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After the drought, what next?

Elwynn Taylor, professor and Extension climatologist, Agronomy, Iowa State University

Historical events hint that the Midwest may be on the verge of crop weather reminiscent of the 70s and 80s. Abnormally active weather systems can bring a mix of record high yield crop years interspersed with adverse production conditions. Agriculture will remain the world’s largest and most basic industry, but will become more dependent on technological advances and on effective risk management than was demanded over the past 20 years.

U.S. corn yield

The U.S. corn yield has increased consistently since the Late 1930s. That is the yield per acre trend has consistently increased. Following considerable academic discussion by climatologists and agronomists it was determined that the “most meaningful” normal and trend determinations are obtained from the analysis of 30 consecutive years of record, be it crop yields or climate being evaluated (I mention this because today I am hard-pressed to identify anyone other than myself that was in attendance at those particular society meetings of the 1950s and early ’60s). By the nature of “normal” distributions of anomalies in yield and in weather it would be expected that about half of all years would exceed normal and half fall below the norm. A 56-year plot of U.S. corn yield (Figure 1) shows that in the 1950s the observed yield fell below the trend for 1953-1956 (4 consecutive years) and was slightly shy of the trend through 1960. Another episode of sub-trend corn yields is noted from 1974-1977. These two depressed yield episodes corresponded with two historically strong climate events that would subsequently be termed “La Niña,” (Figure 2).

The United States recently experienced 6 consecutive years of above trend corn yield (Figure 3). Then 2010 ushered in the second strongest La Niña event in the history of keeping records of this sort of weather event. The strong La Niña brought weather tending to be on the extreme side, although not all weather events during 2010 were consistent with a La Niña. The shifting impacts of this major weather anomaly added up and the impact on U.S. corn yield was three consecutive below trend corn crops and may be setting up for a fourth. At least two (mainly independent) major weather cycles are playing out at this time: 1) an apparent shift in world weather to a pattern of La Niña dominance...such patterns may persist 1 to 4 years. 2) Conditions of the North Atlantic are giving the indication of favoring severe winters in the Eastern half of the United States. Couple the trends together with the subsoil moisture not likely to fully recharge after two seasons of limited precipitation and a 4th consecutive year of below trend U.S. corn yields looks likely. It is possible that weather will be more extreme during the coming score of years than has been experienced since 1994.

Diminished U.S. corn in 2010, 2011, and 2012 accompanied a deep (hydrologic) drought that would, in Texas and Oklahoma, rival (and in isolated spots exceed) that of the 1950s episode. Long-term (or hydrological) drought results when precipitation is not sufficient to maintain soil moisture at levels where runoff and/or percolation can maintain ground water and stream flow levels. Three notable episodes of hydrological drought are depicted in Figure 4. Factors were much alike between the 1950s, 1970s, and 2010s throughout the Earth (including drought, flooding (upper Missouri river), and tornado outbreaks).

Periods of consistent and of erratic yield have been observed for crops since the mid-1800s and are indicated over at least the past 800 years by tree ring analysis. Episodes of erratic yield tend to persist for about 25 years followed by 19 years of relatively consistent yields (Figure 5). In addition to the erratic period an apparently independent cycle of harsh winters (associated with ocean currents in the Atlantic) appears to have initiated (Figure 6). Winters do have major economic impact in the Midwest but seldom have over-riding influences on the subsequent crop year (flooding because of winter moisture being the most notable exception).
Figure 1. US corn yield from 1950-1985. A “best fit” trend line for reported corn yields in the United States for the period 1950 through 1985 depicts two episodes of consecutive years below the trend line. The deviation from trend is notable for consistency and is not considered as representing periods of great extremity for crops. The years did include extreme tornado and regional drought events, however. Source: nass.usda.gov

Figure 2. Historical graph of relative strength of El Niño and La Niña events computed from multiple parameters associated with the occurrence of these anomalous climatic conditions. The strongest La Niña events (negative standardized departures) are noted in the mid-’50s, the mid ’70s, and the 2010-2012 period. Positive departures are indicative of El Niño conditions. Graphic produced by: http://www.esrl.noaa.gov/psd/enso/mei/
Figure 3. U.S. Corn yield from 1982-2011. The “best fit” yield trend together with 10% above and 10% below trend lines are shown. Yields are considered as exceptional when they fall outside the interval delimited by the lines. The years following 1974 tended to have yields consistently within the interval. Yields below the trend -10% line are considered as “disaster” yield levels.
Figure 4. Hydrologic type drought as depicted by Palmer analysis. When hydrological drought begins the locality has likely been in Agricultural drought for some time. When hydrological drought ends, the Agricultural drought had ended beforehand. http://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers.php
Figure 4 (continued). Hydrologic type drought as depicted by Palmer analysis. When hydrological drought begins the locality has likely been in Agricultural drought for some time. When hydrological drought ends, the Agricultural drought had ended beforehand. http://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers.php
Figure 4 (continued). Hydrologic type drought as depicted by Palmer analysis. When hydrological drought begins, the locality has likely been in Agricultural drought for some time. When hydrological drought ends, the Agricultural drought had ended beforehand. http://www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers.php
Figure 5. U.S. corn 1925 – 2011. Alternating intervals of consistent and of erratic corn yield are likely caused by a cycling of climatic conditions that are apparent in the tree-ring record since the 1300s and in the Midwest corn yield record that dates to the mid-1860s. The Midwest may be entering a period of increased yield volatility.

Figure 6. Winter condition of the North Atlantic Oscillation (NAO). Relative winter harshness (temperature and to a lesser extent snow accumulation) is related to the negative strength of the NAO in the central and eastern US (the effect is the opposite in Western Europe). Graphic from: www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/seasonJFM.nao.gif
The impact of the drought on grain quality and grain processing

Charles R. Hurburgh, Jr., professor, Agricultural and Biosystems Engineering, Iowa State University; Alison Robertson, associate professor and Extension crop plant pathologist, Plant Pathology and Microbiology, Iowa State University.

The drought conditions sharply cut the quantity of corn at a time when demand was increasing at a rapid pace. Drought also creates grain quality issues such as the threat of aflatoxin, low test weight, loss of soybean protein and oil, and other problems. Current data shows that some predictions were right and while others were not. The emergence of food safety as a major focus of all food/feed industries presented some new challenges as well, because aflatoxin is classified as an Adulterant by the US Food and Drug Administration (FDA).

General crop quality in the drought of 2012

Corn in many areas reached maturity earlier, by Labor Day weekend. Soybeans stopped and started with late rains, but pod count and seed size were established by Labor Day as well. This was a year to talk to crop insurance carriers early and often because some quality issues are covered; others are not. In general, quality issues that occur in the field and before any storage and handling occur are covered perils. Quality deficiencies are covered in crop insurance by deducting an additional percentage of production before settlement.

Corn

The primary general corn quality issues were expected to be low test weight/small kernels, significant mold pressure of all kinds in the many acres of downed corn and a general potential for aflatoxin at some level. Stalk strength was poor which contributed to downed corn.

Test weight-kernel size-composition

We expected kernels to be less dense and, therefore, lower in test weight. Low test weight from drought typically still means average protein and oil levels, which is good news for livestock feed. Expectation was not reality. Table 1 shows composition and test weight results from a series of strip trial plots that we have been analyzing every year. Test weight and protein were the highest in 2012 of the four years. Our explanation is that corn hybrids are very efficient at moving nutrients from the stalk to the ears, creating densely packed, but smaller kernels.

<table>
<thead>
<tr>
<th>Year</th>
<th>Yield bu/a 15% M</th>
<th>Test weight lb/bu as-is</th>
<th>Moisture % as-is</th>
<th>Protein % 15% M</th>
<th>Oil % 15% M</th>
<th>Starch % 15% M</th>
<th>Density gm/cc 15% M</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>194.1</td>
<td>54.0</td>
<td>25.6</td>
<td>7.6</td>
<td>3.6</td>
<td>61.1</td>
<td>1.244</td>
</tr>
<tr>
<td>2010</td>
<td>184.9</td>
<td>57.6</td>
<td>14.3</td>
<td>6.7</td>
<td>3.5</td>
<td>61.6</td>
<td>1.255</td>
</tr>
<tr>
<td>2011</td>
<td>207.6</td>
<td>58.7</td>
<td>16.8</td>
<td>7.2</td>
<td>3.6</td>
<td>61.2</td>
<td>1.271</td>
</tr>
<tr>
<td>2012</td>
<td>152.0</td>
<td>60.1</td>
<td>16.5</td>
<td>8.2</td>
<td>3.4</td>
<td>60.6</td>
<td>1.287</td>
</tr>
</tbody>
</table>

Four plots per year, same locations each year, 20-50 hybrids per plot.

Storage

The largest storage issue turned out to be mixed moisture; very dry in one part of a field and very wet in another. The first half of harvest had these problems. The corn was also very warm coming out of the field. Mixed moisture corn will not equalize quickly, certainly not in one pass through a dryer. Corn will segregate somewhat by moisture if it is drop filled in a bin; this means that both the high moisture and the fines will collect in the center. It will
be very important to remove the center core right away; in large bins (over 50 feet dia), two removals would be advisable.

Corn was harvested with high outside temperatures, in the 80s and 90s, and was dried in the same conditions. This means corn in bins at much higher temperatures than normal. Early harvest corn will require at least two additional cooling cycles to reach the desired eventual temperature of 40°F or below. Low temperature is the major control for grain spoilage after drying is complete.

A cooling cycle is moving a cooling front completely through a bin and is done when the average outside temperatures are 10-15°F below the grain temperature. With 0.1 cfm/bu of aeration, this takes about 150 hours; with 1 cfm/bu, about 15 hours is required. Because the shelf life of the grain is temperature dependent, it is important to begin these cycles as soon as a 10-15 degree temperature drop can be achieved. With higher initial temperatures, at least two additional (beyond normal) cycles will be needed. If the grain waits for a month to be cooled, the shelf life will be reduced and future spoilage is much more likely. Moisture variation means further reduces shelf life and creates more storage risk.

Review the yield monitor moisture output to estimate which fields are likely to be a future storage problem from moisture variations. Crop insurance will not cover quality issues after harvest. Table 2 gives the usual estimates of shelf life for moisture and temperature conditions. Reduce these by 50% if you had large moisture variations in the field.

**Table 2. Maximum storage time (months) for corn and soybeans. Based on 0.5% maximum dry matter loss - calculated on the basis of USDA research at Iowa State University. Corresponds to one grade number loss, 2-3% pts in damaged seeds. Soybeans approximated at 2% lower moisture than corn.**

<table>
<thead>
<tr>
<th>Corn temp.</th>
<th>13%</th>
<th>14%</th>
<th>15%</th>
<th>16%</th>
<th>17%</th>
<th>18%</th>
<th>24%</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>°F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>150</td>
<td>61</td>
<td>29.0</td>
<td>15.0</td>
<td>9.4</td>
<td>6.1</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>84</td>
<td>34</td>
<td>16.0</td>
<td>8.9</td>
<td>5.3</td>
<td>3.4</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>47</td>
<td>19</td>
<td>9.2</td>
<td>5.0</td>
<td>3.0</td>
<td>1.9</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>26</td>
<td>11</td>
<td>5.2</td>
<td>2.8</td>
<td>1.7</td>
<td>1.1</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>15</td>
<td>6</td>
<td>2.9</td>
<td>1.6</td>
<td>0.9</td>
<td>0.9</td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>

**Soybeans**

The primary soybean quality impact of the drought was small and in some cases, flat and shriveled soybeans. In the drought of 1988, shiveled and wrinkled (shrinkled) soybeans occurred. A definition was created by USDA-GIPSA as wrinkled soybeans that do not fall through the small foreign material screen and are not considered splits. Price discounting will be at the discretion of the buyer, if at all. Shrinkled soybeans have a reasonably good protein and oil profile, but do not crack into pieces as required for efficient oil production at solvent extraction soybean plants. Expect residual oil levels in soybean meal to be higher than the normal 1%.

Soybean protein content was low because dry weather does not favor nitrogen fixation. Table 3 shows the same strip plot locations as in Table 1 for corn, for 2012 compared to the previous three years. Protein was reduced but oil was higher by almost an offsetting amount. If recoverable, this will be to the advantage of processors because oil is more valuable per unit than protein.
Table 3. Soybean Quality 2009-2012

<table>
<thead>
<tr>
<th>Year</th>
<th>Yield bu/a</th>
<th>Moisture %</th>
<th>Protein %</th>
<th>Oil %</th>
<th>Fiber %</th>
<th>Sum %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>13% M</td>
<td>as-is</td>
<td>13% M</td>
<td>13% M</td>
<td>13% M</td>
<td>13% M</td>
</tr>
<tr>
<td>2009</td>
<td>58.7</td>
<td>13.7</td>
<td>34.7</td>
<td>18.5</td>
<td>4.9</td>
<td>53.2</td>
</tr>
<tr>
<td>2010</td>
<td>58.7</td>
<td>10.5</td>
<td>35.5</td>
<td>18.5</td>
<td>4.8</td>
<td>54.0</td>
</tr>
<tr>
<td>2011</td>
<td>65.9</td>
<td>10.5</td>
<td>34.2</td>
<td>18.4</td>
<td>4.9</td>
<td>52.6</td>
</tr>
<tr>
<td>2012</td>
<td>52.5</td>
<td>8.7</td>
<td>33.9</td>
<td>19.9</td>
<td>4.8</td>
<td>53.8</td>
</tr>
</tbody>
</table>

Four plots per year, same locations each year, 10-40 hybrids per plot.

Aflatoxin in 2012

Aflatoxin, a toxic secondary metabolite of *Aspergillus flavus*, occurred this year because of the hot, dry weather persisting from pollination through grain fill. The Aug. 2 issue of the ICM Newsletter explained the biology and conditions required for aflatoxin. Preharvest scouting for the fungus was the best way of advance warning; the actual toxin is not formed until the corn is below 30% moisture, and then only in warm conditions during the drydown period. Aflatoxin is adjusted for crop insurance in the field, not after the crop has gone into the bin. Aflatoxin testing has a 25-50 percent sampling error; only a USDA-RMA approved third-party lab can determine aflatoxin in crop insurance samples.

Market impacts of aflatoxin

The general tolerance for aflatoxin in interstate commerce is 20 parts per billion. Aflatoxin is classified as an adulterant in U.S. Food and Drug regulations. The most sensitive industries for aflatoxin are dairy (because of pass through to milk), pet food (pets are very sensitive to aflatoxin) and ethanol/processing plants. The toxin concentrates threefold in the feed/food co-products such as distillers grains. Some DDGS may have to be marketed selectively to large animal feeding. Table 4 shows the recommended feeding levels and the milk tolerance.

Table 4. Recommended feeding levels and milk tolerance.

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn for lactating cows</td>
<td>20 ppb</td>
</tr>
<tr>
<td>Milk</td>
<td>0.5 ppb</td>
</tr>
<tr>
<td>Corn for breeding beef/swine/poultry</td>
<td>100 ppb</td>
</tr>
<tr>
<td>Corn for finishing swine &gt;100 lb</td>
<td>200 ppb</td>
</tr>
<tr>
<td>Corn for finishing cattle</td>
<td>300 ppb</td>
</tr>
</tbody>
</table>

Source: Iowa Beef Center

Expect grain buyers, both elevators and processors, to be monitoring for aflatoxin. If the overall level of aflatoxin in a region does not approach the 20ppb limit, then the buyer may elect to test composite samples of all loads in a period (half-day, day, etc) to verify that, on average, the grain is acceptable. If the composites show a regional or local issue, then individual load testing may be needed. This is time consuming and costly.

The FDA approved a temporary blending policy for aflatoxin in Iowa and surrounding states. This policy was released September 19 by the Iowa Department of Agriculture and Land Stewardship. The key point is that if corn is blended to reduce aflatoxin in the resulting blend to useable levels, the blended corn must be marketed with documentation of aflatoxin levels and intended use. Corn above 500 ppb cannot be blended at all. Producers accepting a crop insurance settlement for aflatoxin are subject to this blending policy. Corn that has received a crop insurance settlement for aflatoxin should not be returned to the general market without documentation.

From previous experiences in 1983, 1988 and 2005 we expected that aflatoxin would be a steady problem in 2012.
From previous experiences in 1983, 1988 and 2005 we expected that aflatoxin would be a steady problem in 2012. In 1983 and 1988, with similar weather conditions, the average aflatoxin level of Iowa corn was right at the 20 ppb limit. Incidence was actually less than expected. As yet unpublished USDA-GIPSA reports of aflatoxin through October indicates less than 20% of Iowa corn with more than 20 ppb. Incidence varies across Iowa, but overall, the 2012 incidence was about half that of 1988 and 1983. The average of Iowa corn will likely be less than 20 ppb in 2012, which will reduce the need for individual load testing. Monitoring of averages will be needed through the year.

The 2012 data looks better than expected, but risks remain:
- Sensitive users will have to remain vigilant.
- Producers feeding their own, and therefore less blended, corn should get a good test before use.
- Grazing animals in harvested fields carries risk; the corn will get eaten first.
- Wet corn (over 17% moisture) that was held before drying, or that was dried in heated-air bin dryers using temperatures below 120F may show increased aflatoxin when taken out of storage.

A list of testing labs, including the USDA-GIPSA agencies serving Iowa, is at www.iowagrain.org. The USDA - Risk Management Agency has posted a fact sheet on aflatoxin testing for insurance purposes. The ICM Newsletter has two articles specifically about sampling and testing for aflatoxin.

Aflatoxin levels must be above 20 parts per billion before insurance payments are impacted. The important points for crop insurance are 1) that crop insurance must be called before harvest; no settlements will be made for corn already in storage; 2) that producers getting a settlement for aflatoxin must direct the corn to an approved use for the level present, with documentation of test results and 3) that all measurements, samples, and testing must be done under the supervision of the adjuster. Settled corn must be directed, with documented proof, to an approved feed use. Corn settled for aflatoxin should not be offered back to the general market without notice; the new food safety legislation (Food Safety Modernization Act) creates significant liability if a downstream issue can be traced back to a production source.

Corn laying on the ground can have more toxin risks than just the aflatoxin, for which there is general potential. This corn should be tested for the series of mycotoxins of most concern – aflatoxin, vomitoxin, fumonisin and zearalenone. Testing laboratories are listed on the Iowa Grain Quality Initiative website; the Iowa State University Veterinary Diagnostic Lab will also test samples for mycotoxins.
Aflatoxin and grain storage

Aflatoxin is not removed by drying or freezing, but does not usually increase in storage. *Aspergillus flavus* is not a strong storage mold; it is quickly crowded out by others. Storage at 17 percent moisture and above, with temperatures above 70°F could cause an increase in aflatoxin, but normal grain cooling and drying practices will be effective in controlling further production. Natural air, stirred and other bin drying methods will work if the wet grain is not held warm awaiting drying. Evaporative cooling (check the dewpoint temperatures) normally keeps natural air and low temperature drying systems cool enough.

Bin dryers operated at medium temperatures (below 120°F) can create issues. The optimum temperature for aflatoxin production is 75-95°F with moistures greater than 17 percent. A bin dryer operating with input air below 120°F will “store” the grain during drying at warm temperatures. If the bin is full, drying times of four to six days are not uncommon. In this case, grain already containing the *Aspergillus* fungus can experience increased aflatoxin levels.

The correction is to increase drying air temperatures beyond 120°F. Some bin drying systems with rapid stirring systems can go as high as 160°F; others with less grain circulation may be limited to around 140°F. Half batches will also help; shallower grain depth will increase airflow and cause less grain be held at higher moistures. It would be better in this case to dry two half batches instead of one full batch.

High temperature batch and continuous flow dryers are not susceptible to this problem, but wet corn should be held in high airflow wet holding (to maintain cold temperatures) or in the field. As an example, today’s conditions of about 80°F and 30 percent relative humidity will hold aerated wet grain at about 45-50°F because of evaporative cooling of dry air. This is below the growth conditions for *Aspergillus flavus* mold, although in time other more temperature resistant fungi will grow at those temperatures. Low temperature-natural air drying will also work under these conditions because the wet grain will not be warm enough to sustain the fungus.
Corn management: Understanding yield and the impact of growth variability on yield

Roger W. Elmore, professor and Extension corn agronomist, Agronomy, Iowa State University; Warren Pierson, graduate research assistant, Agronomy, Iowa State University.

The ‘drought of 2012’ actually started impacting Iowa crops as early as August of 2011. Ominous-looking, animated maps showed the extent and slow, creeping spread of extremely dry conditions across Iowa and the Corn Belt during the fall of 2011 and the 2011/2012 winter. Spring rains were not sufficient to recharge soil moisture. Corn planting proceeded ahead of normal (Figure 1). Although much of the corn ended up in what some considered ‘perfect’ seed beds, sidewall compaction and other early-season problems handicapped emergence and early-season growth. Warm temperatures (especially high-night temperatures) resulted in rapid progression through crop growth stages. Dry conditions aggravated the situation. The crop silked well ahead of normal. That trend continued through the reproductive period resulting in an early harvest. As a result of the early harvest we had drier grain and reduced drying costs.

Figure 1. Iowa corn crop progress and condition, 2012. National Agricultural Statistics Service.

Statistics tell the rest of the 2012 corn crop story. Less than 20% of Iowa’s corn ranked in the good to excellent category by mid-July (Figure 1). Fall USDA-NASS yield forecasts reflected the season dramatically in part due to poor conditions at silking and the rapid seed fill period the crop experienced. Figure 2 shows both Iowa and U.S. yield trends and current 2012 yield forecasts. Yield forecasts for both Iowa and the U.S. range around 22% below trend line yields. For comparison, yield in 1988, the last major drought, was about 29% below trend line. For more
Part 1: Understanding yield

Grain yield is the summation of components in sequence that include plant population, ear numbers per plant, kernel rows per ear, kernels per row and kernel weight. Understanding the timing of determination of these important grain yield components and the stresses that occur during these vegetative and reproductive developmental times helps to understand their impact on final grain yield.

The primary ear is initiated at about V6 (Abendroth et al., 2011) and kernel rows per ear is determined around V7. Number of kernels per row is also initiated around V7 and potential kernels per row determined by about V15-V16. Total leaf area - referred to as Leaf Area Index (LAI) - is related to stresses during vegetative development. Increasing LAI correlates to increased light interception. With more light interception there is more photosynthesis (Lindquist et al., 2005). Increased photosynthesis is strongly related to increased biomass production and grain yield production (Edwards et al., 2005).

The sequence of events at the beginning of the reproductive period is important too. Anthesis silking interval (ASI) represents the timing between pollen shed and silking (R1). Grain yield is strongly affected by stresses during this period. Water stress then causes lower plant growth rates and increases the ASI. Increasing ASI results in lower grain yields by reducing the number of kernels per ear and ears per plant. Increasing light interception at silking increases kernel number per plant. Stress reduction during silking results in more kernels per plant and increased grain yield. Biotic factors like silk feeding by root-worm beetles as well as weeds and diseases add to stress during this critical time. They, thus, reduce yield through changes in final kernel numbers and/or kernel weights.

Understanding these basic concepts of plant growth and development helps us better grasp the impacts of abiotic factors we faced during the 2012 growing season: high temperatures coupled with low precipitation.
Part 2: Impact of growth variability on yield

Farmers use starter fertilizer placed 2×2 in below and to the side of planted corn seeds to increase early-season growth and promote crop development. Researchers show that starter fertilizers increase early-season growth under cool and wet conditions; however, grain yield responses have been variable (Mallarino et al., 2011). Some have shown that variability in plant emergence and growth and development reduces grain yield (Liu et al., 2004) and (Nafziger et al., 1991). Our objective was to identify how starter fertilizer affects the progression of corn development and variability in growth. A second objective was to determine the impact of variation in early-season growth and development resulting from starter fertilizer on final grain yield.

We had locations near Ames and Nashua in 2011 and 2012; our results presented in this article are from the Ames location in 2011. Our experimental treatments included three hybrids, three populations (30,000, 36,000 and 42,000 seeds ac⁻¹), and two levels of starter fertilizer (with and without 10-34-0 at a rate of 8 gal ac⁻¹). We measured stem diameter ½ inch above soil surface until V6 and between the 7th and 8th nodes after V9, extended leaf plant height, and vegetative development on ten tagged plants at V2, V4, V6, V9, V15, and R2. At each sampling date, identical measurements were collected on five plants in another row and then destructively sampled to attain plant and root dry weights. A model was created using PROC REG (SAS Institute, 2010) to estimate the biomass of the tagged plants using the stem diameter and height at each stage. Roots on destructively sampled plants were analyzed at V2 and V4 for root length, surface area, average diameter, number of tips and number of forks using WinRHIZO (Regents Instruments, 1996). Per plant grain yield components and plot yield and grain moisture were also measured.

Starter fertilizer increased the average developmental stage of corn and decreased days to silking and anthesis. Starter fertilizer increased the estimated biomass of plants at V4, V6 and V9; however, final plant size was not different. Starter fertilizer increased estimated biomass coefficient of variation (CV) at a seeding rate of 30,000 seeds ac⁻¹ at stages V4, V9, and V15, however decreased estimated biomass CV at a seeding rate of 42,000 seeds ac⁻¹ at stages V6. Starter fertilizer increased root biomass at V4. The seeding rate of 30,000 seeds ac⁻¹ had greater root length, surface diameter, number of tips and number of forks than the seeding rates 36,000 and 42,000 seeds ac⁻¹. Starter fertilizer had no effect on plot grain yield. Increased variability in growth did not result in increased variability in grain yield components, and although starter fertilizer increased early-season growth, yield was not different with starter fertilizer. However, plant grain moisture was lower with starter fertilizer and increased seeding rate increased per plant grain yield variability.

Although starter fertilizer increased variability in estimated biomass at the low population and decreased variability at the high population, there was no effect of starter fertilizer on grain yield or per plant yield variability. At the time of writing, we are finishing data collection and continuing with data analysis for the 2012 growing season. We hope to be able to present our findings from both years during the ICM conference.

References


Management tips for drought-stressed forages
Stephen K. Barnhart, professor and Extension forage agronomist, Iowa State University

The Midwest U.S. has seen some of the most extreme drought conditions of recent memory. Some rain has come recently for most of this area, but not enough for most of us to feel comfortable about. Pastures may still be in poor condition. Many hayfields had enough regrowth that a late fall cut was taken. Regionally, hay supplies are tight and prices are high. Forage management considerations are many. Here are some things to think about as you prioritize your options.

Hay and pastures: The goal is to help keep perennial forage plants ‘perennial’
Most of our well-adapted, perennial forage grasses and legumes will survive the winter, even if they were stressed during the past summer and mismanaged in the fall. During the fall weeks, perennial forage legumes and grasses respond to shortening days and cooling average daily temperatures and progress through their gradual “cold hardening” process. The genetics of the variety and local climatic conditions determine how cold tolerant the plant crown and taproot can be during the winter months. Most successfully winterhardened perennial forage legumes and grasses can withstand soil temperatures in the crown area to about 0 to 4 degrees F without crown tissue damage. At lower soil and crown temperatures, varieties and individual plants will vary in the degree of cold damage they may experience.

To best acquire their potential for winter survival, perennial forage plants should get 5 to 6 weeks of uninterrupted growth to accumulate root carbohydrates and proteins before a fall ‘killing freeze’ and winter dormancy. It is difficult to define when the plants are actually dormant, but a season-ending, ‘killing freeze’ is usually a cold night of about 23-24F for several hours.

If you did cut one more hay cutting or grazing, it is important to manage fall harvests or grazings to give the plants the best chance for strong winter survival. Leaving a 5-6 inch stubble and any continued growth after the late cut will help to catch snow and maintain better crown insulation.

The same goes for late season growth management of pastures. Try to allow 3 to 4 weeks of fall recovery before a killing freeze, and then, if you are going to graze again, leave an average of 3 inches or so of lower stem bases on the grasses.

Stand evaluation
When evaluating winter injury in alfalfa fields, consider both the number of plants per square foot, the age of the stand. Crown and root diseases develop as stands age and often reduce stand density. So, plants should also be checked for dead, dying, or diseased tissue. Winter-injured plants are often slow to recover in spring, so a quick decision to destroy a winter injured stand is not recommended.

Wait until the spring regrowth is about 3 to 4 inches high. Select random stand count sites that represent the variability of the field. Check at least one 1-square-foot site for every 5 to 10 acres. Dig up all of the plants in the 1-square-foot area. Pick at the crown and buds with a knife to determine if the tissue is still alive. Then count the number of live plants per square foot. Use Table 1 to begin your rating of the stand. Next, split the taproots and evaluate their general health. See Figure 2. The interior of healthy taproots is firm and creamy-white. Damaged or dying taproots are yellowish-brown to chocolate-brown in color and watery or dry and fibrous in texture. Only healthy plants will contribute significantly to yield, so if any of the taproots are more than 50 percent diseased, reduce your initial stand count accordingly.
Table 1. Age of stand and rating of winter survival.

<table>
<thead>
<tr>
<th>Year following seeding</th>
<th>Good</th>
<th>Marginal 1</th>
<th>Consider reseeding</th>
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<tbody>
<tr>
<td>&gt; 12</td>
<td>8 - 12</td>
<td>&lt; 8</td>
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<td>&gt; 8</td>
<td>5 - 6</td>
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<td>4 years and older 2</td>
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1 Alfalfa plants in thin stands often produce more individual stems per plant and compensate some in yield potential
2 If 50 percent or more of the plants have crown or root rot, consider reseeding.

Alternatively, use the ‘stems per square foot assessment method. See Figure 1. It takes about 55 or more stems per square foot to indicate that ‘stand density’ is not limiting yield. Also use Figure 2 to evaluate general ‘health’ of taproots with the ‘stems per square foot’ assessment method. Whether using ‘plants/square foot’ or ‘stems/square foot’ and adjust stand assessment as needed.

When evaluating stands for other forage legumes such as red clover, use the same general guidelines as were used for alfalfa. Grasses are not as easily identified as individual plants or tillers, so use a general assessment of % ground cover of recovering grasses, and their general vigor. Pasture areas with greater than 70 percent live sod cover are most desirable. With less than 70 percent sod cover, consider frostseeding or interseeding, as describe in the reference publications. Winter-injured pasture plants are often slow to recover in spring, so a quick decision to destroy a winter injured stand is not recommended.

Plan your management this season, based on your stand evaluation. Hay fields and pastures that do survive the winter in a weakened condition will benefit form a less-than-normal use pressure during 2013.

- If stands are winter-injured, but will be harvested this season, allow plants to mature to 10 to 25% bloom or later, before cutting.
- Increase cutting height to 3 to 4 inches
- Maintain good fertilizer and insect management
- If stands are severely winter injured, and you will incur a significant loss in 2013, plan to reestablish a new hay field this spring, and begin to plan for any needed supplemental harvested and stored forage needs until the new seeding becomes adequately productive.
Repairing and reseeding

Reseeding into existing hayfields might be a viable option. Reseeding more alfalfa into or immediately after a 2-year old or older stand is not recommended. However, overseeding or drilling grasses or red clover into thin or winter damaged stands can be done in March or April. Delaying seeding later into the spring increases the risk of plant competition and seedling loss to increasingly dry and hot soil surface conditions of early summer.

Consider ‘interseeding’ or ‘frostseeding’ drought-thinned pastures next late winter or early spring. Frostseeding is the broadcasting of legumes or additional grass seed in late winter when the last few weeks of night-freeze and daytime-thaw, and the first few weeks of early spring rain splash aid in seed coverage. Interseeding is using a drill to no-till legumes or forage grasses into an existing sod. Spring interseeding dates are mid-March through late-April. Frostseeding works best with legumes on the thinnest, least competitive sod areas. Grasses are generally more effectively established with interseeding than with frostseeding. With both frostseeding and interseeding, having the existing pasture sod grazed closely (like many of our pastures following the summer drought stresses) reduces early season competition. Further competition for shade sunlight and soil moisture can be reduced by timely and thoughtful rotational grazing for the first few months of new seedling establishment. More details about these establishment methods and suggestion for their success are listed in the ‘Reference’ section for this article.

Fertilization

Fall is a good time to soil test and fertilize both hay and pastures with needed potassium (K) and phosphorus (P). This will help drought-stressed forage stands to overwinter and improve regrow and yields next spring. Applying 25 to 40 lbs of nitrogen to grass pastures during the last few weeks of their fall growth will aid in stimulating more fall tillering (branching) and for more vigorous recovery in the spring.

Give recovering hay and pasture stands time to ‘catch up’ or regain more vigor next spring

If fall recovery was not favorable, or you did cut or graze late in the season in 2012, the recovering forage plant may still be under some physiological stress. Hay and pasture plants will benefit from allowing a bit more recovery and growing time next spring before they are cut or grazed. For best ‘recovery management’ delay the first cut of alfalfa stands until they reach early- to mid-bloom. For pastures, allow 3 to 4 inches of growth in the spring before livestock turnout.

References

Establishing new forage stands http://www.extension.iastate.edu/Publications/PM1008.pdf
Evaluation for winter injury http://www.extension.iastate.edu/Publications/PM1362.pdf
Interseeding and No-till renovation http://www.extension.iastate.edu/Publications/PM1097.pdf
Selecting forage species http://www.extension.iastate.edu/Publications/PM1792.pdf
2013 Crop market outlook
Chad Hart, associate professor and Extension economist, Economics, Iowa State University

Despite the drought, the agricultural crop sector continues to record breaking crop values. Even though corn and soybean production fell dramatically in 2012, both corn and soybeans will set records in terms of the values of the crops due to the high prices being received. A decade ago, the corn crop was worth $20 billion. The 2012 corn crop is currently valued at over $80 billion. In 2002, the national soybean crop had a production value of $15 billion. The current crop is valued at nearly $45 billion. So crop agriculture continues to produce significant economic value, even as the rest of the economy has struggled to grow.

The impact of the drought worked very quickly into the crop markets as prices this summer reached record levels. As the harvest rolled in, prices have softened a bit, but the markets are still offering very strong values. And the lack of production this year has the markets offering stronger prices for next year’s crops as well. Many sectors of demand have backed off with the drought and the higher prices, but demand is still outpacing supply. Biofuels continue to be the leading source of crop demand. Exports have been supportive for soybeans. And livestock feed remains a critical part of the demand picture.

The supply picture for 2012 was drastically altered by the drought. As we started the year, there was the potential for record production as corn and soybean plantings were increased. Corn area increased by 5 million acres and soybean area increased by 2.2 million acres in 2012. But the drought sharply reduced yields and lowered production. Compared to last year, corn yields were down 17% nationally, 19% here in Iowa, and 38% in Illinois. For soybeans, national yields were down 10%, Iowa was down 17%, and Illinois fell 18%.

Given the supply shortfall, prices have risen and demand has weakened. Last year, ethanol passed domestic livestock feed as the #1 use of U.S. corn. Corn demand via ethanol topped the 5 billion mark for the 2011 crop. The outlook for the 2012 corn crop suggests ethanol usage of corn will fall in the current marketing year. As Figure 1 shows, the ethanol industry cut back on production this summer as the drought took hold. Just as higher corn prices represent higher feed costs for livestock producers, they also represent higher feedstock costs for ethanol plants. With somewhat steady oil prices and higher corn prices, ethanol production margins were squeezed and the industry pulled back on production. A few ethanol plants shut down, while many others slowed down. Overall, the ethanol industry retreated 10% this summer and had not ramped back up this fall.

One of the bigger for the ethanol industry is that with gasoline consumption declining over the past few years, the potential market for ethanol has shrunk. And the industry has grown large enough to fill that potential market and provide some ethanol for the export market. Ethanol stocks now fluctuate between 750 and 950 million gallons. Those stocks keep ethanol prices fairly low and limit production margins. So the growth in corn demand via ethanol has stabilized, taking away the major growth factor in the market over the past five years.

Corn feed and residual demand for the 2012 crop is projected at 4.15 billion bushels, as feed demand continues to shift lower. Returns to the livestock industry have retreated again as livestock prices could not keep pace with feed costs. Livestock production is in decline across the board as beef, pork, and poultry production is projected to lower in 2013. As was true last year, a big issue is price competition in feeds. Given corn’s relatively high price in comparison to other feeds, livestock feeders have moved to replace corn in part of the ration with lower cost feed.

Corn export demand is estimated at 1.15 billion bushels, down significantly from last year. The feed competition due to high corn prices is limiting corn exports. Figure 2 displays export sales so far this marketing year. All segments of the corn export market are lower this year. And the losses are significant. Sales to Japan and Mexico are down over 30%. Chinese purchases are down 50%. And exports to South Korea and Taiwan are off by more than 75%.

As like last year, exports remain the big story for soybeans, especially exports to China. While USDA has lowered its export estimate to 1.265 billion bushels, actual sales so far this year have higher than last year’s pace. The early sales data show strong demand from several countries. China leads the way, purchasing roughly 100 million bushels more thus far. But other countries such as Japan, Taiwan, and the European Union have also increased their soybean imports. As Figure 3 shows, current soybean exports are running nearly 40% above last year’s pace.
Figure 1. Weekly corn use by ethanol plants

Figure 2. Corn exports through late October (Source: USDA-FAS)
From their early October outlook, USDA had projected ending stocks for corn at 619 million bushels, over 250 million bushels less than last year. Soybean ending stocks were estimated at 130 million bushels, down 39 million bushels from last year. So U.S. ending stocks remain tight. Currently, USDA projects 2012/13 season-average prices at $7.80 for corn and $15.25 for soybeans. The futures markets have backed off from those levels though. Current futures prices (as of Nov. 1, 2012) point to 2012/13 season-average prices around $6.95 per bushel for corn and $14.37 per bushel for soybeans.

With the sustained high prices for both crops, the acreage competition for 2013 should be interesting again. Corn again looks to have the upper hand in the competition. Futures (as of Nov. 1) indicate 2012/13 season-average prices in the $6 range for corn and $13 range for soybeans. Crop input costs are expected to rise slightly next year. But the biggest issue in the acreage decision may be soil moisture. Most of the country still remains under drought conditions. While some hurricane-induced rains have reduced soil moisture problems in the Eastern Corn Belt, the western Corn Belt continues to dry out. And given the shift of corn and soybean acres to the north and west, advancing into the Great Plains, soil moisture problems could continue to plague corn and soybean production.

For the fourth year in a row, the crop years look to be profitable for Iowa corn and soybeans. As I wrote for the last two years, “With cash prices above $5 per bushel for corn and $11 per bushel for soybeans, there are strong marketing opportunities currently. And futures are showing strong marketing opportunities for both crops in the future as well.” That picture still holds.
Figure 4. Projections for 2013 season-average prices based on futures
ScoutPro mobile field scouting applications for corn and soybean

Michael Koenig, president and CEO, ScoutPro

A new way to scout

ScoutPro, a startup business from the Agricultural Entrepreneurship Initiative at Iowa State University (ISU), developed corn and soybean scouting apps for use on tablets (such as iPad and Android-based devices) and Smartphones. ScoutPro was founded by Michael Koenig in 2011, while studying at Iowa State University. Michael, who grew up on a farm in south central Iowa and had spent summers working as a crop scout, knew there had to be a better and more accurate method for crop scouting. The goal of this app is to help farmers and agribusinesses make better-informed decisions concerning pest (weeds, insects and diseases) control. The apps increase access to information and provide helpful tools for pest identification and record keeping. Additional ScoutPro apps are planned for other crops. Features of the apps include:

- Ease of access and simple to use
- An identification process that helps users narrow down a pest by identifying attributes
- Photos of identified pests along with pest’s background, life cycle, and threshold information
- The ability to generate field specific scouting reports through provided data entry fields including staging of pests, weather, plant population, stand count, pest pressure, etc.
- User uploaded images to scouting report for better record keeping
- Customizable data fields allowing users to add comments and/or directives for the scouted field
- Field mapping capabilities to allow cellular data enabled users to map fields via GPS coordinates for increased accuracy in reporting
- Identified pests are automatically recorded on a field map via GPS coordinates (for cellular data enabled users) to help identify concentrated problem areas needing immediate attention
- Scouting reports can be saved, stored on the ScoutPro hosted, user specific website and/or emailed to be shared or archived for reference in future crop years

These apps provide benefits for corn and soybean farmers and agribusiness, including:

- User assistance when working to identify field pests or disorders, helping to ensure field scouting and treatment recommendation accuracy
- The ability to keep accurate, field specific scouting reports throughout the growing season
- A mapping system that automatically records GPS coordinates, allowing geo-reference specific pest “hot spots” in fields, leading to better spraying efficiencies
- Decreased communication lag by allowing users to input and upload easy to read information and then allowing them to share the information instantly
- Archived data provides users with accessible information to make better information crop input and management decisions for upcoming seasons

Partnership with Iowa State University Extension and Outreach

Recent extension publications from Iowa State University such as the Corn Field Guide, Soybean Field Guide, Weed Identification Field Guide, and others, were useful print tools for the field, but the information was not available as an app. Iowa State University Extension and Outreach partnered with ScoutPro in the development of the scouting apps, which are based on these ISU field guides and diseases publications, by supplying the information for the apps and helping to review and guide the development process.
First Year Analytics

Analytics of the ScoutPro apps for 2012 are as follow (information from both Soybean and Corn apps unless specified):

- The top five most common weeds identified in fields this season were velvetleaf, giant ragweed, giant foxtail, common waterhemp, and common lambsquarter
- The top diseases identified in soybeans were Septoria brown spot, bacterial blight, alfalfa mosaic, bacterial pustule, brown stem rot, charcoal rot
- The top diseases identified in corn were common rust, common smut, gray leaf spot, and Anthracnose leaf spot
- The top five insects reported in soybeans were Japanese beetle, grasshopper, two spotted spider mite, bean leaf beetle, and imported longhorn weevil
- The top five insects in corn were Japanese beetle, corn rootworm, seven-spotted lady beetle, stalk borer, and grasshopper

Conclusion

ScoutPro continues to look for ways to better serve the agricultural industry and farmers who are interested in scouting and, more importantly, basing future management decision off of this scouting information. ScoutPro's apps are designed to make scouting easier and more convenient to keep records of the scouting activities. We welcome constructive feedback to make these apps even better.
Yellow nutsedge

Comments
Reproduces by seed, rhizomes, and tubers. Prefers poorly drained soils.

Stems
Erect, unbranched and 3 sided; triangular cross section. Rhizomes are wiry and scaly with nutlike tubers produced at the tips.

Ligules
None

Scientific Name
Cyperus esculentus

Leaves
Shiny, yellow-green and hairless with a distinct ridge along the midvein. Leaves are produced in groups of 3 at the base of the plant. No nodes are present.

Other Name
Yellow nutgrass, chufa

*Staging of plant
v5

*Field Recommendations
Needs Attention Soon

*Weather
Sunny

Plant Population

Temperature
60

Stand Count

This field looks good overall with some nutsedge in the north east corner of the field. Also some bean leaf beetles were found near the field entrance.
Global demand for energy continues to increase as the planet’s population grows past 7 billion and incomes rise, especially in developing countries. The increasing demand for energy has spurred many countries to explore alternative energy platforms. Over 50 countries throughout the world have active bioenergy programs. The U.S. has moved to the front of this activity as we have grown to become the largest producer of biofuels and as we alternate between the world’s largest importer and exporter of ethanol. In 2007, the federal government provided a blueprint for biofuel development over the next decade with the Renewable Fuels Standard (RFS). Figure 1 shows the RFS and details targets for various types of renewable fuels. Looking forward over the next decade, the government is seeking significant expansion of cellulosic biofuels. The target for cellulosic biofuels expands from 250 million gallons in 2011 to 16 billion gallons in 2022.

As part of the government’s efforts to meet the RFS targets, USDA has funded several efforts to investigate the development of sustainable bioenergy platforms. Iowa State University and collaborators from several other states have been awarded funds for a project that is:

1) exploring the feasibility of producing advanced transportation fuels derived from perennial grasses grown on land that is unsuitable or marginal for row crop production and

2) improving the sustainability of existing corn/soybean systems by reducing agricultural runoff of nutrients and soil and increasing carbon sequestration.

