Energy in the Corn Belt: Is Maize Production Sustainable?

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ENERGY IN THE CORN BELT: IS MAIZE PRODUCTION SUSTAINABLE?

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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ABSTRACT

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Technological and scientific innovation has transformed agricultural production. Corn production methods changed from a sustainable, nutrient recycling production system to one reliant on imported fossil energy inputs. Located in the Western Corn Belt, Union County, South Dakota was chosen as the study area. Changes in production methods are represented by four technological epochs: 1) The Draft Horse Epoch, 1890-1920; 2) The Tractor Epoch, 1920-1950; 3) The Fertilizer Epoch, 1950-1980; and 4) The Biotechnology and Precision Agriculture Epoch, 1980-2010. The energy budget method was used to measure the energy sustainability of corn production. The findings show that the volume of corn grain yield credited to fossil fuels and inorganic fertilizer energy inputs represents the magnitude of the corn crop that is neither sustainable nor renewable.

Key Words: Corn Belt, maize, food security, energy, sustainability, agriculture.

CHAPTER 1: INTRODUCTION

Problem Identification and Description

Farming in the United States continues to be driven by technological advancements. The rising productivity of Corn Belt cropland is a prime example of agriculture's progression to industrial reliance. This thesis focuses upon how farmers transitioned to an industrial model of agricultural production between 1890 and 2010. Presently, Corn Belt farmers continue to rely on manufactured inputs.

Since the industrial revolution, applied scientific progress has been responsible for the increases in the productivity of cereal agriculture. The internal combustion engine changed the energy balance of production agriculture. Tractors, energized by fossil-fueled engines replaced the work of renewably fueled draft animals (Pimentel and Pimentel, 1996). Also, the Haber-Bosch synthesis allowed for the affordable mass production of ammonia. Ammonia (NH_3) is important to modern corn and other crop production because it is the most widely used source of synthetic nitrogen for fertilizer, "without which some forty percent of today's humanity would not be alive" (Smil 2006, 13).

There is a direct connection between food production and inorganic soil amendments. This was acknowledged by the fertilizer industry early in the 20th Century when companies admitted that their goal was to supply the human race with "concentrated synthetic foods" (Landis 1929, 131). Inorganic soil amendments were to be spread on the soil by farmers, resulting in higher crop yields (Borgstrom 1973, 216).

The major difficulty in sustaining crop yields with fertilizers and other inputs produced from fossil fuels and mineral deposits is that those inputs are nonrenewable and are finite (Pimentel and Pimentel 1996, 17). British Petroleum estimated the depletion time in years at 2003 production levels for the known reserves of oil, coal, and natural gas by region. The longest of these were 88 years for Middle Eastern oil, greater than 100 years for Middle Eastern natural gas, and a 354 year timeline for South and Central American coal reserves (Lincoln 2005, 622). Recently, BP estimated that the "world proved natural gas reserves at end-2011 were sufficient to meet 63.6 years of production" (BP 2012). While the Middle East still has the highest proven gas reserve with a projected reserves to production ratio of about 150 years (BP 2012).

The difference between a renewable and a non-renewable resource is that a renewable resource replenishes itself during a biological time-frame. A biological time-frame, for the purpose of this study, is less than 530 years (Fichtler, Clark, and Worbes 2003, 306). Non-renewable resources, such as oil, and other fossil fuels, can only generate within geologic time-frames, which are measured in periods including millions of years (Aubry et. al. 2009; Heiman and Solomon 2004).

Corn is considered to be a renewable crop because it reproduces itself biologically; however, hybrid corn has to be bred through an artificial process and does not reproduce on its own, meaning that most Corn Belt farmers have to buy their hybrid corn seed from seed producers (Griliches 1960). This research shows that even though the corn plant itself is a renewable, biological system, much of the grain being produced by Union County farmers should be defined as a non-renewable resource because much of its yield depends upon the application of synthetic fertilizer and other non-renewable inputs.

Purpose

The purpose of this thesis is to determine how much of Union County, South Dakota's corn crop can be credited to nonrenewable inputs. This is important because scarcity of nonrenewable inputs may cause global corn yields to fall, potentially resulting in an expansion of corn land acres in an attempt to make up for the deficiency in the amount of available corn supplies for food, feed, and fuel. I applied the geographic theories of land use and land cover change in addition to the energy budget method to study corn production in the Corn Belt (Figure 1). Union County, South Dakota, was chosen as the study area (Figure 2). This study spans 4 technological epochs of agriculture beginning in 1890 and ending in 2010.

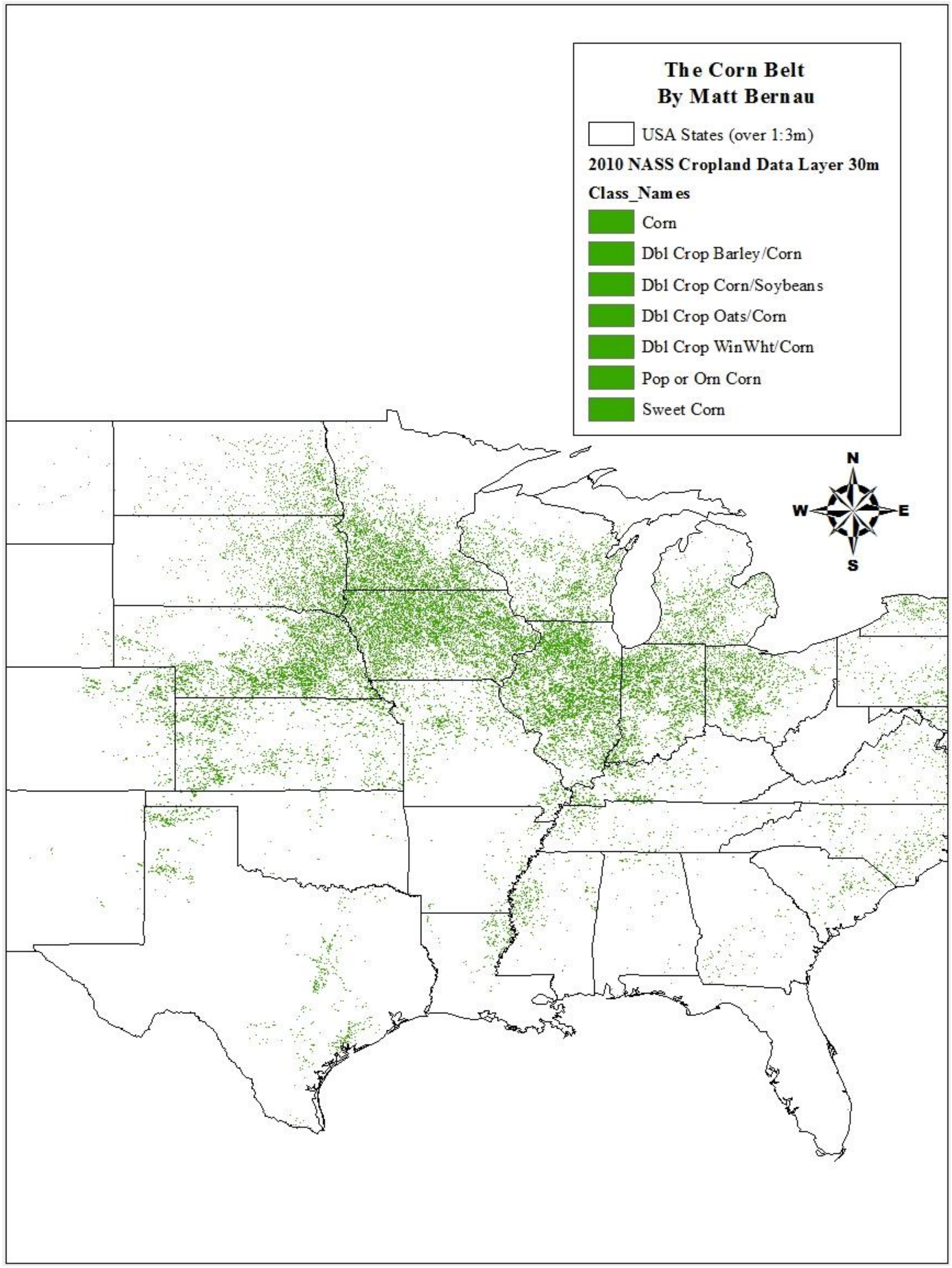


Figure 1. The 2010 Corn Belt

Source: NRCS Data Download U.S. Counties Accessed August 15, 2013; USDA National Agricultural Statistics Service Cropland Data Layer 2010. Published crop-specific data layer Online. Available at http://nassgeodata.gmu.edu/CropScape/ (accessed (November 17, 2013)) USDA-NASS, Washington, DC.

The Corn Belt "Produces more feed for livestock and more meat for man than any other area of equal size in the world" (Baker 1927, 447). The Corn Belt region was described as being located in parts of "Ohio, Indiana, Illinois, Iowa, Southwestern Minnesota, Southeastern South Dakota, Eastern and Southern Nebraska, Northern Kansas, and most of Northern Missouri" (Baker 1927, 447).

This study answers the following questions: 1) How much of the modern corn crop can be considered renewable? 2) Can the current yields of corn production be maintained on individual farms if fossil energy inputs are no longer available?

A county-level energy and land use analysis of corn grain production was conducted with an emphasis on the Corn Belt where farmers have utilized the most modern technology available. Corn cropping has been a major land use in Union County since pioneer settlement (Baker 1927). I identified four epochs of corn production in Union County: 1) The Draft Horse Epoch, 1890-1920; The Tractor Epoch, 1920-1950; The Fertilizer Epoch, 1950-1980; and The Precision Agriculture and Biotechnology Epoch, 1980-2010. These epochs were times during which specific sets of technologies were available to farmers. The use of these technologies affected farm management decisions and impacted the land use and land cover in the study area over time.

I chose Union County, South Dakota as the study area because it met the requirements of historical geography methodology including landform homogeneity and close proximity to a central marketplace (Norton and Conkling 1974, 45).

Framing the Topic

Union County, South Dakota is located in southeastern South Dakota and has long been identified as being part of the Corn Belt (Baker 1927). The study area, Union County, South Dakota (Figure 2), lies in the southeasternmost corner of the state at the confluence of the Missouri and Big Sioux rivers. The topography of the county includes the Missouri River bottomlands in the south with uplands in the northern two-thirds of the county (South Dakota Crop and Livestock Reporting Service 1967, 1). The upland portion of the county changes from gently rolling in the west to steeper hills in the east near the Big Sioux River (Driessen 1978).

