Historical Assessment of Improvements in Management Practices Associated with Corn Production

A report to the Minnesota Corn Growers Association

by Jake Galzki, Leif Olmanson and David Mulla

University of Minnesota

September 30th, 2018
Introduction

Traditional farming practices of early Midwestern settlers consisted of a mixed system where a basic rotation of corn, a small grain, and hay was used. This system was employed for a century and a half following the revolutionary war. The green revolution popularized hybrid seed corn along with commercial fertilizer applications, which both saw a dramatic increase in use following World War II. The cultivated landscape of Minnesota has since changed from a mixed rotational use to predominantly one for commodity grain production (Hart, 1986).

The production of corn (Zea mays L.) in Minnesota has dominated the agricultural landscape of the state for almost a century. The same time period has seen a dramatic shift in the way agricultural inputs and outputs are utilized and managed. Enhancing the sustainability of this vast agricultural industry is in the best interest of both producers and consumers alike for this important commodity crop. This report will attempt to summarize management changes associated with Minnesota corn production over the last several decades. Improvements in management will be highlighted as well as recommendations for further improvement. Trends in management will also be assessed in the context of a changing climate.

Minnesota’s landscape transitions from the heavily forested Northeast to a prairie pothole landscape in the Southwest. The latter covers almost two-thirds of the state and is where a majority of Minnesota’s row crop cultivation occurs. Cultivated land covers 20 million acres in Minnesota, which represents over one-third of the total state area (Fig. 1). Proper management of this cultivated land is essential to protect Minnesota’s abundant groundwater, 10,000+ lakes, and 6,000+ rivers and streams, which comprise the headwaters of the Mississippi River Basin and eventually drain into the Gulf of Mexico.
Corn Production Summary

In 1970, approximately 5 million acres were dedicated to both corn and small grain production, with another 3 million acres growing soybeans. Small grains have gradually been reduced, while soybean production has increased. Corn and soybean crops were planted on just over 8 million acres in Minnesota’s 2017 growing season. For the first time ever that year, soybean acres slightly outnumbered the amount of corn acres in the state (Fig. 2)
The productivity of corn is at an all-time high in Minnesota; the state has seen record yields and maximum land dedication to the crop within the last 5 years. Statewide average yields have advanced from around 30 bushels per acre in the 1930s (Cardwell, 1982) to a six-fold increase of over 180 bushels per acre today (USDA NASS, 2018). Moreover, yields have nearly doubled in the past two decades; 100 bushel per acre yields seen in the 1990s are dwarfed by current production rates of over 200 bushels per acre on the most fertile farmland.

Yield increases are closely related to genetic improvements, as well as decreases in row spacing and increases in planting density (Fig. 3). The distance between rows of planted corn is more than a foot narrower today than it was in the early 20th century (Cardwell, 1982). This has allowed for a large increase in the density of corn plants on the landscape. Planting densities were approximately 12,000 plants per acre in the 1930s, which has almost tripled to over 30,000 plants per acre today (USDA, 2017). Cardwell found that 21% of the yield increases seen in Minnesota corn were attributed to row spacing, which was one of the leading factors contributing to yield increases in the 20th century.
The state is divided into nine agricultural districts (Fig. 4), which will be utilized to display and analyze corn production data trends. Yields generally increase as one travels south in the state; the southern agricultural districts in Minnesota average nearly 200 bushels per acre. Corn yields drop to around 170 bushels per acre in the central districts and around 150 bushels per acre in the northern districts (USDA NASS, 2018).
The majority of corn is harvested in Minnesota’s southern districts as well as the Central and West Central districts (Fig. 5), where each district grows between 1 and 1.5 million acres of corn. The largest increase in corn acres over the last 50 years has occurred in the West Central and Northwest districts, which added 728,000 acres (+84%) and 464,000 acres (+1,100%) respectively. These increases are followed by the Central district, with an increase of 355,000 acres (+35%), the South Central district, up 337,000 acres (+27%), the Southeast district, up 312,000 acres (+44%), and the Southwest district, which added 208,000 acres (+16%) (USDA NASS, 2018).

Record yields (Fig. 5) and harvested acres (Fig. 6) have combined to create significant increases in total corn production. The 1970 harvest of 400 million bushels has nearly quadrupled to 1.5 billion bushels in 2017 (USDA NASS, 2018). This represents approximately 10% of total US corn production and puts Minnesota behind only Iowa, Illinois, and Nebraska as leading producers of corn grain (NGCA, 2018). Although corn production has steadily increased over the last 50 years, a small number of years saw dramatic decreases in corn production. These are largely based on climatic factors; warm and dry growing seasons of 1976 and 1988 corresponded to 10 year minimums in corn production, as did the short and wet growing season of 1993. Economic factors also influenced the final downward spike in production; a large surplus of corn grain in the early 1980s resulted in the USDA instituting a payment-in-kind program to reduce corn acres by compensating farmers not to plant corn grain (McMinimy, 1983).

Figure 5. Average corn yield (bu/acre) by agricultural district in Minnesota from 1970-2017 (USDA NASS, 2018).
Figure 6. Acres of corn harvested by agricultural district in Minnesota from 1970-2017 (USDA NASS, 2018).

