CONSERVATION AGRICULTURE RESEARCH REPORT

REAL FARMS, REAL YIELDS, REAL RESULTS

THE HOWARD G. BUFFETT FOUNDATION

MAKING THE CASE FOR CONSERVATION AGRICULTURE

I have been farming for nearly 40 years: on U.S. farms in Nebraska, Illinois and Arizona, and for many years on a large research farm in South Africa. I have had many professional experiences in my life, but I consider myself a farmer first and foremost. It is with that background and experience that I share this observation: I am amazed at how frequently non-farmers are charged with recommending solutions that will have tremendous influence on how farmers operate. It is the equivalent of asking a non-medical person to perform surgery. Just as trained doctors are best equipped to perform medical procedures, farmers are best equipped to understand the issues facing farmers, and they are best equipped to participate in developing practical solutions that work in the real world, not in hypothetical situations. When hypothetical solutions developed by academics or bureaucrats drive farm regulation, it is a recipe for failure.

The belief that farmers should take the lead on developing solutions for the challenges we face has guided our Foundation's farm research and is reflected in the information you will find in these pages. I am a big proponent of conservation agriculture as an improved system of farming, both for economic reasons and for the long-term sustainability of our soils, water and our farming livelihoods. But I also understand that farmers need to see and understand the benefits in a way that makes sense in the context of their operations. It's not enough to show a farmer a statistically significant graph of improvements on research plots that bear little resemblance to real-world operations. That's why we approach our research differently. We won't meet the standards of an academic publication, nor do we try to. Our goal is to test ideas in ways that real-world farmers can relate to, and show how to use better practices to both make more money and protect our most precious natural assets: our soils and our water. When we can make that case to farmers, everybody wins.

We face a serious mindset challenge within our farming ranks and from the many different external factors farmers rely on when it comes to adopting best practices like no-till and cover crops. For example, in one state where we farm, we struggled with limited success with cover crops on one field and couldn't understand why the results were so different from our experiences in other fields. We consulted and shared information with our chemical supplier, but eventually discovered after several years that the custom applicator continued to apply chemicals that were not compatible with the cover crops we were using. Unfortunately, we had to figure out the problem for ourselves. On one of our other farms, year after year when our fields were sprayed, the company we contract with would cut across our rows in their effort to rush back to refill the sprayer, leaving serious ruts that required tillage to correct. Other times they would run floater tires that crushed our corn stalks, destroying the uniformity of the field, an important factor in no-till. At times they used machines with row crop tires and sprayed diagonally across our rows of soybeans, creating ruts that would last for years unless they were filled in with tillage. They created havoc with our no-till system. Our experiences demonstrate that many agricultural companies do not have the necessary experience with no-till or cover crops. This creates a large hurdle for farmers trying to adapt more sustainable farming techniques.

Farmers will face more and more pressure to adopt better practices. And as drought or contaminated water impacts more cities, agriculture is going to lose the inevitable fights over water rights unless we make it clear we are doing our part to provide solutions. We have proven practices that can address many of the concerns being debated about in agriculture today, but we need a different mindset. We need a systems approach that incorporates best practices like no-till, nutrient management, cover crops and crop rotation.

Academic research is unlikely to convince many farmers to adopt different production practices. Farmers value the experience of other farmers. Few researchers have depended on farming for their livelihood, and some accept funding from companies with an agenda that may align more with the companies profit than with farmers' best interest. Government grants have been cut, and research costs have increased, so researchers must find alternative sources for funding. This funding can be about meeting their academic needs, rather than the practical needs of farmers. Of course this doesn't apply to all research or to all researchers. This report features research completed by universities, which our Foundation funded. We believe this to be important work and our partnership with these universities has been essential.

However, our Foundation began undertaking our own research, as well as funding others' activities through grants to understand research at farm-scale. In the following pages you'll read about the insights we have developed from a series of full-scale farm studies—some one-time experiments and others ongoing. In each case, we included enough acreage to simulate how a farmer would experience these techniques on his or her own land.

Farmers in the U.S. didn't become the world's greatest producers by accident. We can continue to be global leaders, but we must demonstrate continued leadership and implement improved practices. We can help define "sustainable" or we will be forced to use someone else's definition. Researchers have contributed significantly to our success. But success in 2025 will not look like what we defined as success over the last 50 years. Times have changed and we need to keep changing with them. We hope we make the case here for why conservation agriculture needs to be part of that future success story and therefore at the center of your farming operations.

Many U.S. farmers have participated in development work in other countries. Therefore, we have included some grant-funded research in countries outside of the U.S. that we believe may be of interest.

Howard G. Buffett

Howard G. Buffett is Chairman and CEO of the Howard G. Buffett Foundation. He has farmed for over 36 years and the Foundation has invested nearly $700 million in research to improve agriculture and in agriculture- and nutrition-related programs globally.

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PLANT HEALTH & VIABILITY

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SOIL PRODUCTIVITY, HEALTH & RESTORATION

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THE STUDY: The ROI on No-Till

When is no-till more profitable than conventional till?

THE GOAL: Show no-till's viability and profitability potential for large-scale farm production.

LOCATION: Central Illinois **DURATION:** 2014–Present

For many years, farmers have measured tillage success by the number of acres they've turned "black." Because conservation ag and no-till don't provide that same visual satisfaction and confirmation, it's a mindset hurdle for farmers to overcome. With that in mind, we structured a series of field trials to give producers a comparison of conservation ag practices versus conventional tillage practices. We set out to demonstrate the improved profit potential of no-till over conventional till.

HOW WE DID IT

We compared conventional till versus no-till. While academic studies are typically limited to small-scale plots in a very controlled environment, our studies were designed to simulate full-scale agricultural production on a typical farm.

For conventional tillage, we did a single pass with a John Deere 2720 disk ripper in the fall, and in the spring, two passes with a John Deere 2310 mulch finisher. **We utilized nearly 5,000 acres within 12 different fields, both in corn/soybean rotation and continuous corn.**

Tillage was the only management difference between the sections. Having the sections side by side in the same field reduces the variability and provides a much tighter comparison, with each section experiencing the exact same environmental conditions.

SUCCESS STARTS WITH SMART MANAGEMENT

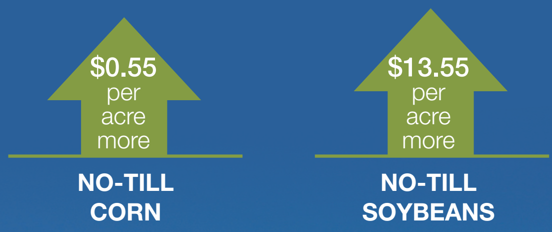
Good management in no-till is critical for success, and paying attention to the details is key. Setting up equipment specifically for no-till makes a significant difference in performance and yield. This includes properly equipped planters set up for no-till, with row cleaners and a ripple disk blade in front of the row units as well as the proper closing wheels. If you set up a no-till machine properly, you can plant into a field with higher moisture content sooner than a conventionally-tilled field, primarily because the soil structure can support the planter without creating too much compaction or other negative effects.

In addition, it's important to understand there is a difference in soil temperature in a no-till field containing a lot of cover. Soil temperatures will warm up slower in the spring, and that may affect germination. This can sometimes mean waiting a few days to plant, to ensure good germination and emergence.

FIGURE 1: THE PROOF IS IN THE PROFIT

2014–2017 profit differences between different tillage strategies

No-TIll Profit Per Acre Over Conventional Till



Profit increase calculated from the yearly base rates of Iowa custom rate charts for tillage.

Howard G. Buffett and Doug Oller, Chief Operations Officer for the Sequoia Farm Foundation, inspect and review research data on a no-till cornfield in Illinois.

SUCCESSES

Field trials make a compelling case that no-till practices produce production cost savings over conventional tillage. During the study period, the three-year average price of corn was $3.63; for beans the average price was $10.10. Average tillage cost was $29.08 ahead of corn and $46.34 ahead of beans. No-till requires no cost for field preparation. No-till produced $0.55 per acre profit over conventional tillage for corn and $13.55 more profit per acre for beans over the course of our studies to date.

In addition, no-till fields produced similar yields as conventionally tilled fields. On top of economic benefits, no-till is shown to improve soil health, drought resilience and weed suppression.

CHALLENGES

In both corn and soybeans, we did see a lower percentage of successful germination with no-till, but it did not impact yields. Other studies have shown a small percentage loss in population does not affect yield. Soybeans especially have an internal physiological mechanism that allows them to assess their surroundings and produce more pods and bigger stalks to compensate in times of stress.

WHAT WE LEARNED

- No-till is more profitable than conventional till.
- Under good management, conservation ag practices are not a drag on yield.
- Proper spring management is critical to success in no-till. This includes planting speeds and planter settings, especially row cleaners to move trash for consistent planting.
- Measuring the potential of no-till and other conservation ag efforts requires research at a large production scale.

LIGHTBULB MOMENT

Increased population doesn't always translate to increased yield. In fact, it can negatively impact results. For example, overlapping end rows in corn might not produce ears because of competition for nutrients, soil, etc. Rather than asking if your population is high enough, the key question to ask is do we have enough population to reach maximum potential? It's all about finding the sweet spot.

THE STUDY: Corn Maturity & Cover Crop Management

Can extending the cover crop season increase profitability?

THE GOAL: Determine if the use of shorter maturity corn varieties extends the cover crop growing season enough to reduce inputs and reach similar or increased profitability.

LOCATION: Illinois, Arizona **DURATION:** 2014–Present

Small, tightly controlled university studies have shown potential for using short maturity corn to extend the cover crop season, improving establishment and allowing for reduced inputs like nitrogen and increased cost savings. These savings, in theory, could overcome the typical yield drag we see with shorter maturity corn varieties. But can these same benefits be replicated at full-scale production? We began a series of field-scale trials to find out if short-season and long-season corn produce similar profits with longer periods for cover crop growth, reducing nitrogen requirements and costs.

HOW WE DID IT

To investigate whether or not using shorter maturity corn would provide enough time for better establishment of a legume cover crop and therefore, reduce fertilizer requirements, we began by selecting 80-, 90-, 100- and 110-day corn varieties. In plots of 17 to 107 no-till acres, we planted corn with and without hairy vetch cover crops, in both continuous corn and corn/soybean rotation fields.

We harvested the corn as early as possible, when the moisture content was at an acceptable level (15% to 18%), then planted the cover crop as soon as possible to maximize the cover crop season.

SUCCESSES

While the study is still in progress, results so far show potential for 100-day and 110-day corn produced with cover crops to be comparable in profitability to standard maturity corn produced without cover crops. Another aspect of the research is whether certain cover crops used in continuous corn production can reduce or eliminate yield losses sometimes associated with continuous corn. We're testing if a legume cover crop essentially acts as a crop rotation.

So far we're cautiously optimistic. In 2016, for example, 100-day corn with and without cover crops produced nearly the same profit—the additional 16 bushels per acre produced by the cover crop acreage was profitable enough to offset the additional cover crop cost.

CHALLENGES

As this study continues, we'll reduce the amount of nitrogen we apply to further lower costs. While we've established a baseline in the research to date, it's too early to say definitively whether yield drag on shorter varieties can be overcome with the use of cover crops and the reduction of inputs. We're seeing too much yield drag on 80- and 90-day corn, but 100- and 110-day corn show potential.

Likewise, at our field trials in Arizona, we conducted the same test, with a couple of differences due to the shorter six to eight weeks of "winter." Cover crops typically only grow until the end of November, with a short dormancy period before spring growth returns by late February or early March. Even with Arizona's warmer conditions, it's too soon to determine if reduced input costs will outweigh the yield drag of the shortest varieties.

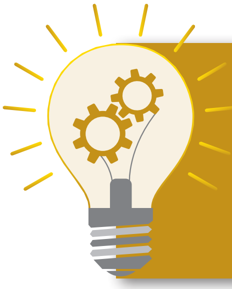
Spring termination of the cover crop, both timing and method, is critical to successful planting of the grain crop. However, it does present several challenges.

Crimping is one method for cover crop termination; it flattens and crimps the stalk before the plant reaches maturity. The plant stalk needs to be mature enough so the nutrients/water are unable to get to the plant after crimping the stem, causing the plant to die. The challenge in crimping is doing so at the ideal time and having the ideal plant growth, but not waiting so long that it creates a mat so heavy that emergence is hindered by the thick mat of plant residue.

The other crop termination method we used was herbicides, which at times were necessary due to less-than-ideal field conditions in areas that had poor termination from the crimper. This was the most consistent termination method but presents other management challenges: Farmers in developing countries cannot always access or afford herbicides; chemical use can have negative impacts on subsequent crops; and chemicals can affect water quality.

What is clear: Management is critical to the overall success of any cover crop program.

Utilizing crimping for cover crop termination at our research farm in Arizona.



LIGHTBULB MOMENT

This trial grew out of what we've learned so far in another cover crop test. It's just one of the benefits of large-scale field studies—they often lead to new research opportunities. Because farm-scale research doesn't operate in a silo with a narrow focus, we're often able to transfer and apply knowledge to investigate other potential ways to enhance production.

FIGURE 1: 100-DAY CORN DURING 2016 CROP YEAR

	With Cover	Without Cover Crop	Difference
Yield in bu./acre	156.96	139.42	**17.54**
Income/acre (with a corn price of $3.67)	$576.04	$511.67	**$64.37**
Hairy vetch seed cost	$1.95/lbs.		
Seed rate	25 lbs./acre		
Drill cost	$14.75/acre		
Cover crop cost/acre	**$63.50**		

Both fields had 180 lbs. of nitrogen applied on the same day.

Profit/acre advantage of cover crop field	**$64.37**
Cover crop cost/acre	**$63.50**
Net profit/acre improvement in cover crop field	**$0.87**

FIGURE 2: APPROACH CONSERVATION AG AS YOU WOULD ANY INVESTMENT

IF YOUR GOAL IS	CHOOSE Triticale	CHOOSE Hairy vetch	CHOOSE Brassica
Weed control	✔	✔	
Reduced fertilizer		✔	✔
Reduced soil compaction	✔		✔

Bottom line: There is always a management tool that fits into your conservation ag toolbox. You can find more information at *HarvestingthePotential.org.*

WHAT WE LEARNED

- Extended-season cover crops paired with 100- and 110-day corn show the potential for lower yield drag than other shorter maturity varieties, offsetting the cost of using cover crops.
- Effective spring termination of the cover crop, both the method and timing, is critical to crop productivity.
- More trials on 100- and 110-day corn are needed to definitively determine if using cover crops overcomes the yield drag of shorter maturity corn and reduces input costs sufficiently to improve overall profitability.

THE STUDY: Perennial Cover Crops in a Row Crop System

Can perennial cover crops be beneficial in a row crop system?

THE GOAL: Determine if live perennial cover crops provide benefits for soil health and water management without impacting crop yields or management in corn and soybean production.

LOCATION: Nebraska **DURATION:** 2015–2016

While small-scale university trials show potential with live perennial cover crops, our experience in field-scale production using living cover crops has presented insurmountable challenges. Traditional conservation ag practices call for annual cover crops, and this research helped confirm why using perennial cover crops is a challenge.