Figure 1. Renewable Fuels Standard
The project, known as CenUSA, is a multi-state and multi-disciplinary effort being led by Iowa State University. Project activities will take place in Iowa, Indiana, Wisconsin, Minnesota, Nebraska, Illinois, Vermont and Idaho by researchers from Iowa State University, Purdue University, University of Illinois, University of Minnesota, University of Nebraska, University of Wisconsin, University of Vermont, Idaho National Laboratory and from USDA Agricultural Research Service offices in Wisconsin, Nebraska, Illinois, Pennsylvania, and Iowa.

CenUSA has 9 broad platforms within the project:

1) Feedstock Development,
2) Sustainable Production Systems,
3) Feedstock Logistics,
4) System Performance,
5) Feedstock Conversion,
6) Markets and Distribution,
7) Health and Safety,
8) Education, and
9) Extension and Outreach.

Each platform has specific goals. Three of these platforms will have presentations at the 2012 ICM conference. Dr. Rob Mitchell is presenting information on the establishment and management of perennial grasses for bioenergy use. Dr. David Laird is presenting on biochar development and use. And Dr. Keri Jacobs is presenting on the current understanding of the economic considerations for perennial grass production in bioenergy markets.

Figure 2 shows the grand vision for the project, the integration of perennial grasses on marginal lands within our traditional crop production system. We are in the first stages of the project. Feedstock development has concentrated on the establishment of new breeding and evaluation trials for switchgrass, big bluestem, and indiangrass. These trials were planted at 12 locations across the upper Midwest. The trials include examinations of mixed feedstocks, fertilizer applications, and soil conditions. Over the years, these trials should provide information on the potential production from perennial grasses.

Preliminary studies have been done to examine the cost and energy requirements of harvesting grasses with various types of equipment. This data is being analyzed to inform the environmental and economic modeling efforts within the project. Early grass biomass samples have been processed by pyrolysis to explore the possible range of bioenergy and other products that could be developed. Educational modules have been developed on perennial grass establishment and management, harvesting and storage systems for bioenergy grasses, and logistical modeling of feedstock production systems. Biochar applications have been setup within the Master Gardeners’ program.

This session will provide a general overview of the CenUSA project and highlight recent accomplishments within the project.
Figure 2. CenUSA Grand Vision
Understanding the economics of a system of perennial grasses for bioenergy in the Central United States

Keri Jacobs, assistant professor and Extension economist, Economics, Iowa State University

Through policies and programmatic commitments, the United States is exploring the use of alternative transportation fuels as means to meet the growing global demand for energy and the nation’s RFS targets. The CenUSA Bioenergy project is a five year, multi-state, and multi-disciplinary coordinated research and education effort to develop a sustainable system for the production of biofuel feedstocks derived from perennial grasses on land marginal for row crop production. The project, funded by the USDA under the NIFA-AFRI Sustainable Biofuels Initiative (project #2010-05074), focuses on the production of perennial grasses integrated within the row crop landscape in the region consisting of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. CenUSA is comprised of researchers, scientists, and educators working in nine objective areas to move the project forward: 1) feedstock development, 2) sustainable production systems, 3) feedstock logistics, 4) system performance, 5) feedstock conversion, 6) markets and distribution, 7) health and safety, 8) education, and 9) extension and outreach.

A feasible and sustainable regional system of biofuels derived from perennial grasses requires a comprehensive strategy that addresses impacts to and requirements of markets and distribution systems. The markets and distribution platform (objective 6) is responsible for, among other things, evaluating farm-level adoption decisions and exploring policy, market, and contract mechanisms that facilitate broad scale adoption by farmers. Recognizing that adoption by farmers will be voluntary, the production of biomass for biofuels must be shown to have economic value to the farmers who will be considering it in their farm business management decisions. Further, to entice adoption, switchgrass production must be competitive with traditional row-crop production on the same quality land.

Placement of switchgrass for the purpose of biofuels is envisioned to be on lands unsuitable or marginal for row crop production; lands near streams and waterways are of particular interest. The U.S Department of Energy estimates that nearly 20 million hectares of land in the United States is available to support perennial grasses for bioenergy crops (2011). One placement scenario the CenUSA project is considering is plantings of biomass crops on current or past Conservation Reserve Program (CRP) lands. Switchgrass may provide a return advantage to the farmer over the CRP and alleviates contractual obligations that accompany CRP enrollment. However, unlike the steady CRP payment, switchgrass production is susceptible to weather, production, and marketing risks. Further, current high commodity prices make production on marginal lands, even past CRP lands, profitable.

Farm scale production costs of switchgrass, including those for establishment, management, harvest, and storage, have been estimated at $65.86 per metric ton of biomass dry matter (2003 prices, includes land cost of $147.45/ha ($60/acre)) over a 5-year rotation with biomass-type cultivars expected to yield approximately 5.0 metric tons per hectare (Perrin et al 2012). Cost projections are lower for a 10-year rotation of switchgrass with a slight drop in yields in later years of the rotation.

The economic return to switchgrass production for landowners includes not only the coverage of costs by expected returns from marketing but also an accounting of the additional on-farm benefits the system may provide, such as erosion control benefits and the value of biochar as a soil amendment. Social benefits from the reduction of nutrient run-off and greenhouse gas emissions could be substantial. CenUSA collaborators estimate that switchgrass production results in an increase of long-term carbon sequestration, particularly at the deeper soil depths (0 to 150 cm), and are working to quantify these and other impacts of the perennial grass system and their economic value.

The project is led by Iowa State University and partners with researchers and scientists at Purdue University, University of Illinois – Champaign, University of Minnesota – Twin Cities, University of Vermont – Burlington, University of Wisconsin – Madison, and the USDA ARS – Ames, Iowa; Lincoln, Nebraska; Wyndmoor, Pennsylvania; Madison, Wisconsin.
References


Industrial harvesting of corn stover as a biomass feedstock

Matt Darr, assistant professor, Agricultural and Biosystems Engineering, Iowa State University

Introduction

Harvesting corn stover as a biomass feedstock is a growing practice within the Midwest US. Corn stover harvesting generally occurs soon after corn grain harvest is complete and ahead of fall tillage or fertilization. Corn stover is generally baled to create high density packages that can be transported efficiently. Both round bales and square bales can be formed depending on the end use. Round bales are generally more suitable for lower volume uses like animal bedding while large square bales are preferred for industrial uses like cellulosic biofuels.

This report provides an overview of the basic machinery systems used in corn stover production. While applicable to any end use of corn stover, this report is specifically aimed at industrial corn stover production which will supply cellulosic biorefineries.

Windrowing

Windrowing involves collecting corn stover into concentrated strips in a field to facilitate collection by a baler. Three primary methods exist to windrow corn stover; combine windrow, rake, and stalk chopping windrower.

Combine windrowing is achieved by disengaging the spreaders on the back of a combine and allowing the material other than grain (MOG) to drop directly onto the ground behind the combine. This creates a concentrated windrow directly behind the combine at the time of grain harvest. In typical corn production this will produce a windrow with approximately 0.75 ton/acre of material.

Two types of rakes provide viable windrowing options in corn stover. Bar rakes use rotating parallel bars with mounted teeth to convey material into a center windrow (Figure 1). Wheel rakes use rotating wheels with attached teeth to sweep corn stover into a center windrow as well. Both can be optionally configured to be hydraulically powered which give the operator more control over the speed and flow of material across the rake.

The corn stover harvest rate can be controlled by changing the height of the rake off the ground. Rakes will generally produce corn stover windrows between 1.25 – 2 tons/acre under normal operations. Care should be taken to ensure that the rake teeth never touch the ground and maintain appropriate clearance off the ground in order to minimize the amount of soil contamination that is entrained in the windrow.

Figure 1. Hydraulically powered bar rake forming a corn stover windrow.

Windrowing stalk choppers use a series of rotating knives to chop or shred corn stalks. Stalk choppers are commonly used in many areas of the corn belt to help break down stalk material particularly in continuous corn production. The windrowing stalk chopper is modified to include an auger along the rear of the windrower which conveys shredded material to a central discharge area (Figure 2). Depending on the model, the windrow discharge
may be located at the center or the end of the stalk chopper.
Like rakes, the harvest yield from stalk choppers can be adjusted by changing the clearance between the chopping knives and the ground. Because the stalk choppers have less opportunity to engage the soil, the soil contamination or ash level of corn stover produced with a stalk chopper is generally less than with a raked windrow.

![Side discharge windrowing stalk chopper forming a corn stover windrow.](image)

**Figure 2.** Side discharge windrowing stalk chopper forming a corn stover windrow.

**Baling**

Balers are used to convert loose corn stover windrows into densified packages that can be transported throughout the supply chain. Round balers and large square balers can be used, although industrial corn stover production favors large square balers because of their higher productivity level and the handling advantages of large square bales over round bales.

Round balers are common throughout the majority of the Midwestern US. The dimensions of round bales vary based on the specific equipment model used, but for corn stover production round bales generally are 5 feet wide and have diameters ranging from 5.5 – 6 feet. Round balers can require up to 75 PTO horsepower. For adequate drawbar power and to maximize the productivity of the baler it is recommended that a tractor with 120+ horsepower be used for industrial baling operations. High density round balers with chopping pretreatment can achieve bale densities of 10 lb/ft³.

Large square balers are less common across the grain belt, but are widely used in regions of the US that are active in commercial forage production (Figure 3). Large square bales offer advantages in their stacking and transportation characteristics which make them the preferred baling platform for high volume applications. Three models of large square balers are available. The most common model produces a 3 ft by 4 ft bale cross section. The length of the bale is controlled by the operator although the industry standard length is 8 ft. Two other models which produce a 3 ft by 3 ft and a 4 ft by 4 ft cross section bale are also available. For most industrial applications, the 3 ft by 4 ft baler is preferred because it can achieve higher bale densities and the bales can be legally stacked three high on a semi-trailer which creates effectively a 9 ft high transportation package. High density balers, which have only been on the market since 2010, can produce bale densities of over 12 lb/ft³ in optimal crop conditions.
Figure 3. Three foot by four foot large square baler used in corn stover production.

Large square balers require considerably more power than round balers. High density and high capacity large square balers typically list a minimum of 180+ horsepower on manufacturer’s literature. Baler speed in corn stover is often higher than in hay crops due to the lower per acre yield of corn stover. Due to the higher travel speeds and increased motion resistance of the baler in soft Midwestern soils, a minimum of 250 horsepower is recommended for corn stover baling.

For industrial scale corn stover supply chains, the bale density and bale length should be closely monitored to ensure the bale characteristics match the end user requirements. Higher density and appropriate length bales will minimize how many individual bales are created. Fewer bales with higher density will reduce transportation and storage costs.

Similar to the windrowing machinery, the pickup on the baler should be accurately set to maximize the amount of the windrow that is collected while minimizing the amount of soil that is swept into the bale. Baler pickup tines should never come into contact with the ground. Operators should check this setting regularly to ensure high quality biomass production.

**Single Pass Harvesting**

Single pass harvesting involves creating baled corn stover simultaneously during grain harvest (Figure 4). This is achieved by towing a baler behind a combine and directly baling all MOG directly out of the combine before the material hits the ground. By direct baling the corn stover, soil contamination is eliminated and a much higher percentage of cobs are captured in the bale. Single pass baled corn stover has an average ash content of 3.5% which is equivalent to the structural ash of corn stover. Currently single pass balers are being marketed commercially by AGCO and Tuthill Drive Systems.

Harvest rates with single pass baling equipment vary significantly based on the combine header configuration. When using a standard grain header, harvest rates of only 0.7 tons/ac are achievable with a high percentage of cobs in the baled fraction. High take rate headers including row crop headers can increase the harvest rate significantly. Additionally, changing the vertical position of the combine header can increase the biomass collection rate. Production single pass baling systems with these appropriate header modifications have been shown to produce harvest rates of up to 2 tons/ac.
Towing a single pass baler will generally reduce the combine productivity by up to 30% when harvesting at 2 tons/ ac. The loss of productivity is associated both with the additional draft force required by the combine to tow the baler through the field as well as the additional power to thresh the corn grain and additional biomass. Under typical harvest conditions, this reduction will often not impact the overall field productivity unless grain handling is completely optimized.

**Bale Collection**

Once corn stover bales are produced they should be collected and moved off the field as quickly as possible to allow for subsequent fall field operations. Multi-bale collection wagons exist for round bales and large square bales. These wagons are typically tractor drawn and hydraulically powered to lift and carry individual bales. Models for large square bales are normally equipped with a hydraulically powered lift table which is used to stack bales at the edge of the field. Self-propelled models are also available.
Figure 6. Large square bale collection wagon used to collect bales and create a field stack.

**Conclusions**

- Industrial corn stover production includes three unique machinery activities; windrowing, baling, and bale collection.
- Stalk chopping windrowers generally produce higher quality corn stover (lower ash content) that is best suited for use in cellulosic biofuels industry.
- Large square bales offer better handling and transportation characteristics for high volume biomass than round bales.
- To maximize the productivity of large square balers, tractors with greater than 250 horsepower are required.
- Bale collection wagons can efficiently collect bales within a field.
Economics of corn stover

William Edwards, professor and Extension economist, Economics, Iowa State University; Chad Hart, associate professor and Extension economist, Economics, Iowa State University; Kelvin Leibold, Extension farm management specialist, Iowa State University

The biomass market

In the midst of rising energy prices, Congress sought to incentivize the development of alternative fuel systems. One major component of that incentive was the passage of the 2007 Energy Act. The 2007 Energy Act established the current Renewable Fuels Standard (known as RFS2) and categorized renewable fuels into four basic areas: conventional biofuels, cellulosic biofuels, biodiesel, and additional advanced biofuels.

Figure 1. The Renewable Fuels Standard.

Three of these four areas had well established fuel systems. The conventional biofuel component is being filled by corn-grain-based ethanol. Biodiesel is being created using a number of feedstocks, including soybean oil. The additional advanced biofuel component is being filled by sugarcane-based ethanol. But the cellulosic biofuel component did not have a well-established fuel system. Both the U.S. Departments of Energy and Agriculture have examined the country's potential for biomass production and the resulting energy products that could possibly be created from biomass. As the following map shows, many areas of the country could produce sizable quantities of biomass.
These biomass resources range from forest thinnings in the Pacific Northwest to wheat straw in the Great Plains to rice straw in the Mississippi Delta. One of the largest sources of biomass is corn stover. Thus, corn stover is being targeted as the feedstock for the first two commercial-size cellulosic biofuel plants, the POET plant in Emmetsburg and the DuPont plant in Nevada.

As cellulosic biofuel would be a brand new market, there is a lot of uncertainty about many aspects of biomass production, pricing, and markets. Corn producers already create the stover as part of their normal business, producing corn, but questions remain about the potential revenues from stover and the costs of stover removal. Also, what are the potential revenues and costs from cellulosic biofuel production and how will these revenues/costs be distributed between crop producers and biofuel plants?

In a first step to address some of these questions, both POET and DuPont have contracted with corn producers to purchase corn stover. The contracts are legally binding agreements that outline the risk-return tradeoff between the biofuel plants and corn producers. And these contracts address many of the major benefits/challenges that corn producers have about the harvest and sale of corn stover.

Jarboe, et al. (2012) examined many of these issues in a survey of Iowa crop farmers. They found while many crop producers have moderate knowledge about corn-grain ethanol, their knowledge of cellulosic biofuels was limited. Crop producers showed more interest in providing corn stover for biofuel development than other types of biomass, including grasses, trees, and legumes. However, the producers also indicated they had concerns about soil erosion and nutrient loss due to corn stover harvesting.
Table 1 outlines the top 10 challenges crop producers face when exploring participation in the potential cellulosic biofuel market. The POET and DuPont contracts have been written to address some of these challenges and to highlight the potential benefits to producers of participating in the cellulosic biofuel supply chain.

Table 1. Producer challenges to corn stover marketing

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Average Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nutrient loss</td>
<td>5.55</td>
</tr>
<tr>
<td>Distance to markets</td>
<td>5.52</td>
</tr>
<tr>
<td>Long-term biomass market viability</td>
<td>5.44</td>
</tr>
<tr>
<td>Biomass price volatility</td>
<td>5.26</td>
</tr>
<tr>
<td>Soil erosion issues</td>
<td>5.19</td>
</tr>
<tr>
<td>Percent of biomass removed</td>
<td>5.13</td>
</tr>
<tr>
<td>In-field transport and compaction</td>
<td>5.00</td>
</tr>
<tr>
<td>Contract opt-out clauses</td>
<td>4.99</td>
</tr>
<tr>
<td>Contract terms of storage</td>
<td>4.93</td>
</tr>
<tr>
<td>Residue management</td>
<td>4.92</td>
</tr>
</tbody>
</table>

1 A rating of 1 indicated “Not concerned,” while a rating of 7 indicated “Very concerned.”
Source: Jarboe, et al. (2012)

Valuing corn stover

The value of the stover can be derived in several ways. The minimum price is the cost of corn stover removal from the perspective of the seller (the corn producer). Those costs include the cost of harvesting the stover (unless the buyer does the harvesting) and the added fertilizer expense to make up for lost nutrients. The maximum price is the potential value of the stover to the buyer. For biofuels, this value is tied to the prices of crude oil, gasoline, and other biofuels (including corn-grain ethanol). For stover used as a supplemental livestock feed, the maximum price the livestock producer can pay is the value of the alternative feeds replaced. The negotiated price for the corn stover must be between the minimum and maximum values.

Feed value

Corn stover is an abundant source of winter feed for beef cows in Iowa. When supplemented with protein, vitamins, and minerals, stover can supply the nutritional needs of cows that are in moderately good body condition during fall and early winter. The obvious advantage of utilizing corn stover is its wide availability and low cost. This has created a small but important market for stover, both as a harvested product and as a standing crop in the field. The following procedure estimates the value of baled stover to the buyer based on the cost of the feedstuffs it replaces for wintering beef cows.

Corn stover can substitute for medium quality mixed hay in a ration for wintering beef cows, if a protein supplement such as dried distillers grains (DDGS) is added. Table 2 shows two recommended rations, with and without corn stover, for 1,200-pound and 1,400-pound beef cows.
Table 2. Estimated feed disappearance for a producing beef cow.

<table>
<thead>
<tr>
<th>Cow weight</th>
<th>Alfalfa-brome hay + DDGS</th>
<th>Alfalfa-brome hay + cornstalks + DDGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,200 pounds</td>
<td>2.4 T. hay + .3 T. DDGS</td>
<td>1.0 T. hay + 1.2 T. stalks + .55 T. DDGS</td>
</tr>
<tr>
<td>1,400 pounds</td>
<td>2.6 T. hay + .3 T. DDGS</td>
<td>1.1 T. hay + 1.3 T. stalks + .60 T. DDGS</td>
</tr>
</tbody>
</table>

Assumes 125 days of winter pregnancy and 30 days of lactation before spring calving, and 10% waste.
Source: Managing 2007-08 Cow Herd Feed Needs, Iowa Beef Center, Iowa State University.

Comparing the two rations for each cow weight, each ton of corn stalks added to the ration substitutes for about 1.16 tons of legume-grass hay. Plus, an additional 0.22 tons of DDGS are added. Thus, the value of a ton of stover can be equated to the value of 1.16 tons of mixed hay, minus the value of 0.22 tons of DDGS.

Example 1.

1.16 tons of mixed hay @ $125 = $145.00
Minus .22 tons of DDGs @ $260 = $ 57.20
Value of feed replaced = $ 87.80 per wet ton
Minus transport cost (5 mi. @ $.25/bale) = $ 2.08
Feed value at the farm = $ 85.72 per wet ton

Cost value

The cost of chopping, raking, and baling corn stover can be estimated from typical farm custom rates, such as are reported in Ag Decision Maker file A3-10, Iowa Farm Custom Rate Survey. Rates used in Example 2 were taken from the 2012 survey. If bales must be transported, that cost should be included, as well. Wrapping the bales with plastic netting instead of twine adds about $1 per bale to the total cost. Chopping and raking may not be necessary for feed use if the combine leaves residue in a row, or collects it.

Example 2.

Custom stalk chopping = $ 11.05 per acre
Custom raking = $ 6.20 per acre
Custom baling ($11.50 / bale x 4 bales/acre) = $ 46.00 per acre
Transport ($0.05/mile x 20 mi. x 4 bales/acre) = $ 20.00 per acre
Total harvesting cost = $ 83.25 per acre

In addition, extra nutrients removed by harvesting must be replaced for future crops. Replacement costs of $.53 per pound for P and $.55 per pound for K are assumed.
Example 3.

Weight of round bale is 1,200 lbs (.6 tons)

- Phosphate removal value = 5.9 lb. @ $.53 = $ 3.13 per dry ton
- Potash removal value = 25 lb. @ $.55 = $ 13.75 per dry ton
- Total value of nutrient removal = $ 16.88 per dry ton
- x 1.92 dry tons harvested per acre = $ 32.40 per acre
- + total harvesting cost = $ 83.25 per acre
- Total cost per acre = $115.62 per acre
- Divided by 2.4 wet tons per acre = $ 48.18 per wet ton

The actual price paid may be negotiated somewhere within this range. In the examples above, the range would be from $48.18 to $85.72 per wet ton. If the stover is sold standing in the field, that is, the buyer harvests the stover, the minimum price would only need to cover the costs of added fertility, which in the example is $16.88 per dry ton or $13.50 per wet ton at 80% dry matter. Stover values under other assumptions can be analyzed using the Corn Stover Price decision file on the Ag Decision Maker website (see references).

Market Value

Although market prices for harvested corn stover are not reported on a regular basis, bales are sometimes sold at hay auctions. Some auctions report prices on their websites, which can be located by searching on “hay auction.” Recent auction prices in Iowa for large round bales of corn stover ranged from $25 to $35 per bale, or $50 to $75 per ton, according to USDA hay price reports. These sales would be mostly large round bales suitable for cattle feed or bedding, but not for ethanol production.

References


DuPont cellulose ethanol: Sustainable corn stover harvest for biofuel production

Andy Heggenstaller, Agronomy Research Manager, DuPont Pioneer

DuPont has been developing technology to produce ethanol from cellulosic biomass for over a decade. In 2012, DuPont Industrial Biosciences will take the first steps to commercialize this revolutionary technology by commencing construction on a first-of-its-kind cellulosic biorefinery near Nevada, Iowa. This biorefinery, which is expected to begin operation in 2014, will produce 25 million gallons of ethanol annually from corn stover. All of the stover required to operate the biorefinery will be collected from within a 30-mile radius of the plant location.

To lead the way in meeting the feedstock needs of next generation of biofuels, DuPont partnered with Iowa State University in 2010 to initiate a corn stover supply chain research and development program in central Iowa. Over the past three years, this program has been working to develop and scale-up a cost-effective, high-quality and sustainable supply of corn stover biomass for the Nevada biorefinery. At full commercial capacity, DuPont’s Nevada biorefinery will consume roughly 350,000 tons of corn stover each year (Figure 1).

Figure 1. Anticipated corn stover supply chain scale-up for DuPont’s Nevada, IA biorefinery.

Corn stover supply chain model

For the past three years, DuPont has been working to develop a corn stover supply chain that delivers high quality, cost-competitive feedstock, while also successfully integrating into, and adding sustainable value to, the farming operations of Iowa corn growers (Figure 2). Key features of the DuPont corn stover supply chain model include: (1) contracted access to corn fields following grain harvest; (2) third-party stover harvest; (3) packaging of stover as high density, large square bales; (4) temporary field-edge feedstock storage; (5) long-term, covered feedstock storage at distributed satellite locations; and (6) “just-in-time” delivery of feedstock to the biorefinery. Stover harvest is currently achieved using two field passes (shredder-windrower followed by baler), but the supply chain is
designed to accommodate “single-pass” grain and stover harvest technology currently under development by several equipment manufactures.

**Figure 2. Corn stover supply chain model being developed for DuPont’s Nevada, IA biorefinery**

**Agronomic impacts of corn stover harvest**

Increasing corn yields have been accompanied by similar increases in the quantity of stover remaining in fields following grain harvest (Lorenz et al. 2010). The development of higher yielding hybrids with stronger stalks that delay the onset of decomposition, has contributed to residue management becoming a growing challenge for many growers. Corn stover also immobilizes soil nitrogen (Green and Blackmer, 1995), and serves as a source of inoculum for damaging corn diseases. Therefore, in addition to the direct value growers receive as payment for harvested stover, removing a portion of this material from fields has the potential to deliver additional agronomic value. Currently, limited information exists regarding the impacts of commercial corn stover harvest operations on crop production.

**DuPont Pioneer corn stover harvest research trials**

To better define the agronomic impacts of stover harvest, DuPont Pioneer partnered with Iowa State University in 2011 to establish eight on-farm stover harvest strip trials. Each strip trial is approximately 40 acres and includes two treatments, each replicated three times. In one treatment, a portion of corn stover is harvested in the fall using the same equipment and methods employed in DuPont’s commercial harvest system (~50% stover removal). The second treatment consists of a control, where corn stover is not harvested. Corn stover harvest treatments were initiated in fall 2011, at which time extensive soil sampling was conducted at all trial locations to characterize background site characteristics for long-term monitoring of soil fertility and organic matter. All research locations were planted to corn in 2012. Crop establishment rates were assessed in spring 2012 and grain yields were determined in fall 2012.

**Corn establishment and yield following partial stover harvest**

Repeated stand counts indicated that early corn emergence was generally enhanced by partial stover harvest (Figure 3). Assessed 7-10 days after planting, corn emergence was significantly greater at six of eight locations (P < 0.1) and trended greater at the remaining two locations with partial stover harvest. Across locations, 68% of the planted population emerged 7-10 days after planting with partial stover harvest, compared to 54% without stover harvest. Though corn emergence was more rapid following partial stover harvest, final populations were similar for the two residue management treatments.
Figure 3. Corn emergence 7-10 days after planting (DAP) with and without partial stover harvest (~50% removal) at eight locations in central Iowa.

Partial stover harvest also enhanced corn grain yield at seven of eight locations (Figure 4). Averaged across locations, partial stover harvest increased corn yield by 3.3% compared to no stover harvest (P < 0.01). Increased corn yields were likely due to the positive effects of stover harvest on stand establishment and soil nitrogen (N) availability during vegetative growth (data not shown). Ongoing monitoring of DuPont's Pioneer's corn stover research trials will help to further define partial corn stover harvest impacts on crop performance and soil fertility.

**Nutrient content of corn stover**

Stover harvest increases the total amount of plant material removed from a field, resulting in greater quantities of nutrients also being removed. Estimates of stover nutrient content are available in various state soil fertility extension publications. Many extension sources report stover nutrient content for corn plants at physiological maturity. Nutrient removal estimates based on silage harvest or for corn stover at physiological maturity typically overestimate the amount of nutrients actually removed by commercial corn stover harvest.

DuPont and Iowa State analyzed the phosphate (P<sub>2</sub>O<sub>5</sub>) and potash (K<sub>2</sub>O) content of approximately 300 large, square bales collected during commercial harvest operations in central Iowa in 2010 and 2011. Nitrogen content was also assessed for a subset of bales. From this analysis, the nutrient content of commercially harvested bales was confirmed to be less than that generally reported for corn stover by regional extension services (Figure 5). Reduced nutrient content for commercially harvested stover is believed to result from: (1) the reduction in potassium - which exists in stover in a soluble form - that occurs between plant physiological maturity and the time of stover harvest (Sawyer and Mallarino, 2007); and (2) the fact that commercial stover harvest disproportionately removes the upper portion of the corn plant, which typically has a lower nutrient content than the lower portion of the plant (Johnson et al., 2010).
Figure 4. Corn yield advantage with partial stover harvest (~50% removal) at eight locations in central Iowa.

Figure 5. Nutrient (N, P$_2$O$_5$, and K$_2$O) content of corn stover baled by DuPont and Iowa State in 2010 and 2011, compared to that reported by four university extension services. References are: (1) Sawyer et al. 2011; (2) Gould 2007; (3) Bundy 1998; and (4) Fernández 2007.
**Corn stover harvest sustainability**

Corn stover plays several important roles in a cropping system, including mitigation of soil erosion and maintenance of soil organic matter. Because of the value that corn residues provide in maintaining soil productivity, a portion of corn stover must be retained in fields to meet critical soil quality needs. Research conducted by the USDA provides general guidelines for how much stover must be retained in fields to prevent soil erosion and maintain soil organic matter (Wilhelm et al. 2007). Tillage practices and crop rotation both affect sustainable stover rates, as does the productivity of the field. Regardless of management practices or productivity level, the need to maintain soil organic matter ultimately sets the limit for how much stover can be harvested in a sustainable manner.

![Figure 6.](image)

**Figure 6.** Quantity of corn stover that needs to be retained in the field to prevent soil erosion from exceeding tolerable (T) values established by the Natural Resource Conservation Service (NRCS), and to maintain soil carbon in steady state. Adapted from Wilhelm et al. 2007.

**DuPont sustainable stover harvest recommendations**

DuPont provides sustainable harvest recommendations to growers participating in its stover harvest program. These recommendations are based on guidelines established by USDA research (Wilhelm et al. 2007). In practice, DuPont’s sustainable stover harvest recommendation has three key components:

1. Partial stover harvest – A portion of stover must be retained in fields to prevent soil erosion and sustain soil organic matter. DuPont limits stover harvest to a rate of two tons acre⁻¹, which is generally less than half of the total stover produced in harvested fields.

2. Field characteristics – Stover harvest is limited to appropriate fields. DuPont advises growers to only harvest stover from fields that have a recent yield history of 180 bushels acre⁻¹ or greater and a slope of 4% or less. Additionally, DuPont positions stover harvest on fields that are managed with conservation or no-till practices.
3. Harvest frequency – Stover is not harvested off of the same field every year. For fields that are managed in continuous corn, DuPont advises that stover be harvested no more than three out of every four years. For fields in a corn-soybean rotation, it is recommended that stover harvest take place only two out of every five years that the field is in corn. Varying harvest frequency helps to insure that soil organic matter is maintained over the long term.

**Stover harvest cropping considerations**

Although DuPont has purposefully developed a stover harvest program that allows corn growers to participate with minimal or no changes to their current farming practices, stover harvest does create new crop production opportunities. Most obviously, growers participating in a stover harvest program do not need to perform fall residue management activities such stalk chopping and/or AMS application. In some cases, it may also be possible to eliminate tillage operations that are directed primarily toward residue management. Finally, because partial stover harvest provides some of the same benefits as rotation with soybean, certain management challenges associated with producing corn following corn can be potentially be avoided.

**References**


Crop diversification: Impact on weeds, soybean sudden death syndrome and crop productivity

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Crop diversification has diminished in the USA during the past 50 years, and monocultures and short rotation sequences are currently the prevalent cropping systems (Brummer, 1998; Cook, 2006). Simplification of cropping systems has been accompanied by greater reliance on synthetic pesticides and fertilizers to manage weeds, diseases and soil fertility, creating concerns about contamination of underground and surface water by nitrogen, herbicides and soil sediment (Hartwig and Ammon, 2002). Learning how to reduce reliance on synthetic fertilizers and pesticides without compromising farm productivity and profitability is a key priority for Iowa and other parts of the U.S. Corn Belt (Gomez et al., 2012; Cruse et al., 2010). In this report we discuss the impacts of cropping system diversification on weed management, soybean productivity, sudden death syndrome, and root health, based on results from a long-term crop rotation study in Iowa.

Design and management of the experiment

The experiment was initiated in 2001 at the Iowa State University Marsden Farm, located in Boone County, Iowa, to compare three cropping systems: a conventional 2-year corn-soybean rotation, a 3-year corn-soybean-oat+red clover rotation, and a 4-year corn-soybean-oat+alfalfa-alfalfa rotation. The experiment was arranged as a split-plot design. Main plot size was 60’ by 285’. Each crop within each rotation sequence was grown each year, constituting nine main plots in each of the four replicate blocks. The main plots corresponding with corn and soybean were split in halves; one of two sets of management strategies, either genetically engineered (GE) or not genetically engineered (non-GE), was assigned to each subplot. For corn, the GE management strategy consisted of a genetically engineered hybrid (Agrigold 6395BtRW) plus the broadcast application of preemergence herbicides; the non-GE strategy consisted of a non-genetically engineered hybrid (Agrigold 6395) plus the application of postemergence herbicides in a 15” band over the crop row. The GE corn hybrid had genes to control both European corn borer and corn rootworms. For soybean, the GE strategy used a genetically engineered variety with resistance to the herbicide glyphosate (Kruger 287RR/SCN), plus the postemergence broadcast application of that herbicide; the non-GE strategy consisted of a non-genetically engineered hybrid (Agrigold 6395) plus the application of postemergence herbicides in a 15” band over the crop row. Banded herbicide applications in the non-GE corn and soybean plots were supplemented with interrow cultivation. Oat stubble in the 3- and 4-year rotations was mowed 28 to 35 days after grain harvest to control weeds. No explicit weed control was performed in established alfalfa plots.

Synthetic fertilizers were applied in the 2-year rotation at conventional rates based on soil tests, whereas composted cattle manure and reduced rates of synthetic fertilizers were applied in the 3-year and 4-year rotations. Manure was applied to plots of red clover and alfalfa preceding corn in the 3- and 4-year rotations at a rate of 7 tons/acre (fresh weight basis). Corn in the 2-year rotation received 100 lb N/acre at planting as urea, whereas corn in the 3- and 4-year rotations received no at-planting fertilizer. The late spring nitrate test was used for corn in each rotation system to determine treatment-specific rates for post-emergence side-dress N applications. Mean synthetic N fertilizer application rates for corn during the period of 2008-2012 were 146 lb N/acre in the 2-year rotation, and 18 lb N/acre in the 3-year and 4-year rotations.

Impacts on weeds

Weed dry matter production was determined in corn and soybean plots in 2008-2012 by clipping all weed shoot material from eight 10’ x 30’ sampling areas in each plot (25 square feet/plot), in September or early October, and then drying and weighing the samples.
As shown in Table 1, weed dry matter production in soybean was very low in all rotation systems and with both technology packages, i.e. the two varieties and their associated herbicide strategies. No significant effects of rotation system (p=0.2878) or technology package (p=0.1293) were detected. Similarly, for corn, weed dry matter production was low in all rotation systems and with both technology packages of hybrids and associated herbicide strategies, though weed biomass in corn tended to be higher than it was in soybean (Table 1). No significant effects of rotation system (p=0.1919) or technology package (p=0.1668) were detected for weeds in corn.

Table 1. Mean weed dry matter production measured in soybean and corn phases of contrasting rotation systems in 2008-2012. Standard errors are shown in parentheses. Two soybean varieties and two corn hybrids were grown in each rotation system. Soybean cultivar Kruger 287RR/SCN was treated with a broadcast application of glyphosate and was not cultivated, whereas Kruger 2918/SCN was treated with a band application lactofen, flumiclorac pentyl ester, and clethodim and was cultivated between rows. For corn, Agrigold 6395BtRW received a broadcast application of S-metolachlor and isoxaflutole and was not cultivated, whereas Agrigold 6395 received a band application of mesotrione, rimsulfuron, and nicosulfuron and was cultivated between rows.

<table>
<thead>
<tr>
<th>Rotation system</th>
<th>2-year</th>
<th>3-year</th>
<th>4-year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kruger 287RR/SCN</td>
<td>1.0 (0.2)</td>
<td>1.7 (0.5)</td>
<td>0.7 (0.3)</td>
</tr>
<tr>
<td>Kruger 2918/SCN</td>
<td>3.9 (0.6)</td>
<td>10.1 (7.6)</td>
<td>1.4 (0.5)</td>
</tr>
<tr>
<td>Agrigold 6395BtRW</td>
<td>12.8 (5.1)</td>
<td>45.4 (26.6)</td>
<td>17.3 (7.5)</td>
</tr>
<tr>
<td>Agrigold 6395</td>
<td>9.1 (3.9)</td>
<td>57.9 (34.5)</td>
<td>24.8 (8.3)</td>
</tr>
</tbody>
</table>

Statistical contrasts

| 2-yr vs. (3-yr + 4-yr)/2 | p=0.9681 | p=0.6396 | p=0.3620 | p=0.1184 |
| 3-yr vs. 4-yr | p=0.8322 | p=0.0521 | p=0.2339 | p=0.1623 |

Impacts on yield and economics

Yields of corn and soybean were determined from sample areas of about 0.1 acres, comprising 6 rows in the central area of each plot, using a combine harvester and a weigh wagon. Oat grain yields were determined in the same way from whole plots (about 0.4 acres). Yields of alfalfa hay were determined by weighing bales harvested from whole plots. After determining crop moisture concentrations, yields were adjusted to moisture levels of 15.5% for corn, 13.0% for soybean, 14% for oat grain, and 15.0% for alfalfa hay.

Soybean yields were strongly affected by rotation systems (Table 2). Depending on the variety, yields were up to 13% to 28% greater in the longer rotations than in the 2-year rotation (p<0.0001). No significant differences in soybean yields were detected between the 3-year and 4-year rotations. The GE soybean variety (Kruger 287RR/SCN) yielded more than the non-GE soybean variety (Kruger 2918/SCN) and this difference was greater in the 2-year rotation system (+17%, p<0.0001), than in the longer rotations (+4%, p=0.0176).

The impact of rotation systems differed between the two corn hybrids (Table 2). For the non-GE hybrid (Agrigold 6395), yield was 6% higher (p=0.0053) in the longer rotation systems than in the 2-year system. No significant effect of rotation system was detected for the GE hybrid (Agrigold 6395BtRW), though there was a numerical trend for higher yields in the longer rotations. No significant difference in yield was detected between the two corn hybrids (p=0.0848).

Mean oat yields during 2008-2012 were 96.6 bu/acre in the 3-year rotation, in which oat was seeded with red clover, and 102.2 bu/acre in the 4-year rotation, in which oat was seeded with alfalfa; the difference between rotation systems was significant (p=0.0032) suggesting greater competition from red clover against oat than from alfalfa.

Mean alfalfa yields during 2008-2012 in the 4-year rotation were 0.7 tons/acre during the seeding year and 4.4 tons/acre in the year following establishment.
Table 2. Mean yields of two soybean varieties and two corn hybrids in contrasting rotation systems in 2008-2012. Standard errors are shown in parentheses.

<table>
<thead>
<tr>
<th>Rotation system</th>
<th>Soybean yield bu/acre @13% moisture</th>
<th>Corn yield bu/acre @15.5% moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kruger 287RR/SCN</td>
<td>Kruger 2918/SCN</td>
</tr>
<tr>
<td>2-year</td>
<td>50.2 (1.5)</td>
<td>42.8 (2.7)</td>
</tr>
<tr>
<td>3-year</td>
<td>55.7 (1.6)</td>
<td>53.1 (1.7)</td>
</tr>
<tr>
<td>4-year</td>
<td>56.8 (1.6)</td>
<td>54.7 (1.5)</td>
</tr>
</tbody>
</table>

Statistical contrasts

- 2-yr vs. (3-yr + 4-yr)/2
  - p<0.0001
  - p<0.0001
  - p=0.1923
  - p=0.0053

- 3-yr vs. 4-yr
  - p=0.5213
  - p=0.3386
  - p=0.8049
  - p=0.9962

Labor requirements, costs, and returns for the different rotation systems were assessed using data from several sources. Labor times for machinery operations were based on values reported by Hanna (2001a) and costs for labor and machinery wear and maintenance were assigned based on data from Duffy (2008 and subsequent years). Costs for manufactured fertilizers, seeds, pesticides, interest on loans, crop insurance, and miscellaneous items were estimated using data from Duffy (2008 and subsequent years) and local agricultural dealers. We assumed manure was generated by on-farm livestock and therefore without cost for the material, but with labor and machinery costs for spreading based on data from Hanna (2001b), Edwards (2009), and Duffy (2008 and subsequent years). Iowa market year crop prices were obtained from the USDA National Agricultural Statistics Service (2008 and subsequent years), and gross revenue was calculated for each plot in each year as the product of crop price and yield.

We determined the economic performance characteristics of whole rotation systems under contrasting management strategies, as well as the economic performance of individual crop phases within the different rotations. For whole rotation systems, we evaluated net returns to land and management on a unit land area basis, with land units divided in two equal portions for corn and soybean in the 2-year rotation; three equal portions for corn, soybean, and oat with red clover in the 3-year rotation; and four equal portions for corn, soybean, oat with alfalfa, and alfalfa in the 4-year rotation. Net returns to land and management represented returns to a farm operation calculated without accounting for costs of land (e.g., rent or mortgage payments), management time (e.g., marketing), or possible federal subsidies.

For the period of 2008-2011, gross revenue for the 2-year rotation system as a whole was greater than for the 3-year and 4-year rotations (Table 3). Labor costs increased with rotation length, though they did not differ greatly among rotation systems (Table 3). In contrast, non-labor costs were substantially lower for the longer rotation systems than for the 2-year system (Table 3). Net returns to land and management were greatest for the GE and non-GE technology packages in the 3-year rotation, least for the non-GE technology package used in the 2-year rotation, and intermediate for the other rotation system x technology package combinations (Table 3). The substantial cost reduction for the 3-year rotation can be attributed to lower requirements for purchased nutrients; red clover was not harvested, whereas alfalfa was, and the application of manure did not entirely make up for the nutrient exported with the alfalfa hay.
Table 3. Mean gross revenues, non-labor production costs, labor costs, and returns to land and management for contrasting rotation systems and technology packages in 2008-2011. Subsidy payments were not included in this analysis. Data for 2012 season are being analyzed. GE: genetically engineered; non-GE: not genetically engineered.

<table>
<thead>
<tr>
<th>Rotation system, crop phase, and technology package</th>
<th>Gross revenue</th>
<th>Non-labor production costs</th>
<th>Labor cost</th>
<th>Returns to land and management</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-year rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn, GE</td>
<td>915</td>
<td>424</td>
<td>7</td>
<td>484</td>
</tr>
<tr>
<td>Corn, non-GE</td>
<td>891</td>
<td>355</td>
<td>9</td>
<td>527</td>
</tr>
<tr>
<td>Soybean, GE</td>
<td>545</td>
<td>202</td>
<td>8</td>
<td>335</td>
</tr>
<tr>
<td>Soybean, non-GE</td>
<td>442</td>
<td>203</td>
<td>11</td>
<td>228</td>
</tr>
<tr>
<td>Rotation average, GE</td>
<td>730</td>
<td>313</td>
<td>8</td>
<td>409</td>
</tr>
<tr>
<td>Rotation average, non-GE</td>
<td>666</td>
<td>279</td>
<td>10</td>
<td>377</td>
</tr>
<tr>
<td>3-year rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn, GE</td>
<td>952</td>
<td>330</td>
<td>15</td>
<td>608</td>
</tr>
<tr>
<td>Corn, non-GE</td>
<td>939</td>
<td>262</td>
<td>17</td>
<td>660</td>
</tr>
<tr>
<td>Soybean, GE</td>
<td>619</td>
<td>162</td>
<td>8</td>
<td>449</td>
</tr>
<tr>
<td>Soybean, non-GE</td>
<td>579</td>
<td>165</td>
<td>11</td>
<td>403</td>
</tr>
<tr>
<td>Oat + red clover</td>
<td>355</td>
<td>132</td>
<td>9</td>
<td>215</td>
</tr>
<tr>
<td>Rotation average, GE</td>
<td>643</td>
<td>208</td>
<td>11</td>
<td>423</td>
</tr>
<tr>
<td>Rotation average, non-GE</td>
<td>625</td>
<td>186</td>
<td>12</td>
<td>426</td>
</tr>
<tr>
<td>4-year rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn, GE</td>
<td>951</td>
<td>357</td>
<td>15</td>
<td>578</td>
</tr>
<tr>
<td>Corn, non-GE</td>
<td>945</td>
<td>290</td>
<td>17</td>
<td>638</td>
</tr>
<tr>
<td>Soybean, GE</td>
<td>636</td>
<td>190</td>
<td>8</td>
<td>438</td>
</tr>
<tr>
<td>Soybean, non-GE</td>
<td>609</td>
<td>193</td>
<td>11</td>
<td>406</td>
</tr>
<tr>
<td>Oat + alfalfa</td>
<td>443</td>
<td>242</td>
<td>15</td>
<td>186</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>515</td>
<td>157</td>
<td>21</td>
<td>336</td>
</tr>
<tr>
<td>Rotation average, GE</td>
<td>636</td>
<td>237</td>
<td>15</td>
<td>385</td>
</tr>
<tr>
<td>Rotation average, non-GE</td>
<td>628</td>
<td>221</td>
<td>16</td>
<td>391</td>
</tr>
</tbody>
</table>

Impacts on Sudden Death Syndrome

Sudden death syndrome (SDS) is one of the greatest threats to soybean production in the US (Roy et al., 1997). Management of SDS is based on the use of resistant varieties, improving soil drainage, and avoiding planting in cool, wet soils, but none of these approaches is completely effective against the disease. There is limited information about the impact of crop rotations on SDS (Rupe et al., 1997). The long term crop rotation study offered an opportunity to observe the effect of crop rotation on SDS.

