% \)) surface residue cover would be maintained in the various tillage systems.

6. The agronomic and economic feasibility of the non-chemical weed control systems would be a function of the base weed density.

This research was conducted on The Pennsylvania State University Agronomy Farm at the Russell E. Larson Agricultural Research Center. Cumulative growing degree days (GDD) were calculated using a base of 50°F and maximum of 86°F from April 1 to harvest. The study contained 10 treatments consisting of combinations of the tillage operations and herbicide programs (Table 1). Conventional no-till (Treatment 1) served as a control or standard treatment to represent an herbicide-based weed control program commonly used in the region. Seeds of weeds common in the region such as giant foxtail, common lambsquarters, a complex of smooth and redroot pigweed (pigweed hereafter), horseweed, and common ragweed were broadcast on the soil surface by hand. The weed seeds were collected from local populations in the same fall that they were distributed. The weed seed densities supplemented in this experiment are considered high relative to the resident weed seed bank and were established to ensure that adequate weed populations were present to effectively evaluate the different weed control treatments. The area outside of the subplots having this relative low weed seed bank will hereafter be referred to as the “resident weed density.”

Discussion

Corn populations varied between the study years, and there was some evidence that they were decreased by some of the mechanical weed control operations. The lower corn population in 2008 compared with 2009 may have been a result of the cool and wet conditions in early May of 2008, followed by a prolonged dry period after planting. Surface crusting was evident (visual observations), and the first rotary hoe operation before crop emergence did not appear to alleviate those conditions. Although one of the primary purposes of the rotary hoe is to increase crop populations by breaking soil crusts, this may not be feasible in some no-till soils, even with additional down pressure added to the rotary hoe in this study. The 8% reduction in corn population from the combination of the rotary hoe plus the high-residue cultivator is partially
consistent with results from other studies. Inter-row cultivation using a Danish S-tine style in conventional tillage systems or a shielded high-residue cultivator in reduced-tillage systems was reported to not produce a measurable reduction in corn populations compared with no-till systems. Minimizing crop damage from inter-row cultivation can be achieved by coupling an experienced operator with cultivation aids such as shield and/or automatic guidance systems. Automatic guidance systems also facilitate faster operating speeds, which will reduce operation costs associated with cultivation but may increase soil movement that could result in crop injury.

The hypothesis in this study that the mechanical-intensive weed control systems would maintain surface residue cover to acceptable (i.e. >30%) levels for soil conservation purposes was partially rejected. Residue cover in systems that included the high-residue cultivator tended to be somewhat below 30%, whereas systems relying on the vertical coulter/rotary harrow were above 30% residue cover. Because soil inversion is nominal with the

tillage implements used in this study, the lower levels of residue observed with these implements may be the result of reducing the residue size to smaller than the small diameter minimum required under the line transect method and/or redistribution of the residue on the surface from the inter-row into the crop row with the cultivator. Although residue cover is an important regulator of soil erosion potential, other factors influenced by the cropping and tillage systems in this study would also play a role in determining if soils are prone to erosion. Rapid crop development occurring at the V6 crop growth stage when the cultivation was conducted would help buffer the reduction in residue cover that accompanied cultivation, whereas cultivation will likely improve the infiltration potential of the soil by increasing surface roughness compared with untilled soil. To thoroughly evaluate the erosion potential of a system, factors such as compaction from additional trips across the fields in the tillage-intensive system, slope of the terrain, and intensity of the rainfall event also need to be considered.

The weed emergence data in this study indicate that the pre-plant weed control from the vertical coulter/rotary harrow system was similar to the glyphosate-based burndown herbicide program, suggesting that this tillage system may be a viable substitute to control small annual weeds before planting in reduced-tillage systems at a cost that is comparable to custom burndown herbicide programs. Such an approach would reduce the burndown herbicide-based selection pressure on weed populations and thereby help slow the development of herbicide-resistant weed communities. Although not evaluated in this study, the researchers did not expect the vertical coulter/rotary harrow system to be sufficiently aggressive to control established perennial weeds. There was also no evidence to support the hypothesis that the pre-plant vertical coulter/rotary harrow operation caused a disturbance-induced weed emergence flush that could be controlled by the subsequent tillage operations or herbicides and ultimately contribute to a decline in the soil seed bank populations. These data were supported by soil temperature data (2008 only) that indicated no detectable difference in soil temperatures among the tillage regimes.