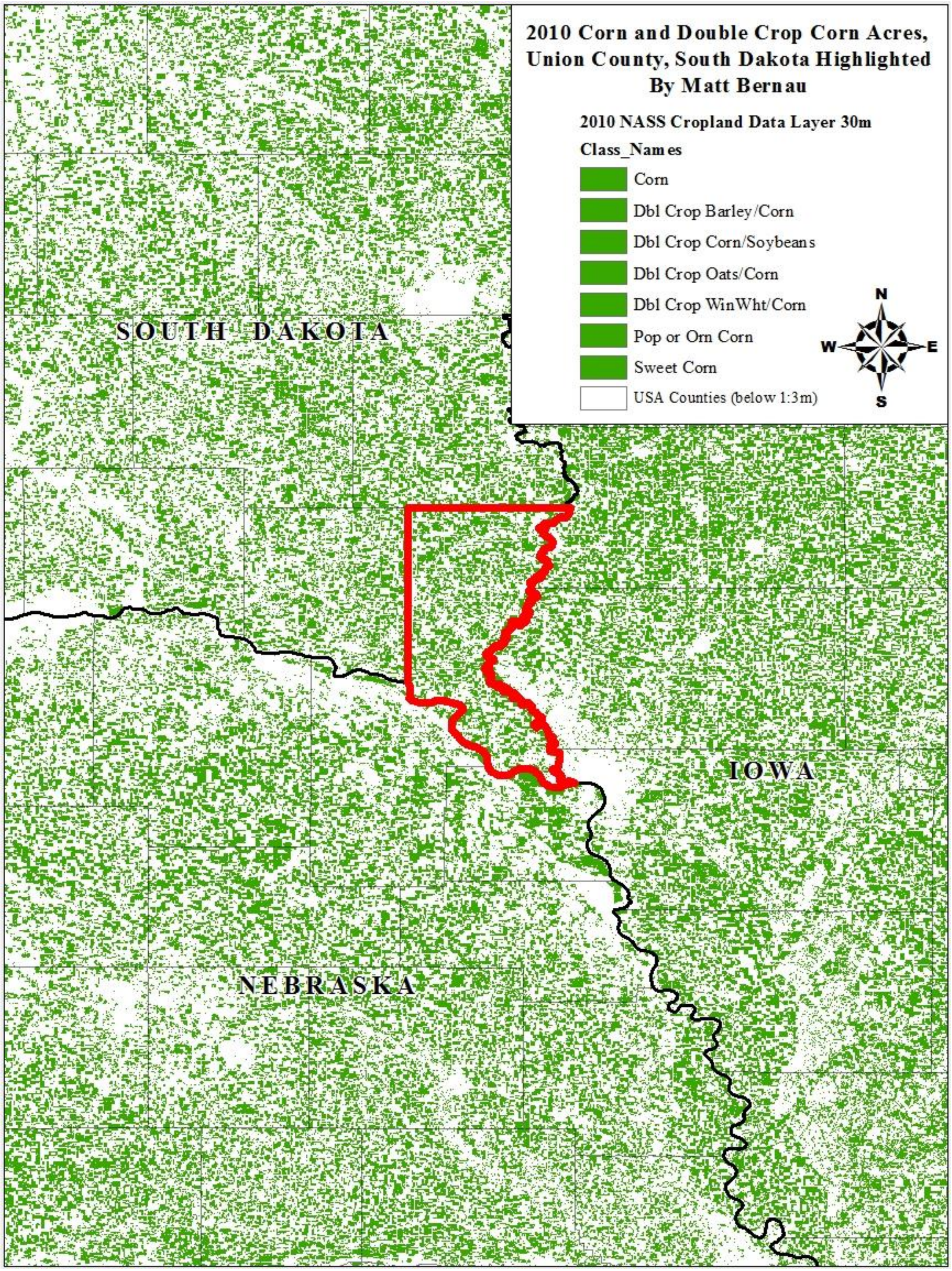


Figure 2. Union County, South Dakota (Highlighted) Corn and Double Crop Corn Acres, 2010

Sources: NRCS Data Download U.S. Counties Accessed August 15, 2013;
USDA National Agricultural Statistics Service Cropland Data Layer 2010. Published crop-specific data layer Online. Available at http://nassgeodata.gmu.edu/CropScape/ (accessed (November 17, 2013)) USDA-NASS, Washington, DC.

Union County farmers brought in more money producing livestock (cattle and hogs) than crops in 2008 according to the USDA NASS/ South Dakota Field Office (2008). It has been noted that there is a correlation between corn and hog production because feeding corn to hogs adds value to the corn crop (Shaw 1936). Furthermore, Union County cropland comprised over 53% in corn acres with about 35% in soybeans and approximately 4% in alfalfa and other crops (USDA NASS/South Dakota Field Office 2008).

Sioux City, Iowa (Figure 3) historically functioned as a gateway city to a hinterland that included northwestern Iowa and settlements in Dakota and Nebraska (Cochran 1886, 8). The Sioux City industry and trade sectors revolved around agriculture, with farmers selling their products and purchasing retail goods before leaving town (Cochran 1886, 9).

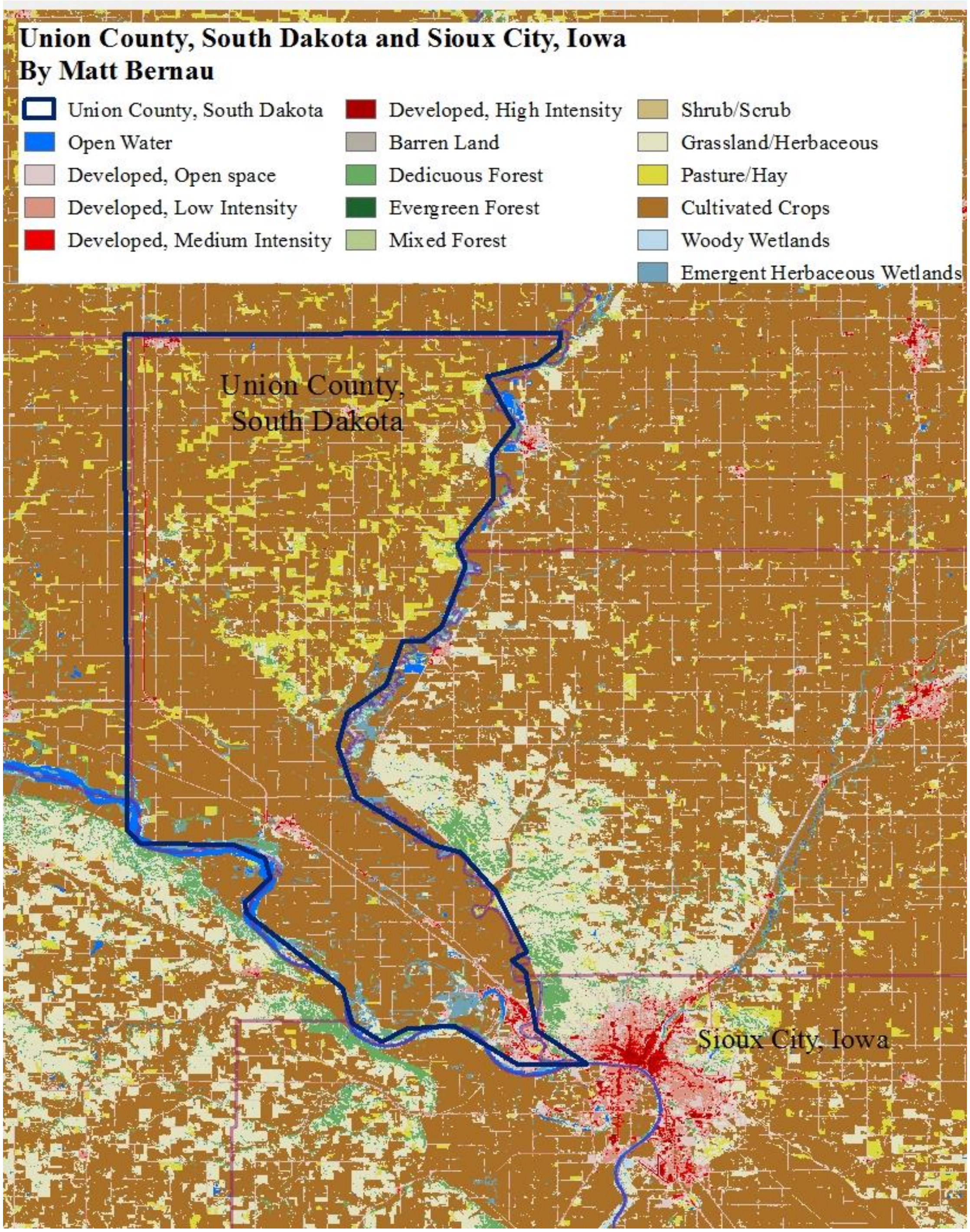


Figure 3. Sioux City, Iowa and Union County, South Dakota

Sources: National Land Cover Dataset 2006; NRCS Data Download U.S. Counties Accessed August 15, 2013.

As early as 1885, Sioux City boasted a meatpacking company, stockyards, and railroad hub (Cochran 1886). Direct railroad access to the Sioux City market was available in Union County towns. This direct market accessibility drove economic decisions made by area farmers. Those decisions included corn, cattle, and hog production, which have affected the land use and land cover of Union County since early settlement.

Changes to the end uses of the U.S. corn crop occurred between 1919 and 2008, whereas the share of the crop fed to livestock decreased from 85% to 43% (Table 1).

Table 1. Comparison of the End Uses of Corn Grain During the years 1919 and 2008

1919 Uses of Corn Grain	**2008 Uses of Corn Grain**
40% Fed to Hogs	43% Livestock Feed
20% Fed to Mules	30% Used for Ethanol Production
15% Fed to Cattle	15% Exported
7% Ground in Flour Mills	8% Used for Starch, Corn Oil, and Sweeteners
6% Fed to Stock not on Farms	
4% Fed to Poultry	
4% fed to Humans on Farms	
3% Other Uses	
1.5% Exports	
1% Sheep	

Sources: Leighty et.al. 1922; iowacorn.org.
http://www.iowacorn.org/User/Docs/2009%20US%20Corn%20Stats.pdf

Thesis Statement

Corn yields in the study area increased between the years 1890 and 2010. The largest increases occurred after fossil-based fuels and fertilizers became available to Union County corn producers. This thesis research answers the question: “How much of the historical Union County corn crop has been produced from non-renewable resources?”

Objectives

1) Identify how corn production changed in the study area between 1890 and 2010, and classify these changes by defining epochal shifts based on the changes in agricultural technology. 2) Determine how much energy (measured in Mega joules per acre) can be attributed to corn production inputs applied during each epoch using the energy budget method. A joule "is the basic unit of energy, following the International System (SI) of units" (Pimentel and Pimentel 1996, 11). "One kilocalorie equals 1000 calories, or 4,184 joules) (Pimentel and Pimentel 1996, 11). A megajoule (MJ) equals one million joules (10^6), and 2.69 MJ equals one Horsepower hour (Pimentel and Pimentel 1996).

3) Identify which corn production inputs and the resultant yield increase can be defined as renewable or non-renewable resources. 4) Determine how changes in corn production technology affected corn yields and land use change in the study area from 1890 to 2010. 5) Calculate the renewable to non-renewable energy ratio of the corn production system prevalent in the study area for each epoch. 6) Identify which corn production inputs drove the increase in corn yields in the study area from 1890 to 2010. 7) Discuss the potential vulnerability of the fossil food supply chain as it relates to the sustainability of modern corn agriculture practices.

Data Collection

The data used to complete this project was gathered from several sources, including the United States Census, the South Dakota Census, National Agricultural Statistics Service data on crop and livestock production, the Census of Agriculture, the Iowa Yearbooks of Agriculture, the United States Yearbooks of Agriculture, Cooperative

Extension Service publications, fertilizer distribution reports for the State of Iowa, refereed journal articles, and additional primary and secondary historical accounts and records.

The most important research sub-problem was finding a published corn production energy budget focused on draft animals in the Corn Belt. However, economic crop production budgets for corn farming were available, and were used as a substitute. Another research obstacle was obtaining county level fertilizer data necessary for this project since county-level fertilizer data is not available for South Dakota. I obtained county-level fertilizer distribution data for the state of Iowa and applied the fertilizer data for Plymouth County, Iowa to Union County Conditions (Figure 4).