Figure 7. Total corn production (billions of bushels) per agricultural district in Minnesota from 1970-2017 (USDA NASS, 2018).

Corn silage and sweet corn represent a portion of corn production that is not included in grain production (Fig. 8). Silage involves harvesting and fermenting the entire corn plant and is used as feed for livestock, while sweet corn is harvested as a vegetable for human consumption. Silage reached a peak in the mid-1970s when 1.5 million acres were harvested for livestock feed. It has since declined to less than 500,000 acres harvested in 2017. The amount of sweet corn harvested has been relatively stable during the 20 year record; average acres harvested has been just over 100,000 per year.
Nominal price received for corn remained relatively stable from the 1970s to the early 2000s when price was generally around $2.00 per bushel. It steadily climbed to a maximum of $7.25 per bushel in 2012 and has quickly fallen back to around $3.00 per bushel in 2017.

When corn production is added to the analysis, the nominal value of Minnesota’s total corn crop can be determined (Fig. 10). The period between 1970 through 2000 again saw stability in the total corn crop value, which hovered between 1 and 2 billion dollars. Total crop value began to increase greatly in the early 2000s, and reached a maximum of almost 10 billion dollars in 2012. The previous 5 years saw an abrupt decline to the current value of around 5 billion dollars.
Fertilizer Use

Nitrogen

Nitrogen is by far the most applied fertilizer on corn acres in Minnesota followed by potassium and phosphorus. Over 1.5 billion pounds of nitrogen fertilizers were sold in Minnesota during 2017, and more than 70% of that fertilizer was applied to corn acres (USDA NASS, 2018). Nitrogen fertilizer use on corn has doubled in the last 50 years from 500 million to over 1.1 billion pounds of N.

While nitrogen fertilizer use is steadily on the rise (Fig. 11), the form of nitrogen source has shifted in the last few decades (Fig. 12). The two most prevalent forms of nitrogen used in Minnesota are Urea (U) and Anhydrous Ammonia (AA). AA was the dominant form in 1990s, but has since decreased in use by about 50%, while U use has more than doubled. The shift is caused by several advantages of U, including its increased storage safety, versatility of timing and form of application, and stability and cost effectiveness in transport (Gilbert et al., 2006). Results of a 2010 survey of over 3,000 Minnesota farmers growing corn concluded that 63% of AA applications occurred in the fall, whereas only 4% of U was fall applied (Bierman et al., 2012). A dramatic increase in the application of U and decrease in AA is likely associated with a trend preferring spring application, which has been shown to reduce nitrate-N losses to surface water (Randall and Vetsch, 2005). This shift from AA to U also has the potential to reduce greenhouse gas emissions; in continuous corn or corn-soybean rotations, U fertilization produced half of the amount of $N_2O$ emissions compared to using AA (Venterea et al., 2010).
Recent use of nitrification inhibitors has increased (Fig. 13), which will also yield environmental benefits. These additives delay the conversion of ammonium-N to nitrate-N and can reduce N losses from leaching or denitrification (Randall and Vetsch, 2005). Fall application of nitrogen fertilizer provides the highest risk for N loss, but may be the most convenient choice for farmers because they usually have more available time and field conditions are more suitable (Randall and Sawyer, 2008). In
the 2010 farmer survey, a common nitrification inhibitor, N-serve®, was used on 29% of fall applications of AA statewide (Bierman et al., 2012). Sale of N-serve® would equate to the treatment of approximately 500,000 corn acres in that year. In just the last 5 years, sales of N inhibitors have doubled, and are estimated to be applied on over 1,000,000 acres of corn.

![Estimated Corn Acres with either N-Serve® or Instinct® Applied](image1)

Figure 13. Estimated corn acres with Nitrogen Inhibitors applied from 1996-2017 (Montgomery and Bruening, 2018).

Although use of nitrogen fertilizers has doubled in the last half century, this increase has been outpaced by improvements in corn yield. In other words, nitrogen use on corn is more efficient today than ever (Fig. 14). For every pound of nitrogen used in the 1970s, approximately 0.8 bushels of corn were produced. This use efficiency has nearly doubled in recent years, and today nearly 1.4 bushels of corn are produced for every pound of N used as fertilizer.

![N Use Efficiency](image2)

Figure 14. Nitrogen use efficiency (bushels of corn/lb. of N) from 1970-2017 (USDA NASS, 2018).
Phosphorus

Phosphorus fertilizers are also widely used on corn. Nearly 300 million pounds of elemental phosphorus fertilizers were sold in Minnesota in 2016, of which nearly 70% were applied on corn acres. Diammonium phosphate (DAP) is the most widely used form of phosphorus, although its use has declined in the past 2 decades, while monoammonium phosphate (MAP) use has increased. The preference for use of MAP or DAP is largely based on antecedent soil pH, the former being preferred when soil pH is higher. DAP contains approximately 60% more N than MAP fertilizers, which should be considered during fertilizer placement. Agronomic studies have not found crop yield differences between the use of MAP or DAP fertilizers (Kaiser and Pagliari, 2018), thus management of the rate of phosphorus applied is more important than the form chosen.