Table 2. Mean weed biomass for the high-density and resident-density plot areas by treatment in 2008 and 2009. Means followed by the same letters are not significantly different at $p < 0.05$ according to a least squared means test.

<table>
<thead>
<tr>
<th>Treatment†</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High density</td>
<td>Resident density</td>
</tr>
<tr>
<td>1. Conventional no-till</td>
<td>306 d</td>
<td>23 b</td>
</tr>
<tr>
<td>2. BDCST Pre + Cult</td>
<td>113 d</td>
<td>36 b</td>
</tr>
<tr>
<td>3. VC/RH + BDCST Pre</td>
<td>256 d</td>
<td>61 b</td>
</tr>
<tr>
<td>4. VC/RH + Hoe + Post</td>
<td>10 d</td>
<td>1 b</td>
</tr>
<tr>
<td>5. Burn down + Hoe + Cult</td>
<td>3,882 b</td>
<td>744 b</td>
</tr>
<tr>
<td>6. VC/RH + Hoe + Cult (Banded Pre)</td>
<td>1,166 d</td>
<td>240 b</td>
</tr>
<tr>
<td>7. VC/RH + Cult (Banded Pre)</td>
<td>1,706 cd</td>
<td>335 b</td>
</tr>
<tr>
<td>8. VC/RH + Hoe + Cult</td>
<td>3,393 bc</td>
<td>1,792 ab</td>
</tr>
<tr>
<td>9. VC/RH + Cult</td>
<td>4,726 b</td>
<td>1,641 ab</td>
</tr>
<tr>
<td>10. Weedy check</td>
<td>8,511 a</td>
<td>3,510 a</td>
</tr>
</tbody>
</table>

† BDCST Pre = broadcast pre-emergence herbicide program; Cult = high-residue cultivator; VC/RH = vertical coulter/rotary harrow; Hoe = high-residue rotary hoe; Post = postemergence herbicide program; Banded = banded pre-emergence herbicide program.
Multiple rotary hoe operations significantly reduced weed densities in 2008 by 39 to 57% compared with non-hoed systems with similar pre-plant weed control regimes, but not in 2009. In 2008, the weed control achieved with the multiple rotary hoe operations was similar to that achieved with the broadcast pre-emergence residual soil-applied herbicide program under the resident weed densities but significantly lower than the broadcast residual herbicides under high weed densities. These results suggest that the rotary hoe may be most effective under a reduced tillage condition when weed densities are relatively low. Although the rotary hoe operations were relatively inexpensive compared with the broadcast pre-emergence residual herbicide program, the inconsistent weed control achieved with the rotary hoe coupled with the additional management constraints associated with this implement (i.e., proper timing relative to rainfall events, requirement of multiple passes, etc.) limit its utility in conservation tillage systems that lack any primary tillage. Based on the personal experience of the authors, they speculate that the weed control performance of the rotary hoe may be better when used in soils that are more friable than the Hagerstown silt loam soil in the current study.

The high-residue cultivator significantly reduced weed density relative to the weedy treatment in 2009, but not in 2008. In 2009, weed density in the cultivated systems was further reduced by approximately 50% by the inclusion of the banded pre-emergence residual herbicide program. Averaged over both weed densities and study years, the high-residue cultivator reduced weed biomass 53% without the banded herbicide and 88% when combined with banded herbicide relative to the weedy check treatments (Table 2). The best overall weed control, however, was typically achieved with the herbicide-intensive treatments with over a 98% reduction in weed biomass compared with the weedy check treatments. These results agree with a previous study showing that the high-residue cultivator (with and without other mechanical weed control operations) is not consistently equivalent to herbicide-intensive systems and will likely need to be supplemented with additional management tactics.

