Identifying and promoting opportunities for the success of Minnesota corn growers is a key part of our mission. As part of that mission, Minnesota Corn Growers Association (MCGA) and Minnesota Corn Research & Promotion Council (MCR&PC) are committed to funding independent research that seeks to enhance opportunities for Minnesota corn farmers by improving agricultural practices and creating new markets for what they produce.

Minnesota corn checkoff dollars are funding a wide range of research projects that directly affect local business and families, including the development of value-added products, the management of corn inputs, issues related to ethanol use, the evaluation of genetic traits, and the relationship between agricultural management practices and water quality.

This publication highlights completed research projects jointly funded by MCGA and MCR&PC that address each of these topic areas. Results of these studies are made available to growers in multiple formats, including this Minnesota Corn Research Summary. Growers are invited to apply this information to their own farm operations to help optimize best management practices and increase yield and returns.

For more information on projects funded by Minnesota’s corn organizations, contact Adam Birr, Ph.D., at the MCGA office: abirr@mncorn.org or 952-233-0333.
Minnesota corn farmers and their families work hard to produce high quality crops while preserving soil, water and air resources for future generations. That’s why farmers are proud to invest millions of dollars each year through the corn checkoff to fund third-party research that helps farmers protect the environment. Because of your investment, we’re farming smarter than ever. Learn more at mncorn.org.
Objectives
With high seed costs and fluctuating grain prices, it is critical that corn growers make sound decisions about planting and the use of purchased inputs. Research was conducted in southern and west-central Minnesota to evaluate:

- Corn response to plant population
- Determine whether corn response is affected by planting date, hybrid maturity, and row width

Study Description
Various combinations of row spacing, hybrid maturity, hybrid traits, plant population, and planting date were evaluated in replicated field trials in high-yield continuous corn systems near Lamberton, Morris, and Waseca, MN, from 2009 through 2011.

Results and Discussion
Corn response to plant population was not affected by row width or hybrid relative maturity (RM). However, when corn planting was delayed until late May, a higher final plant population was needed to maximize yield (Figure 1). Across all trials, yield was maximized with a final stand near 33,000 plants/acre, and was not reduced with plant populations as high as 44,000 plants/acre.

Narrow rows did not increase corn yield, but yield was greater with mid- and late-maturity hybrids than early-maturity hybrids (Figure 2). The early-, mid-, and late-maturity hybrids evaluated in this study were 95-, 101-, and 105-day RM in southern Minnesota, and 91-, 94- and 99-day RM in west-central Minnesota.

There was little yield reduction when planting was delayed until mid-May, but yield dropped off quickly as planting was delayed beyond mid-May (Figure 3). Yield reductions due to delayed planting were less than expected.
The Dynamic Threat from Corn Rootworms: Risk, Transgenics, and Management in Changing Production Situations (2009)
Ken Ostlie and Bruce Potter
University of Minnesota

Objectives
- Confirm whether or not Bt resistance was occurring in Minnesota
- Evaluate Western Corn Rootworm (WCR) susceptibility to Bt-RW corn
- Compare performance and returns to various corn rootworm management options in fields that have experienced Bt-RW performance problems

Study Description
Beetles from three performance-problem fields in Minnesota (one near Eyota and two near Luverne) collected in 2009 were evaluated for shifts in susceptibility to Bt-RW proteins using diet bioassays.

An on-farm study in 2010 examined comparative performance of Bt traits in a Cry3Bb1 (VT Triple™) problem field for declines in root injury protection and reduced efficacy, as measured by beetle emergence. The study featured all Bt traits with and without an overlay of tefluthrin (Force™ 3G) applied in-furrow.

Results and Discussion
Bioassays completed by Custom BioProducts, an independent contractor conducting all bioassays of this type across the U.S. for all seed companies. Egg viability was insufficient to bioassay the Eyota collection. Bioassays were only run on the two Luverne collections. Both Luverne populations had significantly higher LD50 s than the standard lab colony. The LD50 increased from 43 to over 171 μg/cm2, a resistance ratio over 4X for the Luverne B population, and to over 102 μg/cm2, a resistance ratio nearly 2.5X for the Luverne C populations.

Efficacy of Bt-RW traits at the Dennison MN site were compared to a nearby susceptible population at Rosemount, MN. At Rosemount, VT Triple provided about 91% control (relative to the RR isolate), SmartStax about 96% control compared to Force 3G on refuge corn at 38% control. In contrast, efficacy dropped to 25% for VT Triple and 64% for SmartStax in the prospective resistance field. Efficacy and emergence delays in the Dennison field remained largely unchanged for mCry3A (3000GT) and Cry34/35 Ab1 (P9910XR) performance on susceptible populations.

In contrast, the delay experienced in VT3 and SmartStax (typically 13-14 days) dropped dramatically where performance problems occurred. The reduced efficacy and loss of emergence delay confirm that the Dennison population is resistant to Cry3Bb1. No signs of cross-resistance to mCry3A or Cry34/35 was detected.

Bruce Potter, Jeff Coulter, Dale Hicks, Seth Naeve, Dan Kaiser, John Lamb, Jeff Strock, George Rehm, Dean Malvick and Kent Olson
University of Minnesota

Objectives

- Collect and analyze data on soil fertility and biotic changes in various input strategies from a high-yield study at the University of Minnesota Southwest Research and Outreach Center. Specifically we ask:
  - Can yield be increased by higher management?
  - Can higher management minimize the rotation effect for corn?
  - Can extended rotations increase soybean yield?
- Initiate new long-term high-yield studies at multiple locations in Minnesota
- Create a framework to identify input components for high yield production systems

Study Description

This study was located at the University of Minnesota Southwest Research and Outreach Center from 2004 to 2010. Four corn soybean rotations were established for this study: 1) Continuous Corn, 2) Corn-Corn-Soybean, 3) Corn-Soybean and 4) Soybean-Corn. Rotation 4 was included to ensure at least one soybean crop was present each year. Space did not permit a cyclic counterpart to treatment 2 and all rotational combinations for both crops are not present every year. These rotations were selected to look at yield penalties for non-rotated corn and whether an extra year of corn (rotation 2) would improve soybean yields over an annual rotation.

A high-yield or intensive management was compared to a management system more commonly practiced by area farmers. The high-yield system included manure, higher corn seeding rates and split nitrogen applications in corn. Hereafter, these management schemes are referred to as “intensive management” and “common practices management”. The resulting eight treatments are shown in Figure 1.

Data collected included annual yields, soil tests and disease assessments.

Results and Discussion

Intensively managed continuous corn (manure and high fertility and plant populations) out-yielded conventionally managed rotated and continuous corn but yielded less than intensively managed rotated corn. Both corn and soybean yields were increased by rotation but more than two years of corn were needed to produce a soybean yield response over an annual rotation. Corn appeared to respond to higher fertility and consistently responded to banded applications of sulfur with increased yield. Soybeans did not respond to direct fertilizer application but yields were higher where previous corn crops were intensively managed.

This study provides evidence that sulfur can reduce yields if other parts of the system are limiting. Nitrates accumulate in the soil profile during corn production. Soybeans reduced residual soil nitrates when included in the rotation.

![Figure 1. Experimental design (rotations and management levels) for high-yield studies at Lamberton, 2004-2010.](image-url)
Transforming Corn from a Commodity Crop to a Higher-Energy, Multipurpose Biofuel Crop (2010)
Rex Bernardo, Ronald L. Phillips, Nathan M. Springer, Roger Ruan and Douglas G. Tifanny
University of Minnesota

Objectives
- Discover the underlying genetics of Korean High Oil
- Breed high-oil corn lines with good agronomic performance
- Develop and analyze a process for biorefining high-oil corn
- Determine the economic feasibility of producing and biorefining high-oil corn

Study Description
We utilized a high-oil corn strain obtained by the University of Minnesota from North Korea, via a South Korean intermediary. We applied DNA fingerprinting and sequencing technology to try to discover the underlying genes for high oil, used standard field-breeding procedures to develop a non-transgenic high-oil line, compared high-oil and normal kernels for their biorefining properties, and examined different cost scenarios for growing high-oil corn hybrids and extracting oil by different techniques.

Results and Discussion
On average, the DGAT gene from Korean High Oil (KHO) increases kernel oil by roughly one percentage point. Converted versions of three yellow dent lines with the DGAT gene from KHO have been developed.

KHO is genetically distinct from three other known high-oil strains in the U.S.: Illinois High Oil, Iowa High Oil, and Alexander High Oil (AHO).

AHO-1, a pure-breeding line developed from KHO, has 22% oil and a relative maturity of about 112 days. We have obtained the genome sequence of AHO-1.

Kernel oil percentage in a hybrid can be reliably manipulated by introducing different proportions of KHO germplasm. Oil percentages with different amounts of KHO in the hybrid were 4% oil in yellow dent corn, 8% oil in a hybrid with ¼ KHO germplasm, 12% oil in a KHO × yellow dent corn hybrid, 16% in a hybrid with ⅔ KHO germplasm; and 20% in pure KHO.

In several KHO × yellow dent corn hybrids, yield drag in field trials was 18% (28 bushels per acre). This amount of yield drag per percentage-point increase in oil is consistent with the 10% yield drag among the high-oil hybrids (with 8% oil) in the 1990s.

In biorefining to maximize biodiesel yield, tempering with short time soaking in an acid solution helped germ separation. Direct in situ transesterification removed the oil extraction step, resulting in significant cost savings.

Different sequential combinations of milling (M), germ separation (S), fermentation (F), and in situ transesterification (T) can be used to produce bioethanol and biodiesel. The M-F-T route produced the highest bioethanol yield while the S-T-F route produced the highest biodiesel yield.

KHO hybrids have lower starch yields per acre, and this deficiency in starch could be a major issue because of lower ethanol production per acre. Instead of yielding 2.75 gallons of ethanol per bushel in the case of conventional corn, the two best KHO hybrids would yield 1.84–1.96 gallons of ethanol per bushel.

Figure 1. Small endosperm (top) and large embryos (bottom) for Korean High Oil.
On-Farm Validation of Economically Optimum Corn Plant Populations (2010)

Jeff Coulter and Doug Holen
University of Minnesota

Objectives
Evaluate corn hybrids with differing levels of ear-flex potential and whether the economically optimum plant population differed for these hybrids.

Study Description
This study evaluated corn response to seeding rate using field-scale equipment in west-central Minnesota (near Ashby) in 2010. Two hybrids were evaluated: 1) Pioneer P8581R (85-day hybrid with less potential for ear-flex); and 2) Pioneer 39N98 (89-day hybrid with greater potential for ear flex).

Results and Discussion
Yield was maximized with a final stand of 43,000 plants/acre for the 85-day hybrid, and with 37,300 plants/acre for the 89-day hybrid. In comparison, the optimum seeding rate was on average about 5,000 seeds/acre higher with the 85-day hybrid than the 89-day hybrid. The economically optimum seeding rates in this study were higher than anticipated, particularly for the 85-day hybrid. These results support recent findings from research trials in northwestern Minnesota, where the optimum seeding rates have been higher than those in southern and central Minnesota. This may be related to the shorter-season (<90-day) hybrids grown in this region.

<table>
<thead>
<tr>
<th>Seeding rate (seeds/A)</th>
<th>P8581R (85-day)</th>
<th>Pioneer 39N98 (89-day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Final stand</td>
<td>Grain yield</td>
</tr>
<tr>
<td></td>
<td>(plants/A)</td>
<td>(bu/A)</td>
</tr>
<tr>
<td>20,500</td>
<td>18,100</td>
<td>147</td>
</tr>
<tr>
<td>25,500</td>
<td>22,900</td>
<td>160</td>
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<tr>
<td>30,500</td>
<td>25,800</td>
<td>172</td>
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<tr>
<td>35,500</td>
<td>30,200</td>
<td>183</td>
</tr>
<tr>
<td>40,500</td>
<td>34,700</td>
<td>184</td>
</tr>
<tr>
<td>45,500</td>
<td>38,300</td>
<td>189</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>2,000</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 1. Corn response to seeding rate near Ashby, MN, in 2010.

*NS, not significant at the 0.05 probability level.
On-Farm Evaluation of Four Tillage Systems in a Corn-Soybean Rotation (2010)
Jodi DeJong-Hughes and Jeff Coulter
University of Minnesota

Objectives
Provide on-farm evaluation of four tillage systems in a corn-soybean rotation to address concerns of:
- Reduced fuel usage
- Enhancing or maintaining soil productivity
- Saving time by decreasing the number of passes across a field
- Increasing yield

Study Description
A range of tillage treatments were evaluated at on-farm trials near Clarkfield and Carlisle, MN. The field-length replicated plots received fall and spring tillage treatments using field-scale equipment. Residue coverage after planting was measured immediately after planting and stand counts and corn height were measured at the V3-V4 corn stage.

Results and Discussion
Clarkfield– A three-year summary of surface residue coverage and corn and soybean yields is reported in Tables 1 and 2. There were differences in residue coverage among tillage systems in both crops. However, corn and soybean yields did not differ among tillage systems. Cost per acre was calculated using new equipment prices, depreciation, maintenance, tractor usage, fuel consumption, and labor.

Carlisle– A three-year summary of surface residue coverage and corn and soybean yields is reported in Tables 3 and 4. In 2011, there was a difference in residue levels after planting soybeans, with no-till leaving more residue than vertical tillage. However, tillage and residue levels did not affect soybean yield. The two-year average of corn planted into soybean residue showed significantly less residue in the spring field cultivation while strip till and vertical till maintained 60% residue levels. Yields ranked strip till > field cultivation > vertical till at the 10% confidence level.

Over the three-year period of this study, high-residue systems like strip-till resulted in higher levels of surface residue coverage while having better or no significant impact on plant population and yield of corn and soybean. Cost per acre was reduced when less passes were made across the field.

Table 1. Three-year (2010-2012) average surface residue coverage after corn planting, corn yield, and tillage cost by tillage system at Clarkfield, MN.

Table 2. Three-year (2010-2012) average surface residue coverage after soybean planting, soybean yield, and tillage cost at Clarkfield, MN.

Table 3. Residue coverage and soybean yield for Carlisle location for 2011.

Table 4. Residue coverage and corn yield average over two years (2010 and 2012) near the Carlisle location.

Lizabeth Stahl and Jeff Coulter
University of Minnesota

Objectives

- Determine if row width (30-inch vs. 22-8-inch twin rows) influences corn grain yield, harvest moisture, stalk lodging, and economic return.
- Determine if corn planted in twin-rows has a greater response to an increased seeding rate than corn planted in 30-inch rows.

Study Description

On-farm trials were initiated the spring of 2010 in southern Minnesota near Welcome and Wilmont. Treatments were arranged in a 2 x 3 factorial experiment in a randomized complete block design with four replications. Two row widths (30-inch vs. 22-8-inch twin rows) at three target plant populations (33,000, 38,000, and 43,000 plants per acre (ppa)) were evaluated. Corn stand, stalk lodging, grain yield, moisture, and test weight were evaluated. ANOVA was used for statistical analysis and means compared using Fisher’s Protected LSD at the 0.05 significance level.

Results and Discussion

Stalk lodging was greatest at the highest population but was not significantly affected by row spacing.

Grain moisture was not affected by row spacing averaged across populations, or population averaged across row spacing. Slight differences were found among row spacing x target population combinations, but differences detected were of little practical significance.

Test weight was not affected by population and row spacing, and there was no significant interaction between these factors for test weight.

Averaged across site years, yields were greater in twin rows at the highest population compared to the lower populations, although this result was strongly influenced by one site year. This indicates that corn has the potential to take advantage of a higher planting population better in twin rows than in 30-inch rows. The likelihood of a yield response, however, would need to be considered against the increased cost involved with planting at such a high population.

<table>
<thead>
<tr>
<th>Target Population</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Welcome</td>
<td>Wilmont</td>
<td>Welcome</td>
</tr>
<tr>
<td></td>
<td>30” Rows</td>
<td>Twin Rows</td>
<td>30” Rows</td>
</tr>
<tr>
<td>33,000 (plants per acre)</td>
<td>33730</td>
<td>32550</td>
<td>30070</td>
</tr>
<tr>
<td>38,000 (plants per acre)</td>
<td>37910</td>
<td>36770</td>
<td>35950</td>
</tr>
<tr>
<td>43,000 (plants per acre)</td>
<td>42490</td>
<td>41340</td>
<td>40530</td>
</tr>
<tr>
<td>LSD (.05)</td>
<td>NS</td>
<td>850</td>
<td>NS</td>
</tr>
</tbody>
</table>

Table 1. Evaluation of interaction between row spacing and target population on actual stand and yield by individual site year (2010 to 2012).
Fungicide Effects on Corn Yield as Influenced by Crop Rotation and Residue Management (2011)
Tom Hoverstad
University of Minnesota

Objectives
Understand the impact of foliar fungicide application on corn productivity under various crop residue systems.

Study Description
Research was initiated in 2011 to investigate foliar fungicide application effects on corn yield. Three crop rotations were evaluated as main plots. The rotations were: 1) continuous corn, 2) continuous corn with the residue removed, and 3) a corn soybean rotation.

These rotation blocks were divided into subplots of three different tillage systems, an aggressive tillage system, a conservation tillage system and a minimal tillage system. In continuous corn, the aggressive system was moldboard plow. In a corn soybean rotation, the aggressive tillage system was chisel plow. The conservation tillage system consisted of chisel plow in continuous corn. In the corn soybean rotation, the conservation tillage system was chisel plow following corn and no fall tillage following soybean. The minimal tillage system consisted of strip tillage in continuous corn and no tillage in a corn soybean rotation.

Each tillage subplot was divided into four sub-subplots that were a combination of two corn brands with and without fungicide treatment. The corn brands used for this research were DKC 52-59 and DKC 50-66. These two brands of corn were chosen because the DKC 52-59 brand was reported to be more likely to respond to fungicide applications than other brands and DKC 50-66 was reported to be genetically not similar to DKC 52-59. The fungicide application evaluated in the research was Headline AMP applied at 10 oz/A with 0.25% v/v nonionic surfactant at the R1 stage of corn.

Planting dates were May 6, April 25 and May 15 for 2011, 2012 and 2013 respectively. Weeds were controlled by using Roundup Weathermax at 32 oz/A before planting as a burndown treatment for no-till and strip-till treatments. All treatments received a preemergence application of Surestart at 2 pts/acre followed by an in-season application of Roundup Weathermax at 32 oz/A. Fungicide applications were made on July 25, July 17 and August 6 during 2011, 2012 and 2013 respectively. All plots were harvested with a modified plot combine recording grain weight and moisture percentage.