Figure 15. Phosphorus sales by form in Minnesota (millions of lbs. P) from 1989-2017 (Montgomery and Bruening, 2018).

Phosphorus found in agricultural runoff can contaminate surface waters and promote freshwater eutrophication (Sharpley et al., 1994). Soil test phosphorus (STP) indicates the amount of plant available phosphorus in agricultural soils. Increases in STP are correlated with increased amounts of phosphorus in overland runoff (Sharpley et al., 1996). Corn yields increase with the addition of phosphorus fertilizers when STP levels are less than optimum (<20 Bray ppm); however, no yield increase has been measured when STP levels are high (>21 Bray ppm) (Sawyer et al., 2002; Dodd and Mallarino, 2005). The International Plant Nutrition Institute (IPNI, 2012) surveys STP values across the United States and Canada. Their data indicate that Minnesota STP values in the low range (6-10 Bray ppm) have decreased from about 22% of samples in 2001 to 12% of samples in 2015 (Fig. 16). Categories of very low (<5 ppm), medium (11-15 ppm), and high (16-20 ppm) have been relatively stable over the past two decades. The largest change has been in the very high category (>21 ppm); samples in this category made up 40% of data from 2001 but nearly 55% of samples from 2015. This indicates an
increased surplus of phosphorus in Minnesota soils over the past 20 years. Better management of phosphorus fertilizer is recommended in the future and could produce both environmental and economic benefits.

**Soil Test Phosphorus sample distribution 2001-2015**

![Soil Test Phosphorus sample distribution](image)

*Figure 16. Soil test phosphorus frequency distribution from 2001-2015 (IPNI, 2018)*

**Manure**

Livestock manure is a significant byproduct of animal agriculture in Minnesota. Proper management of manure can supply important nutrient inputs for cultivated crops, while mismanagement can threaten contamination of surface waters and pose public safety risks. Census of Agriculture records (Fig. 17) indicate that Minnesota cattle numbers have remained fairly stable over the last few decades, laying chickens have declined, while turkeys, broilers, and swine numbers have all doubled in recent decades (USDA NASS, 2018).

The Nutrient Use Geographic Information System (NuGIS) estimates the amount of excreted manure and manured recovered as agricultural nutrient inputs using these inventory numbers coupled with methods from Kellogg et al. (2000). Increases in N, P, and K were seen in the early 2000s, and have declined slightly in the 2012 analysis (Fig. 17). Average nutrient recovery rates for N, P, and K were 29%, 63%, and 64% respectively (Fig. 18).
Figure 17. Minnesota livestock and poultry inventory from 1987-2012 (USDA NASS, 2018).

Figure 18. Estimated tons of manure nutrients excreted and recovered from 1987-2012 (IPNI, 2012).

The NuGIS estimates for recovered manure nutrients were compared to sales of inorganic fertilizers over the last 30 years (Fig. 19). On average, recovered manure nutrients make up 9% of the total N applied to crops. This proportion is much larger for P (25%) and K (22%).
Figure 19. Estimated recovered manure nutrients compared to statewide sales of inorganic fertilizer (millions of lbs) [IPNI, 2012; USDA NASS, 2018].

Although the NuGIS estimates consider a general confinement factor in their calculation, which reflect higher recovery rates due to larger animal operations in recent years, there are significant livestock feeding changes that are not reflected in the analysis. Animal producers have recently adopted more rigorous nutrient management plans; precision feeding of dairy cows has been shown to decrease P excreted in manure from 62 to 40 pounds per animal (Swink et al., 2008). Phytase in monogastrics has also greatly reduced the amount of P excreted in manure. Fixen et al. (2012) illustrates this shift with feed grade phosphate sales, which peaked in the mid-1990s. These sales steadily declined since the introduction of phytase in feed, and have since bottomed out at nearly one-third of the mid-1990s peak. Although a considerable portion of this decline may have been offset by the use of dry distiller’s grains (DDG) from the ethanol industry, Nahm (2002) found the use of phytase supplements resulted in manure P reductions of 25 to 35% in chickens and 25 to 60% in pigs. According to David Preisler, CEO of the Minnesota Pork Producers Association, there is a high adoption rate of phytase in pork production. He estimates 80% of pork producers have been utilizing phytase in the last decade, which would translate to a reduction of approximately 25 million pounds of swine manure P excretion.

Changes in manure management over the last 50 years are difficult to quantify, although several improvements have been made during this time period. In an interview with David Wall, Minnesota Pollution Control Agency’s Watershed Division, qualitative improvements of manure management were discussed. These include a shift from small scrape and haul operations where manure was surface applied, to larger operations with better storage and application techniques, such as injection or incorporation, better accounting for manure nutrient credits due to increased manure content testing, consolidation of swine operations, with a shift toward liquid manure that is injected, as opposed to solid
manure that is surface applied, and better management of poultry manure due to consolidation with more stockpiling, less intensive applications near barns, and better utilization of the litter resource.