Assessments of SDS disease intensity and pathogen density in soil were conducted during the period of 2010-2012. Plots were rated for SDS incidence (% plants showing symptoms) and severity (% leaf area with symptoms) in August of each year. In addition, soil samples were collected before and after planting to determine population densities of *F. virguliforme* in soil.
In 2010 there was a major outbreak of SDS in Iowa and differences in disease levels were evident among the rotation treatments. Analysis of variance on the 2010 data showed that SDS incidence and severity were greater (P<0.0001) in the 2-year rotation than the 3- and 4-year rotations, but there were no differences between the 3- and 4-year rotations. Similar effects of crop rotation were observed for SDS severity in 2011 (P=0.03) and 2012 (P=0.007), and for incidence in 2012 (P=0.004), even though environmental conditions were not favorable for SDS during these years. When averaged for the period of 2010-2012, mean SDS incidence and severity were greater (P < 0.0015) in the 2-year rotation than the 3- and 4-year rotations for the non-GE variety (Fig. 1); similar numerical trends were observed for the GE variety (Fig. 1), but differences were not significant (P>0.05). There were no significant differences (P>0.05) in SDS between the 3- and 4-year rotations.

Data for 2011 and 2012 showed a general trend for lower \textit{F. virguliforme} population density in the longer rotations compared to the 2-year (Fig. 2), but there were no significant differences (P> 0.05) among rotations. A possible reason for the lack of statistical significance is the patchy distribution of the fungus in field soil; this can result in a dilution of the pathogen density in the soil samples taken to represent the entire field plot. Although the correlation between \textit{F. virguliforme} density in soil and disease is not very strong, data from 2010 and 2011 suggest that the longer rotations may be less favorable for pathogen buildup in soil than the corn-soybean rotation.

![Figure 1. Mean incidence and severity of sudden death syndrome for the period of 2010-2012.](image1)

![Figure 2. Population density of the SDS pathogen, \textit{Fusarium virguliforme}, in soil in 2010 and 2011.](image2)
Impacts on root health

Root rot and root growth were assessed at the R6 growth stage. Root ratings were conducted on whole roots of ten plants sampled per plot. Roots were washed in running tap water and rated for root rot severity (% root area showing discoloration), root vigor (1 - 5 scale, 1=poor vigor and 5 =high vigor), and root dry weight (g). A comparison of root fungal communities in the different rotation treatments was conducted in 2012. For this purpose, 10 root pieces from each of the 10 plants sampled per plot were plated on PDA; the total number of fungal isolates was counted and the main fungal genera were identified.

In 2010 and 2011, soybean plants in the 2-year rotation plots had more severe root rot, lower vigor and smaller root dry weight (P<0.05) than plants in the longer rotations. In 2012, root dry weight was lower (P<0.05) in the 2-year rotation compared to the 3- and 4-year rotations for the non-GE variety, but there were no differences for the GE variety. Combined analysis for the period of 2010 to 2012 showed that root rot severity was higher, and root vigor and root dry weight were lower (P<0.05) in the 2-year rotation than in the two longer rotations (Table 4). This data suggests that the corn-soybean rotation is less favorable to root development and more favorable to root rot than the longer rotations.

Table 4. Root dry weight, root vigor, and root rot severity at R6 stage, and results from the analysis of variance conducted for the period of 2010-2012.

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Root rot severity (%)</th>
<th>Root Vigor (1-5 scale)</th>
<th>Root dry weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GE</td>
<td>Non-GE</td>
<td>GE</td>
</tr>
<tr>
<td>2 year</td>
<td>39.05</td>
<td>40.70</td>
<td>3.45</td>
</tr>
<tr>
<td>3 year</td>
<td>25.76</td>
<td>26.55</td>
<td>3.71</td>
</tr>
<tr>
<td>4 year</td>
<td>21.62</td>
<td>25.30</td>
<td>3.89</td>
</tr>
<tr>
<td>SEM</td>
<td>7.03</td>
<td>7.03</td>
<td>0.16</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>P</th>
<th>Rotation</th>
<th>0.024</th>
<th>0.004</th>
<th>ns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>ns</td>
<td></td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>Rotation x Variety</td>
<td>ns</td>
<td></td>
<td></td>
<td></td>
<td>ns</td>
</tr>
<tr>
<td>S2 vs. (S3 + S4)/2</td>
<td>0.009</td>
<td>0.002</td>
<td>0.047</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S3 vs. S4</td>
<td>ns</td>
<td></td>
<td></td>
<td></td>
<td>ns</td>
</tr>
</tbody>
</table>

Root isolation data from 2012 suggests that the corn-soybean rotation is more favorable for root infection than the longer rotations. On roots sampled at R6 stages, *F. virguliforme* was isolated more frequently from roots in the 2-year rotation, compared to roots from the longer rotations (Fig. 3). This finding is consistent with the greater disease severity and incidence observed in the 2-year rotations. In addition, the frequency of isolation of *Trichoderma* and *Gliocladium* also tended to be greater in the 2-year rotations, but isolations of other *Fusarium* species were similar among rotation treatments. This greater frequency of isolation of fungi from the 2-year rotation plots shows that crop rotations have an impact on fungal communities infecting roots.
Figure 3. Mean number of colonies of different fungal genera isolated from soybean roots grown in 2-year (S2), 3-year (S3) and 4-year (S4) rotations, for the genetically modified (GE) and non-genetically modified (non-GE) varieties in 2012.

References
Gomez, R., Liebman, M., Sundberg, D. N., Chase, C. A. 2012. Comparison of crop management strategies involving crop genotype and weed management practices in conventional and low-external-input cropping systems. Renewable Agriculture and Food Systems, FirstView Article, pp 1-14 DOI: http://dx.doi.org/10.1017/S1742170512000142

**Probability of return on investment with using soybean seed treatments**


With soybean commodity prices at record high prices, the number of questions regarding key management considerations also remains high. One of the question that we often receive regards the use of seed treatments, in particular the use of seed treatment fungicides and/or insecticides. Since 2008, we have conducted trials throughout Wisconsin to examine if seed treatments are economically viable for soybean production. In particular, we are most interested in trying to answer the following question: “what is the probability that if I use a seed treatment, the cost of the application is covered?”

Our research trials have been conducted under what we call generation one (2008-2010) and generation two (starting in 2011). The first generation trials were conducted at nine locations each year, for a total of 27 location-years. Results from these trials were recently published in the journal Crop Science (Esker, P.D., and Conley, S.P. 2012. Probability of yield response and breaking even for soybean seed treatments. Crop Science 52:351-359) and have also been discussed during the past several winter extension meeting seasons. In this article, we will focus on summarizing those results in some detail.

In our generation one trials, two seed treatments and an untreated control were examined. They were: ApronMaxx RFC (fludioxonil + mefenoxam) and CruiserMaxx (fludioxonil + mefenoxam + thiamethoxam) (Syngenta Crop Protection, Inc., Greensboro, NC). There were four soybean varieties per location per year and the varieties did differ over years, although within a year, the same varieties were examined at all locations.

In addition to examining the effect of seed treatment and variety on yield, we were very interested in quantifying the probability of breaking even. To do this, we examined different components of cost and expected return. For example, the two seed treatments differ in the cost per unit ($4 for ApronMaxx RFC and $10 for CruiserMaxx, respectively). Also, the observed yield across trial years ranged from 35 to 85 bushels per acre so it was important to examine what we might term are “low” (40 bushels per acre), “medium” (60 bushels per acre), and “high” (80 bushels per acre) yield potential environments. Lastly, it was important to examine these responses across a variety of soybean commodity prices and we started by examining $6, $9, and $12 per bushel soybean. Using the different cost-price structures, we quantified the probability of breaking even based on the percentage increase or decrease in yield with the use of a seed treatment compared to the untreated control.

Results from the generation one trials suggest that the decision to use a fungicide and/or insecticide seed treatment is not a simple yes/no answer. Across the 27 location-years where we tested these products, the relative yield ranged from -6.4 to +11.6% across environments. The relative yield ranged from -3.2 to +7.7% across the seven varieties that were also examined over the course of the study.

Specifically examining the two seed treatments indicated that the probability of at least a break-even response to the seed treatment was driven by both cost of seed treatment and yield environment (Table 1). For example, at $6 per bushel soybean and a 40 bushel per acre yield environment, the probability that the use of a seed treatment covered the cost of the application was 42% for ApronMaxx and 3% from CruiserMaxx. As both yield potential and soybean commodity price increased, the probability of covering cost also increased to well over 50%. How does this translate back to yield though? Across the different relative yield ratios and cost-price structures, the actual increase in yield ranged from 0.6 bushels per acre to 2.3 bushels per acre. Our original analyses that did not factor the cost-price structures but just focused on yield response were very similar with what we found factoring in the cost-price structures.
Table 1. Probability of breaking even with the use of either seed treatment fungicides (ApronMaxx) seed treatment fungicides and insecticide (CruiserMaxx) across different environments and soybean varieties.

<table>
<thead>
<tr>
<th>Product</th>
<th>Grain sale price=$6/bu</th>
<th>Grain sale price=$9/bu</th>
<th>Grain sale price=$12/bu</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AY = 40</td>
<td>AY = 60</td>
<td>AY = 80</td>
</tr>
<tr>
<td></td>
<td>bu per acre</td>
<td>bu per acre</td>
<td>bu per acre</td>
</tr>
<tr>
<td>ApronMaxx</td>
<td>1.5 *</td>
<td>42 c</td>
<td>72</td>
</tr>
<tr>
<td>CruiserMaxx</td>
<td>2.9 *</td>
<td>3</td>
<td>56</td>
</tr>
</tbody>
</table>

a Relative ratio (RR) is the percentage gain or loss in terms of yield with a seed treatment compared to the untreated control. The * indicates a relative ratio that was significantly different from 0 at a level of 0.05.

b Actual yield (AY) is the observed yield based on these trials, standardized to a “low” (40 bu/ac), “medium” (60 bu/ac), and “high” (80 bu/ac) yield potential environment.

c The value in each cell is the probability (as a percentage) that the use of a seed treatment covered the cost of the product across all trial conditions.

How can such information be used? Our experience has been that when spring conditions are cool and wet and when planting date is in late April to early May, the use of seed treatment fungicides are an effective tool, especially given the current value of seed. Additionally, the probabilities we quantified in our generation one trial provide a framework for the grower to improve their understanding of how often they might expect a response over time thus enabling questions such as: (1) holding my seeding rate constant, what does the additional cost per unit for seed that is treated require in terms of yield to maximize the return on investment, and (2) given the increase in cost per unit for seed, can I consider reducing my seeding rate without affecting yield? Lastly growers can use this table to impose their own level of risk to determine the value of a seed a treatment to their own operation.

Acknowledgements

We thank the Wisconsin Soybean Marketing Board for partial funding support for these studies.
Managing rotten corn: An overview of corn ear rots
Kiersten Wise, associate professor and Extension plant pathologist, Botany and Plant Pathology, Purdue University

Ear rots of corn can reduce yield and grain quality. Several economically important ear rots impact the Corn Belt, including Diplodia ear rot, Gibberella ear rot, Fusarium ear rot, and Aspergillus ear rot. A different fungus causes each of these rots, and the environmental conditions at and just after silking influence which ear rot may be problematic in a given year. Additionally, some of these fungi are able to produce mycotoxins as a byproduct of the infection process. Mycotoxins can be toxic to humans and livestock, and are carefully regulated in food and feed. Proper identification of ear rots is key for managing affected grain.

Aspergillus ear rot
Aspergillus ear rot is caused by the fungus Aspergillus flavus, and is one of the most concerning ear rots due to its associated mycotoxin, aflatoxin. This fungus infects during hot, dry weather after pollination occurs. Drought stressed areas are most affected by the disease. Aspergillus ear rot is typically identified by an olive green, dusty mold that is often at the tip of the ear, but can be scattered on kernels throughout the ear. Symptoms usually appear first in fields with dry soils or other issues, such as nutrient deficiencies, or insect damage. The mycotoxin aflatoxin is a potent carcinogen, and is regulated in feed and silage. Table 1 specifies the U.S. Food and Drug Administration (FDA) action thresholds for various end uses of grain. Aflatoxins are of concern to dairy producers in particular because the FDA regulations require aflatoxin residues in milk to be less than 0.5 ppb. To prevent the carry over of aflatoxins into milk, silage and other feed components should not contain greater than 20 parts per billion (ppb) aflatoxin.

Table 1. U.S. FDA action levels for aflatoxin contaminated corn. Source: FDA Regulatory Guidance for Toxins and Contaminants. www.ngfa.org/files/misc/Guidance_for_Toxins

<table>
<thead>
<tr>
<th>Aflatoxin action level (parts per billion)</th>
<th>End use of grain</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Corn for animal feed and feed ingredients for dairy animals</td>
</tr>
<tr>
<td>20</td>
<td>Corn for human consumption</td>
</tr>
<tr>
<td>100</td>
<td>Corn grain for breeding cattle, swine and mature poultry</td>
</tr>
<tr>
<td>200</td>
<td>Corn grain intended for finishing swine of 100 lbs or greater</td>
</tr>
<tr>
<td>300</td>
<td>Corn grain intended for finishing beef cattle</td>
</tr>
</tbody>
</table>

Diplodia ear rot
Diplodia ear rot is caused by the fungus Stenocarpella maydis, and is very common in cornfields across the Corn Belt. This fungus survives in residue and infects plants approximately two weeks after pollination. Humid weather and rains prior to and after pollination will favor disease development. Diplodia ear rot is identified by white fungal growth on the cob, often forming a mat of fungus across the ear. Infected kernels may also be brown-gray in appearance. Small, black fungal structures called pycnidia may form on the kernels or the cob. The fungus is reported to produce a mycotoxin called diplodiatoxin in South America and South Africa, however, no reports of toxic effects of grain on livestock or humans due to Diplodia ear rot have been reported in the United States. Grain dockage may still occur, however, due to moldy grain.
Fusarium ear rot
Fusarium ear rot is primarily caused by the fungus *Fusarium verticillioides*. This fungus infects corn after pollination, and often overlaps with Aspergillus ear rot since infection is favored by warmer temperatures. Fusarium-infected ears may have white fungal growth on the cob, or symptoms may appear as discolored kernels scattered throughout a cob or associated with insect feeding. Visible fungal growth may not be obvious on the cob, but a white “starburst” pattern in kernels can sometimes be observed on ears infected by this fungus. The mycotoxin fumonisin is associated with Fusarium ear rot.


<table>
<thead>
<tr>
<th>Animal</th>
<th>Maximum fumonisin levels allowed in grain or grain by-products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equids and Rabbits</td>
<td>5 ppm (not to exceed 20 percent of ration with finished feed = 1 ppm)</td>
</tr>
<tr>
<td>Swine and Catfish</td>
<td>20 ppm (not to exceed 50 percent of diet with finished feed = 10 ppm)</td>
</tr>
<tr>
<td>Breeding ruminants, breeding poultry</td>
<td>30 ppm (not to exceed 50 percent of diet with finished feed = 15 ppm)</td>
</tr>
<tr>
<td>Ruminants 3 months or older being raised for slaughter</td>
<td>60 ppm (not to exceed 50 percent of diet with finished feed = 30 ppm)</td>
</tr>
<tr>
<td>Poultry being raised for slaughter</td>
<td>100 ppm (not to exceed 50 percent of diet with finished feed = 50 ppm)</td>
</tr>
<tr>
<td>All other species or classes of livestock and pet animals</td>
<td>10 ppm (not to exceed 50 percent of ration with finished feed = 5 ppm)</td>
</tr>
</tbody>
</table>

Gibberella ear rot
Gibberella ear rot, caused by the fungus *Gibberella zeae*, is common during cool, rainy years. The fungus infects during early silking and pollination, and is favored by cooler temperatures than the previously described ear rots. This fungus produces a fungal mat on the ear, similar to Diplodia ear rot, but often with a pink or reddish color to the mold. *Gibberella zeae* produces the mycotoxin deoxynivalenol (DON), commonly referred to as vomitoxin. This mycotoxin can be extremely harmful to swine, and is carefully regulated according to the FDA action levels defined in Table 3.


<table>
<thead>
<tr>
<th>Animal</th>
<th>Maximum DON Level Allowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swine</td>
<td>5 ppm (not to exceed 20 percent of ration with finished feed = 1 ppm)</td>
</tr>
<tr>
<td>Ruminating beef and feedlot cattle (more than 4 months old)</td>
<td>10 ppm (not to exceed 50 percent of diet with finished feed = 5 ppm)</td>
</tr>
<tr>
<td>Poultry</td>
<td>10 ppm (not to exceed 50 percent of diet with finished feed = 5 ppm)</td>
</tr>
<tr>
<td>All other animals</td>
<td>5 ppm (not to exceed 40 percent of diet)</td>
</tr>
</tbody>
</table>
Mycotoxins

Mycotoxins are a byproduct of fungal infection, and are not living organisms themselves. Often farmers or crop advisors incorrectly believe that they can kill or remove mycotoxins from grain, which is not the case. Mycotoxins are extremely stable in grain and plants, and heat, freezing, and chemicals will not degrade these compounds. Mycotoxins are at higher levels in fines and foreign material in grain and it is possible to screen or clean grain to remove these smaller particles containing mycotoxins. Coring bins can also help reduce mycotoxins if affected grain accumulates in this area. None of these practices remove mycotoxins directly from grain, but remove grain affected by mycotoxins.

Testing for mycotoxins

Sample collection and preparation are extremely important to get an accurate test for mycotoxins in silage or grain. A sample submitted for analysis should be made up of several samples combined and taken from different areas within the silage mass or grain. Sampling several different times from a moving stream of grain while the grain is loaded or unloaded is the preferred method for sample collection. The USDA Grain Inspection Handbook has specific recommendations and methods for sampling to ensure that the sample to be tested represents the grain population accurately. This handbook can be found at www.gipsa.usda.gov/GIPSA/.

Mycotoxin production in silage represents a particular challenge. Mycotoxins will occur in the area of silage exposed to air, so samples from moldy silage should also be submitted for analysis. If sampling moldy silage for analysis, it is important to take a separate sample from an area that is not moldy and submit that also. Care should be taken with handling samples to assure that mycotoxins do not accumulate in the sample during shipping. Drying the sample below 15% moisture will slow fungal growth and mycotoxin production. Freezing the sample and shipping on ice by a one-day delivery service is another option. It is important to test silage for mycotoxins, such as aflatoxin, since chemicals such as nitrates can cause similar animal symptoms to those caused by mycotoxins.

Mycotoxins can be assessed by using several different chemical and immunocapture technologies, but analyzing mycotoxins can be a challenge due their complex nature. It is important to not rely solely on visual methods, such as the blacklight test, for confirmation of mycotoxins. Visual test results can be inconsistent, and therefore samples should be sent to professional laboratories for analysis.

Ear rot management

Preventative management of ear rots is critical, and can be accomplished by selecting less susceptible hybrids and reducing the amount of corn residue that can serve as a source for the fungus to overwinter. This is accomplished through crop rotation and tillage. In-season management of ear rots is limited at this point, with few fungicides and anti-fungal products available for specific ear rots. Efficacy data for these fungicides are limited.

If conditions in-season are favorable for ear rot development, farmers should scout fields prior to harvest and determine the level of incidence of any ear rot in the field. If ear rots are observed in a field, affected areas should be harvested early and grain segregated to avoid mycotoxin contamination of non-infected grain. Silage and grain harvested with suspected ear rots should be dried to below 15% moisture. If grain or silage (with kernels present) is kept above this moisture content, mycotoxin can continue to accumulate in grain. All grain contaminated by any ear rot fungus should be stored separately from good grain, and if stored long term, stored below 13% moisture to prevent further growth of fungi.

References

Excerpts from this article from: Kuldau, G.A., and Woloshuk, C.P. Screening for Mycotoxins in Silage.
Research update on seedling diseases of corn and soybean caused by oomycete pathogens

Alison Robertson, Azeem Ahmad, Rashelle Matthiesen-Andersen, James Peitzman, Erika Salaau-Rojas and Stith Wiggs, Plant Pathology and Microbiology, Iowa State University; Martin Chilvers, Janette Jacobs and Alejandro Rojas, Plant, Soil and Microbial Sciences, Michigan State University.

Uniform emergence and development of corn and soybean seedlings is key to maximize farmer profitability. In corn, poor stand and plant-to-plant variability lower yield potential as smaller plants compete with their larger neighbors for resources. With the dramatic increase in soybean seed costs within the past decade, farmers now plant fewer seeds per acre and thus depend on improved emergence and better stand establishment to achieve an even stand and maximize yield potential.

Uneven plant emergence and poor stands can occur as a result of many factors, including seedling disease. In 2005, an estimated 829 thousand tonnes of soybean were lost in the U.S. due to seedling disease, excluding losses due to P. sojae (Wrather and Koenning, 2006). In a recent survey (March 2012) of certified crop advisors (CCA) in the Midwest and southeastern U.S., 77 percent of CCAs indicated they had encountered soybean stand establishment problems on 15% of the acreage they had scouted over the past five years and 20 percent of the problems were attributed to seedling diseases and/or seed rot.

Seedling disease of corn and soybean can be caused by fungal pathogens, e.g., Fusarium spp. and Rhizoctonia solani, and oomycete pathogens, e.g., Pythium spp. and Phytophthora sojae (soybean only). These pathogens each require different environmental conditions to infect and cause disease. Flooded conditions favor seedling diseases caused by oomycetes since this group of organisms produces swimming spores, known as zoospores that swim in free water and infect germinating seedlings. Moreover, infection by one species can predispose seedlings to infection by other species.

Even though seedling diseases are among the most widely distributed diseases of corn and soybean, our knowledge of the complex of pathogens that infect these crops, and the environmental conditions that favor disease development is very limited. Almost 20 years ago, Rizvi and Yang (1996) reported six Pythium spp., Phytophthora sojae and Rhizoctonia solani, as the major casual organisms associated with soybean seedling disease in Iowa. More recently, similar seedling disease surveys in Ohio recovered 22 species of Pythium from diseased corn and soybean seedlings (Broders et al., 2007, Broders et al., 2008). Some species are highly pathogenic on both crops, while other species may be more aggressive on soybean than corn and vice versa.

Sensitivity to seed treatment fungicides can also vary across and within Pythium spp. Broders et al (2007) evaluated the sensitivity of 13 Pythium spp. to four seed treatment fungicides and found no fungicide provided control for all 13 species.

Regional assessment of seedling disease of soybean

Currently we are collaborating with other soybean pathologists in the north central region on two projects on soybean seedling disease that are being funded by USDA-NIFA (2011-2014) and the United Soybean Board (USB) (2012-2014). An extensive survey of pathogens associated with soybean seedling disease in the region is being completed.

Data collected from the first two years of the seedling disease survey has provided baseline information on oomycete pathogens affecting soybean in the north central region. In 2011, 19 species of Pythium were recovered from diseased soybean seedlings in Iowa (Robertson, 2012), and a similar number of species is expected in 2012. This included five of the six species that had previously been reported by Rizvi and Yang (2006) but also several species that have not previously been reported as pathogens of soybean In Iowa, and at least two species not reported in Ohio by Broders et al. (2007). Across the north central region, 54 species of Pythium were associated with diseased soybean seedlings in 2011 (Rojas et al., 2012).

The portfolio of Pythium spp. recovered in each year of the survey varied, which is perhaps not surprising since the
2011 planting season was characterized by cool, wet conditions across much of the region, while 2012 was warm and dry. Across the north central region it was found that soil temperature, precipitation and soil texture influenced the species composition between states and regions (Rojas et al., 2012).

Statewide evaluation of commercial seed treatments for soybean in 2011

The use of seed treatments on soybeans has increased considerably over the past few years. Seed treatments protect seed from seedling diseases, caused by *Pythium*, *Phytophthora*, *Fusarium* and *Rhizoctonia*, and insect pests such as the bean leaf beetle. Although a seed treatment may help ensure uniform emergence and optimum stands, such benefits do not always result in greater yields.

In Iowa, the benefits of a seed treatment on soybean have not been well studied. Over the past two growing seasons we have evaluated the effect of commercially available fungicide and insecticide seed treatments on seedling disease, insect pests, and yield of soybean. In both 2011 and 2012, the study was done at three locations in Iowa: ISU Northeast Research and Demonstration Farm (NERF), Nashua, Ames (central), ISU Southeast Research and Demonstration Farm (SERF) near Crawfordsville and a farmer's field in Nevada (two planting dates). In 2012, an additional location at the ISU Field Extension and Education Laboratory (FEEL) near Boone was also planted. The following data were collected: Stand counts at 14 and 21 days after planting (dap), seedling disease at 28 dap, seedling disease incidence, foliar and stem disease severity, Bean leaf beetle and aphid population counts, and yield.

In 2011, we planted into excellent seedbed conditions. No seedling disease or insect damage occurred at any location. There were no differences in stand counts at either 14 dap or 28 dap in three of the four trials. At the first Nevada planted field, stand counts at 14 dap for the CruiserMaxx and CrusierMaxx Plus treatments were statistically greater than the control (untreated seed). At 28 dap, stand counts for the Trilex 6000 +Heads up treatment were statistically greater than the control.

At Crawfordsville, soybean seedlings from seed treated with CruiserMaxx were more vigorous (taller) (P<0.1) than untreated control. At the early planting date at Nevada, seedling vigor of the AgriGardian Micro Mix and Foliar blend treatment was lower than the untreated control (P<0.1). For all other treatments, seedling vigor did not differ. There was no evidence of an effect of seed treatment on seedling vigor at Nashua or the later planting date at Nevada.

Weather conditions during grain fill were not favorable for foliar disease development. At Nashua, there was some *Cercospora* leaf blight, and an application of Headline+Leverage at R3, reduced disease severity (P<0.001). Sudden death syndrome occurred in the trial at Crawfordsville but at very low incidence and no treatment effects were evident.

Soybean aphids were not present at any of the locations at R1, while at Nevada and Crawfordsville populations were extremely low (<10 aphids per plant) later in the growing season. At Nashua, the mean number of aphids per plant at growth stage R4.5 ranged from 41 to 63 in the treatments, well below threshold levels.

Yield varied across locations ranging from 51.1 to 63.3 bu/ac in the untreated control (Table 1). There was evidence of an effect of seed treatment on yield at all locations (P<0.1). At Crawfordsville, the yield of soybean treated with CruiserMaxx was greater than the untreated control (71.6 bu/A versus 63.3 bu/A). In the early planting date trial at Nevada, the CruiserMaxx (58.1 bu/A), CruiserMaxx Plus (58.1 bu/A), “Pioneer premium” (56.8 bu/A) and AgriGardian (56.5 bu/A) foliar blend treatments all yielded higher than the untreated control (51.3 bu/A). Yield of soybean treated with Trilex 6000 plus HeadsUp was greater than that of the untreated control in the later planting date trial at Nevada (54.5 bu/A versus 51.1 bu/A). Lastly, at Nashua, the Trilex 6000 plus HeadsUp (64.3 bu/A) and “Pioneer Premium” (64.3 bu/A) treatments yielded higher than the untreated control (57.9 bu/A).

At the ISU FEEL, we planted twelve demonstration plots on April 15, just as two weeks of very wet, cold weather conditions started. Six of the plots were inoculated with *Pythium* spp., and six with the SDS pathogen, *Fusarium virguliforme*. Untreated seed was planted in one plot inoculated with each pathogen; the remaining five plots inoculated with each pathogen were each planted with soybean seed treated with a commercial seed treatment. Stand count was assessed 21 dap and 28 dap. At 21 dap, three seedlings had emerged across the 12 plots; at 28 dap, 41 percent of the non-treated seeds had emerged in each plot compared to 78 to 84 percent of the treated seeds in the remaining 10 plots. The benefits of seed treatments on soybeans have been well documented when planting conditions are not optimal, specifically if conditions at planting or soon after planting are cold and wet, and the plots at FEEL clearly bore this out.
Table 1. Seed treatment products tested in soybean seed treatment trials at three locations in Iowa in 2011 and mean yield (bu/A) of each treatment

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Crawfordsville</th>
<th>Nevada early</th>
<th>Nevada late</th>
<th>Nashua</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>63.3</td>
<td>51.3</td>
<td>51.1</td>
<td>57.9</td>
</tr>
<tr>
<td>Untreated *</td>
<td>72.7</td>
<td>52.5</td>
<td>47.1</td>
<td>64.7</td>
</tr>
<tr>
<td>Trilex 6000</td>
<td>61.0</td>
<td>56.1</td>
<td>53.6</td>
<td>60.8</td>
</tr>
<tr>
<td>Trilex 6000 *</td>
<td>64.3</td>
<td>59.3**</td>
<td>49.0</td>
<td>66.3</td>
</tr>
<tr>
<td>Inovate System</td>
<td>62.8</td>
<td>56.1</td>
<td>47.2</td>
<td>60.4</td>
</tr>
<tr>
<td>Inovate and Metastar</td>
<td>62.2</td>
<td>51.5</td>
<td>50.1</td>
<td>55.6</td>
</tr>
<tr>
<td>Inovate and Metastar *</td>
<td>61.9</td>
<td>58.7**</td>
<td>48.0</td>
<td>70.7**</td>
</tr>
<tr>
<td>AgriGardian foliar blend b</td>
<td>-</td>
<td>55.2</td>
<td></td>
<td>49.4</td>
</tr>
<tr>
<td>AgriGardian foliar blend c</td>
<td>-</td>
<td>56.5*</td>
<td>52.4</td>
<td>-</td>
</tr>
<tr>
<td>CruiserMaxx</td>
<td>62.3</td>
<td>58.1*</td>
<td>50.0</td>
<td>60.4</td>
</tr>
<tr>
<td>CruiserMaxx Plus</td>
<td>71.6*</td>
<td>58.1*</td>
<td>49.1</td>
<td>60.5</td>
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<tr>
<td>CruiserMaxx Plus *</td>
<td>63.6</td>
<td>50.4</td>
<td>51.2</td>
<td>67.1</td>
</tr>
<tr>
<td>“Pioneer Premium”</td>
<td>62.9</td>
<td>56.8*</td>
<td>50.7</td>
<td>63.9*</td>
</tr>
<tr>
<td>Trilex 6000 and Heads up</td>
<td>60.6</td>
<td>52.3</td>
<td>54.5*</td>
<td>64.3*</td>
</tr>
<tr>
<td>Trilex 6000 and L1940-A</td>
<td>64.2</td>
<td>52.7</td>
<td>49.8</td>
<td>62.3</td>
</tr>
<tr>
<td>Acceleron fungicide</td>
<td>62.5</td>
<td>55.4</td>
<td>48.8</td>
<td>62.1</td>
</tr>
<tr>
<td>Poncho / VOTIVO</td>
<td>63.6</td>
<td>55.8</td>
<td>52.1</td>
<td>60.1</td>
</tr>
<tr>
<td>Acceleron Fungicide and Insecticide</td>
<td>62.8</td>
<td>53.9</td>
<td>51.8</td>
<td>58.5</td>
</tr>
<tr>
<td>AgriGardian Micro Mix d</td>
<td>-</td>
<td>50.5</td>
<td>47.9</td>
<td>-</td>
</tr>
<tr>
<td>AgriGardian Micro Mix and Foliar blend</td>
<td>-</td>
<td>51.0</td>
<td>47.5</td>
<td>-</td>
</tr>
<tr>
<td>LSD (0.1)</td>
<td>6.0</td>
<td>4.9</td>
<td>3.3</td>
<td>5.8</td>
</tr>
</tbody>
</table>

* Sprayed with Leverage and Headline at R3
b AgriGardian foliar blend infurrow 16 oz/ac followed by two 16 oz/ac foliar sprays with Roundup
c AgriGardian foliar blend infurrow 8 oz/ac followed by two 8 oz/ac foliar sprays with Roundup
d AgriGardian Micro Mix infurrow 6.4 oz/ac followed by 6.4 oz/ac foliar spray with Roundup
e AgriGardian Micro Mix infurrow 6.4 oz/ac followed by two 6.4 oz/ac Micro Mix and 16 oz/ac Foliar blend tank mix with Roundup

* Indicates significantly different from untreated control with no application of Leverage and Headline at R3
** Indicates significantly different from untreated control with an application of Leverage and Headline at R3

Seedling blight of corn in southeastern Iowa

In 2012, several thousand acres of corn in southern Iowa were replanted in late May because of poor stands caused by seedling disease. Emergence issues due to seedling disease have been prevalent in the southern part of the state for the past few years. In 2011, farmers in Lee County replanted twice because of stand loss due to disease.

The seedling disease issues that have occurred in southern Iowa are often associated with a period of several days of cold (<55F), wet soils that occur soon after planting. These types of conditions favor *Pythium* spp. In 2012, between April 28 and May 8, two to six inches of rain fell across southern Iowa and soil temperatures dropped below 55F for four to five days. Seedling disease issues were most prevalent in fields planted just prior to the cool, wet weather.

Seedling disease risk can be reduced with fungicide seed treatments. Mefenoxam/metalaxyl (e.g., Apron®, Allegiance®) have traditionally been used to manage seedling disease caused by *Pythium* spp. More recently strobilurins, e.g., Trilex®, Dynasty®, also have been used, although they are not as effective. Reduced sensitivity of *Pythium* spp. to...
mefenoxam and some strobilurin fungicides was reported from Ohio (Broders et al., 2008). Although all corn seed is treated with fungicides, growers in southeastern Iowa have been applying additional metalaxyl/mefenoxam to corn seed before planting in an effort to reduce Pythium seedling blight. This practice has had limited success.

In May 2012, we visited 28 cornfields in which emergence was affected due to seedling disease in southern and southeastern Iowa and collected diseased corn seedlings. We identified the Pythium spp. associated with symptomatic seedlings and assessed the isolates we collected for sensitivity to several fungicides used in commercial seed treatments and two additional fungicides.

Nine Pythium spp. were recovered from seedlings collected from 19 of the 30 fields sampled. Over 80 percent of the isolates collected were identified as P. torulosum, a species that is favored by cold, wet conditions. Data from fungicide sensitivity assays in vitro will be presented at the conference.

References


Corn and soybean diseases 2012: A drought year in review

Daren S. Mueller, assistant professor, Plant Pathology and Microbiology, Iowa State University; Alison Robertson, associate professor, Plant Pathology and Microbiology, Iowa State University

Introduction

Disease development is dependent on three factors: the presence of a suitable host, a source of disease-causing inoculum, and favorable weather conditions so that the disease can develop. Together, these factors are called the plant-disease triangle, and all three “corners” of the triangle are required for disease to become a problem in corn and soybean. If any of the factors are missing or inadequate, disease has trouble becoming established. As anyone who raised crops in 2012 was aware, there was a definite shortage of water for many parts of Iowa and elsewhere, coupled with very hot weather. This weather produced an environment that was not only not conducive to crop growth, but also detrimental to disease development. Moisture plays a large part in the ability of a disease-causing agent to infect and grow.

However, despite the disease (and yield)-suppressing weather, there were disease issues in Iowa in 2012. Some diseases, such as soybean cyst nematode and charcoal rot, can actually injure crops more during hot and dry seasons. Soybean vein necrosis, a new disease in Iowa, was also reported. The most prevalent concern in corn was aflatoxin contamination associated with Aspergillus ear rot. An outbreak of Southern rust in central Iowa required that some farmer’s spray a fungicide.

Early season

Frogeye leaf spot, Cercospora leaf blight, and brown spot were reported on seedlings. A few very early planted fields in northern Iowa were reported to have damping off. A dry harvest in 2011 may have contributed to lower seed quality than normal in 2012, which predisposes plants to infection by disease.

Several reports of losses in corn stand due to seedling disease were reported from eastern and southeastern Iowa. Most of the seedling disease issues that were reported were from fields that were planted April 23 to 27, just before we had a period of cold wet conditions and soil temperatures dipped back down below 50 F. Samples received by the Iowa State University Plant Disease and Insect Clinic and Robertson Lab were plated. At that point in the season, the pathogen causing seedling disease appeared to be *Pythium* spp. Further discussion of the seedling blight epidemic can be found in “Research update on seedling diseases of corn and soybean caused by oomycete pathogens” in this proceedings.

There are numerous species of *Pythium* that can affect corn, and many of these species also cause disease on soybean. Research from Ohio State University found a significant variation in sensitivity to commonly used seed treatment fungicides within and amongst species. Thus, a seed treatment might provide adequate protection against seedling disease in one field, but may not be sufficient in another field.

Mid-season

Near the end of June, many farmers and agronomists across Iowa were starting to ask if or when to apply fungicide on soybeans. With the price of soybean and fields being sprayed for spider mites or Japanese beetles, questions around “throwing in a fungicide” have been coming in. Like the past few years, there have been very little early season foliar problems. By the end of June, brown spot was really the only foliar disease still being reported, although soybeans usually grow out of any early season brown spot infection. There were also a few fields with Cercospora leaf blight.

Southern rust was reported in several fields in Butler and Grundy counties near the beginning of July. Leaf samples were received by the ISU Plant Disease and Insect Clinic, and confirmations were made. Because common rust was widespread in cornfields in Iowa, it was important for farmers and agronomists to correctly distinguish between
these two rusts, especially if a fungicide decision was to be made. Southern rust can develop rapidly under favorable conditions and foliar fungicides are often required to protect yield. The earlier during the grain fill period that southern rust occurs, the greater the impact it can have on yield. Although we see southern rust in Iowa in most growing seasons, it is usually only reported in mid- to late August as the crop nears maturity. This outbreak of southern rust in central Iowa was unusually early, grain fill had just started, and therefore, the outbreak was of concern. Furthermore, weather conditions in central Iowa near mid-July were very conducive to disease development. Several farmers in this area applied fungicide to manage the disease outbreak.

Goss's leaf blight symptoms were observed in our foliar product efficacy trials in southwest Iowa and central Iowa. And Goss's leaf blight on drought-stressed corn was reported in northeast Iowa. The ISU Plant and Insect Diagnostic Clinic also received several leaf samples with Goss's leaf blight. All reports of Goss's wilt occurred on fields with a history of the disease in 2011 that had been planted to a Goss's-susceptible hybrid in 2012.

**Late season**

Near the end of August, yellow patches were observed developing in soybean fields across Iowa. These patches were caused by several different things, including spider mites and soybean cyst nematode. However, there were three additional problems that were causing these patches: sudden death syndrome, charcoal rot and top dieback.

Symptoms can be very similar among the diseases, but they can be distinguished from each other. All three can have yellowing leaves in the upper canopy. For top dieback, the yellowing occurs on the outer margins of the leaves in the top of the canopy. Top dieback has been associated with potassium deficiency, but there is no clear-cut situation that precludes disease development.

Charcoal rot had been reported in the past, but in 2012 it was showing up earlier than usual. The pathogen causing charcoal rot can survive many years in the soil. Conditions experienced in 2012 – hot and dry – are conducive for development of this disease. Interveinal yellowing of the leaves, an early symptom, can look a bit like sudden death syndrome.

To distinguish charcoal rot from sudden death syndrome, there are a couple of things that can be done. First, you can look at the lower stem for microsclerotia. These can be found in the outer or inner stem tissue. A second way to tell the diseases apart is to wait until imminent death occurs. Plants with sudden death syndrome drop leaves but the petioles remain attached to the stem. Charcoal rot-infected plants that die may have leaves attached to the plants.

There were no management strategies available near the end of the season for all three diseases. But knowing what caused the spots may affect management in future years. For example, if you had top dieback in 2012, you may consider checking soil for potassium levels or soybean cyst nematode. Management of SCN or applications of potassium may alleviate this problem. Selecting resistant cultivars will help with sudden death syndrome. Finding ways to alleviate stress to future soybean crops can reduce charcoal rot.

In mid- to late August, there were several reports of aflatoxin detected in southern Iowa and also a few reports from central Iowa. At this time, levels of aflatoxin ranged from 8 ppb to almost 200 ppb. The FDA action level for aflatoxin in grain is 20 ppb. In the corn fungicide trials conducted around the state, the incidence and severity of Aspergillus ear rot was very low. Grain samples from those trials will be analyzed for aflatoxin during the winter. By the end of the season it was apparent that aflatoxin was not as widespread as had first been predicted. Elevators in western and eastern Iowa reported receiving loads of grain testing positive for aflatoxin from scattered fields in the region.

**Conclusion**

Despite the drought conditions experienced in 2012, there were still some disease issues in corn and soybean. Many diseases were suppressed and were not a problem, which is at least a little bit of relief for farmers and agribusiness who were otherwise hurt by the weather conditions. Disease histories of each field should be recorded and taken into account as we prepare for next year disease history will affect the risk of disease in future years, plus the lessons learned and observations made will help to make us better farmers and agronomists.
Spray adjuvants: The rest of the story
Rich Zollinger, Extension weed scientist, Plant Sciences, North Dakota State University.

Introduction

Questions about adjuvant selection are common. Adjuvants are not regulated by the EPA or any other regulatory agency allowing an unlimited number of adjuvants. Adjuvants are composed of a wide range of ingredients which may or may not contribute to herbicide phytotoxicity. Results vary when comparing specific adjuvants, even within a class of adjuvants. POST herbicide effectiveness depends on spray droplet retention, deposition, and herbicide absorption by weed foliage. Adjuvants and spray water quality (Paragraph A6) influence POST herbicide efficacy. Adjuvants are not needed with PRE herbicides unless weeds have emerged and labels include POST application.

Spray adjuvants generally consist of surfactants, oils and fertilizers. The most effective adjuvant will vary with each herbicide, and the need for an adjuvant will vary with environment, weeds, and herbicide used. Adjuvant use should follow label directions and be used with caution as they may influence crop safety and weed control. An adjuvant may increase weed control from one herbicide but not from another. To compare adjuvants and determine adjuvant enhancement, herbicide rates should be used at marginal weed control levels. Effective adjuvants will enhance herbicides at reduced rates and provide consistent results under adverse conditions. However, use of below labeled rates exempts herbicide manufacturers from liability for nonperformance.

Surfactants (nonionic surfactants = NIS) are used at 0.25 to 0.5% v/v (1 to 4 pt/100 gal of spray solution) regardless of spray volume. NIS rate depends on the amount of active ingredient in the formulation, plant species and herbicides used. The main function of a NIS is to increase spray retention, but at a lesser degree, may function in herbicide absorption. When a range of surfactant rates is given, the high rate is for use with low herbicide rates, drought stress and tolerant weeds, or when the surfactant contains less than 90% active ingredient. Surfactants vary widely in chemical composition and in their effect on spray retention, deposition, and herbicide absorption.

Silicone surfactants reduce spray droplet surface tension, which allow the liquid to run into leaf stomata (“stomatal flooding”). This entry route into plants is different than adjuvants that aid in absorption through the leaf cuticle. Rapid entry of spray solution into leaf stomata from use of silicone surfactants often does not result in improved weed control. Silicone surfactants are weed and herbicide specific just like other adjuvants.

Oils generally are used at 1% v/v (1 gal/100 gal of spray solution) or at 2 pt/A depending on herbicide and oil. Oil additives increase herbicide absorption and spray retention. Oil adjuvants are petroleum (PO) or methylated vegetable or seed oils (MSO) plus an emulsifier for dispersion in water. The emulsifier, the oil class (petroleum, vegetable, etc.), and the specific type of oil in a class all influence effectiveness of an oil adjuvant. Oil adjuvants enhance POST herbicides more than NIS and are effective with all POST herbicides, except Liberty and Cobra, and will antagonize Roundup. The term crop oil concentrate (COC) is used to designate a petroleum oil concentrate but is misleading because the oil type in COC is petroleum and not a crop vegetable oil.