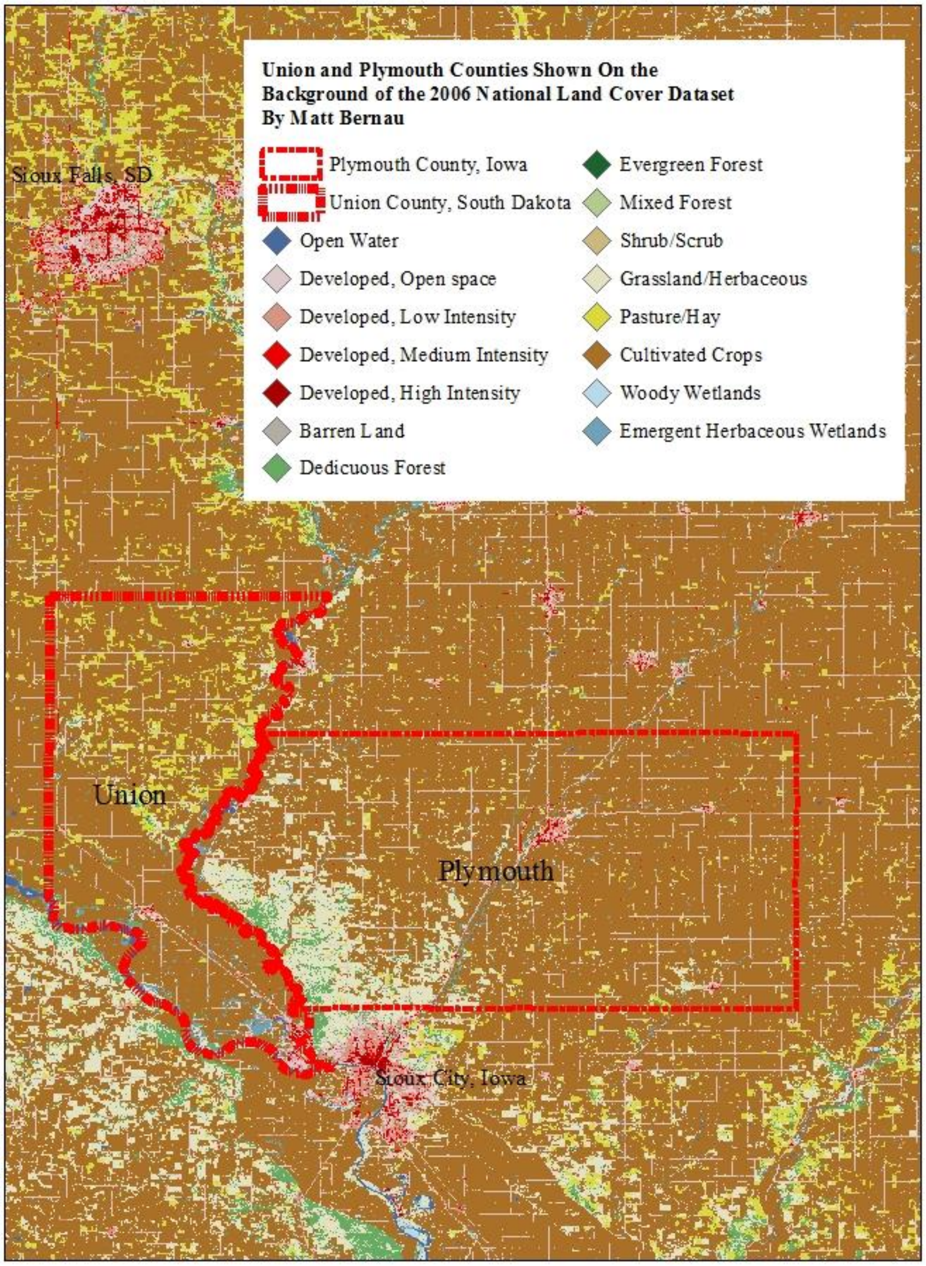


Figure 4. Union County, South Dakota and Plymouth County, Iowa
Sources: National Land Cover Dataset 2006; NRCS Data Download U.S. Counties (Accessed August 15, 2013.

Corn production in Union County is an energy-driven system. The energy conversion from fossil fuels to food occurs when farmers apply fertilizers and pesticides to their crops in order to increase yield. Producing more crops from each acre is one way to meet the increasing global demand for food (Smil 2008). How sustainable and secure will food production be when finite inputs, including fertilizer, are no longer available for agricultural use?

Data Interpretation

The prevailing corn production methods specific to each epoch were evaluated using the energy budget method. The energy budget method is an input-output analysis that "consists of collecting data on the physical quantities of fuels and electricity used in producing a commodity" (Smil, Nachman, and Long II 1983, 2). I used a variation of this method which included a process-based approach for the energy analysis. Process analysis focuses on the details of a production system and has been proven to be valuable when studying the energy inputs of an agricultural commodity (Smil, Nachman, and Long II 1983, 2). Each input used in the four epochal corn production systems was calculated to MJ per acre as a common denominator (Smil, Nachman and Long II 1983). The sustainability of corn production was measured using the renewable: non-renewable energy input ratio, which highlighted the relationship between the renewable and non-renewable energy inputs per acre. The total input: output ratio was also measured in MJ per acre for each epoch. Comparisons of these ratios were made between all four epochs.

CHAPTER 2: THE LITERATURE REVIEW

Land Theory and Cropland

Early economists considered land the epicenter of wealth creation; the measure of that set the income level of a population. This idea centered on Adam Smith's economic theory of land where a central economy depended upon the goods produced from the nearby landscape (Chisholm 1980, 257, 258). Johann Heinrich von Thunen expanded Adam Smith's land theory by creating a model based on a central place (Johnson 1962, 213). Von Thunen's central place theory equalized the variables of agricultural crop production, such as soil fertility and land use, and focused on transportation as the limiting economic variable between the town and its surrounding farmland when cost is considered (Johnson 1962, 215). Norton and Conkling (1974) used von Thunen's central place theory to study agricultural land use in the hinterland of Toronto, Canada. They found that the goal of the pioneers was to actively participate in the economy of Toronto (Norton and Conkling 1974, 55).

Aside from economics, the remaining limiting factors in grain crop production are biological and environmental (Page 1996, 380). These limiting factors include: climate, moisture, temperature, length of the growing season, fertility requirements, soil types, photosynthetic processes, and vulnerability to weed and pest damage. Scientists have been able to offer solutions to some of these problems by offering farmers pesticides and fertilizers which "replaced agricultural goods with industrially produced inputs" (Page 1996, 381). This observation reinforces the assertion by Landis (1929, 131) that the goal of fertilizer manufacturing firms was to feed the human race by selling their fossil food energy source as fertilizer to farmers. Under this industrial model, the role of cropland as a basic wealth generator was reduced to that of an industrial node used to convert nonrenewable inputs into palatable human food.

Energy Analysis of Corn Production

Energy density (J/m^3) is used to quantify the amount of energy per unit volume contained in a fuel or feedstuff (Smil 2008, 19). Energy concentration (J/m^2) is the amount of energy contained in spatial resources, such as natural grasslands, or managed fields of corn (Smil 2008, 19). Smil, Nachman, and Long II (1983, 37) used MJ/acre as a common denominator when they compared the corn production practices of 1945 to those of 1974.

David Pimentel preferred to use kilocalories per acre or hectare to measure the energy concentrations found in agricultural production systems (Pimentel et. al. 1973, 444). A study titled “Food Production and the Energy Crisis,” by Pimentel et. al. (1973) was similar to Smil, Nachman, and Long II’s work (1983) titled “Energy Analysis and Agriculture: An Application to U.S. Corn Production,” because it also focused upon U. S. corn production during the years 1945-1970. Both groups of researchers recognized that farmers relied upon nonrenewable resource inputs extracted from fossil fuels to raise corn and they each measured the energy efficiency of the production systems (Smil, Nachman, and Long II 1983, 1; Pimentel et. al 1973, 448). Smil, Nachman, and Long II (1983) compared the importance of the increased energy efficiency of corn production to the energy used by the entire nation. They concluded that corn farmers only used .67 % of the nation’s total energy consumption and that the efficiency of fossil-fueled corn production is respectable and predicted that it will continue into the future (Smil, Nachman, and Long II 1983, 162).

Pimentel et. al. (1973) offered a set of alternative energy solutions that U.S. corn producers may have to use in order to reduce the amount of fossil fueled energy inputs if those inputs become economically prohibitive. These included the use of green manure crop rotations and increasing human labor relative to machine usage (Pimentel et. al 1973, 448). Smil (2008) considered the implications of a larger societal transition from a fossil-fueled civilization to one only dependent upon solar radiation. He pointed out the fact that our industrial infrastructures are based on fuels that have high concentrations of energy per unit volume, and that a transition to solar energy would require a massive land use change (Smil 2008, 383). This change would require farmers to transition away from fossil inputs for crop production, thus destabilizing global food security because:

> "Only solar energy transformed into phytomass through heavily subsidized photosynthesis (in order to eliminate any water and nutrient shortages and to protect the harvest from pest attack) can be harvested and used predictably" (Smil 2008, 383).

Corn Production Inputs in the Corn Belt

Edgar Nelson Transeau (1926), called for expanded research into plant photosynthesis because fossil fuels are limited. He reported that in order to replace gasoline with alcohol derived from corn; the entire United States harvest would be needed. The national 1926 corn crop was approximately two-billion bushels, while the 2010 crop was about 12 billion bushels, (United States Department of Agriculture. nass.usda.gov. (Accessed November 21, 2013). Transeau concluded that the best possible source of an unlimited energy supply in the future would be to improve the photo-chemical process of photosynthesis, especially since a 100-bushel per acre corn crop only uses 1.6 percent of the solar energy available for use (Transeau 1926). Corn photosynthesis is not limited by the amount of solar energy available to the plant to carry out its required processes (Transeau 1926).

Justus von Liebig introduced the ‘Law of the Minimum’ as it applies to plant growth during the mid-nineteenth century. He reported that if one nutrient is deficient, the growth of the plant will be limited even though other required elements may be available to it (Usher 1923). Liebig’s theory was important, because it fostered research in soil amendments to increase crop production. Plant scientists have since determined that there are sixteen essential elements needed for plant growth. The three most important are: carbon, hydrogen, and oxygen, which are available from the atmosphere (Aldrich, Scott, and Leng 1975, 104). The remaining thirteen are generally placed in one of three classes: primary and secondary macronutrients, and micronutrients (Mullen, Lentz, and Watson 2005, 19). The primary macronutrients are nitrogen, phosphorous, and potassium. The secondary macronutrients are calcium, magnesium, and sulfur. Nitrogen, phosphorous, and potassium, the primary macronutrients, are needed in the highest amounts for plant growth (Mullen, Lentz, and Watson 2005, 19). There is a problem with the nitrogen, phosphorous, and potassium found in the soil because these nutrients are only available to plants in small amounts (Mullen, Lentz, and Watson 2005). The plant available nutrients are removed from the soil as part of the harvested crops; over time, this can cause soil degradation and result in lower yields (Bumb and Baanante 1996, 1).

The only way to maintain the yield levels gained by modern crop genetics is by supplementing natural soil nutrients with external sources of fertilizer (Bumb and Baanante 1996, 1). Additionally, Bumb and Baanante (1996, 2) observed that much of the growth in crop production since 1961 has been due to higher yields and that the future of food production relies upon the intensification of agricultural output through fertilizer applications. The United States Department of Agriculture also reported that the rising yields of farm products were due to a fundamental shift in resource use by farmers as they focused their efforts on replacing human labor and land with substitutes. These included the off-farm inputs of machinery, fertilizers, and chemicals (Daly 1970, 344).