Results and Discussion
Results showed a significant corn yield response to rotation and tillage. Corn yields were higher in continuous corn where residue was removed and in the corn soybean rotation compared to continuous corn with residue remaining. Aggressive and conservation tillage yielded higher than the minimal tillage system. DKC 50-66 yielded slightly more than DKC 52-59 during this trial.

The response to fungicide was not significant over the course of this research. However, a significant rotation x fungicide interaction was significant. This was the result of a positive response to fungicide applications only in continuous corn. This response was observed in just the year 2013.
Performance Problems with Bt-RW Corn: Exploring Causes (2011)
Ken Ostlie, Dan Kaiser and Trisha Franz
University of Minnesota

Objectives
- Evaluate Western Corn Rootworm susceptibility to Bt-RW corn to determine if resistance is occurring
- Explore how nitrogen application affects Bt-RW protein expression in corn roots and resulting root protection

Study Description
Beetles from performance-problem fields were collected in 2011 to determine whether or not resistance is occurring in MN to Bt-RW protein found in VT Triple™ and VT Triple Pro™. Eggs from three performance problem fields (Dawson, MN, Luverne, MN, and Dennison, MN) and four non-problem fields near Rosemount MN were used in diet bioassays to determine if susceptibility to three Bt-RW proteins (Cry3Bb1 [Monsanto], Cry 34/35Ab1 [Dow/Pioneer], mCry3A [Syngenta]) had changed.

Two field studies to investigate the role of N in Bt-RW trait performance were conducted at the Rosemount Research and Outreach Station, Rosemount, MN in 2011. The design was a factorial combination of three hybrids (Round-Up Ready, VT Triple, and SmartStax) and six nitrogen application rates (0, 50, 100, 150, 200, 250 lbs per acre). Data was collected on protein expression and resulting root injury, beetle emergence, lodging and yield.

Results and Discussion
Diet bioassays revealed that the Rosemount population was susceptible to all Bt proteins and did not differ from the susceptible lab colony. However, the populations from performance problem fields exhibited varying levels of resistance to Cry3Bb1 [VT Triple]. Surprisingly, cross-resistance was detected to mCry3A [NK 3000GT] with both Hills and Madison, MN, populations. In contrast, no cross-resistance to Cry34/35Ab1 was detected at any site. Resistance definitely underlies field performance problems with Cry3Bb1 and be careful using either protein type in problem fields.

Both sites had significant corn rootworm injury, injury declined with increasing N rate in RR corn and to a much lesser extent with Bt-RW corn. Beetle emergence also increased with N rate Bt-RW protein expression increased with N rate peaking at ca. 200 lbs. Beetle emergence exhibited a similar pattern, peaking at a slightly lower N rate (150 lbs). This pattern has management implications. Increasing root system size with increasing N rate enhances corn rootworm survival (beetle emergence) while simultaneously diluting root feeding so injury decreases. At higher N rates, the increasing protein expression levels eventually outweigh the benefits of greater root system size and beetle emergence drops. Bottom line: For optimal root protection, make sure that N rates are sufficiently high.
The Story of Corn – Interactive Web-Based Learning Materials on Corn (2011)
Craig Sheaffer, Kristine Moncada, Jeff Coulter, John Lamb, Jill Sackett, Amy Jacobson and Jeff Gunsolus
University of Minnesota

Objectives
- Develop interactive web-based materials on corn appropriate for high school and college curricula
- Provide positive educational materials on corn to demonstrate its many contributions to the food, fiber and energy sectors of our society

Study Description
Our educational modules are similar to PowerPoint® presentations, but with greatly enhanced multimedia capabilities such as narration, music, animation and interactions. The modules have built-in narration similar to how a professor would lecture in class, but at the convenience of the student. Most important to educational materials, Adobe Presenter® allows interactivity to enhance the learning process. Not only can quiz questions be graded and results known to the student immediately, students who are unable to answer questions on a topic can immediately return to the section for further review. These resources will be available without cost to educators, students or anyone with an interest in corn production at mncorn.org.

Results and Discussion
The materials include four Lessons – Biology of Corn, Corn Uses, Corn Breeding, and Corn Production. The Lessons are sub-divided into 11 total modules, which are summarized below:

Corn Uses – Students are taught the widespread and myriad uses of corn in our society. From industrial uses to livestock feed to nearly every part of our diet, people have utilized and developed remarkably different uses for the components of corn. Corn Uses 1 covers corn grain types and kernel composition, while Corn Uses 2 covers the primary uses of corn in the United States.

Biology of Corn – Students are introduced to several branches of plant biology in this module, including the characteristic features of plant species, plant physiology, and naming and classifying species. Biology of Corn 1 covers botany, Biology of Corn 2 covers growth and development, and Biology of Corn 3 covers corn taxonomy and classification.

Corn Breeding – Corn has made remarkable yield gains, especially as compared to other common crops. Students learn the background behind our present-day yields and the work being done for the inevitable improvement of corn in the future. Corn Breeding 1 covers the origins of corn and Native American breeding, Corn Breeding 2 covers hybrid innovation, and Corn Breeding 3 covers modern breeding techniques.

Corn Production – Students unfamiliar with agriculture may have only basic ideas about how crops are grown. We introduce general cropping system concepts and lead to specifics on the requirements of growing corn. Corn Production 1 covers cropping systems and crop growth requirements, Corn Production 2 covers corn production including tillage, planting and fertilizing, and Corn Production 3 covers pest control, harvest and storage.

In developing these materials, our goal was to cover the topics as comprehensively as possible, while at the same time, taking the knowledge level and attention spans of the potential learners into consideration. Our project has provided much-needed quality e-learning materials about corn for high school and college students. We intend to provide access to these materials over the long-term. Thus, our next steps will be to maintain the website with the modules, be available to educators to answer questions, and to troubleshoot any problems that arise.

Ken Ostlie, Bruce Potter, Lee French, Jeff Coulter, Trisha (Franz) Leaf, Elizabeth Schacht and Megan Carter

University of Minnesota

Objectives
This proposal continues a two-pronged research approach to the evolving Bt-RW resistance issue:

- Examine the role of corn rootworm developmental synchrony on Bt-RW corn performance
- Compare performance and returns to various corn rootworm management options in fields that have experienced Bt-RW performance problems

Study Description
Planting date effects on the performance of Bt-RW and refuge hybrids were explored near Rosemount, MN, in 2012. The study featured a factorial design of three hybrids (SmartStax™, VT Triple™, and RR2 hybrid) with four planting dates (May 3, May 12, May 26, June 10). Data was collected on root protection by traits and their effects on corn rootworm survival and development, corn rootworm emergence and its agronomic implications.

Four on-farm with Bt-RW performance problem were used for this research sites in 2012: Harmony, Northfield and Hills, MN, and Milbank, SD. Treatments in each field included all commercially available Bt-RW traits, single and pyramided plus appropriate refuge hybrids. Each hybrid was planted with and without an overlaid soil insecticide (Force 3G). Data was collected on root injury, beetle emergence plus the impact on agronomic variables.

Results and Discussion
Corn root injury in unprotected corn generally declined as planting dates progressed until negligible at the June 8 date. Force 3G efficacy improved as planting date progressed. Root injury was reduced 59.1% (May 3), 76.9% (May 12), 89.7% (May 26). Bt-RW traits were much more effective than the soil insecticide with SmartStax providing better control than VT Triple. Adult corn rootworm emergence generally declined as planting dates progressed until negligible with June 8 date. Surprisingly the greatest emergence occurred with the soil insecticide with emergence progressively reduced by the single and pyramided Bt-RW traits.

As expected, VT Triple, did not perform well in the problem fields with significant corn rootworm pressure (Milbank, Hills, Northfield), which provided field confirmation of resistance. In problem fields, VT Triple performance was not a complete failure; partial protection indicates resistance is not complete in populations. Cross-resistance between Cry3Bb1 and mCry3A was evident at all 3 sites. Force 3G provided significant yield protection for the compromised VT Triple trait at most sites, however, working Bt-RW traits out-yielded the combination of a failing trait + Force. When Bt-RW traits were working, overlay of Force 3G generally did not increase yield. The best performance was provided by switching to a working single trait (Cry34/35 Ab1) or a stack containing Cry34/35 Ab1 (SmartStax) as soon as a Cry3Bb1 or mCry3A problem was detected.

Figure 1. Planting date and its effects on root protection by Force™ 3G and Bt-RW traits, Rosemount, MN, 2012.

Figure 2. Planting date and its effects on adult emergence (1000s/A) from refuge corn, and corn protected by Force™ 3G and Bt-RW traits, Rosemount, 2012.
Objectives
- Evaluate the impact of nitrogen (N) fertilization at multiple locations in Minnesota
- Determine the effect of variable N fertilization rate on corn grain, stover, and cob yield in diverse corn growing regions of Minnesota
- Measure the sugar content and ethanol production potential of corn stover and cobs
- Determine stover and cob mineral content

Study Description
Research was conducted at four sites in Minnesota in 2008 and 2009. Each year the sites were in a similar location. The locations included two dryland sites near Lamberton and Red Lake Falls, Minnesota, and two irrigated sites near Hastings and Becker, Minnesota.

The experiment design was a randomized complete block with four replications. Soils were fertilized with recommended levels of all soil nutrients for corn production except for N. Because of its importance, N was the only soil fertility variable. The N rate treatments, except at Becker in 2008 and 2009, were rates of 0, 30, 60, 90, 120, 150, 180, and 210 lb per acre. At Becker in 2008, the N rates were 0, 40, 80, 120, 160, 200, and 240 lb per acre while in 2009, a 280 lb N per acre rate was added. These rates were applied as urea and incorporated into the soil in the spring prior to planting at the dryland sites, while at the irrigated sites the N rates were split applied with half of the rate applied at planting and the rest applied when the corn is 8 to 12 inches tall.

The corn plots were 6 rows wide and 30 to 50 feet long depending on the location. The plots were harvested at maturity for corn grain, stover and cob. The corn stover and cob material was analyzed for sugars and an ethanol yield was calculated. The stover and cob samples were also analyzed for N, phosphorus (P) and potassium (K).

Results and Discussion
Nitrogen fertilization had a consistent positive effect on yield of grain, stover and cob except at the most northern location, Red Lake Falls, where growing conditions likely limited yield potential. At the southern Minnesota locations, Becker and Hastings, stover and cob yields as high as 9000 and 2000 lb/acre, respectively, were observed. Nitrogen fertilizer effects on stover and cob ethanol gallon per ton and per acre were inconsistent over locations.

Although affected by year and N fertilizer rate, for most treatments, stover ethanol production per ton ranged from 80 to 100 gallon/ton of biomass. Cob ethanol production ranged from 109 to 114 gallon/ton of biomass. Stover ethanol yields were as high as 400 gallon/acre while cob ethanol yields were only as high as 110 gallon/acre. Ethanol yields were greatly affected by biomass yield (ton/acre), as ethanol production in gallon per ton of biomass was fairly constant or declined over a range of N fertilizer rates.

Removal of N, P, and K (uptake) is a consideration if stover and cob are harvested for energy production. Nitrogen fertilization consistently increased stover N concentration and uptake and, to a lesser extent, cob N concentration and uptake. At the highest N fertilizer rate, N uptake ranged from 40 to 70 lb/acre while cob N uptake was at the most 9 lb/acre. The effect of N fertilization on P and K concentration and uptake by stover and cob was less consistent over locations, and was more of a function of the N application affecting the stover or cob biomass than the actual concentrations of P and K. Nitrogen fertilization either had no effect or decreased P and K uptake of the stover. Likewise N fertilizer had little effect on cob P uptake but had a very inconsistent effect on cob K uptake. The maximum (average over years) stover and cob K uptake was 140 and 14 lb/acre, respectively, while maximum stover and cob P uptake averaged 4.5 and 0.5 lb/acre, respectively. While cob biomass yields are considerably less than for stover, cobs have very little N-P-K content and may make a better fuel source for ethanol production than stover.


Demonstrating Corn Cob Collection as Biomass Feedstock for Ethanol Production (2008)

Michael Reese and Bill Lee
CVEC Ethanol Plant and University of Minnesota, Morris

Objectives
Demonstrate the field-to-facility supply of corn cobs to biomass energy systems and to:

- Determine cob yield
- Determine cost per ton for harvested and delivered cobs
- Evaluate and compare cob harvest systems
- Evaluate storability and deliverability of cobs

Study Description
A demonstration and evaluation of corn cob harvest occurred in the fall of 2008. Approximately 3,200 acres of corn cobs were harvested utilizing two different cob harvest systems. The resulting corn cobs were stored and then delivered to the Chippewa Valley Ethanol Company (CVEC). At CVEC, the corn cobs were gasified in the biomass energy system.

The West Central Research and Outreach Center (WCROC) participated in the acquisition and evaluation of data including the collection of cob samples, cob moisture, cob yield, harvest and transport costs, harvest capacity, energy consumption, and storability. CVEC farmer members participated in the demonstration by hosting the cob harvesters on their fields.

Two eight-row combines with stalk chopping heads were utilized with each combine using a unique cob harvest system. The Vermeer CCX was a pull-behind cob harvester that contained its own power source. The second cob harvest system evaluated was a Ceres Cob System. The Ceres unit consisted of a separator and blower mounted to the back and a storage tank mounted to the top of the combine. The three field days were open to the public and were well attended by farmers, policy makers, energy consumers and other citizens.

Results and Discussion
Two cob harvest systems were used across a total of 3,172 acres with the Vermeer CCX and the Ceres Cob System, covering 1,804 and 1,368 acres respectively (Table 1). The combines and harvesters consumed between 3.90 and 3.84 gallons of diesel fuel per hour. Cob harvest roughly doubled the combine time and fuel required. During harvest, 28 fields were sampled across a 60-mile region. The results indicate an average grain yield of 192 bushels per acre (adjusted to 15.5% moisture), an average cob yield of 996 lbs per acre (on a dry matter basis), and average respective grain and cob harvest moisture levels of 23.6 and 39.5%. Based on the respective corn grain and cob yields, a predictive model for cob yield was developed for producers (Table 2). Corn varieties were also noted in the evaluation. The results indicate there is a significant cob yield difference between the varieties.

The cost per ton of cobs was difficult to determine in this evaluation. The cob harvester data compared to normal combine harvest time and fuel consumption seems to indicate the harvest cost will double with cob harvest. If the assumption is made that cob harvest takes an extra two gallons of fuel per acre and twice as much time in harvesting, a producer can expect an additional cost of $20 to 30 per acre. This would suggest a cost per ton for cob harvest to be at least $50 per dry ton. Transportation and storage losses also need to be added. Based on a 15 mile average haul and average load of 20 wet tons, the transportation costs are approximately $3 per ton or $5 per dry ton.

An initial evaluation indicates an average loss of cob dry matter at approximately 1% per month. This loss does not consider the reduction of energy value of the remaining material. If cobs are stored for an average of six months, then a 6% decrease in dry matter is anticipated. This should result in a 6% increase in the amount of biomass required and a similar increase in the cost per dry ton of biomass consumed by the biomass energy system.

On average, the cob storage piles maintained very good condition from time of harvest through the end of July 2009. The 2008 harvest season was extremely wet which resulted in corn and cob moisture levels to be very high, averaging 23.6% and 39.5% respectively. Cobs ranged up to over 53% moisture.

continued on following page
Once the cobs were placed into piles, there was a concern that some may begin to heat and combust. Moisture and temperature data was collected every two weeks from the fall harvest to August 2009. Initially, two piles began to approach temperatures over 150 degree F and were mechanically ventilated. Moisture and temperature moderated in winter, began to increase slightly in the wetter spring months, and then moderated again in summer 2009. The piles most susceptible to deteriorate were given highest priority to be delivered to the CVEC facility for processing and utilization. Considering the unusually wet conditions in the fall of 2008, outside cob storage appears be a viable option.

In conclusion, corn cobs can be harvested, stored, and transported under real world production conditions. The results indicate that cobs may be a viable and economical feedstock for biomass energy systems.

<table>
<thead>
<tr>
<th>Harvest System</th>
<th>Acres Harvested</th>
<th>Corn Grain Yield / Ac (bu)</th>
<th>Separator Ac / Hr</th>
<th>Combine Ac / Hr</th>
<th>Fuel Consumed Gal / Ac*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vermeer Cob Caddy</td>
<td>1804</td>
<td>157.3</td>
<td>7.48</td>
<td>6.20</td>
<td>3.90</td>
</tr>
<tr>
<td>Ceres Cob System</td>
<td>1368</td>
<td>165.1</td>
<td>7.78</td>
<td>3.23</td>
<td>3.84</td>
</tr>
</tbody>
</table>

Table 1. Cob harvest system comparison. *Includes fuel consumed for grain harvest.

<table>
<thead>
<tr>
<th>Expected Corn Grain Yield (Bu / Ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Projected Cob Yield</td>
</tr>
<tr>
<td>Dry Matter Basis (Lbs / Ac)</td>
</tr>
<tr>
<td>Projected Cob Yield</td>
</tr>
<tr>
<td>40% Moisture (Lbs / Ac)</td>
</tr>
</tbody>
</table>

R² = 0.243

Table 2. Predicted cob yield at various grain harvest levels.

Figure 1. Vermeer CCX unloading cobs.
Figure 2. Ceres Cob Harvest System mounted on the top and back of the combine.
Figure 3. Ceres Cob System unloading cobs on-the-go.
Lowell Rasmussen  
University of Minnesota, Morris

**Objectives**
Design and build a size and scale appropriate corn stover preprocessing and densification platform to serve the Morris campus.

**Study Description**
A 60 hp (44.8 kW) demonstration scale roll press compaction machine was purchased from Bepex International LLC (Minneapolis, MN) and was located at the University of Minnesota, Morris campus.

Compaction tests were conducted on the unit for corn stover, corn cobs and wood chips. Each test was performed for about 2 to 3 minutes. Throughput (t/h) of the roll press was calculated. Energy consumption (MJ/t) of the roll press (machine plus compaction energy) was calculated from the total kWh consumption for the operation of roll motor plus screw feeder motor. Bulk densities of biomass feedstock (before compaction) and compacted materials (after compaction) were measured according to ASTM (2009).