MSO adjuvants greatly enhance POST herbicides much more than NIS and PO adjuvants. MSO adjuvants are more aggressive in dissolving leaf wax and cuticle resulting in faster and greater herbicide absorption. The greater herbicide enhancement from MSO adjuvants may occur more in low humidity/low rainfall environments where weeds develop a thicker cuticle. MSO adjuvants cost 2 to 3 times more than NIS and PO adjuvants. The added cost of MSO and increased risk of crop injury when used at high temperatures have deterred people from using this class of adjuvants. Using reduced herbicide rates with MSO adjuvants can enhance weed control while lowering risk of crop injury.

Some herbicide labels restrict use of oil adjuvants and recommend only NIS alone or combined with nitrogen based fertilizer solutions. Follow label directions for adjuvant selection. Where labels allow use of oil additives, PO or MSO adjuvants may be used.

NDSU research has shown wide difference in adjuvant enhancement of herbicides. However, in many studies, no or small differences occur depending on environmental conditions at application, growing conditions of weeds, rate of herbicide used, and size of weeds. For example, under warm, humid conditions with actively growing weeds, NIS + nitrogen fertilizer may enhance weed control to the same level as oil adjuvants. The following are conditions where MSO type additives may give greater weed control than other adjuvant types:
1. Low humidity, hot weather, lack of rain, and drought-stressed weeds or weeds not actively growing due to some stress condition.
2. Weeds larger than recommended on the label.
3. Herbicides used at reduced rates.
4. Target weeds that are somewhat tolerant to the herbicide. (buckwheat, lambsquarters, ragweed to Pursuit or Raptor, or yellow foxtail to Accent).
5. When university data supports reduced herbicide rates. Most herbicides, except Roundup, give greater weed control when used with MSO type adjuvants.

**Oil adjuvant applied on a volume or area basis**

Labels of many POST herbicides recommend oil adjuvants at 1% v/v. At water volume of 15 or 20 gallons per acre (GPA), 1% oil adjuvant will provide a minimum adjuvant concentration (1% v/v PO in 17 gpa = 1.4 pt/A). The optimum rate of a PO is 2 pt/A. State surveys show common spray volumes are 10 gpa or lower. PO at 1% v/v in 8.5 gpa = 0.68 pt/A and does not provide an sufficient amount of oil adjuvant. Further, in aerial applications at 5 GPA, PO at 1% v/v will not provide sufficient adjuvant. For example, Pursuit and Raptor labels require oil adjuvants to be added at 1.25% v/v or 1.25 gal/100 gal water for aerial application at 5 GPA.

Some herbicide labels contain information on adjuvant rates for different spray volumes. To insure sufficient adjuvant concentration, add oil adjuvant at 1% v/v but no less than 1.25 pt/A at all spray volumes. Surfactant at 0.25 to 1% v/v water is sufficient across all water volumes.

**High surfactant oil concentrates** (HSOC) were developed to enhance lipophilic herbicides without antagonizing glyphosate. HSOC adjuvants contain at least 50% w/w oil plus 25 to 50% w/w surfactant, are PO or MSO based, and are usually applied at ½ the oil adjuvant rate (area basis). Glyphosate must be applied with other herbicides to control glyphosate tolerant weeds and crops and to delay resistant weeds. Glyphosate is highly hydrophilic, is enhanced by NIS and nitrogen fertilizer surfactant type adjuvants, and is antagonized by oil adjuvants. Postemergence herbicides preferred by growers to mix with glyphosate to increase weed control are lipophilic (Select, Banvel, Laudis, others) and require oil adjuvants for optimum herbicide enhancement. Surfactants are less effective in enhancing lipophilic herbicides. Oil adjuvants, including PO and MSO adjuvants, may antagonize glyphosate. NDSU research has shown wide variability among PO based HSOC adjuvants with many performing no different than common PO adjuvants. However, MSO based HSOC adjuvants enhance both glyphosate and the lipophilic herbicide. MSO based HSOC adjuvants can enhance lipophilic herbicides more than PO based HSOC, MSO and PO adjuvants.

**Some water pH modifiers** are used to lower (acidify) spray solution pH because many insecticides and some fungicides degrade under high water pH. Most solutions are not high or low enough in pH for important herbicide breakdown in the spray tank. A theory has long been postulated that acidifying the spray solution results in greater absorption of weak-acid-type herbicides. pH-reducing adjuvants (water conditioners/AMS replacement) were developed under this belief. However, low pH is not essential to optimize herbicide absorption.

Many herbicides are formulated as various salts, which are absorbed as readily as the acid. Salts in the spray water may antagonize formulated salt herbicides. In theory, acid conditions would convert the herbicide to an acid and overcome salt antagonism. However, herbicides in the acid form are less water soluble than in salt form. An acid herbicide with pH modifiers may precipitate and plug nozzles when solubility is exceeded, such as with high herbicide rates in low water volumes. Antagonism of herbicide efficacy by spray solution salts can be overcome without lowering pH by adding AMS or, for some herbicides, 28% UAN.

Acidic AMS replacement (AAR) adjuvants contain adjuvants including monocarbamide dihydrogensulfate (urea and sulfuric acid) and some adjuvants in this class are similar to NIS + AMS in enhancing glyphosate and other weak-acid herbicides. The sulfuric acid forms sulfate when reacting with water and can prevent herbicide antagonism with salts in water. The conversion of urea to ammonium is slow but the ammonium formed can partially enhance herbicides. AAR adjuvants must be applied at 1% v/v or greater to achieve the same level of herbicide enhancement as AMS.
Basic pH blend adjuvants are blends of nonionic surfactant, fertilizer, and basic pH enhancer and are used at 1% v/v regardless of spray volume. Data indicate basic blend adjuvants at 1% v/v from 5 to 20 GPA will provide adequate adjuvant enhancement for similar weed control.

**Basic pH blend adjuvants** are surfactant based, increase spray solution pH, and contain nitrogen fertilizer to enhance herbicide activity. They contain a surfactant to aid in spray retention, spray deposition, and herbicide absorption, and a buffer to increase water pH. Basic pH blends adjuvants increase water pH to near pH 9 which increases water solubility of some herbicides and can increase herbicide phytotoxicity. Within the sulfonylurea chemistry the magnitude of solubility from high spray solution pH can increase from 40 fold (Harmony GT) to 3,670 fold (UpBeet). The solubility of herbicides in other chemical families increase with high pH: Achieve (1-Dim), florasulam (2-TPS), Everest (2-SACT), Sharpen (14), and diflufenketal (19), Callisto and Laudis (27-triketone), and pyrasulfotole and Impact (27-pyrazolone) (numbers represent herbicide mode of action).

Some herbicides degrade rapidly in high pH spray solution. Cobra (diphenylether), Resource and Valor (N-phenylphthalimide), and Sharpen (pH 9) degrade within a few minutes in high pH water but are stable for several days at low pH. Optimum use of pH adjusting adjuvants requires some knowledge of herbicide chemistry or experience. Research has shown that basic pH blend adjuvants may enhance weed control similar to MSO adjuvants and can be used in situations where oil adjuvants are restricted.

Commercial adjuvants differ in effectiveness with herbicides. Data from the table below are from experiments conducted at six NDSU R&E Centers in ND from 1992 through 1995 and repeated in 2005 and 2006 comparing commercial adjuvants with Roundup. In 1993-95, Roundup was applied at 1 to 1.5 oz ae/A to 16 grass and broadleaf weed species. In 2005-06 Roundup was applied at 1 to 4 oz ae/A to 26 grass and broadleaf weed species (272 averages). Higher rates were used in western ND because of low activity in low humidity.
Table 1. Commercial adjuvant effect on glyphosate phytotoxicity.

| Surfactants | Rate % v/v | Grass 1993-95 | Grass 2005-06 | Broadleaf 1993-95 | Broadleaf 2005-06 | % control
|-------------|-------------|----------------|----------------|-------------------|-------------------|----------
| None        | 0.5         | 49             | 68             | 31                | 42                |          |
| R-11        | 0.5         | 74             | 90             | 51                | 66                |          |
| APSA 80     | 0.5         | 74             | 87             | 50                | 62                |          |
| Wet-Sol 99  | 0.5         | --             | 86             | --                | --                |          |
| Premier 90  | 0.5         | --             | 81             | --                | --                |          |
| Purity 100  | 0.5         | --             | 82             | --                | --                |          |
| Preference  | 0.5         | 67             | 79             | 38                | 58                |          |
| Liberate    | 0.5         | --             | 76             | --                | --                |          |
| X-77        | 0.5         | 66             | 70             | 40                | 52                |          |
| Spray Booster S | 0.5    | 64             | --             | 41                | --                |          |
| Activator 90| 0.5         | 64             | 69             | 41                | 50                |          |
| LI-700      | 0.5         | 58             | 66             | 42                | 41                |          |
| Silwet L-77 | 0.25        | 56             | --             | 40                | --                |          |
| AMS         | 8.5 lb/100 gal | --         | 86             | --                | 68                |          |
| Surfactant + AMS Fertilizer |           |                |                |                   |                   |          |
| Class Act   | 2/2.5       | 90             | 94             | 75                | 76                |          |
| R-11 + AMS  | 0.5+8.5 lb/100 | --     | 93             | --                | 76                |          |
| R-11 + Bronc Max | 0.5 + 0.5 | --          | 92             | --                | 73                |          |
| Surfate     | 1           | 89             | 93             | 75                | 74                |          |
| Dispatch    | 2           | 85             | --             | 69                | --                |          |
| R-11 + Cayuse | 0.5 + 0.5    | 82            | --             | 66                | --                |          |
| AMS Replacement / Water Conditioning Agent |           |                |                |                   |                   |          |
| N-Tense     | 0.5         | --             | 90             | --                | 67                |          |
| Alliance+Preference | 1.25 + 0.5 | --    | 89             | --                | 68                |          |
| Citron + Preference | 2.2 lb/A + 0.5 | --    | 84             | --                | 66                |          |
| Quest + Preference | 0.5 + 0.5    | --          | 83             | --                | 62                |          |
| Choice + Liberate | 0.5 + 0.5    | --          | 81             | --                | 60                |          |
| Herbolyte   | --          | 79             | --             | --                | 55                |          |
Conclusions from the study
1. Not all adjuvants are created equal.
2. Small numerical differences in data is significant as data was averaged across 68 means making outlying values have less affect to change the mean.
3. Most adjuvants enhanced Roundup but some did not enhance Roundup more than no adjuvant added.
4. The better adjuvants in 93-95 are the same as 05-06.
5. Data is arranged in numerically descending order showing similar enhancement in both 93-95 data and 05-06 data.
6. Adjuvants are non-regulated. Changes in individual adjuvant formulations have probably occurred since 1995. However, this data shows relatively little change in herbicides enhancement of Roundup* over time.
7. The 05-06 data is approximately 15 to 20 points higher probably due to higher Roundup* rates used in 05-06.
8. Surfactant + AMS fertilizer adjuvants as a group were more effective than the surfactants or AMS Replacer / Water Conditioning Agent adjuvants.
9. The results are averaged over various locations and may not represent adjuvant effectiveness for all situations.
10. Adjuvants differ in effectiveness and users should compare several products for their specific conditions or select an effective adjuvant from the list.

Spray carrier water quality
Minerals, clay, and organic matter in spray carrier water can reduce the effectiveness of herbicides. Clay inactivates paraquat, diquat, and glyphosate. Organic matter inactivates herbicides. Hard water cations or micronutrients such as calcium, magnesium, manganese, sodium, and iron reduce efficacy of all weak-acid herbicides. Cations antagonize glyphosate efficacy by complexing with glyphosate to form salts (e.g. Glyphosate-Ca) that are not readily absorbed by plants. Antagonistic minerals can inactivate the activity of most POST herbicides, including glyphosate, growth regulators (not esters), ACCase inhibitors, ALS inhibitors, HPPD inhibitors, and Ignite. The antagonism is related to the salt concentration. At low salt levels, loss in weed control may not be noticeable under normal environmental conditions but will occur when weed control is marginal because of drought or partially susceptible weeds. The precise salt concentration in water that causes a visible loss in weed control is difficult to establish because weed control is influenced by other factors.

ND water often contains a combination of sodium, calcium, magnesium, and iron and these cations generally are additive in the antagonism of herbicides. Water in ND, SD, and MT is often high in sodium bicarbonate which does not normally occur in other areas of the U.S. Calcium levels above 150 ppm and sodium bicarbonate levels above 300 ppm in spray water can reduce weed control in all situations. Water with 1600 ppm sodium bicarbonate can occur in ND, but total hardness levels can exceed 2,500 ppm.

Ammonium nitrogen increases effectiveness of most weak-acid herbicides formulated as a salt. Fertilizers should always be used with herbicides unless prohibited by label. Ammonium ions greatly enhance herbicide absorption and phytotoxicity even in the absence of antagonistic salts in the spray carrier. However, enhancement of Roundup* and most other POST herbicides from ammonium is most pronounced when spray water contains large quantities of antagonistic cations. Herbicide enhancement by nitrogen compounds appears in most weed species but is most pronounced in species like volunteer corn and species that accumulate antagonistic salts on or in leaf tissue (lambquarters, velvetleaf, and sunflower).

AMS enhances phytotoxicity and overcomes salt antagonism for weak-acid herbicides formulated as a salt including glyphosate, growth regulators (not esters), ACCase inhibitors, ALS inhibitors, HPPD inhibitors, and Ignite. The antagonism may be overcome by increasing the glyphosate concentration relative to the cation content or by adding AMS and some water conditioners to the spray solution. Effective water conditioners include EDTA, citric acid, AMS, and some acidic AMS replacements. Of these, AMS has been the most widely adopted. When added to a spray solution, the ammonium (NH$_4^+$) ion complexes with the glyphosate molecule and reduces glyphosate interaction with the hard_water cations, and the sulfate (SO$_4^{2-}$) ion complexes with the hard_water cations (e.g. calcium sulfate), causing the salt to precipitate from solution. This combined effect increases absorption and efficacy. Natural
sulfate in water can be disregarded but can reduce antagonism if the sulfate concentration is at least three times the calcium concentration.

Antagonism of Roundup by calcium in a spray solution was overcome by sulfuric but not nitric acid, indicating that the sulfate ion was important, but not the acid hydrogen ion. The importance of the sulfate ion explains the effectiveness of ammonium sulfate, and not 28% UAN, in overcoming calcium antagonism of glyphosate. Other herbicides that become acid at a higher pH than Roundup may realistically benefit from a reduced pH as has been shown for Poast. However, Poast does not require a low pH for efficacy: pH of 4 has overcome sodium antagonism of Poast, but nitrogen fertilizer or AMS also will overcome sodium antagonism of Poast without lowering the pH. The ammonium ion provided by these fertilizers is apparently the important ion.

AMS is recommended at 8.5 to 17 lb/100 gal spray volume (1 to 2%) on most Roundup labels. However, AMS at 4 lb/100 gal (0.5%) is adequate to overcome most salt antagonism but more than 4 lb/100 gal may be required to fully optimize herbicides. AMS at 0.5% has adequately overcome antagonism of glyphosate from 300 ppm calcium. Use at least 1 lb/A of AMS when spray volume is more than 12 gpa. The amount of AMS needed to overcome antagonistic ions can be determined as follows:

\[ \text{Lbs AMS/100 gal} = (0.002 \times \text{ppm K}) + (0.005 \times \text{ppm Na}) + (0.009 \times \text{ppm Ca}) + (0.014 \times \text{ppm Mg}) + (0.042 \times \text{ppm Fe}) \]

This does not account for antagonistic minerals on or in the leaf tissue in species like lambsquarters, sunflower, and velvetleaf which may require additional AMS.

AMS may contain contaminants that may not dissolve resulting in plugged nozzles. Use spray grade AMS to prevent nozzle plugging. Commercial liquid solutions of AMS are available and contain approximately 3.4 lbs of AMS/gallon. For 8.5 lbs of AMS/100 gallons of water add 2.5 gallons of liquid AMS solution.

28% UAN fertilizer is effective in enhancing weed control and overcoming mineral antagonism of most POST herbicides, but not calcium antagonism of Roundup. Sodium bicarbonate antagonism of Poast is overcome by 28% UAN and AMS. AMS or 28% UAN does not preclude the need for a oil adjuvant with lipophilic herbicides. Generally, 4 gal of 28% UAN/100 gal of spray has been adequate. AMS and 28% UAN enhance herbicide control of most weeds even in water without antagonistic salts. Nitrogen fertilizer/surfactant blends may enhance weed control of most herbicides formulated as a salt.

Analysis of spray water sources can determine water quality effects on herbicide efficacy. Water samples can be tested at the NDSU Soil and Water Laboratory:

**USPS:** NDSU Dept 7680, Fargo, ND 58108-6050,

**UPS and Physical Address:** Waldron Hall 202, 1360 Bolley Dr. NDSU, Fargo, ND 58102. (701) 231-7864.

Analysis is approximately $25.00 to $29.00.

The analysis may report salt levels in ppm or grains. To convert from grains to ppm, multiply by 17 (Example: 10 grains calcium X 17 = 170 ppm calcium). AMS at 2% (17 lb/100 gallons water) will overcome antagonism from the highest calcium and/or sodium concentrations in North Dakota water. However, AMS at 4 lb/100 gal is adequate for most North Dakota water. Iron is also antagonistic to many herbicides but not abundant in ND water.

**Water conditioner adjuvants** are liquid for user preference, applied at low use rates, may contain no or very little AMS, may lower spray solution, and are advertised to replace AMS, and thus are also called AMS replacement adjuvants. Pesticide applicators prefer the convenience of low use rate water conditioners, but performance has been inconsistent. Glyphosate plus commercial water conditioner products that included AMS at the equivalent rate of 1% w/w can give similar control to 1% w/w (8.5 lbs/100 gal) AMS. Commercial water conditioners that do not provide an equivalent amount of AMS give less control than glyphosate with 1% or 2% w/w AMS and are often no better than glyphosate alone.

**Acidic AMS replacement** (AAR) adjuvants have been developed for use with glyphosate and other weak acid herbicides. Claims have been made to enhance herbicide activity, and negate the effects of antagonistic salts in spray water and the antagonism from micronutrient solutions added for crop health. Most adjuvants in this class contain monocarbamide dihydrogen sulfate or AMADS (urea plus sulfuric acid) which lowers spray solution pH to 1.4 to 3. The low pH is below the pKa of postemergence herbicides causing most herbicide molecules to be in the acid state which results in fewer molecules binding to positively charged salts.
Some water conditioner adjuvants and acidic AMS replacement adjuvants (AAR) are marketed to modify spray water pH, but low pH is not required for herbicide efficacy. The type of acid or components of buffering agents and the specific herbicide all need to be considered before using pH-modifying agents. Several commercial AAR adjuvants applied with glyphosate in distilled water were tested and ranked as follows: surfactant + AMS > AMS > NIS = AAR. A commercial AAR adjuvant composed primarily of sulfuric acid was much less phytotoxic than most AAR adjuvants which support the concept and use of ammonia to enhance weak acid herbicides. Generally, AAR adjuvants applied with glyphosate in 1000 ppm hard water (Ca and Mg) gave similar weed control as when applied in distilled water supporting the theory of non-binding herbicide molecules when pH is below the pKa of the herbicide. Clearly, commercial adjuvants vary greatly in function, use, and chemical and biological effect.

Low spray volumes (5 to 10 gpa) have been equally or more effective than higher spray volumes for many herbicides. Low spray volume originally was considered important to glyphosate efficacy because it would reduce the ratio of glyphosate and antagonistic cations in the spray solution. However, low spray volumes have enhanced glyphosate efficacy because of higher glyphosate concentration in the spray deposit. Greater efficacy from higher concentrated droplets has been shown with many other herbicides but is logical that the highly concentrated droplets with low volume would be positive for translocated herbicides (NDSU Pile Theory). Contact herbicides (Cobra, Cadet, Ignite, Flexstar/Reflex, paraquat, Sharpen) require higher spray volume for adequate and thorough coverage to enhance control.

Low spray volumes usually imply use of low-volume nozzles that produce small droplets which can increase off-target movement. However, drift-reducing nozzles have been developed that produce large droplets at low volume. In low spray volumes, larger droplets produced by drift-reducing nozzles have been equally effective as small droplets with several translocating herbicides. However, coarse or larger droplets may be less phytotoxic than fine and medium size droplets for sethoxydim, imazethapyr, tembotrione, and 2,4-D. Limited research is available about efficacy based on droplet size although will become important as regulation requires larger droplet size to mitigate drift from small droplets.
Weed management update: 2013
Micheal D. K. Owen, associate chair, professor and Extension weed specialist, Agronomy, Iowa State University

Introduction
The success of weed management programs, more specifically herbicide programs, varied considerably during 2012 reflecting the importance of environmental conditions on all aspects of crop production. Variability of success was seen not only in the postemergence herbicide applications that continue to dominate herbicide use but also in the soil-applied residual herbicides; all herbicide applications were strongly influenced by tillage system, crop planting date, timing and amount of rainfall, and resulting weed emergence timing. While more soil-applied herbicides were used in Iowa during 2012, there are still too many acres of corn and soybean that are treated only with glyphosate thus moving the evolution of glyphosate resistant weed biotypes forward (Figure 1). Importantly, the trend of no new herbicide sites of action continues and while new herbicides will be available in 2013, they have old sites of action, many of which have existing resistant weed populations. The new products and changes in herbicides will be described in this paper. The implications of the 2012 drought on herbicide degradation and the potential for herbicide carryover will be addressed. Furthermore, an update on the development of new herbicide resistant crops and the anticipated implications of these technologies when deregulated and available commercially will be discussed. Finally, preliminary data from a research project supported by the Iowa Soybean Association to assess the extent of evolved resistance to herbicides in Iowa and a brief discussion about Palmer pigweed (Amaranthus palmeri) will be provided.

![Graph showing the use of glyphosate and alternative herbicides in Roundup Ready® corn and soybean.](adapted_from_Sortes_2012_WSSA_annual_meeting)

Figure 1. Use of glyphosate and alternative herbicides in Roundup Ready® corn and soybean. (Adapted from Sortes (2012) WSSA annual meeting)

New products and company updates
While a number of new products and premixtures are available or anticipated to be available in 2013, none of these products represent new herbicide sites of action. Given the existing resistances to available herbicide sites of action, this lack of discovery and development of new products will be increasingly problematic for weed management in Iowa agriculture and reinforces the need for a better understanding about how to best use the available herbicides to steward their continued performance. The following update includes companies that provided information about their proprietary products; inclusion in this paper does not signify endorsement nor does exclusion constitute a lack of support of the products.
**BASF**

BASF has received registration for Zidua herbicide in corn including popcorn and sweetcorn. This product has the active ingredient pyroxasulfone which is the herbicide KIH-485 on which Iowa State University Weed Science conducted research for a number of years however the rate of pyroxasulfone used was higher than what is currently registered. Pyroxasulfone is a group 15 herbicide and inhibits very long chain fatty acid (VLCFA) synthesis; this is the same mode of action for other commercially available products such as metolachlor (e.g. Dual) and acetochlor (e.g. Warrant) (Tanetani et al., 2009). The specific molecular site of action has not been confirmed. Group 15 herbicides do not inhibit germination but rather inhibit shoot elongation of germinated susceptible seedling weeds. These herbicides control many annual grasses and some small-seeded annual broadleaf weeds. Zidua is formulated as an 85% water dispersible granule (WG) and the 0.212 lbs A.I. can be applied early preplant (up to 45 days before planting), preplant incorporated, preemergence, early postemergence and in the fall. Fall application is not the best application timing for residual weed control in the spring and early post emergence applications must be timed prior to weed emergence. Do not apply Zidua through irrigation systems nor aerially. Only one application is allowed to corn each spring.

BASF is also developing a new formulation of dicamba for application on dicamba-resistant soybean cultivars. The new formulation will be called Engenia by BASF and is suggested to have a lower potential for volatilization than current dicamba formulations. The weed spectrum and relative efficacy is similar to available dicamba formulations. This formulation has been evaluated in more than 300 soybean field trials in 2011 and 2012 according to a recent BASF announcement and will be targeted to help control herbicide resistant weeds such as common waterhemp (Amaranthus tuberculatus). Iowa State University has evaluated this product and has observed off target movement to susceptible soybean cultivars. While the risk of volatilization drift may be reduced compared to current dicamba formulations, it is not zero. Furthermore, physical drift will require the same considerations that impact all herbicides. The potential for tank contamination resulting in injury to susceptible crops is also an important management consideration.

**Bayer Crop Science**

While Bayer Crop Science did not provide any specific update information, they are moving forward their stewardship efforts by holding “Respect the Rotation” field days and promoting the use of Liberty Link corn and soybeans and Liberty herbicide. The inclusion of the trait and the herbicide as part of a more diverse weed management program makes good sense. Bayer Crop Science has also developed a very good brochure describing herbicide resistance, current herbicide resistant weeds, management tactics for herbicide resistant weeds, and herbicide modes of action. This brochure is available at [http://www.bayercropscience.us/news/2012_RTR/2013WeedResistanceManagementBrochure.pdf](http://www.bayercropscience.us/news/2012_RTR/2013WeedResistanceManagementBrochure.pdf).

**Dow AgroSciences**

Dow AgroSciences continues to develop 2,4-D resistant traits in soybeans and corn under the name Enlist™ Weed Control System. There is a chance that the corn may be deregulated for a limited commercial launch in 2013 while the earliest deregulation of the soybean cultivars is in 2015. Enlist Duo will be the Dow AgroSciences proprietary premixture of glyphosate and 2,4-D choline. This new formulation of 2,4-D is suggested to have lower volatility, less physical drift potential and other favorable characteristics compared to current 2,4-D formulations. Drift reducing agents are included in the formulation. Weed control is similar to other 2,4-D products. Dow AgroSciences is developing a strong stewardship program and to minimize off-target issues with Enlist Duo, this program must be followed closely.

**DuPont**

DuPont has registered a new premixture of rimsulfuron (4.17%) and mesotrione (41.67%) and have named this product Instigate™ which is formulated as a water dispersible blend. DuPont is suggesting that this mixture provides burndown activity as well as residual activity in corn. There is some confusion with regard to the Herbicide Group number that is included on the Instigate label; DuPont indicates that this product has an Herbicide Group 2 product (rimsulfuron) and an Herbicide Group 28 product (mesotrione). However, Syngenta suggests that mesotrione is a member of Herbicide Group 27. The confusion reflects differences in designation comparing the Weed Science Society of America and the Herbicide Resistance Action Committee. Regardless, Instigate has one ALS inhibitor herbicide and one HPPD inhibitor herbicide. Instigate can be applied 14 days prior to planting up to V2 corn.
This product is restricted for application only on corn and seed corn, popcorn, ornamental corn and sweet corn should not be treated with Instigate. Do not make an application of another HPPD inhibitor herbicide (e.g. Callisto) following an application of Instigate. Other restrictions on the label need to be followed.

Realm™ Q was registered for corn by DuPont in July 2012 and is a postemergence premixture of rimsulfuron (Group 2) and mesotrione (Group 27 – see above) herbicides and isoxadifen, a potent safener that will minimize the potential for crop injury from the rimsulfuron. This product provides burndown activity as well as some residual control of some annual grasses and broadleaf weeds. The amounts of rimsulfuron and mesotrione are 7.5% and 31.25% respectively by weight in the water dispersible granule formulation. Apply 4 oz product per acre to corn up to 20” tall or exhibiting 7 leaf collars, whichever is more restrictive. Crop oil concentrate or nonionic surfactant and AMS must be included and atrazine is also recommended. Do not include Basagran or foliar-applied organophosphate insecticides with Realm™ Q. Realm™ Q should not be applied aerially or through irrigation systems. The soybean rotational interval is 10 months. DuPont cautions that a potential interaction with Realm™ Q and Counter and Lorsban soil-applied insecticides that can result in severe crop injury and yield loss.

DuPont has labeled Cinch® (82.4% s-metolachlor) (Group 15) for postemergence application in soybeans. Note that s-metolachlor does not demonstrate activity on weeds that have emerged prior to application.

**FMC**

FMC received registration for Anthem™ a premixture of pyroxasulfone (Group 15) and fluthiacet-methyl (Group 14) herbicides. Anthem™ is formulated as a suspoemulsion and contains 2.15 lb. active herbicide ingredient. This premixture can be applied fall or spring, preplant, preplant incorporated preemergence or postemergence. When applied postemergence to weeds, it is critical to note the weed type and size as Pyroxasulfone does not demonstrate activity on emerged weeds and fluthiacet-methyl has limited activity on some small broadleaf weeds although velvetleaf control is good. Do not apply Anthem™ aerially or by irrigation equipment. Observe harvest intervals as detailed on the label. Anthem™ applied at 13 oz/A will contain 0.212 lb a.i. of pyroxasulfone. Registration of Anthem ATZ (Groups 5, 14, and 15) is pending.

**Monsanto**

Monsanto has registered Warrant® herbicide (acetochlor, Group 15) is now registered for preplant, at-planting and preemergence surface application in soybeans. Incorporation of the encapsulated acetochlor is not recommended and up to 4 quarts of Warrant® can be applied per season. These additions to the label supplement the previously labeled post emergence application in soybean. Acetochlor does not demonstrate activity on emerged weeds.

Monsanto has also detailed their 2013 recommendations in Roundup Ready corn and soybeans. A number of application scenarios are described in several tillage systems if glyphosate resistant weeds are present or absent. Monsanto is providing incentives to use alternate herbicides in combination with glyphosate for all application timings. This effort to incentivize stewardship is laudable however it specifically provides stewardship for glyphosate. All herbicide sites of action should be stewarded and it is important to consider tactics for weed management other than additional herbicides. Importantly, given the herbicide resistances that have evolved in Iowa (see later in this paper), it is critical to make sure that the alternate herbicides are active on the target weeds to best utilize the Monsanto recommendations and incentives.

Monsanto continues to develop the dicamba-resistant soybean cultivars and it is anticipated that Roundup Ready Xtend may be commercially available in 2014. The available soybean cultivars demonstrate excellent tolerance to dicamba and weed control of selected broadleaf weed was also good. However in large-plot trials conducted by Iowa State University in 2012, off-target movement of the new dicamba formulation was observed and it is clear that the utilization of this technology will require focused attention in order to minimize issues of off-target and tank contamination.

**Syngenta**

Syngenta has changed the formulations of three of their proprietary products to allow better handling, mixing, compatibility with sulfur-containing fertilizers and cleanup. These products include Lumax® EZ, Lexar® EZ and a Camix replacement, Zemax™. The ratio of herbicides in Lumax EZ is also different such that the product amount applied has increased.
Valent

Valent has registered Fierce™ herbicide on corn for fall and spring burndown applications or preemergence in no tillage and minimum tillage systems. Conventional tillage corn production systems are not described on the label. Fierce™ is formulated as a 76% water dispersible granule and is a prepackage mixture of flumioxazin (Group 14) and Pyroxasulfone (Group 15) herbicides which provides contact and residual activity on susceptible weeds. The maximum seasonal application rate of 4.5 oz/A results in 0.12 lb a.i. pyroxasulfone. This product is not registered for sweet corn, popcorn or corn grown for seed. Fierce™ can be applied aerially.

Valent has provided detailed information and description on how to clean sprayers, mixing vessels and nurse tanks daily after the use of Valor, Chateau, Valor XLT, Gangster and Fierce herbicides. Valent requires the use of Valent Tank Cleaner which is described to neutralize and remove these herbicides from tanks, hoses and nozzles when mixed at the correct concentration and kept in the equipment over night.

Herbicide carryover

Given the lack of rain during the summer and fall 2012, the potential for herbicide carryover must be a consideration for 2013 plans. However, the extent of herbicide carryover and the actual risk of carryover injury to rotational crops will vary widely in Iowa and will be strongly influenced by a number of factors including but not limited to the specific herbicide, rate and timing of application and the weather, particularly the conditions that exist for the rotational crop in 2013. An article describing these factors can be found at http://www.extension.iastate.edu/CropNews/2012/0807hartzlerowen.htm. Specific herbicides and an assessment of carryover potential are listed in Table 1.

Generally, if herbicides applied in 2012 were allied in a timely fashion and if growing conditions for the 2013 crop are favorable, the likelihood of herbicide carryover that results in significant crop injury is slight. However, if multiple applications of the same herbicide or herbicide mechanism of action (e.g. multiple applications of HPPD inhibitor herbicides) were used, if high rates of the herbicides were applied and the herbicides were applied later in the growing season, the risk of carryover increases.

There is no good way to determine the potential for herbicide carryover. While there have been discussions about conducting bioassays to assess the level of carryover, these are not going to provide an accurate assessment of the carryover. Importantly there is a good chance of either a false positive (carryover is likely) or a false negative (carryover is unlikely). If you determine, by whatever means, that carryover is a strong possibility, it may be advisable to plant a rotational crop that is not sensitive to the herbicide. Past experiences on changing tillage plans do not suggest that this is an advisable solution for a number of reasons, not the least of which that changing tillage is unlikely to resolve the potential for herbicide carryover.

<table>
<thead>
<tr>
<th>Risk assessment</th>
<th>Herbicide</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Atrazine</td>
</tr>
<tr>
<td></td>
<td>Chlorimuron (e.g. Canopy, Authority XL, Envive, Valor XLT and others)</td>
</tr>
<tr>
<td></td>
<td>Imazaquin (e.g. Scepter)</td>
</tr>
<tr>
<td></td>
<td>Simazine (e.g. Princep and others)</td>
</tr>
<tr>
<td>Moderate to slight</td>
<td>Fomesafen (e.g. Reflex, Flexstar, Prefix)</td>
</tr>
<tr>
<td></td>
<td>Clopyralid (e.g. Hornet)</td>
</tr>
<tr>
<td></td>
<td>Cloransulam (e.g. FirstRate, Hornet, Gauntlet and others)</td>
</tr>
<tr>
<td></td>
<td>Imazethapyr (e.g. Pursuit)</td>
</tr>
<tr>
<td></td>
<td>Dinitroaniline herbicides (e.g. Prowl, Treflan and others)</td>
</tr>
<tr>
<td></td>
<td>HPPD inhibitor herbicides (e.g. Balance Flexx, Callisto, Lumax, Lexar, Laudis, Caprino, Impact and others)</td>
</tr>
</tbody>
</table>
Palmer pigweed

Palmer pigweed has been a significant problem in cotton and soybean production in the Mississippi Delta and the Southeastern United States. Interestingly, this weed originated in the arid Southwestern United States and was not a major concern until the unprecedented adoption of the glyphosate-resistant crop technologies and the subsequent use of glyphosate as the primary if not sole tactic to control weeds in these crops. In many respects, Palmer pigweed is similar to common waterhemp (A. tuberculatus) which dominates fields in the Midwest United States. These weeds are dioecious (male flowers and female flowers on separate plants), adapted to current tillage and crop production systems, produce incredible numbers of seeds and have opportunistic germination habits. Palmer pigweed, like common waterhemp has evolved resistances to several herbicides including the ALS inhibitor herbicides and glyphosate. However, Palmer pigweed seems to be more aggressive in growth and competitive habit with crops. Research conducted at Kansas State University a number of years ago demonstrated that Palmer pigweed and common waterhemp would approach the same heights but Palmer pigweed produced approximately 30% more dry matter. The problem is that with current agricultural practices, the mobility of weeds no longer is a function of natural processes (i.e. gravity or water) to move seeds. Palmer pigweed seeds have been documented in cotton meal which is used as livestock feed and in manure. When these products move across state lines and are used, they provide a new opportunity for Palmer pigweed to become a serious problem. As a result, Palmer pigweed infestations are appearing many states away for the original infestations. Palmer pigweed infestations have been identified in Southwest Michigan and Wisconsin (Figure 2). Missouri, Kansas and Nebraska all have Palmer pigweed and recently, several locations in Illinois have been identified (see http://bulletin.ipm.illinois.edu/article.php?id=432 and http://bulletin.ipm.illinois.edu/article.php?id=1688). While there are no documented samples of Palmer pigweed found in the Ada Hayden Herbarium at Iowa State University, and while no verified Palmer pigweed infestations have been identified by Iowa State University weed scientists, it is highly likely that Palmer pigweed populations exist in Iowa and if established, will adapt quickly to Iowa production systems.

The best way to keep Palmer pigweed from becoming a serious problem in Iowa is to identify the initial infestations and control them prior to seed production. Use whatever extraordinary tactics as deemed necessary. However, given the likelihood that the Palmer pigweed will have evolved herbicide resistance(s), the best tactic is hand removal. An excellent pigweed identification brochure is available at http://www.weeds.iastate.edu/weed-id/waterhemp/default.htm from Iowa State University. If a suspected infestation is discovered, please save one plant and send to Iowa State University at: Micheal D.K. Owen, 3218 Agronomy Hall, Ames, IA 50011 with the contact information. Then destroy all of the other plants before they flower.

Figure 2. Midwest States with documented infestations of Palmer pigweed (Amaranthus palmeri)

Iowa herbicide resistant weed update

In 2008, approximately 220 fields with common waterhemp populations were sampled arbitrarily and screened for resistance to glyphosate. In 2011, the Iowa Soybean Association requested that Iowa State University submit
a proposal to evaluate herbicide resistance in Iowa and subsequently funded the project. More than 200 common waterhemp populations and a number of giant ragweed (*Ambrosia trifida*) and horseweed (aka. marestail, *Conyza canadensis*) were collected in 2011 and similar collections were made in 2012 (Figure 3). Evaluations of the populations are currently underway and approximately 60% of the 2011 common waterhemp collections have been evaluated for resistance to five sites of herbicide action; the populations of giant ragweed and horseweed will be evaluated after the common waterhemp populations have been completed. The herbicide sites of action included in the evaluations are representatives of the ALS inhibitor herbicides (Group 2), PSII inhibitors (Group 5), EPSPS (Group 9), PPO inhibitor herbicides (Group 14) and HPPD inhibitor herbicides (Group 27). Representatives of each of these herbicide sites of action were applied postemergence to common waterhemp populations in the greenhouse at the typical field use rates and at four times this rate. A summary of the evaluations thus far can be seen at: http://www.weeds.iastate.edu/mgmt/2012/resistancereport.html.

![Figure 3. Iowa weed populations collected in 2008, 2011 and 2012 used to assess herbicide resistance.](image)

**Table 2. Rates of herbicides included in the greenhouse evaluation of Iowa weed populations**

<table>
<thead>
<tr>
<th>Herbicide</th>
<th>Field rate of product (1x)</th>
<th>4X rate of product</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALS inhibitor (Pursuit)</td>
<td>4 oz/A</td>
<td>16 oz/A</td>
</tr>
<tr>
<td>PSII inhibitor (atrazine)</td>
<td>1 lb/A</td>
<td>4 lb/A</td>
</tr>
<tr>
<td>GLY (glyphosate)</td>
<td>22 oz/A</td>
<td>88 oz/A</td>
</tr>
<tr>
<td>PPO inhibitor (Cobra)</td>
<td>12 oz/A</td>
<td>48 oz/A</td>
</tr>
<tr>
<td>HPPD inhibitor (Callisto)</td>
<td>3 oz/A</td>
<td>12 oz/A</td>
</tr>
</tbody>
</table>

The herbicides were applied and appropriate additives included when the common waterhemp were two to four inches tall. Evaluations were made 7, 14, and 21 days after herbicide application. Resistance was assessed on the relative control of the populations when compared to a known susceptible common waterhemp populations. Evaluations were on a 0 to 100% control where 0 indicated no herbicide activity and 100% indicated all plants
were sensitive. Values below 90% control when compared to the susceptible population were deemed to indicate that resistance had evolved in the specific population. Most of the populations that were designated as resistant still contain sensitive plants but resistance will become the primary phenotype if the herbicide(s) continue to be used. These evaluations are ongoing and as new populations are evaluated, the information will be included in the website.

As anticipated, most of the common waterhemp populations in Iowa have evolved resistance to the ALS inhibitor herbicides (Figure 4). More than 95% of the populations evaluated thus far demonstrate a resistant phenotype when challenged with a field rates of imazethapyr applied. When the rate increased to 4X 88% of the populations were still evaluated as resistant. The rate of the PSII herbicide did not change the relative percentages of the resistant populations as 58% and 57% of the common waterhemp populations had a resistant phenotype to 1X and 4X atrazine, respectively (Figure 4). When the populations evaluated thus far were treated with a field rate of glyphosate, 54% of the common waterhemp populations were assessed to be resistant while the number declined to 22% when the glyphosate rate was quadrupled (Figure 4). Assuming that the mechanism of resistance to glyphosate is similar to that reported for Palmer pigweed (Tranel, personal communication), the rate response demonstrated in the common waterhemp populations evaluated thus far is appropriate (Gaines et al., 2011; Tranel, 2007; Tranel, 2011).

There was no effect of lactofen rate on the percentage of resistance in common waterhemp; 6% were resistant to the field rate while 5% were resistant to the 4X rate (Figure 4). There was a significant effect of rate for mesotrione as 28% of the common waterhemp populations evaluated thus far were assessed to be resistant to the field rate of mesotrione while the percentage declined to 4% at the 4X rate (Figure 4). Resistance to the HPPD inhibitor herbicides is suggested to be attributable to metabolism. Thus, the rate response to the higher rates is appropriate and explicable based on a metabolic type of resistance.

![Figure 4](image.png)

**Figure 4.** Preliminary data describing Iowa common waterhemp (*Amaranthus tuberculatus*) populations collected in 2011 resistance(s) to field application rates (1X) and four times this rate of five herbicides* (preliminary data)

*Herbicides included are imazethapyr (ALS), atrazine (PSII), glyphosate (GLY), lactofen (PPO), and mesotrione (HPPD).
One important aspect of the research sponsored by the Iowa Soybean Association, compared to the assessment of glyphosate resistance in Iowa common waterhemp populations that was conducted in 2008 was the ability to assess multiple resistances in the populations. Given that common waterhemp has demonstrated the ability to evolve resistance to six different sites of herbicide action (the five included in this study and the auxinic herbicides dicamba and 2,4-D), it is critically important to know exactly what herbicides are still effective when planning a common waterhemp management program. When populations have evolved resistance to more than one site of herbicide action, the herbicide options available quickly decline.

A majority of the common waterhemp populations from the 2011 collections evaluated thus far demonstrated multiple resistances (Figure 5). The most prevalent multiple resistant phenotype was populations of Iowa common waterhemp that were resistant to ALS inhibitor herbicides, PSII herbicides and glyphosate (29%). Common waterhemp populations that had evolved resistance to two sites of herbicide action accounted for 32% of the field evaluated thus far. Resistance to three herbicide sites of action included 37% of the populations (the dominate phenotype was resistance to ALS/PSII/GLY) while resistance to four herbicide sites of action included 14% of the populations. Three populations (2%) were resistant to all herbicide sites of action tested while 2% of the populations evaluated thus far were sensitive to all five herbicide sites of action.

Based on the preliminary data, it is clear that managing herbicide resistant populations of common waterhemp will become increasingly challenging in the near future. Of great concern is the resistance to the HPPD inhibitor herbicides. It is important to recognize that the data is preliminary but if the trend established thus far holds when the 2012 collections are completed, the prevalence of resistant phenotypes will make weed management in corn and soybean increasingly difficult. Recognize that this screen is with the postemergence application of these herbicides; there is a possibility the common waterhemp populations may respond differently to soil-applied herbicides. Furthermore, the heritability of resistance, particularly the HPPD inhibitor herbicides, will influence how quickly this phenotype emerges in common waterhemp. Regardless, these preliminary data indicate that better management of weeds in Iowa is of utmost importance and alternatives strategies must be quickly adopted in order to maintain effective weed management.

**Conclusions**

While there have not been any new herbicide sites of action discovered and made commercially available in over 20 years, many manufacturers continue to develop older products and products based on older sites of action. However, the likelihood of having a truly new herbicide in the next ten years is not good. Thus, it is critical that we begin to use the available products more wisely and include more diverse weed management tactics in order
to preserve the herbicides and crop traits currently available. Other issues brought about by unfavorable weather conditions will add further complexity to decisions about which herbicides to use and how to use them in 2013. Finally, the weed community has not been sedentary and continues to demonstrate the principles of natural selection; resistance in weeds, particularly common waterhemp, continues to increase at an increasing rate. Multiple resistances within populations are becoming more prevalent. All of these indicate the need for diligence and management in order to maintain effectively weed control. The simplicity and convenience of using only glyphosate, as was done in the previous decade and unfortunately continues in this decade, has resulted in problems that cannot be addressed with any one tactic or herbicide. Better weed management begins with the inclusion of more diverse tactics, scouting and using multiple herbicides with alternative effective sites of action.