In this study, the systems that integrated the banded pre-emergence residual herbicide with the high-residue cultivator (Treatments 6 and 7) did have somewhat lower yields than the herbicide-intensive systems (Table 3, Treatments 1, 3, and 4), but comparable net returns at the resident weed densities in 2008 and the pooled weed densities in 2009 (Table 4). The productivity of these integrated systems (Treatments 6 and 7) was achieved with a 60% reduction in soil residual herbicide active ingredients and is consistent with previous reports. The addition of the vertical 1 coulter/rotary harrow operations allowed the researchers to further reduce reliance on burndown herbicides achieving a 70% reduction in herbicide. Applying the residual soil-applied herbicides in a 30-cm band over the crop row rather than as a broadcast application should reduce herbicide-based selection pressure on the weed community and thereby slow the proliferation of herbicide-resistant weeds as well as reduce the leaching potential of these herbicides.

Under the tillage regimes tested in this study, the hypothesis that it would be feasible to adequately control weeds with only mechanical operations was not supported by the weed control, crop productivity (Table 3), or net return data (Table 4). The net return data underscore the importance of high crop productivity coupled with strong commodity prices in the profitability of corn production in the northeastern region of the U.S. Production costs were largely a function of differential reliance on labor, machinery, and herbicides among the systems. Oppor-

### Table 3. Corn grain yield by weed control treatment and weed density area in 2008 and by weed control area pooled over weed density areas for 2009. Means followed by the same letters are not significant difference at $p < 0.05$ according to a least square means test.

<table>
<thead>
<tr>
<th>Treatment †</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High density</td>
<td>Resident density</td>
</tr>
<tr>
<td>1. Conventional no-till</td>
<td>8,945 a</td>
<td>8,489 ab</td>
</tr>
<tr>
<td>2. Herbicides + Cult</td>
<td>8,592 a</td>
<td>8,437 ab</td>
</tr>
<tr>
<td>3. VC/RH + Herbicides</td>
<td>8,710 a</td>
<td>8,540 ab</td>
</tr>
<tr>
<td>4. VC/RH + Hoe + Post</td>
<td>8380 a</td>
<td>8,825 a</td>
</tr>
<tr>
<td>5. Burn down + Hoe + Cult</td>
<td>5,220 bc</td>
<td>7,680 abc</td>
</tr>
<tr>
<td>6. VC/RH + Hoe + Cult (Banded)</td>
<td>7,007 ab</td>
<td>7,835 abc</td>
</tr>
<tr>
<td>7. VC/RH + Cult (Banded)</td>
<td>6,908 ab</td>
<td>7,897 abc</td>
</tr>
<tr>
<td>8. VC/RH + Hoe + Cult</td>
<td>4,687 bc</td>
<td>6,526 bcd</td>
</tr>
<tr>
<td>9. VC/RH + Cult</td>
<td>3,860 cd</td>
<td>6,305 cd</td>
</tr>
<tr>
<td>10. Weedy check</td>
<td>1,334 d</td>
<td>4,765 d</td>
</tr>
</tbody>
</table>

† BDCST Pre = broadcast pre-emergence herbicide program; Cult = high-residue cultivator; VC/RH = vertical coulter/rotary harrow; Hoe = high-residue rotary hoe; Post = postemergence herbicide program; Banded = banded preemergence herbicide program.
tunities associated with the different implements need to be considered along with the aforementioned long-term effects on system productivity, herbicide resistance, and soil/water conservation benefits or detriments.

Conclusions

Overall, mechanical tillage implements alone did not provide adequate weed control, whereas integration of these implements with reduced herbicide inputs showed potential to provide comparable weed control, crop yields, and net economic returns as the herbicide-intensive systems. The vertical coulter/rotary harrow combination did reduce surface residue cover but provided weed control that was similar to the burndown herbicide program. The high-residue rotary hoe had a nominal effect on surface residue cover but did not provide consistent weed control to merit the multiple passes in the field that this implement required. The high-residue cultivator caused the greatest reduction in surface residue cover but provided the greatest level of weed control. Integrating the vertical coulter/rotary harrow operations with banded residual herbicides and one to two passes of the high-residue cultivator appears to provide consistent weed control and comparable agronomic productivity to the herbicide-intensive systems with a 70% reduction in herbicide inputs. Such integrated systems, however, will require more complex management implementation and flexible labor availability than conventional herbicide-based management systems, which may hinder the adoption of these alternative systems.