HOW WE DID IT

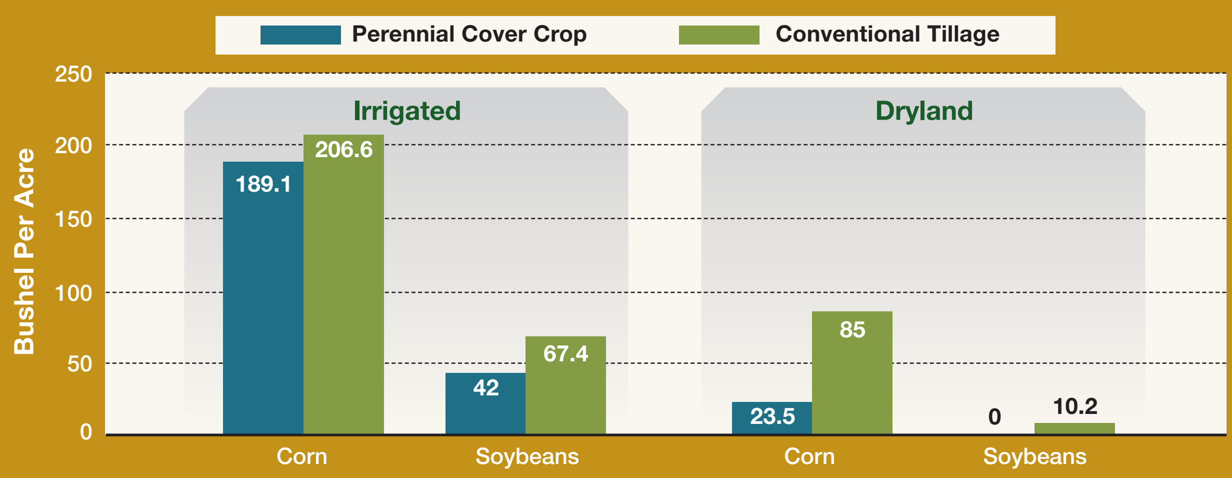
In this study we took two 160-acre fields with 130 acres under center pivot irrigation systems, along with their respective dryland corners, and split each pivot in half. On one half of each of the two pivots, we planted a perennial grass cover crop and allowed it to establish the year prior to starting the research, allowing the grass to get to 18 to 24 inches tall and then mowing it down to 6 inches by fall. When we drilled the cover crop mix, we blocked every fourth outlet, thus allowing a space to plant our row crops the next season at 30-inch centers.

The following spring we performed conventional tillage on one half of each pivot opposite the cover crop halves, only under the irrigated portion. The dryland corners were to be planted no-till. We then planted corn on one pivot and soybeans on the other pivot along with their respective dryland corners.

CHALLENGES

Controlling the live cover crops proved difficult, especially in soybeans. As the bean leaves died back and more sunlight penetrated the canopy, cover crop regrowth took off. In order to harvest soybeans in the live cover crop, the bean head had to be raised approximately 3 inches to keep the green plants from wrapping around the reel and clogging the head. Raising the head this far resulted in significant yield sacrifices and required reduced harvest speeds. To compensate, we also experimented with using growth regulators to set back the growth of the cover crop, but the cover crop simply grew back later in the season.

FIGURE 1: CORN AND SOYBEAN YIELDS ON BRULE FARM



RESULTS

The conventional-tilled corn was able to profit $106 more per acre than the corn planted into the perennial cover crop. The conventional-tilled soybeans profited over $240 per acre versus the soybeans planted into the perennial cover crop. The perennial cover crop significantly lowered yields and added production challenges to reduce profit margins.

The soybeans in the dryland corners with the perennial cover crop failed to establish a stand, leading to a total crop failure. In the irrigated soybeans, the conventional-tilled field out-yielded the soybeans planted into the perennial cover crop mix by 1.5 times. This is likely due to the soybeans being slower to establish a closed canopy, resulting in a longer growing period for the cover crop grass mix.

As explained in the Challenges section, there was yield loss due to the difficulties during harvest.

We have yet to find a practical and effective way to manage the living cover crop at a field scale, and more thought needs to go into a way to control the cover crop.

Controlling the live cover crops proved difficult.

The perennial cover crop caused issues during harvest. The platform could not be run on the ground, causing a yield loss. In corn, the plants could not emerge from the heavy cover; in beans, the inevitable intake of cover crop plugged up the combine.

WHAT WE LEARNED

- Perennial cover crops left unchecked and not terminated will take over production crops, especially soybeans.
- To harvest soybeans planted in live cover crops, the combine head must be raised so high that too much yield is sacrificed.
- Corn produced in a perennial cover crop sacrifices less yield than soybeans, but still may not be economically appealing.
- Using live cover crops in row crop production would require more investigation to be economically feasible.

THE STUDY: Financial Impact of Conservation Ag

Can conservation ag be profitable year to year at the full farm-scale level?

THE GOAL: Calculate and compare the costs and revenue potential of conservation ag versus conventional ag to determine net profitability difference.

LOCATION: Central Illinois **DURATION:** 2011–2014

While much is made of the potential benefits of conservation ag, it has been difficult for farmers to assimilate best practices and quantify their impact. Part of this is due to the fact that measuring conservation ag requires assessment over a long period of time—a “trial run” of a conservation ag practice such as no-till may not produce a clear net benefit because of factors unrelated to the practice. Unlike a variable such as yield, which can unequivocally be measured in a single years’ success, conservation ag may take multiple years of practice and dedication to understand the full potential of benefits. For many farmers, this is a difficult commitment to make. With the amount of capital involved in operating today’s farms, many farmers are understandably risk-averse.

Conservation ag requires a long-term investment mindset because the most significant benefits—improved soil health and reduced soil erosion—take time to achieve. That is one reason why farmers who only try no-till for a single season may be dissatisfied with the results. Think of conservation ag adoption as a farm strategy change, not a simple method change.

With this in mind, we began full-scale farm studies to help quantify the net profit benefits of a conservation ag strategy. We believe what you take to the bank should be more important than what you take to the elevator.

HOW WE DID IT

We began by analyzing the results of multiple years of farm-scale research trials, including studies on the key components of a conservation ag strategy: no-till, cover crops and crop rotation.

As part of this, we also began new large-scale studies. We used continuous corn in a conventional-till system as our baseline. Then we planted plots from 33 to 80 acres each, using a monoculture of hairy vetch for our cover crop. We compared no-till continuous corn, conventional-till corn/soybean rotation, no-till corn/soybean rotation, and each with and without cover crops.

This allowed us to see if there was a gain in one practice over another practice, and additionally, if combining conservation ag practices provided gains, or if there was a cap on benefits.

RESULTS

One benefit of crop rotation is profit over time. While it’s true that soybeans provide soil nitrogen that benefits the next corn crop in that field, that doesn’t explain all of the gain over long periods of time.

Comparing yield-adjusted production costs and using a $6.28 per bushel three-year average price of corn for 2011-2013, we calculated an incremental net profit of $0.99 per bushel for conservation ag as compared to conventional ag. We saw a net improvement for each conservation ag practice (no-till, cover crops and crop rotation), which suggests that layering conservation ag methods—using more than one tactic in the same field—increases profit with each added technique.

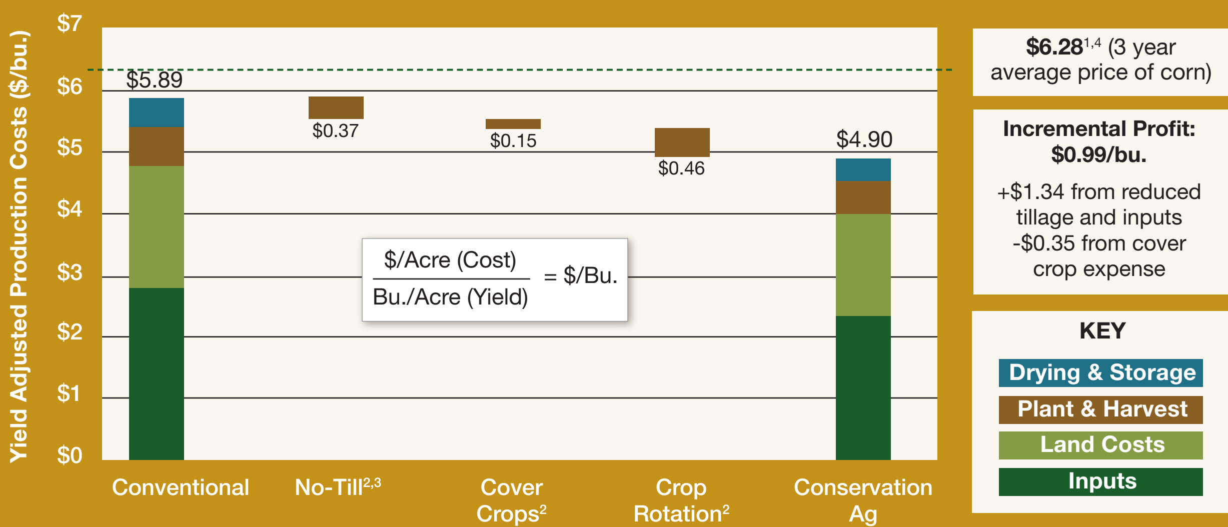
When commodity prices decrease, the economic benefits of no-till become more important.

WHAT WE LEARNED

- Conservation ag is more profitable than conventional ag after three years.
- Corn/soybean rotation fields consistently produce more profit than continuous cornfields.
- Conservation ag successes should be measured over the long term after multiple years in practice. Yields are the only factor that can be measured in single-year successes. Erosion and soil health can take many years to see measurable results.
- Results suggest using more than one conservation ag practice at a time has an additive effect on a field's profit increase potential.
- Adopting a conservation ag farm strategy is a long-term investment in improving soil health and reducing soil loss from erosion.

FIGURE 1: CONSERVATION AG BY THE NUMBERS—ESTIMATED COST & PROFIT

After three years, conservation ag demonstrated a significant impact on profit.



[1]USDA National Agricultural Statistics: Crop Values 2013 Summary (Feb 2014) [2]Net improvement percentage for each experiment applied to average production cost from all conservation ag experiments [3]5% no-till benefit = 8% production cost benefit found between no-till and strip-till minus the 3% production cost incurred when moving from conventional tillage to strip-till [4]$6.28 based on average price of corn between 2011–2013

Source: Lake Partners analysis; Based on data from years 2011–2013

THE STUDY: Bt Corn & Insecticide Use Rates

Is there an economic benefit to using insecticide with Bt corn?

THE GOAL: Determine whether farmers can reduce pesticide use and costs when growing pest-resistant genetically modified corn.

LOCATION: Central Illinois **DURATION:** 2011–2014

The rise of genetically modified corn has given farmers another piece to put into their production puzzle. Especially appealing: Bt corn varieties altered to express proteins from the bacterium *Bacillus thuringiensis* that are toxic to certain insects such as the corn rootworm. But if you have a pest repellent built into your crop, do you still need insecticide at full power? We developed a series of farm-scale studies to find out. Sometimes, the best outcomes and opportunities for learning aren't even part of the original plan. Although we did find valuable information related to the actual goal of the study, the biggest takeaway involved refuge corn.

THE UNEXPECTED TAKEAWAY

In some cases, we saw better yields with refuge corn than with genetically modified corn. For example, in one field with a full rate of Force 3G (tefluthrin) application we saw nearly 188 bushels per acre in the non-Bt corn versus 181 bushels per acre with the Bt corn. We also didn't see the crop failures due to pests.

This presents quite the conundrum, as pure refuge corn, which we used for the study, is no longer available. Today, seed companies only offer refuge corn blended with the higher-priced corn, at a cost of $230 per bag, compared to $313 per bag for Bt corn.

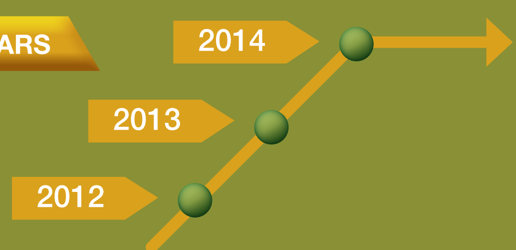
When we extrapolate production costs, the per-acre cost for Bt seed corn without a Force 3G application is $133, compared to refuge corn with a full rate application of Force 3G (which costs $13.93 per acre) at $111.68. Given the noted yield differences and the production cost differences, refuge corn was more economical to produce per acre than Bt corn. These are issues that tend to become more evident with larger-scale production. It leads us to wonder: Are we paying more for less yield potential?

THE ORIGINAL BT STUDY: HOW DID WE DO IT?

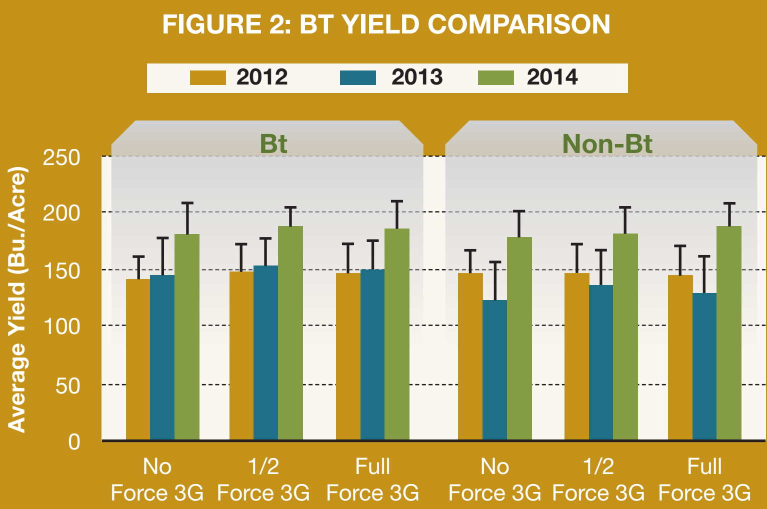
To compare insect activity in Bt and non-Bt (refuge) corn varieties, we planted two fields totaling 108 acres with glyphosate-resistant hybrids. We split a planter to be able to plant part of each field with Force 3G in-furrow insecticide. One-third of the rows received a full rate (4.4 ounces per acre); one-third received a half rate (2.2 ounces per acre) and one-third received no treatment.

We evaluated insect pressure three times: once at V6-V8 (for leaf damage), full tassel-VT/R1 (for western corn rootworm) and R3-R4 (for damaged kernels). We also did a root dig at R2 to examine western corn rootworm larval feeding and root damage, performing a total of 162 root evaluations. We rated damage using the Iowa Root Node

FIGURE 1: INSECT PRESSURE THRESHOLD AT THREE YEARS



By 2014, we saw significant increases in root node damage for all treatments, leading us to speculate that we've reached a threshold for rootworm pressure in these fields.



Yield results from the first three years indicate that soil insecticide is an unnecessary cost to a young continuous Bt corn system.

WHAT WE LEARNED

- Soil insecticide may not be necessary in the first three years of a continuous Bt corn system.
- Refuge corn with the full rate of Force 3G is more profitable than Bt corn with no insecticide application.
- Farmers who aren't using Bt corn should consider using insecticide to control corn rootworm.

Injury Scale, 0 being no damage and 3 being a root with three or more nodes completely destroyed by feeding.

From the planned study, we observed the following results: approximately 25% more western corn rootworm beetles in the non-Bt corn than in the Bt variety, with the Bt fields having the least amount of insect damage.

By the last year of the study, we saw significant increases in root node damage for all treatments for both Bt and refuge corn, leading us to speculate that we reached an economic threshold for rootworm pressure in these fields. With the exception of the full-rate Force 3G-treated rows, all areas exceeded minimum estimates for economic loss. The strip of non-Bt corn had the highest root node damage and suffered some economic loss, but it was not as significant as the root node damage would indicate it should be.

The study suggests that Bt corn may control insect or pest activity in the short term (three years). Long-term control (past three years) in continuous corn may require using additional insecticide.

As we brought in the grain, the yield comparisons between refuge corn and genetically modified corn were surprising.

THE STUDY: Disease Management with Fungicides

Will fungicides as a standard practice provide better profitability?

THE GOAL: Evaluate if preventive fungicide treatments are made cost effective by increasing yields.

LOCATION: Central Illinois **DURATION:** 2011–2014

“Higher yields” became the mantra of many producers during the boom of the mid-2000s, and with this, preventive fungicide treatments became standard practice on many farms. When corn reached $8 (Chicago Board of Trade, Aug. 20, 2012), farmers could afford to focus more on yield than profitability. A few very tightly controlled, small-scale university studies have shown mixed results: Some showed yield sacrifices when fungicide was left out of the mix, others showed little impact without treatment. We wondered what yield impact we would see with a full-scale farm production study: When it comes down to putting more bushels in the bin, will fungicide do the job every year—and does this always translate to higher profitability?