**Results and Discussion**
The maximum throughput of the roll press was 2.9 ton/h for corn cobs. For both corn stover and corn cobs, the bulk density of compacted materials was 240 kg/m³ (15 lb/ft³) or higher. The energy consumption for the roll press compaction was 168 MJ/t for corn stover and 33 MJ/t for corn cobs. Future work is required to study the effects of roll pressure, biomass species, particle size, and moisture content, and to optimize the demo-scale roll press compactor.
Optimization of Denitrifying Bioreactor Performance with Agricultural Residue-Based Filter Media (2011)
Gary Feyereisen
United States Department of Agriculture-Agricultural Research Service (USDA-ARS)

Objectives

- Identify agriculturally derived materials that will maintain required hydraulic properties in a bioreactor
- Improve the nitrate-N removal rate of bioreactors using agriculturally derived materials rather than wood chips
- Investigate the cost for bioreactors using agriculturally derived materials and compare to the cost for wood chips

Study Description

The USDA-ARS researchers conceived the study to investigate the potential for Minnesota-derived agricultural residues to improve the rate of removal of nitrate-nitrogen from tile drainage water in denitrifying bioreactors under cold springtime temperatures. Candidate materials – corn cobs, corn stover, barley straw, wood chips, an in-series combination of corn cobs and wood chips and of corn cobs and a high-surface area plastic medium – were packed into 6-inch diameter by 19-inch long PVC tubes, and water-containing nitrate-nitrogen was continuously pumped through them.

The test was run for six months each at 60°F and 35°F. Candidate materials were also tested for hydraulic conductivity by loading them into a 12-inch diameter by 8-foot long PVC vessel and running a standard test procedure. A cost estimate of using corn cobs as a denitrifying bioreactor medium was developed, using a previous study of wood chips as a template. The overall goal of the project was to determine the performance and economic viability of readily available agricultural residues for denitrifying bioreactors.

Results and Discussion

The nitrate-nitrogen removal rates of the agricultural residues exceeded that of wood chips (Table 1). The experimental treatments with corn cobs were highest; the corn stover and barley straw treatments were losing capacity to support denitrification toward the end of the six-month trial at 60°F. The removal rates were 3 to 5 times lower at 35°F than at 60°F, although the corn cob treatment rates were higher at 35°F than the wood chip rate was at 60°F. The hydraulic conductivities of the agricultural residues were somewhat less than that of wood chips, however, not significantly so.

The cost analysis projects a range of $0.39 – 2.06 to remove one lb of nitrate-nitrogen in tile drainage in a corn cob bioreactor. Work in Iowa (Christianson et al. 2013. Financial comparison of seven nitrate reduction strategies for Midwestern agricultural drainage. Water Res. Econ. 23:30-55) indicates a range of $0.60 – 1.24/lb for wood chips. A value of $1.38/lb has been reported for Illinois (M. David, November 20, 22014). The greater uncertainty with corn cobs results from lack of field testing.

The higher nitrate-nitrogen removal rates of corn cobs at both temperatures indicates they have promise as a denitrifying bioreactor medium. The design of a bioreactor using corn cobs could be different than for wood chips. The higher removal rate would permit a smaller footprint, however, corn cobs would need to be replaced more often than wood chips, necessitating a replacement-friendly design. Additional research at the field scale is needed to address the design issues and longevity unknowns.

RESEARCH SUMMARY

CORN UTILIZATION

Table 1. Nitrate-nitrogen removal rates of denitrifying bioreactor media candidates: CS (corn stover), CC (corn cobs), CC-WC (corn cobs in series with wood chips), BS (barley straw), WC (wood chips), and CC-K (corn cobs in series with a high-surface area plastic medium).
Implications of Corn Producer Participation Rates on Stover Biomass Markets (2011)

Joel Tallaksen
University of Minnesota, Morris

Objectives
- Determine Minnesota corn producer interest in selling corn stover biomass
- Identify producers’ comfort level in their knowledge of the issues surrounding biomass harvest
- Determine which factors are most likely to influence producer opinions of biomass harvesting
- Identify information that undecided producers might want before forming their opinions
- Evaluate where facilities would be best able to find willing stover suppliers

Study Description
The University of Minnesota West Central Research and Outreach Center (WCROC) researchers organized a survey-based study to examine agricultural biomass producers’ willingness to supply corn stover and develop an understanding of factors affecting producers’ biomass-related farm management decisions.

Surveys were sent to 2,500 Minnesota producers randomly selected from a list of USDA program participants. Using this data, the goal was to create a regional biomass availability model and evaluate statewide biomass availability patterns. Biomass yields and producer participation interest data were mapped using GIS software to create availability maps. The ultimate goal of WCROC’s work is to develop conditions that support an economically stable, environmentally sound biomass market.

Results and Discussion
Overall, the survey found a high number of producers were undecided or not interested in selling agricultural biomass at this time. Though some producers are firmly against selling biomass, many appear to be waiting for more information before considering participation in a biomass market. If a new biomass project depends on a high participation percentage in a specific region, they will likely need to be proactive in providing this data to producers in the region to make their project successful. The information that would be most important to them is the economic feasibility and soil quality impact data.

After factoring in farmer interest and conservation, there appears to be a fairly homogeneous area of southern Minnesota that would be able to supply a larger 500,000+ ton facility. However, central locations may not support a facility much larger than 100,000 tons. Based on production estimates and conservation considerations, a map with likely locations for facilities is presented (below).
Agricultural Processing Co-Products Assessment (2013)
Luca Zullo, Richard Hemmingsen and Roberta Dahlstrom
VerdeNero LLC and Windjammer Solutions, LLC

Objectives
- Identify, quantify and characterize the waste streams generated throughout Minnesota from agricultural processing
- Economic analysis of the current utilization of the waste streams, including the market value of co-products being utilized, cost of disposal, and potential value-added uses for undervalued and underutilized co-products
- Determine potential value-added opportunities for those co-products that are undervalued or underutilized

Study Description
A survey of Minnesota-based agricultural product processors was carried out. The goal of the survey was to identify which, if any, lower value co-products may present opportunities for value generation beyond current use. In particular, but not exclusively, we wanted to identify any material stream that may have marginal or negative value and whose current disposition, if not a waste, was marginal, at best.

The target audience for the study was entities directly involved with the processing of agricultural commodities into food, fuel, or feed products. The survey focused on these categories: 1) Food processing facilities that convert primary agricultural commodities into consumer and industrial products (i.e., oil seed crush, flour mills, etc.); 2) Biofuel producers, corn ethanol plants and biodiesel plants; 3) Dairy processors, mainly cheese processors and milk derivate (i.e., whey protein) producers; and 4) Meat processors, (i.e., rendering and secondary processing plants).

Results and Discussion
We found that the industry segments covered by this analysis in Minnesota are extremely efficient using their feedstock, and a relatively small amount of underutilized co-products are present. Some of these co-products are subject to environmental regulation, and none are a considerable environmental liability, as of the time of taking the survey.

When co-products are present, typically very little, if any, are a real waste, i.e., intended as material ultimately destined to landfill, since the feed market readily absorbs any co-products with nutritional value. The relatively high cost at the time of the survey of feed and the fact that most of the respondents have developed local supply chains, which do not require expensive transportation, ensures enough value to cover the costs associated with the disposal of the materials and frequently provides a modest income.

The sale of co-products as feed provides flexibility when only seasonal, as the market adapts quickly to variable supply. Feed demand is also highly distributed, each producer having developed its own cluster of local customers. Disposal for energy generation has been studied in the past and has proven to be economically challenging. The main barriers are not technical and this may become more attractive in the future. These streams do not contain high value components that could not be easily obtained from the original feedstock. Hence, market value feed is a very adequate representation of their greatest intrinsic value.

The exception to the statement above relates to streams from the dairy industry, whose properties and composition are not quite as well known by the producers. For dairy co-products further investigation may be worthwhile, primarily to improve product characterization.
Objective
Develop a technology for processing Dried Distillers Grains and Solubles (DDGS) into biofuels (biodiesel and second generation ethanol), corn zein, and high protein feed product (HPDG).

Study Description
The Natural Resources Research Institute (NRRI) Laboratory of Chemical Extractives has developed an add-on technology that can process DDGS from ethanol plants as an integrated biorefinery or it can operate as a stand-alone facility.

The new technology for processing DDGS offers new opportunities to capture more value from every bushel of corn. An integrated biorefinery will process DDGS creating greater variety of value-added products, including high-protein and antibiotic free animal feed, corn zein, and additional biofuels (Figure 1).

Results and Discussion
Application of the proposed integrated technology to an average 55 million gal/year ethanol plant should result in the following: 1) Improved energy efficiency coefficient NEB by +15%; 2) Increased annual profits by +$19M; 3) Increased transportation biofuel output by +20%. Further benefits could include reducing greenhouse gas emissions, reducing dependence on foreign oil imports by increasing domestic biofuel production, and improving the farm economy by stabilizing corn prices and providing higher value livestock feeds. Improved efficiency and new processes outlined by NRRI’s research and development program provide a platform for a major paradigm shift to move the industry of corn ethanol from simple fermentation technology to transitional and transformational technologies. Development of this technology is conducted in cooperation with industrial partners Crown Iron Works and GlycosBio Technologies.

Higher Value Product from Corn Ethanol (2012)
Lawrence Wackett
University of Minnesota

Objectives

- Investigate the chemical conversion of bioethanol to produce a more valuable commodity chemical, ethylene carbonate
- Determine if the chemical conversion of bioethanol is viable on an industrial scale

Study Description
The process we studied is the conversion of ethanol through two increasingly valuable chemical intermediates, ethylene and ethylene oxide. Ethylene oxide is then reacted with carbon dioxide to produce ethylene carbonate and the carbon dioxide can be obtained from trapping that gas during the corn ethanol fermentation process. This chemical process, coupled with corn ethanol processes, is both economically and environmentally attractive.

Results and Discussion
The project showed the feasibility of converting ethylene oxide to ethylene carbonate, cleanly and in high yield. The conditions are not extreme and thus the reaction could be carried out on an industrial scale and not use expensive equipment. The major issues relevant to corn ethanol are the reactions converting ethanol to ethylene and ethylene oxide. These are carried out by several companies and the patent landscape is large and complex. Thus, market studies are needed to determine the competitive landscape, coupled to the efficiency and cost-effectiveness of the overall process as illuminated by the present study.

The final product incorporates one molecule of carbon dioxide for each molecule of bioethanol produced, so that all carbon atoms are retained and the process is completely carbon neutral.

A key goal of the research was to demonstrate that ethylene carbonate can be efficiently and cleanly prepared from ethylene oxide.

Figure 1. Ethylene oxide is reacted with carbon dioxide to produce ethylene carbonate. The carbon dioxide can be obtained from trapping that gas during the corn ethanol fermentation process.
The Economics of Eco-Performance Fuel (2013)

Dean Drake, Gary Herwick, Thomas Walton, David Aldorfer and Thomas Darlington
Defour Group, LLC

Objectives

- To examine the costs and benefits of ethanol blends currently available to consumers
- To examine the energy security benefits of displacing gasoline with biofuels
- To estimate the costs and benefits of a mid-level blend suitable to fuel future higher-compression engines needed to meet 2017-2025 MY fuel economy and tailpipe CO2 emission standards

Study Description

The authors used publicly available data and information from a variety of sources to conduct their analyses and make their projections, including (but not limited to) the U.S. Energy Information Administration, the Nebraska Ethanol Board, the U.S. General Accounting Office, the Society of Automotive Engineers, the National Highway Traffic Safety Administration, the U.S. Environmental Protection Agency, the U.S. Department of Transportation, the University of Missouri Food and Agricultural Policy and Research Institute, as footnoted in the full report.

Results and Discussion

Ethanol and gasoline prices decoupled at the end of 2011. Since then, it has been cheaper to mix ethanol and sub-regular blendstock 10%/90% by volume than to use aromatic hydrocarbons derived from crude oil to meet octane requirements. On an energy-adjusted basis, we estimate conservatively that consumers save $0.058 per gallon of regular E10 versus pure gasoline (E0) and that current RFS requirements drove consumer savings of nearly $8 billion in 2013.

We find a $0.66 per gallon current benefit in enhanced energy security due to the use of biofuels to displace gasoline in motor fuel, $0.46 from biofuel impact on world oil process and $0.20 from lessening of oil price shocks.

Laboratory testing shows that the higher octane (93AKI) required to prevent premature combustion in future higher-compression engine designs can be satisfied by mid-level blends (20-30% ethanol). Results indicate that such engines using E30 may overcome the fuel economy loss associated with E10 and E85 used in current technology engines. Based on 2013 prices, we estimate that E30 premium could be $0.09 per gallon less than E10 regular costs today. Engines optimized for E30 would produce 7 – 11% lower CO2 emissions than current engines using E10. If introduced by 2017, by 2035, we estimate that fuel ethanol demand could exceed 25 billion gallons per year, double today’s consumption.
Assessment of DDG’s and E. coli in Beef Cattle Rations (2008)

Grant Crawford, Alfredo DiCostanzo, Jeffrey Jaderborg, Devan Paulus, Ryan Fink, Francisco Diez-Gonzalez and Jim Droulliard
University of Minnesota and Kansas State University

Objectives

- Determine the effect of substituting modified distillers grains (MDGS) and soy glycerin for steam-flaked corn (SFC) in finishing diets on performance
- Determine the impact of feeding MDGS on incidence of E. coli O157:H7 resulting from natural infection or inoculation

Study Description

Forty-eight cattle were fed a 79% steam-flaked corn (SFC) based diet (dry basis; balance was 11% grass hay and 10% supplement) where MDGS replaced 35% of the SFC or soy glycerin replaced 10% of the SFC or both MDGS replaced 35% and soy glycerin replaced each 35% and 10% of the SFC, respectively for 124 or 173 days. Cattle were monitored for incidence of E. coli O157:H7 shedding.

In a second study, young Holstein calves fed 48% dry rolled or steam-flaked corn diets and 35% MDGS with or without 10% soy glycerin (dry basis) were inoculated with a strain of E. coli O157:H7 that was easily traceable and measurable in the laboratory.

Results and Discussion

Dry matter intake was greater for cattle fed diets containing MDGS. Gain was not affected by feeding either co-product. A tendency for poorer feed conversion efficiency was observed for cattle consuming diets with MDGS. Hot carcass weight, ribeye area, 12th rib fat depth, yield grade and marbling score were not affected by dietary treatment. Cattle in this experiment only shed E. coli O157:H7 during the first 14 days on feed.

In the second experiment, dietary treatment had no impact on the duration of E. coli O157:H7 shedding in inoculated calves. Shedding of E. coli O157:H7 by calves decreased to a minimum after 20 days on feed regardless of diet fed in this experiment demonstrating no role of dietary ingredients particularly steam flaked corn, modified distillers grains or soy glycerin in supporting E. coli O157:H7 growth.

Figure 1. Concentration of E. coli O157:H7 in fecal samples of Holstein calves inoculated with E. coli O157:H7 and fed steam-flaked or dry rolled corn and 35% modified distillers grains plus solubles with or without 10% glycerin. The graph demonstrates no difference in shedding due to treatment. Further, by day 20, all calves had stopped shedding.
Ryan Cox, Grant Crawford and Alfredo DiCostanzo
University of Minnesota

Objectives
Evaluate the effect of replacing corn with 35% low-fat dried distillers grains with solubles (LFDGS) on carcass characteristics, moisture loss, fabrication percentage, and sensory attributes.

Study Description
Angus steers (n = 48) averaging 699 ± 17 lb initial body weight (BW) were fed a dry-rolled corn (DRC) based diet (59 Mcal/cwt NEg) where conventional dried distillers grains plus solubles (DDGS: 27.6% CP, 10.9% fat) or low-fat, high-protein dried distillers grains plus solubles (LFDGS: 39.0% CP, 5.0% fat) replaced 35% of the DRC for 118 days.

At harvest, carcass characteristics were measured and samples of strip loins, shoulder clods and inside rounds were purchased back to evaluate quality and sensory traits on steaks and summer sausage.

Results and Discussion
In spite of slightly greater dry matter intake by steers fed the control diet, no differences in gain or feed conversion efficiency (feed per lb gain) were observed among treatments, demonstrating that energy value of both low and conventional fat DGS approximate that of corn grain. Furthermore, no effects of feeding LFDGS as a replacement for a portion of corn grain were observed on carcass characteristics such as loin eye area or marbling score. Shear force values (a measure of steak toughness) was not affected by feeding either type of DGS.

Consumer sensory scores for overall liking, texture liking, flavor liking, toughness, juiciness and off-flavor did not differ among treatments for strip steaks. Cooked sausage prepared with clods from steers fed the control diet rated the highest for overall liking and flavor liking. Similarly, concentration of lipid oxidation end-products were greater when measured at 7 days of shelf-life but not at 0 days for ground beef derived from cattle fed LFDGS (see Figure 1).

Figure 1. Concentrations of malonaldehyde (a lipid oxidation end-product associated with rancidity) at day 0 or 7 days in ground beef from steers fed a dry rolled corn (DRC)-based diet or diets where 35% of the DRC was replaced with conventional dry distillers grains plus solubles (DDGS) or low-fat, high-protein dry distillers grains plus solubles (LFDGS) after storage in a simulated retail case. At 7 days, concentrations of malonaldehyde in ground beef from cattle fed DDGS or LFDGS was greater than that from cattle fed only DRC. Greater concentrations of this end-product are reflective of greater oxidation (rancidity) in the product.
Interaction of Distillers Grains Sulfur Concentration and Dietary Roughage on Beef Cattle Feedlot Performance (2009)
Grant Crawford and Alfredo DiCostanzo
University of Minnesota

Objectives
Determine the interaction between dietary sulfur (S) in distillers grains plus solubles diets and roughage concentrations on feedlot performance and carcass characteristics.

Study Description
Eighty-four Angus, Limousin, and Charolais steers (initial BW 1,016 ± 79 lbs) were fed one of six diets resulting from the full combinations of dietary concentrations of S (0.28%, LS or 0.56%, HS) and roughage (5%, LR; 10%, MR; 15%, HR). Sulfur was added as gypsum in a ground corn carrier to achieve the two concentrations of S.

Modified distillers grains with solubles (48% DM) was fed at 40% of the diet dry matter while dietary dry rolled corn and grass hay concentrations were varied to accommodate target roughage concentrations. Cattle were harvested after either 134 or 92 days on feed and carcass characteristics were measured at the commercial abattoir.