May–June 2012
self-study quiz

Integrating mechanical and reduced-chemical weed control in conservation tillage corn (no. SS 04262)

1. Reduced-tillage corn production systems are particularly reliant on herbicides because
   □ a. mechanical weed control options are too expensive.
   □ b. mechanical weed control options are too time intensive.
   □ c. mechanical weed control options are typically not available.
   □ d. mechanical weed control options do not work.

2. In corn production systems, resistance evolution of
   □ a. *Amaranthus* and *Ambrosia* species is of concern.
   □ b. *Setaria* and *Chenopodium* species is of concern.
   □ c. redweed and horseweed is of concern.
   □ d. giant foxtail and common lambsquarters is of concern.

3. Which mechanical weed control implement was NOT discussed in this article?
   □ a. Rotary harrows.
   □ b. Vertical coulters.
   □ c. High-residue row cultivators.
   □ b. High-residue tiller-harrows.

4. Data in this study suggest that the vertical coulter/rotary harrow system may be a viable substitute to control small annual weeds before planting in reduced-tillage systems at a cost that is
   □ a. comparable to custom burndown herbicide programs.
   □ b. significantly less than custom burndown herbicide programs.
   □ c. comparable to high-residue row cultivators.
   □ d. significantly less than high-residue row cultivators.

5. Which of the following was NOT listed in the article as something that limits the utility of the rotary hoe in conservation tillage systems that lack any primary tillage?
   □ a. The additional equipment required.
   □ b. Requirement of multiple passes through the field.
   □ c. Need for proper timing relative to rainfall events.
   □ d. Inconsistent weed control.

6. Under the tillage regimes tested in this study, the hypothesis that it would be feasible to adequately control weeds with only mechanical operations was
   □ a. supported by the weed control and crop productivity data, but not by the net return data.
   □ b. supported by the weed control data, but not by the crop productivity or net return data.
   □ c. not supported by the weed control, crop productivity, or net return data.
   □ d. supported by the weed control, crop productivity, and net return data.

7. Averaged over both weed densities and study years, the high-residue cultivator reduced weed biomass
   □ a. 35% when combined with banded herbicide and 58% when combined with the rotary hoe relative to the weedy check treatments.
   □ b. 53% when combined with the rotary hoe and 88% when a pre-emergence residual herbicide was used relative to the weedy check treatments.
   □ c. 35% with the broadcast herbicide and 58% with the banded herbicide relative to the weedy check treatments.
   □ d. 53% without the banded herbicide and 88% when combined with banded herbicide relative to the weedy check treatments.

Quiz continues next page
8. According to the study, the rotary hoe may be most effective
   □ a. under a reduced-tillage condition when weed densities are relatively low.
   □ b. under a high-residue condition when weed densities are relatively high.
   □ c. under a one-pass system when soils are relatively dry.
   □ d. under conditions where soils are less friable than the Hagerstown silt loam soil.

9. The vertical coulter/rotary harrow combination
   □ a. reduced surface residue cover and provided weed control that was better than the burndown herbicide program.
   □ b. reduced weeds and provided surface residue cover that was similar to the burndown herbicide program.
   □ c. increased surface residue cover and provided weed control that was better than the burndown herbicide program.
   □ d. reduced surface residue cover but provided weed control that was similar to the burndown herbicide program.

10. According to the article, before widespread adoption can occur, integrated systems such as the vertical coulter/rotary harrow with banded residual herbicides and one to two passes of the high-residue cultivator will require
    □ a. more complex management implementation and flexible labor availability.
    □ b. improved weed reduction results and a greater reduction in herbicide inputs.
    □ c. commercially available machinery that is less labor intensive.
    □ d. improved yield results and a reduction in the cost of the machinery.

Self-Study Quiz Registration Form

Name: ____________________________  City: ____________________________
Address: ____________________________  Zip: ____________________________
State/province: ____________________________  CCA certification no.: ____________________________
☐ $20 check payable to the American Society of Agronomy enclosed.
☐ Please charge my credit card (see below)
Credit card no.: ____________________________  Name on card: ____________________________
Type of card:  ☐ Mastercard  ☐ Visa  ☐ Discover  ☐ Am. Express
Expiration date: ____________________________
Signature as it appears on the Code of Ethics: ____________________________

I certify that I alone completed this CEU quiz and recognize that an ethics violation may revoke my CCA status.