HOW WE DID IT

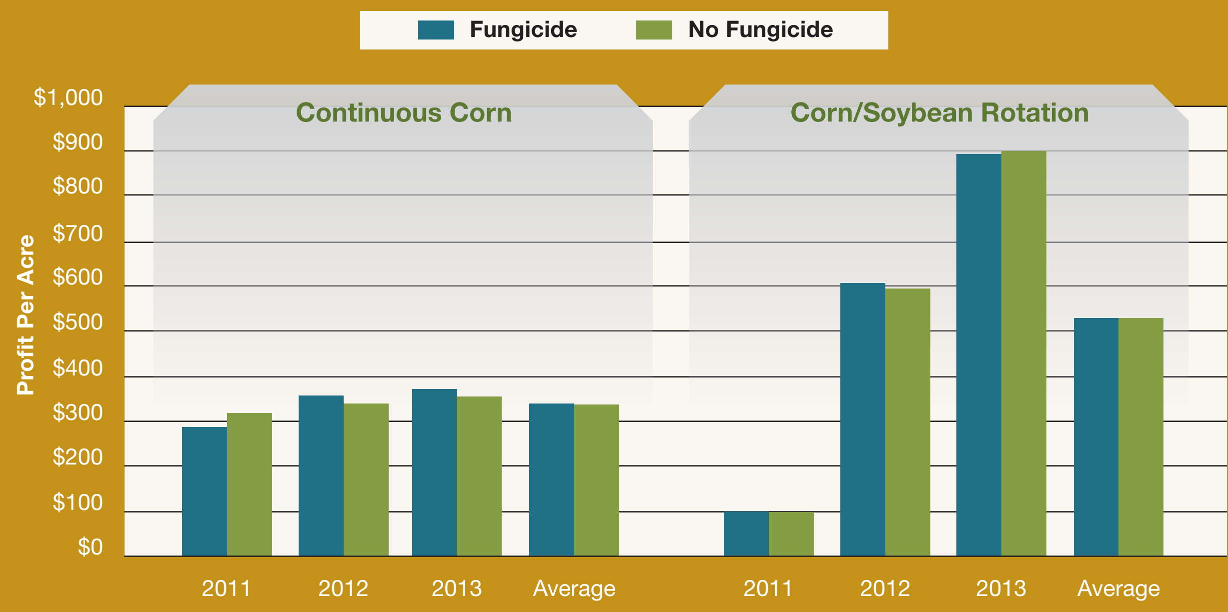
On four 80-acre fields with both corn/soybean rotation and continuous corn ground, we ran a 24-row planter to plant 12 rows each of two different varieties: one more susceptible to disease with a higher maximum yield potential, and one less susceptible to disease with a lower maximum yield potential.

Then, approximately 79 days after planting at VT (when the last branch of the tassel is visible), we applied a fungicide treatment to one field of rotated ground and one field of continuous corn ground, leaving one field of each without fungicide as the controls. We used Quilt Xcel fungicide (active ingredient azoxystrobin, 13.5%; propiconazole, 11.7%) at 10.5 ounces per acre.

We rated disease incidence and severity by randomly selecting 10 plants at 10 points per field at each location, measuring severity on a scale of 1 to 5, with 5 being the most severe. We looked at both the upper and lower parts of the plant and collected foliar samples to identify pathogens. Gray leaf spot (70%) and common rust (28%) were the most prevalent. We also found very small, low-severity incidences of northern corn leaf blight and diplodia leaf streak.

Focusing on yield increases does not guarantee profitability.

FIGURE 1: NO SIGNIFICANT PROFIT DIFFERENCES WITH OR WITHOUT FUNGICIDE



RESULTS

We saw no significant profit or yield differences between acreage with or without fungicide. This was true for both corn and soybeans planted on rotated ground, and held true even in a year with a 35% to 40% infection rate in soybeans. The same was true for continuous corn—profit and yields were virtually the same with or without fungicide treatment. What we learned: Using fungicide every year just because that's what you've always done might not increase your bottom line. Take a look at disease levels before you automatically include fungicide in your crop strategy.

WHAT WE LEARNED

- Fungicide as a standard annual practice is not profitable—it should be a year-to-year decision.
- In our study, we only had one year with improved yield from fungicide use—and that was only breakeven for profitability.
- The decision to use fungicide comes down to active management—scouting to determine active disease levels.
- Focusing on yield increases does not guarantee profitability.

THE STUDY: Conservation Ag's Impact on Ground & Surface Water

Can water quality be improved by conservation ag?

THE GOAL: Show the long-term effects of conservation agriculture on surface, ground and soil water quality at farm-scale.

LOCATION: Central Illinois **DURATION:** 2009–Present

Much has been made in recent years of agriculture's effects on water quality, both ground and surface, and more agricultural research is being done to try and address the issue. But many academic studies take a lab-scale approach to their research, making any findings difficult to determine what applies to the average farmer. Conservation ag practices have the potential to offer an effective solution to address the concerns about water quality, and many of them are already in play on farms across the country. To show conservation ag's potential at farm-scale, we wanted to compare how substances like nitrogen and phosphorus fertilizer, pesticides, Bt proteins and insecticides move through ground and surface water when farming using conventional versus conservation ag management practices.

HOW WE DID IT

In order to assess conservation agriculture's effects on water quality for the typical farm, we began studies on three large plots totaling 186.41 acres. Each of these fields was a minimum of 50 acres, had similar soil types and allowed us to assess three different watersheds. It provided a unique opportunity to see side by side the impact on water quality on a large scale.

To create a baseline for soil and water quality, these plots were no-tilled for five years. After that, one field was no-tilled with cover crops, another no-tilled without cover crops and the third conventionally tilled without cover crops. On the cover crop field, we used a triticale cover crop before soybeans and a hairy vetch cover crop before corn. We terminated the cover crops by crimping as well as by applying herbicide.

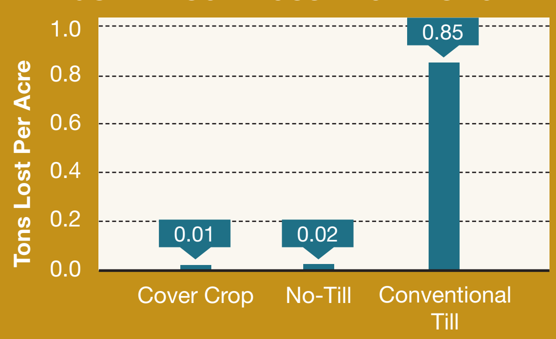
Our equipment included an advanced climate station consisting of a wind monitor, rain gauge, pyranometer, and temperature and relative humidity probe. In addition, we monitored soil volumetric water content at three different depths and slope positions.

Each watershed contains four sites with 20-foot deep and 10-foot deep groundwater wells to monitor shallow groundwater quality. In addition, 10 lysimeters were installed 1 to 2 feet below ground surface in each watershed. (A lysimeter collects water from soil pore spaces and identifies constituents in the water.) In our fields, the lysimeters were constructed in combinations of 6-inch and 2-foot lengths so that we can collect soil water at various depths, as well as on footslopes, backslopes and shoulders, when soil water is sufficient.

We sampled runoff water from the grass waterways through a flume, automated water sampler, probe module and liquid level actuator in each watershed.

For each plot we measured runoff water quality, soil nitrates and soil phosphorus. Timing for soil samples includes preplanting in April, as well as monthly from May through August. We collected runoff samples whenever rain events produced enough water to sample (typically a minimum of 1 to 2 inches of rain).

FIGURE 1: SOIL LOSS FROM RUNOFF



SUCCESSES

Soil nitrate levels were lowest in the conservation ag field using both no-till and cover crops (22.9 lbs./acre average over one five-month period compared to 27.9 lbs./acre for the conventionally tilled field). We attribute this to cover crop uptake of nitrogen, which in turn produces less chance of leaching into groundwater.

In one year alone, cover crops reduced soil nitrates by 2 to 7 parts per million. By April of that year, triticale had taken up 34 lbs./acre of nitrogen, with no nitrogen applied. By October, the soil nitrogen of all fields was virtually equal, leading us to believe the nitrogen was available for the grain crop.

During three significant rain events in spring 2017, conventional tillage had significantly more soil loss from runoff compared to no-till—0.85 tons per acre compared to just 0.02 for no-till and 0.01 for the no-till with cover crops field. (Soil particles in turn have nutrients attached to them and will be part of runoff.)

The success of crimping depends on timing. In this field, we crimped behind the planter; in other fields, we tested crimping ahead of the planter, trying to determine the most efficient process.

Planting directly into cover leaves the majority of the soil undisturbed and reduces soil erosion and water runoff.

CHALLENGES

High natural phosphorus levels in parts of the fields made assessing soil levels of phosphorous in those areas difficult. While we accounted for these high levels in our treatments, they are something we will need to continue to monitor. We did see a small increase in phosphorous in the cover crop field by December, so we will observe that field to see if it continues to have a higher amount of soluble phosphorus in the soil.

THE COST OF EROSION

Understanding what impacts the true cost of erosion is necessary when considering conservation agriculture methods as a solution. First, we consider the USDA/NRCS estimates for the average pounds lost and cost of nitrogen and phosphorus per ton of soil loss. Combined with the estimates for topsoil erosion and the direct cost of land value per ton of soil loss, the estimated cost of soil erosion for farmers totals $54.78 per acre/year.

WHAT WE LEARNED

- Runoff water quality and soil erosion control is better with no-till and no-till with cover crop compared to conventionally tilled fields.
- Profitability is greater with no-till than conventional till because of fewer field passes, which means lower costs.
- The cost of erosion (as high as $54.78 per acre/year.) is a factor we can't continue to ignore.

We have installed three Parshall flumes to measure soil and nutrient runoff under different farming conditions.

THE STUDY: Herbicide Impacts on Water

Do two of the most commonly used herbicides in agriculture affect groundwater and non-target species when used over an extended period of time?

THE GOAL: Track atrazine and sulfentrazone herbicides in soil and water to evaluate the environmental risk to non-target species due to exposure individually and in combination.

LOCATION: Central Illinois **DURATION:** 2013–2014

Atrazine, used since 1958, became one of the U.S. farmer's most commonly used herbicides for broadleaf weed control in corn—in fact, 61% of the country's corn was treated with it in 2010. On soybeans, sulfentrazone enjoyed similarly high usage levels. Based on our short research, both appear to be exceptionally mobile, leaching into groundwater and aquatic systems.

HOW WE DID IT

Our study included a total of 80 acres rotating corn and soybeans and using atrazine and sulfentrazone herbicides. We measured concentrations of each herbicide over a two-year period by collecting soil, runoff water and groundwater samples. We selected 98 soil sample points, installed 16 well sites and collected surface water samples after each rainfall of 0.5 inches or more. We extracted the soil and water samples, then sent them to a lab for analysis by a high-performance liquid chromatograph.

Our model estimates that 1.4% of atrazine applied to the field eventually reaches water bodies including creeks, streams, lakes, ponds and subsurface wells, most often by runoff, then by erosion and spray drift. Similarly, the model estimates that 2.7% of sulfentrazone reaches the water body, almost exclusively (93.2%) by runoff, then by spray drift and erosion.

Then we evaluated survival of water fleas and bluntnose minnows. We also assessed fathead minnow, green algae and duckweed growth. Tests included laboratory bioassays and field samples to assess the factors.

WHAT WE LEARNED

- Atrazine and sulfentrazone do coexist in rotational fields.
- Both herbicides impact non-target species.
- Atrazine affects fathead minnow larvae growth, as well as duckweed and green algae.
- Sulfentrazone affects duckweed survival.

RESULTS

Atrazine concentrations in soil and water peaked at 175.8 nanograms per gram (ng/g) dry and in runoff water at 4719 nanograms per liter (ng/L) over a three-year period. Sulfentrazone residues from the 2012 application were also present, with an average soil concentration of 18.76 ng/g dry and an average runoff water concentration of 154.3 ng/L.

The atrazine was 50% dissipated in 45 days and the sulfentrazone was 50% dissipated in 116 days, suggesting that the two products do coexist in the field. Even at low concentrations, atrazine has shown an impact on larval fathead minnow growth, as well as negative signs of growth on plants including duckweed and green algae—both non-target plant species. In addition, maximum sulfentrazone concentrations have shown a negative impact on duckweed.

THE STUDY: Effects of Insecticide Runoff

Does insecticide runoff impact the larger food chain?

THE GOAL: Show the effects of cyfluthrin and phostebupirim runoff on non-target species and those further down the food chain.

LOCATION: Central Illinois **DURATION:** 2011–2013

While Aztec remains a widely used insecticide, its mobility has been well documented. But how far-reaching are these effects? We began a large-scale farm assessment to study how cyfluthrin and phostebupirim move in soils, runoff waters and sediment, and the impact on non-target species together and alone.

HOW WE DID IT

On an 80-acre field we collected results three ways: on half the field using conventional tillage, on the other half of the field using strip-till and on the field as a whole. To determine insecticide movement, we installed six runoff samplers to collect soil from the surface. After each significant rain event (at least 0.5 inches), we collected 20 samples, half within the rows and half between the rows. This allowed us to study the insecticides' horizontal movement on the soil surface.

We collected soil surface samples following the field cultivator on the conventional tillage section as well as five days after planting on both sections. After that, we collected samples monthly through December, with the last sample taken 15 days after conventional tillage in the fall. (The weather and wet fields kept us from making a strip-till pass in the fall of the last study year.)

We then tested toxicity for earthworms, amphipods, water fleas, zebrafish and fathead minnows.

Howard G. Buffett begins planting a farm-scale study in Illinois.

RESULTS

In one year alone, we found cyfluthrin and phostebupirim levels in most runoff water samples. The highest concentrations were collected after planting.

In the last year of the study, cyfluthrin concentration peaked at 4.2 ng/L. Phosteburpirim was detected in all runoff water samples for the 2013 field season with higher than average concentrations in the strip tillage field. However, due to high variability, the difference in the measured concentration between conventional and strip tillage was not statistically significant ($p>0.05$). Peak phostebupirim content was measured at 2,500 ng/L in runoff water.

Runoff sediment samples were extremely variable with one sample in a strip-till area following planting measuring 307 ng/g dry weight (dw). This explains the higher concentration measured in strip-till versus conventional-till areas a few days after planting.

Despite the variability, we found similar levels of cyfluthrin and phostebupirim in runoff sediment. The highest concentration of phostebupirim in sediment testing was 192 ng/g dw, with concentrations three times higher in November than February. Cyfluthrin concentrations were, on average, five times higher in November than in February that year, with mean concentrations of 0.5 ng/g dw in February and 2.6 ng/g dw in November.

In soil, maximum concentrations in the last year of the study were 558 ng/g dw of cyfluthrin (collected post-planting in conventional tillage) and 3,268 ng/g dw of phostebupirim (collected in June in strip-till area). Both insecticides were higher in the conventional-till section right after planting, followed by increased concentrations in strip-till areas 27 and 49 days following planting.

Concentrations of both dropped by December, but were still six to seven times higher than in February. Measurements were higher after spring tillage.

Risk quotients (RQs) were calculated based on the maximum possible exposure (highest mean concentration measured in the field for one sample event) and toxicity benchmarks for each species. The calculations determine potential risk to non-target species. RQs greater than 0.1, which was the case for amphipods, water fleas and earthworms, might present an acute risk to species for restricted-use formulations, such as Aztec. Levels for the fathead minnows and zebrafish did not exceed 0.1 RQs.

We also investigated the bioaccumulation of earthworms because they live in the soil that received the insecticide. A direct relationship between body tissue and soil concentrations was observed after exposure to Aztec for 14 days. In the field, earthworms might accumulate the two insecticides in the same manner, which could cause a risk to higher non-target species in the food chain.

WHAT WE LEARNED

- High cyfluthrin and phostebupirim concentrations were detected in both runoff water and sediment.
- These concentrations can be toxic to non-target organisms.
- Earthworms might be at the most risk from exposure and accumulating the two insecticides, which causes a risk to higher non-target species.
- More work is needed to document the potential long-term effects of the movement of the chemicals in both soil and water.

THE STUDY: Seed Treatment, Soil Mobility & Runoff

Does tillage increase seed treatment mobility and in turn, water quality?

THE GOAL: Show how tillage impacts the movement of clothianidin through soil and into surface, ground and runoff water.