**Crop Nutrient Balances**

Estimates of agricultural nutrient balances for nitrogen, phosphorus, and potassium are tracked geographically with the NuGIS database (IPNI 2012). The balance represents the annual difference between fertilizer and manure nutrients and the nutrient removal (or fixation) of 21 major crops. NuGIS data indicate that there is a net surplus of nitrogen on Minnesota’s agricultural lands (Fig. 20). Recent estimates of approximately 200,000 tons of N are supplied to Minnesota soils in surplus; however this figure has been reduced from nearly 300,000 tons in the 1990s. Phosphorus has historically been in surplus according to this model; however, the net balance was nearly zero in the 2012 analysis. This implies that all phosphorus being applied to agricultural lands is nearly equal to crop removal. However, since over 50% of acres with a soil test are in the very high category (Fig. 16), a significant number of acres are being over-fertilized. Finally according to this analysis, there is a net deficiency of potassium from the crop nutrient balance.

![Figure 20. Minnesota crop nutrient balance (tons) from 1987-2012 (IPNI, 2012).](image)

Removal to use efficiency ratios have been calculated as crop nutrient removal divided by nutrient inputs (Fig. 21). There is a positive trend for all nutrients ratios in the analysis since 1987. This implies that fertilizer and manure inputs have been utilized with more efficiency over the last 30 years of Minnesota crop production.
Pesticides

Herbicides

Total herbicide use on Minnesota corn has been tracked for the last 30 years (USDA NASS, 2018). Peak use was in the early 1990s, when 22 million pounds of herbicides were applied to corn (Fig. 22). Total herbicide use declined to more than half of that figure in the early 2000s, and has slightly risen in previous years to approximately 17 million pounds. There has been a decrease in use of metolachlor and atrazine in the 30 year record, and alachlor has been completely phased out. Although no single herbicide has been proven to be harmless in the environment, these three latter chemicals have specific human health risks, pose high toxicity risk to aquatic plants, and have been shown to leach into groundwater (Potter and Carpenter, 1995; Fairchild et al., 1998; Boyd, 2000). Glyphosate and acetochlor are the only two forms of herbicides that show an increasing trend in use. Benbrook (2012) notes that glyphosate resistant (GR) crops have had commercial success in the United States since their introduction in the 1990s; this has been associated with a decrease in use of more toxic herbicides such as atrazine, metolachlor and alachlor. Due to an increase in weed resistance to glyphosate, it is suggested that precision and/or integrated weed management systems should be incorporated with a reduced reliance on GR corn to extend the useful lifespan of herbicide resistant technologies.

Figure 21. Nutrient removal to use ratios from 1987-2012 (IPNI, 2012).
Insecticides

Insecticide use on corn in Minnesota has decreased dramatically since the 1990s (Fig. 23). A maximum of nearly 800,000 pounds of insecticides were used in the early 1990s, but usage has since dropped by 95% to only 43,000 pounds in 2016. A large portion of the decline in use is likely related to genetic engineering advances in the corn industry. Insect-resistant crops have been linked to reductions in insecticide application rates of 25 to 50% over the past 20 years (Benbrook, 2012). *Bacillus thuringiensis* (BT) has been introduced to genetically modified corn and has proven an effective way to suppress the primary pest *Ostrinia nubilalis* (European corn borer) (Hutchinson et al., 2010). BT corn is generally considered safe for non-target species (Saxena and Stotzky, 2001) and is actively managed with non-BT corn to prevent resistance in affected insects (Hutchinson et al., 2010). Continued management of BT corn and responsible insecticide use in general should lead to effective pest suppression for years to come.
Declining use of organophosphate and carbamate insecticides has been offset by increased usage of seed treatments involving neonicotinoid insecticides (Hladik et al., 2014). In corn, the most commonly used neonicotinoid seed treatments include clothianidan, imidacloprid and thiamethoxam. Clothianidan, the most commonly used seed treatment in corn, degrades slowly in soil (half life 545 days), and is moderately mobile ($K_{oc}$ 126 mL/g), leading to enhanced risk for neonicotinoid pollution of tile drainage discharge and surface runoff. Neonicotinoids have also been implicated as one of the causes for colony collapse in bees and harmful effects on other pollinators (Spivak et al., 2011). In Minnesota, neonicotinoid seed coatings are widely used in corn and soybean, and are thought to control aphids in soybeans, but research has shown that there are few benefits to this practice (Krupke et al., 2017).

**Conservation Practices**

The Conservation Reserve Program (CRP) removes environmentally sensitive lands from agricultural production and represents the largest conservation effort on private lands in the United States (USDA, 2018). Implemented in the mid-1980s, the program is intended to provide soil and water quality benefits as well as important wildlife habitat. At peak enrollment (1994 and 2007), nearly 1.8 million acres in Minnesota were enrolled in CRP (Fig. 24), which represents almost 10% of all cultivated lands in the state. The amount of enrolled acres has recently declined to around 1.1 million acres. Easement contracts are generally 10 to 15 years in length, and expiration of contracts are associated with low enrollment years. As enrollment is currently on a downward trend, new CRP land acquisitions are recommended on marginal lands to continue the success of the program.
Figure 24. Statewide enrollment of conservation reserve program acres from 1986-2016 (USDA FSA, 2018).