This quiz issued May 2012 expires May 2015

Self-Study Quiz Evaluation Form

Rating Scale: 1 = Poor  5 = Excellent

Information presented will be useful in my daily crop-advising activities: 1 2 3 4 5
Information was organized and logical: 1 2 3 4 5
Graphics/tables (if applicable) were appropriate and enhanced my learning: 1 2 3 4 5
I was stimulated to think how to use and apply the information presented: 1 2 3 4 5
This article addressed the stated competency area and performance objective(s): 1 2 3 4 5

Briefly explain any “1” ratings: ____________________________

Topics you would like to see addressed in future self-study materials: ____________________________
Summer cover crops fix nitrogen, increase yields, and improve soil–crop relationships

Earn 1 CEU in Crop Management by reading this article and completing the quiz at the end. Fill out the attached questionnaire and mail it with a $20 check (or provide credit card information) to the American Society of Agronomy. Or, you can save $5 by completing the quiz online at www.certifiedcropadviser.org/certifications/self-study.

Cover crops provide additional biomass input, reduce soil erosion, and promote nutrient cycling, but their impacts on subsequent crop yields and quantitative relationships with soil properties such as physical properties deserve further scrutiny. Because performance of cover crops may vary with crop type, soil type, tillage management, and climate, a site-specific assessment of soil–crop relationships under different cover crops is warranted.

Cover crops may or may not increase yields of subsequent crops. Their impact on subsequent crop yields and soil properties most likely depend on precipitation input, species, growing season (summer vs. winter crops), amount of biomass return, tillage management, and length of cover crop management. Under favorable climatic conditions, high-biomass-producing and high-N-fixing summer or tropical legume cover crops such as sunn hemp may have more rapid and greater effects on increasing crop yields and improving soil properties than crops with low biomass input.

Because of high biomass input, summer legumes can provide an effective protective cover to soil and supply significant amounts of N to subsequent crops. Reports of high biomass production, and subsequent increased corn yields, by sunn hemp have been published, and more studies along these lines are needed to better understand summer cover crop effects.

Research has shown that summer legume crops such as sunn hemp and late-maturing soybean, when used as summer cover crops, reduced soil’s susceptibility to compaction and increased wet aggregate stability, water infiltration, earthworm population, and soil organic carbon concentration. These cover crop-induced changes in soil properties may also benefit yields of subsequent crops. While cover crops may not always increase crop yields and improve properties in all soils, some have hypothesized that this practice will increase crop yields if soil physical properties improve and soil organic carbon and soil N concentration increase with cover cropping.

Many have studied the effect of soil properties on crop yields, but little data are available on the changes in soil physical parameters and soil organic carbon concentration affecting crops yields in intensively managed no-till cropping systems. Soil physical properties may affect crop growth and yield by influencing aeration, water transmission and retention, heat flux, organic matter decomposition, N mineralization, nutrient release, and microbial activity. Some physical properties such as compaction may directly affect plant growth, while others such as aggregate stability may have indirect effects. In a recent article in *Agronomy Journal*, researchers assessed the effects of no-till summer cover crops on subsequent wheat and sorghum yields as well as their relationships with soil physical properties, soil organic carbon, and soil total N concentration on an Udic Argiustoll in south-central Kansas.

Materials and methods

Crop yield data and soil properties for this study were collected from a long-term (15 year) experiment of cover crops under a no-till winter wheat and grain sorghum...
Rotation at Hesston, KS. The experiment was initiated in 1995 and terminated in 2009 and consisted of a factorial combination of three cover crop treatments and four N rates. The main rotation was winter wheat–grain sorghum in which wheat was no-till planted into sorghum stubble in the fall and harvested in June of the next year. The cover crops were planted after wheat; and sorghum was planted in June of the following year.