LOCATION: Central Illinois **DURATION:** 2011–2015

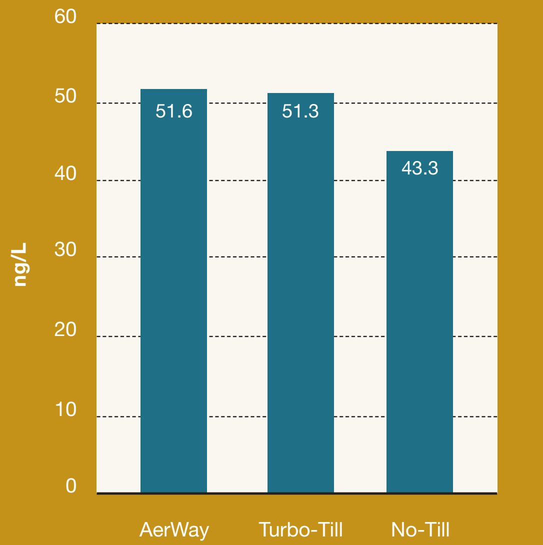
Since combination insecticide and biological seed treatments became available over a decade ago, farmers have relied on them to improve yields. Farmers value the flexibility to choose an increased level of protection if it has the potential to consistently improve yield, but they also need to be aware if there are trade-offs that should be considered as well: Does having higher levels of chemicals in the coating lead to greater soil movement and in turn, negatively impact water quality? Do different tillage strategies further aggravate the issue? We initiated a field-scale research study to better understand these questions.

HOW WE DID IT

We chose a 230-acre plot, and divided it into three sections receiving different tillage treatments: vertical tillage with AerWay, vertical tillage with Turbo-Till and a no-till field. Each field was planted in a corn/soybean rotation. We used a 24-row planter to seed 12 rows of Poncho 500 and 12 rows of Poncho 250.

To determine the two seed treatments' effects on water quality and soil movement, we collected samples, including surface soil, groundwater, runoff water and soil-pore waters, five time per year. Collection timing included before planting, after planting and key times during the growing season and harvest. We analyzed each sample for clothianidin.

FIGURE 1: VERTICAL TILLAGE EFFECTS ON CLOTHIANIDIN CONCENTRATION



Seed treatment concentration in runoff water on no-till ground is lower than ground that has been worked with vertical-tillage methods.

RESULTS

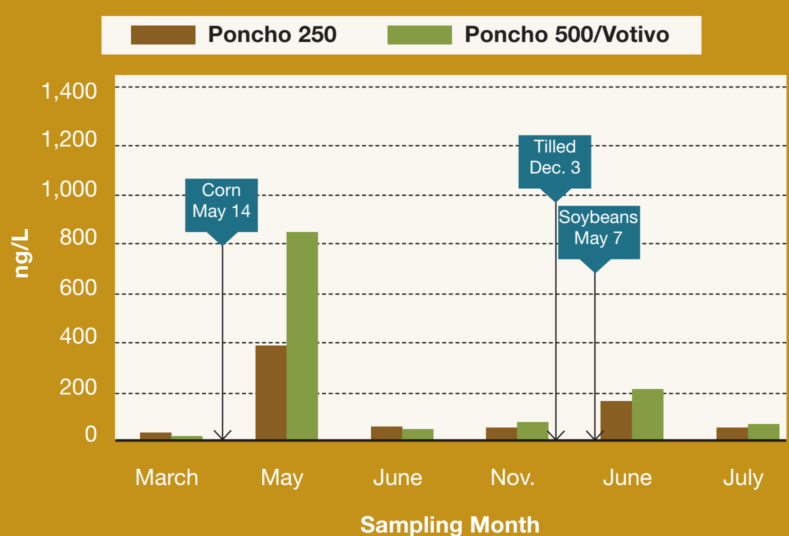
We found clothianidin residue in all samples (groundwater, runoff water, surface soil and soil-pore water), though the no-till field had 16% to 17% less clothianidin than the two tilled fields.

Additionally, Turbo-Till affected Poncho 500 soil concentrations before planting, suggesting that fall tillage with Turbo-Till encourages movement through the soil. Levels increased, then fell a month after planting, likely because tillage brought previous residue to the surface. We didn't see this trend with the AerWay or no-till treatments.

Vertical tillage had little impact on clothianidin concentrations in the Poncho 250 treatments. We measured low levels of clothianidin in runoff water and groundwater. Concentrations in soil pore water increased after planting, then stabilized.

Our findings suggest Poncho 500 is more stable with no-till or with the AerWay. In vertical-tillage situations using the Turbo-Till, using Poncho 250 (not Poncho 500) reduces the potential of higher amounts of clothianidin movement in soil and water.

FIGURE 2: CLOTHIANIDIN RUNOFF WATER CONCENTRATIONS



Mean runoff water clothianidin concentrations; samples collected after rain events (>1.27 cm rain) in Poncho 250 and Poncho 500 seed treatments (n=9). There were no significant differences between seed treatments. Arrows indicate the date the corn was planted in 2013 and when the soybeans were planted in 2014. The Tilled Dec. 3 arrow indicates when the tillage pass was made.

WHAT WE LEARNED

- Clothianidin residue appeared in all samples: runoff, surface soil, soil-pore water and groundwater.
- Soil movement and contamination of groundwater from runoff is most prevalent in vertical-tillage systems at higher treatment concentrations (e.g. Poncho 500).
- No-till fields release less clothianidin into groundwater.

THE STUDY: Nutrient Management with Cover Crops

Do cover crops reduce input costs while maintaining yield?

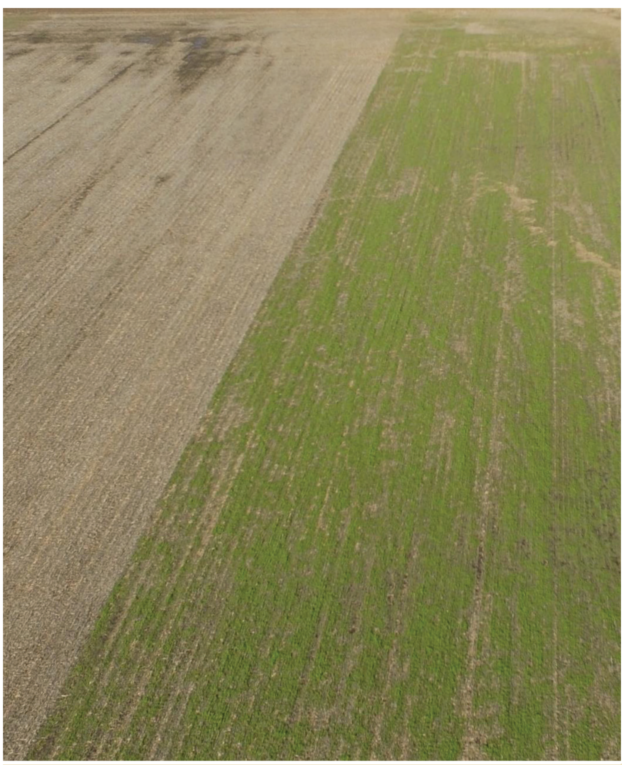
THE GOAL: Demonstrate the benefits of using cover crops for large-scale production.

LOCATION: Central Illinois **DURATION:** 2012–Present

The potential of cover crops has been demonstrated in small-scale university research plots and other settings, but what about their viability for large-scale production on typical production agriculture farms? With that question in mind, we funded field-scale research to explore nutrient management with cover crops in an effort to provide real-world, practical information for farmers. Would using cover crops provide enough benefit that farmers could reduce their input costs while still maintaining yield numbers?

HOW WE DID IT

For our initial study, we chose two farm sections totaling 100 acres in central Illinois and divided the acreage into 11 fields. We selected ground with both continuous corn and corn/soybean rotation. All fields are no-till.



The legume hairy vetch is shown on one field within our 107-acre research study.

SUCCESSES

After only one year our results are promising: We produced 221 bushels of corn with just 100 lbs. of nitrogen and a legume cover crop—in this case hairy vetch—and 216 bushels of corn with 100 lbs. of nitrogen with no cover crop. This compares to a standard nitrogen application rate of approximately 180 lbs. per acre.

During one trial year, we saw a 55 bushel per acre increase compared to fields without cover crops, which we are working to produce consistently. These are preliminary results but still notable and promising. Hairy vetch costs $48.75 per acre for seed and $14.50 per acre for custom drilling, so at $4.00 corn, we have to see yields increase by 16 bushels per acre to reach breakeven on hairy vetch cover crops ahead of corn.

While we didn't reach breakeven overall on the cover crops on this single test year, we did find that nitrate levels in fields with hairy vetch and a 100-lb. nitrogen application were nearly double the nitrate levels in the other fields.

We also observed good hairy vetch nodulation, which is important for nitrogen uptake the following spring. Plus, nitrate levels in cover crop fields remained much more stable than those without hairy vetch, ensuring that plants receive the nutrients they need throughout the production cycle.

In addition, we noted significant soil health improvements using cover crops, including more earthworms, less compaction, decreased runoff and reduced winter erosion. While it is difficult to put a specific value on these benefits, they will eventually improve the condition and production of the farm.

CHALLENGES

The biggest challenge we faced came from chemical use. While some chemicals say they're safe for cover crops to be planted the following year, many factors can negate this guidance. Chemical carryover caused issues in our cover crop production, which became apparent when we overlaid the chemical spray map. A small sprayer skip in the field had hairy vetch that grew to its full potential. The rest of the field that was covered by the sprayer had hairy vetch growth that was reduced from herbicide residual.

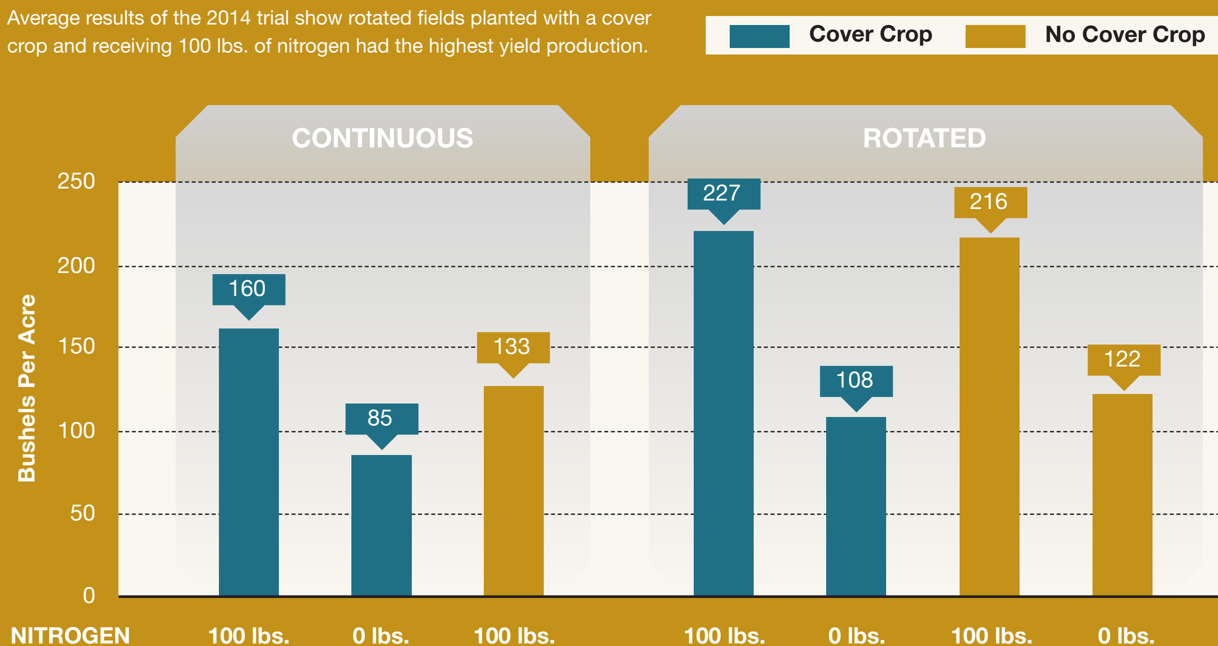
Field location and inherent characteristics also presented challenges. The farm sections we chose seem to be consistently wet. We will continue to monitor this to ensure that planting into subpar conditions doesn't undermine the results.

Perhaps most significantly, we face an ongoing learning curve in the management of cover crops on a large scale. Due to the nature of cover crops, we spent two years believing an underperforming crop was the result of winter kill, when in fact it was due to chemical carryover. This management learning curve has extended longer than we expected. Still, we continue to refine our management and production techniques to suit large-scale cover crop production.

Good hairy vetch nodulation in fields that received a 100-lb. nitrogen application—a predictor of good nitrogen uptake the following spring.

FIGURE 1: COVER CROPS ADD UP

Average results of the 2014 trial show rotated fields planted with a cover crop and receiving 100 lbs. of nitrogen had the highest yield production.



Color variance clearly depicts the differences in nitrogen levels and cover crops.

FIGURE 2: CORN-SOYBEAN ROTATION

FIELD 1
- No nitrogen
- Legume cover crop
- Typical herbicide regimen

FIELD 2
- 100 lbs. of N
- Legume cover crop
- Typical herbicide regimen

FIELD 3
- No nitrogen
- No cover crop
- Typical herbicide regimen

FIELD 4
- 100 lbs. of N
- No cover crop
- Typical herbicide regimen

FIELD 5
- No nitrogen
- Legume cover crop
- Cover crop-safe herbicide regimen

FIELD 6
- 100 lbs. of N
- Legume cover crop
- Cover crop-safe herbicide regimen

FIELD 7
- No nitrogen
- No cover crop
- Cover crop-safe herbicide regimen

FIELD 8
- 100 lbs. of N
- No cover crop
- Cover crop-safe herbicide regimen

CAN WE BANK NITROGEN?

Based on our limited experience, a legume cover crop ahead of soybeans seems to improve yields. Rotating soybeans with a legume cover crop shows a bump in bean yields—in some years, the soybean yield increase is greater than the corn yield increase. This leads us to ask, “Can we ‘bank’ nitrogen?” Can we stack nitrogen benefits on top of each other, so that we see a benefit to soybeans, even though we primarily look for nitrogen-fixing cover crops to benefit the corn crop? We will continue to monitor the effects of the hairy vetch cover crop ahead of soybeans and nitrogen levels.

WHAT WE LEARNED

- Hairy vetch added yield in the no-nitrogen environment and increased yield potential in general. As we work through our management learning curve, we look forward to finding the ideal break-even point. At $4.00 corn, we have to increase yield by 16 bushels to break even on using hairy vetch ahead of corn.
- Nodulation on vetch was good in all fields, which is promising for nutrient uptake the next spring.
- We are seeing soil health improvements using cover crops. These include an increase in the number of earthworms and a decrease in compaction, runoff and winter erosion.

We are seeing soil health improvements using cover crops, including a decrease in winter erosion.

A CUSTOM CRIMPER

Our choice for cover crop termination was using a roller crimper. A key part of our study: commissioning a custom-built, 60-foot crimper from John Deere. This allowed us to crimp directly ahead of or directly behind the planter. Until this point, research studies done in small plots used 6- to 8-foot crimpers—nowhere near what the average farm would use, raising questions about whether the methods were actually transferrable to typical farming operations. Even though this machine was built as a one-off prototype for this research, John Deere's collaboration demonstrates large agricultural companies are committed to finding ways to make conservation agriculture work for farmers. This specially-built crimper not only helped us get good, consistent contact with the root to terminate the cover crop, it let us accomplish this in Illinois' short window for crimping. (Crimping must be done at a specific plant maturity point, when the stem is brittle enough to be broken off.)

To test crimping at a field-scale that would be typical for many farmers in the U.S., we first had to build the equipment. John Deere provided a stripped-down, 1770 24-row planter bar, which included the hydraulic and electrical systems but no planting equipment. We then had it custom-fitted with roller crimper drums. This created a 60-foot crimper capable of folding to a transport width of 12-feet wide. We can typically roller crimp 30 acres per hour with this custom tool bar.

THE STUDY: Nutrient Management with Fertilizer

Is there an effective replacement for standard fertilizer treatments in farm production of corn?

THE GOAL: Show the viability of ESN as a replacement for NH_3 in anticipation of potential governmental regulation.