Results and Discussion
Dry matter intake (DMI) increased with increasing roughage concentration while dietary S concentration decreased DMI (Table 1). Yet, average daily gain was not affected by roughage or S concentration (Table 1). In spite of its effect on DMI, S concentration had no effect on feed conversion efficiency while increasing roughage concentration decreased feed conversion efficiency (Table 1). Carcass traits were not affected by roughage or S concentration. Results suggest that increasing dietary roughage concentration increases DMI while high dietary S concentrations decrease DMI.

<table>
<thead>
<tr>
<th>Item</th>
<th>Dietary Roughage Concentration</th>
<th>Dietary S Concentration</th>
<th>P-values¹</th>
<th>SEM²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5%</td>
<td>10%</td>
<td>15%</td>
<td>0.28%</td>
</tr>
<tr>
<td>Initial BW, lb</td>
<td>1,012</td>
<td>1,018</td>
<td>1,018</td>
<td>1,018</td>
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<tr>
<td>Final BW, lb</td>
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<td>1,418</td>
<td>1,393</td>
<td>1,411</td>
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<tr>
<td>DMI, lb/d</td>
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<td>23.2</td>
<td>23.6</td>
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<tr>
<td>ADG, lb</td>
<td>3.22</td>
<td>3.28</td>
<td>3.04</td>
<td>3.20</td>
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<td>Feed:Gain</td>
<td>6.59</td>
<td>6.94</td>
<td>7.56</td>
<td>7.07</td>
</tr>
</tbody>
</table>

Table 1. Effects of dietary roughage and sulfur concentrations on feedlot performance of beef steers.

¹ R Linear = Linear effect of dietary roughage concentration; R Quad = Quadratic effect of dietary roughage concentration; S = Main effect of dietary S concentration; R x S = Interaction between dietary roughage and S concentrations.
² Standard error of the mean.
Use of Manganese Oxide to Attenuate Negative Effects of High Sulfur Concentrations in Distillers Grains (2009)
Alfredo DiCostanzo, Grant Crawford and G. Cliff Lamb
University of Minnesota

Objectives
- Determine manganese oxide (MnO) concentrations by reducing hydrogen sulfide release in vitro and in vivo
- Determine MnO concentrations by reducing negative effects of Sulfur (S) on performance

Study Description
A series of two experiments (in vitro and in vivo) were conducted to test what concentrations of MnO could reduce release of hydrogen sulfide production in vitro and in vivo with ultimate positive effects on performance in vivo. Supplementing manganese (Mn) as MnO at 1,000 ppm proved to be effective in vivo; therefore, 182 cattle were fed distillers grains plus solubles diets with concentrations of S at 0.35% or 0.60% supplemented or not with additional 0 or 1,000 ppm Mn as MnO for 173 days. Cattle performance and carcass characteristics were measured.

Results and Discussion
When 1,000 ppm Mn as MnO were added to in vitro batch cultures, hydrogen sulfide (H2S) concentrations were lower than when substrate contained no MnO (Figure 1). This concentration (1,000 ppm) is considered the maximum tolerable dietary Mn concentration and was subsequently tested in vivo, which led to lower ruminal pH 1 h pre-feeding, and to a tendency for lower hydrogen sulfide concentration in the rumen of cattle supplemented with 1,000 ppm Mn as MnO (Figure 1). Supplementation of Mn at 1,000 ppm as MnO prevented negative effects of S on performance during the first 28 days (Figure 1) of the feedlot experiment, but not for the entire feeding period.

Thus, MnO is effective at helping cattle adapt to high S diets on arrival, but its efficacy is lost beyond 28 days on feed; other measures or approaches may be needed to reduce negative effects of S on performance.

Figure 1. Concentrations of hydrogen sulfide observed in studies conducted in vitro (µmol/24 hours) and in vivo (µmol/mL) or feed conversion efficiency (lb feed per lb gain) observed during the first 28 days on feed when rumen fluid or cattle were supplemented with 0 or 1,000 ppm manganese as manganese oxide. Values differed significantly demonstrating positive effects of manganese supplementation as 1,000 ppm manganese oxide.
Studies to Improve the Assessment of DDGS Nutritional and Economic Value for Swine and Poultry Using NIR (2009)

Gerald Shurson and Mu Li
University of Minnesota

Objectives

- Define variation in energy and digestible amino acid content among DDGS sources, and to describe various “nutritional tools” that have been developed and implemented to assess nutrient content
- Determine the accuracy and feasibility of two in vitro procedures to predict amino acid digestibility among DDGS sources, and evaluate the use of near infrared spectroscopy to estimate nutrient content and digestibility of DDGS

Study Description

Data measuring the concentration of nutrients were collected from the literature (Spiehs et al., 2002). In addition, variability in nutrient concentration among sources of corn and soybean meal (Cromwell et al., 1999) was included for comparisons with DDGS. Data on gross, digestible, and metabolizable energy were collected from the literature (Stein et al., 2006; Pedersen et al. 2007; Anderson et al. 2012; Stein et al., 2009; Mendoza et al., 2010) and prediction equations were also tested for their ability of predicting literature data (Anderson et al. 2012; Mendoza et al., 2010). Data for amino acid concentration and standardized ileal digestibility were extracted from the literature (Stein et al., 2005, 2006; Fastinger and Mahan, 2006; Pahm et al., 2008; Urriola et al., 2009).

In addition, variability in nutrient concentration was measured in a survey of 217 samples of corn DDGS from various ethanol plants in all regions of the U.S. All samples were analyzed for moisture, fat, ash, acid detergent fiber, neutral detergent fiber, complete amino acid profile, and minerals (calcium, phosphorus, and others).

All 217 samples of DDGS were scanned twice using a Perten DA 7200 Feed Analyzer and Perten DA Advanced Software to manage and transform spectral data. Calibrations were developed using partial least squares, second derivative mathematics, and standard normal variant. The standard error of prediction and bias were calculated to evaluate the predictive capabilities of the calibrations.

Results and Discussion

Variability in concentration of digestible, metabolizable, and net energy as well as nutrient sources of corn DDGS has been widely reported (Spiehs et al., 2002) as well as variability in the concentration of standardized ileal digestible lysine (Urriola et al., 2009).

Using color brightness (L*) partially explains variability in lysine digestibility among sources of DDGS of dark color ($r^2 = 0.48$), but not in light color ($r^2 = 0.03$). Other method such as Aminored® and IDEA® had limitations in predicting digestibility of lysine, too. Rapid, inexpensive, and accurate method to predict the concentration of digestible lysine remains a challenge. Calibrations of near-infrared spectroscopy (NIR) were possible for multiple nutrients (dry matter, protein, fat), but accuracy in predicting the concentration of amino acids was low.

In summary, several “nutritional tools” have been developed to estimate metabolizable energy (ME) and digestible amino acid content in DDGS for swine, but more refinements and validation are needed.
**DDGS in Swine Diets (2009)**


University of Minnesota and Kansas State University

**Objectives**
Evaluate the effect of dietary glycerol and DDGS on growing-finishing pig performance, carcass characteristics, and iodine value (IV) of belly fat, jowl fat, and backfat (BF).

**Study Description**
Kansas State University conducted an experiment at a commercial swine research facility in southwest Minnesota. A total of 1,160 barrows (PIC, initially 68.4 lb) were used in a 97-day study to determine the influence of glycerol and dried distillers grains with solubles (DDGS) on growing-finishing pig performance, carcass characteristics, and fat quality. Pigs were blocked by weight and randomly allotted to one of six dietary treatments with seven replications per treatment. Pigs were fed corn-soybean meal-based diets arranged in a 2 × 3 factorial with main effects of glycerol (0, 2.5, or 5%) and DDGS (0 or 20%).

**Results and Discussion**
Overall (day 0 to 97), there were no glycerol × DDGS interactions (P > 0.12) for growth performance, carcass characteristics, and carcass fat iodine value (IV). Increasing glycerol did not affect (P > 0.14) Average Daily Gain (ADG) or Feed/Gain Ratio (F/G). Adding 20% DDGS to the diet did not affect ADG. However, pigs fed diets with 20% added DDGS had greater (P < 0.02) Average Daily Feed Intake (ADFI) resulting in poorer (P < 0.01) F/G than pigs fed diets with no DDGS.

For carcass characteristics, pigs fed increasing glycerol tended to have increased (linear, P < 0.11) yield. Pigs fed diets with added DDGS had increased (P < 0.01) jowl fat, belly fat, and backfat IV compared with pigs fed diets with no DDGS. However, increasing dietary glycerol tended to decrease (linear, P < 0.11) back-fat IV.

In conclusion, feeding pigs 20% DDGS worsened F/G and increased carcass fat IV, whereas feeding glycerol did not influence growth performance but tended to improve carcass yield and reduce backfat IV.

Table 1. Influence of DDGS and glycerol on pig performance and carcass characteristics.

<table>
<thead>
<tr>
<th>Item</th>
<th>DDGS, %:</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>20</th>
<th>20</th>
<th>20</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Glycerol, %:</td>
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<td>2.5</td>
<td>5</td>
<td>0</td>
<td>2.5</td>
<td>5</td>
<td></td>
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<tr>
<td>ADG, lb</td>
<td>2.14</td>
<td>2.11</td>
<td>2.12</td>
<td>2.14</td>
<td>2.12</td>
<td>2.13</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>ADFI, lb</td>
<td>5.37</td>
<td>5.28</td>
<td>5.30</td>
<td>5.39</td>
<td>5.41</td>
<td>5.53</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Feed/gain</td>
<td>2.51</td>
<td>2.50</td>
<td>2.50</td>
<td>2.52</td>
<td>2.56</td>
<td>2.60</td>
<td>0.02</td>
<td></td>
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<tr>
<td>Carcass wt, lb</td>
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<td>204.7</td>
<td>203.1</td>
<td>201.6</td>
<td>202.5</td>
<td>204.3</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>Carcass wt CV, %</td>
<td>9.0</td>
<td>9.4</td>
<td>9.2</td>
<td>8.8</td>
<td>8.1</td>
<td>8.9</td>
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<td>Yield, %</td>
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<td>75.7</td>
<td>74.5</td>
<td>75.9</td>
<td>75.7</td>
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</tr>
<tr>
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<td>49.1</td>
<td>49.1</td>
<td>49.3</td>
<td>49.4</td>
<td>49.3</td>
<td>0.24</td>
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<td>Backfat</td>
<td>66.1</td>
<td>65.7</td>
<td>65.5</td>
<td>73.6</td>
<td>71.5</td>
<td>72.9</td>
<td>1.07</td>
<td></td>
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<td>Iodine value, g/100 g</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Jowl fat</td>
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<td>69.6</td>
<td>68.9</td>
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<td>73.3</td>
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<td>66.8</td>
<td>65.5</td>
<td>73.6</td>
<td>71.5</td>
<td>72.9</td>
<td>1.07</td>
<td></td>
</tr>
<tr>
<td>Backfat</td>
<td>66.1</td>
<td>65.7</td>
<td>65.5</td>
<td>73.6</td>
<td>71.0</td>
<td>71.8</td>
<td>1.22</td>
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Evaluation of Low Fat Solubles Dry Distillers Grains on Ruminal Fermentation and Digestibility when Included in Finishing Feedlot Rations (2010)

Grant Crawford and Alfredo DiCostanzo
University of Minnesota

Objectives
To evaluate the effect of low-fat dried distillers grains with solubles (LFDDGS) on organic matter total tract digestibility and ruminal fermentation parameters.

Study Description
Six Holstein steers (698 lb initial BW) fitted with flexible ruminal cannula were used in a replicated 3 x 3 latin square design to study effects of replacing 35% of the dry rolled corn (DRC) with either conventional DDGS or LFDDGS. This design permitted studying diet digestibility, ruminal pH and fermentation end-product concentration in a total of six replications per treatment applied over three subsequent periods.

Results and Discussion
Intake was greater for cattle fed either type of distillers grains and solubles (DGS). Ruminal pH was similar among treatments, but ruminal ammonia-nitrogen (N) concentration was less for steers fed DRC only or those fed 35% LFDDGS than for those fed DDGS. Ruminal total volatile fatty acid (VFA) concentration was greater for cattle fed DRC only or those fed 35% LFDDGS than those fed DDGS (Figure 1). Taken together, less ruminal ammonia-N and greater total VFA concentration for cattle fed DRC only or those fed 35% LFDDGS suggest increased use of ammonia-N and growth of ruminal microbes for lower-fat containing rations.

In conclusion, inclusion of LFDDGS resulted in lower ammonia-N concentration and increased ruminal VFA compared with traditional DDGS, which may be the consequence of enhanced growth of ruminal microorganisms as a result of reduced dietary fat. Partial replacement of DRC by LFDDGS, and its potential effects on growth of ruminal microbes and ammonia-N utilization, led to no change in ammonia-N or VFA while that by conventional DDGS led to increased ammonia-N concentration and decreased ruminal VFA concentration.

![Figure 1. Concentrations of volatile fatty acids (VFA) in the rumen fluid of cattle fed finishing diets containing 84% dry rolled corn (DRC) or having 35% DRC substituted with dried distillers grains plus solubles (DDGS) or low-fat dried distillers grains plus solubles (LFDDGS). Cattle fed 35% DDGS had lower concentrations of VFA indicative of lower microbial activity.](image)
**Objectives**

- Identify a range of dietary electrolyte balance (DEB) values for diets containing distillers dried grains with solubles (DDGS) and canola meal that would not affect market tom turkey performance under practical formulation and typical rearing conditions.
- Determine if addition of phytase modifies the DEB in a diet with a high level of alternative feed ingredient inclusion.
- Develop a modified DEB calculation (mDEB) utilizing other electrolyte contributions such as sulfur for use with alternative ingredients.

**Study Description**

Male turkey poults were fed the test diets starting at two weeks of age to 14 or 17 weeks of age. Diet effect on turkey performance (growth and feed efficiency) was analyzed statistically as was the impact of diet on litter moisture.

In the first study, three different base diets with and without DDGS and canola meal were formulated with three different levels of chloride (.22, .32, and .42% Cl) to form nine diet treatments. The diet formulations were meant to represent DEB ranges under typical feeding conditions. Sodium level was kept constant in all diets. Chloride levels were adjusted with salt, sodium bicarbonate and/or ammonium chloride.

In the second trial, a factorial design was used with factors of phytase supplement and chloride level. Phytase was either supplemented or not with a commercial enzyme product to provide 500 units/kg. Chloride level was set at four levels .2, .3, .4, and .5 %. The DDGS/canola meal diet was used as the base diet. A control corn-soy diet containing .3% Cl was also included in the study.

**Results and Discussion**

Inclusion of DDGS (20%) in market tom turkey diets while resulting in similar body weight to turkeys fed corn-soy control diets to 14 weeks of age had poorer feed efficiency indicating that assignment of the appropriate metabolizable energy value to DDGS is needed in order to achieve optimal feed efficiency. In corn-soy diets and diets with 20% DDGS, chloride levels of .42% were without effect on market tom turkey performance.

Under conditions of increasing chloride level, inclusion of both canola meal (10%) and DDGS (20%) resulted in either poorer feed conversion and/or growth (Figure 1). Supplementation of the diet with phytase (500 ftu/kg) allowed reductions in expensive ingredients of dicalcium phosphate and supplemental fat and provided similar performance to that of non-phytase supplemented diets. Increasing diet chloride content in combination with phytase produced a curvilinear response in feed efficiency, where minimum feed efficiency was obtained at .3% chloride. Extrapolating from the research diets, minimum dietary electrolyte balance in market turkey tom diets with high levels of alternative feed ingredients, in this case, canola meal and DDGS changed with bird age. Minimum dietary electrolyte balance based on observed growth should not be less than 217, 200, and 171 meg/kg of diet during 8-11, 11-14 and 14-17 weeks of age when using both DDGS and canola meal.

The overall conclusion reached was that there should be careful consideration in the level of use of both canola meal and DDGS in market turkey diets and that both diet chloride level and electrolyte balance should be considered to minimize any potential negative performance effects and wet litter condition in the turkey barn.

![Figure 1. Feed efficiency (8-14 weeks of age) of market tom turkeys to chloride level (.22, .32, .42% of diet) in diets containing 20% DDGS and 10% canola meal. Interaction of chloride level and diet series (P<.0017).](image-url)

Gerald Shurson and Brian Kerr
University of Minnesota and United States Department of Agriculture-Agricultural Research Service (USDA-ARS)

Objectives

- Obtain sources of corn distillers dried grains with solubles (DDGS) varying in nutrient and energy concentration
- Develop prediction equations for Digestible Energy (DE) and Metabolizable Energy (ME)

Study Description

Two experiments were conducted where we measured the concentration of energy among sources of DDGS with variable concentration of fat and variable concentration of fiber. Fat concentration ranged from 4.88 to 10.88% in Experiment 1 and from 8.56 to 13.23% in Experiment 2. The concentration of fiber (NDF) also varied among the four corn-DDGS sources was 2.25 and 3.40 percentage units, respectively, in Experiment 1. But, variation was greater among the 11 corn-DDGS sources evaluated in Experiment 2, where they differed by 6.46 and 15.18 percentage units, respectively.

These sources of DDGS were fed to growing pigs with body weight between 80 and 110 kg. Total excretion of feces and urine were collected for a period of four days after pigs had consumed DDGS for 10 days of adaptation. Ingredients, diets, feces and urine were analyzed for the concentration of gross energy.

Results and Discussion

There were differences in the concentration of DE and ME among sources of DDGS in Experiment 1 and Experiment 2. There was a 15% difference between the sources of DDGS with the least and greatest concentration of ME (3,266 to 3,696 kcal/kg DM). This wide range corresponds with variability observed in the literature.

These differences in DE and ME also allowed developing prediction equations based on multiple variables. The best fit equations included total dietary fiber, gross energy, bulk density or combinations with ether extract. The best fit DE equation was $\text{DE (kcal/kg DM)} = 1,601 - (54.48 \times \% \text{total dietary fiber}) + (0.69 \times \% \text{gross energy}) + (731.5 \times \text{bulk density})$ with a high $R^2 = 0.91$ and moderate standard error $SE = 41.25$. On the other hand, the best fit for ME prediction was $\text{ME (kcal/kg DM)} = 4,558 + (52.26 \times \% \text{EE}) - (50.08 \times \% \text{TDF}) [R^2 = 0.85, SE = 48.74]$.