Between 1995 and 2000, hairy vetch was used as a winter cover crop. The three treatments during this period were hairy vetch early termination, hairy vetch late termination, and control. Beginning in 2002, sunn hemp and late-maturing soybean were grown as summer cover crops in the plots where hairy vetch treatments had been in place, and the remaining plots retained the no-cover crop treatment. Wheat under no-till was grown without fertilizer across all plots in the transition year between 2000 and 2002. The summer cover crops were planted in early July after wheat harvest in the corresponding years except in 2006 when they were planted in early August due to late seed arrival. The summer cover crops were last grown in the summer of 2008 followed by sorghum in 2009.

Results and discussion

Cover crop height and residue yield

Monthly and annual mean precipitation during the summer cover crops study is given in Table 1. Year to year and monthly fluctuations in precipitation are reflected in the yield performance of cover crops as well as the main crops (Tables 1 and 2; Fig. 1 and 2). Despite some really dry years, summer cover crops afforded enough time between fall termination and succeeding grain crop for soil moisture replenishment. In this experiment, summer cover crops were never terminated early. Wheat depended more on timely fall precipitation than sorghum since wheat followed as a double crop after sorghum. Wheat yield was somewhat low but not uncommon for this region.

Results indicate that summer cover crops, particularly sunn hemp, can produce significant amounts of residues in as little as 12 weeks, despite fluctuating rain. The high aboveground residue input can have beneficial effects on crop yields and soil properties as discussed later. The increased height of sunn hemp may also be beneficial for shading and smothering weeds.

Cover crop effects on grain sorghum and winter wheat yield

Cover crops and N application rates increased sorghum (Fig. 1) and wheat (Fig. 2) yield. The cover crop × N rate interaction was significant in some years. Sunn hemp increased sorghum and wheat yield following the first year of the cover crop’s establishment, particularly in nonfertilized plots, suggesting that summer cover crops may have rapid effects on increasing yields of subsequent crops. Late-maturing soybean did not increase sorghum yield in 2003, but it increased sorghum yield at 0 lb N/ac in 2005 and at all levels of N application except at 90 lb N/ac in 2009.

Wheat appeared to be more responsive to N application than sorghum. For example, from 0 to 90 lb N/ac, wheat yield in non-cover crop plots increased by 4.3 times in 2004, 6.9 times in 2006, and 4.2 times in 2008, while sorghum yield in the same plots increased only by 2.1 times in 2005 and 1.5 times in 2007 and 2009. A similar greater wheat response to N application was observed in plots under sunn hemp and late-maturing soybean. The greater wheat yield increase with N fertilization suggests: (i) less cover crop-derived N may have been available for wheat than for sorghum, which succeeded cover crops
before wheat; (ii) sorghum may scavenge more N from the soil than wheat; and (iii) differences in soil water content between sorghum (spring) and wheat (fall) planting may have affected crop response to N application.

The significant and rapid increase in no-till wheat and sorghum yields with the inclusion of cover crops shows the potential benefit of these crops for increasing subsequent crop yields in no-till systems. These results suggest that cover crops may sufficiently supplement applied N to maintain crop yields in a profitable range all while suppressing weeds, lowering input costs for herbicides and fertilizers, and preserving soil moisture.

Cover crops and soil nitrogen fixation

Crop yield data in Fig. 1 and 2 suggest that summer cover crops supplement N at both low and optimum levels of N application. Fixation of N through legume cover crops may reduce the excessive dependence on inorganic N fertilizers in this region. It is important to note that this study only reports soil total N.

Studies in other regions have also found high N contribution from tropical legume cover crops. Summer cover crops return a high amount of N-enriched biomass. Because of their rapid growth and high biomass production and N fixation, legume summer crops such as sunn hemp may supplement N for subsequent crops and reduce inorganic N fertilizer use. A high N application rate masks the benefits of soil N derived from cover crops and appears to have limited effects on crop yields.

While this study did not quantify microbial biomass and activity, it has been observed that plots with summer cover crops had a greater number of earthworms than plots without the cover crops. This finding suggests that greater biological activity in plots with cover crops may contribute to N release from cover crop residues into the soil. Studies have shown that N derived from cover crops can be readily mineralized through biological activity and made available as nitrates for the subsequent crops with little or no loss of N through leaching. Fertilizer management (rate and timing) of sorghum and wheat and precipitation input can be critical to optimize the use of N derived from cover crops.