The Minnesota Board of Water and Soil Resources (BWSR) has tracked conservation efforts online with their eLINK database since 2003. Nearly 40,000 conservation practices have been recorded since that year (BWSR, 2017). Examples of practices include filter strips, terraces, grassed waterways, critical area plantings, and cover crops to name a few. More detailed records have been kept since the Clean Water Fund was established in 2010. From 2010 to 2017, nearly 7,000 best management practices have been installed, which have been estimated to reduce 117,000 pounds of phosphorus and 121,000 tons of sediment runoff statewide (Fig. 25).

The Minnesota Nutrient Reduction Strategy (MPCA, 2014) established long-term goals for a 45% reduction in nitrogen (N) and phosphorus (P) export to Minnesota’s surface waters. The strategy for reaching these goals includes recommendations for reducing nonpoint source N and P losses to surface waters. This strategy includes recommendations for better management of nutrient inputs on cropland (e.g. timing and rate of N application and precision management of phosphorus), for increased control of field erosion (e.g. increased crop residue cover), for increases in living vegetative cover (e.g. cover cropping and perennial crops), and for increases in treatment and storage of tile drainage discharge through structural management practices (e.g. controlled drainage and bioreactors). Many of the recommendations for better nutrient management have already been or are in the process of being adopted by Minnesota corn growers (e.g. nitrification inhibitors and a gradual transition to spring application of N fertilizer). However, many other recommendations are not widely adopted, partially because of a pressing need for more research to enhance the effectiveness and economics of management alternatives (e.g. VRT N and P management, cover cropping, perennial crops, and bioreactors for simultaneous N and P removal in ditches).
Figure 25. Clean water fund projects and estimated pollution reductions by Minnesota major river basin (BWSR et al., 2017).
Cover Crops

Cover crops generally refer to crops grown to cover the ground to protect the soil from erosion and from loss of plant nutrients through leaching and runoff (Reeves, 1994). An extensive literature review provided by Dabney et al. (2001) concludes that cover crops have the potential for numerous soil and water quality benefits including reduction of overland wind and water erosion, improvements in soil quality, reduction in nitrate leaching losses and increases in available N to following crop, sequestration of atmospheric carbon, and the ability to compete with and control weeds. When managed correctly, the utilization of cover crops has been found to have little to no effect on corn yields (Tonitto et al., 2006; Olson et al, 2014). Despite the abundance of benefits, cover crops are not widely used in the Midwestern corn belt; a farmer survey found approximately 10% of Minnesota farmers implemented cover crops in at least one year from 2000-2005, which was about the average for Midwestern corn belt states (Singer et al. 2007). The study found that when implemented, cover crops were only used on 6% of the land area of a farm.

Recent remote sensing data indicate that cover crops are becoming more prevalent in the Midwestern corn belt; one study reports that cover crops planted on corn or soybean acres has nearly doubled from 5.1% in 2010 to 9.4% in 2016 (Seifert et al., 2018). Remote sensing estimates of cover crop acreage in Minnesota for 2016 were about 1.5% of cultivated cropland area (Mulla et al., 2018). The greatest barriers to planting cover crops include unfavorable fall weather conditions that lead to poor germination, short window of opportunity for killing or tilling cover crops in spring, and extra costs of planting cover crops. The first barrier can be overcome by seeding cover crops into short season crops that include sweet corn and corn silage. Another option is aerial seeding of cover crops into a standing corn crop.

Crop Residue

Historical estimates of crop residue cover in Minnesota were traditionally obtained using tillage transect surveys. This method is time consuming and only assesses a small fraction of agricultural fields within a given county. Traditionally, staff in the local Soil and Water Conservation Districts carried out windshield crop residue surveys. Because so many staff were involved across the state, there were differences in crop residue measurements from one county to another due to subjectivity of the methods used.

Recently, the Board of Water and Soil Resources (BWSR) funded a project at the University of Minnesota to estimate crop residue cover using satellite imagery. Using two years of satellite imagery and crop residue field measurements in eight counties (2016 and 2017), we have developed an algorithm using atmospherically corrected satellite imagery for crop residue mapping. We used the surface reflectance product based on Landsat imagery from the EROS data center to estimate historical crop residue cover across Minnesota for four selected time periods (1988, 1996-1997, 2007-2008 and 2017). Satellite images used for this analysis were taken one to two weeks after half the corn acres had been planted in each time period.
Estimates of historical crop residue cover in Minnesota (Fig. 26) show that county averages are generally above 21% residue cover for all four time periods. Crop residue cover peaked in 1996-1997, with many counties having greater than 41% residue cover and many others having greater than 61% cover. Crop residue cover in 2017 (as well as other recent years not shown) appears to be lower than in all three other time periods, with widespread areas in the 21-40% residue cover range (most of these are actually 21-30% residue cover). Cooler, wetter spring climatic conditions generally are associated with crop residue cover levels at planting that are less than 30%. To some extent, the downward trend in crop residue cover may have also resulted from an increased acreage of soybeans.
**Ethanol Production**