Taken together, these data suggest that measures of dietary fiber are more important than concentration of fat when determining the concentration of DE and ME among sources of DDGS.

Determination of Potential Human Health Benefits from Diets Containing Corn Distiller’s Co-products (2010)

University of Minnesota and Agricultural Utilization Research Institute (AURI)

Objectives
Examine the potential health benefits of DDGS to understand the potential for the use of DDGS as a functional food.

Study Description
Samples (n = 16) of DDGS from sixteen different production plants were characterized. DDGS samples had approximately twice the vitamin E concentration of corn. Antioxidant capacity, which is the ability of a substance to resist oxidation, was three to five times greater in DDGS samples than corn. Ferulic acid is an antioxidant present in cereals that may have anti-cancer and anti-diabetes properties. Ferulic acid content of DDGS samples was approximately three times greater than in corn.

Thus, DDGS is greatly enriched in a number of potentially beneficial compounds present in corn. Therefore, we examined the effect of feeding 1) DDGS, 2) a DDGS solubles fraction, and 3) corn bran on liver cholesterol, excretion of cholesterol and bile acids, and xanthophyll bioavailability in cholesterol-fed rats.

Results and Discussion
Liver cholesterol was significantly decreased by feeding DDGS and the DDGS solubles fraction, relative to a control diet. The corn bran fraction also lowered cholesterol, but to a lesser extent. Bile acids are synthesized from cholesterol in the liver and secreted into the small intestine to aid fat absorption. Increasing bile acid excretion is well known to lower cholesterol. Relative to the control diet, DDGS, the DDGS soluble fraction, and corn bran, all increased bile acid excretion. DDGS also tended to increase excretion of cholesterol and its bacterial metabolites. Increased excretion of bile acids and cholesterol appears to be part of the mechanism for the cholesterol lowering effect of these DDGS, DDGS solubles fraction and corn bran.

Attempts were also made to assess xanthophyll bioavailability. Xanthophylls are colored compounds in corn that may help prevent macular degeneration. However, even using highly sensitive LC-MS instrumentation, no xanthophylls could be detected in plasma or tissues after consumption of DDGS or the DDGS solubles fraction. Since food components that lower liver cholesterol in rats generally lower plasma cholesterol in humans, these studies suggest that DDGS and the DDGS soluble fraction may be effective at lowering cholesterol in humans.

Finally, the ability of DDGS, DDGS solubles fraction, and corn bran to reduce atherosclerosis, the leading cause of heart disease, was examined in a mouse model prone to atherosclerosis. After four months of feeding the diets, the area of atherosclerotic lesions in the aortic arch of mice fed the DDGS diet was less than that of mice fed the DDGS solubles fraction but only tended to be lower than mice fed the control or corn bran diets. Serum cholesterol, which is highly elevated in this animal model, did not differ among the groups.

Thus, DDGS, a co-product of fuel ethanol production, appears to show promise as a functional food ingredient. DDGS is a highly concentrated source of vitamin E and ferulic acid, which may have beneficial health effects. DDGS was shown to substantially lower liver cholesterol in a cholesterol-fed rat and tended to reduce atherosclerosis in a mouse model of atherosclerotic disease. Thus, further study of DDGS for its ability to reduce heart disease risk seems warranted.
Fate and Biological Activity of Antibiotics used in Ethanol Production (2010)
Gerald Shurson, Alfredo DiCostanzo, Devan Paulus-Compart, Angela Carlson, Grant Crawford, Ryan Fink and Francisco Diez-Gonzalez
University of Minnesota

Objectives
Quantify the concentration of various antibiotic residues in distillers grains and to determine their possible biological activity.

Study Description
During ethanol production, specifically during fermentation, antimicrobials can be added to control bacteria growth and reduce competition with yeast for starch fermentation. The lists of antibiotics utilized in ethanol production include erythromycin, penicillin G, tetracycline, tylosin, and virginiamycin. Antibiotics residues are of concern because residues may increase undesirable resistance in bacteria. It is possible that antibiotic residues are destroyed during the subsequent steps of ethanol and DDGS production. However, there are no studies evaluating the concentration of antibiotics in distillers grains.

Therefore, we collected twenty dried distillers grains and twenty wet distillers grains samples from various ethanol plants over the course of one year. The concentration of residues were analyzed in solid phase extraction and analysis in liquid chromatography and ion trap tandem mass spectrometry. We also measured the biological activity of these antibiotics using sentinel bacteria Escherichia coli and Listeria monocytogenes.

Results and Discussion
From all samples collected (n = 159), 13%, contained low (< 1.12 ppm) antibiotic concentrations. Residues were observed to Erythromycin and Penicillin G, while no residues were observed for Tetracycline or Tylosin. However, one sample was able to inhibit growth of E. coli at 104 CFU/mL, but this source of DDGS didn't contain any antibiotic residue. The data indicates that antibiotics, despite use during ethanol production, are destroyed post fermentation. This destruction process reduces the risk of residues in distillers' grains and in animal feeds.


Effect of Distillers Dried Grains and Soy Glycerin in Beef Finishing Diets on Fresh and Further Processed Beef Quality Characteristics (2011)
Ryan Cox, Grant Crawford and Alfredo DiCostanzo
University of Minnesota

Objectives
Evaluate the effects of feeding modified distillers grains with solubles (MDGS) at 35% and crude soybean glycerin at 10% inclusion in beef cattle finishing diets on carcass characteristics, meat color, fatty acid profiles, and sensory attributes of fresh and processed beef.

Study Description
Forty-eight cattle had been fed a 79% steam-flaked corn (SFC) based diet (balance was 11% hay and 10% supplement) where MDGS replaced 35% of the SFC or soy glycerin replaced 10% of the SFC or both MDGS replaced 35% and soy glycerin replaced each 35% and 10% of the SFC, respectively for 124 or 173 days.

At harvest, carcass characteristics were measured and samples of strip loins, shoulder clods and inside rounds were purchased back to evaluate quality and sensory traits on steaks and summer sausage.

Results and Discussion
Dietary treatment had no effect on any specific fatty acid, vacuum purge or cooking loss, Warner-Bratzler shear force values (a measure of steak toughness), strip steak or ground beef objective color values (instrument-derived observations of lightness, redness or yellowness). Steaks from cattle fed SFC only and those fed MDGS had higher values for consumer overall liking and texture liking.
Investigation of Relationships of Chemical Composition, Viscosity, and Metabolizable Energy of Distillers Grains for Poultry (2011)
Sally Noll and Alexa Copeland
University of Minnesota

Objectives
- Determine metabolizable energy and chemical composition of varying sources of DDGS
- Determine digesta viscosity from young turkeys fed DDGS containing diets

Study Description
Thirteen samples of dried distiller's grains with solubles (DDGS) were collected from the Midwest region of the United States. Each sample was analyzed for proximate components, gross energy, and color (CIE scale, L*, a*, b*). Crude protein was estimated from nitrogen determination through combustion. Each sample was assayed for apparent metabolizable energy (AMEn, corrected for nitrogen). A subset of samples was analyzed for metabolizable energy using the True Metabolizable Energy procedure (TMEn, corrected for nitrogen). All metabolizable energy assays were conducted with young turkeys.

Results and Discussion
The results of the project demonstrated that feeding a variety of different DDGS at a level of 15% did not increase intestinal viscosity in young turkey poults and therefore should not be associated with an increase in undesirable bacteria in the gut. As crude fat decreased, the crude protein content of the DDGS increased. The determined and predicted AME content of the DDGS when grouped by crude protein content indicated a decline in AME content of the DDGS (Table 1).

A second outcome of the project was the determination of a relatively simple regression equation to predict DDGS apparent metabolizable energy value (AMEn) using crude protein (dry matter basis). Addition of other variables to the prediction equation such as crude fat, viscosity, color and gross energy were not effective in enhancing the model fit. While crude fat content was correlated with gross energy content of the feed, it was not highly correlated with the AME content.

<table>
<thead>
<tr>
<th>Range Cr. Protein, dm %</th>
<th>Number of samples</th>
<th>Average Analyzed (dm basis)</th>
<th>Predicted AMEn, kcal/kg</th>
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</thead>
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<tr>
<td>Cr. Protein</td>
<td>Crude fat</td>
<td>AMEn</td>
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</tr>
<tr>
<td>%</td>
<td>%</td>
<td>kcal/kg</td>
<td></td>
</tr>
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<td>P-value</td>
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Table 1. AMEn of dried distillers grains with solubles categorized by crude protein content.

a,b Means with different superscripts are statistically different (P<.05).
Vitamin E and Selenium Status of Pigs Fed DDGS Diets and Relationship to Mulberry Heart Disease (2011)
Gerald Shurson
University of Minnesota

Objectives
Determine if feeding DDGS for prolonged time to sows and their progeny reduces growth performance and induce oxidative stress in young nursery pigs that results in development of Mulberry Heart Disease (MHD).

Study Description
Vitamin E (Vit E) and selenium (Se) are important nutrients that support a wide variety of functions in metabolism. Depletion of the concentration of these nutrients may lead to metabolic diseases such as MHD in young pigs, especially of fast growth. Depletion of Vit E and Se concentrations in tissues of young pigs may occur due to low dietary concentration, low intake during lactation, and high utilization as antioxidants during feeding peroxidized DDGS.

We tested the effect of these 3 conditions by feeding DDGS to 12 sows over 3 parities in gestation and lactation diets. Then, we selected 108 pigs from the litters of these 12 sows. Pigs weaned and fed 1 of 3 diets: 1) 0% DDGS, 2) 30% DDGS with 1 x NRC (1998) levels of Vit E, and 3) 30% DDGS with 5x NRC (1998) level of Vit E. Serum and milk samples were collected from sows on day of farrowing, on day 17 and 19 (at weaning). Piglets serum was collected on 0, 7, 19, 47, and 68 days of age. Pigs were harvested on day 68 of age and samples of liver and hearts were analyzed for concentration of α-tocopherol (Vit E) and Se, as well as signs of MHD.

Results and Discussion
Pigs from sows fed DDGS effectively tended to have less serum concentration of vitamin E (5.6 μm) compared with pigs from sows fed the standard corn-soybean meal diet (6.7 μm). This lower serum concentration of Vit E was in agreement with less concentration of Vit E in milk of sows fed DDGS. Despite differences in serum Vit and and Se concentration, no lesions characteristic of MHD were observed in any of the pigs evaluated.

Overall, pig and sow performance were not affected by dietary treatments. In conclusion, feeding sows DDGS had negative impact on Vit E and Se status of pigs preweaning. This lower level of Vit E and Se is related to lower concentration of these nutrients in milk. However, these lower levels of Vit E and Se were not persistent once pigs started to consume their different nursery diets that contained adequate or fortified levels of Vit E. Reductions in serum concentrations of Vit E and Se are not sufficient to induce Mulberry Heart Disease.


Sally Noll, Gerald Shurson and Brian Kerr
University of Minnesota and United States Department of Agriculture-Agricultural Research Service (USDA-ARS)

Objectives
Determine the impact of decreasing levels of crude fat in DDGS on metabolizable energy (ME) content in young turkeys as related to composition and amino acid quality with the intent to develop ME prediction equations.

Study Description
Six samples of DDGS were obtained from Brian Kerr (USDA-ARS, Ames, Iowa), identified as samples A, B, C, D, E, and F. The analyses were conducted at USDA-ARS or samples were submitted to commercial laboratories. The six samples were obtained from six different commercial ethanol plants in IA, IL, MN, MO, and SD. Ether extraction was completed to determine the crude fat content of the DDGS. The range in fat content (dry matter basis, dm) was 6.99 to 13.31% with an average crude fat content of 9.9%. Samples A, B, and F had higher fat content. Samples varied in composition as well in terms of protein, lysine, fiber, and mineral content.

Two methodologies were used to determine the metabolizable energy content of the DDGS samples in young turkeys apparent metabolizable energy (AMEn) and true metabolizable energy (TMEn). Correlations (Pearson’s) of nutrient composition to the determined ME values were determined with calculated probability.

Results and Discussion
Determination of metabolizable energy using the TMEn method was more sensitive in determining differences among six samples of DDGS as compared to determination using AMEn calculation methods.

In contrast to previously published work by Rochell et al. (2011) and Meloche et al. (2013) with chicken broilers, AMEn measures in turkeys were not correlated with DDGS composition, while correlations using TMEn values resulted in only weak correlations to content of crude protein, crude fat, and gross energy composition so prediction equations could not be developed.

Samples of DDGS with higher fat content tended to have greater TMEn values, those with lower fat content tended to have lower but similar TMEn values (Table 1). While de-oiling appears to decrease the ME level, the composition of the six DDGS samples was unique and a larger data set of samples may be required to dissect the impact of the different DDGS components on ME content for turkeys.

<table>
<thead>
<tr>
<th>DDGS Crude Fat (dm,%)</th>
<th>Metabolizable energy (kcal/kg)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Apparent metabolizable energy (AMEn)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>True metabolizable energy (TMEn)</td>
<td></td>
</tr>
<tr>
<td>13.3</td>
<td>3526</td>
<td>2947&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>10.4</td>
<td>3453</td>
<td>2747&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>9.1</td>
<td>3175</td>
<td>2784&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>8.0</td>
<td>2923</td>
<td>2761&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>7.0</td>
<td>3486</td>
<td>2810&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>11.4</td>
<td>3094</td>
<td>3138&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>P-value</td>
<td>NS</td>
<td>.007</td>
</tr>
</tbody>
</table>

Table 1. Metabolizable energy content of test distillers dried grains with solubles for young turkeys determined as apparent metabolizable energy (AMEn) and true metabolizable energy (TMEn) (dry matter basis).

<sup>a,b</sup> Means with different superscripts are statistically different.
Increasing the Usage Level of Corn and Distillers Grains in Market Turkey Diets Through the Use of Supplemental Amino Acids (2013)

Sally Noll
University of Minnesota

Objectives
Determine if supplemental tryptophan and valine can be utilized in market turkey diets with a significant amount of corn protein present without causing a decline in performance.

Study Description
Four feeding trials were conducted examining the performance response of market turkey hens to reduced dietary protein and amino acid supplementation during 0 to 4 and 10-14 weeks of age.

In the first study, dietary reductions in crude protein were achieved by utilizing increasing amounts of supplemental threonine and level of corn in the diets. However, a reduced gain was observed in turkeys.

In the second study, supplements of valine, tryptophan, and/or arginine were added in various combinations to reduced protein diets containing 20% DDGS to examine the potential restoration of performance.

Results and Discussion
The amino acids, arginine and tryptophan, were found to be co-limiting in poult starter diets with 20% DDGS. In grower type diets with 20% DDGS, valine appears to be limiting along with arginine and tryptophan. In both phases, performance was not completely restored with amino acid supplementation. Also, utilization of supplemental valine and tryptophan in diets high in corn protein will be limited by a lack of a commercially available arginine and potentially isoleucine.

Dried distillers grains with solubles was found to decrease diet cost per ton of feed and to decrease cost per unit of gain in grower hen turkeys. However, reduced dietary protein with the resulting decreased rate of gain would affect market weight at a specific age.
Renewable Electrolytic Nitrogen Fertilizer Production (2007)

Ted Aulich, Junhua Jiang and Alexey Ignatchenko
University of North Dakota Energy & Environmental Research Center (EERC)

Objectives
- Optimize thermal and electro catalysts, electrolyte (electrolytic membrane), and reaction conditions needed for the EERC-developed integrated electrochemical–thermal (IET) ammonia production process
- Enable the process to operate at maximum ammonia production rate and minimum energy consumption

Study Description
The IET ammonia process operates at a reaction temperature of 200°–400°C, with inputs of biomass gasification or natural gas reformation-derived syngas, air-extracted nitrogen, and electricity. Unlike traditional Haber–Bosch-based ammonia processes that require the use of expensive high-purity hydrogen and operation at high pressure (3000 psi) to achieve economic viability, the IET process can utilize relatively impure hydrogen and works well at 200 psi, the impacts of which are lower capital and operating ammonia production costs.

This study comprised laboratory-scale activities focused on overall IET process optimization to yield data necessary for preliminarily assessing the economic viability of the process.

Results and Discussion
Project accomplishments include:
- Development of an improved electrolyte membrane and improved electro and thermal catalysts that enable higher-efficiency electricity utilization in IET ammonia production
- IET process optimization at a 20-watt (W) scale
- Design and fabrication of a 200-W IET electrolyzer
- Preliminary design of a 200-W complete IET ammonia production system
- Preliminary commercial viability assessment of the IET process

IET process technical viability was demonstrated in long-term 20-W tests conducted using simulated syngas (comprising 76% H2, 2% CO, 2% CH4, and 20% CO2), the results of which demonstrated:
- High (95%) electric current efficiency in hydrogen extraction from syngas
- Low-pressure (200 psi) formation of ammonia at a five-times-higher catalyst activity and 10% lower energy input requirement than achievable with Haber–Bosch-based ammonia production
- Long-term (at least 26 days) thermal catalyst durability

<table>
<thead>
<tr>
<th>Syngas Price¹</th>
<th>$/MMBtu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Price</td>
<td>$0.05/kWh</td>
</tr>
<tr>
<td>Cost of Electricity²</td>
<td>$120</td>
</tr>
<tr>
<td>Cost of Syngas Input</td>
<td>$142</td>
</tr>
<tr>
<td>Capital Cost</td>
<td>$21</td>
</tr>
<tr>
<td>Operating and Maintenance Cost</td>
<td>$32</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$315</td>
</tr>
</tbody>
</table>

Table 1. Projected per-ton cost of ammonia production via EERC-Developed IET process.

²Based on electricity consumption of 2400 kWh/ton ammonia produced.
Determining Optimum N Rates for Corn after Soybeans in On-Farm Trials in Southern Minnesota (2008)
Gyles Randall and Jeffrey Vetsch
University of Minnesota

Objectives
Determine the optimum nitrogen (N) rate for corn for the purpose of updating the University of Minnesota’s (UMN) N rate database for either validating or adjusting its N rate recommendations to farmers.

Study Description
Four nitrogen rate studies were conducted on farmers’ fields in LeSueur, Rice and Olmsted counties in 2008. Three sites followed soybeans and one site followed corn. UMN personnel established the experimental sites, applied the N fertilizer (urea) treatments prior to planting, took all plant and soil samples, and took grain and stover yields. The farmers tilled the site, planted corn, and applied herbicides at the LeSueur and Rice County sites while UMN personnel performed these tasks at the Olmsted sites.