LOCATION: Central Illinois **DURATION:** 2011–2016

While farmers would be open to a fertilizer alternative to anhydrous ammonia, most options haven't been studied on a large scale. So we began exploring alternatives to NH_3 in a typical farm setting. Our goal was to find an alternative that would provide the fertility crops' requirements, be environmentally friendly and pose little danger from erosion and runoff affecting water quality. ESN (Environmentally Smart Nitrogen) seemed to meet our criteria, but to date, it hasn't been studied in a large-scale production environment, only in the small-scale, controlled environment of an academic study. With this in mind, we structured research on ESN's potential as an alternative to anhydrous ammonia, starting with corn production.

HOW WE DID IT

The study encompassed two farm sections in central Illinois, broken into 16 fields approximately 8 to 13 acres each for a total of 160 acres. While we studied fields in both continuous corn and corn/soybean rotation, soil nitrate tests were performed only on corn treatments.

ESN is typically top spread using a commercial fertilizer dry spreader, but we wanted to investigate application methods using more standard farm equipment, to better manage costs. We used an air drill to incorporate ESN into the soil on no-till fields. The goal is always to provide nutrients at the best time and to provide nitrogen when plants need it most in the growth cycle.

We compared fall- and spring-applied ESN with fall- and spring-applied anhydrous ammonia, as well as a side-dress application of anhydrous. ESN was incorporated as a stand-alone, while the fall and spring NH_3 was applied along with the nitrification inhibitor N-Serve, which delays the microbial conversion from ammonium to nitrate. Sidedressing doesn't require N-Serve, as spring soil temperatures are typically above 50°F, the threshold where inhibitors work best.

FIGURE 1: WHAT IS ESN?

ESN (Environmentally Smart Nitrogen) is urea at 44% nitrogen (44-0-0), enrobed in a time-release coating. As temperatures warm and moisture increases, nitrogen is gradually released into the soil. With ESN, crops receive more of the nitrogen they need at the times they need it most.

SUCCESSES

Spring-incorporated ESN was one of the top-yielding treatments in our study—on par with fall and spring anhydrous and sidedress. Spring ESN produced yields as high as 233 bushels per acre.

In addition, tissue tests showed that plants from treated areas with incorporated ESN had moderate nitrate levels, meaning nitrate would still be available in the soil for the next crop at the beginning of the growing season, when plants need it most.

Our research included fields in both continuous corn and corn/soybean rotation. As expected, the corn/soybean rotated fields showed yield increases over continuous corn, even though nitrogen treatments were not applied in soybean years, and fields treated in the fall, both ESN and NH3, also produced higher yields.

CHALLENGES

Because the polymer coating around ESN relies primarily on soil temperature to determine when to release fertilizer, fall weather can be a challenging factor for ESN's effectiveness. With fall's extreme weather volatility, particularly in the Midwest and in central Illinois where this study was performed, wide temperature swings are common. If an unseasonably warm and moist fall progresses, as it did during this research, ESN can be released into the soil too early in the fall and start disappearing before the crop can begin utilizing it for growth after spring planting.

Anhydrous ammonia, in contrast, requires bacteria to convert ammonia to immobile nitrite and then mobile nitrate. Below 50°F, the bacteria is not active, so the conversion is held off until spring when soil temperatures warm. With ESN already in the ammonia state, no bacteria conversion is required—ESN is movable as soon as it releases from the capsule. So, it's likely that the fall ESN treatment released nitrogen too early, allowing it to leach through the soil profile.

In addition, while yields with ESN and NH_3 appear to be comparable, in the current price situation anhydrous has an economic edge. In our trials, per acre costs for fall anhydrous ranged from $3.94 to $4.57, while ESN came in at $4.26 to $4.83 for fall and $4.47 to $4.69 for spring.

WHAT WE LEARNED

- Spring-incorporated ESN yields were on par with fall- or spring-applied anhydrous ammonia.
- Spring-incorporated ESN achieves similar yields to anhydrous ammonia, but at current prices, it is not as cost effective.
- Incorporated ESN yields outperformed top-dressed ESN applications.
- Fall-applied ESN had the most volatility due to weather factors.

THE STUDY: Returning Crop Production to Flooded Soils

GRANT *FUNDED*

What is the best way to reclaim soils for farming after flooding?

THE GOAL: Help farmers understand soil damage to determine recovery efforts needed to begin farming again after major cropland flooding.

LOCATION: Nebraska **DURATION:** 2012

Following the 2011 Missouri River flood, producers faced challenges returning cropland to profitable production. Unlike most floods that rise, crest and recede in two weeks or less, this flood kept hundreds of thousands of acres in Nebraska and surrounding states under 4 to 5 feet of water for three to four months. Further complicating matters, it hit at the most inopportune time, from late May to mid-September. To help farmers understand how to best reclaim those soils and what fertility strategies might be necessary, we funded a 2012 study through the University of Nebraska–Lincoln.

HOW WE DID IT

To assess the potential soil damage and determine input effectiveness, researchers established corn and soybean plots to determine the effects of phosphorus application rate and method, cover crops, nitrogen rate (corn) and inoculant choice (soybeans). The theory was this would also help provide effective fertility strategies for recovering soils after floods.

CHALLENGES

Challenges farmers faced included removing debris, repairing erosion (sometimes 6 feet of soil was lost) and removing excess sand (as much as 4 inches). Following the flood, producers and operators reported that water didn't soak in as it had previously, leading researchers to speculate that the soil structure and possibly the soil microbial population may have been impacted.

Flooding creates erosion, sedimentation and causes the accumulation of crop residue. Significant flood events, like the one pictured above, can result in the loss of nutrients, leaching and migration of herbicides and pesticides.

WHAT WE LEARNED

- Researchers weren't sure what to expect after prolonged flood conditions, so they were pleased to find that nutrient levels in most of the soils tested at normal levels. While revegetation rendered cover crops unnecessary, they did provide the benefit of stabilizing the soil and preventing more erosion.
- Due to the extreme variability across soil conditions in the flooded areas, researchers determined extraordinary fertility treatments weren't required for the fields to be productive. Their studies did support the use of cover crops to prevent soil erosion—an important component to successful conservation ag strategies.

Floods that cover a significant area for an extended period of time can cause several negative effects: large ditches can form as water recedes; flooded soils can affect microbial functions; sand can cover top soil; and debris can be deposited in areas that may affect a field's ongoing use.

THE STUDY: Developing Climate Resilient Corn Production Systems

Can drought-tolerant corn hybrids provide a solution to yield drawdown in high-stress environments?

THE GOAL: Compare drought-tolerant corn hybrids with standard hybrids, and develop protocols for producing in high-heat, low-water conditions.

LOCATION: Arizona **DURATION:** 2014–2016

Environmental stress is one of the least controllable variables impacting farmers' yields. Corn in particular is highly sensitive to drought, especially during the critical flowering time, when just a 40% decrease in water can cause yields to drop by over 39%. With extreme weather events like drought, genetics and breeding are focusing more on drought tolerance to help take some of the instability out of production, while seed planting guidelines advocate planting the hybrids at higher seeding rates to achieve higher yield. Growers need to know how these new hybrids fit into their production strategies—and how the new varieties stack up against those without the DT (drought-tolerant) feature. With that in mind, the Howard G. Buffett Foundation in collaboration with Purdue University began field trials to compare varieties and develop production strategies for managing drought stress.

HOW WE DID IT

On 20 total acres, we used drip-tape irrigation to create three treatments simulating different levels of drought stress:

- **Non-Stress:** 100% of evapotranspiration (ET) supplied.
- **Mid-Stress:** A mild whole-season (WS) drought with 75% of ET supplied from growth stage V6 to R6.
- **High Stress:** A severe drought during the critical period (CP) with only about 30% to 35% of ET supplied from growth stage V14 to R2 CP.

We examined 10 hybrids, including four DeKalb hybrids (two DT and two non-DT) and six Pioneer hybrids (three DT and three non-DT). We paired DT and non-DT hybrids from each breeder in similar maturity groups.

We tested four planting densities: 20,000; 25,000; 30,000; and 35,000 plants per acre. The common practical seeding rate for these hybrids falls between 30,000 and 35,000. A popular theory is that DT hybrids are so much more drought tolerant that their yields are less likely to be negatively impacted by higher plant populations.

HOW BREEDERS GIVE HYBRIDS DROUGHT TOLERANCE

Pioneer DT hybrids*

- Silk earlier
- Lower ASI values
- Higher kernel weights

*Compared to Pioneer non-DT hybrids.

DeKalb DT hybrids**

- Silk later
- Higher ASI values
- Higher kernel numbers

**Compared to DEKALB non-DT hybrids.

We found no evidence that optimum plant densities were higher in DT than in non-DT hybrids. DT hybrids do not consistently yield higher at the highest density level. At the lowest plant density of 20,000 plants per acre, Pioneer DT hybrids averaged about 12 bushels per acre more than their similar-maturity non-DT hybrids, and DeKalb DT hybrids averaged about 10 bushels more than their similar-maturity non-DT hybrids. This was true in the non-stress treatment with full watering as well as the mid-stress and high-stress treatments with restricted watering. In fact, the yield advantage for DT hybrids was highest in almost every case at the lowest plant population, suggesting DT hybrids seem to be more capable of taking advantage of good conditions when they exist.

SUCCESSES

Our field studies showed drought can reduce yields by as much as 37.4%. Yield reductions due to drought stress treatments tended to be smaller in DeKalb hybrids than in those from Pioneer, but other variables may have affected this result.

With DT versus non-DT varieties, we saw only a small average grain yield advantage for DT hybrids. Averaged over each drought treatment, Pioneer DT hybrids yielded up to 9.4 bushels per acre higher than their non-DT hybrids, and DeKalb DT hybrids yielded up to 12.7 bushels than comparable non-DT hybrids.

To increase yield, the hybrids presented different physiological characteristics, including when they silked, anthesis-silking interval (or ASI, an indicator of stress), kernel weight and number of kernels.

WHAT IS EVAPOTRANSPIRATION?

Evapotranspiration is a great measure of a crop's water stress level. Evapotranspiration is the sum of transpiration and evaporation. Transpiration is evaporation of water from plant leaves; evaporation is water lost to the atmosphere from the ground. When we combine this moisture loss together, we get evapotranspiration. As soil moisture levels decline, so does evapotranspiration. So 100% evapotranspiration can be categorized as no- or low-stress conditions.

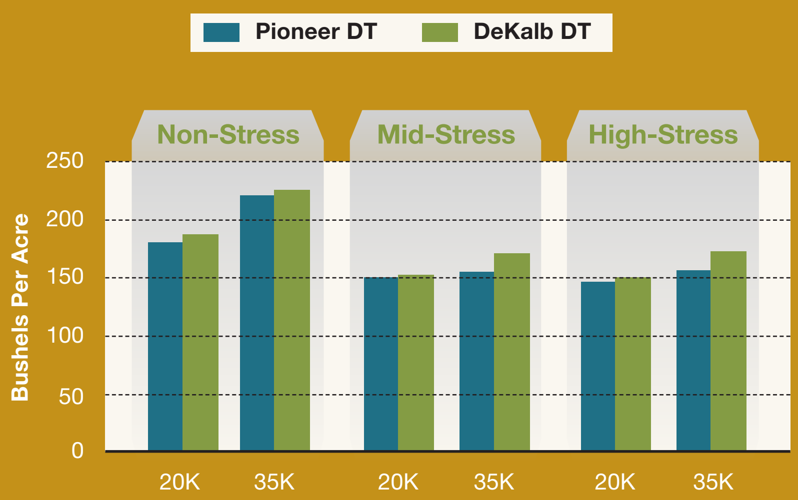
CHALLENGES

In 2015, high and frequent rainfall made it difficult to simulate drought conditions. This is reflected in that year's data, which shows little response to drought conditions.

WHAT WE LEARNED

- Drought reduced yields by as much as 37.4%.
- We found little evidence that drought-tolerant hybrids should be planted at higher densities than those recommended for non-drought tolerant hybrids.
- The yield advantage for drought-tolerant hybrids was highest in almost every case at the lowest plant population.

FIGURE 1: DROUGHT-TOLERANT HYBRIDS PRODUCE HIGHEST YIELDS AT LOWEST POPULATIONS



Three-year average grain yields (bu./ac.) of drought tolerant and non-drought-tolerant hybrids under high-, mid- and non-stress conditions at different plant populations.

THE STUDY: Center Pivot Irrigation for Rice Production

Can center pivot irrigation be used to produce rice using less water in soils that won't hold floodwater?

THE GOAL: Show how center pivot irrigation can be used for rice production in areas where water availability or soil texture does not allow traditional flood production.

LOCATION: South Africa and Missouri **DURATION:** 2011–2013

Rice is typically produced in fields flooded from planting to harvest—using about 2.5 times as much water as wheat or corn crops. In fact, some estimates say rice production accounts for 40% of irrigated water use worldwide. But in much of the world, limited water resources combined with poor soil conditions make rice production a challenge, potentially leading to increased food insecurity in areas where rice is a diet staple. Center pivot irrigation could be a potential solution for farmers to produce rice in water-challenged areas and in areas with medium and coarse textured soils that cannot hold the floodwater needed for traditional rice production. We partnered with Dr. Gene Stevens at the University of Missouri for a study to find out center pivot irrigation's potential for farm-scale usage in rice production.

HOW DID WE DO IT?

We conducted studies in two field locations in Alma, South Africa, and Portageville, Missouri, that cannot hold floodwater for growing rice. The Missouri field does not hold floodwater because it is located on the New Madrid fault. Earthquakes in 1811-12 created fissures filled with intruded sand. For rice production, fields with sand fissures are like a bathtub with the drain open, making flooding impossible. Irrigation rates were based on crop water use calculations from electronic weather stations.

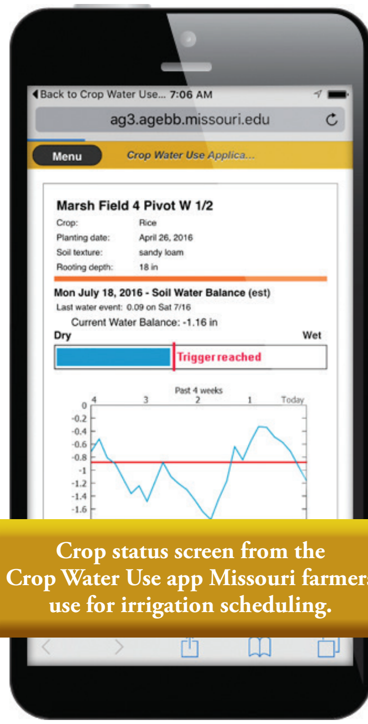
We used Lindsay and Valmont center pivot irrigation systems, and each center pivot had solenoid controls at each sprinkler head to apply prescribed variable rates. We created a soil water balance spreadsheet, using daily short crop evapotranspiration (ET) estimates from an electronic weather station. Daily balances were calculated similar to a checkbook, with irrigation entered as deposits and ET as debits. Typically, irrigation was triggered every third day when the soil water deficit was 0.75 inch, or every other day when the soil water deficit was 0.5 inch. Rice was rotated with soybeans and cotton to minimize pest buildup.

Sampling Nerica-4 rice roots from test plots under center pivot in South Africa. Nerica varieties are crosses between Asian and African rice species.

SUCCESSES

In 2013, we produced 161 bushels per acre using the 0.5 inch soil water deficit, compared to 153 bushels per acre with the 0.75 inch deficit. These are good rice yields for conventional varieties. Hybrids often produce over 200 bushels per acre depending on the growing season. Total water usage was similar for both, but we needed more pivot rotations in the field when we used the 0.5 inch level. We saw the highest yields at irrigation rates that replenished 100% or 120% of evapotranspiration. Results were more variable in South Africa than Missouri. Standard rice herbicides were not available in South Africa making weed control more difficult.

The soil water balance spreadsheet was made into an Extension smartphone app, pictured at right, which the University of Missouri provided to Missouri farmers at no charge. The Crop Water Use app works for rice, corn, soybeans, cotton and peanuts. In 2017, 111 farmers used it for irrigation scheduling on 498 fields in Missouri. In some critical watersheds, the Natural Resources Conservation Service provides incentive funds for farmers to use the program for irrigation management. Work is ongoing to provide the app to farmers outside of Missouri using daily data from electronic atmometers (ETgages), which are 1/10 the cost of conventional weather stations. Daily evapotranspiration readings from atmometers average 15% lower than weather stations, which will need to be calibrated into the app.