Minnesota’s 20 ethanol plants have a capacity of 1,176 million gallons (28 million barrels – Fig. 27) per year (US EIA). In 2007, the Minnesota legislature created a four-year grant program that offered incentives to encourage the adoption of E85. By the end of the program in 2011, Minnesota had 78 public E85 stations. Minnesota now leads the nation with almost 400 public E85 refueling stations, more than one-tenth of the U.S. total. Use of corn grain for ethanol increased rapidly after adoption of the Federal Renewable Fuel Standard in from 2005-2007 (Fig. 27). The increased use of corn grain for ethanol was initially accompanied by an increased shift from a two year corn-soybean rotation to a three year corn-corn-soybean rotation, particularly in western Minnesota. In Minnesota today, roughly 28% of the corn crop is used to produce ethanol.

![Figure 27. Ethanol production (millions of barrels) by state (1990-2016). One barrel equals 42 gallons. (US EIA, 2018)](image)

In late 2017, the US EPA maintained the existing goal for nationwide production of 15 billion gallons of ethanol from conventional sources that include corn ethanol. The goal for cellulosic ethanol for 2018 was reduced slightly to 288 million gallons, but the national production of cellulosic ethanol is presently far lower than this goal. Cellulosic ethanol can be produced using corn stalks, leaves and cobs, as is already being done at Emmetsburg, Iowa, where POET is gearing up to finally produce cellulosic ethanol after many years of delay caused by technical problems. Collecting corn stover from farms for cellulosic ethanol production has the potential to be unsustainable with regards to maintenance of soil organic carbon, wind and water erosion, and nutrient loss to subsurface and surface waters. Wilhelm et al. (2007) estimated the mass of corn stover needed to maintain soil organic carbon for continuous corn versus corn-soybean rotations, and for moldboard plow, chisel plow and no-till systems. In general, more stover can be removed from continuous corn rotations than from corn-soybean rotations, and from no-till systems than chisel plow or moldboard plow systems. Mass of stover to retain is also a function of expected crop yield, with higher crop yields allowing greater stover removal.
**Precision Agriculture**

Minnesota has been a global leader in the development and adoption of precision agriculture. Precision agriculture involves customized subfield management of farm inputs, which are matched to spatial and temporal patterns in crop growth, soil properties, landscape characteristics, prevalence of nutrient deficiencies, and infestations of insects, weeds and disease. With regards to nutrient management, precision agriculture is embodied by subfield implementation of the four R’s: Right rate, right place, right time and right source. Other examples for specialized applications of precision agriculture include variable rate technology (VRT for nitrogen, phosphorus or seeding rate), grid soil sampling and mapping, yield monitoring or yield mapping and autosteer guidance technology.

A recent study by the Economic Research Service (Schimmelpfenning, 2016) summarized adoption of precision agriculture technology on U.S. corn acres. Results (Fig. 28) showed highest rates of adoption on U.S. corn acre (based on 2010 survey data) for yield monitoring (70% of corn acres), followed by autosteer guidance (54%), yield mapping (44%), soil mapping (31%) and VRT (28%). Specific adoption rates for Minnesota corn acres are not known, but trends in Minnesota likely track trends in the nation and Midwestern region.

![Figure 28. Adoption of precision agriculture technologies on U.S. corn farms based on Agricultural Resource Management Survey data from 2010. (US ERS, 2017)](image)

An alternative approach to estimating the adoption of precision agriculture technologies was taken by Holland et al. (2013), who summarized annual surveys of agribusiness service providers administered by Purdue University and CropLife from 2002-2013. Dealers were asked questions about the types of precision farming services offered to their clients, including precision application of fertilizer. In the Midwestern region, dealers responding represented either Cooperatives or locally Independent companies. Of Cooperatives, 65% offered precision application services (e.g. VRT) for a single type of fertilizer, whereas only 36% of locally Independent companies offered these services to their clients. VRT services for a single fertilizer were profitable for 64% of Midwestern dealers, whereas VRT services for multiple fertilizer types were profitable for 67% of dealers.
Implementation of precision agricultural management practices has the potential to improve the sustainability of corn production. Using autosteer guidance can reduce overlap in application of fertilizer and herbicides on successive passes of an applicator. Using grid soil sampling for soil available phosphorus can be used to guide VRT applications of phosphorus fertilizer or liquid manure. Variable rate nitrogen (VRN) based on in-season remote sensing of crop nitrogen deficiency (supplemented by use of crop models such as those offered by Adapt-N, Climate or Farmer’s Edge) can guide variable rate sidedress N applications. Wilson et al. (2018) showed that in the best case scenario (25 inches of growing season precipitation), a sidedress-VRN application rate in southern Minnesota could reduce nitrate-N losses in tile drainage by 12 lb N/ac compared with losses from a relatively high uniform fall application rate of nitrogen fertilizer (a 58% reduction in nitrate-N losses).