Results and Discussion
Economic optimum N rates (EONR) for corn after soybeans were 109, 114, and 115 lb N/acre with accompanying yields of 184, 237, and 181 bu/acre at the three sites.

When corn followed corn, an EONR of 152 lb N/acre was obtained with an accompanying yield of 232 bu/acre. At all four sites, the EONR was within the present optimum N rate guideline range recommended by UMN. Soil N provided 68% of the optimum grain yield when the previous crop was soybean and 38% when corn was the previous crop. For each lb of fertilizer N applied at the EONR, the grain yield response over the zero-N control treatment yield was 0.82 bu for corn after corn and 0.36 bu following soybeans. The poorer efficiency for corn after soybeans was primarily due to soil N providing a greater portion of the yield. Apparent recovery of fertilizer N in the grain was 59% and 51% when following corn and soybean, respectively.

Split-applying (preplant + V6 sidedress) fertilizer N at the two Olmsted County sites did not increase grain yield above preplant-applied N.

Table 1. Corn grain yield and N efficiency factors as influenced by N rate for each of the four sites.

<table>
<thead>
<tr>
<th>N rate</th>
<th>County / Site</th>
<th>LeSueur</th>
<th>Rice</th>
<th>Olmsted 1</th>
<th>Olmsted 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>lb N/acre</td>
<td></td>
<td>Grain Yield (bu/acre)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0/0</td>
<td></td>
<td>100</td>
<td>127</td>
<td>179</td>
<td>192</td>
</tr>
<tr>
<td>30/40</td>
<td></td>
<td>127</td>
<td>150</td>
<td>195</td>
<td>155</td>
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<tr>
<td>60/80</td>
<td></td>
<td>172</td>
<td>172</td>
<td>223</td>
<td>196</td>
</tr>
<tr>
<td>90/120</td>
<td></td>
<td>179</td>
<td>177</td>
<td>231</td>
<td>225</td>
</tr>
<tr>
<td>120/160</td>
<td></td>
<td>180</td>
<td>178</td>
<td>237</td>
<td>228</td>
</tr>
<tr>
<td>150/200</td>
<td></td>
<td>182</td>
<td>185</td>
<td>237</td>
<td>238</td>
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<tr>
<td>180</td>
<td></td>
<td>192</td>
<td>182</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Previous Crop</td>
<td></td>
<td>5b</td>
<td>5b</td>
<td>5b</td>
<td>5b</td>
</tr>
<tr>
<td>EONR (lb N/acre)</td>
<td></td>
<td>109</td>
<td>115</td>
<td>114</td>
<td>152</td>
</tr>
<tr>
<td>Yield @ EONR</td>
<td></td>
<td>184</td>
<td>181</td>
<td>237</td>
<td>232</td>
</tr>
<tr>
<td>% Yield from soil N</td>
<td></td>
<td>54</td>
<td>75</td>
<td>75</td>
<td>39</td>
</tr>
</tbody>
</table>

Table 1. Corn grain yield and N efficiency factors as influenced by N rate for each of the four sites.
\(30/40\) is 30 lb N/acre after soybeans and 40 lb N/acre after corn.
Study Description
The study used the original design for the University of Minnesota Renewable Hydrogen and Ammonia pilot plant to model the anticipated energy usage based on nameplate loads for individual components. The cost of wind energy was modeled based on data collected from a 1.65 MW wind turbine located at the West Central Research and Outreach Center (WCROC) near Morris, MN.

A total cost of production for anhydrous ammonia produced from wind energy was then predicted. Capital costs were modeled by obtaining budgetary pricing for various sized plants. Operating costs were projected. Industry standard transportation costs were applied to a localized ammonia production scenario.

Results and Discussion
The total production of ammonia predicted from the pilot plant is 2,138 lbs of ammonia per day. The total amount of energy consumed by the pilot plant is estimated to be 652 kilowatt hours per day. Therefore, the pilot plant is expected to require approximately 7.3 kW per lb of ammonia produced. Assuming a wind energy price of $0.05 / kWh, the cost of energy per lb of ammonia is projected to be $0.37 per lb or $733 per ton of ammonia.

Through the design process, pricing was received on four differing scales of electrochemical ammonia plants including annual nameplate ammonia production capacities of 22, 340, 880, and 10,000 tons per year. Figure 1 shows the estimated cost per ton of annual ammonia production capacity and the annual ammonia production capacity. As the plant sizes increases, economies of scale are realized. An electrochemical ammonia plant capable of producing 10,000 tons per year has a projected cost equal to $7,090 per ton of nameplate ammonia production.

The industry standard for operation and maintenance costs is generally within 2-3% of the total capital costs. As the scale of the plant is increased, the costs decrease per unit of production. Supervision is generally required on a 24/7 basis. For any sized plant, this would typically mean four to five full-time equivalent personnel. The largest operational expense for an electrochemical ammonia plant is the electrical energy. A plant is expected to use between 5.5 and 7.5 kWh per lb of ammonia. A 10,000 ton per year facility with efficiency of 6.0 kWh per lb of ammonia and an average cost of $.035 per kilowatt hour would have an annual energy expense of $4.2 million.

The industry standard transportation costs for ammonia ranges between $40 and $80 per ton. A local 10,000 ton plant size is estimated to provide the entire ammonia supply for one county. Considering that not all of the ammonia will be sold in one county, a reasonable average distance for transporting locally produced ammonia is 30 miles. A reasonable total annual transportation price would range between $25,000 to $50,000 per year or less than $5 per ton. Considering the significant reduction in transportation costs from the industry standard, it may be possible to reduce storage costs by converting the ammonia to 32 or 28% aqueous ammonia. Aqueous ammonia has several benefits from a cost of storage, safety, and utilization standpoint and may merit further investigation for local electrochemical nitrogen fertilizer production plants.

continued on following page
Figure 1. Relative estimated capital costs of various sized NH3 plants.

Figure 2. Renewable Hydrogen and Ammonia Pilot Plant (post-study).

Figure 3. Ammonia reactor skid installation at the WCROC pilot plant (post-study).
Fertilizer and Manure Management Effects on Phosphorus in Corn and Soybean Production (2008)

Jeff Strock, Jeff Apland, Mike Schmitt, Jim White and Kelley Belina
University of Minnesota

Objectives
- Evaluate phosphorus management scenarios involving tillage, phosphorus source, phosphorus rate, and application method that might lead to enhanced crop production in western Minnesota
- Measure long-term soil phosphorus build-up as well as phosphorus use efficiency
- Measure the effect of residual phosphorus on soil test phosphorus and grain yield

Study Description
Research plots were established for a corn-soybean rotation in southwest Minnesota in Lamberton (Ves Loam, Calcic Hapludoll, 1999). Two plot areas were established, one with soybean and one with corn, such that both crops can be grown each year. Main plot treatments included: no-tillage and conservation tillage (fall chisel plow plus spring field cultivation). Three phosphorus rates [zero P, crop removal (80 lb P2O5/A), and twice crop removal (160 lb P2O5/A)] and two sources of phosphorous (commercial fertilizer and liquid swine manure) were applied in the fall following soybean harvest.

Two methods of phosphorus application (broadcast and subsurface banding) were also evaluated. Manure and commercial fertilizer were incorporated after application. To assure nitrogen sufficiency, 150 lb N/A urea was applied to all treatments in spring before cultivation and planting. Plots were 20 ft. wide by 50 ft. long. All treatments were replicated four times.

Soil samples were collected before fertilizer treatment in the initial year and analyzed for pH and available phosphorus. Thereafter, soil samples were collected after soybean harvest from the 0-12 inch depth in four inch increments. Above ground biomass samples were collected before corn harvest. Yield determinations were made from each plot and corn and soybean grain samples saved. Soil, biomass, and grain sample analysis for phosphorus were used to test that the crops had sufficient phosphorus to attain optimum yield, and to construct a phosphorus budget for this experiment.

Results and Discussion
Yield Summary—The best phosphorus management scenarios for corn and soybean response on this soil were not very different between the crops. Both responded well to banded manure. When comparing the two tillage systems, soybean yielded higher in the conservation till system. This could be attributed to differences in root structure and nutrient use between the two crops. Both corn and soybeans averaged higher yields in the manure systems when compared to fertilizer. Corn also averaged greater yields at higher rates.

Soil—The interactions between tillage system and phosphorus source and placement on soil test phosphorus by depth are shown in Figure 1. The data show that soil test phosphorus level decreased with depth. The highest rates of manure and fertilizer resulted in the highest soil test phosphorus levels in the 0-4 inch depth (Figure 1). The interactions phosphorus source and rate, soil test phosphorus and year are shown in Figure 2. The data indicate a general trend of decreasing soil test phosphorus with time regardless of manure application rate (Figure 2).

The data also indicate a trend of decreasing soil test phosphorus with time for the medium application rate of commercial fertilizer. The soil test phosphorus level for the high application rate of commercial fertilizer resulted in increasing soil test phosphorus with time. The increase in soil test phosphorus in 2004 is noteworthy because conditions for mineralization and yield during this growing season were exceptional. It is also noteworthy that repeated application of liquid swine manure did not result in phosphorus accumulation to levels close to those in high rate, inorganic phosphorus fertilizer-treated soils.

Corn Grain—Tillage system resulted in significantly higher grain phosphorus concentration for corn
in the no-till system, 2.5 ppm, compared to the conservation tillage system, 2.4 ppm. Phosphorus source resulted in significantly higher grain phosphorus concentration for corn when manure was applied compared to commercial fertilizer, 2.5 ppm, compared to 2.4 ppm. Phosphorus rate resulted in significantly higher grain phosphorus concentration for corn at the high rate (160 lb P2O5/A) compared to medium rate (80 lb P2O5/A), 2.6 ppm, compared to, 2.3 ppm. Method of phosphorus placement resulted in significantly higher grain phosphorus concentration for corn when broadcast and incorporated, 2.5 ppm, compared to injected as a band, 2.4 ppm.

Soybean Grain—Tillage system resulted in significantly higher grain phosphorus concentration for soybean in the no-till system, 5.3 ppm, compared to the conservation tillage system, 5.0 ppm. Phosphorus rate resulted in significantly higher grain phosphorus concentration for soybean at the high rate (160 lb P2O5/A) compared to medium rate (80 lb P2O5/A), 5.4 ppm, compared to, 4.0 ppm. Method of phosphorus placement resulted in significantly higher grain phosphorus concentration for soybean when broadcast and incorporated, 5.2 ppm, compared to injected as a band, 5.1 ppm.

Figure 1. Soil test phosphorus results by depth averaged across treatments for the period 1999-2005.

Figure 2. Average soil test phosphorus results for the control, manure, and fertilizer treatments, 0-4 inch depth, 1999-2005.
Carl Rosen, John Lamb and Rodney Venterea
University of Minnesota

Objectives

- Determine if the current guidelines for nitrogen (N) fertilizer are applicable for corn grown on both irrigated and water-stressed coarse-textured soils
- Evaluate the effects of water stress on N fertilizer response and basal stalk nitrate levels
- Characterize the effectiveness of controlled release and stabilized N products for corn production on coarse-textured soils under irrigated and water stressed conditions

Study Description

This study was conducted during the 2008, 2009 and 2010 growing seasons at the Sand Plain Research Farm in Becker, Minnesota, on a Hubbard loamy sand soil. Ten N treatments were evaluated in 2008 and 12 N treatments in 2009 and 2010.

The following 10 N treatments were tested under irrigated and water stressed conditions in 2008: split applied urea at 40, 80, 120, 160, 200, and 240 lb N/A and three rates of preplant applied Environmentally Smart Nitrogen, a polymer coated urea manufactured by Agrium Inc. (ESN) at 120, 160, and 200 lb N/A. A zero N control was also included. The water stressed treatment was initially intended to be a nonirrigated treatment, but due to an extremely dry July in both 2008 and 2009, some irrigation was needed to prevent death of the plants due to drought.

In 2009 and 2010 the following treatments were added: split applied urea at 40, 80, 120, 160, 200, 240, and 280 lb N/A; two rates of preplant applied Environmentally Smart Nitrogen, a polymer coated urea manufactured by Agrium Inc. (ESN) at 120, 160, and 200 lb N/A; one rate of preplant applied urea at 160 lb N/A; and one rate of preplant applied SuperU (manufactured by Agrotain, now Koch Industries), a urea product stabilized with a urease and nitrification inhibitor at 160 lb N/A.

As in 2008, a zero N control was also included in both 2009 and 2010. Plots were hand harvested on Oct. 17, 2008, Oct. 13, 2009, and Sept. 20, 2010. Ears were harvested from 20 ft of row from each of the middle two rows of each plot. Eight-inch stalk samples were collected six inches above the ground from ten plants. Samples were ground and then extracted with water subsequent nitrate determination. The economic optimum N rate (EONR) was determined using an N price to crop ratio of 0.1.

Results and Discussion

Even though water was applied to the 2008 water stressed plots in time to prevent total loss of the crop, yields were adversely affected by the severely dry conditions. This was potentially due to pollination occurring before the water was applied.

These results clearly indicate the current N guidelines for irrigated corn on sandy soils are too low. It is also interesting to note that the EONR under water-stressed conditions when lack of pollination did not affect yield (i.e. in 2009 and 2010), the EONR was also higher than the current N guidelines. This research has been continued on a wide range of irrigated sandy soils in Minnesota to refine the N guidelines. These new guidelines are expected to be available in 2015.

At equivalent N rates, yields with split applied urea were higher than yields with ESN and SuperU applied preplant. Of interest in 2009 and 2010 at equivalent N rates (160 lb N/A) and with irrigation, yields with preplant ESN and SuperU were higher than those with preplant urea. These results indicate that the products are working, but they are not as efficient as split urea applications.

In contrast under water stressed conditions, the coated and stabilized products at equivalent rates and timing had no effects on yield. These results indicate that conditions for N loss and higher yield potential are needed for these products to work properly. Basal stalk nitrate increased with increasing N rate and with water stress. However, these results clearly suggest that if the crop is water stressed, the interpretation of the stalk nitrate test could be compromised.

<table>
<thead>
<tr>
<th>Year</th>
<th>EONR</th>
<th>Yield at EONR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Irrigated</td>
<td>Stressed</td>
</tr>
<tr>
<td></td>
<td>lb N/A</td>
<td>bu/A</td>
</tr>
<tr>
<td>2008</td>
<td>262</td>
<td>257</td>
</tr>
<tr>
<td>2009</td>
<td>221</td>
<td>225</td>
</tr>
<tr>
<td>2010</td>
<td>185</td>
<td>197</td>
</tr>
</tbody>
</table>

Table 1. EONR and yield at EONR during the three-year study.
Ammonia Production from Electricity, Water and Nitrogen (2009)
Ted Aulich and Kan Luo
University of North Dakota Energy & Environmental Research Center (EERC)

Objectives
Develop/optimize an electrolytic membrane material ("electrolyte") with the properties needed to enable its effective use in an electrolytic cell capable of high-efficiency, low-pressure ammonia production.

Study Description
The EERC is developing an electrolytic ammonia synthesis process that utilizes inputs of electricity, nitrogen and water or a hydrogen-rich "syngas," a mixture of hydrogen and carbon monoxide (CO) produced via steam-reforming of methane or gasification of coal or biomass.

Unlike Haber–Bosch-based ammonia production processes that utilize high pressure and temperature (up to 3000 psi and 450°C), the EERC electrolytic process is conducted at ambient pressure and a temperature of 250°–350°C. Because the process is electrically driven and capable of achieving optimal efficiency soon after start-up, it is compatible with intermittent operation, which means it offers potential for use as a power plant load management tool and/or for monetization of wind-generated and other renewable electricity without the need for transmission capacity expansion. Because earlier work had developed electrocatalysts needed for the electrolytic ammonia process, this study was focused on development and optimization of an electrolytic membrane (electrolyte), another key process component.

Results and Discussion
Key project activities included 1) design and fabrication of test systems for evaluating membrane materials based on proton conductivity, 2) membrane sample fabrication and evaluation, and 3) design, fabrication, and evaluation (based on ammonia production rate) of small-scale ammonia production systems referred to as "membrane–electrode assemblies" (MEAs).

Table 1 compares EERC-developed MEA systems on the basis of ammonia production rate in moles/seconds-centimeter² (mol s⁻¹ cm⁻²) and uses these laboratory-scale data to project commercial-scale electricity consumption (in kilowatt-hours [kWh]) and cost for producing one ton of ammonia (NH₃).

Using the projected $272/ton NH₃ electricity cost and adding estimated per-ton-NH₃ production costs of $132 and $45 for capital and operating expenses, respectively, equates to a projected cost of $449/ton NH₃ production. With a 15% increase in process efficiency achievable with moderate improvement to the best-performing MEA system, the projected production cost decreases to $370/ton. According to data from the U.S. Department of Agriculture, the U.S. average ammonia price in March 2012 was $783/ton.

Although more work is needed to improve its proton conductivity and durability, the project-developed polymer-based membrane has been demonstrated to perform at a significantly higher temperature than its commercially available counterparts and offers the potential for use in ammonia production, higher-temperature proton exchange membrane fuel cells (with no susceptibility to CO poisoning) and, possibly, other electrochemical applications.

<table>
<thead>
<tr>
<th>Cathode Catalyst</th>
<th>Potential, volts</th>
<th>Temp., °C</th>
<th>Electrolyte Membrane</th>
<th>NH₃ Production Rate, mol s⁻¹ cm⁻²</th>
<th>Electricity, kWh/ton NH₃</th>
<th>Electricity Cost, $/ton NH₃*</th>
</tr>
</thead>
<tbody>
<tr>
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<td>298</td>
<td>Type I</td>
<td>3.41 x 10⁻¹¹</td>
<td>1.44 x 10⁵</td>
<td>5760</td>
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<tr>
<td>Pt/C</td>
<td>1.8</td>
<td>298</td>
<td>Type I</td>
<td>9.8 x 10⁻¹²</td>
<td>8.34 x 10⁵</td>
<td>334</td>
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<tr>
<td>Iron</td>
<td>1.8</td>
<td>260</td>
<td>Type II</td>
<td>1.31 x 10⁹</td>
<td>6.76 x 10⁵</td>
<td>272</td>
</tr>
</tbody>
</table>

*Based on electricity cost of $0.04/kWh.

Table 1. Ammonia synthesis MEA performance and electricity consumption/cost.