Crop status screen from the Crop Water Use app Missouri farmers use for irrigation scheduling.

Hybrid long-grain rice growing with center pivot irrigation in southeast Missouri. The same research was conducted in South Africa.

WHAT WE LEARNED

- Rice under center pivot irrigation produced the highest yields when pivots were triggered at a 0.5 inch soil water deficit.
- Silicon deficiency can be a concern for disease resistance when producing rice with center pivot irrigation.
- A silicon fertilization program for use with center pivot irrigation is needed and is under continued development.
- More breeding and testing is needed to improve rice varieties suited to production under center pivot irrigation.

We saw the highest yields at irrigation rates that replenished 100% or 120% of evapotranspiration.

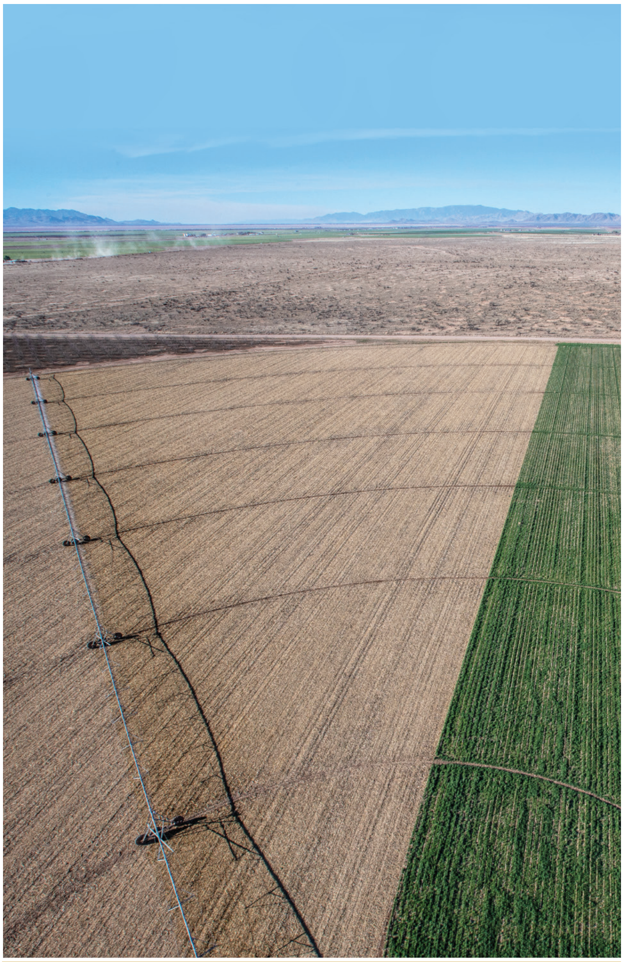
CHALLENGES

Sandy soils present unique challenges for rice production. They are low in organic matter as well as cation exchange capacity, making proper herbicide rates essential to prevent crop damage and kill weeds. Soil nematodes thrive in sandy soil, but the most common chemical to control them, carbofuran, can prevent rice from metabolizing propanil herbicide. To prevent this, we applied carbofuran at least two weeks after the last application of propanil.

Another challenge came at the most basic level: genetics. U.S. rice varieties have been bred for flood irrigation. While more research is needed to develop varieties compatible with center pivot irrigation, we were able to obtain more drought-tolerant varieties screened by USDA-ARS rice breeding. Through field trials in Missouri and South Africa, we found the two best options and are crossing these with other rice varieties.

Silicon is an abundant element in most soils but is usually found in insoluble forms that plant roots cannot uptake. Silicon availability increases when fields are flooded for traditional rice production and is important for resistance to rice diseases like blast. As our project proceeded, we found that silicon deficiency was a concern, both in small and large farm-scale plots, with levels repeatedly showing below the critical 34,000 mg Si kg-1 target. To address this, we broadcast calcium silicate fertilizer at six different rates.

In 2018, the EPA approved a new Dow herbicide, Loyant™, which improves weed control in pivot rice. Rice yields may be higher using this herbicide because it does not cause rice crop injury like old chemicals and is able to control tough weeds like pigweed.



Another challenge came at the most basic level: genetics. The majority of U.S. rice varieties have been bred for flood irrigation, not pivot irrigation.

THE STUDY: Comparing Irrigation System Efficiencies

What type of irrigation is most efficient for crop production?

THE GOAL: Compare subsurface drip, low pressure center pivot and flood (also referred to as furrow or surface) irrigation to determine which uses water most efficiently in corn production and how capital costs could influence short versus long-term decision making.

LOCATION: Arizona **DURATION:** 2015–Present

Irrigation is one of a producers' most important, and variable, tools, so knowing which type of watering system offers the most efficiency could have a significant impact on net profit. Tight commodity prices make maximizing your inputs more important than ever before. Efficiencies drive product development, too, though testing is often at a small academic scale. So how would the three common irrigation systems compare on efficiency in a scaled-up version from University test plots? We wanted to find out.

HOW WE DID IT

We took three adjacent 5-acre plots with similar soil types and compared three different types of water delivery methods for efficiency in corn production. We set up one under a center pivot, another using sub-surface drip and the third as flood.

The center pivot was set up with low elevation drop nozzles with 30-inch spacing and nozzles for 70 gallons per minute (gpm) delivery.

The sub-surface drip was set up with 30-inch tape spacing and 12-inch emitter spacing and installed at a depth of 9 inches with each emitter to deliver 0.25 gallons per hour (gph).

The flood field was set up using 10-inch gated aluminum pipe with 30-inch gate spacing.

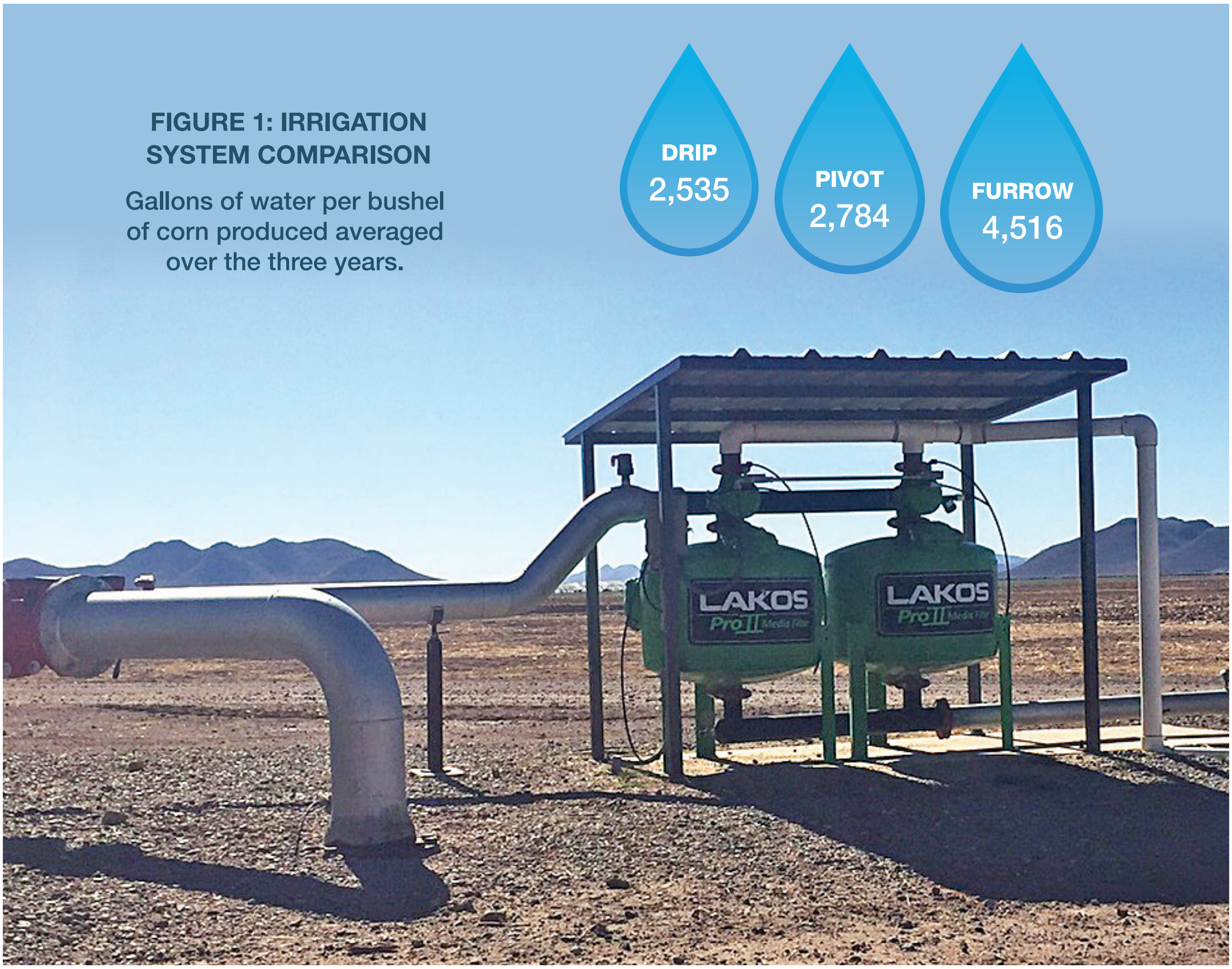
Each field has two soil moisture sensors installed after planting that wirelessly deliver soil moisture content every 30 minutes from a depth of 4 inches down to 48 inches deep. In addition to the moisture probes, the plots have a weather station on-site to assist with calculating and monitoring the daily evapotranspiration as well as rainfall events.

The fields are planted with the same variety, maturity and population of corn each season. Approximately two weeks after germination, each watering event for each field was dictated by the soil moisture reading from their respective soil moisture probes, with water applied to elevate their respective soil moisture content back to between 0.50 inch up to 1 inch, depending on the current and forecasted weather conditions.

Fertilizer used on these three fields has consistently been UN32 injected into the water delivery system, and all fields received the exact same total amount of fertilizer throughout the entire season. We compiled daily crop water use (crop evapotranspiration) values for the corn crop under each of the three irrigation systems.

FIGURE 1: IRRIGATION SYSTEM COMPARISON

Gallons of water per bushel of corn produced averaged over the three years.



RESULTS SO FAR

Our research has shown that the drip field has typically been the most efficient as measured by water use and also produced the highest average yield of the three fields, with the pivot running a close second. The flood field is and has been the most inefficient use of water and the most labor intensive. With current water costs in southeast Arizona ranging from $90 to $120 per acre foot, water is definitely a key expense. Although the main focus of this experiment was water use efficiency, it is worth noting the management time differences between the three different fields. The drip and pivot systems require minimal oversight, aside from checking nozzles on the pivot, scanning for leaks on the drip early in the season and monitoring the flow rate to the drip. The flood system takes significantly more management throughout the growing season to ensure water is flowing to the end of the plot in each and every row in a timely manner.

WHY DO WE CARE ABOUT ET?

Evapotranspiration (ET) is actually two processes combined: Water is lost from the soil surface through evaporation and from plants by transpiration. As rainfall levels fade, and especially in drought conditions, plants can't extract water fast enough to keep up with ET. ET is an important component of irrigation scheduling and management.

Drip and pivot systems require less management oversight compared to flood irrigation systems. Pivots can also be controlled operated remotely via digital device such as a computer, tablet or smart phone. In many situations, pivots are the most practical irrigation system on larger fields when factoring in capital costs, maintenance and water use. However, this decision is also crop dependent.

> The drip field produced the highest average yield of the three, with pivot a close second.

CHALLENGES

Initially, system maintenance was a big issue with the drip field because of gophers. Pocket gophers regularly chewed holes in the drip tape, requiring maintenance when it came to monitoring flow rates and repairing leaks. The gophers also impacted the flood field when one of their tunnels became exposed in a furrow line, diverting that water underground and away from the plot. The furrow field also required significant management to keep every row flowing to the end of the field, by opening up a row that was clogged with residue or adjusting gates to change the flow. When the gopher issues are minimized, less maintenance is required.

From a capital cost perspective, the drip system is significantly more per acre to install than either the flood or center pivot. Based on our current research, the minimal average yield differences indicate that the pivot system is the most practical method.

WHAT WE LEARNED

- Subsurface drip is the most efficient irrigation system in terms of water use, followed closely by the center pivot system, with flood irrigation as the least efficient.
- Optimal irrigation water management is key, particularly with drip and center pivot.
- Flood systems are the most management intensive of the three irrigation options, offer the fewest control options and consistently have the highest water use costs.

Flood irrigation requires significant field prep–furrows carrying the water down each production row must be built up by a lister. The water flows from one end of the field to the other by gravity so furrows must be designed with the correct slope and kept clear of blockages.

THE STUDY: Water Use Efficiency from Real-Time Irrigation Monitoring

GRANT FUNDED

Does irrigation monitoring technology provide enough savings at farm-scale?

THE GOAL: Show the potential water savings growers can achieve with real-time irrigation monitoring.

LOCATION: California, Other States & Mexico **DURATION:** 2006–2013

With events such as the extended drought in California, efficient water use management has become an even more vital component of a grower's production strategy. Real-time irrigation monitoring may be an important tool for farmers, but studies to date have been more predictive in nature, rather than measuring the results of practical application at farm-scale. We wanted to understand the potential to use real-time irrigation monitoring to improve water use management on the average farm.

HOW WE DID IT

We enlisted research partner California State University, Fresno to gather and analyze six years of real-time irrigation monitoring data for 3,000 farmers, located in California, Oregon, Washington, Idaho, Texas, Florida and Mexico farming a combined 188,552 acres.

Using the first full year of data as a base or control, the data was separated into different time periods by location and compared against the base year to see which water use trends would emerge.

The data analysis was supplemented with interviews of farmers who were using real-time irrigation monitoring to record their perspectives on its benefits, its limitations and what its future potential might hold.

SUCCESSES

The analysis revealed that producers using irrigation monitoring systems have the potential to see up to a 6% water savings in an average year. In wetter years, that number could reach 9%.

Through the research, which was funded by the Howard G. Buffett Foundation, Cal State Fresno was able to develop a simple online water savings calculator that farmers can use to estimate the potential water savings they can achieve by using irrigation management technology. The calculator is available at *http://rtimstudy.azurewebsites.net/#/interact*.

Irrigation monitoring systems can potentially provide up to 6% water savings in an average year.

Irrigation systems have become a vital component in growers' production strategies.

FIGURE 1: AVERAGE CHANGE IN WATER USE BY YEAR, ADJUSTED FOR AVERAGE RAINFALL

With the soil moisture monitoring system present, growers increased their water use by 3% to 6% in dry years and reduced their water use by 9% in wet years, relative to a hydrologically average year.

	To: 2010 Average	2011 Wet	2012 Dry	2013 Dry
From: 2009 Average	-6%	-9%	3%	6%

CHALLENGES

Weather plays a major role when it comes to irrigation and water conservation. Climate heavily influences irrigation decisions, and in years that are drier or wetter than normal, those choices can vary from the norm. Because the data collected did not account for microclimates, it was adjusted using a best-estimate of standard behavior.

In addition, many growers do not place the irrigation monitoring system in the same place each year. The variable geographic placement itself could affect water use and needs, but could also mean the system is monitoring different crops year-over-year. The raw data could not be adjusted to account for those factors.

While the growers surveyed were pleased with the savings irrigation monitoring systems provide, cost remains a concern. For this reason, many have not adopted the technology for their entire farm, choosing instead to target it in a specific section of concern, such as areas where they previously didn't have visual confirmation.

WHAT WE LEARNED

- Real-time irrigation monitoring systems have the potential to reduce water use by 6% in an average year.
- Savings could be as much as 9% in wetter years.
- Cost of the technology remains a concern for farmers.
- More controlled field studies are necessary to more accurately reflect microclimate and crop use differences.

THE STUDY: The Non-Green Revolution

What are the limits of using hybrid seeds to address food insecurity in the developing world when other inputs are not readily available or affordable?

THE GOAL: To demonstrate that using hybrid seeds alone is not adequate for long-term productivity gains.