References


Tranel, P. J. Predicting the evolution and spread of glyphosate-resistant waterhemp. Pages 68-69 in Proceedings of the Illinois Crop Protection Technology Conference. Champaign, IL.

Effectiveness of using multiple sites of action to battle herbicide resistance

Bob Hartzler, professor and Extension weed specialist, Agronomy, Iowa State University

Introduction

The ‘Age of Convenient Weed Control’ is coming to an end. Some say it is already over. While glyphosate resistance has garnered the headlines, it is important to realize that the problem facing agriculture is herbicide resistance in general. Weeds such as waterhemp have ‘quietly’ evolved resistance to other herbicides such as the PPO and HPPD inhibitors. Less fanfare has been given to these developments since these products do not dominate the market in the way glyphosate has for the past 16 years. However, since these herbicide classes are needed to fight glyphosate resistance, the significance of the spread of resistance to them should not be overlooked. Now is the time to change our attitude towards weed management to insure that we have a diverse range of tools available to battle weeds in the future.

Both industry and universities have developed lists of weed management strategies for managing resistance. Many of these tactics are traditional stewardship practices often overlooked in an era of highly effective herbicides. An example would be providing the crop an even start with weeds. The current corn-soybean system limits the opportunities to incorporate many of the cultural or mechanical tactics that are the backbone of more diverse cropping systems. Thus, the manner in which herbicides are used is a key component of herbicide resistance management programs in Iowa. This paper will describe a process in which a herbicide program’s effectiveness in battling herbicide resistance can be objectively evaluated.

Herbicide mode and site of action

The terms mode and site of action are used to describe how herbicides kill plant. They often are used interchangeably, but they are different and it is important to understand these differences when managing resistance. Mode of action refers to the physiological process that a herbicide disrupts. Examples of modes of action are inhibition of photosynthesis or inhibition of amino acid synthesis. Herbicides inhibit these processes by binding to a specific protein and inhibiting that protein’s function. This protein is referred to as a herbicide’s site of action. For a few herbicides, the specific site of action has not been identified.

Managing resistance with herbicides involves using herbicides that kill plants in different ways. Differentiating between the mode and site of action is important since there often is more than one way to inhibit a physiological process. Thus, herbicides with the same mode of action may have different sites of action, whereas all herbicides with the same site of action have the same mode of action. Resistance management requires using herbicides with different sites of action.

A numbering system has been developed that makes it easier for persons involved in weed management to determine a herbicide’s site of action. A Herbicide Group number is assigned to each unique site of action. The Group Number of herbicides commonly used in corn and soybean production are listed in Table 1. The Herbicide Group number (site of action) is prominently displayed on the first page of most herbicide labels.
Table 1. Herbicide Group numbers and sites of action of herbicides used in corn and soybean production.

<table>
<thead>
<tr>
<th>Group No.</th>
<th>Site of Action</th>
<th>Mode of Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ACC-ase</td>
<td>Membrane integrity via lipid synthesis</td>
</tr>
<tr>
<td>2</td>
<td>ALS</td>
<td>Branched change amino acid synthesis</td>
</tr>
<tr>
<td>3</td>
<td>Tubulin</td>
<td>Cell division inhibition</td>
</tr>
<tr>
<td>4</td>
<td>Auxin binding site</td>
<td>Mimic activity of auxin</td>
</tr>
<tr>
<td>5</td>
<td>D1 protein</td>
<td>Photosynthesis via electron transfer in PS II</td>
</tr>
<tr>
<td>6</td>
<td>D1 protein</td>
<td>Photosynthesis via electron transfer in PS II</td>
</tr>
<tr>
<td>9</td>
<td>EPSPS</td>
<td>Inhibition of shikimic acid pathway</td>
</tr>
<tr>
<td>10</td>
<td>Glutamine synthetase</td>
<td>Photosynthesis via ammonium incorporation</td>
</tr>
<tr>
<td>13</td>
<td>DPX synthase</td>
<td>Photosynthesis via carotene synthesis</td>
</tr>
<tr>
<td>14</td>
<td>PPO</td>
<td>Photosynthesis via chlorophyll synthesis</td>
</tr>
<tr>
<td>15</td>
<td>Unknown</td>
<td>Very long chain fatty acid synthesis</td>
</tr>
<tr>
<td>19</td>
<td>Unknown</td>
<td>Auxin transport</td>
</tr>
<tr>
<td>22</td>
<td>Photosystem I</td>
<td>Photosynthesis via electron transfer in PS I</td>
</tr>
<tr>
<td>27</td>
<td>HPPD</td>
<td>Photosynthesis via carotene synthesis</td>
</tr>
</tbody>
</table>

Herbicide management

The current production system of Iowa is based on herbicidal control of weeds. To preserve the effectiveness of these production tools, they must be used in a different manner than they have been used in recent decades. The days of selecting the least cost, or most convenient, program that provides effective weed control are over. In addition to achieving effective weed control, herbicide programs should be selected based on their ability to manage herbicide resistance. This involves including multiple Herbicide Groups that are effective against specific, problem weeds in the field.

Agronomic fields have diverse weed communities typically consisting of 20 or more weed species. In most fields, these communities are dominated by a few species - the dominant weeds are those best adapted to the current production system. When developing herbicide programs that minimize risks associated with herbicide resistance, the focus should be on the weeds that are prone to evolving resistance. In Iowa, the number one concern is waterhemp. Other resistant-prone weeds include giant ragweed and horseweed/marestail.

A useful exercise is evaluating programs to determine the number of Herbicide Groups that place effective selection pressure on individual weed species. A herbicide is considered to place selection pressure on a weed if that herbicide would provide acceptable control of the weed if it were applied by itself at the rate and timing that it is used in the herbicide program.

A herbicide program recommended by a local coop for no-till corn is presented below. This program includes active ingredients from six different Herbicide Groups (2, 4, 5, 9, 19 and 27). Each active ingredient in this program contributes significantly to overall weed control, but how many of these products would place significant selection pressure on waterhemp in the manner they are used in this program?
Table 2. Example of a typical corn herbicide program used in Iowa.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>1.7 oz Prequel</td>
<td>2 and 27</td>
<td>28 oz Roundup WeatherMax</td>
<td>9</td>
</tr>
<tr>
<td>+ 0.75 lb atrazine</td>
<td>5</td>
<td>+ 2.5 oz Status</td>
<td>4 and 19</td>
</tr>
<tr>
<td>+ 0.5 pt 2,4-D</td>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total number of sites of action (herbicide groups) 6

Number of effective sites of action on waterhemp 1, 2, 3, 4, 5 or 6?

Analysis of the activity of individual components on waterhemp (using Table 2 example)

Prequel: Premix of rimsulfuron (Group 2) and isoxaflutole (Group 27). Label rate is 1.66 - 2.5 oz/A.
- Rimsulfuron: Almost all waterhemp is resistant to Group 2 herbicides, so rimsulfuron would not contribute to waterhemp control.
- Isoxaflutole: Active on waterhemp, but 1.7 oz Prequel provides the equivalent of 1 oz of Balance Pro. The label rate of Balance Pro is 1.5-3.0 oz/A. The amount of isoxaflutole in the Prequel is not likely to provide full-season waterhemp control.

Atrazine (Group 5): 0.75 lb/A is too low of a rate to provide full-season waterhemp control. In addition, triazine resistant waterhemp populations occur throughout Iowa.

2,4-D (Group 4): Included to control weeds present prior to planting; little waterhemp will have emerged at the time of the preplant application, thus 2,4-D places little selection pressure on waterhemp.

Roundup WeatherMax (Group 9): 28 oz should provide effective control of susceptible waterhemp.

Status: Premix of dicamba (Group 4) and diflufenzopyr (Group 19). Label rate is 5-10 oz/A when applied alone.
- Dicamba: Effective on waterhemp, but this is a reduced rate (equivalent to 2 oz Clarity) that is unlikely to provide effective control of waterhemp.
- Diflufenzopyr: Primary role is to enhance activity of dicamba, so alone will not control waterhemp.

Whether a herbicide provides effective control of waterhemp, or another weed of concern, is dependent upon the rate used, application timing, presence of resistant biotypes, environment, and other factors. The decision on whether to give a specific herbicide credit for controlling a particular species is subjective. Based on the analysis above, only glyphosate would place significant selection on the waterhemp population. Other herbicides included in the program (isoxaflutole, atrazine, 2,4-D, dicamba) have activity on waterhemp, but in this program they are used in a manner that limits their effectiveness. Some people might argue that the Prequel provides sufficient isoxaflutole to be considered effective on waterhemp, whereas others would make the case that 2.5 oz of Status is sufficient to control waterhemp (5-10 oz is the recommended rate). The process of evaluating herbicide programs is more important than the individual decisions on the effectiveness of each component of the program.

How many effective Herbicide Groups are needed each year to manage herbicide resistance? There is no correct answer to this, but we know that two sites of action are better than one, and three are better than two. It also is important to evaluate programs over time to make sure the same sites of action are not being relied on year after year.

Conclusions

Herbicides are valuable resources that need to be conserved. While new herbicides are continually introduced, it has been more than 20 years since a new Herbicide Group was discovered. During the first 50 years of the chemical era of weed management, the dominant weeds found in our fields were species adapted to mechanical weed control (foxtails, velvetleaf, cocklebur, etc.). In the past 20 years, weeds adapted to chemical forms of weed control have become the main problems. These include waterhemp, giant ragweed and horseweed. To sustain the current production system, we must develop more complex approaches to weed management.
Managing herbicides efficiently will be the first step in reducing herbicide resistance problems for most growers. Not only is it important to incorporate multiple Herbicide Groups into a program, but individual herbicides must be used in a way that insures they place significant selection pressure on the weeds of concern. This involves considering the herbicide rate, timing of application, and application variables (spray volume and pressure, and spray additives).

Due to a limited number of Herbicide Groups, it is unlikely that efficient herbicide use alone will be sufficient to stop the spread of herbicide resistance. Growers must determine which cultural and mechanical tactics are appropriate for their production systems, and incorporate these whenever possible. Iowa has several advantages (soils, climate, etc.) compared to the southeast U.S. where Palmer amaranth has devastated cotton production. It would be a shame to squander these advantages due to complacency.
Spider mite management for corn and soybean
Erin W. Hodgson, assistant professor and Extension entomologist, Entomology, Iowa State University; Mike McCarville, graduate student, Entomology, Iowa State University

Twospotted spider mite, *Tetranychus urticae* (Arachnida: Acari: Tetranychidae), is an occasional pest of corn and soybean in Iowa. However, spider mite damage is more pronounced in crops during moisture-stressed growing conditions (Haile and Higley 2003). In 2012, many fields had significant spider mite feeding and subsequent yield loss (Hodgson 2012).

Description and biology
Adult twospotted spider mites are oval, hairy, and minute (1/50th of an inch long or about half as big as a first instar soybean aphid). Body color can range from tan, brown, yellow, orange or red depending on the species and quality of the host plant. Adults will have eight legs and two dark spots on top of the body. Spider mites are considered common pests in temperate zones and can be found throughout the United States. Females move out of row crops in the fall and deposit overwintering eggs. In the spring, eggs hatch and nymphs begin feeding on weeds, grasses and other permanent vegetation. As these areas are mowed or decline in quality, mites will move back to crops by ballooning on silken webs. In most years around Iowa, we find twospotted spider mites in corn and soybean in August. But this year, we could find them in field crops in June due to the drought. Having spider mites present during vegetative growth can be very stressful to plants and an early indicator of outbreak conditions during the important grain fill stages. The last time spider mites were a widespread, economic issue was the summer of 1988.

Twospotted spider mites normally produce 10-20 generations every year in Iowa. This pest can have exponential growth when temperatures are consistently above 85 degrees, humidity is less than 90 percent, and plants are lacking sufficient moisture. Under ideal conditions, spider mites can mature from egg to adult in 5 days; cooler temperatures can extend development to 19 days.

Damage and distribution
Spider mites injure plants by crushing cells and removing sap. Heavily infested plants will experience lower chlorophyll content and decreased photosynthesis. Injured plants will have decreased transpiration rates (i.e., cooling potential) compared to healthy plants (Haile and Higley 2003). Yield losses exceeding 40 percent are possible in drought-stressed growing conditions (Bynum et al. 1990). Spider mite damage is not reversible on injured leaves. But rain events and mite suppression can help new growth on plants.

Spider mites prefer to feed on the undersides of leaves, and typically start building colonies in the lower plant canopy and along field edges. Initial feeding injury can be described as white spots, stippling or discoloration of the leaves. As mite populations increase, they will move to the upper canopy to feed. Large infestations are usually accompanied with fine silken webbing. Prolonged spider mite feeding can cause premature leafdrop and death.

How to scout for spider mites
Mites are very small pests and some people have trouble seeing them with the naked eye. A hand lens will help with the first detections on leaves. Consider shaking leaves on a piece of white paper and watching for mites to start moving around (they resemble specks of dust). Scout for spider mites on a regular basis throughout the growing season, especially during drought-stressed growing seasons. To see if a field should be scouted, first look at plants along the field edges. If you find mites, take time to sample the entire field by walking a “W” or “Z” pattern. Stop at 20 locations and check 2-3 plants at each location. Note the presence of mites, location on plants, webbing and any discoloration from feeding.
Treatment thresholds

There are not specific spider mite density thresholds (i.e., # mites/leaf). Instead foliar applications should be based on your estimation of plant quality. For corn, the goal is to prevent spider mites from reaching the ear leaf. Consider treating when most plants are infested in the lower canopy and discoloration is starting. Treatments should be made before R1 – R4 (silking – dough). The most important soybean growth stages to protect are R4 – R5 (full pod – beginning seed set). In soybean, consider using a 0-5 rating scale to make treatment decisions:

- 0 – no spider mites or feeding damage observed;
- 1 – spider mites detected on a few plants, minor stippling on lower leaves;
- 2 – spider mites detected on most plants, stippling common on lower leaves, and small patches of yellowing plants can be found;
- 3 – spider mites can be found in the middle canopy, yellow plants common and some premature leaf loss (THRESHOLD);
- 4 – spider mites can be found in the upper canopy, premature leafdrop is common, and stippling can be seen in the upper canopy (ECONOMIC LOSS); and
- 5 – spider mites are easy to find in the upper canopy, plants are browning, some plants are dead.

Pesticide considerations

Product selection is extremely important for spider mite management (Ostlie and Potter 2012a, 2012b). Some products will not kill eggs, and populations can rebound and continue to injure plants. Most products rely on direct contact to successfully reduce spider mites. Therefore, use sufficient volume to reach mites in the lower canopy and on the undersides of leaves (e.g., 20 gpa by ground or 5 gpa by aerial application). Continue scouting after an application to determine if additional sprays are required. Consider rotating chemistries if additional sprays are needed.

Pyrethroids

In general, pyrethroids are not effective in reducing spider mite populations. Pyrethroids have poor efficacy on spider mites, and some populations have developed resistance to this chemistry. Pyrethroids will kill natural enemies and can allow mites to flare to higher densities than before the spray. In some regions of the United States, pyrethroid applications actually trigger females to increase their reproductive rate. One exception, bifenthrin, is shown to be effective against spider mites in soybean. Also consider pyrethroids typically do not perform as well under high temperatures (i.e., above 90 degrees).

Organophosphates

Several active ingredients are available for spider mites in corn and soybean. Dimethoate should perform well against spider mites, but has a short residual. Others, like propargite, spiromesifen and etoxazole, are efficacious against all mite life stages on corn, but are most effective when used as a preventative because they are slow acting products. For soybean, another effective option is chlorpyrifos.

Fungicides

Naturally-occurring beneficial fungi can reduce spider mite populations, but environmental conditions must be ideal for sporulation. The application of fungicides can eliminate beneficial fungi that kill spider mites and allow for exponential growth of the existing population.

2012 Comparison of spider mite treatments

In 2012, we initiated an efficacy evaluation for soybean pests in soybean at the ISU Northeast Research Farm in Floyd County, Iowa. Plots (six 30-inch rows wide x 50 ft long) were randomized in a complete block design and replicated four times per treatment. Syngenta soybean variety 05RM310021 was used for all the soybean aphid susceptible treatments, and Syngenta soybean variety 07JR801843 was used for the soybean aphid-resistant (i.e., Rag1) treatments. Unless specifically noted, seed did not have a pesticidal seed treatment. Twenty nine treatments were evaluated in 2012, including a combination of insecticides and fungicides, seed treatments and foliar
applications, and host plant resistance to soybean aphid (Table 1).

Soybean plots were sampled weekly in 2012 from 1 June through 30 August (plant stages V1-R7). Although soybean aphids and other soybean pests were monitored, they had a very low abundance all season. Spider mites were evaluated in two ways. The first way was based on the 0-5 injury rating scale outlined above. The second method was to randomly select 10 leaflets from each plot and note the presence or absence of live spider mites. Yield was determined by weighing grain with a hopper and correcting moisture to 13 percent. An analysis of variance (ANOVA) was used to determine treatment effects within each experiment. Means separation was achieved with a general linear mixed model and least significant difference (LSD) test using SAS software (2011).

**Results**

Plots were generally not infested with twospotted spider mites until late July, when plants were in R4, or full pod set. Throughout August, visual ratings ranged from 0-2, and plots never exceeded 40 percent infestation of leaves. At this density, we would not expect yield differences between treatments due to spider mite injury.

Our ANOVA ($\alpha = 0.10$) indicated time was significant of spider mite density indicated time was significant ($F = 32.92, P < 0.0001$) and the interaction of time*treatment was also significant ($F = 1.44, P = 0.0406$). This allowed us to analyze mite densities by the five sampling dates (2, 7, 16, 21, 30 August). Two dates had significant treatment differences, including 16 August ($F = 1.61, P = 0.0451$) and 21 August ($F = 1.67, P = 0.0338$); these two dates were six and eleven dates after foliar application of most treatments. Soybean yield ranged from 52-60 bushels per acre (Figure 1). A mean separation ($\alpha = 0.05$) test of soybean yield was also significant between treatments ($F = 14.53, P < 0.0001$). A discussion of trends between treatments will be provided during the presentation.

**Management Summary**

- Scout corn and soybean for twospotted spider mites regularly throughout the summer, especially during moisture-stressed growing seasons.
- Monitor for developing and dispersing mite populations and plant injury.
- Treat spider mites before widespread plant discoloration and leafdrop occur; continue to monitor fields for resurgent populations.
- If practical, use sufficient volume and pressure with organophosphates to achieve the greatest efficacy.

**Acknowledgments**

I would like to thank Greg VanNostrand for the ongoing data collection of this project. I am also grateful to the Iowa Soybean Association and the soybean checkoff for financial assistance of this project, and the following industry support: BASF, Bayer CropScience, Cheminova, Dupont, Dow AgroSciences, Syngenta, and Valent.

**References**


### Table 1. List of spider mite treatments for the Northeast Farm in 2012

<table>
<thead>
<tr>
<th>Treatment*</th>
<th>Active Ingredient(s)</th>
<th>Rate(^b)</th>
<th>Timing(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated Control</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Rag1</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>CruiserMaxx Beans</td>
<td>thiamethoxam + mefenoxam + fludioxonil</td>
<td>56g/100kg seed</td>
<td>ST</td>
</tr>
<tr>
<td>Rag1 and CruiserMaxx Beans</td>
<td>thiamethoxam + mefenoxam + fludioxonil</td>
<td>56g/100kg seed</td>
<td>ST</td>
</tr>
<tr>
<td>Rag1 and CruiserMaxx Beans and Warrior II CS</td>
<td>thiamethoxam + mefenoxam + fludioxonil</td>
<td>56g/100kg seed</td>
<td>ST</td>
</tr>
<tr>
<td>Warrior II CS</td>
<td>lambda-cyhalothrin</td>
<td>1.92 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Rag1 and Warrior II CS</td>
<td>lambda-cyhalothrin</td>
<td>1.92 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Warrior II CS</td>
<td>lambda-cyhalothrin</td>
<td>1.92 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Lorsban Advanced EC</td>
<td>chlorpyrifos</td>
<td>1 pt</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Dimethoate 4E</td>
<td>dimethoate</td>
<td>1 pt</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Cobalt Advanced EC</td>
<td>lambda-cyhalothrin + chlorpyrifos</td>
<td>13.0 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Warrior II CS + Lorsban Advanced EC</td>
<td>lambda-cyhalothrin + chlorpyrifos</td>
<td>1.6 fl oz + 16.0 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Brigade 2EC</td>
<td>bifenthrin</td>
<td></td>
<td>10 Aug</td>
</tr>
<tr>
<td>Belay SC</td>
<td>clothianidin</td>
<td>3.0 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Belay SC and Brigade EC</td>
<td>clothianidin + bifenthrin</td>
<td>2.0 fl oz + 2.3 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Belay SC</td>
<td>clothianidin</td>
<td>4.0 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Declare CS</td>
<td>gamma-cyhalothrin</td>
<td>1.02 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Declare CS and Dimethoate 4E</td>
<td>gamma-cyhalothrin + dimethoate</td>
<td>1.02 fl oz + 4.0 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Leverage 360</td>
<td>imidacloprid + beta-cyfluthrin</td>
<td>2.8 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Leverage 360</td>
<td>imidacloprid + beta-cyfluthrin</td>
<td>2.8 fl oz</td>
<td>19 July</td>
</tr>
<tr>
<td>Leverage 360 and Stratego YLD</td>
<td>imidacloprid + beta-cyfluthrin + prothioconazole + trifloxystrobin</td>
<td>2.8 fl oz + 4.0 oz</td>
<td></td>
</tr>
<tr>
<td>Fastac EC</td>
<td>alpha-cypermethrin</td>
<td>4.0 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Endigo ZC</td>
<td>lambda-cyhalothrin + thiamethoxam</td>
<td>4.5 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Quilt Xcel SE</td>
<td>azoxystrobin + propiconazole</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warrior II CS and Quilt Xcel SE</td>
<td>lambda-cyhalothrin + azoxystrobin + propiconazole</td>
<td>1.92 fl oz + 13.0 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Cobalt Advanced EC and Headline EC</td>
<td>lambda-cyhalothrin + chlorpyrifos + pyraclostrobin</td>
<td>24.0 fl oz + 12.0 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Besiege ZC</td>
<td>lambda-cyhalothrin + chlorantraniliprole</td>
<td>9.0 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Asana XL</td>
<td>esfenvalerate</td>
<td>9.6 fl oz</td>
<td>10 Aug</td>
</tr>
<tr>
<td>Asana XL and Lannate LV</td>
<td>esfenvalerate + methomyl</td>
<td>8.0 fl oz + 8.0 fl oz</td>
<td>10 Aug</td>
</tr>
</tbody>
</table>

\(^a\) Does not contain a fungicidal/insecticidal seed treatment unless noted  
\(^b\) Per acre unless otherwise noted  
\(^c\) ST = seed treatment
Figure 1. Twospotted spider mite efficacy evaluation at the Northeast Farm for 2012 showing treatment comparisons of soybean yield. Different letters represent a significant difference between treatments.
Assessment of sulfur deficiency in crops: What tools can you use?

Daniel E. Kaiser, assistant professor and Extension nutrient management specialist, Soil, Water, and Climate, University of Minnesota

Introduction

With input and crop prices significantly fluctuating in the last few years soybean growers have been looking for ways to maximize profits per acre. Sulfur application has been increasingly questioned as a method at increasing corn yields across southern Minnesota. However, past research has not shown a positive yield benefit for sulfur applied to corn unless the soils are sandy with low organic matter (Rehm, 2005) and most research has found that soil tests for sulfur do not work in fine textured soils. Currently, 25 lbs of sulfur per acre is recommended for corn when grown on coarse textured low organic matter soils (Rehm et al., 2006). If producers are banding sulfur then recommended rates are cut to 12 to 15 lbs. For many producers band application takes place in the form of starter fertilizer (small amount of fertilizer applied with the seed at planting). In Minnesota ammonium polyphosphate [APP (10-34-0)] is a popular choice for many producers as a starter fertilizer. However, many are tempted to mix sulfur containing products with APP in order to boost yields which is risky since this is not a recommended practice due to concerns with stand loss from the seed applied fertilizer (Rehm et al., 2006). Since many producers apply their dry fertilizers in the fall there are concerns with the loss of sulfate sulfur in the early spring through leaching and not adding yield to the next year’s crop.

Over the past five to ten years yellow areas attributed to nitrogen deficiency in fields have developed that have not responded to additional applications of nitrogen fertilizer. Additionally, work in Northeast Iowa has shown that sulfur deficiencies are possible in fine textured soils (Sawyer and Barker, 2002; Sawyer et. al., 2009) that were eroded or had low organic matter content. Other research in southern Minnesota has noted occasional crop responses in areas where none were expected in the past (Randall and Vetsch, unpublished data). Many fields in Southcentral and Southeastern Minnesota have a rolling topography. In many of these fields yellowing can be visually noted throughout the growing season which could be a symptom of either sulfur or nitrogen deficiency. The question is can a specific nutrient deficiency be separated out in these areas and what kind of variability in the response to nutrient can be expected across a landscape.

A replicated strip trial study was conducted at multiple southern Minnesota locations with the following objectives:

1. Examine how different soils in a landscape may respond to sulfur fertilization
2. Evaluate how the application of nitrogen and phosphorus fertilizers mixed with sulfur may affect plant growth and the overall uptake and response from sulfur fertilization

Experimental methods

Four corn trials were established in 2008 and 2009 (Table 1). A replicated strip trial methodology was used at each location. Fertilizer strips measuring 10 to 20 feet (4 to 8 30 inch corn rows) wide and 520 to 880 feet long were established parallel to the direction of the corn rows in which six treatments were applied, randomized, and were replicated three to four times at each location. Treatments were a control with no starter or sulfur fertilizer, broadcast sulfur applied at 25 lbs S per acre and four starter fertilizer mixes were applied as field length strips. The starter fertilizer treatments consisted of 20 lbs of N/acre, 20 lbs of P₂O₅/ac, and 25 lbs of S/acre applied in combinations of N only, N+P, N+S, and N+P+S. Liquid fertilizer treatments were applied two inches beside and below the seed with a John Deere 7000 series planter equipped to simultaneously apply 28% UAN, ammonium polyphosphate (10-34-0), and ammonium thiosulfate (12-0-0-26s) to achieve the targeted starter rates. Dry potassium sulfate (0-0-50-18s) was used as the broadcast sulfur source and potassium chloride (0-0-60) was applied at high enough rates to limit crop response to strips not receiving potassium sulfate (potassium application rate was identical across the trial areas). Additional nitrogen and phosphorus fertilizer and lime were applied according to recommended rates by the farmer.

Within each rep across treatment strips the field areas were segmented into 120 foot increments for soil sampling. These increments represented grid cells within the trial area measuring 60 to 120 feet wide and 120 feet long.
Results and discussion

Analysis of strip mean data at each location showed no significant (P<0.05) increase in yield at any location in spite of large variations in numerical values within treatments (Table 2). For example, at Albert Lea the control treatment averaged 168 bu/acre while the N + S treatment was 212 bu/acre. It is likely that the large variation in potential for yield response across some locations were affecting the analysis. Large variations in soil test values may influence the potential for yield responses within individual locations. Soil test phosphorus and sulfur were used to compare treatment responses but results were inconclusive therefore data are not shown. The relationship between 0-6” soil test sulfur and yield response to sulfur was better correlated than any other factor. Data in Figure 1 shows yield response to sulfur compared to soil organic matter level at Clarkfield, Clarks Grove, and Albert Lea. Data from Isanti was left out due to potential interactions with low soil test P within that location. The regression between soil organic matter (0-6”) and yield response to sulfur shows a yield increase until 2.6% (r²=0.39). However, several points from Albert Lea included in the data set appeared to be responsive to a higher soil organic matter value. These data points were excluded from the analysis, but their inclusion only resulted in a change of 0.1%. This data was used to divide soil organic matter levels into Low, Medium, and High levels to analyze individual areas within the trials separately similar to an analysis conducted by Bermudez and Mallarino (2002).

Since relative yields were generally lower when soil organic matter levels were below 2.0% this value was considered Low. Responses above 4.0% were rarely seen therefore this level was considered High. Yield responses were sometimes between 2.0 and 4.0% therefore this level was considered to be Medium. Figure 2 shows the analysis by soil organic matter levels for each location. At Clarkfield organic matter levels were Medium and High and there was no response to any starter or sulfur treatment at his location (LSD P<0.05). At Isanti all cells fell in the low category but there was no significant yield response. This was likely due to interactions between low P and S at this location. In addition this site was significantly limited by soil moisture mid to late in the growing season which caused some plots to have very low yields limiting the potential for yield responses. This field would likely see a high potential for response to sulfur during most years. At Clarks Grove the trial was divided into both Low and Medium organic matter values, but yields were only increased by sulfur when organic matter levels were Low (<2.0%). In this case single degree of freedom contrasts indicated a significant increase in yield from sulfur applied as a starter. This field also tested low is soil P, but there was no evidence of a yield increase due to this nutrient. It was surprising that broadcast sulfur did not increase yields compared to starter applied sulfur. This effect could be a result of the band placement or a potential interaction between nitrogen and sulfur which could not be determined with the experimental design. The Albert Lea location had the greatest differences in soil organic matter levels with areas testing Low, Medium, and High. These areas represented hilltop, sideslope, and toeslope positions, respectively. When soil organic matter was High there was no yield increase from sulfur or starter fertilizer treatments and yield potential was the highest within the field. When soil organic matter levels were Low sulfur increased yields the greatest and nitrogen increased yields slightly less. This indicates that sulfur may give the greatest potential yield increase at these organic matter levels, but nitrogen may also influence yield and may be an important factor as well. When soil were greater than 2.0% but less than 4.0% the starter applied sulfur resulted in the greatest yield increase while starter N and broadcast S also increased yields, but not at the same magnitude. It is likely that for similar field the application of sulfur would generally result in a positive yield benefit and that targeted application of sulfur may provide the best return for a corn producer.

Since the Albert Lea location had the largest potential yield increase than the other sites, an analysis was done within that location to study different predictors for yield increases due to sulfur. Both plant and soil factors were
considered with the yield response to applied sulfur. Plant response data are given in Figure 3. Four factors were considered, V5 whole plant sulfur concentration, V5 sulfur uptake (concentration times individual plant mass), ear leaf sulfur concentration at R2, and sulfur concentration in the harvested grain. Sulfur concentration at V5 provided the poorest correlation with response to sulfur. In fact there was no significant relationship between the two variables. The correlation was better for both V5 sulfur uptake and ear leaf sulfur concentration but was the greatest between grain sulfur concentration and response to applied sulfur. This indicates that plant analysis is a better predictive tool when samples are collected later in the season. However, this late of a collection date does not allow for any corrective measures if a deficiency is detected. The relationship with sulfur uptake at V5 is somewhat surprising. However, examination of the data shows some a few significantly higher points that are likely affecting the relationship. If those points were deleted it is likely that there would be a poorer relationship between uptake and yield response to sulfur. Visual deficiency symptoms were seen at this location early in the season. However, their appearance may not have been fully reflected in final yield of the plant.

Soil test sulfur collected prior to planting did not correlate well to final yield (Figure 4). The test used in this instance was KCl extractable S which differs from the recommended test for the north central region. However, in other research we have not seen a better correlation with other tests and yield (data not shown). A two foot sample was used in this case but there still was no effect when considering soil test sulfur concentration. However, when sulfur was converted into lbs per acre there was a significant linear relationship. When considering the R² value there was little predictability of final yield (R²=0.16). The best relationship was seen with 0-6" soil organic matter concentration. At this location there appeared to be increases in yield up to about 7.5% soil organic matter concentration within the top 6 inches. This is higher than other research and may be reflective of a higher potential for sulfur response at this particular field in during the year of the study. It does appear that soil test sulfur may be the best predictor before planting of where a response to sulfur may occur.

Conclusions

Sulfur concentration in the grain and soil organic matter concentration in the top 6 inches provided the best predictors of where a sulfur response will occur. Sulfur fertilization increased corn yields consistently when soil organic matter levels were below 2.0% and sometimes between 2.0 and 4.0%. Since the data provided applied sulfur at the same rate, we cannot determine the amount of sulfur that should be applied. Further research is needed to establish whether rates need to be varied for the differing organic matter levels.

References


Brown, JR 1998 Recommended chemical soil test procedures for the North Central region North Central Regional Publ 221 (Revised) Missouri Agric Exp Stn, Columbia, MO.


Table 1. Soil test averages across grid cells for corn locations from the 0-6, 6-12, and 12-24" soil depths.

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>County</th>
<th>Series</th>
<th>Class</th>
<th>Depth</th>
<th>Olsen P</th>
<th>Potassium</th>
<th>pH</th>
<th>AVG</th>
<th>StDEV</th>
<th>AVG</th>
<th>StDEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Clarkfield</td>
<td>Y. Medicine</td>
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<td>89</td>
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<td>3.1</td>
<td>1.7</td>
<td>4.5</td>
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† Cl, clay loam; L, loam; FSL, fine sandy loam; SL, silt loam
I AVG, average across grid cells; StDEV, standard deviation across grid cells.

Table 2. Corn grain yield average values across trial locations for treatment with and without sulfur. Treatments means within locations with the same letter following numbers are not significantly different (LSD P<0.05)

<table>
<thead>
<tr>
<th>County</th>
<th>No Starter†</th>
<th>Starter N</th>
<th>Starter N + P</th>
<th>P&gt;F</th>
</tr>
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<tr>
<td></td>
<td>- S</td>
<td>+ S</td>
<td>- S</td>
<td>+ S</td>
</tr>
<tr>
<td>Clarkfield</td>
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<td>Clarks Grove</td>
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<td>159</td>
<td>164</td>
<td>176</td>
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<tr>
<td>Isanti</td>
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<td>82</td>
<td>77</td>
<td>83</td>
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<tr>
<td>Albert Lea</td>
<td>168</td>
<td>187</td>
<td>188</td>
<td>212</td>
</tr>
</tbody>
</table>

† No Starter, strip average that did not receive starter fertilizer without (-S) and with (+S) broadcast sulfur.

When SOM(0-6")<2.57:  20.7+62.3x-12.1x^2
r^2=0.38  P<0.0001

Figure 1. Comparison of relative corn yields for treatments with and without sulfur versus soil organic matter (0-6") at all locations with clay- or loam soil textures. Points within the outlined box were not included in the final data analysis.
Figure 2. Analysis of actual corn grain yield by soil organic matter level at each location for Low (0-2%), Medium (2-4%), and High (>4%) levels in the top 6” of soil based on data in Figure 1. Small letters above bars represent LSD values (P<0.05) within organic matter levels. (**. Indicates a significant response according to single degree of freedom contrasts)
Figure 3. Summary of V5 sulfur concentration, V5 sulfur uptake, ear leaf sulfur concentration at R2, and sulfur concentration in the harvested grain versus yield response to applied sulfur at the Albert Lea location in 2009.

Figure 4. Soil test summaries for samples collected in Spring 2009 prior to treatment application versus yield response to applied sulfur. Yield response was compared to sulfur concentration and total sulfur (lbs/ac) in a 2’ composite soil sample and soil organic matter concentration in the top six inches.
Nitrogen and tillage management for corn following alfalfa

Jeff Coulter, Extension corn specialist, University of Minnesota; Matt Yost, graduate research assistant, University of Minnesota; Michael Russelle, research soil scientist, USDA-Agricultural Research Service.

Yield boost when corn follows alfalfa

Rotating alfalfa with corn can increase corn yield potential through improved soil physical properties that enhance water infiltration and root extension, a reduction in disease and pest pressure (i.e., corn rootworm), and an enhanced soil microbial community. For example, over 15 years on a silt loam soil in southwestern Wisconsin with nitrogen (N) fertilizer applied at rates high enough to maximize corn yield in all crop rotations, yield was 19% (27 bushels/acre) higher for first-year corn after alfalfa than continuous corn, while second-year corn after alfalfa and corn after soybean yielded similarly and 10% (16 bushels/acre) higher than continuous corn (Stanger et al., 2008). In comparison, over 26 years on a loam soil in northeastern Iowa with N fertilizer rates sufficient for maximum yield, corn grain yields were highest for first-year corn after alfalfa and corn after soybean, intermediate for second-year corn after alfalfa, and lowest with continuous corn and second- or third-year corn after soybean (Mallarino and Ortiz-Torres, 2006). Conversely, high water removal by alfalfa can reduce the yield of the following corn crop in dry years if there is insufficient recharge of water in the soil profile during the fall or spring prior to corn.

Substantial nitrogen credits from alfalfa to corn

Another benefit from alfalfa is the N that is supplied to the following corn crops. When compared to continuous corn, guidelines from universities in the Midwestern U.S. suggest that fertilizer N needs following the termination of a good stand of alfalfa (at least four plants/square foot) can often be reduced by up to 100% for first-year corn and by up to 50% or more for second-year corn (Table 1). These N credits from alfalfa to corn are largely the result of N-rich inputs to the soil organic matter pool. These inputs which include alfalfa leaves and stems lost during harvest, alfalfa leaves abscised during regrowth, alfalfa stand losses over time, turnover of thin alfalfa roots, and exudation of substances from alfalfa roots, can rapidly mineralize after alfalfa stand termination and release N for at least two years.
Table 1. Nitrogen (N) credit recommendations from universities in the Midwestern U.S.

<table>
<thead>
<tr>
<th>State</th>
<th>1st-year N credit</th>
<th>2nd-year N credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illinois</td>
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<td>30</td>
</tr>
<tr>
<td>Indiana</td>
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</tr>
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<td>Iowa</td>
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<td>---</td>
</tr>
<tr>
<td>Michigan</td>
<td>140</td>
<td>---</td>
</tr>
<tr>
<td>Minnesota</td>
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<td>75</td>
</tr>
<tr>
<td>Missouri</td>
<td>100</td>
<td>---</td>
</tr>
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<td>Nebraska</td>
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<td>150</td>
<td>75</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>150</td>
<td>50</td>
</tr>
</tbody>
</table>

*Guidelines from Iowa State University suggest 0 to 30 lb N/acre for first-year corn following alfalfa, and 0 to 60 lb N/acre for second-year corn following alfalfa.

Previous research in the northern U.S. found that the grain yield of first-year corn following alfalfa was not increased with fertilizer N in 91% of 140 fields (cited in Yost et al., 2012). These fields had good alfalfa stands at the time of termination, were in alfalfa production for at least one full year prior to termination, were typically terminated in the fall and with tillage, and generally had deep soils with medium to fine texture. Fields with the most frequent N response tended to have fine-textured soils that were inadequately drained or course-textured soils, coupled with excess rainfall between the time of alfalfa termination and early-season corn growth.

Recent on-farm research confirms first-year nitrogen credits from alfalfa to corn

To determine whether alfalfa N credit guidelines for first-year corn still apply with contemporary, high-yielding corn crops, we conducted research on 31 farms across Minnesota and western Wisconsin from 2009 to 2011. The first study evaluated the response of first-year corn yield to fertilizer N applied near planting on five farms in 2009 and on five farms in 2010 that had good alfalfa stands at the time of termination and medium- to fine-textured soils (Yost et al., 2012). First-year corn yield averaged over 195 bushels grain/acre on seven of the ten farms and over 24 tons silage/acre (at 65% moisture content) on seven of the nine farms where it was measured, yet first-year corn grain and silage yields were not increased when fertilizer N rates up to 160 lb N/acre were applied. On seven of these ten farms, residual soil nitrate-N was measured to a depth of four feet in the fall after corn harvest. Results showed minimal increase in residual soil nitrate-N when 40 lb N/acre was applied near planting, likely due to luxury consumption by the corn crop. However, residual soil nitrate-N increased rapidly when more than 40 lb N/acre was applied. A high amount of residual soil nitrate-N remaining after harvest is a concern because the N is susceptible to loss through leaching and denitrification.

The second study that we conducted evaluated the response of first-year corn to fertilizer N, and whether this was affected by the amount of alfalfa regrowth in the fall and the timing of tillage (disk-chiseling) for alfalfa termination (Yost et al., 2012). 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. Surprisingly, the presence of fall alfalfa regrowth did not affect first-year corn grain or silage yields or their response to fertilizer N applied near
planting (0-160 lb N/acre), even though this alfalfa regrowth ranged from 4 to 18 inches with 9 to 52 lb N/acre among the six farms. Similarly, there was no effect of tillage timing on first-year corn grain and silage yields. These results indicate that growers should harvest alfalfa regrowth in the last year on medium- to fine-textured soils with good alfalfa stand densities, and that growers have some flexibility in tillage timing when terminating alfalfa. In this study, first-year corn grain yield responded to fertilizer N at only one of six farms, even with average yields of 180 to 231 bushels/acre. On the one responsive farm where 70 to 81 lb N/acre were 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. However, across all farms fertilizer N was needed (42-64 lb N/acre) to economically optimize corn silage yield, even though silage yield was increased by just 3% with fertilizer N.

No-till can work well for first-year corn after alfalfa

In 2010 and 2011, we conducted a third study on seven no-till farms across southern Minnesota and western Wisconsin to evaluate the response of first-year, no-tillage corn grain and silage yields to N fertilizer applied near planting (0-160 lb N/acre) (Yost et al., 2012). These farms had medium- to fine-textured soils and good alfalfa stands at the time of alfalfa stand termination, and the cooperating farms applied a small amount of starter fertilizer N at planting. Grain yield on these seven farms averaged 199 to 220 bushels/acre and silage yield averaged 21.1 to 30.3 tons/acre (at 65% moisture content) on the four farms where it was measured, yet grain and silage yields were not increased with fertilizer N. On one of these farms with clay loam soil in southwestern Minnesota we also compared no-till with fall disk-chiseling, but found no differences in grain yield or its response to fertilizer N.

When nitrogen is needed for first-year corn after alfalfa, a small sidedress rate can suffice

In 2011, a fourth study was conducted on eight farms in southern and central Minnesota with medium- to fine-textured soils and good alfalfa stands at the time of termination with tillage. In this study, we evaluated the response of corn grain yield to fertilizer N applied near planting or as a sidedress application when corn was at the six leaf collar stage. Grain yield was increased with fertilizer N on just two of these eight farms. When N fertilizer was applied near planting, the economically optimum N rate was 40 lb N/acre on one farm and 80 lb N/acre on the other, but equivalent yields were obtained on both farms with a sidedress application of only 40 lb N/acre. Response to fertilizer N on these two farms in 2011 was likely related to above-average early-season precipitation and low oxygen levels in the soil that limited mineralization of N.

Management summary

- There is increased yield potential when corn is planted after alfalfa compared to other crops.
- If possible, harvest alfalfa regrowth in the fall before stand termination, especially if the alfalfa stand density is good.
- No-till can work well for first-year corn after alfalfa, even on fine-textured soils.
- In recent trials in Minnesota and western Wisconsin on medium- to fine-textured soils with good alfalfa stands at termination, first-year corn grain yield was increased with fertilizer N on only 3 of 31 farms (Figure 1).
- For first-year corn after alfalfa, it may be more common for silage corn to respond to a small amount of N than grain corn.
- Soil nitrate-N after harvest can increase greatly if rates above 40 lb N/acre are applied to first-year corn after alfalfa when supplemental N is not needed to optimize yield.
- The chance of first-year corn after alfalfa responding to N can increase if there is significant rainfall between alfalfa termination and early-season corn growth on coarse-textured soils or on fine-textured soils that are inadequately drained.
- If one anticipates that N fertilizer will be needed for first-year corn after alfalfa, consider a small amount of N in a starter fertilizer, or consider a small sidedress application (around 40 lb N/acre) depending on early-season weather and crop conditions rather than a high N rate applied near planting.
Figure 1. Economically optimum fertilizer nitrogen (N) rate for N applied near planting on 31 farms in Minnesota and western Wisconsin from 2009 to 2011, based on a fertilizer N cost ($/lb N)/grain price ($/bu) ratio of 0.07. Fertilizer N increased corn grain yield on just 3 of 31 farms.

Acknowledgements
The authors greatly appreciate the financial support for this research, which was provided by the Minnesota Corn Growers Association, the Minnesota Agricultural Fertilizer Research and Education Council, the USDA-Sustainable Agriculture Research and Education Program, the Minnesota Agricultural Water Resource Center, the Hueg-Harrison Fellowship, and the USDA-Agricultural Research Service.