Dan Kaiser, Jeff Coulter, Seth Naeve and Ki-In Kim
University of Minnesota

Objectives

- Determine the response of corn grain yield to N and P fertilizer across the landscape where spatial and temporal variation exist
- Determine the economically optimum N fertilizer rate (EONR), nitrogen use efficiency (NUE), grain moisture at harvest, and grain quality
- Determine potential optimum soil fertility management strategies for growing corn in southern Minnesota

Study Description

Two field locations were studied over seven to eight years. Fields were managed with a two-year corn-soybean rotation. Treatments were established using field length strips. Treatments at both locations consisted of a factorial arrangement of large strips with and without phosphorus (main plots) which were sub-divided into five nitrogen rate strips (sub-plots). Strip width was dependent on the size of applicator used (N rate strips were around 60 feet wide at each location).

Grain yield measurements were taken every 40 feet along the treatment strips by harvesting the middle two rows with a research grade combine. Soil samples were collected from the same area where yield measurements were taken. Treatments were re-applied before every year that corn was grown. Since DAP (18-46-0) was the primary source of phosphorus fertilizer no true 0 N rate strip was included with this study.

Results and Discussion

Nitrogen and phosphorus had separate effects on crop yield. Sites varied in soil test phosphorus and crop response was greater and more frequent in field areas that test low. Part of this study was to determine if nitrogen response varied by phosphorus management. The phosphorus by nitrogen interaction was only significant at one of the locations during one growing cycle. There was significant variation in yield across the trials which were a result of spatial variation in elevation and yearly variation in temperature and precipitation. The economic optimum nitrogen rate varied significantly across the study area but the variation could be related to soil factors collected at each site. Variability in yield among plots with similar nitrogen rate was less where P was applied which likely was a result of variation in soil test phosphorus.

The addition of phosphorus did tend to increase the economic optimum nitrogen rate of corn but it is unclear if this is was an actual increase or if the smaller economic optimum nitrogen rate was due to poor utilization of nitrogen due to phosphorus limiting yield potential. Utilization of GIS could help farmers better manage inputs such as nitrogen and phosphorus. Yield data must be cleaned and carefully analyzed to ensure errors are not made when analyzing and interpreting data.

Figure 1. An example of yield variation at one of the locations that was due to treatment and spatial variation in soil properties related to elevation and previous fertilizer management.

Figure 2. Three-year average response to nitrogen based on soil P treatment for one of the study locations. Addition of phosphorus fertilizer did not result in a greater response to N at this location over the three years studied.
Objectives
High-yield continuous corn research was conducted to determine the effects of corn residue removal, tillage system, and N fertilization on:

- Corn grain and residue yield
- Nitrogen uptake
- Economically optimum nitrogen fertilizer rates
- Potential cellulosic ethanol yield
- Soil carbon

Study Description
When Minnesota growers are presented with the opportunity to sell corn residue, they need to be aware of how this influences best management practices such as N fertilization and tillage, along with the effects on crop and soil productivity.

All combinations of corn residue management (removed or retained), tillage system (disk-rip, strip-till, or no-till), and six N fertilizer rates were evaluated in replicated field trials in continuous corn from 2009 through 2012 near Lamberton and Waseca, MN.

Results and Discussion
Corn emergence was 92% or greater within all combinations of residue management and tillage except with no-till and residue retained (Figure 1). Residue removal increased corn grain yield by four to 12% among tillage systems (Figure 2). However, there were limited differences in grain yield among tillage systems within a given residue management strategy. Lower yields when residue was retained were associated with lower early-season soil temperatures and reduced early-season corn growth. The response of corn grain yield to N fertilization was not affected by residue management, but was greater than anticipated (Figure 3).
Corn Response to Starter Fertilizer as Affected by Planting Date and Maturity (2010)

Dan Kaiser and Jeff Coulter
University of Minnesota

Objectives

- Assess the relative impacts of planting date, hybrid relative maturity, and starter fertilizer use on corn growth
- Determine the effects of planting date and hybrid relative maturity on corn yield response (actual and economic) to starter fertilizer
- Study the effects of advanced corn maturation resulting from starter fertilizer use on grain quality

Study Description

Two locations were established in each of three years at the Southern Research and Outreach Center at Waseca and the Southwest Research and Outreach Center at Lamberton. The study utilized factorial design within a randomized complete block design with four replications. Factor One consisted of three hybrid relative maturities (94, 99, and 104 day RM). Factor Two consisted of three planting dates which were late April, early May and late May. Factor Three was either 0 or 5 gallons of 10-34-0 applied directly on the seed (in-furrow or “pop-up”).

Results and Discussion

Starter fertilizer use consistently increased early plant growth and lessened the time to silking by an average of 1-2 days across hybrid RM and planting dates. There was no significant interaction among hybrid RM, planting date, and starter use. Corn grain yield and grain moisture at harvest were consistently affected by hybrid RM and planting date. Grain yield and grain harvest moisture were seldom affected by starter fertilizer use.

Soils tested medium to high in soil test phosphorus indicated that phosphorus in the soil could supply crop needs at most sites. Any yield response was more likely related to decreased time to silking. However, an advancement of 1-2 days likely was not enough to fully realize a yield benefit. If the growing season is long enough, any advancement in silking would not be fully realized in decreased grain moisture at harvest and increased yield. Overall, the results indicate that early or late planting do not increase the likelihood of starter resulting in greater economic benefits for corn growers.
Maximizing On-Farm Nitrogen and Carbon Credits from Alfalfa to Corn (2008) and Predicting On-Farm Nitrogen Credits from Alfalfa to Second-Year Corn (2011)

Jeff Coulter, Matt Yost and Michael Russelle
University of Minnesota and United States Department of Agriculture-Agricultural Research Service (USDA-ARS)

Objectives
Determine nitrogen credit guidelines over a two year period for corn following the termination of a good alfalfa stand in a rotation.

Study Description
The first set of on-farm trials evaluated the response of first-year corn following alfalfa to nitrogen (N) fertilizer, and whether this was affected by the amount of alfalfa regrowth in the fall and the timing of tillage for alfalfa termination. This research was conducted on six farms in southern and central Minnesota in 2010 with medium- to fine-textured soils and good alfalfa stands at the time of termination.

The second set of on-farm trials evaluated the response of second-year corn following alfalfa to N fertilizer applied near planting and as a sidedress. This was done on three farms in 2011 and on eight farms in 2012 in southern and central Minnesota with medium- to fine-textured soils.

Results and Discussion
In the trials of first-year corn following alfalfa, the presence of fall alfalfa regrowth did not affect first-year corn grain yield or its response to N fertilizer applied near planting, even though this alfalfa regrowth ranged from 4 to 18 inches among the six farms. Similarly, there was no effect of tillage timing on first-year corn grain yield. These results indicate that growers should harvest alfalfa regrowth in the last year on medium- to fine-textured soils with good alfalfa stands, and that growers have some flexibility in tillage timing when terminating alfalfa.

In this study, first-year corn grain yield responded to N fertilizer at only one of six farms, even with average yields of 180 to 231 bu/acre. On the one responsive farm where 70 to 81 lb N/acre was needed to economically optimize grain yield, there was fine-textured soil, abundant early-season rainfall, and inadequate drainage, which likely slowed N mineralization due to low oxygen levels in the soil.

When the results of these six on-farm trials were combined with the results of 25 other trials that were conducted in Minnesota and western Wisconsin from 2009 through 2011, grain yield of first-year corn following alfalfa was not increased with N fertilizer in 28 of the 31 trials.

In the trials of second-year corn following alfalfa, there was a response of corn grain yield to N fertilizer in all three on-farm trials in 2011, and the economically optimum N fertilizer rate ranged from 40 to 60 lb N/acre when applied near planting. In 2012, five of the eight on-farm trials had a grain yield response to N fertilizer. The optimum N fertilizer rate in these five trials ranged from 72 to 175 lb N/acre when applied near planting, and N use efficiency was slightly greater in some trials when N fertilizer was applied as a sidedress rather than near planting.

When the results of these 11 on-farm trials were combined with the results of 56 other trials that had previously been conducted in the U.S., there was no response of grain yield to N fertilizer in 45% of the 67 trials (Figure 1). In the responsive trials, the optimum N fertilizer rate ranged from 35 to 180 lb N/acre.

In conclusion, the results from these on-farm trials of first- and second-year corn following alfalfa indicate a great potential to reduce N fertilizer application without reducing corn yield if non-responsive fields can be identified prior to the time of N application, and if more site-specific N rate guidelines can be developed for responsive fields.

Figure 1. Economic optimum N fertilizer rate in 67 trials of second-year corn following alfalfa that include 11 on-farm trials conducted in Minnesota from 2011 to 2012, along with 56 other trials from the literature. There was no response to N fertilizer in 45% of these 67 trials. The economic optimum N rate is based on a 0.10 ratio for N fertilizer cost/corn grain price.
Dan Kaiser, Carl Rosen, John Lamb and Andria Bonde
University of Minnesota and CHS Inc.

Objectives
- Evaluate timing and rate of sulfur (S) and potassium (K) application on plant K availability early-, mid-, and late season
- Evaluate whether split timing of K or S will increase yield relative to a single pre-plant application
- Determine the potential for sulfur and potassium leaching in coarse-textured irrigated soils

Study Description
The purpose of this study was to determine if potassium or sulfur should be split applied under irrigation. While sulfur is mobile in soils, potassium is considered an immobile nutrient. However, soils with a low cation exchange capacity have a lessened ability to hold potassium such that it can be leached.

In this study separate sulfur and potassium studies were established at four locations over two years. Sulfur (0, 12.5, 25, and 37.5 lbs S per acre) and potassium (0, 80, 160, and 240 lbs of K2O per acre) were applied at planting. At the V4 to V5 growth stage, each pre-plant treatment was subdivided into four plots and similar rates as those applied at planting were applied to the split plots giving a total of 16 different combinations of pre-plant and side-dress sulfur or potassium rates.

Fertilizer efficiency was assessed using plant tissue data collected at V5 (whole plant samples) and R2 (ear leaf samples) and by measuring grain yield. Sulfur and potassium movement was measured by installing lysimeters in selected plots. Plots sampled included no fertilizer applied pre-plant or side-dress, no fertilizer applied pre-plant and the highest rate side-dress, the highest rate pre-plant and no fertilizer side dress, and the highest rate pre-plant and the highest rate side dress. Soil pore water sulfate-sulfur or potassium concentration was measured each week and following excessive leaching events. The design could not determine the amount of sulfur or potassium lost throughout the growing season.

Results and Discussion
Corn grain yield was not affected by the application of potassium or sulfur at any of the four study locations. Soil test potassium tested low (41-80 ppm) at two sites and high to very high (>121 ppm) at two others. The amount of sulfate-sulfur in the soil surface was typically low at the sulfur sites indicating a potential for a crop response to sulfur.

Like potassium, there was no yield response following the application of sulfur in spite of visual deficiency symptoms early in the growing season. The amount of sulfate in well water samples collected at all sites was high. Factoring in the amount of irrigation water applied, the amount of sulfate-sulfur applied in irrigation water was between 10-20 lbs of S per acre which is more than enough to satisfy crop needs. It can be questioned whether a greater potential for response may occur if less irrigation was applied.

Application of sulfur or potassium did increase the respective nutrient concentration in the ear leaf tissue even when there was no difference in yield. The lack of yield response is a good indicator that there was no benefit to split application of either sulfur or potassium. When comparing ear leaf tissue at R2 the concentration of nutrient in the tissue was similar for the same rate applied pre-plant versus at side-dress. The lack of difference among the application timing indicates a similar efficiency regardless of application timing and no benefit for delaying application to later in the growing season.

Lysimeter data showed a greater potential for sulfur leaching which was expected based on the negative charge of sulfate. There was no difference among treatments sampled for the potassium study during most of the growing season. There was a spike in potassium concentration in the pore water sampled at two feet at the beginning of the study which may indicate that if potassium does move on coarse textured ground, the movement may be rapid and may occur close to the time of application.

continued on following page
Sulfur leaching varied by surface soil texture and the amount of rainfall that occurred at each site. Large increase in sulfate concentration occurred during the middle of the growing season at one site with a very coarse surface soil texture. Movement appeared to have slowed for soils with a loam surface texture mixed with gravel. Split application of sulfur does make more sense according to the leaching data but is not supported considering the final yield of the crop.
Achieving Maximum Profit and Minimal Nitrate Loss in Drainage by Optimizing Nitrogen Rate for a High-Yield Corn-Corn-Soybean Rotation (2008)

Gyles Randall and Jeffrey Vetsch
University of Minnesota

Objectives
To determine the effects of nitrogen (N) rate and timing in a corn-corn-soybean rotation on corn yield, N use efficiency (NUE), profitability, and nitrate concentrations and losses in tile drainage water.

Study Description
This was the second year of a four-year study. The treatments consisted of three crops each year (a corn-corn-soybean rotation) and nine N management treatments for each crop, totaling 27 treatments. Each treatment was replicated three times with 10 of the treatments being located directly on 30 tile drainage plots. Each drainage plot measured 20 feet wide by 30 feet long, simulating a 50-foot drainage spacing. Nitrogen rates on the drainage plots were 0, 100 (60 + 40, split-applied), and 120 (preplant) for first-year corn; 0, 140 (60 + 80, split-applied), and 160 (preplant) for second-year corn; and zero-N for soybeans so that the residual effects of the N treatments for corn could be determined.

All experimental procedures including the collection and analyses of all soil, plant, and water samples, were performed by University personnel. Water samples for flow rate and nitrate-N analysis were collected from the tile lines on a M-W-F basis.

Results and Discussion
The amount and distribution of rainfall had a marked influence on the grain yield and nitrate loss results. Although spring rainfall was slightly above normal through mid-July, only four inches was received between July 18 and the end of September. As a result, yields were slightly less than anticipated in early August (Table 1). Split application (60 lb N/acre preplant and the remainder at V3) did not increase yields above the single preplant treatment.

The apparent 5 to 8 bu/acre advantage for preplant application was consistent for both first- and second-year corn but was not statistically significant at the P=0.10 level. Economic return to fertilizer N was $26 and $14/acre greater for a single preplant application for first-year and second-year corn, respectively, compared with split application, when using a 0.10 ratio ($0.35/lb N and $3.50/bushel corn). NUE in terms of bu of corn produced per lb of fertilizer N was greater for split application. This was expected since the N application rate was 20 lb/acre less when split applied. Nitrate-N concentrations in the drainage were influenced by the fact that 90% of the sparse 3.3” of drainage occurred in April-June.

Thus, the higher but rather uniform concentrations for first-year corn reflected nitrate being lost from the previous soybean crop rather than the N applied on May 10 (Table 1). Similarly, nitrate-N losses in second-year corn and in soybeans reflected the first-year corn and second-year corn treatments in 2007. Nitrate-N concentrations did not exceed 12.3 mg/L and a consistent advantage was not shown for split application.

<table>
<thead>
<tr>
<th>N Rate / Time Preplant</th>
<th>Grain Yield</th>
<th>Economic Return</th>
<th>NUE</th>
<th>Nitrate Conc.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bu/acre</td>
<td>$/A</td>
<td>lb/bu FN</td>
<td>mg/L</td>
</tr>
<tr>
<td>0</td>
<td>120</td>
<td>--</td>
<td>--</td>
<td>11.6</td>
</tr>
<tr>
<td>60</td>
<td>100</td>
<td>187</td>
<td>194</td>
<td>0.67</td>
</tr>
<tr>
<td>120</td>
<td>120</td>
<td>195</td>
<td>220</td>
<td>0.62</td>
</tr>
<tr>
<td>First-Yr Corn</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>71</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>60</td>
<td>80</td>
<td>140</td>
<td>173</td>
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<tr>
<td>160</td>
<td>160</td>
<td>178</td>
<td>317</td>
<td>0.63</td>
</tr>
<tr>
<td>Second-Yr Corn</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>49</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>46</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>48</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Soybeans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Corn grain yields, economic return to fertilizer N, NUE, and nitrate concentrations in the drainage water as affected by crop, N rate, and time of application in a C-C-Sb rotation in 2008.
Evaluation of Stream Bank Erosion: Lidar Quantification (2009)
Satish Gupta, Andrew Kessler, Holly Dolliver, and David Thoma
University of Minnesota, University of Wisconsin, and the National Park Service

Objectives
Quantify sediment, total phosphorus, and soluble phosphorus loads resulting from bank erosion in Blue Earth County Rivers.

Study Description
Excess sediment reaching Lake Pepin from the Minnesota River Valley was once thought to be primarily from soil erosion in cultivated lands. This study investigated the role of river bank erosion/sloughing in Blue Earth County to excess sediment loads at the mouth of the Blue Earth and the Le Sueur Rivers, tributaries of the Minnesota River. We used two light detection and ranging (lidar) scans taken in 2005 and 2009 to first quantify volume change in river valleys of the Blue Earth, Watonwan, Perch Creek, Le Sueur, Maple, Big Cobb, and Little Cobb rivers in Blue Earth County.

These volume change measurements were then converted to fine sediment and associated total and soluble phosphorus (P) losses using the analysis of 37 river bank materials representing three parent materials.

Results and Discussion
Volume change in river valleys as a result of bank erosion amounted to 1.71 million cubic meters over four years. This volume change value translated to fine sediment (silt + clay) contributions of 48 to 79% of the measured total suspended solids at the mouth of the Blue Earth and the Le Sueur rivers. Corresponding soluble P and total P contributions ranged from 0.13 to 0.20% and 40 to 49%, respectively. Although tall banks (>3 m high) accounted for 33% of the total length and 63% of the total area, they accounted for 75% of the volume change in river valleys.

We conclude that river bank erosion/sloughing is a major source of fine sediments and associated total P to the Minnesota River and then on to Lake Pepin.

Table 1. Fine sediment, soluble P, and total P losses as a percentage of the measured values at the mouth of the Blue Earth River (Blue Earth River, Watonwan River, and Perch Creek) or the Le Sueur River (Le Sueur River, Maple River, Big Cobb River, and Little Cobb River). The losses were estimated for each of the three parent materials using specific fine sediment content, bulk density, and soluble P and total P contents.
Satish Gupta, Andrew Kessler and Melinda Brown
University of Minnesota

Objectives
Characterize the effect of climate on river flows and associated base flows from different watersheds in Minnesota

Study Description
Increased streamflow and its associated impacts on water quality have frequently been linked to changes in land use and land cover (LULC) such as tile drainage, cultivation of prairies, and increased adoption of soybeans in modern day cropping systems.