Farmers in the West North Central region of the United States used very little commercial fertilizer before 1920 (Nelson and Parker 1990, 105). South Dakota reportedly only consumed 200 tons of commercial fertilizer in 1920 (Nelson and Parker 1990, 105). The lack of demand for commercial fertilizer amendments in the North Central states was due to several factors including crop rotation practices and manure applications (Nelson and Parker 1990). The cropping system used in Union county was the same as in other parts of the Western Corn Belt (Nelson and Parker 1990, 101). The technological shift from renewable to non-renewable fertilizer applications in the study area did not occur until after 1945 because the prairie soils held high nutrient levels that took years to consume. This change is responsible for the intensified cropland use and unprecedented yield levels (Nelson and Parker 1990; Smil, Nachman, and Long II 1983).

The sustainability of high yielding crop production systems is important if U.S. farmers are going to continue meeting the product demands from a growing world population (Bumb and Baanante 1996, 2). Researchers have thought that the output of the corn grain production system is a renewable resource (Eksridge 1978). This may be misleading because domestic corn crops are built from both renewable and non-renewable resources for yield maintenance and growth. Unfortunately for the future of agriculture, the fossil and mineral fertilizer technology used to increase crop yields depends upon finite resources, whereas, system sustainability cannot be maintained when adversely affected by change (Russell 1997).

Can the U.S. corn crop continue to be considered a renewable resource in light of the fact that fossil inputs are applied during the production process in order to reach desired yield goals? This question will be answered by conducting a case study of the corn production methods used on Union County, South Dakota farms from 1890 to 2010.

CHAPTER 3: THE CASE STUDY: THE SUSTAINABILITY OF CORN PRODUCTION IN UNION COUNTY

Introduction to the Draft Horse Epoch

The landscape of the Great Plains encountered by European settlers was estimated to have been covered by more than 400 million acres of prairie grasslands (Samson and Knopf 1994). Eastern South Dakota contained about 7.4 million acres of tallgrass prairie before European settlement (Samson and Knopf 1994, 419). The natural land cover of Union County, SD consisted of tallgrass prairie plants with woodland along the Missouri and Big Sioux rivers and their tributaries (Driessen 1978, 82).

The native prairie grass species that once covered Union County included "big bluestem, blue grama, green needlegrass, indiangrass, switchgrass, and western wheatgrass" (Driessen 1978, 82). Even though these grasses dominated the landscape, the tallgrass prairie ecosystem was home to several other plant species. Piper and Gernes (1989) sampled existing tallgrass prairie sites in Kansas and found that the prairie is home to several plant families; including "12-26% legumes, 6-12% composites, 4-9% mints, and 5% Lilies" (Piper and Gernes 1989). Legumes were important to the annual yield of phytomass per prairie acre because of their nitrogen fixation capabilities (Smil and Cleveland 2007).

The tallgrass prairie was a renewable resource because its annual and perennial plant diversity renewed within a biological time frame. As the plant material from each growing season decomposed, it contributed organic matter and nutrients to the soil. A study of root distribution in prairie soils conducted in Eastern Nebraska found that the dense mass of prairie roots in the upper soil horizons breaks down eventually, thus contributing organic matter, nitrogen, and other nutrients to the soil (Weaver, Hougen, and Weldon 1935, 416). The root mass of the tallgrass prairie vegetation in Central Minnesota was 5,416 kilograms/hectare, or 4,824 pounds/acre (Ovington, Haitkamp, and Lawrence 1963, 57). While the oven dry weight of the root mass per corn acre, according to a Nebraska study was one-half ton (Kiesselbach 1951). The dense sod layer of the Tallgrass Prairie was the land cover encountered by homesteaders as they settled Union County. Desperate to produce a crop, farmers sometimes chopped holes in the sod with their axes and planted corn in the exposed soil (Schell 1976, 115). The native tallgrass prairie would later succumb to the plow. The Union County land cover conversion from prairie to cropland increased after 1870 and continued for several decades (Figure 5).

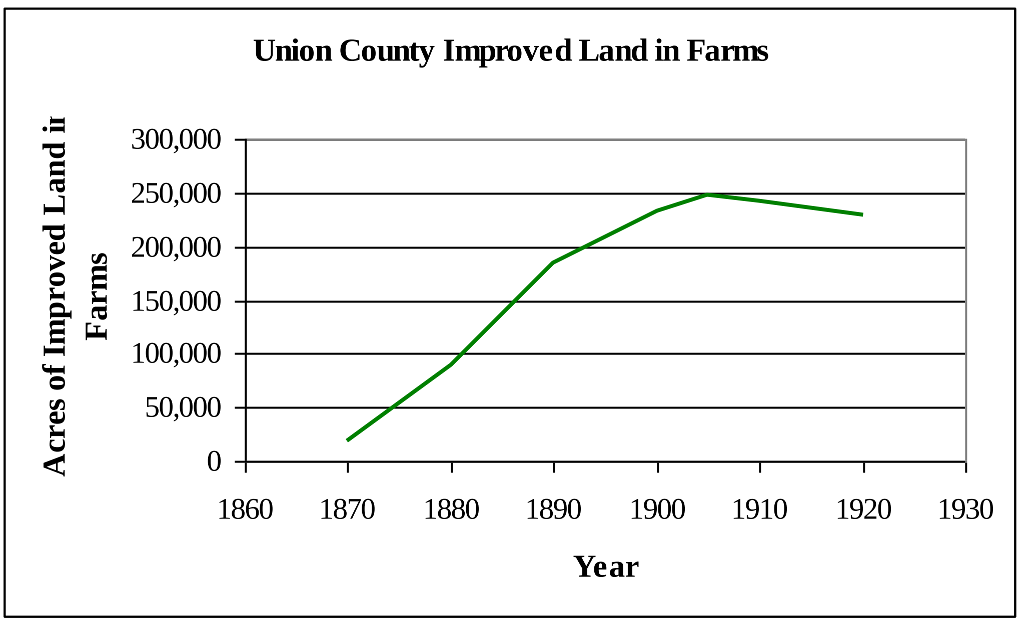


Figure 5. Union County Improved Land in Farms: 1870-1920
Sources: Austin 1922; Bureau of the Census 1914; Robinson 1905; Scott 1915; South Dakota Crop and Livestock Reporting Service 1967; U. S. Census 1883; Department of the Interior 1895; Powers 1902; Bureau of the Census 1914; U.S. Census 1920; United States Department of Agriculture. National Agricultural Statistics Service 2012; Walker 1872.

The percentage of improved land in farms in the study area expanded from 1870 to 1910 as farms were built and the land was plowed. The number of farms in Union County declined from about 1650 in 1900 to 1421 in 1920, by about 16 percent (Figure 5).

Twelve Decades of Agricultural Change

The environmental and technological changes that took place between 1890 and 2010 in Union County need to be considered on a macro-basis. These changes included climatic factors because they provided the environmental limits to crop yields (Figure 6).

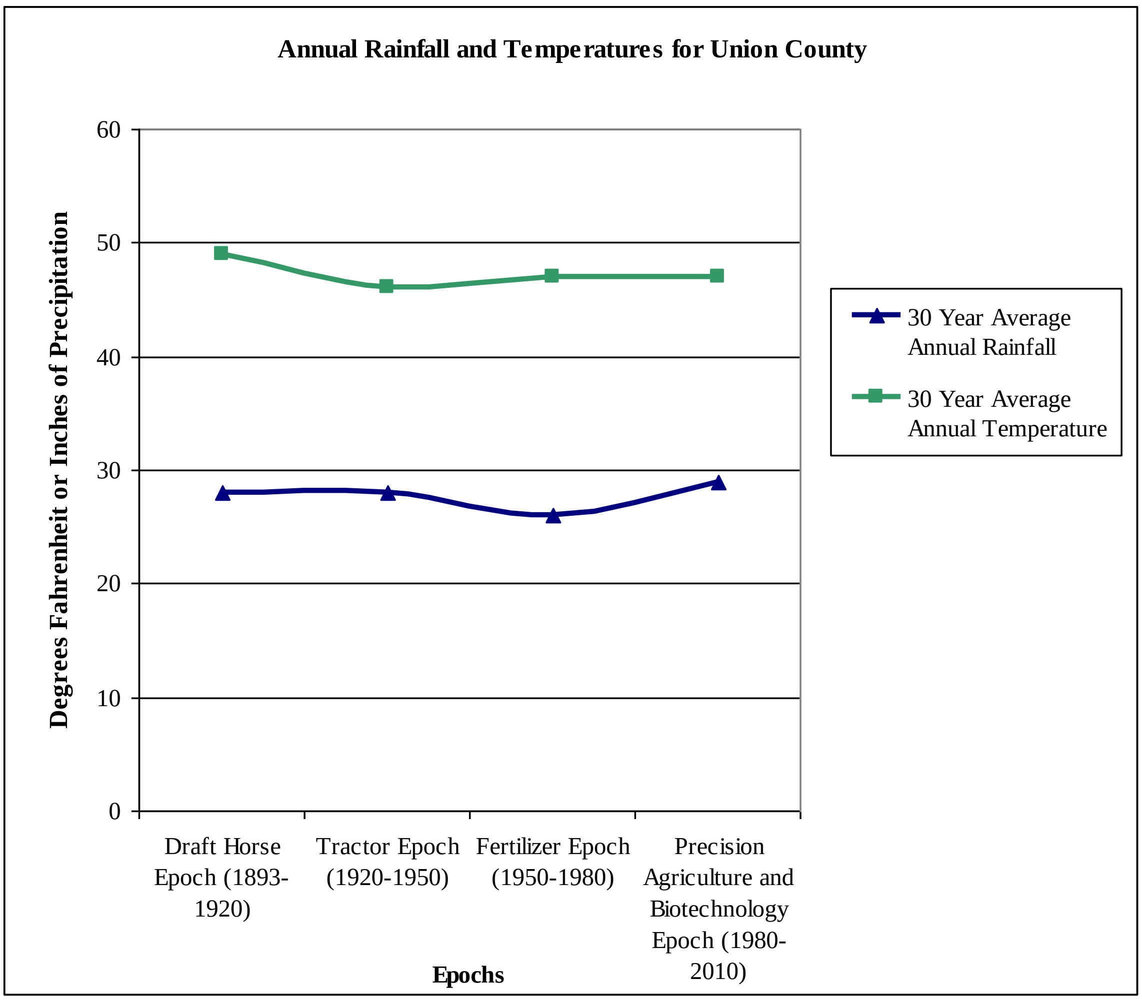


Figure 6. **Climate of Union County: 1890-2010**
Sources: http://mesonet.agron.iastate.edu/climate/year.phtml Accessed 8/19/2012.

The variation in total precipitation during the period under study was 3 inches, while the average temperature varied by 3 degrees Fahrenheit. These are annual averages and I did not consider the growing seasons separately because data for growing season lengths as well as the possible actual average planting dates for corn production were not available. The energy provided by the sun and through natural precipitation is outside the input control of farmers, and as such, is outside the scope of this thesis.

Union County farmland use changed during the study period, where farm size and the number of corn acres per farm increased while farm numbers decreased (Figure 7).