References


Enhancing continuous corn production in high residue conditions with N, P, and S starter fertilizer combinations and placements

Jeffrey Vetsch, assistant scientist, Southern Research and Outreach Center, University of Minnesota; Daniel Kaiser, Extension nutrient management specialist and assistant professor, Soil, Water, and Climate, University of Minnesota; and Gyles Randall, professor emeritus, Southern Research and Outreach Center and Dept. of Soil, Water, and Climate, University of Minnesota.

Introduction

Crop rotations in the Midwest have changed from the traditional corn-soybean rotation to more corn-intensive rotations. Due to the expanding demand for corn to supply the ethanol industry and the increasing insect and disease challenges facing soybean producers, some farmers are switching to a corn-corn-soybean rotation or for some, continuous corn. These rotations produce large amounts of biomass (corn stover) that often remain on the soil surface with present day tillage systems. This is good in terms of erosion control, but can be a significant problem from the stand point of seedbed preparation, early corn growth, and yield.

Corn dominated crop rotations present a huge tillage challenge to corn producers on many poorly drained, colder soils of the northern Corn Belt because corn yields following corn are generally reduced significantly when conservation tillage practices are used. Research by Randall and Vetsch (2010) has shown many of the early growth and yield problems associated with corn after corn could be eliminated by using conventional tillage (i.e. moldboard plow) in combination with fluid starter fertilizers. Generally, for most northern Corn Belt farmers the moldboard plow is not an option, because of increased potential for erosion, lack of equipment, or the labor/time needed to plow large acreages. This research also showed fluid starter fertilizers [ammonium polyphosphate (APP, 10-34-0) applied in furrow or APP and urea ammonium nitrate (UAN, 28-0-0) dribbled on the soil surface] significantly increased early growth of corn by 13 to 43% and corn yield by 5 to 7 bu/ac. This study did not address a commonly asked question, would dual placement (APP in furrow and UAN dribbled on the soil surface) further enhance corn production.

Continuous corn generally shows slow early growth, pale spindly plants, and reduced yields with reduced tillage systems. Sulfur deficiency in corn has contributed to some of these pale looking plants. Corn yield responses to sulfur have been reported on medium and fine-textured soils in Minnesota and Iowa (Vetsch and Randall, 2010). In Minnesota we have very little data on the optimum rate and placement of sulfur containing fluid starter fertilizers for corn. With increased costs and price volatility of fertilizers, farmers have questions about what products, placements, and rates, give them the most “bang for their buck”.

The objectives of this study were to: 1) determine the effects of fluid starter fertilizer combinations and placement of 10-34-0 (APP), 28-0-0 (UAN), and 12-0-0-26 ammonium thiosulfate (ATS) on second-year corn production in reduced tillage/high-residue conditions and 2) provide management guidelines on placement and rates of UAN, APP, and ATS combined as a starter for crop consultants, local advisors, and the fertilizer industry as they serve corn producers trying to meet the growing needs for corn grain by the ethanol industry and livestock producers.

Experimental procedures

Two field experiments were established each spring in 2010 and 2011. One on a Webster clay loam soil at the Southern Research and Outreach Center, Waseca and another on a Mt Carroll silt loam near Rochester. All sites were planted to corn the previous year and were fall chisel plowed after harvest. Fourteen total treatments were arranged in a randomized, complete-block design with four replications. Twelve of the 14 treatments comprised a factorial combination of sources and rates of three fluid starter fertilizers: 0 or 4 gal/ac of APP (5+16+0, lb/ac of N, P2O5, and S, respectively); 0 or 8 gal/ac of UAN (24+0+0); and 0, 2, and 4 gal/ac of ATS (2 gal = 3+0+5.8 and 4 gal = 5+0+11.5). The APP fluid starter was applied in-furrow with the seed while UAN and ATS were applied as a dribble band on the soil surface about 2” off the seed row. Two additional treatments were included to measure crop
response when adding 1 gal/ac of ATS in-furrow with 4 gal/ac of APP with and without 8 gal/ac of UAN dribbled on the soil surface. Each plot was 10’ wide (4 30-inch rows) by 50’ long. Soil samples (0-6” depth) were taken from each rep to characterize the research plot areas. Soil test P and K at 3 of the 4 sites were in the high to very high range (Kaiser et al.), except at Rochester in 2011 where Bray P₁ = 13 ppm (medium) and exchangeable K = 68 ppm (low). Because of low soil test K, 120 lb K₂O/ac was injected mid-row at Rochester on June 9, 2011.

Corn was planted at 35,000 seeds/ac in early May in 2010 and mid-May in 2011. Weeds were controlled with a combination of pre and post emergence herbicide applications. Surface residue cover was measured using the line transect method. It ranged from only 12% at Rochester in 2011 to 45% at Waseca and averaged 34% across sites. In early June, stand counts were taken on the center two rows of each plot and were thinned to a uniform plant population. At V2 to V3, UAN was injected at various rates midway between the rows to give a total (planting + V2-3) N rate of 180 lb/ac in 2010 and 200 lb/ac in 2011. At the V7-8 growth stage of corn 8 random plants from each plot were cut at ground level, dried, weighed to determine dry matter yield, ground, and analyzed for N, P, K and S concentration and uptake in plant tissue. On the same dates, extended leaf plant heights from 10 random plants per plot were also measured. At R1, SPAD meter readings were taken from the ear leaf of 30 plants in each plot. Relative leaf chlorophyll content was calculated from these measurements. Grain yield and moisture content were determined by harvesting the center two rows of each plot with a research plot combine. Grain yields were calculated at 15.5% moisture.

Results and discussion

The 2010 growing season was warm and wet. Two months [June (9.64”, 5.42” greater-than-normal) and September (12.66”, 9.47” greater-than-normal)] set 96-year records for precipitation at Waseca (Table 1). The June + July total precipitation (16.25”) and the growing season total (34.61”) were also records. Growing season precipitation at the Rochester location was about 50% greater-than-normal. With much of the excess falling during the months of June, August, and September. At Waseca, growing degree units (GDU) for the entire growing season May 1 through October 3 (first frost) totaled 2,606 which was 8% greater-than-normal.

The 2011 growing season started out cool and wet at Waseca (Table 1). A wet April and May resulted in delayed planting and slow early growth of corn. Over 3 inches of rain occurred in the two week period after planting. The months of May, June and July all had greater than normal precipitation. July was very warm, air temperatures averaged 5° greater than normal (data not shown). August and September were dry with precipitation for the two months totaling 6.64 inches below normal. The dry conditions in the latter part of the growing season probably reduced yields and increased variability in the data. Growing degree units (GDU) from May 1 through September 15 (first frost) were near normal.
Table 1. Precipitation at Waseca and Rochester and growing degree units (GDUs) at Waseca.

<table>
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<tr>
<th>Month</th>
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<th>Precipitation</th>
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<td></td>
<td>Current</td>
<td>Normal&lt;sup&gt;1/&lt;/sup&gt;</td>
<td>Current</td>
<td>Normal&lt;sup&gt;1/&lt;/sup&gt;</td>
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<tr>
<td></td>
<td></td>
<td>inches</td>
<td>inches</td>
<td>inches</td>
<td>inches</td>
</tr>
<tr>
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</tr>
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<td>18.85</td>
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</table>

<sup>1/</sup> 30-Yr normal, 1981-2010.

The early part of the 2011 growing season at Rochester was cool but not as wet as Waseca (Table 1). Although the amounts were not great, frequent rains delayed planting and field operations in the area. July was warm and wet; precipitation totaled 4.66 inches greater than normal. August was dry, but September had near normal precipitation which aided late season grain fill and enhanced yields. Growing season precipitation totaled one inch below normal. Because of differences in climate and response to treatments, each location-year will be discussed separately.

Waseca 2010

Treatment effects on grain moisture and grain yields are presented in Table 2. Grain moisture was reduced 0.9 percentage points with APP (4 gal/ac vs 0 gal) and UAN (8 gal/ac vs 0 gal) application. Grain moisture was reduced 1.5 and 2.5 percentage points with the 2 and 4 gal/ac rate of ATS, respectively, compared with 0 gal of ATS and averaged across APP and UAN treatments. The driest grain (16.5%) was obtained when N, P, and S were applied at planting (treatment # 12). The wettest grain (20.7%) was found in the control plot (treatment # 1). Corn grain yields were not affected by the application of APP or UAN at planting, although APP and UAN application enhanced early growth and reduced grain moisture. Grain yields were 9 bu/ac greater than the control with 2 gal/ac of ATS, when averaged across APP and UAN treatments. Yields were not different between the 2 and 4 gal/ac rates of ATS. Applying 1 gal/ac of ATS and 4 gal/ac of APP in-furrow increased yields 12 bu/ac compared with APP alone (treatments 13 vs 7). A significant UAN×ATS interaction for grain yield showed a 19 bu/ac response to ATS when UAN was not applied, but no response to ATS when 8 gal/ac of UAN was applied at planting (data not shown).
# Table 2. Grain moisture and yield, plant stand, final plant population, relative leaf chlorophyll, plant height, dry matter yield and nutrient uptake at Waseca in 2010.

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**Stats for RCB design (all 14 treatments)**

| P > F: | 0.001 0.021 0.057 0.022 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 |
| Average LSD (0.10): | 1.1 10 0.9 0.4 1.6 1.4 91 3.7 0.44 4.3 0.20 |

**Stats for a Factorial Design (Treatments 1-12)**

**APP (10-34-0) applied in-furrow**

| None | 18.6 214 34.5 33.7 95.1 32.7 683 26.4 3.04 31.9 1.41 |
| 4 gal/ac | 17.7 214 34.0 33.5 95.6 35.3 767 28.5 3.36 35.7 1.51 |
| P > F: | 0.001 0.998 0.059 0.252 0.223 0.001 0.005 0.080 0.026 0.006 0.112 |

**UAN (28-0-0) applied as a surface dribble band**

| None | 18.6 216 34.3 33.6 94.9 32.4 617 23.3 2.70 28.8 1.26 |
| 8 gal/ac | 17.7 212 34.2 33.6 95.8 35.5 834 31.6 3.70 38.8 1.67 |
| P > F: | 0.002 0.193 0.566 0.963 0.022 0.001 0.001 0.001 0.001 0.001 0.001 |

**ATS (12-0-0-26) applied as a surface dribble band**

| None | 19.5 209 34.3 33.7 91.1 32.5 650 24.3 2.86 30.3 1.23 |
| 2 gal/ac | 18.0 218 34.6 33.7 96.1 34.6 763 29.3 3.36 35.9 1.52 |
| 4 gal/ac | 17.0 215 33.9 33.4 98.8 34.8 764 28.8 3.38 35.1 1.64 |
| P > F: | 0.001 0.012 0.081 0.037 0.001 0.001 0.003 0.002 0.005 0.003 0.001 |
| Average LSD (0.10): | 0.5 5.1 0.5 0.2 0.8 0.7 59 2.41 0.28 2.7 0.13 |

**Interactions (P > F)**

| APP×UAN | 0.675 0.194 0.248 0.035 0.736 0.001 0.187 0.062 0.056 0.452 0.052 |
| APP×ATS | 0.341 0.680 0.802 0.854 0.032 0.593 0.529 0.680 0.148 0.116 0.637 |
| UAN×ATS | 0.649 0.009 0.645 0.705 0.018 0.353 0.306 0.395 0.274 0.155 0.825 |
| APP×UAN×ATS | 0.488 0.719 0.109 0.026 0.872 0.383 0.886 0.922 0.973 0.840 0.916 |

* One gal/ac rate of ATS applied in-furrow with seed and 10-34-0.
Treatment effects on plant stand, final population and relative leaf chlorophyll content (RLC) are presented in Table 2. Initial plant stand was reduced slightly (500 plants/ac) with APP fertilization, when averaged across UAN and ATS treatments. Initial stand and final plant population were affected by ATS application in this study, but the differences were generally very small and would not have affected corn production. When 1 gal/ac of ATS and 4 gal/ac of APP were applied in-furrow (treatment # 13), initial plant stand and final population trended lower, but they were not significantly less than 4 gal/ac of APP alone (treatment # 7). Significant interactions for final plant population were found, but the differences were small about 300 plants/ac and would not have influenced corn production. 

Relative leaf chlorophyll content at VT-R1 increased slightly with 8 gal/ac of UAN applied at planting compared with 0 gal of UAN, when averaged across APP and ATS treatments. The 2 and 4 gal/ac rates of ATS increased RLC 5.0 and 7.7 percentage points, respectively, compared with the control (0 gal/ac), when averaged across APP and UAN treatments. One gal/ac of ATS and 4 gal/ac of APP applied in-furrow increased RLC significantly compared with 4 gal/ac of APP alone. No difference in RLC was found when the 1 gal/ac of ATS plus 4 gal/ac of APP applied in-furrow treatment (# 13) was compared to the 4 gal/ac of APP applied in-furrow plus 2 gal/ac of ATS applied as a surface dribble band treatment (# 8). The significant APP×ATS interaction for RLC showed without ATS, APP increased RLC slightly (1-2 percentage points). Whereas with ATS at 2 or 4 gal/ac, APP application had no affect on RLC (data not shown). The significant UAN×ATS interaction for RLC was similar to the APP×ATS interaction. It showed at the 0 and 2 gal/ac rates of ATS, UAN application increased RLC slightly, whereas at the 4 gal/ac rate of ATS, UAN application had no affect on RLC (data not shown). These data show a small amount of N at planting, either from APP applied in-furrow or UAN applied as a surface dribble band, increased VT-R1 RLC values slightly in the absence of ATS. However when ATS was applied, the response in RLC was significantly large and masked any effect of APP or UAN. Interestingly, the 1 and 2 gal/ac rates of ATS resulted in corn plants that were pale (significantly less RLC) when compared to the 4 gal/ac rate, but these treatments produced similar grain yields as the 4 gal/ac treatments. This suggests at this site only a small amount of S (1 gal/ac of ATS = 2.9 lb S/ac) applied in the seed furrow at planting was needed to get a yield response on this high organic matter soil. 

Plant heights and whole plant dry matter yields were affected by all three of the treatment main effects in the factorial analysis of treatments 1-12 (Table 2). Heights and yields were increased when APP was applied in-furrow and when UAN and ATS were applied as a surface band. The 4 gal/ac rate of ATS did not increase heights or yields above the 2 gal/ac rate, when averaged across APP and UAN treatment main effects. A significant APP×UAN interaction for plant height was explained by the magnitude of the response in plant height when fertilized with one vs both of these nutrients. Plant heights increased about 4” when fertilized with either UAN or APP, compared with plots without UAN and APP. Whereas plant heights increased only 2” when fertilized with both UAN and APP, compared with either UAN or APP. The 1 gal/ac of ATS plus 4 gal/ac or APP applied in-furrow treatment increased V7 plant heights and yields compared with 4 gal/ac of APP alone. 

Nutrient uptakes in V7 corn plants were affected by the treatment main effects in this study (Table 2). Applying 4 gal/ac of APP in-furrow increased N, P, and K uptake, when averaged across UAN and ATS treatments. Nitrogen, P, K and S uptakes in corn plants were increased when UAN and ATS were applied at planting. Generally the nutrient uptake responses to treatment main effects found in this study were a result of small plant DM yield responses to treatments and not to increased nutrient concentrations. Significant APP×UAN interactions for N, P and S uptake in V7 corn plants were a result of increased growth and have the same explanation as the APP×UAN interaction for plant height in the previous paragraph (data not shown). 

**Waseca 2011**

Treatment effects on grain moisture, grain yield, and relative leaf chlorophyll content (RLC) are presented in Table 3. Grain was quite dry at harvest (October 3) considering the later than normal planting date (May 17). Application of APP or UAN at planting did not affect grain moisture at this site. Grain moisture increased 1.0 percentage point with 4 gal/ac of ATS compared with 0 gal/ac, when averaged across APP and UAN treatments. Corn grain yields were not affected by the application of APP, UAN or ATS at planting and there were no significant interactions. The wet spring followed by a dry August and September increased yield variability at this site. Yields ranged from 184 to 201 bu/ac. An analysis of all 14 treatments found no significant differences for grain moisture and/or yield. Relative leaf chlorophyll content at R1 was not affected by any of the treatments at this site. Initial plant stand and final plant population were reduced 1200-1300 plants/ac with ATS fertilization, when averaged across APP and UAN treatments (Table 3). The cool and wet period after planting likely contributed to the stand reductions observed in these data. Highly significant APP×ATS and UAN×ATS interactions were found for
initial stand and final plant population. When averaged across UAN rate, plant populations were greatest when APP and ATS were not applied (data not shown). When APP was not applied, populations decreased linearly as the ATS rate increased; whereas, when APP was applied plant populations decreased with 2 gal/ac of ATS but not at the 4 gal/ac rate. These data showed under difficult climatic conditions ATS applied as a surface dribble band can reduce stand, however applying APP (in-furrow) plus ATS (dribble) did not reduce stand further. When averaged across APP rate, surface dribble banding UAN and ATS reduced plant populations compared with ATS alone. Strangely, applying UAN without ATS increased populations. This interaction showed, unlike the response found with APP, applying UAN and ATS may increase the potential for stand reductions.

Plant heights and whole plant dry matter yields were affected by all three of the treatment main effects in the factorial analysis of treatments 1-12 (Table 3). Heights and yields were increased when APP was applied in-furrow and when UAN and ATS were applied as a surface band. Plant heights were greatest with the 4 gal/ac rate of ATS. However, yields were not different among the 2 and 4 gal/ac rates of ATS, when averaged across APP and UAN treatment main effects. A significant APP×UAN×ATS interaction for plant height showed a large increase in plant height with increasing rates of ATS, when APP and UAN were not applied. Whereas, when APP and/or UAN were applied the plant height response to ATS was inconsistent. The significant APP×UAN×ATS interaction for dry matter yield was similar to what was found for plant height. One gal/ac of ATS plus 4 gal/ac or APP applied in-furrow did not affect V7 plant heights or yields compared with 4 gal/ac of APP alone.

Nutrient uptakes in V7 corn plants were affected by the treatment main effects in this study, however the data were quite variable probably due to the cool and wet conditions in late May and June (Table 3). Four gal/ac of APP increased uptake of N, P, K and S. Phosphorus, K, and S uptakes were increased when ATS was applied as a surface band. The nutrient uptake responses to treatment main effects found in this study were generally a result of increased plant dry matter (yield responses) and not to increased nutrient concentration. Several significant two and three way interactions were found for nutrient uptake in V7 corn plants. Generally, the APP×UAN×ATS interactions for N, P and S uptake were explained by the response found for dry matter yield discussed earlier. Adding 1 gal/ac of ATS to 4 gal/ac of APP applied in-furrow, did not affect nutrient uptakes in V7 corn plants, compared with 4 gal/ac of APP alone.

**Rochester 2010**

Treatment effects on grain moisture, grain yield, initial plant stand, final plant population, and relative leaf chlorophyll content are presented in Table 4. Grain moisture was reduced 0.9 percentage points with 4 gal/ac of APP compared with 0 gal/ac, when averaged across UAN and ATS treatments. Application of UAN reduced grain moisture slightly (0.3 percentage points), when averaged across APP and ATS treatments. Three significant interactions (APP×ATS, UAN×ATS and APP×UAN×ATS) were found for corn grain moisture. Generally these interactions showed when APP was not applied, grain moisture was reduced with ATS with or without UAN. However, when APP was applied, the grain moisture response to ATS with or without UAN was erratic. Corn yields only ranged from 207 to 213 bu/ac across all 14 treatments in this study. No significant differences were found among treatments, and there were no interactions. No differences in final plant population were found among treatment main effects. At VT-R1 RLC ranged from 94.6 to 99.1% and was not affected by the main effects of APP and UAN application. The 2 and 4 gal/ac rates of ATS increased RLC about 1 percentage point compared with the 0 gal/ac rate of ATS, when averaged across APP and UAN main effects.

Treatment effects on early growth of small corn plants harvested on June 24 (V7-8 stage) are presented in Table 4. Plant heights and dry matter yields were increased with 4 gal/ac of APP applied in-furrow compared with 0 gal/ac, when averaged across UAN and ATS treatments. Plant heights and dry matter yields were not affected by the main effects of UAN and ATS application, and there were no significant interactions. This suggests the early growth response at this site was primarily due to P in the APP starter. Adding 1 gal/ac of ATS to 4 gal/ac of APP in-furrow had no effect on plant height and dry matter yield compared with APP alone. The large increase in dry matter yield with APP fertilization observed in this study, resulted in increased N, P, K, and S uptake compared with plots that did not get APP. Adding 1 gal/ac of ATS to 4 gal/ac of APP in-furrow, generally did not affect nutrient uptakes in small corn plants compared with APP alone. The highly significant APP×ATS interactions for K uptake in V7-8 corn plants showed without APP, K uptake declined when ATS was applied. Whereas with APP, K uptake increased as the rate of ATS increased (data not shown). Lowest K uptakes were found when APP was not applied and 4 gal/ac of ATS was applied (data not shown). These results were not found at the S-responding Waseca site.
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<th>Fertilizer rate</th>
<th>Grain</th>
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<th>Whole Plant Samples at V7</th>
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Stats for RCB design (all 14 treatments)

P > F: 0.270 0.181 0.001 0.001 0.198 0.001 0.001 0.040 0.001 0.001 0.028

Average LSD (0.10): NS NS 1.3 1.3 NS 2.0 103 5.2 0.46 5.1 0.24

Stats for a Factorial Design (Treatments 1-12)

APP (10-34-0) applied in-furrow

None 18.5 194 31.7 31.7 97.6 34.3 719 24.3 2.88 35.1 1.22
4 gal/ac 17.9 198 31.8 31.8 97.5 37.1 827 27.4 3.34 40.2 1.37

P > F: 0.108 0.170 0.708 0.735 0.796 0.010 0.040 0.001 0.170 0.000 0.022

UAN (28-0-0) applied as a surface dribble band

None 18.3 195 31.9 31.9 97.8 35.0 751 26.2 3.14 36.9 1.30
8 gal/ac 18.2 197 31.6 31.6 97.3 36.4 795 25.5 3.08 38.4 1.29

P > F: 0.785 0.662 0.300 0.314 0.301 0.010 0.083 0.602 0.618 0.171 0.860

ATS (12-0-0-26) applied as a surface dribble band

None 17.8 196 32.6 32.5 97.3 34.6 721 24.3 2.82 35.5 1.17
2 gal/ac 18.1 197 31.4 31.4 97.9 35.4 787 27.0 3.25 36.7 1.37
4 gal/ac 18.8 196 31.3 31.3 97.4 37.1 810 26.3 3.26 40.8 1.36

P > F: 0.046 0.824 0.005 0.004 0.494 0.001 0.194 0.004 0.001 0.014
Average LSD (0.10) 0.7 NS 0.6 0.6 NS 1.0 51 NS 0.23 2.3 0.12

Interactions (P > F)

APP×UAN 0.649 0.685 0.409 0.459 0.238 0.042 0.818 0.582 0.854 0.753 0.853
APP×ATS 0.519 0.156 0.011 0.010 0.301 0.272 0.547 0.964 0.496 0.026 0.691
UAN×ATS 0.642 0.768 0.015 0.018 0.178 0.016 0.041 0.042 0.019 0.001 0.150
APP×UAN×ATS 0.333 0.212 0.088 0.094 0.368 0.001 0.031 0.023 0.014 0.023 0.058

* One gal/ac rate of ATS applied in-furrow with seed.
Treatment effects on grain moisture, grain yield, initial plant stand, final plant population and relative leaf chlorophyll content (RLC) are presented in Table 5. Grain moisture was reduced 1.4 percentage points when APP was applied at planting. A significant APP×ATS interaction for grain moisture showed when APP was not applied ATS reduced grain moisture slightly. However when APP was applied grain moisture was considerably less and applying ATS did not further reduce moisture (data not shown). Corn grain yield increased 4 bu/ac with 4 gal/ac of APP compared with 0 gal/ac of APP, when averaged across UAN and ATS treatments. Yield was greater (202 bu/ac) with 4 gal/ac of ATS compared with 2 gal/ac (196 bu/ac) and 0 gal/ac (194 bu/ac) of ATS, when averaged across APP and UAN treatments. Applying 1 gal/ac of ATS and 4 gal/ac of APP in-furrow had no affect on grain yields compared with 4 gal/ac of APP alone. Initial plant stand and final plant populations were reduced slightly (≤600 plant/ac) with APP application. The 4 gal/ac rate of ATS also reduced initial stand about 500 plants/ac. These small reductions would not have affected grain yields. No significant interactions were found for corn grain yield, initial plant stand and final plant population. Relative leaf chlorophyll content at R1 was greater with 2 and 4 gal/ac of ATS compared with 0 gal/ac of ATS. A highly significant APP×UAN interaction for RLC showed when APP was not applied, UAN application reduced RLC. However when APP was applied, UAN application increased RLC (data not shown). A significant APP×ATS interaction for RLC showed when APP was not applied, 2 and 4 gal/ac of ATS increased RLC compared with 0 gal/ac of ATS; whereas when APP was applied, RLC increased as the rate of ATS increased (data not shown).

Generally, plant heights and whole plant dry matter yields were affected by all three of the treatment main effects in the factorial analysis of treatments 1-12 (Table 5). Heights and yields were increased when APP was applied in-furrow and when UAN was applied as a surface band. When averaged across APP and UAN rates, dry matter yields were greater with 4 gal/ac of ATS applied as a surface band compared with 0 or 2 gal/ac of ATS, although plant heights were not significantly greater (P-value = 0.105). No significant interactions were found for plant height and dry matter yield. These data were similar to the Waseca site and showed a consistent early growth and plant vigor advantage when fluid starter fertilizers were placed in or near the seed row at planting. Adding 1 gal/ac of ATS to 4 gal/ac of APP applied in-furrow had no affect on plant heights or dry matter yields compared with 4 gal/ac of APP alone.

Nutrient uptakes in V7 corn plants were affected by the treatment main effects in this study (Table 5). Four gal/ac of APP applied at planting increased whole plant N, P, K and S uptake. Nitrogen, P and S uptake in V7 plants were increased by UAN and ATS application at planting. No significant interactions were found for nutrient uptake.

**Summary**

Starter fertilizer treatment effects on continuous corn production across sites and years include:

Applying 4 gal/ac of APP in-furrow: 1) reduced grain moisture at three of four location-years; 2) increased grain yield at one of four location-years (4 bu/ac increase at Rochester in 2011); and 3) increased plant height at the V7 growth stage in all four location-year comparisons. Applying 8 gal/ac of UAN as a surface band: 1) reduced grain moisture in two of four location-years; 2) did not affect corn grain yield; and 3) increased plant height in three of four location-year comparisons. Applying ATS as a surface band: 1) reduced grain moisture in one of four location-years; 2) increased grain yield at two of four location-years (6-9 bu/ac at Waseca in 2010 and 8 bu/ac with 4 gal/ac of ATS at Rochester in 2011); and 3) increased plant height in two of four location-years comparisons. A combination of N, P and S fluid starter fertilizers as APP, UAN and ATS increased plant height by 21% compared with the control (data not shown).

During this study period, applying APP and ATS independently or in combination had the greatest likelihood for increasing corn grain yields. Applying UAN as a nitrogen starter fertilizer did not affect grain yield in this study. Generally, APP, ATS and UAN applied as starter fertilizers increased early growth and vigor of continuous corn under reduced tillage and may reduce grain moisture at harvest.

**Acknowledgement**

Grateful appreciation is extended to the Minnesota Agricultural Fertilizer Research and Education Council and the Fluid Fertilizer Foundation for funding this research.
### Table 4. Grain moisture and yield, plant stand, final plant population, relative leaf chlorophyll, plant height, dry matter yield and nutrient uptake at Rochester in 2010.

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Stats for RCB design (all 14 treatments)

- P > F: 0.001 0.938 0.020 0.038 0.031 0.001 0.016 0.048 0.049 0.049 0.024 0.749 0.581 0.326
- Average LSD (0.10): 0.7 NS 0.8 0.5 1.8 2.0 389 12.6 1.67 26.3 0.73

Stats for a Factorial Design (Treatments 1-12)

- **APP (10-34-0) applied in-furrow**
  - None 17.4 208 34.7 34.2 97.3 36.8 1472 52.3 6.02 51.0 3.12
  - 4 gal/ac 16.5 210 34.5 34.1 97.5 40.0 1923 65.3 7.76 73.0 3.88
- P > F: 0.001 0.211 0.431 0.550 0.581 0.001 0.001 0.001 0.001 0.001 0.001

- **UAN (28-0-0) applied as a surface dribble band**
  - None 17.1 209 34.6 34.2 97.3 38.2 1649 57.1 6.80 61.2 3.33
  - 8 gal/ac 16.8 209 34.5 34.1 97.5 38.6 1746 60.5 6.98 62.8 3.66
- P > F: 0.081 0.952 0.531 0.595 0.735 0.389 0.213 0.210 0.572 0.750 0.035

- **ATS (12-0-0-26) applied as a surface dribble band**
  - None 17.1 209 34.2 34.0 96.7 38.2 1687 57.8 6.83 63.8 3.35
  - 2 gal/ac 17.0 209 34.8 34.3 97.8 38.3 1714 58.9 6.92 60.1 3.51
  - 4 gal/ac 16.8 210 34.7 34.2 97.7 38.7 1693 59.6 6.92 62.1 3.63
- P > F: 0.332 0.681 0.058 0.147 0.067 0.652 0.954 0.853 0.964 0.844 0.310

Average LSD (0.10): NS NS 0.4 NS 0.9 NS NS NS NS NS NS

Interactions (P > F)

- APP×UAN 0.191 0.625 0.134 0.103 0.401 0.363 0.345 0.462 0.561 0.804 0.316
- APP×ATS 0.071 0.953 0.824 0.596 0.041 0.174 0.287 0.226 0.136 0.024 0.290
- UAN×ATS 0.015 0.767 0.100 0.098 0.414 0.914 0.734 0.546 0.762 0.201 0.489
- APP×UAN×ATS 0.031 0.699 0.286 0.419 0.008 0.660 0.596 0.652 0.651 0.108 0.637

* One gal/ac rate of ATS applied in-furrow with seed.
Table 5. Grain moisture and yield, plant stand, final plant population, relative leaf chlorophyll, plant height, dry matter yield and nutrient uptake at Rochester in 2011.

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Stats for RCB design (all 14 treatments)
P > F: 0.001 0.011 0.244 0.430 0.001 0.001 0.001 0.001 0.001 0.023 0.001
Average LSD (0.10): 0.8 7 NS NS 1.4 1.9 102 3.2 0.36 3.2 0.23

Stats for a Factorial Design (Treatments 1-12)
APP (10-34-0) applied in-furrow
None 21.3 195 35.3 34.6 97.1 28.7 467 16.6 1.18 12.1 0.99
4 gal/ac 19.7 199 34.7 34.4 97.5 33.1 667 23.9 1.81 15.6 1.38
P > F: 0.001 0.011 0.025 0.086 0.017 0.001 0.001 0.001 0.001 0.001 0.001
UAN (28-0-0) applied as a surface dribble band
None 20.6 197 34.9 34.6 97.5 30.3 530 18.6 1.35 13.4 1.10
8 gal/ac 20.5 198 35.1 34.6 97.1 31.5 605 21.9 1.64 14.2 1.27
P > F: 0.501 0.718 0.570 0.596 0.026 0.011 0.007 0.001 0.002 0.358 0.007
ATS (12-0-0-26) applied as a surface dribble band
None 20.9 194 35.1 34.6 96.2 30.2 520 18.5 1.36 13.5 1.03
2 gal/ac 20.5 196 35.2 34.6 97.6 31.1 558 19.7 1.46 13.3 1.17
4 gal/ac 20.4 202 34.6 34.4 98.1 31.4 623 22.5 1.68 14.6 1.35
P > F: 0.117 0.001 0.083 0.216 0.001 0.105 0.009 0.005 0.016 0.375 0.001
Average LSD (0.10): NS 3 0.5 NS 0.6 NS 54 1.9 0.18 NS 0.12

Interactions (P > F)
APP×UAN 1.000 0.908 0.673 0.275 0.001 0.419 0.321 0.669 0.594 0.337 0.583
APP×ATS 0.027 0.624 0.513 0.649 0.141 0.484 0.159 0.244 0.123 0.230 0.237
UAN×ATS 0.084 0.179 0.794 0.517 0.026 0.407 0.127 0.239 0.493 0.409 0.369
APP×UAN×ATS 0.908 0.435 0.523 0.219 0.817 0.628 0.739 0.882 0.909 0.940 0.874

* One gal/ac rate of ATS applied in-furrow with seed.
References


Nutrient considerations with corn silage and stover harvest

John E. Sawyer, professor and Extension soil fertility specialist, Agronomy, Iowa State University; Antonio P. Mallarino, professor and Extension soil fertility specialist, Agronomy, Iowa State University.

Introduction

Harvested cornstalk residue (corn stover) after grain harvest has traditional use as bedding and co-feed for livestock. Interest is increasing with other uses, especially for energy production such as direct burning and cellulosic ethanol. The potential growth for cellulosic ethanol is large as two plants in Iowa are either proposed or in initial construction. If proven feasible and economical, cellulosic ethanol production and concurrent stover demand could increase substantially.

While silage harvest has been practiced for many years, and nutrient removal with silage is well known, corn stover harvest and related nutrient removal is different due to the timing of harvest and a separate grain harvest. Also, stover harvest being promoted by companies for ethanol production must have low soil contamination and total removal may not be desirable for soil sustainability reasons. Therefore, stover harvest will be less than total aboveground vegetation. Company suggested stover harvest rates appear to be approximately one-half of the stover, which is much less than removed when silage is harvested (with silage could be 90-95+ % of total aboveground material). Therefore, grain plus some stover harvest will remove lesser amounts of biomass carbon (C) and plant nutrients compared to silage harvest. The frequency of stover harvest in a specific rotation will determine long-term impact on nutrient removal and recycling to soil.

Corn silage nutrient removal

Corn silage harvest often removes the majority of aboveground plant biomass. This makes nutrient removal much higher than with grain only harvest. For high quality silage that stores properly, harvest typically is recommended when silage moisture is 60-70%. Waiting for the plant to reach physiological maturity (often evidenced by a black layer on the kernel tip or no milk remaining at the kernel base) is too late as the silage will be too dry. Therefore, silage harvest often takes place before plant maturity. This means total aboveground biomass (and grain yield) has not yet accumulated and total plant nutrient uptake and grain nutrient content are not final. Therefore, nutrient content in silage (aboveground plant parts including grain) will be less than at plant physiological maturity.

There are published average values for silage nutrient content; for example Iowa State University Extension publication PM 1688, General Guide for Crop Nutrient and Limestone Recommendations in Iowa, lists phosphorus (P) and potassium (K) content per ton of corn silage at 65% moisture as 3.5 lb P₂O₅ and 8.0 lb K₂O. On a dry matter (DM) basis these values are 10 lb P₂O₅ and 23 lb K₂O. With the silage harvested amount and these estimates, the removal of P and K can be easily determined. The increase in amount of P and K removed with corn silage compared to grain differs because the relative amounts of these nutrients are different in vegetative parts than in grain. For P there can be an approximately four times greater amount of P per ton of dry matter in grain than vegetative parts, but for K the opposite occurs, on average with almost three times greater amount of K per ton of dry matter in the vegetative parts.

Drought conditions (as this year) can complicate the estimate of nutrient removal with silage harvest due to potential change in nutrient concentrations and uptake in different plant parts, and associated effects of the timing of drought and time of silage harvest relative to plant growth stage. These effects are difficult to predict, therefore, analysis of silage samples can aid in determining nutrient concentrations. No matter the method used to estimate silage P and K concentration, the amount of silage harvested per acre has the greatest impact on nutrient removal. Therefore, it is important to have a good estimate of silage harvested and moisture content.

Over the years, P and K have been the nutrients of interest with silage harvest due to the large removal amounts, but not nitrogen (N) or other nutrients. This is changing as more focus is being placed on C and N due to effects on sustainability of the soil resource with silage and stover harvest, and for N also effects on water quality.
Corn stover nutrient content

Determining corn stover nutrient content is complicated because nutrients, especially K, can be leached out of plant tissue from maturity to grain harvest, and after grain harvest. This means that nutrient concentrations of stover can be quite different depending on the rainfall pattern from plant maturity to time of stover harvest.

Table 1 gives a complete nutrient analysis of corn at maturity for the grain, vegetative components, and cob. The grain dry matter is approximately one-half of the aboveground vegetative plus cob dry matter. Since the C concentration is similar for all plant components, the grain C is also approximately one-half of the vegetative plus cob components. The nutrient content of cobs is quite low, and for the data set in Table 1 were not measured except for C and N. The cob N is very low, there is more N and P in the grain than the vegetative component, and more K in the vegetative component than grain. This difference in relative P and K content of vegetative tissues compared to grain is why nutrient removal has to be calculated differently for grain, silage, or stover harvest. As is typically found, the concentration and amount of micronutrients is low in both the grain and vegetative component. There is some additional Ca and Mg removed with stover harvest, but that amount is easily corrected by normal liming, or is not an issue in soils with neutral pH or with free lime (calcareous).

Table 1. Corn nutrient composition at plant maturity by plant part.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Grain</th>
<th>Veg.</th>
<th>Cob</th>
<th>Grain</th>
<th>Veg.</th>
<th>Cob</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb/acre</td>
<td>lb/ton (DM)</td>
<td></td>
<td>lb/ton (DM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3717</td>
<td>795</td>
<td>840</td>
<td>787</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>110</td>
<td>24</td>
<td>12</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P2O5</td>
<td>55</td>
<td>12</td>
<td>3</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K2O</td>
<td>37</td>
<td>8</td>
<td>22</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>8</td>
<td>2</td>
<td>9</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>9</td>
<td>2</td>
<td>6</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>8</td>
<td>2</td>
<td>1</td>
<td>--</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>0.14</td>
<td>0.030</td>
<td>0.031</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn</td>
<td>0.03</td>
<td>0.006</td>
<td>0.069</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu</td>
<td>0.02</td>
<td>0.004</td>
<td>0.015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.04</td>
<td>0.009</td>
<td>0.015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>0.22</td>
<td>0.047</td>
<td>0.281</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry Matter</td>
<td>9355</td>
<td>7816</td>
<td>1192</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


A better estimate of potential corn stover nutrient concentration is from data collected at grain harvest (Table 2). The concentrations in Table 2 are for stover that includes the cob, and stover was collected where there would be little or no soil contamination. The P concentration is similar to the data in Table 1 (collected from whole standing plants at maturity), but the K concentration is lower. This would be due to leaching from the vegetation, mostly leaves, after maturity and until grain harvest. Of note is the large range in nutrient concentrations across the study sites (Table 2). This range is greater than found for grain nutrient concentrations, and makes estimation of actual stover nutrient removal from specific fields difficult. However, the actual amount of stover baled would have a great impact on removal. One could sample stover bales and have samples analyzed if a more precise estimate of concentration is needed. However, sampling stover bales can be difficult. That method may also reflect soil contained in the baled stover, and concentrations including soil would overestimate the actual nutrient amount from just the stover material, but not total nutrient removal from the field. Also, nutrients in baled stover originating from soil could have less agronomic value compared to that in the stover due to different crop availability when originating from soil versus stover (the soil component would be a total amount, not a reflection of just plant available nutrient).
Table 2. Corn stover nutrient concentration at the time of grain harvest.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>19</td>
<td>44</td>
</tr>
<tr>
<td>Ca</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Mg</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>S</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Zn</td>
<td>0.033</td>
<td>0.052</td>
</tr>
<tr>
<td>Mn</td>
<td>0.096</td>
<td>0.167</td>
</tr>
<tr>
<td>Cu</td>
<td>0.013</td>
<td>0.024</td>
</tr>
<tr>
<td>B</td>
<td>0.010</td>
<td>0.011</td>
</tr>
<tr>
<td>Fe</td>
<td>0.148</td>
<td>0.171</td>
</tr>
</tbody>
</table>


Figure 1 shows the decrease in corn stover P and K concentration across time after corn maturity (from information presented at the 2011 ICM conference). The largest decrease occurred from black layer to grain harvest. After that, there was a slow but steady decline for K (with rainfall) in the fall and spring, but P concentration was the same in the fall and then decreased slightly across the wintertime. As mentioned earlier, this change in nutrient concentration with time after grain harvest makes estimates of P and K removal more complicated. However, a reasonable estimate based on the recent research in Iowa would be 3 lb P<sub>2</sub>O<sub>5</sub>/ton and 19 lb K<sub>2</sub>O/ton (dry matter based).

Figure 1. Phosphorus and K concentration in corn stover across time after plant maturity, R.R. Oltmans and A.P. Mallarino, 2011. At each sample time, average (black squares), 50% central distribution (grey boxes), and range (vertical lines) across nine trials and eight plots per trial.

Estimating corn stover production

Although the nutrient concentration in corn stover affects the amount of nutrient removed with stover harvest, but often the amount of biomass harvest has a greater impact. Therefore, a good estimate of the amount of stover harvested is important. The grain harvest index (proportion of total aboveground dry matter as grain) is approximately 50%. Therefore, about one-half of aboveground biomass is in grain and half in vegetative plus cob.
components. Corn grain, at a 56 lb/bu and 15.5% moisture equivalent, has 47.32 lb dry matter per bu. Therefore, one can quickly estimate the amount of corn stover dry matter by multiplying grain yield times 47.32. This conversion (harvest index) will vary due to season and hybrids, but should give a reasonable estimate of stover production. The amount actually removed for a specific harvest (especially dry matter basis) will be harder to determine as the weight per acre harvested has to be determined at or after baling, along with the stover moisture content which can vary considerably depending on many factors such as moisture at grain harvest, dry down after harvest, and rainfall.

**Economic value of nutrients in corn stover**

Table 3 gives the value of nutrients (macro and secondary nutrients) in corn grain and stover with plants sampled at maturity. The calculations assume prevailing Midwest prices for commonly used fertilizers. The normal method is to account for P and K in harvested grain when figuring crop removal. Applying the same process to stover, the cost for P is much less in stover, but the cost for K is much greater. The values given in Table 3 reflect total stover harvest. Actual harvest, for example 2 ton/acre, would reduce the cost proportionally.

**Table 3. Nutrient value equivalent to fertilizer in corn grain and stover when sampled at plant physiological maturity.**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Grain</th>
<th>Stover</th>
<th>Grain</th>
<th>Stover</th>
<th>Price</th>
<th>Nutrient</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>- - lb/acre - -</td>
<td>- - $/acre - -</td>
<td>$/ton</td>
<td>$/lb</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>110</td>
<td>54</td>
<td>52.80</td>
<td>25.92</td>
<td>768</td>
<td>0.48</td>
<td>Ammonia</td>
</tr>
<tr>
<td>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</td>
<td>55</td>
<td>14</td>
<td>28.05</td>
<td>7.14</td>
<td>645</td>
<td>0.51</td>
<td>DAP</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>37</td>
<td>99</td>
<td>18.50</td>
<td>49.50</td>
<td>615</td>
<td>0.50</td>
<td>Potash</td>
</tr>
<tr>
<td>Ca</td>
<td>8</td>
<td>41</td>
<td>0.24</td>
<td>1.23</td>
<td>20</td>
<td>0.03</td>
<td>Lime</td>
</tr>
<tr>
<td>Mg</td>
<td>9</td>
<td>27</td>
<td>0.27</td>
<td>0.81</td>
<td>20</td>
<td>0.03</td>
<td>Lime</td>
</tr>
<tr>
<td>S</td>
<td>8</td>
<td>5</td>
<td>3.36</td>
<td>2.10</td>
<td>750</td>
<td>0.42</td>
<td>Elemental</td>
</tr>
<tr>
<td>Total</td>
<td>103.22</td>
<td>86.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Table 4 gives the nutrient value per ton stover (dry matter basis) at grain harvest. Those values can be used directly to calculate actual cost of removing nutrients in stover (with a conversion to stover moisture when baled). For example, if stover was harvested at 2 ton dry matter per acre, the cost for P would be $3.06/acre and K would be $19.00/acre. Typically, other nutrients are not accounted for with grain harvest when figuring nutrient replacement cost, and the same often is done for stover harvest. However, increased removal of other nutrients, most notably S, could increase potential for nutrient deficiency of subsequent crops.