LOCATION: Illinois, Arizona, South Africa **DURATION:** 2010–2017

As concerns for global food insecurity increase, some policymakers and development professionals have suggested that solving the problem is as simple as increasing access to genetically superior seeds for farmers in the developing world. But are better seeds alone enough to make a difference? Can smallholder farmers in the developing world successfully produce crops year after year without reliable or affordable access to the appropriate fertilizer, herbicides and other modern farming techniques? What role can conservation ag techniques play in restoring soil productivity? We conducted studies in South Africa, Illinois and Arizona to find answers.

HOW WE DID IT

In 4- to 21-acre plots, we established two trials of continuous corn using conventional tillage consistent with methods of smallholder farmers in developing countries. Within these plots, one field received no fertilizer and only manual weed control (conditions you'd most likely see in developing countries); one field was treated with 50 lbs. of nitrogen and a complete weed control program; and a control field, which was managed using a program to maximize production.

In Arizona and South Africa, fertilizer rates were 0, 50 and 150 lbs. of nitrogen per acre. In Illinois, rates were 0, 50 and 180 lbs. of nitrogen per acre. Arizona and South Africa fields were pivot irrigated; Illinois fields were not irrigated.

CHALLENGES

Simply providing better seed is not enough. Many hybrid seeds have key traits bred into them to achieve specific performance, which requires the proper use of nutrients to meet their yield goals. Using hybrids will deplete nutrients faster since they are designed to produce higher yields.

After five years, we saw a clear decline in yield in field one—to essentially zero yield. Our zero nitrogen Illinois field dropped from a high of 30 bushels per acre in 2011 to just 0.3 bushels per acre in 2014. In South Africa, after just two years, the 0 N field yield dropped below 11 bushels per acre.

Farming through the generations. A woman among a team of farmers prepares a field for planting in Angola.

Our Arizona plots saw nutrient depletion, but not as rapidly as the Illinois or South Africa plots. Our working theory is that this is due to the irrigation in Arizona, which must provide a small amount of required nutrients. We can compare this to developing countries, where you see a similar result in fields near rivers or floodplains compared to those farther inland.

The Illinois zero nitrogen plot (on fields in excess of 4% organic matter content) saw the most aggressive yield declines and was consistently very low in yield—nearly zero, demonstrating that even with improved seed, fertilizer inputs and weed control are critical to crop production. This also showcases the difficulties farmers in developing countries face with degraded soils—even with access to improved seed, they face significant deficits. Success doesn't lie in the seed alone—it takes a holistic, integrated, comprehensive approach to produce successful results.

WHAT WE LEARNED

- Improving access to genetically modified seeds (GMs) isn't enough to make farmers successful.
- After five years using GM seed without fertilizer or herbicides, yields decline to essentially zero.
- Proper fertility makes or breaks crop yields—even limited use of inputs produces improved yield.

Left: A farmer in South Africa manually applies fertilizer. Right: A primitive-style planter is used in Senegal–it may be a slight improvement over planting by hand but it is unlikely to achieve uniform and even seed placement, good seed-to-soil contact or consistent seed cover.

THE STUDY: Soil Restoration—The New Brown Revolution

GRANT FUNDED

Can depleted soils be restored by utilizing cover crops and non-synthetic techniques?

THE GOAL: Use inputs and techniques commonly available in developing countries to restore productivity in soils exhausted by continuous farming without nutrient replacement.

LOCATION: Illinois **DURATION:** 2015–Present

HOW WE DID IT

In 2015, we began studying three of the same pieces of ground from our Non-Green Revolution study, six fields approximately 4 acres each, to see if we can restore soil health using conservation ag measures: without synthetic fertilizer, using different crops and different rotations. To do this we're using inputs and techniques that are available for use in Africa, such as cowpeas as a cover crop and crops including corn and millet in rotation.

Each field is subdivided into sections receiving zero, 28% and 100% fertilizer with and without cover crops, and planted in rotation with corn and millet. The 28% rate was applied as follows: corn, 50 lbs. of nitrogen per acre; and millet, 25 lbs. of nitrogen per acre. The 100% rate was applied as follows: corn, 180 lbs. of nitrogen per acre; and millet, 90 lbs. of nitrogen per acre.

RESULTS SO FAR

In the first year of our efforts to restore soil productivity, we saw corn yields increase by 28 bushels per acre in zero input areas by adding herbcide. In addition, the millet with a higher level of nitrogen and cover crops yielded about 5 bushels per acre more than the national average. By year three, corn yields went up to 53 bushels per acre after adding cowpeas ahead of the corn crop. As we have said previously, conservation ag techniques typically produce the most benefits after multiple years of use.

Our hope is that we will be able to develop a conservation ag strategy that allows smallholder farmers in the developing world to improve soil health and productivity on the land they currently farm. Today many smallholders resort to clearing new pieces of land, farming it for a few years until the soil nutrients are depleted, and then moving on to another piece of land with no intention or knowledge of how to restore soil health. That's not a sustainable strategy for global food security. That's where we believe conservation ag can succeed—in helping them bring productivity back to the land.

SUCCESSES

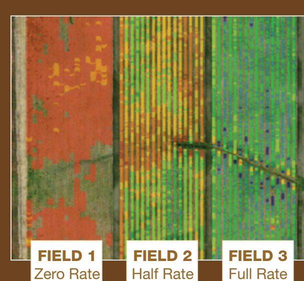
It is important to note, especially for the benefit of developing countries, using genetically superior seeds with even a limited use of appropriate inputs produced an increase of three to 460 times in yield compared to using genetically superior seeds with no additional inputs. Profits increased with additional fertilizer and weed control, showing that yields increase as sufficient nutrients are supplied. Even limited use of fertilizer and effective weed control can significantly increase food security for subsistence farmers.

These are field results; they do not take into consideration access to inputs, available credit, impact of markets, etc., which all have a significant impact on subsistence farmers.

Yield map (below) and typical ears from the plots (left), with zero rate to full rate applications shown left to right. Here you can clearly see the impact nutrients and proper management have on productivity.

Bushels Per Acre

0-40	161-200
41-80	201-240
81-120	241-280
121-160	



WHAT WE LEARNED

- Weed control is critical for successful production.
- We're cautiously optimistic about using natural regenerative processes to restore soil productivity in depleted soils.

THE STUDY: Water Smart Agriculture in Central America

GRANT *FUNDED*

How can conservation agriculture impact food security in extreme climates?

THE GOAL: Improve productivity and resilience of small-scale farmers through improved soil health and water management.

LOCATION: Dry Corridor of Central America in El Salvador, Guatemala, Honduras and Nicaragua

DURATION: 2016–2021 (ongoing)

El Salvador, Guatemala, Honduras and Nicaragua have some of the highest levels of food insecurity in Latin America and are among the areas in the world most vulnerable to extreme weather events. Severe droughts and excessive rainfall have occurred with increasing frequency over the past 50+ years, and harmful farming practices such as overgrazing and burning crop residue have further degraded soils. In recent years, farmers have experienced losses of staple corn and bean crops as high as 80% due to midsummer droughts. In the face of high and increasing levels of poverty and food insecurity, people living in rural areas are migrating out of Central America in search of better economic opportunities.

Given this context, adoption of sustainable soil health and water management practices can have a substantial impact on food security. We are working with a team of agronomists and scientists from Catholic Relief Services to train producer groups in conservation agriculture (CA) with an emphasis on cover cropping and soil fertility management. When combined with soil testing, soil fertility management and cover crops, CA can boost the biomass production that improves soil properties and soil quality. With restored soil health and better retention of soil moisture, CA producers in rainfed farming areas of the Dry Corridor can increase crop yield and net income, thereby improving food security and economic opportunity while reducing migration incentives.

HOW WE DID IT

The Water Smart Agriculture (WSA) program manages soil health in order to better manage water use through practices that increase infiltration of rain and storage of water in the soil. Practices are based on the three elements of conservation agriculture: no-till, crop rotation and continuous soil cover by retaining residues and/or planting cover crops. Together, these practices increase water infiltration, soil moisture retention and therefore make more water available to the crop. The result is increased production of crop biomass for increased yields and greater returns to the soil for restoration of soil health.

Working with farmers to evaluate results, we used a set of soil health, crop productivity and economic indicators in side-by-side comparisons between WSA practices and conventional farming practices on 1,128 small-farm corn plots. Practices include 4R nutrient management (right source of nutrients, right rate, time and place), control of soil acidity (liming), conservation agriculture and additional cover cropping.

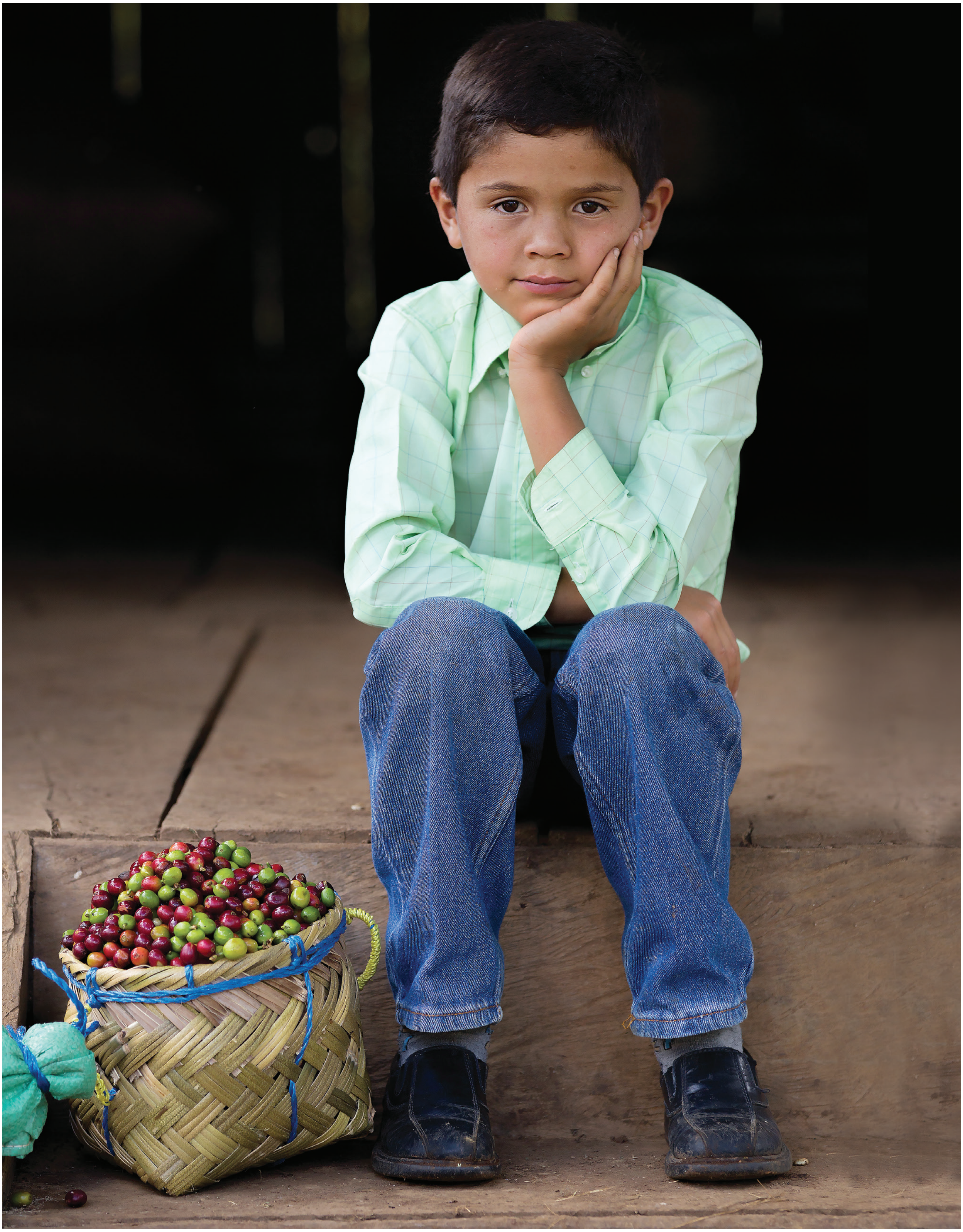


FIGURE 1: CORN YIELD

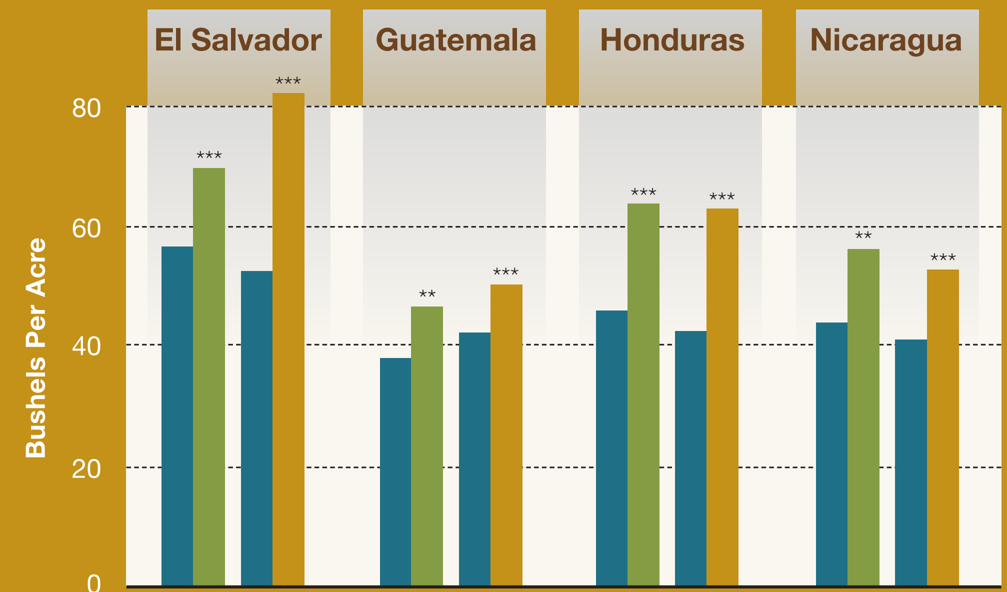
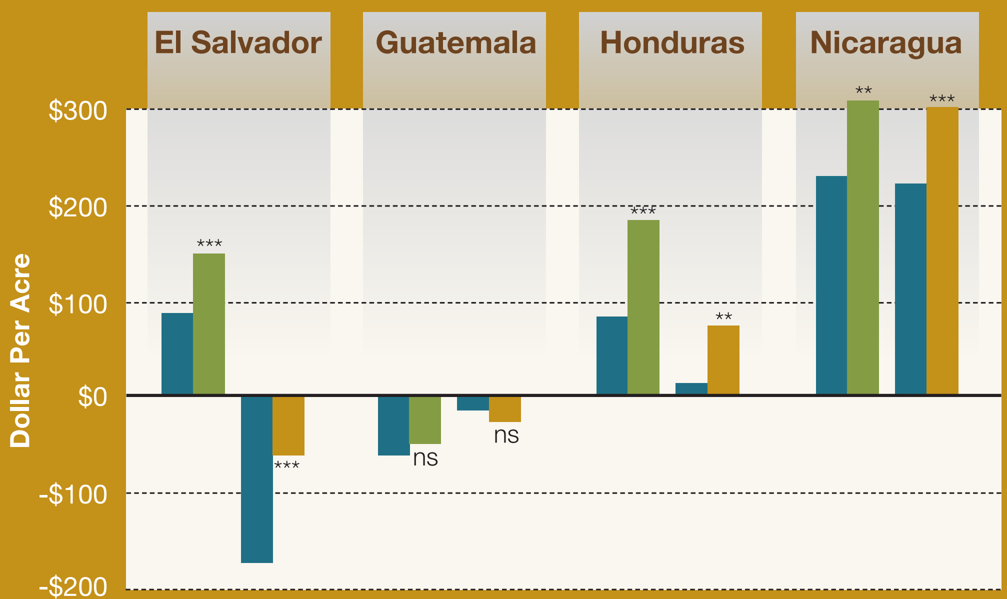


FIGURE 2: NET INCOME



1,128 on-farm trials where farmers' standard practices were compared to 4R fertility management, conservation agriculture and cover cropping. Statistically significant differences are shown where *** refers to $P<0.0001$ and ** refers to $P<0.001$, indicating a high degree of confidence that the observed differences were due to the treatment effects.