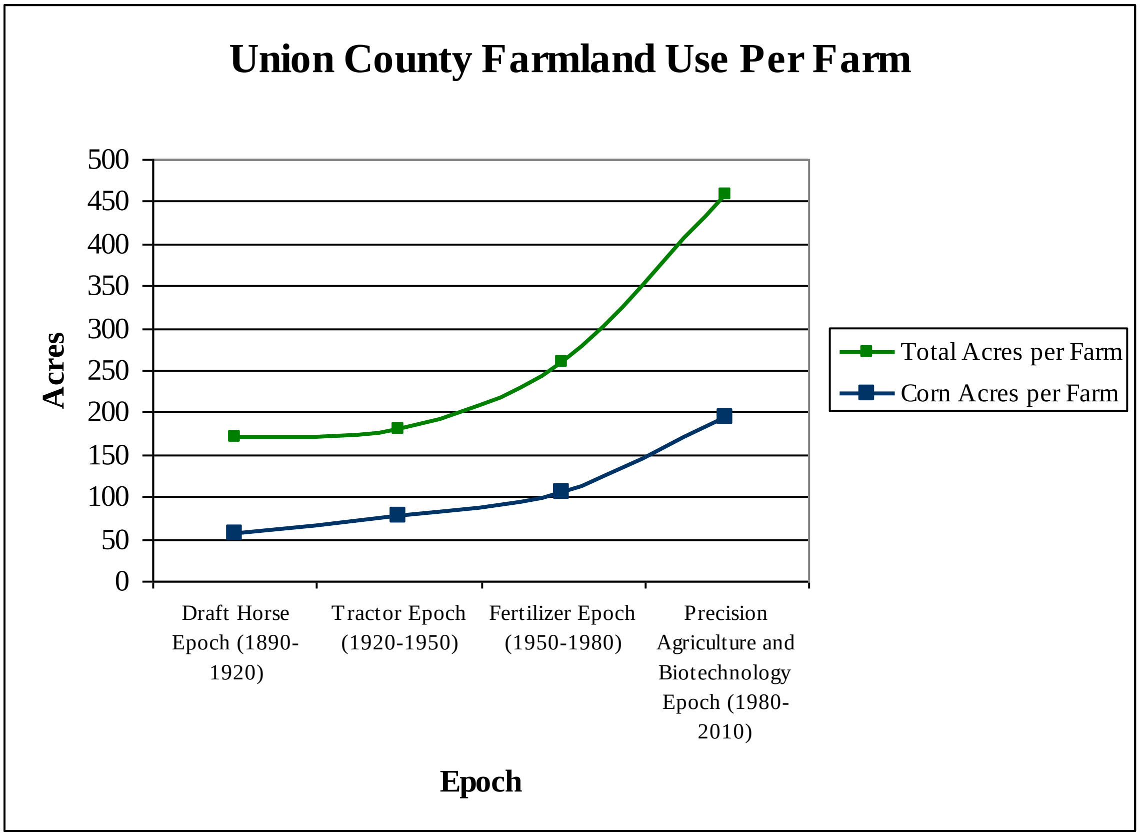


Figure 7. Union County Farmland Size and Corn Acres

Sources: Austin 1922; Austin 1932; Bureau of the Census 1914; Bureau of the Census 1977; Bureau of the Census 1984; Bureau of the Census 1989; Census of Agriculture 1992; Census of Agriculture 1999; Census of Agriculture 2002; Census of Agriculture 2004; Census of Agriculture 2009; Department of the Interior 1895; Hurley 1952; National Agricultural Statistics Service. http://www.nass.usda.gov/Statistics_by_State/South_Dakota/index.asp. (Accessed March 3, 2012); Powers 1902; Robinson 1905; Scott 1915; South Dakota Crop and Livestock Reporting Service 1967; United States Government Printing Office 1936; United States Government Printing Office 1946; United States Government Printing Office 1956; United States Government Printing Office 1967.

The prime mover transition from draft animals to tractors directly affected corn production. Prime movers are “machines for driving other machines,” such as muscle, air, water, and mechanical heat (Rankine 1870, 13). Draft animals, (horses and mules) on farms were phased out almost completely by 1950 and their labor was replaced with electricity and internal combustion engine technology (Smil 2000). The Union County draft animal herd was replaced by the fossil-fueled farm tractor (Figure 8). Tractors increased farm income in two major ways. First, the imported fossil fuels substituted for the land used by farmers to produce grain, hay, and grazing to support the draft animal herd. Second, labor costs decreased because tractors did not need to be fed and cared for on a daily basis.

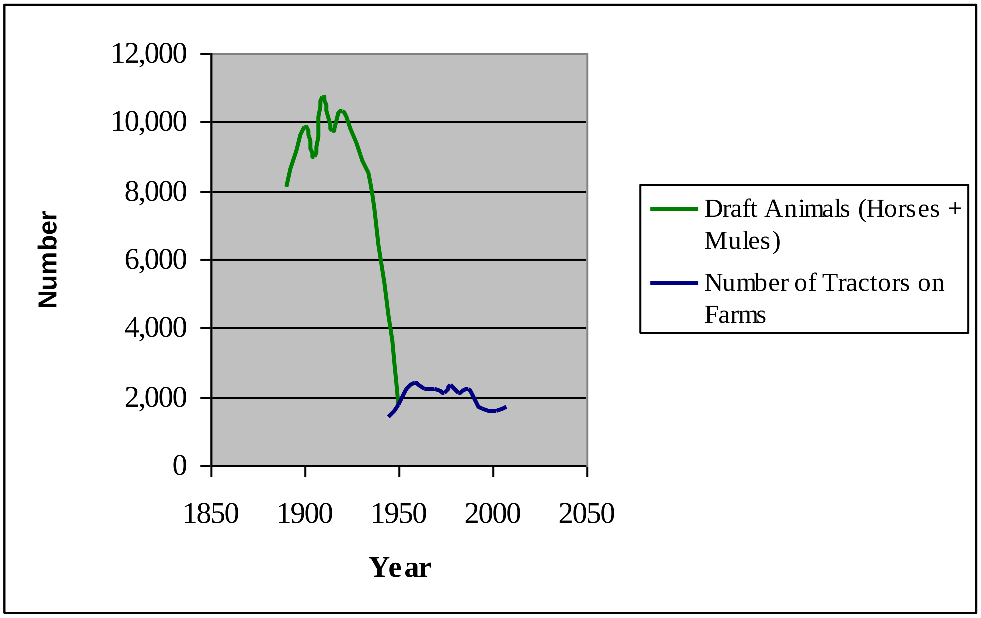


Figure 8. The Transition from Draft Animals to Tractors in Union County

Sources: Austin 1922; Austin 1932; Bureau of the Census 1914; Bureau of the Census 1977; Bureau of the Census 1984; Bureau of the Census 1989; Census of Agriculture 1992; Census of Agriculture 1999; Census of Agriculture 2002; Census of Agriculture 2004; Census of Agriculture 2009; Department of the Interior 1895; Hurley 1952; National Agricultural Statistics Service. http://www.nass.usda.gov/Statistics_by_State/South_Dakota/index.asp. (Accessed March 3, 2012); Powers 1902; Robinson 1905; Scott 1915; South Dakota Crop and Livestock Reporting Service 1967; United States Government Printing Office 1936; United States Government Printing Office 1946; United States Government Printing Office 1956; United States Government Printing Office 1967.

Union County corn yields rose steadily after 1950 because of the introduction of synthetic fertilizers, and other changes in farm management systems (Figure 9).

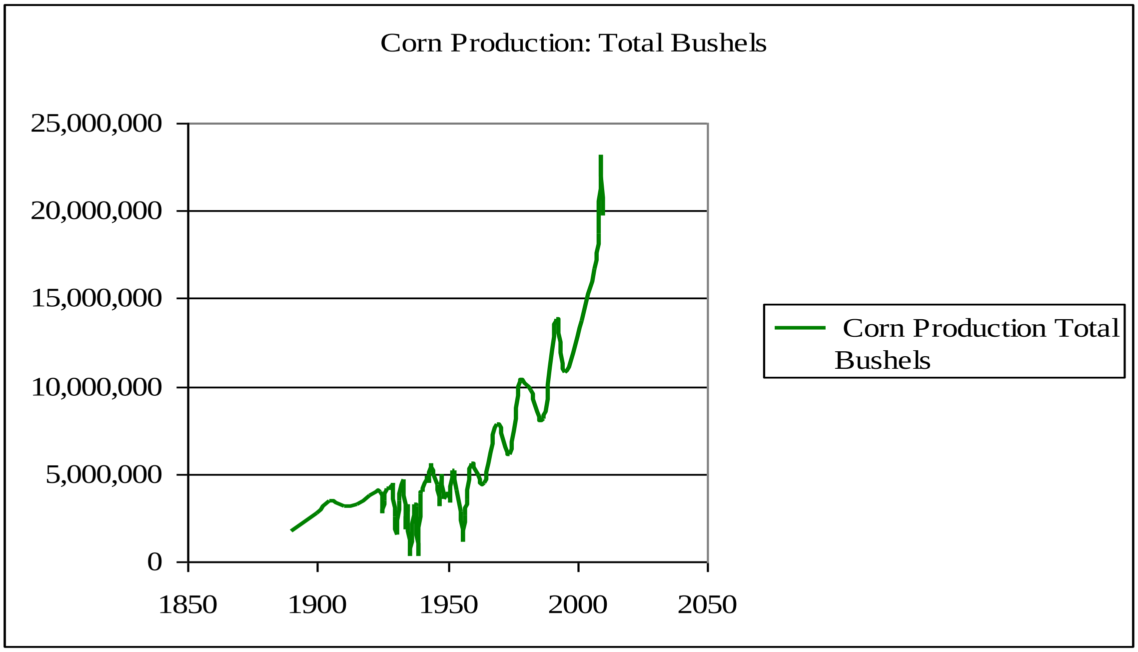


Figure 9. Union County Corn Production in Total Bushels

Sources: Austin 1922; Austin 1932; Bureau of the Census 1914; Bureau of the Census 1977; Bureau of the Census 1984; Bureau of the Census 1989; Census of Agriculture 1992; Census of Agriculture 1999; Census of Agriculture 2002; Census of Agriculture 2004; Census of Agriculture 2009; Department of the Interior 1895; Hurley 1952; National Agricultural Statistics Service. http://www.nass.usda.gov/Statistics_by_State/South_Dakota/index.asp. (Accessed March 3, 2012); Powers 1902; Robinson 1905; Scott 1915; South Dakota Crop and Livestock Reporting Service 1967; United States Government Printing Office 1936; United States Government Printing Office 1946; United States Government Printing Office 1956; United States Government Printing Office 1967.

The percentage of the county in cropland and the percentage of the cropland in corn changed over time. Figure 10 shows those percentages for the years 1910, 1964, and 2007, when data was available. Corn acres, as a percentage of the 'Improved Land in Farms' data reported by the United States Government, averaged 37% of Union County cropland use between 1890 and 1920, which closely matched Hart's (1986) estimate for the Corn Belt, "In 1920 only two-fifths of the cropland in four Corn Belt states was used for corn" (Austin 1922; Bureau of the Census 1914; Department of the Interior 1895; Hart 1986; Powers 1902; Robinson 1905; Scott 1915).