**Table 4. Nutrient value equivalent to fertilizer in corn stover when sampled at the time of grain harvest.**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Corn Stover Per Ton DM</th>
<th>Fertilizer/Lime</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb/acre</td>
<td>$/acre</td>
</tr>
<tr>
<td>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</td>
<td>3</td>
<td>1.53</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>19</td>
<td>9.50</td>
</tr>
<tr>
<td>Ca</td>
<td>8</td>
<td>0.24</td>
</tr>
<tr>
<td>Mg</td>
<td>4</td>
<td>0.12</td>
</tr>
<tr>
<td>S</td>
<td>1</td>
<td>0.42</td>
</tr>
<tr>
<td>Total</td>
<td>11.81</td>
<td></td>
</tr>
</tbody>
</table>

Little or no soil contamination. R.R. Oltmans and A.P. Mallarino, 2011.
Nitrogen fertilization after corn stover harvest

Results of an on-going corn stover harvest project in continuous corn were presented at the 2011 ICM conference. Although N removal from the field is not normally considered with grain harvest, it is sometimes of interest with stover harvest due to potential impacts of less residue return. In this research, the effect of stover harvest was a reduction in the N rate needed for maximum economic yield. The economic optimum N rate (EONR) was 20 lb N/acre less with approximately half stover removal and 40 lb N/acre less with full removal. At first this seems backward as N is removed with stover harvest and a greater N application need would be expected. However, with stover removal there is also less addition of C to soil for microbial processing; therefore it appears the change in biomass return (with high C:N ratio) to the soil has a greater influence on N fertilization requirement than less return of N. That study has been in place for only three years, and additional years will help determine if the effect of stover harvest on soil N, microbial mineralization, and EONR remains the same across time.

Table 5. Effect of tillage and corn stover removal on economic optimum N rate (EONR) corn grain yield at the EONR (YEONR) in continuous corn.

<table>
<thead>
<tr>
<th>Residue Removal</th>
<th>Chisel Plow</th>
<th>No-Till</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EONR</td>
<td>YEONR</td>
</tr>
<tr>
<td>None</td>
<td>228</td>
<td>179</td>
</tr>
<tr>
<td>Partial (50%)</td>
<td>203</td>
<td>177</td>
</tr>
<tr>
<td>Full (100%)</td>
<td>185</td>
<td>181</td>
</tr>
</tbody>
</table>


Summary

Corn stover harvest removes additional nutrients compared to grain only harvest. The proportion of nutrients in grain and stover varies by the nutrient. Compared to grain, on a dry matter concentration basis, corn stover has one-half the N, one-fourth the P, and three times more K. This means that different concentrations must be used for estimating harvest removal with grain and stover. For corn stover, suggested concentrations (per dry ton) are 3 lb P₂O₅/ton and 19 lb K₂O/ton. These values are lower than listed in Iowa State University publication PM 1688, General Guide for Crop Nutrient and Limestone Recommendations in Iowa. A main reason is that the values in that publication are for corn stover at plant maturity. Nutrients are lost from plant vegetation between maturity and grain harvest, therefore the P and K concentrations suggested above are lower than at maturity. Nutrient concentrations also vary considerably for corn stover, therefore, you should recognize that calculated removal amounts and associated costs are only estimates. Long-term management, including soil testing for P and K, will determine if stover harvest and nutrient removal are being correctly accounted for. Management of N with stover harvest is not straightforward as there is not a direct relationship between removal and need for additional N application in subsequent corn crops. In recent research a small reduction in needed N fertilization rate for continuous corn was found as a result of less corn biomass return to the soil with partial stover harvest. It is difficult to retain N in soils and simply adding more N to replace that removed in harvested stover will not add directly to soil organic-N, and could increase nitrate losses to drainage water.
Testing field-moist soil samples improves the assessment of potassium needs by crops
Antonio P. Mallarino, professor, Agronomy, Iowa State University.

Potassium soil testing issues
Since 1989 and until the summer of this year, all soil testing laboratories in Iowa and the USA dried soil samples at 35 to 40 °C (95 to 104 °F) and ground them before analysis for potassium (K), phosphorus (P), and other nutrients. Since early fall, however, a laboratory that began operations in Iowa is using testing procedures that involve no soil sample drying, and another laboratory operating in Iowa and other states is offering moist soil testing in addition to the commonly used test based on dried samples. These laboratories are using a moist sample handling procedure that the Iowa State University (ISU) Soil and Plant Analysis Laboratory used and recommended from 1963 to 1988. The re-implementation of the moist test by these laboratories has generated many questions from Iowa farmers and crop consultants.

All soil-test K (STK) methods estimate crop-available soil K by measuring exchangeable K and K present in the soil solution because these forms are readily available or quickly become available. The ammonium-acetate and Mehlich-3 methods are the two K tests used in Iowa and most states of the USA. They provide comparable results, and are suggested methods by ISU (Sawyer et al., 2002) and the North-Central Regional Committee for Soil Testing and Plant Analysis (NCERA-13) (Warncke and Brown, 1998). In spite of extensive field K research in Iowa and the north-central region, predicting crop-available K by soil testing has proven to be a difficult task, and the reliability of soil testing for K has been much lower than testing for P or pH. This is due to complex and largely unpredictable reactions between several soil K pools, interactions with many factors that influence crop-available K levels, and plant K uptake.

Research in Iowa and the north-central region during the 1960s, mainly in the greenhouse, showed that K extracted from undried (field-moist) samples was better correlated with crop K uptake and yield than K extracted from dried samples. Therefore, a procedure for extracting K directly from sieved moist samples or from a soil-water slurry was implemented by the ISU laboratory in the middle 1960s. Unpublished research comparing these two versions of the moist test gave similar results, but showed that for fine-textured soils the slurry facilitated sample handling and improved the repeatability of the analysis. Detailed sample handling procedures for both versions of the moist test were included among sample handling procedures suggested by the NCERA-13 committee during the 1980s (Eik et al., 1980; Eik and Gelderman, 1988).

Iowa interpretations for the moist K test were last published by Voss (1982). As an example, Fig. 1 shows correlations between moist K test results and yield response of corn and soybean published by Mallarino et al., (1991), which summarized data from two Iowa long-term experiments conducted from 1976 until 1989. The categories very low, low, optimum, high, and very high for the moist test were 0-36, 37-67, 68-100, 101-149, and > 150 ppm, respectively.

No other laboratory in the USA adopted the moist test, citing impractical handling procedures, so in 1988 the ISU laboratory discontinued its use. As a consequence, in 1998 the NCERA-13 committee also dropped this procedure from its sample preparation chapter of the updated recommended methods publication (Gelderman and Mallarino, 1998).

Field calibration research for the dry K test with both corn and soybean conducted by Dr. Mallarino and his graduate students from the middle 1990s to 2001 were used to update Iowa K interpretations and recommendations in 2002 (Sawyer et al., 2002). This research was useful to improve the interpretations but continued showing a poor prediction of crop response to fertilization. Therefore, new research began in 2001 to re-evaluate the moist K test as a way of improving the assessment of soil K availability for crops.

Procedures for new field and laboratory research with the moist test
A field study was conducted from 2001 to 2006 in Iowa to compare K testing of dried and moist soil samples by the ammonium-acetate and Mehlich-3 methods. Field response trials with corn and soybean were conducted
across 20 counties and 32 soil series. There were 200 corn site-years and 162 soybean site-years. Crops and soils were managed with chisel-plow/disk tillage for 120 trials and with no-till for 42 trials. Each trial included several K fertilizer rates (granulated 0-62-0) applied in the fall. The fertilizer was broadcast at most sites, except 30 trials where broadcast and planter-band K placement methods were evaluated. Averages across K placement methods were used for the correlations since they seldom differed.

Soil samples (6-inch depth) were sieved, mixed, and divided in two sub-samples. One subsample was prepared for K analysis with the oven-dried sample handling procedure (35 to 40 °C) and the other with the direct version of the field-moist K analysis (no slurry preparation). Soil moisture was determined immediately after sieving by drying a small subsample to constant weight, which ranged from 6 to 31% across samples (20% on average). The K extraction and measurement procedures by the ammonium-acetate and Mehlich-3 methods were similar for the dry and moist sample handling procedures. Grain yield data was expressed as relative responses to K fertilization by dividing the average yield of non-fertilized soil across replications at each site by the average of the highest K rate and multiplying the result by 100.

In spring 2011, soil samples also were collected from many Iowa fields, and were analyzed by P, K, calcium (Ca), and magnesium (Mg) in both moist and dried samples. The sample handling for the dry tests was similar to that described for the earlier study. For the moist test, however, the soil-water slurry version of the method was used. Moist soil was sieved through a 1/4-inch screen and an amount of soil equivalent to 100 g of oven-dry soil was mixed with 200 mL water and stirred to prepare a homogenous slurry. A subsample of the slurry was extracted with the same ammonium-acetate and Mehlich-3 procedures as used for the dry and direct-sieving moist tests, being careful to use the same dry soil/solution ratio and molarity recommended for the dry tests. The P in the extracts was measured colorimetrically, whereas K, Ca, and Mg were measured by inductively-coupled plasma (ICP).

**Comparison of extracted nutrient amounts by dry and moist tests**

**Comparisons for potassium**

Potassium amount extracted from dried soil was higher than for moist soil for most samples collected and analyzed in the 2000s and in 2011. The relative difference between dry and moist K tests decreased with increasing STK levels, however. Results for the ammonium-acetate and Mehlich-3 K methods showed similar differences between dry and moist tests, so only results for the ammonium-acetate test are shown.

Figure 2 shows K test results for the study conducted in the 2000s. The dry K test results averaged 145 ppm and ranged from 56 to 388 ppm. Results for the moist test (using the direct version of the method) averaged 76 ppm and ranged from 30 to 356 ppm. Therefore, on average the dry K was 1.92 times higher than the moist test. The difference and ratio between dry and moist K values decreased with increasing STK levels, although the relationship was very weak for the difference but strong for the ratio. The amounts of K extracted from dried and moist samples tended to be the same for the few values greater than about 200 ppm by the moist test (only six samples tested between 200 and 360 ppm, the highest observed value).

Figure 3 shows K test results for soil samples collected in 2011, for which the slurry version of the moist test was used. Potassium for the dry test averaged 161 ppm and ranged from 73 to 373 ppm and results for the moist test averaged 112 ppm and ranged from 25 to 567 ppm. Therefore, on average the dry K test was 1.44 times higher than the moist K. As with the 2000s data, the difference and ratio between dry and moist K values decreased with increasing STK levels. The highest STK levels observed for this sample set were much higher than for the sample set from the 2000s, however. Therefore, this data set showed that for values higher than about 350 ppm by the moist test the difference between dry and moist tests reversed, and K extracted from dried samples was less than for moist samples. This inverse relationship at extremely high STK values also was observed in studies conducted during the 1960s.

Therefore, the amounts of K extracted from dried and moist samples indicate that no simple factor can be used to relate or “correct” dry and moist K test results. Furthermore, laboratory studies during the 1960s with soils from several states of the north-central region showed that the difference between dry and moist K tests tended to be larger for the western states of the region than for the eastern states. It is relevant to note that the ratio of dry/moist K tests for both sets of samples increased linearly (not shown) with soil clay, organic matter, cation exchange capacity (CEC), and (Ca+Mg)/K ratio, but the strength of the relationships was poor ($r^2 < 0.35$). The ratio of dry/moist K increased with increasing sample moisture content for both sets, but the relationship was very poor ($r^2 <$
Comparisons for phosphorus, calcium, and magnesium

Unpublished results of laboratory research in Iowa during the 1960s showed no significant differences for soil P measured by the Bray-1 method from dried or field-moist samples, as long as the ratio of the extracting solutions to equivalent dry soil was kept the same. Data from samples collected in 2011 (shown in Fig. 4) confirm this result, and show a similar result for the Mehlich-3 method. Small deviations from an intercept of zero and a slope of 1 were not statistically significant or important given the usual variability due to soil sampling or analytical error.

Figures 5 and 6 show the relationships between Ca and Mg measured from dried and moist soil samples by the ammonium-acetate and Mehlich-3 methods. Results for Ca and Mg were more variable than for P and K, and the variability for the difference between dry and moist tests was higher for the ammonium-acetate method (Fig. 5) than for the Mehlich-3 method (Fig. 6). The reasons for the higher variation for the ammonium-acetate method are not clear. Small deviations from a slope of 1.0 for the relationships were not statistically significant.

Correlation between crop response to potassium fertilizer and dry or moist tests

Figure 7 shows relationships between relative corn and soybean yield response to K fertilizer and dry K test results using the ammonium-acetate extractant for the field response trials conducted from 2001 until 2006. Results for the Mehlich-3 method were similar to that with ammonium acetate, and are not shown. The graphs also show the current ISU STK interpretations for the dry K test (Sawyer et al., 2002). Only fertilization based on crop K removal is recommended for the Optimum class. When applying the boundaries of the optimum category, then the optimum category encompasses mean relative yields of 93% for corn and 95% for soybean. The different symbol colors indicate the drainage class for each soil series. The graphs for both crops show that according to the dry test, crops grown on the best drained soils needed a lower STK level than crops grown on soils with poor drainage, and crops grown on soils with moderate drainage were distributed between these two extremes. The different STK values for the different groups of soils and the number of site-years for each group do not allow for determining reasonable separate relationships by drainage group. A classification of soil samples based on clay, CEC, K saturation, cation ratios, and other properties (not shown) did not indicate as clear of a grouping as that shown for soil drainage. Several, but not all, soils with poor drainage also had deep profiles and higher CEC, extractable Ca, and organic matter compared with the other soils.

Figure 8 shows relationships between relative corn and soybean yield responses to K fertilizer and the moist K test results, using the ammonium-acetate extractant. There was a much better relationship for the moist test than for the dry test. This result indicates a better capacity to identify different soil K sufficiency levels for corn and soybean than the dry test, and better prediction of yield response to K fertilization. Moreover, with few exceptions, the data points representing contrasting soil drainage blend into the same general trend for the moist test without the obvious differences shown for the dry test.

The Iowa interpretation category for the moist K test used until 1988 for which maintenance fertilization was recommended (named medium at the time) was 68 to 100 ppm for both corn and soybean. For the old moist K and yield correlation data set (Fig. 1), the boundaries of the old medium category encompass mean relative yields of 96% for corn and 92% for soybean. For the new data set (Fig. 8), the boundaries of the old medium category encompass mean relative yields of 97% for corn and 98% for soybean. The approximately similar fit of the old ISU moist test interpretation classes to the old dataset (Fig. 1) and new dataset (Fig. 8) is remarkable, since in the 1970s and 1980s crop yields were much lower (especially for corn), hybrids or varieties were different, and only two soil series were included in the old research (many years of two long-term experiments), however, 32 soil series and six years were included in the new research.

Therefore, if criteria for establishing the moist test interpretation categories were the same as in the 1980s, similar interpretations could be used today. New field calibration research for the moist test with corn and soybean were conducted in Iowa, and more is being conducted this year. This new research is using the slurry version of the moist test. Therefore, results summarized in this study together with results of the ongoing research will be merged during 2013 to establish updated interpretations for the moist K test and fertilizer recommendations.
Conclusions

Results of the summarized studies strongly suggest that re-implementation of the moist K test in Iowa would significantly improve the assessment of crop-available K and the prediction of crop yield response to K fertilization. Based on new research results and because private laboratories are using the moist sample handling procedure, the NCERA-13 regional committee has re-introduced this procedure to the Sample Preparation chapter of its publication with recommended soil-test procedures (Gelderman and Mallarino, 2012).

New ISU interpretations for the moist test will be developed during 2013, as results of ongoing field and laboratory research become available and can be merged with results of previous research summarized in this article. The interpretations for the moist test for K likely will be similar to those suggested by ISU in the 1980s. Moist test interpretations for P using Bray, Olsen, and Mehlich-3 methods (using colorimetric or ICP procedures) should be similar to those for the dry tests, since data already showed similar test results.

References cited


Figure 1. Relationship between relative corn and soybean yield response to K and soil-test K measured on moist samples for data collected from 1976 until 1989 (Mallarino et al., 1991). VL, L, M, H, and VH identify the 1982 ISU very low, low, medium, high, and very high interpretation classes for the moist test.

Figure 2. Relationship between the difference or the ratio of K extracted from dried or field-moist soil samples collected and analyzed from 2001 through 2006.
Figure 3. Relationship between the difference or the ratio of K extracted from dried or field-moist soil samples collected and analyzed in 2011.

Figure 4. Relationship between P measured on moist or dried samples using the Bray-1 and Mehlich-3 methods (extracted P was measured colorimetrically for both methods).
Figure 5. Relationship between Ca and Mg measured on moist or dried samples using the ammonium-acetate (AA) method.

Figure 6. Relationship between soil Ca and Mg measured on moist or dried samples using the Mehlich-3 (M3) method.
Figure 7. Relationship between relative corn and soybean yield response to K and soil-test K measured on dried samples. Symbols identify data for soil series with different drainage. VL, L, Opt, H, and VH identify current ISU very low, low, optimum, high, and very high interpretation classes for the dry test.

Figure 8. Relationship between relative corn and soybean yield response to K and soil-test K measured on moist samples. Symbols identify data for soil series with different drainage. VL, L, M, H, and VH identify the 1982 ISU very low, low, medium, high, and very high interpretation classes for the moist test.
Nitrogen, carbon, and phosphorus balances in Iowa cropping systems: Sustaining the soil resource

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Cause for concern

The Corn Belt's exceptional productivity depends on high soil organic carbon and nutrient stocks (that is, the amount of carbon and nutrients stored in the soil). However, there is growing concern among scientists and farmers that soil carbon, nitrogen, and phosphorus stocks in corn-based cropping systems may be declining as a result of outputs that exceed inputs. The lack of certainty about the status of soil carbon and nutrient stocks is largely due to the extreme difficulty associated with measurement of inputs, outputs, and stocks of soil organic carbon and nutrients.

In response to this concern, the Iowa legislature requested Iowa State University and the Iowa Department of Agriculture and Land Stewardship to examine and report on nutrient balances in Iowa cropping systems. The results of this work were released in October 2012 (Christianson et al. 2012) and summarized herein.

The report concludes that soil organic matter carbon and nitrogen stocks in Iowa corn-soybean rotations are at risk of significant long-term decline regardless of nutrient input levels. In contrast, the report concludes that continuous corn cropping systems can increase soil organic carbon and nitrogen stocks. The report raises fewer concerns for soil phosphorus stocks.

Soil organic carbon and nitrogen stocks are a function of crop residue inputs. Continuous corn cropping systems have the potential to increase soil organic carbon and nitrogen stocks through large amounts of crop residue inputs. Insufficient crop residue inputs are likely a major factor affecting negative soil organic carbon and nitrogen balances in corn-soybean rotations. Soil nutrient inputs are critical to maintain high crop yields that maximize residue inputs to the soil. However, maximum yields in corn-soybean rotations may not produce sufficient crop residue inputs to maintain soil organic carbon and nitrogen stocks despite a lack of nutrient limitation. The effect of low soybean residue inputs on soil organic carbon and nitrogen stocks is likely compounded by two additional factors: Soybean residues decompose more rapidly than corn residues (Russell et al. 2009). And soybeans grown in Iowa soils appear to remove more nitrogen in grain than they biologically fix; as such, Iowa soybeans may be net removers of soil nitrogen despite their ability to biologically fix nitrogen (Christianson et al. 2012).

Maintenance of soil organic carbon and nitrogen stocks is critical to the future of agricultural productivity and environmental quality. If soil carbon and nitrogen stocks decline, crop yields could decline and water quality improvements will become more difficult. Most nitrogen uptake by corn in any given growing season is from mineralization of the indigenous soil nitrogen stock rather than that year's fertilizer inputs (Stevens et al. 2005; Gardner and Drinkwater 2009). Although fertilizer additions are required to maintain soil nitrogen stocks, fertilizer nitrogen inputs must be cycled through biological systems before they can contribute to long-term soil storage. Accordingly, nitrogen fertilizer inputs in excess of crop demand (that is, the nitrogen application required to achieve economic optimum yield) will lead to environmental nitrogen losses rather than increases in soil nitrogen stocks.

Soil organic carbon and nitrogen are the foundation of soil organic matter. Soil organic matter is positively correlated with crop yield amount and stability across Iowa (Williams et al. 2008). Soil organic matter is also positively correlated with plant-available water holding capacity (Hudson 1994) and indigenous production of crop-available nitrogen (that is, nitrogen mineralization; Booth et al. 2005). High water holding capacity can limit nitrate leaching and boost drought resilience. High nitrogen mineralization can provide resilience to nitrogen losses.
Determination of carbon and nutrient balances

Analytical approach

All nutrient and carbon balances reported herein refer to the change in the soil stock. Soil nutrient stocks represent the balance of nutrient inputs and outputs (collectively, fluxes). Accordingly, changes in soil nutrient stocks can be estimated with two methods. First, the size of soil nutrient and carbon stocks can be measured at two points in time; the net change in stock size represents the average rate of change between the two sampling points (‘stock change over time’ method). Second, nutrient inputs and outputs can be estimated during a period of time; the balance between inputs and outputs represents stock change during the measurement period (‘input-output balance’ method). Major inputs include fertilizer, leguminous nitrogen fixation, and atmospheric deposition. Major outputs include grain harvest, dissolved nitrogen losses, and gaseous nitrogen losses. The first method was used to measure changes in soil nitrogen and carbon stocks. The second method was used to estimate potential changes in soil nitrogen and phosphorus stocks.

Despite the apparent simplicity of these methods, both contain significant uncertainty. Potential annual N stock changes represent an extremely small proportion of the total stock. In common Iowa cropping systems with little erosion, the potential annual change in soil N stocks is typically less than ±1% of the total stock. Measurement of a small change in stock is challenging because analytical measurement error is typically ±5%, and thus measurement uncertainty is greater than the change in stock. Moreover, the potential rate of change is very small when compared to natural spatial variability of soil N stocks. Nevertheless, this method is the only way to measure changes in N stocks with high, quantifiable certainty.

The Christianson et al. (2012) report developed input-output nitrogen balances for continuous corn and corn-soybean rotation systems at three economically derived nitrogen fertilizer rates identified using the Corn Nitrogen Rate Calculator at a fertilizer-to-grain price ration of 0.1 (Sawyer et al. 2006): http://extension.agron.iastate.edu/soilfertility/nrate.aspx. The three selected nitrogen (N) rates were: (1) the ‘Maximum return to nitrogen’ (MRTN), (2) a N fertilizer rate higher than the MRTN that generated a net return of $1 per acre less than the MRTN, and (3) a N fertilizer rate lower than the MRTN that generated a net return of $1 per acre less than the MRTN. Working within the framework of the three N fertilizer input rates in continuous corn and corn-soybean rotation systems, all other N inputs and outputs were estimated from published scientific literature. It is important to note that the amount of N fertilizer inputs affects the magnitude of several other N inputs and outputs. When scientific literature provided sufficient direction, we considered this effect of N fertilizer inputs on other N inputs and outputs. Similar input-output estimates were used to develop phosphorus balances.

The report also used measures of ‘change over time’ to determine long-term trends in soil organic carbon and nitrogen stocks. Soil fertility experiments from four Iowa State University research farms were used including: Ames, Chariton, Crawfordsville, and Sutherland. All experiments included corn-soybean and continuous corn cropping systems with 5 or 7 nitrogen fertilizer rates. All other nutrient levels were maintained at agronomic optimum. Soil samples from 0-15 cm were collected in 1999 or 2000 and again in 2009. The change in soil organic carbon and nitrogen concentrations was reported. Importantly, these experiments and soil sampling strategies were not designed to measure stock changes in soil C and N; accordingly, statistical power was low.

Results

Nitrogen input-output balance

Nitrogen (N) balances for continuous corn at all three N fertilizer input rates were net positive with increasingly positive balances with higher N fertilization input rates (Figure 1; Table 1). The largest inputs and outputs were fertilizer and grain removal, respectively. Although increasing fertilization rates for the three scenarios increased net balances, it is important to note that for these positive N balances to translate into long-term soil N accumulation, the inorganic fertilizer N must be transferred to the soil organic matter through biological (plant or microbe) processes and subsequently protected in stable organic N compounds.
Figure 1. Nitrogen inputs, outputs and net balance (values at top) for continuous corn in Iowa at three fertilization rates (low, MRTN, and high); balances may not sum due to rounding. 1 kg per hectare = 0.89 pounds per acre.

Figure 2. Nitrogen inputs, outputs and net balance (values at top) for a corn-soybean rotation in Iowa at three fertilization rates (low, MRTN, and high); balances may not sum due to rounding. 1 kg per hectare = 0.89 pounds per acre.

In contrast to continuous corn, two-year rotation corn-soybean N balances were all net negative (Figures 2 and 3; Table 1). Higher N fertilizer input rates in the corn phase reduced N deficits, but nevertheless even at the highest rates, corn-soybean N balances remained negative. This result is consistent with previous reports that N removed in soybean grain is greater than the amount fixed by the crop (Barry et al., 1993; Goolsby et al., 1999; NRC, 1993). A global review by Salvagiotti et al. (2008) showed the majority of soybean balances were negative or close to neutral and net negative balances increased with yield. Additionally, Schipanski et al. (2010) highlighted the importance of soybean N fixation by demonstrating that the percentage of soybean N derived from fixation can predict the net direction of corn-soybean rotation N balances.
Although these balance calculations provide an indication of net direction of the nutrient stock, it is important to keep in mind the variability and associated uncertainty of these inputs and outputs. In the continuous corn system, N fluxes with greatest uncertainty were denitrification and atmospheric deposition (Table 2). Because the magnitudes of these two fluxes were relatively small, the overall uncertainty for the continuous corn rotation was relatively small. For example, atmospheric deposition was estimated at 9.8 lb N/ac with denitrification averaging 9.2 lb N/ac across the three fertilization scenarios. Assuming a liberal variation of 50% for these two fluxes and using the Root Sum of Squares error estimation method resulted in an error term of only 6.7 lb N/ac (Christianson et al. 2012). This uncertainty value for the continuous corn rotation was much less than the magnitude of the net balance values for all three scenarios (6.7 lb N/ac < 60, 69, and 76 lb N/ac) lending additional validation of the positive balance for this rotation.

In contrast, uncertainty associated with biological N fixation in the corn-soybean rotation greatly increased the estimated error for this rotation. Even assuming a more conservative potential variation of 33% for deposition, denitrification (average of both phases), and biological N fixation in the corn-soybean rotation, the total error term was 33 lb N/ac, a value that was larger in magnitude than the net N balance deficits (Christianson et al. 2012). Using an uncertainty of 50% (as for the continuous corn rotation) yielded a total error term of 52 lb N/ac which was again much greater than the balance deficits. This highlights the difficulty in obtaining precise estimates of changes in soil nutrient stocks using the balance of inputs and outputs.
### Table 1. Nitrogen input and output values and corresponding net balances for continuous corn (CC) and a corn-soybean (CS) rotations in Iowa at three N fertilization levels. 1 kg per hectare = 0.89 pounds per acre.

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<th>Inputs</th>
<th>Outputs</th>
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<td>Corn Yield</td>
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* Developed using the Corn N Rate Calculator: Iowa sites at 0.1 price ratio for anhydrous ammonia, non-responsive sites not included (Sawyer et al., 2006).
† Low and high scenarios based on a $1.00 per acre reduction from the MRTN (Sawyer et al., 2006).
‡‡ Average Iowa state-wide N application to soybeans from USDA NASS (2012).
¶ Plus 4% and minus 4% of the three year average (2009-2011) Iowa corn yield (173 bu/ac) was used for corn-soybean and continuous corn yields, respectively (USDA NASS, 2012); percentages of maximum yield developed using the N Rate Calculator (Sawyer et al., 2006).
†† Assumed corn and soybean yields were reported at 15.5% and 13% moisture, respectively, and corrected to dry weight here; corn 1.2% N and soybean 6.2% N (Ciampitti and Vyn, 2012; J. Sawyer, personal communication, June 2012; IPNI, 2012).
¶¶ Mean or median from literature review, with the literature review mean for biological N fixation corrected for belowground N (Rochester et al., 1998).
** Based on the relationship developed by Lawlor et al. (2008) for corn fertilization and drainage nitrate-N concentration with drainage volumes from Thorp et al. (2007); leaching during soybean year of CS rotation assumed to be the same as the corn year.
¶¶¶ Based on percentage of N application emitted as nitrous oxide (Hoben et al., 2010) with mean \(N_2O-N/(N_2+N_2O)-N\) ratio of 0.54 developed from Schlesinger (2009) and Gillam et al. (2008).
Soil carbon and nitrogen ‘stock change over time’

Average carbon (C) and nitrogen (N) balances were negative at profitable N fertilizer rates in corn-soybean rotation systems, but they were positive at profitable fertilizer N inputs in continuous corn systems (Figure 4). The mean annual rate of C and N change among the four sites was positively correlated with N fertilizer application rates for both continuous corn and corn-soybean cropping systems. It is important to note that in continuous corn, gains in soil organic C and N with fertilizer inputs cease beyond the profitable N fertilizer input rate. At profitable N fertilizer rates, continuous corn had significantly higher C and N stocks than corn-soybean rotations at all research sites. Corn-soybean rotations had positive C and N balances at only one of four research sites; at the other three sites, C and N balances were negative (Figure 5). Although the empirical data indicate rates of change in N stocks that are less than those estimated by input-output balance in the previous sections of this report (Table 1), this result was expected because the stock change measurements in Figures 4 and 5 only account for changes in the top 15 cm of soil while the input-output balances account for changes in the total soil profile.

Managing nitrogen losses

Importantly, nitrogen (N) drainage losses and denitrification are sizeable outputs for these cropping systems because, for a portion of the year, there is no live vegetation on the soil to capture N and reduce water flux. Replacing these N losses through addition of inorganic fertilizer may not be possible due to the lack of biological storage mechanisms and will not enhance cropping system sustainability with regard to air, soil, and water quality measures (Jaynes and Karlan 2008). In contrast, management strategies such as insertion of cover crops within a rotation or rotating annuals with perennial crops can potentially provide more complete approaches to long-term sustainability of soil nitrogen stocks. Additionally, rather than conclude that increased fertilizer N in the corn-soybean rotation might reduce SON loss, it is important to note that the fundamental limitation of the corn-soybean rotation is the low amount of plant residue returned to the soil during the soybean phase. Such low residue return can also be a challenge during the corn phase if this material is harvested for feed or cellulose; here it was assumed no residue removal occurred. Low residue return cannot be ameliorated with additional fertilizer N that does not increase yield and residue production. However, residue inputs can be augmented through implementation of management practices that maintain or add organic matter to the soil such as some types of manure and cover crops. For example, cover crops can increase crop residue inputs and limit nitrate leaching. When this occurs without a negative impact on corn and soybean yields that negates the cover crop residue input, it can benefit soil quality.
Figure 4. Average annual rates of change in soil organic carbon and nitrogen stocks in the top 7.87" (15 cm) of soil as a function of nitrogen fertilizer inputs to the corn phase of continuous corn and corn-soybean crop rotation systems. Data represent averages of four sites at 0, 120, and 240 lb N/acre (Ames, Chariton, Crawfordsville, Sutherland) and averages of 3 sites at 40, 80, 160, and 200 lb N/acre (Chariton, Crawfordsville, Sutherland). Asterisks indicate the corresponding rate change is different than zero with probability of type I error at: * = 0.1>P>0.05; ** = 0.05>P>0.01; *** = 0.01>P>0.001. Probability of type II error is reported in Christianson et al. 2012. Vertical red lines indicate the Maximum Return to Nitrogen rate for Iowa according to the Nitrogen Rate Calculator (http://extension.agron.iastate.edu/soilfertility/nrate.aspx) at a nitrogen-to-corn grain price ratio of 0.1. Vertical brown lines indicate the N rates above and below the maximum return to nitrogen that are profitable within $1/acre of the maximum return to nitrogen. 1 kg per hectare = 0.89 pounds per acre. Symbols are offset for visual clarity.
Figure 5. Average annual rate of change of soil organic carbon and total soil nitrogen stocks in the top 1.97" (5 cm) of soil over 10 years at Ames, Chariton, and Crawfordsville and over 9 years at Sutherland. Error bars represent standard error. N = 4 replicated plots for continuous corn, N = 8 replicated plots for corn-soybean. 1 kg per hectare = 0.89 pounds per acre. Open circles are corn-soybean rotation, closed circles are continuous corn. Symbols are offset for visual clarity.
**Phosphorus input-output balance**

Like previous phosphorus balances, the major inputs were inorganic fertilizer and the major outputs were grain P removal; smaller fluxes included atmospheric P deposition and losses to surface waters through surface transport or drainage. Balances developed by Christianson et al. (2012) implicitly assumed that potential soil test phosphorus changes in the topsoil would correlate with total soil phosphorus. Moreover, this work did not consider subsoil (below 6 inches, 15 cm) phosphorus depletion by crop removal or buildup by excess phosphorus application. Such subsoil considerations could be very important for long-term changes in total soil phosphorus. However, few data are available on long-term changes in subsoil phosphorus. General indications show there is little change in soil test phosphorus below 12 inches (30 cm) at high phosphorus fertilizer application rates.

High soil test phosphorus scenarios resulted in net negative balances for both crops as appropriate to allow utilization of existing surplus soil phosphorus that was at greater levels (soil test) than needed for crop production (Figures 6 and 7; Table 2). The optimum soil test scenarios resulted in balances very close to neutral, whereas the very low soil test scenarios showed accumulation of phosphorus in the soil (Figures 6 and 7; Table 2). Under the very low soil test scenarios, if phosphorus were applied only at the replacement rate and below the recommended rate, these soils would continue to have low soil phosphorus crop availability (soil test phosphorus). These results verify phosphorus recommendation efforts in that high soil test sites provide higher relative risk of phosphorus export offsite, and reduction of soil phosphorus at these sites due to a net negative phosphorus balance may precipitate improved water quality. Likewise, the near neutral balances for the optimum soil test scenarios resulted from phosphorus application recommendations based upon grain removal. In terms of water quality, export of phosphorus calculated based on the Iowa phosphorus Index resulted in four of the scenarios in a “Very Low” risk category (0-1 P index) and two scenarios in the “Low” risk category (>1-2 P Index) (Table 2) (Mallarino et al., 2002; Iowa NRCS, 2004).

These phosphorus balances were corroborated by long-term soil test phosphorus data at several research farm sites in Iowa (Mallarino et al. 2011). Research investigating phosphorus applications to corn and soybean cropping systems showed that in plots receiving no phosphorus fertilizer, soil tests levels decline approximately 1 ppm (Bray-1) per year (Mallarino and Prater, 2007). Conversely, plots receiving P fertilization experienced increased soil P tests levels over time (Mallarino and Prater, 2007).

![Figure 6. Phosphorus inputs, outputs and net balance (values at top) for corn production in Iowa at three P fertilization rates based upon soil test level.](image-url)
Figure 7. Phosphorus inputs, outputs and net balance (values at top) for soybean production in Iowa at three P fertilization rates based upon soil test level.

Table 2. Phosphorus input and output values and corresponding net balance for corn and soybeans in Iowa at three P fertilization levels based upon soil test level.

<table>
<thead>
<tr>
<th>Fertilizer*</th>
<th>Deposition</th>
<th>Crop Harvest Grain Removal†</th>
<th>Export to Water</th>
<th>P BALANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb P/ac-yr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn - High soil test</td>
<td>0</td>
<td>0.27</td>
<td>19.8</td>
<td>1.1</td>
</tr>
<tr>
<td>Corn - Optimum soil test</td>
<td>19.8</td>
<td>0.27</td>
<td>19.8</td>
<td>0.99</td>
</tr>
<tr>
<td>Corn - Very low soil test</td>
<td>43.7</td>
<td>0.27</td>
<td>19.8</td>
<td>0.88</td>
</tr>
<tr>
<td>Soybean - High soil test</td>
<td>0</td>
<td>0.27</td>
<td>14.7</td>
<td>1.2</td>
</tr>
<tr>
<td>Soybean - Optimum soil test</td>
<td>14.7</td>
<td>0.27</td>
<td>14.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Soybean - Very low soil test</td>
<td>34.9</td>
<td>0.27</td>
<td>14.7</td>
<td>0.91</td>
</tr>
</tbody>
</table>

*From Mallarino (2008) for “Very Low” and “High” and grain removal-based for “Optimum”

† from USDA NASS (2012): Iowa average (2009-2011) 173 bu/ac corn and 50.8 bu/ac soybean; assumed corn and soybean yields reported at 15.5% and 13% moisture and corrected to dry weight here; corn: 0.31 lb P₂O₅/bu and soybeans: 0.76 lb P₂O₅/bu (Mallarino et al., 2011)

Conclusions

Consideration of soil quality and water quality is necessary to achieve long-term productivity and environmental quality goals. This report highlights significant uncertainty in the status of soil nutrient balances, particularly with regard to nitrogen (N). The ability to determine whether N balances in continuous corn and corn-soybean cropping systems are positive, negative, or neutral is limited by the inability to measure or accurately predict several large N fluxes and the lack of long-term soil N stock measurements from cropping systems experiments.

Nevertheless, soil N mass balances developed in this report indicate that long-term soil N stock reductions are certainly possible, particularly in corn-soybean rotations. At the three N fertilizer input rates evaluated in this report...
(Table 1), two-year N balances for the full corn-soybean rotation showed net negative balances of -22, -19, and -15 lb N/ac-yr. However, there is extremely high uncertainty associated with the second largest N input in the corn-soybean rotation, biological N fixation; this resulted in overall uncertainty estimates for this rotation (approximately 50 lb N/ac-yr) that exceeded the net balance values. Previous measurements of long-term changes in soil N stocks in Iowa corn-soybean rotations were limited to two locations and these data were inconclusive due to statistical sampling challenges (Russell et al., 2005). However, negative input-output balances were consistent with negative N stock-change analyses. This report determines that there is significant risk that corn-soybean rotation systems have net negative N balances.

In contrast to the corn-soybean rotation, the N balances developed for continuous corn systems consistently showed positive N balances. At the three N fertilizer input rates evaluated in this report, continuous corn showed increasingly positive N balances for increasing N fertilization input rates (balances of +60, +69, and +76 lb N/ac-yr). The estimated uncertainty values for continuous corn (~7 lb N/ac) were smaller than the associated positive net balances, providing additional validation of the positive balance. At one of two Iowa locations where long-term measurements of total N stock-changes have been published, continuous corn systems receiving 180 kg N/ha-yr (161 lb N/ac-yr) showed a statistically significant positive N balance. At the second Iowa location, N stock changes were positive although not significantly different from zero (no change) due to low statistical power (Russell et al., 2005). Nevertheless, data from these sites are completely consistent with the input-output analysis and ‘stock-change over time’ data reported herein.

One clear pattern in this report was statistically significant positive correlations among N fertilizer inputs, yield, and soil organic carbon and N stocks (Figure 4). These data highlight the importance of N fertilizer inputs to maintain soil organic matter and N stocks in the absence of manure or other significant carbon and N additions. Declines in soil organic matter decrease yield potential. Accordingly, long-term declines in soil organic matter associated N could lead to lower N fertilizer use efficiency and soil organic matter stocks, increasing the challenge of water quality improvements.

Although accurate measurement of phosphorus fluxes can also present challenges, phosphorus fluxes are measured with greater accuracy than N due to the lack of a gaseous phase and biological inputs. The optimum soil testing phosphorus scenarios had nearly neutral phosphorus balances. The high soil phosphorus test scenarios resulted in negative balances for both crops as expected to allow utilization of existing crop available soil phosphorus. Soil phosphorus nutrient stocks can be maintained over time through adherence to removal-based phosphorus application rates in conjunction with soil testing and consideration of phosphorus losses as estimated by the Iowa P Index.

References


CAFOs, NPDES Permits and the 590 Standard: What does it mean for manure management?

Angela Rieck-Hinz, Extension program specialist, Agronomy, Iowa State University; Eric G. Hurley, Nutrient Management Specialist, USDA-Natural Resources Conservation Service

Increased regulatory pressure, policy-driven programs designed to protect water quality, and a concern to make the most profitable use of manure resources are driving manure management issues. This session will look at some of the current events and practices, changes to the 590 Nutrient Management Standard, and some crystal-ball gazing related to manure nutrient management in Iowa.

Concentrated Animal Feeding Operation – CAFOs

A concentrated animal feeding operation (CAFO) is an animal feeding operation (animals confined for at least 45 days, non-consecutive, where vegetation is not grown or maintained) that is defined as a CAFO based solely on size for “large CAFO” and by size and discharge criteria for a “medium CAFO.” An animal feeding operation may also be “designated” a CAFO if it does not meet the size requirements and “permitting authority finds it to be a significant contributor of pollutants to surface water”. At the time this paper was written, the state of Iowa was only using the term CAFO in terms of open lot facilities. The term “CAFO” is not defined in Chapter 65 of the Iowa Administrative Code for confinement feeding operations. It is important to note this significant difference in federal vs. state law. Iowa law does not allow confinement feeding operations (operations in which animals are confined to areas which are totally roofed) to discharge manure so consequently CAFO requirements such as NPDES permits have not been issued for confinement feeding operations in Iowa. This is currently a concern the Environmental Protection Agency (EPA) has with the permitting process in Iowa and is also one of the things that triggers the EPA to look for combined operations (open lot and confinements) as they do their flyovers.

Implementation of CAFO requirements for open lots, primarily beef and dairy operations in Iowa, is an on-going effort. In 2001, the Iowa Department of Natural Resources (DNR) initiated the “Iowa Plan for Open Feedlots”. The purpose of this plan was to help open feedlots comply with state and federal laws through a voluntary registration process that would prioritize environmental impacts of large CAFO feedlots (over 1,000 animal units; i.e. over 1,000 head beef or 700 head dairy). This program was developed with support from many partners and was deemed a success in moving the industry toward environmental compliance.

The follow-up to Iowa Plan for Open Feedlots is now focused at smaller beef and dairy feedlots- or those below the permit threshold of a large CAFO. The current effort is called the “Water Quality Initiatives for Small Iowa Beef and Dairy Feedlot Operations” or more commonly the “Small Feedlot Plan”. This initiative is an educational outreach and demonstration plan designed to assist small and medium size feedlots understand their potential impact on water quality. Education is focused on providing self-assessment materials for producers to use at their own livestock operation, including manure management practices, pen management, and even voluntary water sampling below feedlots. Additional education is focused at a series of field days that show different management practices and manure control structures to help small livestock operations protect water resources and the development of print materials to further identify water quality issues and highlight manure practices and control structures.

National Pollutant Discharge Elimination System Permits – NPDES Permits

If an open lot livestock production systems meets the size and discharge requirements to be defined as a CAFO, they are required by both federal and state law to have a NPDES permit to operate their livestock farm. This permit requires not only operational standards to be met, but also requires a nutrient management plan and a significant amount of recordkeeping.

In many situation livestock producer acknowledge the need for manure control structures or practices to help protect surface water, but many feel the permitting process and subsequent recordkeeping is too burdensome to manage. In some cases producers will take extra steps to protect water resources so they do not have to meet permit
requirements, in some cases, producers choose to ignore the requirements and “hope not to get caught”. In either case, we have to continue to provide outreach and educational materials that not only help producers make good choices, but that actually meet their needs for resource protection, time management and fiscal investment and appropriate use of nutrient resources.

**NRCS 590 Nutrient Management Standard**

The 590 Nutrient Management Conservation Practice Standard provides guidance for Natural Resources Conservation Service technical assistance and programs involved in soil fertility, manure and commercial fertilizer management, and related water quality issues. The standard focuses on the 4Rs of nutrient management, apply the Right nutrient source at the Right rate at the Right time in the Right place to improve nutrient use efficiency by the crop and to minimize nutrient losses to the surface and groundwater and to the atmosphere.

At least every five years the 590 standard is updated to account for changes in technology, new information, and new ideas. The national 590 Nutrient Management Standard was released January 2012.