In practice, the implementation of precision agricultural management practices in Minnesota has not been optimum for sustainability. Grid soil sampling for soil available phosphorus is often used to identify areas which need additional phosphorus fertilizer that is added on top of a uniform basal rate of phosphorus fertilizer. This practice over fertilizes areas in which a crop response to P fertilizer is not expected. More sustainable VRT fertilizer practices would involve avoiding application of P fertilizer in areas where the soil test Bray-P exceeds 21 ppm, and only applying P fertilizer to areas where STP is less than 21 ppm. Greenseeker® technology to identify in-season crop N deficiencies is often used in Minnesota to apply additional N fertilizer on top of a uniform basal rate of N fertilizer that was applied in fall. More sustainable VRT fertilizer practices would involve applying a small amount of N fertilizer in spring pre-plant (e.g. 60 lb/ac), followed by use of remote sensing to identify areas of the field which require additional sidedress N applications.
Climate Change

Minnesota experiences large fluctuations in mean annual temperatures and precipitation, although both display an increasing trend when looking at long term data. Over the last century, mean annual temperature in Minnesota has increased by 2.4°F and mean annual precipitation has increased by 2.8 inches (Figs. 30 and 31). Novotny and Stefan (2007) have observed increases in several hydrologic metrics including increased peak flows due to rainfall events, increased number of days with higher flows, increased base flows in both summer and winter, a larger number of intense rainfall events, more days with precipitation, and earlier and more frequent snow melt events. Increases in stream flow have been attributed to increases in precipitation (Nangia et al., 2010; Gupta et al., 2015), increases in agricultural drainage (Schottler et al., 2014) and increased acreage of soybeans (Zhang and Schilling, 2006).

Figure 27. Annual fluctuations and long-term trend in average annual Minnesota temperature from 1895-2016 (BWSR et al., 2017).
As a consequence of earlier snow melts and warmer and milder winters, the average planting date for corn in Minnesota is becoming earlier in the calendar year (Fig. 32). In the 1980s, the average planting date was around May 12th. Recent data on average planting dates places this figure more than a week earlier on May 4th. Although planting date is trending earlier in the season, there does not appear to be a significant change in corn growing degree days (GDD – Fig. 33). Corn GDDs refer to a formula that accounts for the accumulation of heat during the growing season; higher values imply longer and warmer growing seasons. Data from a station in Lamberton, Minnesota (SWROC, 2018), show fluctuation in GDDs, but the overall trend is level.
Corn production can be adversely affected by temperature and precipitation extremes (Fig. 33). The three most notable departures from an upward trend in corn yield coincide with either warm and dry years (1976, 1988) or cold and wet years (1993).

Increases in precipitation may have the most pressing implications with regard to the future of corn management. Two-thirds of the last 50 years on record have experienced wetter than average summers. When looking at the previous 30 years, only two summers were relatively dry. Wetter springs will affect how and when farmers can perform field work, but soil erosion and export of N and P to surface waters will also increase with a wetter climate. Nangia et al. (2010) modeled agricultural management and climate changes for a period lasting 50 years (Fig. 34). They found that when climatic factors are held constant at 1999-2003 (regardless of management year), management improvements between 1978 and 2001 would have decreased stream discharge by 21.1% and nitrate losses by 13.5%. However, when using actual climatic records (that include an increasingly wetter climate), discharge increased by 19%, while nitrate losses increased drastically by about 100%. Even though agricultural management is improving, the expected benefits are being masked by an increasingly wetter climate.
Management History Trends

This report summarizes relatively long-term trends in management practices on Minnesota’s corn production acres. Many of the trends are positive from the point of view of increased sustainability. From 1970-2017 production of corn tripled, while N use efficiency doubled. Since the mid-1990’s, use of nitrification inhibitors increased five-fold. Since 1990, application of spring applied urea nearly doubled, while application of fall applied anhydrous ammonia was halved. In the last decade, use of phytase supplements in hog feed have been widely adopted, leading to a reduction of approximately 25 million pounds of swine manure P excretion. Use of metolachlor, atrazine, dicamba and alachlor herbicides, as well as organochlorine and carbamate insecticides have all declined dramatically since 1990. Since 2003, there has been significant adoption of vegetative filter strips, terraces, grassed waterways, critical area plantings, and cover crops on Minnesota cropland. From 2010 to 2017, nearly 7,000 best management practices have been installed, which have been estimated to reduce 117,000 pounds of phosphorus and 121,000 tons of sediment in runoff statewide. Over the last two decades, Minnesota corn producers have increasingly adopted precision agriculture technology. These technologies include yield monitoring, autosteer guidance, yield mapping, soil mapping and Variable Rate Technology (VRT) for N and P application.