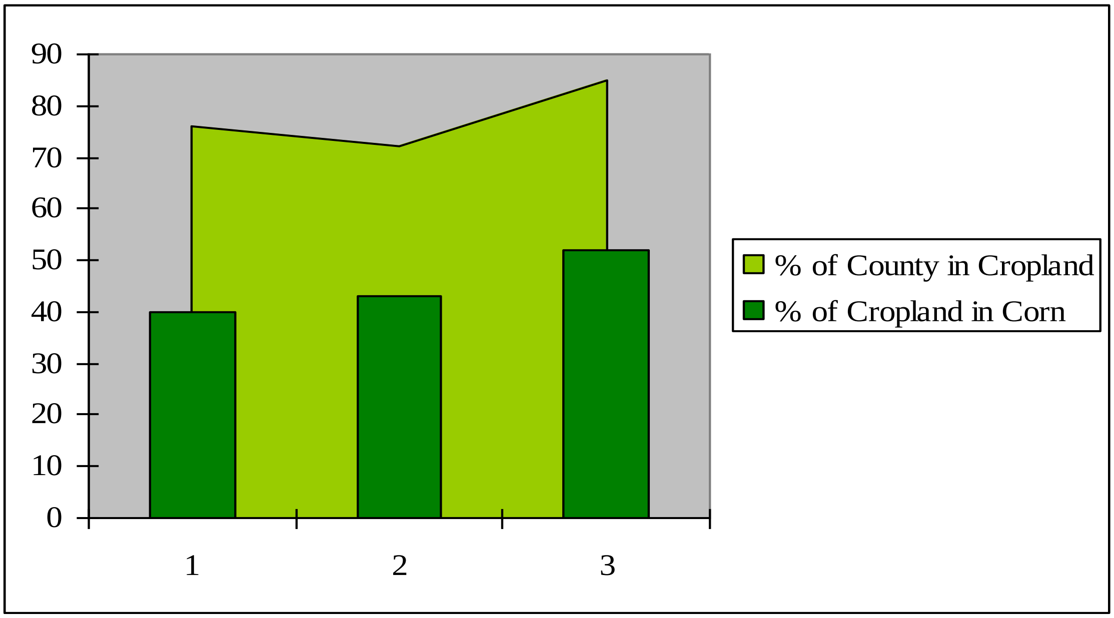


Figure 10. The Percentage of Union County in Cropland and the Percentage of the Cropland in Corn: (1) = 1910, (2) = 1964, and (3) = 2007

Sources: Bureau of the Census 1914; Census of Agriculture 2009; United States Government Printing Office 1967

Slight fluctuations in the number of corn acres planted occurred during each epoch. These changes were made by farmers in response to environmental and economic factors (Figures 11, 12, 13, and 14).

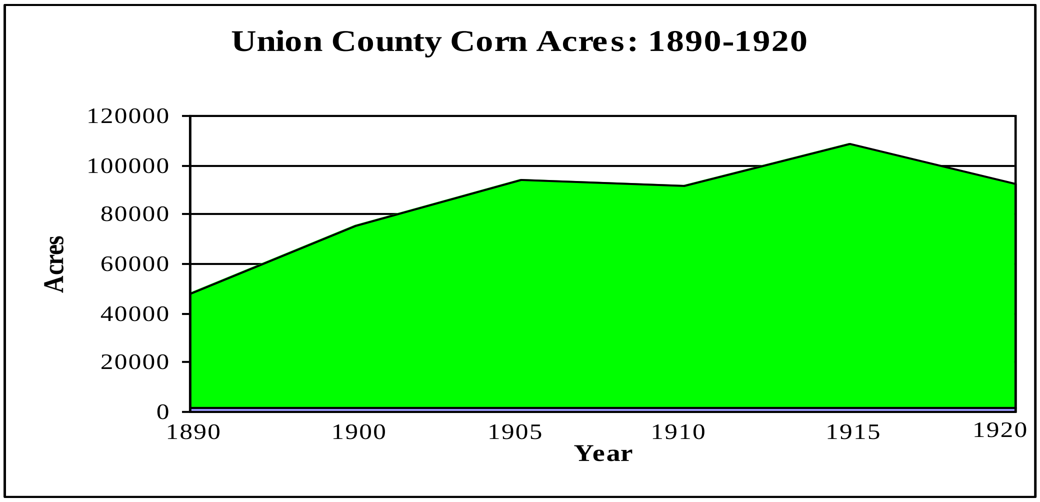


Figure 11. Union County Corn Acres: Draft Horse Epoch

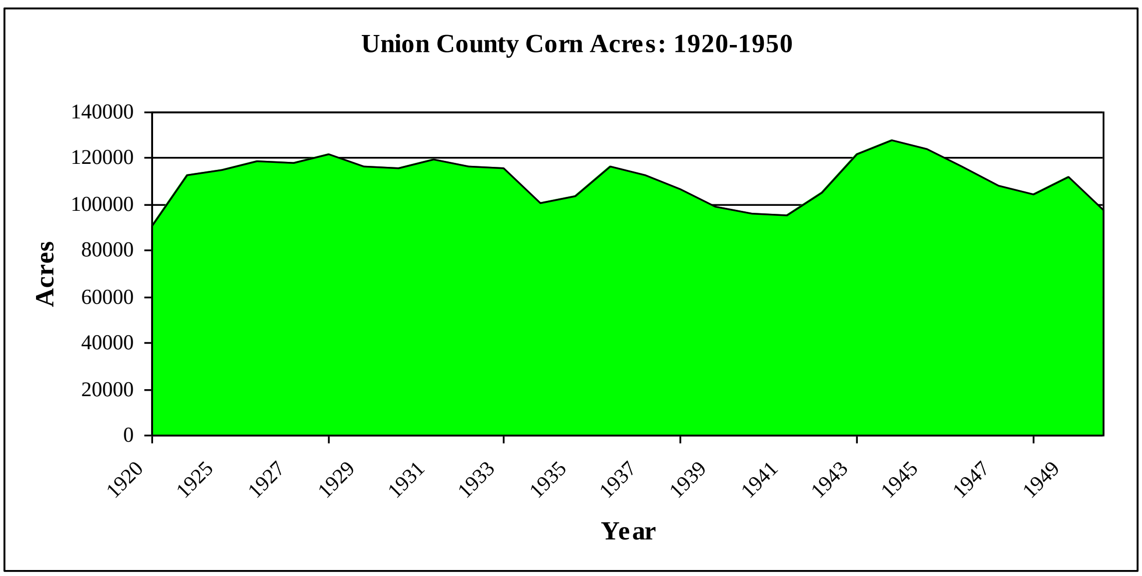


Figure 12. Union County Corn Acres: Tractor Epoch

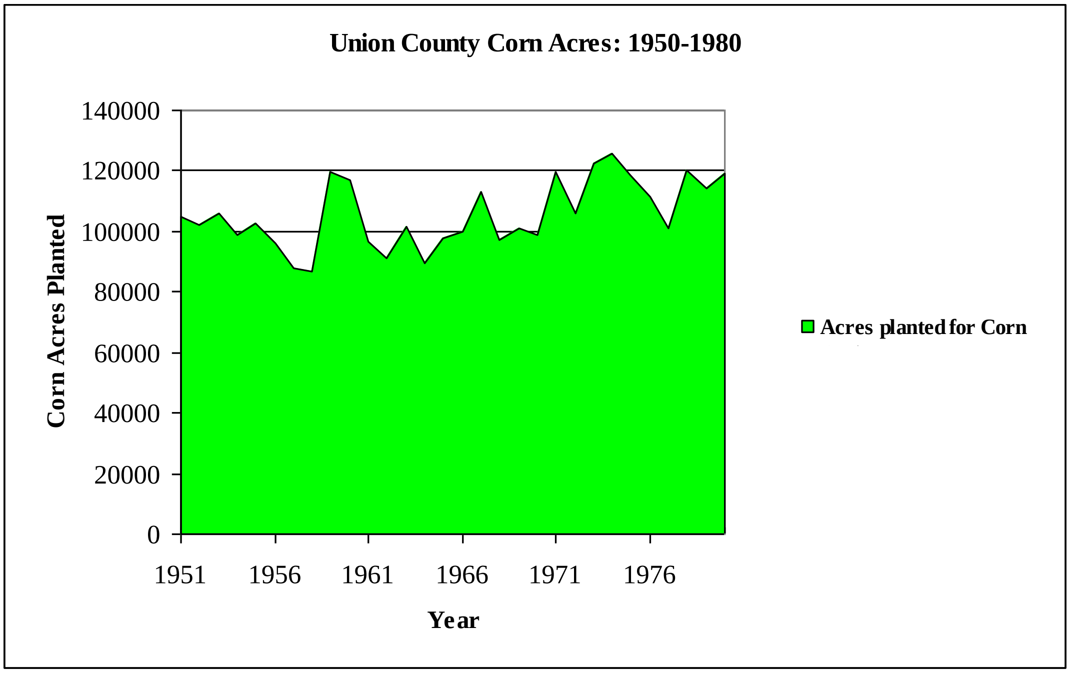


Figure 13. Union County Corn Acres: Fertilizer Epoch

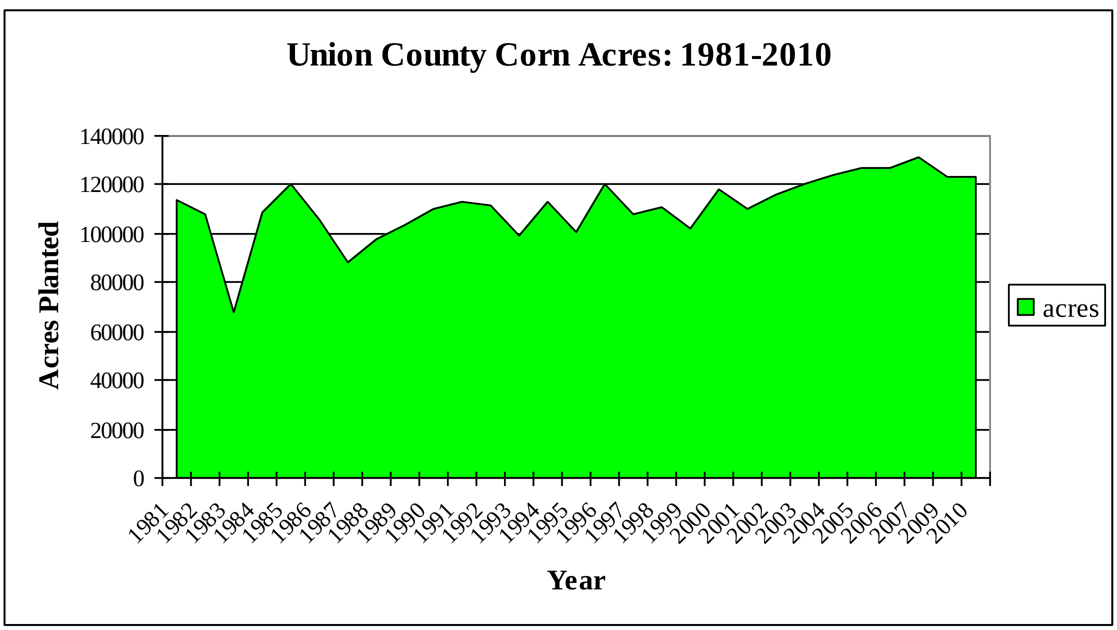


Figure 14. Union County Corn Acres: Precision Agriculture and Biotechnology Epoch

(Austin 1922; Austin 1932; Bureau of the Census 1914; Bureau of the Census 1977; Bureau of the Census 1984; Bureau of the Census 1989; Census of Agriculture 1992; Census of Agriculture 1999; Census of Agriculture 2002; Census of Agriculture 2004;

Census of Agriculture 2009; Department of the Interior 1895; Hurley 1952; National Agricultural Statistics Service. http://www.nass.usda.gov/Statistics_by_State/South_Dakota/index.asp. (Accessed March 3, 2012); Powers 1902; Robinson 1905; Scott 1915; South Dakota Crop and Livestock Reporting Service 1967; United States Government Printing Office 1936; United States Government Printing Office 1946; United States Government Printing Office 1956; United States Government Printing Office 1967).