The soil organic content does not only stimulate crop growth through nutrient cycling but also through improvement in soil physical properties. It reduces soil compact-
ility (soil’s susceptibility to compaction), promotes macroaggregation, increases water retention capacity, increases water infiltration, and absorbs and filters nutrient loss in runoff. The results of the current study support recent emphasis on enhancing the soil organic content pool in agricultural ecosystems for increasing crop yields, improving soil properties, and addressing food insecurity. Similar to soil organic content, the strong positive correlation of yield with soil total N concentration indicates that cover crops can increase crop yields by supplying N.

The positive correlation of wheat and sorghum yield with a cover crop-induced increase in soil water content and the negative correlation with a cover crop-induced decrease in spring soil temperature corroborate the critical importance of soil water and temperature for crop production. It is important to clarify that, in this study, soil water content and soil temperature were measured only once during spring time (one and a half years after cover crop termination). The significant correlations show the influence of cover crop residue mulch on soil water and temperature. In this study, plots mulched with cover crop residues had greater soil volumetric water content and lower soil temperature in spring than plots without cover crops. The increased soil warming in plots without cover crops probably accelerated evaporation and reduced the volumetric water content relative to plots mulched with cover crop residues.

While growing cover crops use soil water and may reduce available moisture for subsequent crops, particularly in semiarid regions, cover crops can maintain or increase soil water content by increasing precipitation capture through increased water infiltration and reduced evaporation. In this study region, precipitation is, in general, adequate for crop production, and thus, use of cover crops may not cause water shortage for subsequent crops. However, in regions with limited precipitation such as the semiarid Great Plains, impacts of cover crops on soil water storage and yields of subsequent crops deserve further scrutiny. Early termination, selection of appropriate cover crops species, and other site-specific management strategies should be developed for the successful use of cover crops in semiarid regions.

Soil temperature influences several physical, chemical, and biological processes in the soil. It affects seed germination, root growth, evaporation, soil moisture content, microbial processes, nutrient cycling, and other processes. The results of this study suggest that because soil water content and temperature are a function of the amount of surface vegetative cover, the addition of residues to the soil surface cover through cover crops can rapidly alter the soil water and temperature dynamics. Crop residue mulch insulates the soil and buffers the abrupt fluctuations of soil temperature. It regulates the near-surface radiation energy balance and the dynamics of heat exchange between the soil and the atmosphere. An increase in surface residue cover with cover crops in no-till fields

Table 2. Plant height and residue yield of two summer cover crops for each rotation cycle at Hesston, KS. Nitrogen fertilizer was applied to main crops consisting of winter wheat-grain sorghum rotation.

<table>
<thead>
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† ns, not significant.
may create different microclimatic conditions favorable for crop production.

**Conclusions**

Sunn hemp and late-maturing soybean used as summer cover crops in a no-till cropping system rapidly increased wheat and sorghum yields on an Udic Argiustoll. These summer cover crops also fixed significant amounts of N in the soil compared with non-cover crop plots, suggesting that they can supplement N especially in cropping sys-

**Fig. 1.** Mean grain sorghum yield as affected by three cover crop treatments for 2003, 2005, 2007, and 2009. The error bars represent LSD values to compare cover crop treatment effects on yield within each level of N application.
tems with limited inorganic N input. Cover crop-induced changes in soil properties were partly responsible for the increase in crop yield. Changes in soil maximum compactibility, soil organic content, and soil total N concentration, aggregate stability, field soil water content, and soil temperature were significantly related to crop yields.

The results suggest cover crops increase crop yields and improve soil–crop relationships.

Based on these results, sunn hemp and late-maturing soybean may be potential summer legume cover crops for no-till wheat–sorghum rotations in the study region. Results also indicate that inclusion of summer legume cover crops in no-till systems can reduce N fertilizer requirements while improving soil physical properties and increasing soil organic content and N concentration. Overall, summer cover crops can be one of the best management practices to diversify and intensify cropping systems, manage N requirements, balance crop production and soil and environmental quality, and contribute to land stewardship and overall long-term sustainability of agricultural production systems.