The new Iowa 590 Nutrient Management standard is being written and will be released the first quarter of 2013. It will be based on the national standard and adapted to Iowa. It has been technically reviewed by advisors from Iowa State University and Agricultural Research Service’s National Laboratory for Agriculture and the Environment in Ames. Additional reviews are being provided by conservation partners in the Iowa Department of Agriculture and Land Stewardship and the Iowa Department of Natural Resources as well as agricultural industry, producer, and environmental representatives.

At the time of this writing, the Iowa 590 Nutrient Management Standard is still in draft form. At the time of the ICM Conference, the 590 will be going through final reviews before release for public comments sometime in December 2012. A preview of proposed changes will be provided. Watch for announcements at the Iowa NRCS website (http://www.ia.nrcs.usda.gov). Check the Technical Resources, Nutrient Management page.

**What does this all mean for manure management?**

It is anticipated that in the next 12-18 months we will see changes to our state regulations in terms of CAFO operations and subsequently the use of NPDES permits. We will also see changes to the 590 standard that will encourage better use of manure nutrients. The usual complications will arise in the fact that agencies have different rules and goals. It is important to recognize how voluntary programs and educational outreach programs contribute to significant adoption of practices to protect water resources by livestock producers. It is also important that you know and understand what this means for your farm or for your clients.

**References**


Tillage system performance in southern Minnesota
Jeffrey Vetsch, assistant scientist, Southern Research and Outreach Center, University of Minnesota.

Introduction
The agronomic performance of tillage practices is influenced by many factors, some of which the farmer cannot control. The weather, something we have little control over, dramatically affects agriculture and crop production. Our weather (climate) is also changing, which affects the agronomic performance of our cultural practices. In the Midwest, climate change has resulted in increased annual precipitation and greater frequency of intense rainfall events (EPA, 2010). Greater annual rainfall results in cold and wet soils, which reduce the number of days for field operations thus delaying important field operations like planting. Increased precipitation and rainfall intensity increases soil erosion. All of these factors along with soil characteristics (texture, internal drainage, parent material) influence our tillage system choices.

Some of the management decisions a farmer makes do influence tillage system choice and performance. Crop rotations have changed from the traditional corn-soybean rotation to more corn dominated rotations. More corn after corn results in more residues and for many that means more tillage or more aggressive tillage to bury residue. Farm size and equipment size which are related can influence tillage decisions. Large farming operations, which rely more on hired labor, generally prefer more conventional tillage systems. Ultimately farmers choose a tillage system that balances their risk: one that does not limit crop yield or profitability and conserves the soil resource. The purpose of this paper is to summarize the last 15-yrs of tillage research conducted in southern Minnesota on glacial till (clay loam) and loess (silt loam) soils.

Methods
Tillage research was conducted at two locations in Minnesota. Several tillage studies were conducted at the University of Minnesota Southern Research and Outreach Center in Waseca from 1997 through 2010. The multi-year small plot studies compared various tillage systems alone and in combination with other crop management factors including: crop rotation, hybrid selection, planting date, nitrogen application timing and phosphorus fertilizer rate and placement. Generally in these experiments tillage systems were established and evaluated on the same site for a minimum of three years. The experiments were conducted on pattern tile drained (75’ spacing) Nicollet–Webster soils. Two four-year studies (1997 to 2000) were located on a well drained Port Byron silt loam soil near Rochester in southeast Minnesota. One study compared four tillage systems for corn in a corn-soybean rotation and another compared four tillage systems in continuous corn.

Results
Corn–soybean rotations
Corn yield responses to tillage are strongly influenced by soil type, climatic conditions and crop rotation. On a well drained silt loam soil, corn yields following soybean were not significantly different, when averaged across the four years of the study (Vetsch and Randall, 2002). On a poorly drained clay loam soil corn yields following soybean averaged 176, 180, 178 and 184 bu/ac with no-till (NT), strip-till (ST), spring field cultivate (SFC), and chisel plow plus spring field cultivate (CP+SFC), respectively (Vetsch and Randall, 2004). Chisel plow produced greater yields than NT and SFC, but similar to ST during the 3-year study. When several studies at Waseca with similar tillage treatments for corn following soybean were averaged (a total of 31 site-years), corn yields following soybean were 161, 170, 171 and 174 bu/ac with NT, ST, SFC, and CP+SFC, respectively (unpublished).
Tillage effects on soybean production were also compared in two studies on clay loam soils at Waseca. In a six-year trial NT soybean yields were two bu/ac less than spring disk and CP+SFC tillage systems (Randall and Vetsch, 2003). In this trial soybeans were planted in narrow rows with a drill for the spring disk and CP+SFC treatments, whereas a coulter-cart drill was used for the NT soybeans. In a three-year study, CP+SFC tillage increased soybean yields in one of three years compared with NT (Vetsch et al., 2007). When averaged across the three-year study period, the yield difference was only one bu/ac.

Corn after corn

Greater than 200 bu/ac corn yields produce vast amounts of crop residue, which can make conservation tillage for corn after corn challenging on cool Minnesota soils. Tillage effects on corn after corn were evaluated in three studies. A four-year study (1997–2000) on a silt loam soil near Rochester found tillage treatments affected corn yields in three of four years (Vetsch and Randall, 2002). Averaged across years, continuous corn yields were least with NT (155 bu/ac), intermediate with ST (162 bu/ac) and two-pass zone-till (163 bu/ac) and slightly greater with CP+SFC (166 bu/ac). The two-pass zone tillage system consisted of 15-inch deep zone tillage in the fall followed by shallow (4-inch deep) zone tillage in spring prior to planting. Two three-year studies on Nicollet-Webster clay loam soils at Waseca compared tillage systems for second-year corn in a soybean-corn-corn rotation. Five tillage systems [15-inch deep zone tillage (ZT), ST, spring disk (SD), CP+SFC and moldboard plow (MP)] for second year corn were compared from 2005 through 2007 (Vetsch and Randall, 2008). Moldboard plow produced eight bu/ac greater yields than CP+SFC and 12 bu/ac greater than ZT and ST (Table 1). In a second phase of the study (2008–2010) the ZT treatment was dropped and replaced with a two-pass disk (fall and spring) treatment (Vetsch and Randall, 2011). Results were similar as MP had nine bu/ac greater yields than CP+SFC and 11 bu/ac greater than ST (Table 2). Moreover in the cool growing season of 2009, MP had 12 bu/ac greater yields than CP+SFC and 19 bu/ac greater than ST (data not shown).

Summary

Tillage effects on crop production are influenced by crop rotation, weather and soil properties. On well drained loess soils in southeast Minnesota conservation tillage practices like strip and zone tillage produce similar yields to chisel plow (mulch tillage) systems. No tillage may result in a slight yield penalty, especially when corn follows corn. On poorly drained glacial till soils in south-central Minnesota, strip tillage, mulch tillage (SFC) and chisel plow had similar yields when corn follows soybean. While no-till yields were about 10 bu/ac less than chisel plow. When corn follows corn, moldboard plow had greater yields than chisel, strip-till and zone-till. In most years strip tillage was equal to chisel in corn after corn.

Table 1. Second-year corn yields as affected by tillage at Waseca (2005-2007 avg.).

<table>
<thead>
<tr>
<th>Tillage treatment</th>
<th>Corn grain yield (bu/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep zone-till</td>
<td>173</td>
</tr>
<tr>
<td>Strip-till</td>
<td>173</td>
</tr>
<tr>
<td>Spring disk</td>
<td>170</td>
</tr>
<tr>
<td>Chisel plow</td>
<td>177</td>
</tr>
<tr>
<td>Moldboard plow</td>
<td>185</td>
</tr>
<tr>
<td>LSD (0.10):</td>
<td>5</td>
</tr>
</tbody>
</table>
Table 2. Second-year corn yields as affected by tillage at Waseca (2008-2010 avg.).

<table>
<thead>
<tr>
<th>Tillage treatment</th>
<th>Corn grain yield (bu/ac)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-pass disk</td>
<td>192</td>
</tr>
<tr>
<td>Strip-till</td>
<td>196</td>
</tr>
<tr>
<td>Spring disk</td>
<td>189</td>
</tr>
<tr>
<td>Chisel plow</td>
<td>198</td>
</tr>
<tr>
<td>Moldboard plow</td>
<td>207</td>
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<td><strong>LSD (0.10):</strong></td>
<td><strong>9</strong></td>
</tr>
</tbody>
</table>

References


Conservation systems: Benefits in managing drought and mitigating yield loss by improving soil quality

Mahdi Al-Kaisi, professor and Extension soil and water specialist, Agronomy, Iowa State University; David Kwaw-Mensah, research associate, Agronomy, Iowa State University; Jose Guzman, graduate research assistant, Agronomy, Iowa State University.

Introduction

Soil conservation is essential to sustain soil quality and improve crop productivity. Soil quality indicators include improved water infiltration and storage, and adequate levels of available soil nutrients for plants and soil carbon. Droughts result from a deficiency of precipitation from statistically normal amounts that when extended makes precipitation inadequate to meet the demands for crop production. Therefore, agriculture is the first economic sector that is visibly impacted by drought because of lack of soil moisture, which affects soil nutrient cycling and crop productivity. The recent drought in Iowa has presented such challenges to corn and soybean production across Iowa. According to the US Drought Monitor report for October, Iowa is 100% abnormally dry with 2.5% of the Northwestern corner of the State under exceptionally drought conditions and 63% of Iowa is under extreme drought conditions (Rippey, 2012). With the current weather challenges, conservation planning is becoming increasingly necessary, as Iowa experiences this extreme weather conditions and their impacts on crop production and soil quality. The USDA National Agricultural Statistics Service is forecasting significant corn and soybean yield losses in Iowa. Expected average bushels of corn grain for Iowa as of October 1, 2012, is 140 bu/acre, (32 bu/acre less than in 2011). Soybean yields are expected to fall by 8 bu/acre compared to the average yield of 51 bu/acre in 2011.

Consequently, Iowa farmers are being urged to avoid soil tillage to retain soil moisture and reduce erosion as dry conditions persist. Soil erosion is always associated with tillage intensity in many parts of the State during the spring when land is most vulnerable to water erosion due to lack of vegetation cover or residue to protect the soil surface from the intensity of rain. Many factors contribute to this problem, but tillage is the prime contributing factor. Many producers have voluntarily adopted conservation practices that lessen the negative impacts of agricultural activities on the environment. The outcome has been significant over the past few decades, with benefits in increased crop productivity, more efficient use of time and equipment, and a reduction in soil erosion. However, the current soil erosion level stands at approximately 5 tons/acre, and in some areas of the State this figure can be exceeded by 10 fold or more. This presents a challenge to examine and sustain our effort of implementing and targeting conservation practices in the most sensitive areas of the State to minimize the impact of soil erosion on soil and water quality. The current commodity prices, coupled with the promotion of tillage technology, presents a significant challenge for producers to adopt a system's approach to conservation practices as an integrated practice of conservation can be very powerful for high economic returns with excellent environmental rewards.

Soil management practices that protect soil quality are not only economically and environmentally necessary, but constitute the right conservation ethic to land stewardship. Therefore, producers should consider adopting conservation plans that are practical, site specific, and integrate them into the overall production system to achieve intended objectives. These conservation plans would include reduced tillage such as no-till and strip-tillage, which leave post-harvest crop residue to cover the soil surface. The following are a number of soil conservation plans producers can consider in this extreme drought conditions: the use of cover crops, the construction of grass waterways, terraces, buffer strips and pasture erosion control systems with manure application and soil testing plans. Conservation planning and implementation need to be carefully considered as solutions to reduce potentially negative impacts of row cropping system on soil and water quality. Consideration of site specifics and the objectives of implementation should be included in the planning process. Finally, the systems approach to conservation must include nutrient loading and sediment reduction plans as effective measures to protect soil and water quality.
**Discussion**

**Drought effects on corn yields in Iowa**

Drought conditions in 2012 significantly reduced corn yields across Iowa with variable severity by region (Fig.1). In the Northcentral (glacial till, poorly-draining soils) and Southwest (loess, well-draining soils) regions, corn yields were reduced compared to 2011 without any significant differences between tillage management. This result might be due to these soils’ excellent water storage capacity at lower depths, which reduced the effects of drought across tillage systems. Persistent drought might deplete this subsoil stored water leading to yield reductions, especially in tilled soils. In the Southcentral region (high clay content, poorly-draining soils), corn yields in 2012 were greater in no-till and strip-till than in tilled soils; CP, DR and MP in 2012, compared with corn yields for NT and ST in 2011, where there was adequate rainfall. Typically, Iowa has adequate rainfall that is essential for good yield. However, when soil moisture is a limiting factor as in 2012, reducing tillage intensity such as strip-tillage or no-till can increase water storage, thus reducing the effects of drought on corn yield. In Northcentral Iowa, corn yield reductions for tillage systems due to drought conditions in 2012 from 2011 are as follow: 60 bu/acre (DR), 80 bu/acre (CP), 80 bu/acre (ST), and 70 bu/acre for NT. Meanwhile, in Southwest Iowa, corn yield reductions are as follow: 58 bu/acre with CP, 66 bu/acre with ST, 73 bu/acre with NT, 72 bu/acre with MP, and 70 bu/acre with DR. Contrary to these findings, corn yields in Southcentral Iowa in 2012 are better than in 2011 by 30 bu/acre with NT and 5 bu/acre with ST while CP, DR and MP yields experienced yield reductions as much as 70, 50, and 75 bu/acre, respectively.

![Figure 1. Tillage effects on corn yield in 2011 and 2012 by region. NT=no-till; ST=strip-tillage; CP=chisel plow; DR=deep rip; MP=moldboard plow.](image)

**Tillage management under drought conditions**

The current drought challenges require proactive planning with the introduction of some management aspects that may not be appealing to many. However, to reduce the potential damage and mitigate some of the impacts of drought on the next growing season, certain management practices need to be considered. The early harvest this fall and the extended period of time before the next growing season can be tempting for farmers to do more tillage. Tillage will not minimize or improve the impact of drought on the soil structure. On the contrary, soil tillage at the current dry soil condition will destroy soil structure and any rain will destroy soil aggregates, seal the soil surface of freshly tilled soils and result in significant soil erosion and loss of residual nutrients not utilized by the crop. Additionally, tillage in this dry condition will compromise any chance to recharge the subsoil, a condition that is desperately needed to make up for water loss during dry conditions.

Studies have shown that agricultural management practices can significantly influence soil hydraulic properties and processes in space and time (Dao, 1993; Green et al., 2003; Kennedy and Schillinger, 2006; Celik and Ersahin, 2011). Conservations tillage systems such as no-till increase water infiltration (Fig.2). In combination with high organic matter content, no-till soils increase soil water storage (Fig.3). Typically, no-till surface soils (0-8 in) have
greater water content at planting than plowed and stubble mulch tilled soils (Dao, 1993). This is attributed to
differences in surface residue cover as tilling prior to planting increases evaporation losses. Studies in many parts
of the country and elsewhere show that full width tillage is not the best solution for improving productivity, soil
quality, energy use, labor, and time. Many conservation systems can work as good as full width tillage such as strip-
tillage, where tilled zone of 8 inches wide and 6 inches deep is done. This system is very efficient and effective in
nutrient placement, where tillage and nutrients application are coupled in a single operation.

![Graph showing cumulative infiltration under five tillage systems. NT=no-till; ST=strip-tillage; CP=chisel plow;
DR=deep rip; MP=moldboard plow.](image)

**Figure 2.** Cumulative water infiltration under five tillage systems. NT=no-till; ST=strip-tillage; CP=chisel plow;
DR=deep rip; MP=moldboard plow.

![Graph showing soil water content from Sep to May.](image)

**Figure 3.** Tillage effects on soil water content between fall tillage and the start of next years the growing season,
(Dao, 1993).
Residue management and cover crops under drought conditions

Crop residues play significant role at several levels of soil sustainability. Primarily, crop residue physically protects the soil from potential erosion during heavy rain events. Crop residue reduces the impact of rain drops by absorbing the kinetic energy of rain drops to create a gentle infiltration and slow movement of water in the soil. Thus, reducing soil erosion and increasing the time opportunity for water to percolate the soil for better water recharge of the subsoil to save crop yield during drought. The effectiveness of residue in achieving these goals depends on how it is managed, which starts during harvest by cutting corn at a minimum height of 12 inches above the ground. The upright residue can be very effective in trapping soil moisture in term of snow and slow water movement (McMaster et al., 2000). Residue should be kept intact to increase its effeciveness. Shredding or chopping residue can create a lot of problems in terms of its ability to reduce soil erosion and potential washout during high intensity rain events.

Post-harvest cover crops can be essential components of drought management to mitigate yield losses. The benefits of cover crops and crop residue include protecting the soil from excessive dryness to prevent cracks and fractures in the soil, thus improving soil water storage and soil microbial activity, nutrient cycling and uptake by plants (Aiken et al., 2003). Cover crops increase water storage by reducing evaporation and increasing water infiltration (Fig. 4). Cover crops take up water when they grow but prevent water losses from the soil surface. Reduction in evaporation from soil surfaces occur if the cover crop is left on the soil surface as mulch, but not if it is incorporated (Fig. 3). The best protection against moisture loss and wind erosion is a good protective cover of growing plants and plant residue.

![Tillage effects on cumulative water infiltration after 24 minutes of simulated rainfall. NT=no-till; ST=strip-tillage; CP=chisel plow; DR=deep rip; MP=moldboard plow.](image)

Figure 4. Tillage effects on cumulative water infiltration after 24 minutes of simulated rainfall. NT=no-till; ST=strip-tillage; CP=chisel plow; DR=deep rip; MP=moldboard plow.

Summary

Drought results from lack of precipitation over an extended period. Soil conservation is essential to manage drought to sustain soil quality and improve crop productivity. No-till soils with stable soil structure and rich in organic matter promote water infiltration and increase soil water storage. With drought conditions, reducing tillage intensity as in ST or avoiding tillage as in NT can protect soil structure, increase soil water storage and reduce the effects of drought on corn yield. In the Southcentral region of Iowa where soils are high in clay content and poorly-drained, corn yields in 2012 were 30 and 5 bu/acre higher with NT and ST systems, respectively compared with corn yields with the same tillage systems in 2011. On the contrary, corn yields from tilled soils declined by 75 bu/acre in MP,
70 bu/acre in CP and 50 bu/acre in DR. In the Northcentral region with glacial till and poorly-draining soils and the Southwest region with loess and well-draining soils, corn yield reductions in 2012 across all tillage systems were in the range of 60-80 bu/acre and 58-73 bu/acre, respectively compared with 2011. The recent drought in Iowa led to early harvest. With the early harvest and extended period between harvest and the next growing season, farmers may be tempted to do more tillage at the risk of damaging the soil structure and subsequently damage the soil aggregate leading to soil surface sealing and a significant amount of runoff and soil erosion during rain events. Cover crops and crop residue are essential components of drought management to mitigate yield losses. Cover crops protect the soil from excessive dryness, prevent soil cracks and fractures, and improve soil microbial activity, nutrient cycling and uptake by plants. Crop residue creates a slow but steady infiltration of water to increase the time opportunity for water to move through the soil and recharge the subsoil that is essential for good yield during drought condition.

References


Balancing tillage, soil loss, and profitability

H. Mark Hanna, Extension ag engineer, Agricultural and Biosystems Engineering, Iowa State University; Matt Helmers, associate professor and Extension ag engineer, Agricultural and Biosystems Engineering, Iowa State University.

Profitability and environmental sustainability are major objectives in crop production. Decisions on whether to till and what operation to use have direct impact on these objectives. Because of potential adverse affects on soil erosion, structure, aggregate stability, and general soil health, potential for benefits should be carefully considered prior to field operations. Tillage objectives include soil loosening, incorporation of fertilizer or pesticide, weed control, and surface leveling after prior tillage to accommodate planting. Reducing surface residue cover may allow topsoil to warm faster in spring, promote soil drying, and alter the environment for some disease pathogens. Conversely, soil on sloping areas is exposed to longer term degradation by erosion and moisture loss in dry conditions is counterproductive.

Yield comparisons

Yield results have been collected since 2003 from long-term tillage comparisons at Iowa State University Research and Demonstration Farms across the state. Results are aggregated in tables 1 – 3 from north-central locations on glacial till soils (Ames and Kanawha), western Iowa loess (Calumet, Castana, and Lewis), and eastern Iowa loess (Chariton, Crawfordsville, and Nashua).

Corn yields have been generally higher across years and sites with a full-width tillage system, however soybean yields were unaffected as no-till yields were as likely to have the highest yield as other tillage systems in individual comparisons. Research farm staff are good crop producers, but it’s worth noting that they often have 20 to 50 or more experiments to establish annually with almost as many research investigators to please in a timely fashion on each experiment. Given the desire to keep management similar across systems (e.g., fertility, pest control) and other work demands, management in reduced tillage (no-till, strip-till) and perhaps other systems may not always be as timely as farmer management of a homogeneous system, i.e. use of a single tillage type across most of the farm.

Table 1. Corn yields in corn-soybean rotation at ISU Research and Demonstration Farms

<table>
<thead>
<tr>
<th></th>
<th>Western Iowa loess</th>
<th>Eastern Iowa loess</th>
<th>Till</th>
<th>State average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moldboard plow</td>
<td>172.7</td>
<td>185.0</td>
<td>193.0</td>
<td>183.7</td>
</tr>
<tr>
<td>Subsoil</td>
<td>172.5</td>
<td>185.2</td>
<td>188.2</td>
<td>182.5</td>
</tr>
<tr>
<td>Chisel plow</td>
<td>172.0</td>
<td>187.7</td>
<td>192.2</td>
<td>184.6</td>
</tr>
<tr>
<td>Strip-till</td>
<td>164.7</td>
<td>178.7</td>
<td>174.7</td>
<td>174.0</td>
</tr>
<tr>
<td>No-till</td>
<td>162.6</td>
<td>170.8</td>
<td>169.6</td>
<td>168.3</td>
</tr>
</tbody>
</table>

41 site-years including 11, 20, and 10 site-years in western Iowa loess, eastern Iowa loess, and till soils, respectively. Al-Kaisi and Hanna.
Table 2. Second year corn yields in corn-corn-soybean rotation at ISU Research and Demonstration Farms

<table>
<thead>
<tr>
<th></th>
<th>Western Iowa loess</th>
<th>Eastern Iowa loess</th>
<th>Till</th>
<th>State average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moldboard plow</td>
<td>188.9</td>
<td>176.5</td>
<td>178.0</td>
<td>180.2</td>
</tr>
<tr>
<td>Subsoil</td>
<td>186.7</td>
<td>168.9</td>
<td>167.6</td>
<td>173.6</td>
</tr>
<tr>
<td>Chisel plow</td>
<td>184.6</td>
<td>169.9</td>
<td>171.0</td>
<td>174.2</td>
</tr>
<tr>
<td>Strip-till</td>
<td>170.7</td>
<td>167.2</td>
<td>156.0</td>
<td>166.0</td>
</tr>
<tr>
<td>No-till</td>
<td>168</td>
<td>153.6</td>
<td>148.2</td>
<td>156.6</td>
</tr>
</tbody>
</table>

25 site-years including 7, 13, and 5 site-years in western Iowa loess, eastern Iowa loess, and till soils, respectively. Al-Kaisi and Hanna.

Table 3. Soybean yields in corn-soybean rotation at ISU Research and Demonstration Farms

<table>
<thead>
<tr>
<th></th>
<th>Western Iowa loess</th>
<th>Eastern Iowa loess</th>
<th>Till</th>
<th>State average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moldboard plow</td>
<td>51.9</td>
<td>57.5</td>
<td>50.9</td>
<td>54.4</td>
</tr>
<tr>
<td>Subsoil</td>
<td>52.6</td>
<td>55.8</td>
<td>50.2</td>
<td>53.6</td>
</tr>
<tr>
<td>Chisel plow</td>
<td>52.3</td>
<td>55.3</td>
<td>49.3</td>
<td>53.0</td>
</tr>
<tr>
<td>Strip-till</td>
<td>52.6</td>
<td>55.5</td>
<td>49.3</td>
<td>53.2</td>
</tr>
<tr>
<td>No-till</td>
<td>54.0</td>
<td>55.8</td>
<td>49.4</td>
<td>53.8</td>
</tr>
</tbody>
</table>

41 site-years including 11, 20, and 10 site-years in western Iowa loess, eastern Iowa loess, and till soils, respectively. Al-Kaisi and Hanna.

Economics

Input costs for land, seed, fertilizer, and pesticides are significant and recur regularly. Although machinery expenses may not be the first item considered when attempting to lower costs and increase profits, it may be more feasible to reduce machine costs if land, seed, and chemical prices aren’t readily negotiable. Management differs as tillage is reduced, necessitating some degree of familiarity and comfort with a different system.

Seed and chemical costs frequently do not change with tillage system. Assuming these do not vary, a partial budgeting approach can be used to compare systems, vis-à-vis, are the cost of additional tillage trips returned by additional crop produced? Current costs for selected tillage operations are shown in table 4.

Table 4. Cost of field operations per acre

<table>
<thead>
<tr>
<th>Operation</th>
<th>New</th>
<th>Used</th>
<th>Custom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disc-subsoiler</td>
<td>$19.04</td>
<td>$17.65</td>
<td>$20.75</td>
</tr>
<tr>
<td>Subsoiler</td>
<td>16.95</td>
<td>14.70</td>
<td>18.45</td>
</tr>
<tr>
<td>Chisel plow</td>
<td>15.38</td>
<td>13.75</td>
<td>14.90</td>
</tr>
<tr>
<td>Field cultivate</td>
<td>13.08</td>
<td>9.96</td>
<td>12.30</td>
</tr>
</tbody>
</table>

Costs were calculated using new equipment or 5 to 10 year-old used equipment. Custom rates are from the Iowa Farm Custom Rate Survey, FM 1698.

Actual costs vary, particularly with age of equipment. Subsoiling ranges from $15 - $20 per acre with costs of $18 to $20 per acre for popular combination disc-subsoiler or newer equipment. Shallower chisel plowing costs are about $15 per acre. At least one secondary tillage pass before planting is usually required to level soil, costing about $12 per acre. Adding one secondary tillage pass, subsoiling adds about $30 per acre and chisel plowing about $27 per acre compared to using no tillage before planting. At current relatively high corn prices, tillage seems economically justified at least in the short term if longer term soil erosion and soil health are not considered. During a period of
$4 – 6/bu corn prices, an extra 5 to 7 bu/acre yield increase would be required for more aggressive tillage systems just to recoup machinery expenses without considering additional soil degradation or loss.

**Energy considerations**

Fuel costs and energy use are directly related to tillage depth. American Society of Agricultural and Biological Engineers data indicate that drawbar pull of most tillage implements is directly related to operating depth. In-field measurements with subsoiler equipment have shown fuel use nearly doubling as operating depth went from 9 to 18 inches.

Some component of energy is required simply to move the tractor and implement in the field, still chisel plowing at 6 to 8-in. depth typically requires about 1 gal/acre fuel use whereas subsoiling at 12-in. depth requires about 1.5 gal/acre. Long-term corn yield averages on ISU research farms typically differ by a fraction of a bushel per acre with yield averages from a chisel plow system often slightly ahead. Yield comparisons from all sites and years between subsoil and chisel plow systems are shown in figure 1. Results suggest that although deep tillage uses more diesel fuel, it doesn’t cover extra costs unless a distinct problem is being corrected.

**Soil loss**

An important factor to consider in choosing a tillage system is the impact on soil erosion and overall soil loss. To investigate the impact that a chisel plow, strip till, or no-till system has on soil loss, the WEPP model was used at eight sites throughout Iowa (Zhou et al., 2009). WEPP is a process-based, distributed parameter prediction model for soil erosion and sediment delivery from hillslopes and small watersheds (Planagan and Nearing, 1995). Processes implemented in WEPP include rill and interrill erosion, infiltration, percolation, sediment transport and deposition, surface runoff, evapotranspiration, snow accumulation and melt, irrigation, channel erosion, residue and canopy effects, and tillage effects. It is useful to simulate the impact of land use and/or field management practices on soil loss and sediment transport on hillslopes and in small watersheds. For the results presented within, a 50-yr weather record for each location was used in the modeling. As shown in Table 5, the no-till and strip tillage systems greatly reduced soil loss from all the sites modeled with, as expected, the most dramatic reductions at the sites with greater slope. This highlights the need for the greatest soil protection on those most sensitive lands. Despite dramatic reductions in soil loss with no-till at sites with slopes greater than 7%, the soil loss was still greater than 1 ton/acre/yr with the no-till. This highlights the potential need for implementation of other in-field or edge-of-field practices. An example of an in-field practice that could reduce soil erosion is a cover crop. It is important to note that while edge-of-field practices such as buffers reduce soil loss from the field they do not reduce in-field erosion. As such, a combination of practices should be used to reduce in-field erosion and soil loss from the field. Another important note relative to these results is that WEPP models the rill and interrill erosion but not ephemeral gully erosion which could be a major contributor to overall soil loss from the field. As such, practices such as grassed waterways that protect those areas susceptible to ephemeral gully erosion may be needed.
Figure 1. First year corn yields from subsoil and chisel plow tillage systems at ISU Research and Demonstration Farms (41 site-years).

Summary
Profitability and environmental sustainability impact tillage decisions. Multi-year tillage comparisons suggest no-till soybeans yield as well as other tillage systems across the state. Conversely corn yields frequently respond to some type of tillage, although when comparing full-width tillage systems shallower chisel plowing yields are equal to deeper subsoiling or ripping yields over time at different sites. From a soil- and energy-saving perspective, growers are encouraged to avoid tillage before planting soybeans and to carefully consider tillage requirements before planting corn. Longer-term environmental sustainability provides further reasons for cautious tillage use.
Table 5. Estimated annual soil loss from the WEPP model at various locations in Iowa

<table>
<thead>
<tr>
<th>Site</th>
<th>Primary Soil</th>
<th>Area (acres)</th>
<th>Mean Slope (%)</th>
<th>Soil loss (ton/acre/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Chisel Plow</td>
</tr>
<tr>
<td>Northwest Iowa</td>
<td>Galva silty clay loam</td>
<td>111</td>
<td>2.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Loess Hills</td>
<td>Ida silt loam</td>
<td>98</td>
<td>10.8</td>
<td>18.9</td>
</tr>
<tr>
<td>Des Moines Lobe</td>
<td>Nicollet loam</td>
<td>113</td>
<td>1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>Western Deep Loess and Drift</td>
<td>Sharpsburg silty clay loam</td>
<td>89</td>
<td>7.1</td>
<td>13.4</td>
</tr>
<tr>
<td>Eastern Deep Loess and Drift</td>
<td>Nira silty clay loam</td>
<td>191</td>
<td>0.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Eastern Till Prairie</td>
<td>Kenyon loam</td>
<td>197</td>
<td>3.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Northeast Iowa</td>
<td>Fayette silt loam</td>
<td>302</td>
<td>9.5</td>
<td>12.5</td>
</tr>
<tr>
<td>Southern Thin Loess and Till Plain</td>
<td>Grundy silt loam</td>
<td>56</td>
<td>7.5</td>
<td>17.7</td>
</tr>
</tbody>
</table>

References


The emerging biochar industry
David Laird, professor, Agronomy, Iowa State University.

Introduction
Biochar is basically charcoal. The term “charcoal” is preferred when the material is use as a fuel for cooking or heating, whereas the term “biochar” is appropriate when the material is use as a soil amendment. In recent years there has been rapid growth in interest in biochar among soil scientists, environmentalists, and entrepreneurs. Soil scientists have recently recognized that 10 to as much as 50% of the carbon in soil organic matter is in fact biochar, a legacy of natural vegetation fires (Skjemstad et al., 2002). Soil scientists are seeking to understand how both native and added biochar impacts soil quality, the leaching of nutrients and pesticides, and agricultural productivity. Environmentalists see biochar as a highly effective means of sequestering atmospheric carbon. Plants remove CO₂ from the atmosphere through photosynthesis. When the plant dies, decomposition of the plant residue quickly returns most of the biomass C back to the atmosphere as CO₂. If, however, the plant residue is pyrolyzed such that 20 to 50% of the biomass C is turned into biochar and that biochar is incorporated into the soil, then the C will be preserved for hundreds if not thousands of years (Lehmann et al., 2006). Entrepreneurs see an emerging industry with untapped markets and large growth potential due to the synergism of positive environmental and agronomic impacts. This article reviews the basic nature of biochar, its impact on soil properties and crop yields, the status of the emerging biochar industry, and the potential for a future role of biochar in the emerging cellulosic bioenergy industry.

Biochar is highly diverse
Biochar is not a single material, but rather a highly diverse group of materials that are made through the incomplete combustion, gasification, or pyrolysis of biomass (Laird et al., 2009). Properties of the biomass feedstock and the thermochemical conditions during the pyrolysis reaction have a big influence on the properties of the resulting biochar (Singh et al., 2010). Low temperature biochars (peak pyrolysis temperature <400°C) contain relatively high levels of O, N, S, and H in addition to C. As a general rule, low-temperature biochars have high cation exchange capacities, low internal porosity, low surface areas, and contain at least some biologically available C. The half-life of low-temperature biochar C in soils ranges from 10s to 100s of years. By contrast, high-temperature biochars (peak pyrolysis temperature >600°C) have high levels of biologically inert C and low levels of other elements; they also have low cation exchange capacities, high internal porosity, and high surface areas. The surfaces of high temperature biochars are typically hydrophobic when freshly prepared. The half-life of C in high-temperature biochars is >1000 years. All biochars contain at least some ash when freshly prepared, which consists primarily of carbonates, oxides and hydroxides of the various inorganic elements that were present in the biomass at the time of pyrolysis. Biochars made from herbaceous biomass, such as corn stover and switch grass, typically contain high levels of ash dominated by silica (SiO₂) and carbonates of Ca, Mg, and K. Biochars made from hardwood and especially softwood contain low levels of ash, which is mostly present as carbonates of base cations. The ash content of biochars increases with the peak pyrolysis temperature.

Biochar reactions in soils
Once in the soil biochars evolve or “age” with time. Although we have incomplete knowledge of the aging process some aspects are known. The carbonates in the ash associated with biochar react with soil acidity; and because of this reaction, most biochars are weak liming agents. The reaction involves the release of CO₂, which may diffuse out of the soil or move with groundwater as bicarbonate, and base cations primarily Ca, Mg, and K which are available as nutrients for plant uptake. Oxidation of biochar surfaces is another major aging reaction. Oxidation slowly enriches the concentration of oxygen containing organic functional groups on biochar surfaces, which transforms the surfaces from hydrophobic to hydrophilic and adds cation exchange capacity primarily in the form of carboxylate groups. There is some question as to how fast carboxylate functional groups form on the surfaces of biochars, with some authors arguing that it may take decades for cation exchange capacity to develop (Cheng et al., 2008), however we clearly measured an increase in cation exchange capacity after a 500 day laboratory incubation (Laird et al., 2010). A third and very important aging process is the adsorption of dissolved organic molecules on biochar surfaces. Organic molecules released to the soil solution during the decomposition of plant and animal residues are readily adsorbed through both hydrophobic and various polar interactions. These molecules may act
as surfactants further transforming the biochar from hydrophobic to hydrophilic and may add cation exchange
capacity and other properties to the biochar. A fourth aspect of aging is the colonization of biochar surfaces by soil
microorganisms (Lehmann et al., 2011). The C of high-temperature biochars is biologically unavailable; however,
low-temperature biochars are a potential source of metabolic energy for microorganisms. Most studies have shown
increases in fungi and actinomycetes populations relative to bacteria, however bacteria clearly live in biochar pores
where they may find refuge from predation. Fungi and actinomycetes may be better adapted for utilizing the C and
nutrients of low-temperature biochars as a substrate. Although high-temperature biochar C is either unavailable or
only very slowly available to microorganisms, biogenic organic compounds adsorbed on biochar surfaces provide a
source of substrate to sustain microbial activity.

The potential for biochar amendments to improve soil quality has been well documented in the soil science
literature (Laird et al., 2010: Atkinson et al., 2010). Biochar is a low density highly porous material; when added to
the soil it acts as a conditioning agent reducing bulk density and increasing porosity, aeration, and drainage. These
changes in soil physical properties have been consistently measured in both soil column incubation studies and in
the field at least three years after a biochar application. As noted above, biochar is transformed from hydrophobic
to hydrophilic after residing in the soil for a relatively short period of time. This transformation together with
the high internal porosity of biochar and lower bulk densities increases the capacity of biochar amended soils to
retain water. Increased water retention may be agronomically important, especially for coarse textured soils. In fine
textured soils, the ability of biochar amendments to increase porosity, aeration, and drainage is often more important
than the increase in water retention capacity. The high cation exchange capacity of aged biochars increases the
capacity of soils to retain cationic nutrients. Ortho phosphate, which is negatively charged, is retained on biochar
surfaces through anion exchange or ligand exchange reactions. Nitrate, however, does not appear to be strongly
adsorbed on biochar surfaces. However, the adsorption of NH$_4$ and organic molecules that contain N may slow
rates of nitrification and mineralization, respectively, and hence reduce the leaching of nitrate. In summary, biochar
amendments improve the physical properties of both coarse and fine textured soils and increase the nutrient and
water retention capacity of most soils.

**Impact of biochar on crop yields**

Field trials assessing the impact of soil biochar amendments on crop yields are currently under way in many parts
of the world (Spokas et al., 2012). The results to date are highly variable. Some studies have reported spectacular
yield increases, but these tend to be studies that involved poor quality soils that initially have very low yields. Most
reports of yield trials on high-quality soils have found only small yield increases or no yield response due to biochar
applications. A few studies have also reported negative yield responses due to biochar applications. The reason
for these negative responses is not always clear. However, some biochars contain significant levels of phytotoxic
polycyclic aromatic hydrocarbons. Other studies have reported physiologic changes in some plant species, which are
consistent with plant hormone activity. The presence of phytoactive compounds is associated primarily with high-
temperature biochars. The results demonstrate the critical importance of biochar quality; hence anyone interested in
experimenting with biochar is advised to use a proven product.

Across the Midwest Corn Belt biochar applications are anticipate to have little or no impact on crop yields for high-
quality well-managed soils. However, on coarse textured soils where yields are limited by low nutrient and water
holding capacities and on fine textured soils where yields are limited by poor aeration and drainage, biochar may
help. Biochar may also be effective for solving compaction problems in some soils. A one-time deep injection of
biochar into soils with hard setting E horizons, for example, could permanently eliminate the need for frequent deep
ripping. Thus we see little benefit from uniform applications of biochar on Midwestern corn and soybean fields,
rather agronomic value is more likely to be associated with site-specific applications designed to alleviate a specific
soil problems.

**The emerging biochar industry**

At this time, the nascent biochar industry in the US consists of a handful of entrepreneurs selling biochar in small
quantities to home gardeners for use in their back yards, to the horticulture industry for use as a component of
soil-less potting media and as a soil conditioning agent, to corporations and government agencies for reclamation
of contaminated soils including mine lands and urban brown fields (Beesley et al., 2011), and for use in systems
designed to capture and temporarily retain urban storm runoff. What these markets have in common is high value
and the need for relatively small quantities of biochar. The current price of biochar is approximately $1000 per ton. At such high prices, biochar is cost prohibitive for most Midwestern corn and soybean farmers. To reduce the price to a level that would be affordable will require a large increase in the supply of biochar. The most likely scenario that could lead to a large increase in supply is the production of a biochar co-product in the emerging cellulosic bioenergy industry.

**Biochar potential in the emerging cellulosic bioenergy industry**

Pyrolysis of corn stover, switch grass, hardwood and other forms of biomass produces three products, syngas, bio-oil, and biochar (Wright et al., 2010; Laird et al., 2009). Syngas is a combustible gas with only about one tenth the energy density of natural gas; none-the-less, syngas can be burned to produce heat, steam, and/or power. The syngas produced during pyrolysis can conveniently be burned to provide some of the heat needed to operate a pyrolysis plant. Bio-oil is a liquid energy raw material with about half the energy density of petroleum. Bio-oil is not an ideal fuel as it is acidic, contains various amounts of water, and has a tendency to gel; however, bio-oil mixed with 20% ethanol can be used as boiler fuel. The use of corrosion resistant fuel injectors, storage tanks, and other components is necessary for this application. Alternatively, bio-oil can be refined through the use of hydrocracking to produce diesel and other products currently produced from petroleum. Pyrolyzers can also be designed to separate aqueous and non-aqueous bio-oil fractions through differential condensation of the pyrolysis vapors. This process produces a superior “biocrude” that can be mixed with petroleum and processed at existing US oil refineries. The acidic aqueous phase is of relatively low value, but potentially could be steam reformed to produce H₂ gas.

Gassification is an alternative thermochemical technology for transforming diverse biomass feedstocks into syngas and biochar. Gassification is exothermic, which means it generates excess heat through the partial combustion of the biomass feedstock. The process heat and heat generated from combustion of the syngas can be used to generate steam for a coupled industrial process or to generate electric power. An obvious example for the Midwest would be to couple a biomass gasifier with an existing grain ethanol plant. In this scenario, the gasification of corn stover would generate the heat and power needed to run the ethanol plant replacing coal or natural gas while generating a biochar co-product.

Syngas can also be transformed directly into synthetic liquid transportation fuels and other products through the Fischer-Tropsch (FT) process. The FT process is used at an industrial scale by Sasol in South Africa to produce synthetic fuels from coal. The industrial scale production of FT synthetic fuels from biomass is technologically doable; however high startup costs and the relatively low energy conversion efficiency have so far been prohibitive. The coupling of a biomass gasifier with an industrial plant, such as the grain ethanol plant scenario discussed above, and the development of stand alone or coupled fast pyrolysis plants are seen as attractive small or medium scale alternatives to large-scale FT plants for the thermochemical production of biofuels from biomass. A distributed network of small and medium scale gasifiers and/or pyrolyzers addresses many of the logistic challenges associated with the handling, storage, and transportation of biomass. At this time numerous small and medium sized industrial gasifiers are operating in the US, commonly using municipal solid waste as a fuel. While this is an efficient way to turn waste into usable energy, the ash or char generated by these systems is generally not suitable for use as a soil amendment, due to the presence of heavy metals or other contaminants. Only a couple of industrial scale biomass pyrolyzers are currently operating in the US, and these are targeting the production of high-value specialty products. However, there is considerable interest among both small entrepreneurial companies and large multinational corporations in the development of industrial biomass pyrolysis for the production of liquid transportation fuels.

For example, Kior inc. (http://kior.com) is building one of the first industrial pyrolyzers in Columbus Mississippi, which is targeting Southern Yellow Pine as a biomass feedstock. Whether or not corn stover based thermochemical bioenergy industry develops in the Midwest will depend on the price of petroleum, the price of natural gas, and the political fate of government regulations designed to encourage renewable energy production.

The sustainability of harvesting crop residues for use as a feedstock in bioenergy production is a significant concern. Most crop residues are currently returned to the soil where they provide substrate for the microorganisms responsible for nutrient cycling and contribute to the formation of biogenic soil organic matter. If crop residues were harvested year after year the quality of Midwestern soils would degrade and ultimately soil productivity would decline. Thus any reliance of the emerging cellulosic bioenergy industry on crop residues as feedstock for either enzymatic or thermochemical processing must be coupled with new agricultural management systems that add carbon to the soil. Such management systems may include greater use of cover crops, no-tillage, crop rotations that include forages, and both manure and biochar applications. Biochar applications in particular will return most of the
inorganic nutrients that are removed from the soil when the biomass is harvested (Schnell et al., 2012), add a highly stabilized form of C to soils, and build soil quality.

**Summary**

In summary, biochar applications are not expected to improve crop yields on high-quality Midwestern soils, but are of potential agronomic value when targeted to solve specific soil quality problems such as low nutrient and water holding capacity, poor drainage, and compaction. Biochar quality is critical; some biochars contain phytoactive compounds, which can adversely affect crop growth. At this time the cost of biochar is prohibitive for large scale production agricultural. Because of the high cost the emerging biochar industry is targeting high-value low-volume applications in horticulture and land reclamation. The best chance for reducing the price of biochar to a level that would be affordable for Midwestern grain and soybean farmers is to increase the supply through the thermochemical conversion of biomass to bioenergy and biochar, co-products. Under such a scenario the use of biochar as a soil amendment would help to enhance sustainability of biomass harvesting by recycling nutrients, sequestering C, and building soil quality.

**References**