- Farmer Practice
- 4R + Conservation Ag
- 4R + Conservation Ag + Cover Crop

SUCCESSES

In all four countries, the WSA approach outperformed conventional practices. Improved soil fertility management and use of CA practices to restore soil health helped farmers improve soil moisture and drainage in variable weather and can increase yields by up to 50% (Figure 1). In particular, cover crops in rainfed areas pushed corn systems to higher productivity and showed the important role of biomass production in feeding the soil with more nutrients and greater soil biological activity.

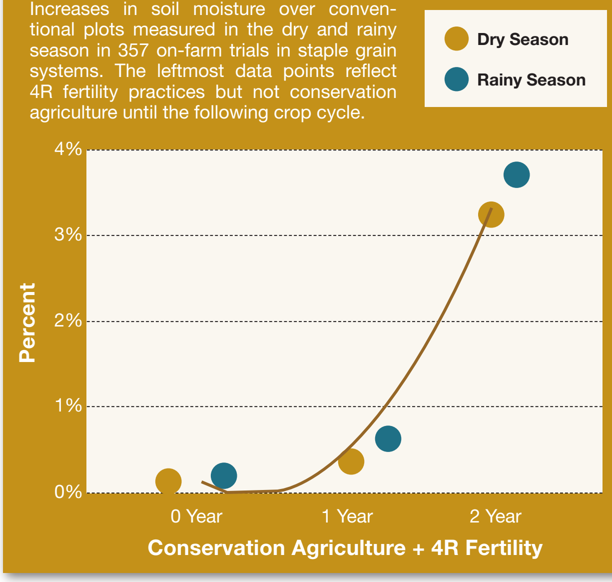
The new practices increased yield on all farms, and significantly raised net income for corn farmers in Honduras and Nicaragua (Figure 2). The increase in bean yields has pushed farmers in all four countries over the historic one metric tonne per hectare (36.74 bushels/acre) yield threshold that has long been an agricultural development goal in the region.

After only two crop cycles, soil moisture was significantly higher at critical points in the growing season. Figure 3 indicates that CA is important to soil moisture retention during the dry season. It also shows that it takes time to detect significant changes in soil moisture. Though not presented here, soil organic matter trends are increasing, with significant changes after two years of conservation agriculture with cover crops.

Because of WSA, the region's largest and most important agricultural institutions have prioritized soil and water management in their agricultural development plans. As the only funders implementing WSA principles at this scale, our goal is in part to connect research with real world practices. With this initiative, we are building a case for implementing conservation agriculture across the entire region.

FIGURE 3: INCREASE IN SOIL MOISTURE

Increases in soil moisture over conventional plots measured in the dry and rainy season in 357 on-farm trials in staple grain systems. The leftmost data points reflect 4R fertility practices but not conservation agriculture until the following crop cycle.



WHAT WE LEARNED

- Biomass production is key to improving soil health, productivity and income.
- Practices must be evaluated for site-specific characteristics and usefulness.
- Although the benefits to soil moisture and yield are often seen immediately, substantial changes in soil organic matter often take several years.
- Soil restoration programs need to promote practices that provide both short- and long-term benefits to stimulate and motivate farmers to continue investing in soil health.
- WSA practices are proving to be an effective approach to boosting small-scale farm productivity and improving resilience to extreme weather events in the Dry Corridor of Central America.

THE STUDY: Coffee Assistance for Enhanced (CAFÉ) Livelihoods

GRANT FUNDED

Can smallholder coffee farmers improve production and yields to capture market opportunities in high-value coffee markets?

THE GOAL: To support over 7,000 smallholder farmers in Mexico and Central America by strengthening their livelihoods through sustainable participation in high-value coffee markets.

LOCATION: El Salvador, Guatemala, Mexico, Nicaragua

DURATION: Three years (2008–2011)

Coffee farming represents the leading livelihood for tens of thousands of smallholder farmers in Central America and Mexico. For many, coffee income is uncertain, due to volatile prices, falling yields and rising production costs. With poor production practices, limited capacity for post-harvest activities, weak farmer organizations and lack of access to essential services, smallholder farmers don't have the proper tools to take advantage of market opportunities in the U.S. and Europe. We partnered with Catholic Relief Services (CRS) to create Coffee Assistance for Enhanced (CAFÉ) Livelihoods, a three-year, four-country initiative to help bolster the livelihoods of 7,100 smallholder coffee farmers in 20 farmer organizations in El Salvador, Guatemala, Nicaragua and Mexico by increasing the value of their coffee and deepening their engagement in high-value coffee markets.

HOW WE DID IT

CAFÉ Livelihoods was designed to help farmers increase their income through improved production practices, including organic and shade farming; increased coffee productivity, yields and quality; expanded access to small-scale infrastructure to achieve added-value; improved financial management of smallholder cooperatives; and diversified markets.

CAFÉ Livelihoods worked with coffee-industry allies on an integrated and market-based approach to access the entire coffee value chain, providing technical assistance in areas of coffee production, post-harvest processing and market management. CAFÉ Livelihoods also enhanced farmer education by providing ongoing technical assistance, financial and business management training and learning events at the local, regional and national levels.

Technical assistance was provided for coffee production, post-harvesting processing and market development while strengthening the management capacity and competitiveness of participating farmers' organizations. In addition, CAFE Livelihoods worked to help smallholder farmers maintain organic certification and to provide the incentives and support necessary for more farmers to move toward organic certification.

The CAFE Livelihoods strategy for improving post-harvest performance involved simultaneous investment in post-harvest investments. These included construction, rehabilitation or upgrade of essential post-harvest infrastructure such as wet mills and/or drying facilities at the farm or community level; implementation of processes that minimize losses and preserve quality, including improvements in wet milling, drying, coffee collection, storage and transportation; and the communication and coordination required to implement them. Together, these interventions were designed to help farmer organizations earn more revenue from their coffee by ensuring it met minimum specialty coffee standards for processing and quality.

In addition, the CAFÉ Livelihoods strategy incorporated industry outreach efforts such as attending the SCAA Expo and Symposium; co-facilitating an interest group discussion at Let's Talk Coffee, one of the most important events on the specialty coffee calendar; and participating in the design of Food Security Solutions, the first multi-stakeholder coffee-industry event devoted exclusively to the issue of hunger in coffee-growing areas.

Additional positioning was accomplished through the CRS Coffeelands Blog, which was created to help CAFÉ Livelihoods establish an influential voice within the coffee industry on issues related to smallholder farmer livelihoods and to contribute to the industry's evolving work on issues of sustainability at origin.

SUCCESSES

CAFÉ Livelihoods helped thousands of smallholder farmers increase productivity over the short term through improved agronomic practices and over the medium-term through heavy investment in renovation for aging coffee fields.

Farmers for whom we tracked productivity data for all three years of the project achieved an average increase in productivity of 19%, from a baseline value of 898 lbs. per hectare to a final value of 1,070. These productivity gains were achieved as farmers were simultaneously earning higher average prices for their coffee, and correspond to an increase in the average revenue per hectare from \$851 to \$2,234. The project's renovation efforts positioned participating farmers for nearly \$50 million in increased incomes over the next 10 years.

Beyond the benefits that accrued to the 7,100 participating farmers, an estimated 35,000 family members also benefited from higher and more stable incomes.

More than 3.8 million new coffee shrubs were planted during the life of the project, with another 1.4 million more plants in nurseries and/or funded with farmer-managed revolving funds capitalized by the project that were deployed over the following three crop cycles. We estimate conservatively that this renovation will generate an additional nearly 28 million pounds of new coffee and more than \$47 million in coffee revenue for smallholder farm families over 10 years.

WHAT WE LEARNED

- Average increase in annual household coffee revenue for project participants was \$2,967.
- Participating cooperatives recorded more than \$6.3 million in increased sales revenues.
- Exports of high-value coffee increased by 1.6 million pounds.
- One of the pilot programs produced a fine coffee that netted the highest coffee price recorded in the project at the time.
- The project's renovation efforts positioned participating farmers for nearly \$50 million in increased incomes over the next 10 years.

THE STUDY: Developing a Research Platform for Generating New Crop Varieties and Cropping Systems Adapted to the High-Stress Soils of Eastern and Southern Africa

***GRANT** FUNDED*

How can smallholder farmers access more soil nutrients to increase production?

THE GOAL: Identify plant root systems that more effectively utilize soil nutrients and test stress-tolerant cropping systems to improve production for smallholder farmers.

LOCATION: South Africa **DURATION:** 2009–2014

We partnered with Pennsylvania State University (PSU) on our research farm in South Africa to test new crop varieties and cropping systems adapted to the high-stress soils of eastern and southern Africa. Poor soil fertility and limited access to productive soils is a challenge for most African farmers, but is a particularly limiting factor for smallholder farmers, who typically cannot access or afford technical expertise and inputs. Our research sought to identify ways to adapt crop varieties and cropping systems to better utilize existing soil nutrients.

HOW WE DID IT

Ukulima ("conservation agriculture" in Swahili), our 9,200-acre farm located in Limpopo Province, South Africa, served as the real-world test site for PSU to begin testing and evaluating maize and common bean varieties to identify root systems that better maintain yields in drought-prone and low-fertility soils. We worked with PSU to establish the Ukulima Root Biology Center (URBC) to improve crop yields in the drought-prone, infertile soils characteristic of much of Africa.

The goal was to identify the key root traits with the potential to improve plant uptake of water, nitrogen and phosphorus, and deploy these traits in traditional non-GMO breeding programs. The project also included training of African scientists and students in root biology.

We set up a fully functional field research lab, with capabilities including image analysis, soil and plant chemical analysis, sample preparation (drying, freezing, lyophilizing, grinding) and crop physiology research (gas exchange, soil/plant water status).

A number of international partners were engaged, including ETH Zurich, Switzerland; ICRISAT, India; IIAM, Mozambique; CIAT, Colombia; CIMMYT, Mexico; University of Nottingham, United Kingdom; Bunda College, Malawi; Forshungszentrum Julich, Germany; Japan International Research Center for Agricultural Sciences; the University of Limpopo, South Africa; University of Wisconsin; and Georgia Institute of Technology, USA.

PSU also examined integrated crop management systems, combining stress-tolerant genotypes and soil conservation to enhance productivity and fertility using local inputs.

Students in South Africa examine and sort roots from their research plot.

SUCCESSES

This project was extremely successful, discovering new root traits with significant value for breeding maize and other crops for improved yield potential with limited application of nitrogen fertilizer. In addition, researchers developed new platforms to identify variation for root anatomical and architectural traits for mature plants under field conditions.

In maize, researchers determined genetic variation in the number and angle of nodal roots and in the anatomical characteristics of the root cortex are related to substantial improvement in crop growth under low nitrogen conditions.

In the common bean, genetic variation in basal root whorl number is associated with better growth under drought and low phosphorus stress. These results were enhanced using laser ablation tomographic equipment, which captured the specific maize root anatomical features. Screening of crop germplasm for root traits at Ukulima has identified regions of the plant genome that control these root traits in maize, common bean and cowpea, and has identified parental sources of root traits that are being used by crop breeding programs in Southern Africa.

The results of this study are already having an impact in breeding more drought-tolerant, phosphorus-efficient legumes in Africa and Latin America, and in more drought-tolerant, nitrogen-efficient maize lines in Africa. They will be invaluable tools for breeding more resilient, resource-efficient crops.

WHAT WE LEARNED

- Specific parts of the plant genome control root traits in maize, common bean and cowpea.
- Identification of key root traits help breed maize and other crops with improved yield potential under limited nitrogen soil conditions.
- New platforms exist to identify root anatomy variations that enable plants to mature under challenging field conditions.

THE STUDY: Tortillas on the Roaster

GRANT FUNDED

Can conservation ag practices help smallholder farmers mitigate the impact of changing weather patterns?

THE GOAL: Show how no-till and nutrient management strategies can help reduce the vulnerability of smallholder farmers affected by changes in climate and more volatile weather patterns.

LOCATION: Central America

DURATION: One-time study projecting climate scenarios over the next 60 years

In an effort to understand long-term, systemic issues affecting agriculture in Central America, we commissioned a study by Catholic Relief Services and research partners the International Center for Tropical Agriculture and the International Maize and Wheat Improvement Center to examine the effects of changing weather patterns on maize and bean farmers in Guatemala, El Salvador, Honduras and Nicaragua.

The Tortillas on the Roaster (TOR) study is designed to help governments and aid organizations develop policies and strategies to improve Central America's food security while addressing challenges the region faces due to extreme weather events.

Smallholder farmers in Central America have long voiced their concerns about how extreme and increasing weather events compound the challenges they face. Changing weather patterns increases the vulnerability and resiliency for more than 1 million smallholder farmers in the region who depend upon maize and bean production for their survival. Until TOR, it was impossible to predict the long-term implications of changing weather patterns and what it will mean for the kinds of crops that can be grown, where and under what conditions.

HOW WE DID IT

The research team pulled historical climate data for Central America from WorldClim's database, then generated climate projections by applying 19 different global circulating models. The team then validated projections during field visits to 12 sites across four countries.

They ran climate projections for two time frames: a near-term scenario for 2010 to 2039 and a mid-term scenario covering 2040 to 2069. The TOR model projects that mean temperatures will rise by 1°C by the period 2010 to 2039 (2020s) and by 2°C by the period 2040 to 2069 (2050s). Minimum and maximum daily temperatures will rise, and water deficits will increase due to less precipitation and higher evapotranspiration rates.

Then, the researchers made predictions of future maize and bean production based on these climate scenarios. They used known physiological characteristics of maize and bean varieties, and their responses to heat and drought stress, to determine the effects of the climate projections on the crop performance of maize/beans. The main parameters analyzed were temperature (minimum/maximum), rainfall and soil quality. As part of this study, they tested approximately 10 new bean varieties recognized for drought tolerance.

Next, the research team gathered socioeconomic information from smallholder farmers in 12 communities across the four study countries. The information they collected included main agriculture activities and trends, main sources of food and income, an analysis of household and community capital (assets), and a general perception of future communal strengths and threats. They also surveyed 120 smallholder households in each country to determine a vulnerability index score for each household including the level of exposure of the maize/bean cropping system to changes caused by fluctuating weather patterns, the level of sensitivity of the household to the change in maize/bean production and the resilience or adaptive capacity of the household.

SUCCESSES

This is the first study of its kind to make specific and local level predictions. One of the study's biggest insights is that the largest maize losses are predicted to occur where there is already severe soil degradation, which could reduce production by one-third in affected areas. For beans, there is a serious threat of reduced rains during the planting season in September, which could reduce yields in all four countries by as much as 25%. The report estimates maize and bean production losses at about $20 million per year by 2020, with likely downstream effects on retail value chains and export markets.

The report underscores the importance of one of the Foundation's leading interventions for smallholder farmers in developing countries: the adoption of conservation agriculture techniques. TOR found that good soil management practices promoted by conservation agriculture, including no-till and nutrient management strategies, protect farmers against the impacts of extreme weather changes and drastically reduce the negative impact on crop yields. By contrast, farmers who continue to use traditional farming methods would likely suffer devastating losses that would make farming as a livelihood untenable.

The results of the study fill a critical gap in our knowledge of the impacts of changing weather patterns on maize/bean production in Central America. With this new information, stakeholders can now shift from a position of uncertainty to a position of risk management. The study shows there is reason for optimism: if action is taken now, the most severe impacts can be managed.

CHALLENGES

Data on pests and diseases are scarce, and the underlying interactions are not yet fully understood, so this factor was dropped from the study.

WHAT WE LEARNED

- Smallholder farmers are highly vulnerable to changing weather patterns.
- Soil quality is negatively affected by extreme weather.
- Losses from weather-related events could reduce production by as much as one-third in affected areas.
- Retail value chains and export markets will likely be affected.
- Good conservation ag soil management practices like no-till and nutrient management will be critical for protection against crop yield impacts.
- Producers who continue with traditional farming methods will likely suffer losses that make it impossible to support themselves and their families.

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