This report also documents long-term trends that have negative implications for sustainability. From 1970 to 2017, application of N fertilizer to Minnesota corn acres more than doubled. Minnesota soil test P (STP) in the very high category (>21 ppm) increased from 40% of acres tested in 2001 to nearly 55% of acres tested in 2015. This indicates an increased surplus of phosphorus in Minnesota soils over the past 20 years. This trend suggests that precision agriculture technology such as grid soil sampling and VRT phosphorus applications have been misused in many cases (build and maintain philosophy). Over the last two decades adoption of conservation tillage and area planted to corn silage have both declined. Since 2003, use of neonicotinoid seed treatments has increased dramatically on corn and soybean acreage, despite evidence that these seed treatments have little value for soybeans grown in the northern portion of the Midwest and may have adverse impacts on pollinators.
Recommendations for Improved Sustainability of Corn Production

An increased emphasis on sustainable production of corn is a worthwhile goal for the Minnesota Corn Growers Association. There is increasing pressure from consumers and government agencies for increased sustainability. Evidence for this includes recent efforts by multinational agribusiness corporations and state governments to track farm management practices and develop certification programs based on these data (e.g. Fieldprint Calculator and the Minnesota Agricultural Water Quality Certification Program). In addition, the Minnesota Department of Agriculture recently updated the Nitrogen Fertilizer Management Plan and is in the process of developing a Groundwater Protection Rule that applies largely to nitrogen fertilizer and cropping systems management in Drinking Water Supply Management Areas. An increased focus on sustainable agricultural production also features prominently in the Minnesota Pollution Control Agency’s Nutrient Reduction Strategy.

Some general principles relating to sustainability are outlined below:

- Recognize that there are constraints to achieving sustainability. The corn-soybean rotation is leaky and involves living vegetative cover for relatively few months in the year. Minnesota’s climate is challenging, with increasing amounts of precipitation and a short growing season. Low prices for commodity crops limit the flexibility that producers have in adopting more sustainable alternatives to existing practices.
- A watershed or groundwater management area approach to sustainability is needed. Sustainable management practices should be targeted to the most vulnerable soils and landscapes.
- Education is important for reducing the barriers to adoption of alternative management practices, as exemplified by the success of Dr. Brad Carlson’s Nitrogen Smart workshops.
- Existing best management practices for corn production may not be sufficient for attaining the goals outlined in the Groundwater Protection Rule or the Nutrient Reduction Strategy. No single management practice is going to be effective at attaining sustainable production of corn. A customized combination of nutrient management, erosion control, vegetative practices and structural practices is often warranted, and the appropriate combination depends on site characteristics, existing management and economic profitability.
- There is a pressing need for research to enhance the effectiveness of existing management alternatives, particularly precision agriculture technologies and structural management practices such as bioreactors.

Some specific recommendations for enhancing sustainability are outlined below.

- Fertilizer and manure application should follow University of Minnesota guidelines, as well and guidelines in the Minnesota Nitrogen Fertilizer Management Plan and the Groundwater Protection Rule (when finalized). An increasing emphasis on shifting away from fall uniform N applications in vulnerable areas is warranted. An increasing emphasis on relatively low spring pre-plant N applications followed by sidedress N applications in June is also warranted.
• Variable rate technology (VRT) for N and P applications should be increasingly emphasized in corn production. For VRT N applications, this could be based on a combination of remote sensing and crop modeling, with an initial spring pre-plant application of about 60 lb N/ac followed by a variable rate sidedress N application at growth stages V6-V10. For VRT P applications, this could be based on grid soil sampling, avoiding any application of phosphorus from manure or fertilizer in areas that have STP levels in the very high category (>21 ppm).

• Research on removal of N and P from agricultural ditches using engineering approaches such as bioreactors should be supported, with a goal of treating a majority of ditch discharge within a decade. Field testing of a dual N and P bioreactor at a Lamberton ditch showed removal of greater than 60% of the N and P in drainage ditch discharge.

• Cover cropping should be promoted through greater emphasis on highboy or aerial seeding of cover crops in feed corn and soybeans, and cover crop plantings after harvest of corn silage.

• Conservation tillage that leaves greater than 30% of the soil covered by crop residue should be promoted on all soil types except heavy clays that developed from lacustrine deposits. There are a number of different approaches for achieving conservation tillage, including strip tillage, avoiding fall tillage of soybean residue, reducing speed and depth of tillage passes, etc.

• Neonicotinoid seed treatments on soybean should be phased out, given their lack of effectiveness against soybean aphids. Greater emphasis should be placed on variable rate herbicide spray application in corn, given the increasing frequency of weed resistance to glyphosate.

• In the event that production of cellulosic ethanol from corn stover becomes commercially viable, corn producers should be cautious to either leave enough stover to ensure that soil organic carbon levels are sustained, or plant cover crops to achieve the same goal.
References


Holland, J., B. Erickson, and D. Widmar. 2013. Precision agricultural services dealership survey results. CropLife, Center for Food and Agricultural Business. Purdue University, W. Lafayette, IN. https://www.agecon.purdue.edu/cab/ArticlesDatabase/articles/2013PrecisionAgSurvey.pdf


Minnesota Board of Water and Soil Resources (BWSR). 2017. Web-based conservation tracking system development (eLINK). http://www.bwsr.state.mn.us/outreach/eLINK/.


https://www.pca.state.mn.us/sites/default/files/wq-s1-80.pdf.


https://www.ncdc.noaa.gov/cag/.


Preisler, D. March 19, 2018. Phone Interview.


Wall, D. March 27, 2018. Email interview.