This study evaluated the relative importance of changes in precipitation and LULC on streamflow in twenty-nine HUC 008 watersheds in Iowa and Minnesota. The evaluation was done through a statistical test comparing the relationships of annual streamflow vs. annual precipitation for the periods prior to 1975 (pre-change period) and after 1976 (post-change period).

A statistically significant shift in annual relationships from the pre- to post-change period was assumed to be an indication of LULC changes whereas a lack of significant shift suggested a single relationship driven by precipitation.

Results and Discussion
Twenty-one out of twenty-nine watersheds showed no statistical difference between the annual relationship prior to 1975 and after 1976. For the eight watersheds showing impacts from LULC changes, a comparison of five-year moving averages of streamflow vs. precipitation relationships revealed that the upward shift in streamflow due to LULC changes was relatively small compared to the upward trend in streamflow from recent increases of about 100 mm precipitation.

The lack of minimal impacts of LULC changes on streamflow appears to be due to near equivalent evapotranspiration in the pre- and post-change periods i.e. higher ET from row crops (corn and soybeans) on an expanded area (even with some loss of wetlands) in post-change period vs. low ET from small grain areas (even with presence of some wetlands and native prairies) in the pre-change period.

Figure 1. Plots of (a) annual streamflow vs. precipitation for the Blue Earth River, MN watershed for the periods 1940 to 1975 and 1976 to 2009.

Figure 2. Maps of 30 year normal precipitation (PPT, mm) distribution in Minnesota for the periods 1921 to 1950, 1951 to 1980, and 1981 to 2010.
Integrated Water Management Systems to Achieve Optimum Corn Production (2010)
Jeff Strock, Gary Sands and Mike Talbot
University of Minnesota

Objectives
- Design and field test a mobile photovoltaic (solar) pump system to provide water for an integrated water management system
- Evaluate performance of various integrated water management system designs using the computer simulation model DRAINMOD
- Evaluate grain yield as a function of integrated water management strategy: non-drained, conventional drainage, controlled drainage, and subirrigation

Study Description
Demonstration plots were established in southwest Minnesota for a corn-corn-soybean rotation at the Hicks family farm near Tracy, MN. The soils at the site were mapped as Havelock clay loam and Nishna silty clay with 0-1% slope. The field was divided into four management zones ranging from 11 to 13 acres. Three of the zones are drained (4 ft. depth and 50 ft. spacing) while the fourth zone does not require drainage.

During the field experiment, the non-drained zone remained undrained (UD), the drained zone was managed in conventional drainage (FD) mode with water in the root zone managed at approximately four feet below the soil surface, and water in the root zone was managed within two feet of the soil surface in the controlled drainage (CD) and drainage with subirrigation (DSI) zones, when water was available to be managed.

The photovoltaic (PV) pump system was used to supplement and transfer water into the subirrigation zone beginning prior to pollination and until early dent through the water level control structure for the zone.

Results and Discussion
Results indicated that CD and DSI may be viable options for improving crop yields in MN although field results differed somewhat from modeled results. Field results indicated that when water is available for storage in the soil under CD and/or DSI, yield improvements are possible.

Overall simulation results showed that conventional drainage significantly improved relative crop yields compared to undrained conditions, and subirrigation significantly improved relative crop yields over conventional drainage. However, controlled drainage showed no significant crop yield improvements over conventional drainage, which is consistent with the literature. More work is needed, however, to assess year-to-year yield variability, CD and DSI performance for more soil types, irrigation source water limitations and timing of application; and explore more rigorous optimization of the model, including weir depths and timing.

Table 1. Soybean grain yield for drainage management zones including conventional free drainage, controlled drainage, subirrigation, and no drainage from 2011.

<table>
<thead>
<tr>
<th>Drainage Water Management</th>
<th>Yield (bu/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional free drainage</td>
<td>33</td>
</tr>
<tr>
<td>Controlled drainage</td>
<td>37</td>
</tr>
<tr>
<td>Subirrigation</td>
<td>40</td>
</tr>
<tr>
<td>No drainage</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 2. Corn grain yield for drainage management zones including conventional free drainage, controlled drainage, subirrigation, and no drainage from 2012.

<table>
<thead>
<tr>
<th>Drainage Water Management</th>
<th>Yield (bu/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional free drainage</td>
<td>181</td>
</tr>
<tr>
<td>Controlled drainage</td>
<td>213</td>
</tr>
<tr>
<td>Subirrigation†</td>
<td>213</td>
</tr>
<tr>
<td>No drainage</td>
<td>199</td>
</tr>
</tbody>
</table>
†Drought prevented subirrigation, soil water storage occurred from adjacent river.
Can River Bank Sediments be a Carrier and then Source of Available P in Lake Pepin? (2010)
Satish Gupta, Ashley Grundtner and Brandy Toner
University of Minnesota

Objectives
- To quantify the potential of phosphorous (P) adsorption by river bank materials in Blue Earth County
- Identify factors that may explain increasing P concentrations in Lake Pepin sediments over historic times

Study Description
Since sediments are a major carrier of P to rivers and lakes, two questions arose: Before European settlement of Minnesota in 1850, could eroded bank materials be a source of particulate P to Lake Pepin? After 1850 could these materials have adsorbed P from polluted river waters and carried it downstream?

The study characterized 34 bank materials in Blue Earth County for particle size distribution, total P, P adsorption isotherms, and solution equilibrium P concentration at zero adsorption (EPC0). Using the selective transport of fine particles and historical pollution, we predicted the inorganic P concentration of sediments in Lake Pepin and compared it with the measured values. Selective transport involved heavier particles such as sand remaining behind in the river basin thus enriching P in a smaller portion of the sediment.

Results and Discussion
The results showed that selective transport of fine particles from eroded riverbanks was the main source of P in Lake Pepin sediment before 1850. Laboratory tests also showed that riverbank materials have a high capacity to attract and tightly hold P from the polluted river water thus providing additional P that could be transported downstream to Lake Pepin. Calculations showed that adsorbed P by bank materials from simulated polluted river waters, along with additional enrichment through silt settlement due to lock and dams, explained the increasing P concentrations in Lake Pepin sediments after 1850.

Since the EPC0 of bank materials was lower than the soluble P concentration currently in river waters, we concluded that controlling P pollution in upstream rivers was the best method to reduce P concentration in future Lake Pepin sediments.

Table 1. Selected properties of the bank materials used in this study.
† OM, organic matter as measured by loss-on-ignition
‡ Loosely bound P analyzed with 0.01 M CaCl2 background solution
§ TP, total phosphorus
¶ Values are reported as mean ± standard deviation

<table>
<thead>
<tr>
<th>Bank Material</th>
<th>Sample Population</th>
<th>pH</th>
<th>Bulk Density</th>
<th>OM †</th>
<th>Olsen P</th>
<th>Loosely Bound P ‡</th>
<th>TP §</th>
</tr>
</thead>
<tbody>
<tr>
<td>Till</td>
<td>19</td>
<td>7.7±0.32</td>
<td>1.86±0.15</td>
<td>0.91±0.30</td>
<td>5.65±4.77</td>
<td>0.19±0.06</td>
<td>405±76</td>
</tr>
<tr>
<td>Alluvium</td>
<td>9</td>
<td>7.7±0.36</td>
<td>1.74±0.38</td>
<td>0.73±0.39</td>
<td>11.86±6.31</td>
<td>0.30±0.15</td>
<td>477±180</td>
</tr>
<tr>
<td>Lacustrine</td>
<td>7</td>
<td>7.6±0.73</td>
<td>1.62±0.21</td>
<td>2.89±4.17</td>
<td>6.75±8.53</td>
<td>0.17±0.09</td>
<td>488±106</td>
</tr>
</tbody>
</table>

Figure 1. Phosphorus adsorption isotherms of nine till bank materials. The solid lines are the best fit Langmuir isotherms, whereas the points are physically measured values.
Quantifying the Impact of Stream Alteration and Streambank Erosion on Sediment and Phosphorous Load to the MN River (2010)

Chris Lenhart
University of Minnesota

Objectives

- Estimate how alteration of the river via channelization, induced cutoffs, levees, entrenchment and increased stream flow have influenced sediment and phosphorous loading in the lower Minnesota River, below Mankato
- Quantify floodplain deposition was a second major goal focusing on the lower floodplain (downstream of Mankato) since European settlement (circa 1850)

Study Description

Field measurement of bank erosion rates and physical soil properties (bulk density and particle size), GIS analysis of river dimension change since 1938, and sediment borings on the floodplain were used to assess depth of sediment deposited since European settlement (1850). Lastly we assessed the potential for eco-hydrological drivers of widening with vegetation growth on point bars to document how reduced sandbar vegetation growth may have contributed to river widening.

Results and Discussion

The lower Minnesota River has widened by 52% since 1938 between St. Paul and Mankato based on GIS measurements (Table 1). The resulting sediment and phosphorus load presented were estimated at 280,000 metric tons (Mg) /year and 153 Mg/year, both a substantial percentage of the overall Minnesota River load.

Stream bank soil samples averaged 46% sand and 54% silt / clay. Sediment deposition measurements produced three major results: 1) Sediment deposition rates are very heterogenous across the floodplain, but generally showed increased rates of deposition since European settlement (1850); 2) The sand levee (adjacent to the stream) and recent oxbows (cutoff since 1960) had the highest rates of deposition by an order of magnitude (10x).

River widening is a major source of sediment in the lower Minnesota River and the many tributaries contributing to water quality and aquatic life problems. While hydrologic change is considered the main driver of elevated erosion rates, decreased establishment of vegetation on sandbars contribute to widening in negative feedback loop. Reduction of sediment load from channel widening will require watershed management to reduce flows and targeted stream restoration and management. Stream flow needs to be reduced through more hydrologic storage in the watershed via wetlands, ponds, controlled drainage and vegetative tools.

Stream restoration and/or channel stabilization projects may be appropriate in situations where a high threshold of sediment loading is exceeded, ecological benefits exist and/or infrastructure is threatened. Vegetated buffers where they do not exist could help reduce bank retreat on highly erodible alluvial soils. The whole river valley should be managed more proactively to prevent further loss of sinuosity at road crossings and to deflect the river where it meanders into high bluffs or threatens infrastructure. Practices that promote reconnection of the floodplain where it has been restricted should be pursued to maintain its sediment deposition function.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Result</th>
<th>Method of Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in river width (1938 to 2009)</td>
<td>36 meter increase since 1938, 52% change ±6 m width</td>
<td>Overlay of digitized channel corridors, 1938 vs. 2009 width integrated over entire length</td>
</tr>
<tr>
<td>Sediment input from channel widening</td>
<td>280,000 ±6,000 Mg year⁻¹</td>
<td>River width change from aerial photos × bank height × soil bulk density</td>
</tr>
<tr>
<td>Phosphorus input from widening</td>
<td>153 ±30 Mg year⁻¹</td>
<td>Gross sediment input × total phosphorus concentration in banks</td>
</tr>
</tbody>
</table>

Table 1. Changes to Minnesota River width since 1938 and contributions to gross sediment and phosphorus load.
Sediment Fingerprinting for Sources and Transport Pathways in the Root River, Southeastern Minnesota (2010)

Patrick Belmont
Utah State University

Objectives
- Measure geochemical tracers in sediment source areas (agricultural fields, forested hillslopes, streambanks, etc.) to determine the erosional history of those landforms.
- Measure geochemical tracers associated with suspended sediment and compare with geochemical signatures of source areas to determine the proportion of sediment derived from each of the sediment sources.

Study Description
The 1660-square-mile Root River watershed is located in southeastern Minnesota. The landscape transitions from flat, previously-glaciated terrain in the headwaters, to the rolling hills and bluff country, before draining into the Mississippi River near Hokah, Minnesota.

The Root River is a multiple-use watershed, but has been listed as impaired for excessive sedimentation. Where is the excess sediment coming from? How much is due to historical land use versus modern land use? Such questions can't be answered simply by measuring erosion manually throughout the landscape because the area is far too large and often the amount of erosion is below the level of measurement on a local scale...but can still add up downstream.

Therefore we measured naturally-occurring geochemical tracers to help us understand the time-integrated history of the landscape and to determine what percentage of sediment was coming from the potential source areas that had been identified. For details about the method, see the final report associated with this project or contact Patrick Belmont.

Results and Discussion
Geochemical analyses indicate that the erosional history of the Root River watershed is highly variable with some locations having experienced significantly more erosion than others over time. Geochemical analyses, in combination with field observations and analysis of high resolution topography data (lidar), indicate that a substantial amount of sediment eroded in the past has been stored within the floodplains of the Root River network.

A considerable amount of variability was observed in the geochemical signatures of source areas as well as suspended sediment samples. However, results support the hypothesis that a substantial percentage and likely a majority of suspended sediment in the Root River today is derived from streambanks and floodplains (estimated range 40-80%).

This study laid the foundation for an ongoing project, funded by Minnesota Department of Agriculture, to develop a sediment budget for the Root River watershed, which will be used to support land management, conservation and restoration planning.

Reference: Contact Patrick Belmont for reprints of two peer-reviewed publications (Stout and Belmont, 2014; Stout et al., 2014).

continued on following page
Figure 2. Colors indicate land use throughout the 1660-square-mile Root River watershed, in southeastern Minnesota. The black line approximately demarcates the boundary between land that was glaciated in the most recent glacial period (which ended about 12,000 years ago) versus land that has not been glaciated in at least 500,000 years, known as the ‘driftless area’.

Figure 3. Suspended sediment fingerprinting results. Bars indicate the full range (not standard error) of tracer concentrations measured in each of the source areas. The range of tracer concentrations associated with suspended sediment samples (circles) indicates that the majority of the sediment was historically derived from agricultural fields (indicated by Beryllium-10 data), but much of the sediment was historically deposited in, and is currently being reworked from, streambanks and floodplains (which causes the shift of the circles from fields toward floodplains in Lead-210 data).
Characterization of Climate Impacts on Bank Erosion/Sloughing in Blue Earth County (2011)

Satish Gupta, Andrew Kessler and Melinda Brown
University of Minnesota

Objectives
- Quantify bank retreat, volume change, and sediment loss rates for rivers in Blue Earth County, MN
- Assess extrapolation of discrete river bank volume loss measurements from bank physical features to quantify net bank erosion for an entire river channel

Study Description
River bank erosion is one of the major sources of sediment in the Minnesota River Basin. In this study, we assessed variations in river bank erosion over time using a combination of 1855 Public Land Survey System PLATs, aerial photographs from 1938-2009, and light detection and ranging (lidar) data from 2005 and 2009 for rivers in Blue Earth County, MN. Using this data base, we also assessed if river bank physical features can be used to predict bank erosion along these rivers, as has been done in previous studies from Minnesota.

Results and Discussion
Results showed that bank erosion was episodic, making comparisons of erosion rates from dissimilar time intervals unreliable. For comparable time intervals, average river bank retreat rates (0.51 m yr⁻¹ from 1855-1938 vs. 0.37 m yr⁻¹ from 1938-2009) were statistically similar (t = 2.13, p = 0.14) suggesting that bank erosion rates have remained stable since European settlement. Comparisons over shorter time intervals of 1938-1971 and 1971-2009 also showed similar statistical trends (t = 0.76, p = 0.45) with average river bank retreat rates of 0.57 m yr⁻¹ and 0.50 m yr⁻¹, respectively. However, an additional 145 observations of bank retreat were found in the period 1971-2009 relative to 1938-1971, indicating that the number of actively eroding river banks has likely increased.

Contrary to assumptions made in previous studies, bank erosion measurements from lidar data showed a poor relationship (r² = 0.01 to 0.36) with river bank physical features (face area, inclined surface area, length, slope, height, and aspect), thus suggesting that extrapolating a limited number of bank erosion observations to the whole length of a river will lead to erroneous predictions.
Rodney Venterea and Jeff Coulter
United States Department of Agriculture - Agricultural Research Service (USDA-ARS) and University of Minnesota

Objectives
- Examine the effects of single versus split urea application on cumulative nitrous oxide (N2O) emissions and soil nitrogen (N) availability in continuous corn and corn-soybean cropping systems across a range of N rates and over two consecutive growing seasons on a silt loam soil in Minnesota
- Investigate a practice that has the potential to reduce N2O emissions, and not necessarily to simulate a practice that is currently common in the region.

Study Description
The experiment was conducted in long-term research plots at the University of Minnesota Research Station in Rosemount, MN, where the soil is a naturally drained Waukegan silt loam. The plots used in this study are part of a long-term experiment with tillage and rotation treatments in place since 1991.

A two-year experiment (2012 and 2013) was conducted using a randomized complete block, split-split plot design with rotation as the main effect, fertilizer N application rate as the split-plot effect, and fertilizer N application timing as the split-split-plot effect. For both application timings, granular urea was broadcast and incorporated at six fertilizer N rates in the corn phase of a corn-soybean rotation and in a continuous corn system over two growing seasons. Daily N2O flux was measured using chambers on 35 dates in 2012 and 40 dates in 2013 and soil nitrate-N concentration was measured weekly.

Results and Discussion
Split application did not affect grain yield and did not reduce N2O (Figure 1) or soil nitrate-N intensity. Across N rates and rotations, N2O was 55% greater with split compared with single application in 2012. Increased N2O with split application in 2012 likely resulted from a prolonged dry period prior to the second split application followed by large rainfall events following the third split application.

Across years and rotations, split application also increased N2O by 57% compared with single application when the maximum N rate was applied. Exponential relationships between N2O and fertilizer N rate explained 62 to 74% of the variance in area-based N2O and 54% of the variance in yield-based N2O. Applying urea to coincide with periods of high crop N demand does not necessarily reduce and may increase N2O emissions. Combining split applications with stabilized N sources and/or chemical inhibitors that resist leaching and microbial transformation might be effective in reducing N losses, but more studies examining such combined approaches are needed to identify effective strategies for reducing N2O emissions and other N losses while maintaining or enhancing crop production.

Reference: Text and figures used by permission of the American Society of Agronomy, Madison, WI, and adapted from Venterea, R.T. and J.A. Coulter. 2015. Split application of urea does not decrease and may increase N2O emissions in rainfed corn. Agronomy Journal, doi:10.2134/agronj14.041s
For more information on projects funded by Minnesota's corn organizations, contact Adam Birr, Ph.D. at the MCGA office: abirr@mncorn.org or 952-233-0333.