May–June 2012
self-study quiz

Summer cover crops fix nitrogen, increase yields and improve soil–crop relationships (no. SS 04263)

1. What type of cover crop mentioned in the article may have more rapid and greater effects on increasing crop yields and improving soil properties?
   - a. high-biomass-producing and high-N-fixing summer or tropical legumes.
   - b. low-biomass-input and low-N-intake grasses.
   - c. cold-tolerant, fall-planted oilseed crops.
   - d. heat-tolerant, summer pulses with aggressive tap roots.

2. Which of the following is NOT mentioned in the article? Summer legumes can
   - a. potentially increase yields of subsequent crops.
   - b. provide an effective protective cover to soil.
   - c. decrease wet aggregate stability.
   - d. supply significant amounts of N to subsequent crops.

3. In this experiment, summer cover crops
   - a. were never terminated early.
   - b. were always terminated early.
   - c. were usually irrigated.
   - d. were always irrigated.

4. Crop yield data in Fig. 1 and 2 suggest that summer cover crops supplement N at
   - a. excessive levels of N application.
   - b. optimum levels of N application.
   - c. low levels of N application.
   - d. both low and optimum levels of N application.

5. It has been observed that plots with summer cover crops had greater ____ than plots without the cover crops.
   - a. numbers of earthworms.
   - b. numbers of nematodes.
   - c. soil compaction.
   - d. soil temperatures.

6. In this study, the greater wheat yield increase with N fertilization suggests
   - a. wheat may scavenge more N from the soil than sorghum.
   - b. more cover crop-derived N may have been available for wheat than for sorghum.
   - c. less cover crop-derived N may have been available for wheat than for sorghum.
   - d. sorghum may scavenge less N from the soil than wheat.

7. In this study, the cropping system was
   - a. wheat no-till planted into sorghum stubble in the fall with the cover crops planted after wheat.
   - b. sorghum planted into wheat stubble in the spring with cover crops planted in the fall.
   - c. sorghum no-till planted into sunn hemp in August and wheat planted the following spring.
   - d. cover crop planted in the fall after wheat harvest followed by planting early maturing soybean in the spring.

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
8. The cover crops used in this study
   □ a. increased soybean yields on an Udic Argiustoll.
   □ b. were planted in the fall after soybean harvest.
   □ c. fixed significant amounts of N in the soil compared
     with non-cover crop plots.
   □ d. increased wheat yields but had no change on sorghum yields.

9. Soil water content and temperature are a function of
   □ a. surface vegetative cover.
   □ b. microbial processes.
   □ c. soil compaction.
   □ d. seed germination.

10. Crop residue mulch regulates the near-surface radiation
    energy balance and the
    □ a. relationship between heat and moisture.
    □ b. dynamics of water exchange between the soil and the
        crop.
    □ c. dynamics of heat exchange between the soil and the
        atmosphere.
    □ d. relationship between crop water uptake and
        evapotranspiration.

Self-Study Quiz Registration Form

Name: ____________________________________________
Address: ____________________________________________ City: ____________________________
State/province: ____________________________ Zip: ____________________________ CCA certification no.: ____________________________

☐ $20 check payable to the American Society of Agronomy enclosed. ☐ Please charge my credit card (see below)

Credit card no.: ____________________________ Name on card: ____________________________

Type of card: ☐ Mastercard ☐ Visa ☐ Discover ☐ Am. Express ☐ Expiration date: ____________________________

Signature as it appears on the Code of Ethics: ______________________________________________________________________________________

I certify that I alone completed this CEU quiz and recognize that an ethics violation may revoke my CCA status.

This quiz issued May 2012 expires May 2015

Self-Study Quiz Evaluation Form

Rating Scale: 1 = Poor 5 = Excellent

Information presented will be useful in my daily crop-advising activities: 1 2 3 4 5

Information was organized and logical: 1 2 3 4 5

Graphics/tables (if applicable) were appropriate and enhanced my learning: 1 2 3 4 5

I was stimulated to think how to use and apply the information presented: 1 2 3 4 5

This article addressed the stated competency area and performance objective(s): 1 2 3 4 5

Briefly explain any “1” ratings: ______________________________________________________________________________________

Topics you would like to see addressed in future self-study materials: ______________________________________________________________________________________
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