The use of commercial fertilizers on cropland acres by Union County farmers increased after 1950 (Figure 15). The number of acres receiving commercial fertilizers increased 318% between 1950 and 1978, and then increased again between 1978 and 2007 by another 167%. By 2007, 83% of Union County cropland received an annual application of synthetic fertilizer as a crop production input.

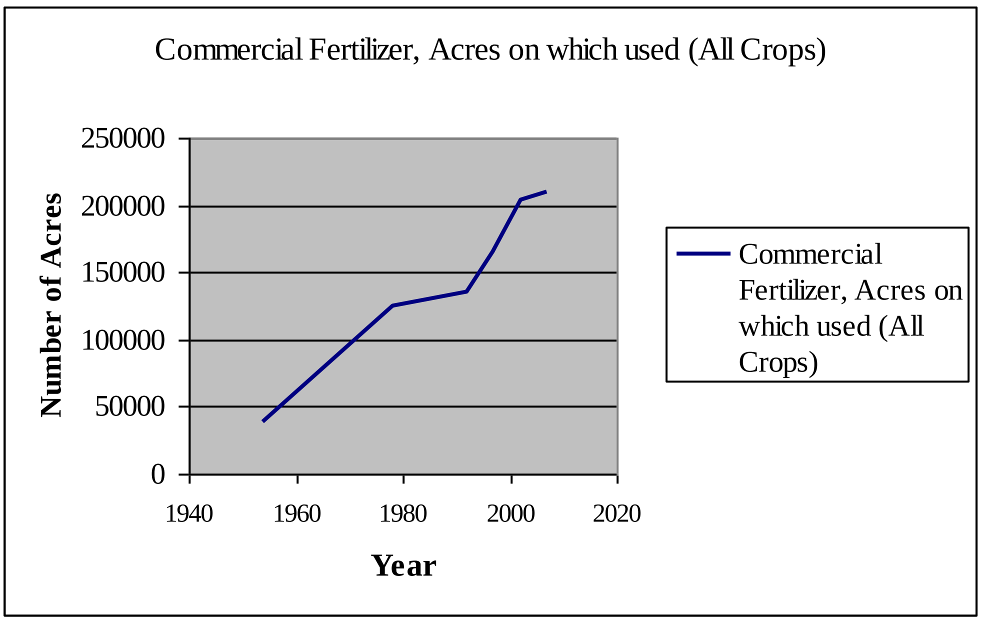


Figure 15. Union County Cropland and Fertilizer Usage

(Bureau of the Census 1977; Bureau of the Census 1984; Bureau of the Census 1989; Census of Agriculture 1992; Census of Agriculture 1999; Census of Agriculture 2002; Census of Agriculture 2004; Census of Agriculture 2009; Hurley 1952; National Agricultural Statistics Service. http://www.nass.usda.gov/Statistics_by_State/South_Dakota/index.asp. (Accessed March 3, 2012); South Dakota Crop and Livestock Reporting Service 1967; United States Government Printing Office 1956; United States Government Printing Office 1967).

There was a linear relationship between annual corn grain yields harvested in Union County and the fertilizer application rate data for the State of South Dakota for the years 1964-2010 (Figure 16).

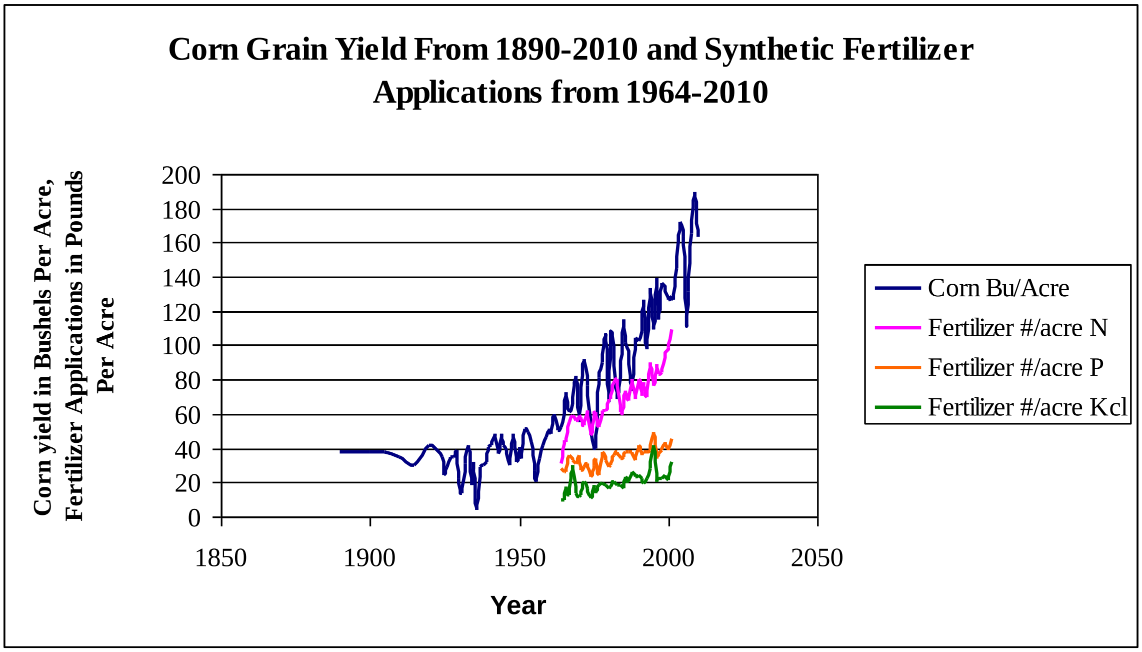


Figure 16. Corn Yield per Acre and Fertilizer Use

A regression analysis was conducted and the results for the correlation between corn yield in bushels per acre and fertilizer nitrogen, phosphorus, and potassium chloride were: $R^2 = .83$, N = 41; $R^2 = .69$, N = 41; and $R^2 = .60$, N =41, respectively.

Source: Austin 1922; Austin 1932; Bureau of the Census 1914; Bureau of the Census 1977; Bureau of the Census 1984; Bureau of the Census 1989; Census of Agriculture 1992; Census of Agriculture 1999; Census of Agriculture 2002; Census of Agriculture 2004; Census of Agriculture 2009; Department of the Interior 1895; Hurley 1952; National Agricultural Statistics Service. http://www.nass.usda.gov/Statistics_by_State/South_Dakota/index.asp. (Accessed March 3, 2012); Powers 1902; Robinson 1905; Scott 1915; South Dakota Crop and Livestock Reporting Service 1967; United States Government Printing Office 1936; United States Government Printing Office 1946; United States Government Printing Office 1956; United States Government Printing Office 1967.

The positive correlation of .83 between applied nitrogen and corn grain yield does not prove a causative relationship by itself, but it was, however, statistically significant enough to prove a relationship exists between the variables. If $|r| \geq 2/\sqrt{41} = .31$, then the R^2 value of .83 proves a relationship exists between the nitrogen, phosphorus, and potassium chloride application rates recommended by agronomists and the resultant corn grain yield. Research agronomists recommend applying 1.2 pounds of nitrogen per bushel of expected corn grain yield (Reitsma et.al. 2008). Fertilizer technology is important to the future sustainability of corn production in the study area and in other regions of the world. Chapter 4, “The Energy Analysis” includes the input/output energy budgets of corn production for each epoch. Chapter 5 summarizes the results of these analyses and concludes with some implications for the future of global food security.

CHAPTER 4: UNION COUNTY CORN PRODUCTION: THE ENERGY ANALYSES

Introduction.

The corn production methods during the draft horse epoch required few inputs aside from labor; those included hand tools and farm implements such as plows and cultivators. Consequently, very little imported energy was used by Union County farmers for crop production. This meant that the corn harvest represented real wealth generated from within the study area.

Aside from corn, other major crops raised in Union County during the draft horse epoch were hay, wheat, barley, and oats. Approximately 2/3 of the harvested corn grain in 1919 was fed directly to livestock; pork consumed the largest amount at 40% (Leighty, et. al. 1922). The object of feeding corn to hogs and other livestock is to convert a low quality plant protein into a high quality protein food for human consumption (Smil 2002). Smil reported that it takes 5 lbs. of feed to produce 1 lb. of live hog weight (Smil 2002).

Given that Corn Belt agriculture is a profit driven system, corn production processes are most commonly reported through economic analysis (Morrison 1936). I applied data from various corn production budgets to the Union County case study. Conversion factors used in this thesis are listed in Appendix A.

Corn Production Energy Analysis: The Draft Horse Epoch

Draft animals were the prime movers for Union County farm field operations between 1890 and 1920 (Table 2). The two most common draft horse breeds known to be used for farm work in South Dakota and other Midwestern states were the Percheron and Belgian (Plumb 1922). Mature Percheron and Belgian draft horses typically weighed between 1600 and 2000 pounds (Plumb 1922).

Table 2. Union County Prime Mover Profile: Draft Horse Epoch, 1890-1920

Yearly Average Numbers of Horses and Mules in Union County	Number
30 yr. Average # of Mules (All Ages on all Farms/Union County	435
30 yr. Average # of Horses (All Ages) on all Farms/Union County	9,174
30 yr. average # of Horses (All Ages) plus Mules per Union County Farm	6

(Austin 1922; Bureau of the Census 1914; Department of the Interior 1895; Powers 1902; Robinson 1905; Scott 1915).

Mules were also used as prime movers on some Union County farms during the draft horse epoch. The county mule population averaged 435 mules annually, when added to the total number of horses of all ages, the mean total draft animal herd was 9,609. This total includes all horses on farms, including horses and mules used for riding. Draft animal labor estimates applied to corn production in the energy budget were derived from economic data for corn production practices (Appendix B; Appendix C; Appendix D; Appendix E; Appendix F; Appendix G).

Feed for the draft animal herd was raised on the same farms they worked. This meant that farmland was used as an energy source to power the field operations necessary for successful crop production. This energy feedstock system worked in the Corn Belt because the same crops that provided draft horse feed were also fed to sheep, cattle, and hogs. Therefore, farmers could use the same line of equipment for their various crops and did not have to have a separate line of equipment to raise a specialty crop to feed their draft animals.

Common draft horse rations in the Corn Belt consisted of corn, oats, hay, and water. I averaged the amount of feed consumed by a draft horse for one average year in the study area. This included 198 days when draft animals were on concentrated feed, including grains, and 167 days when horses were idle and were maintained with fed roughages or pastured (Morrison 1936).

I modified Morrison's (1936) estimate to fit the corn grain farming system used in Union County based on various source data (Austin 1922; Bureau of the Census 1914; Department of the Interior 1895; Miller 1958; Morrison 1936; Powers 1902; Robinson 1905; Scott 1915). The calculations for this modification are shown in Appendix B. The average annual estimated draft animal feed consumption per Union County farm by crop is listed in Table 3.

Table 3. Total Draft Horse Feed Consumed per Horse

Type of Feed	Estimated Union County Draft Horse Consumption per Feedstuff in pounds (Dry Matter Basis) Pastured Time in Months
Oats, lbs	1,737
Corn, lbs	1,920
Other Concentrates, lbs (Wheat Bran)	20
Legume and Mixed Hay, lbs (Timothy and Clover)	2,509
Non-Legume Hay, lbs (Timothy)	1,177
Straw and Stover (Fed during Idled Months) Wheat Straw, Oat Straw, and Corn Stover	1,820
Months on Grass Pasture (Land use)	4
Days on Corn Stalk and Stubble Pasture (Land use)	Approximately 45

(Austin 1922; Bureau of the Census 1914; Department of the Interior 1895; Miller 1958; Morrison 1936; Powers 1902; Robinson 1905; Scott 1915).

Feed grains, such as corn and oats, as well as grass and legume hays contain energy that when fed to draft horses, provided farmers with a source of motive power. The feed grains and hay raised to feed draft horses affected local cropland use because those acres were devoted to an energy crop that was not directly sold, but was converted into power used on the farm. A draft horse consumed approximately 59,000 MJ of dry matter annually (Table 4), the data analysis is shown in Appendix C.

Table 4. Annual Draft Horse Fuel Consumption per Farm in Pounds and MJ

Feedstuff	**lbs Feed/yr/Horse (Dry Matter Basis)**	**MJ/ year (Dry Matter Basis) per Horse, 767 labor hours**
Oats, lbs	1,737	9,071
Corn, lbs	1,920	12,598
Other Concentrates, lbs (Wheat Bran)	19.98	93
Legume and Mixed Hay, lbs (Timothy and Clover)	2,509	21,065
Non-Legume Hay, lbs (Timothy-region 7 Miller 1958)	1,177	10,387
Wheat Straw		
Oat Straw		
Corn Stover		
Straw and Stover, lbs total: Likely Used in Union County (Average Wheat straw, Oat Straw, and Corn Stover) (Fed during Idled Months)	1,820	5,719
Total		**58,933**

(Austin 1922; Bureau of the Census 1914; Department of the Interior 1895; Miller 1958; Morrison 1936; Powers 1902; Robinson 1905; Scott 1915).

Most Union County farms did not have a natural spring or ready access to natural surface waters to use for drinking and watering livestock. Farmers addressed the problem by digging wells to reach groundwater, however, windmill technology was needed to pump water from wells over 50 ft deep (Webb 1931). Common farm wells in Union

County average between 50 and 125 feet, with some as deep as 1,400 feet in the north half of the County (Driessen 1978).

A draft horse consumed approximately 4,380 gallons of water annually (Table 5). I calculated the energy needed to raise water 50 feet (Appendix D), which is a common depth of Union County farm wells (Driessen 1978).

Table 5. Energy Used to Pump Water for Draft Horse Consumption

Gallons of water consumed annually per draft horse	Horsepower used for pumping water	MJ of Wind Energy used to water 1 draft horse annually
4,380 gallons	55	148

(Driessen 1978; Morrison 1936; Walters 1916).

Corn is an annual grain crop, meaning that it is planted and harvested during one growing season. The time constraints of producing a corn crop from planting through harvest have pushed farmers to become more efficient.

The corn field, as an open system, is affected by both unpredictable internal and external conditions. Business researchers refer to those conditions as constraints (Qingzhen, et. al. 1991), while crop scientists call them "yield limiting factors" (Thomison, et.al. 2005), and agricultural economists refer to them as the "cost of crop production" (Duffy 2011).

Farmers are most concerned with maximizing profits by producing the most corn per acre with the least amount of inputs and lowest cost. Ernest Mueller, in a 1906 speech to the Madison County, Iowa Farmer's Institute stated that the best way to study the production of a bushel of corn is to closely follow the “routine of raising corn,” (Mueller 1906).

Mueller (1906) described corn production as a ‘routine.’ This introduced the idea that corn farming itself was an incremental production system. Mueller (1906) listed each step that Madison County, Iowa farmers had to perform throughout the growing season (Table 6). The methods of corn production that were used in the Iowa counties of Buena Vista, Iowa, and Linn are also listed in Table 6.

Table 6. The Production Methods of Raising Corn in Iowa in 1906 and 1911

Madison County (1906)	**Buena Vista County (1911)**	**Iowa County (1911)**	**Linn County (1911)**
Rent	40 Acre Basis	40 acres sod Plowed (1906)	20 acres corn stalk ground
Breaking stalks	Hauling Manure	9 loads of manure per acre	
Raking and Burning	Breaking Stalks with Harrow	Plowing sod	Discing 2 times
Discing before plowing	Plowing (2 ½) acres per day	Discing 3 times	Plowed
Plowing	Harrowing twice before planting (20 acres per day)	Harrowing 4 times	Harrow 6 times
Discing after plowing	Planting 10 acres/day	Planting	Planting
Harrowing	Cultivating (6 acres per day), 3 times over	Seed corn	Cultivated 4 times
Seed	Rainy days, breakdowns, probable discing	Cultivating 5 times	
Planting	Seed Corn		Tested Seed Corn
Harrowing			
Cultivating	Tools (Planter, harrow, cultivator, and plow)		
	Manure spreader		
Husking	Husking (3.5 cents per bushel)	Husking 70 bushels/ acre	Picking and cribbing

(Bowman and Crossley 1911; Mueller 1906).

These production methods were the farm operator's answer to managing the yield-limiting factors of soil fertility, weed pressure, insect pests, and diseases (Barker et. al. 2005). Table 6 shows some of the local variation in corn production management, while similarities include the major practices of plowing, seedbed preparation, planting, cultivating, and harvesting. Figure 17. shows the four counties in Table 6 in relation to the study area of Union County, SD.

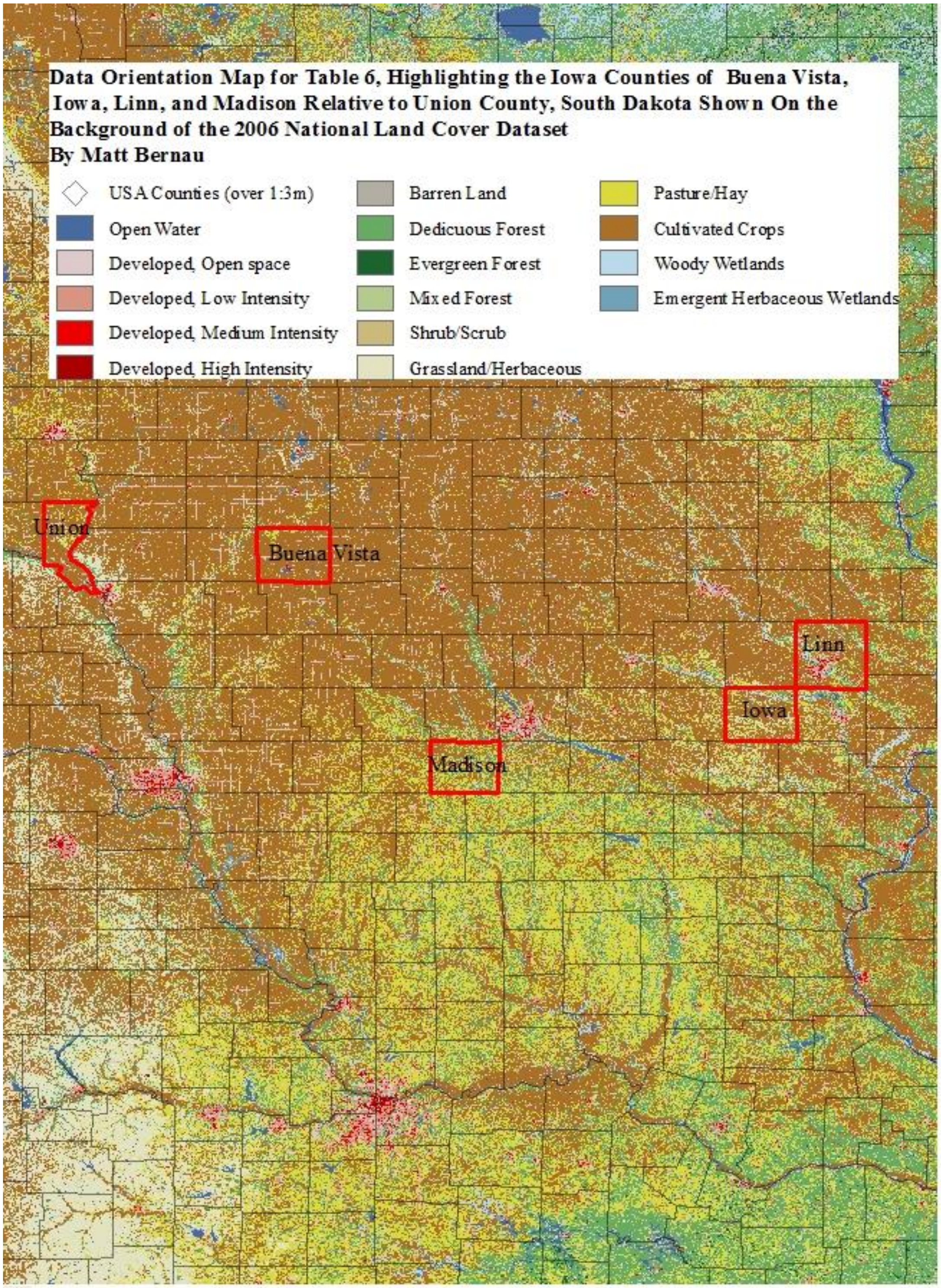


Figure 17. Data Orientation Map For Table 6
(National Land Cover Dataset 2006, Accessed August 15, 2013; ESRI ArcGIS Data Download USA Counties (Accessed August 15, 2013)).

The total amount of labor needed to produce an acre of corn during the draft horse epoch was approximately 23 human hours and 53 horse labor hours (Table 7). I calculated the amount of labor required to apply manure from data reported in Billings (1917), the data is shown in Appendix E, and Tables 1 and 2.

Table 7. Estimated Union County Draft Horse Labor per Acre of Corn Production (Estimated total labor hours rounded to the nearest whole number)

Union County Corn Production (Basis of 1 corn Acre, assume 10 hour day)	Number of Horses	Number of People	Operating Hours per Corn Acre Per Person	Total Horse Labor Hours per Corn Acre
Applying Manure	3	1	1.5	4.5
Breaking stalks with harrow	3	1	0.5	1.5
Plowing 2 1/2 acres/day	3	1	4	12
Harrowing twice before planting (20 acres/day)	3	1	1	3
Planting (10 acres per day)	2	1	1	2
Cultivating (6 acres per day), 3 times over	2	1	5	10
rainy days, breakdowns, and probable discing	3	1	1.5	4.5
Total Pre-Harvest Labor Hours			**14.5**	**37.5**
Husking and Cribbing (Harvest and storage)	2	1	8.19	15.22
Total Labor Hours			**23**	**53**

(Data compiled from various accounts published in Billings 1917; and Bowman and Crossley 1911).

A typical farm work day was 10 hours long (Bowman and Crossley 1911). Each acre of corn required a total of approximately 2 human labor days and 5 horse labor days to produce. The draft horse ration consisted of crops raised on Union County farms. I converted the amount of feed energy consumed by draft horses from pounds of feed to MJ per acre of corn produced (Table 8; Appendix F).

Table 8. Draft Horse Energy Consumption used to Produce One Acre of Corn

Draft Horse Fuel by Crop (1 Horse)	Draft Horse Feed per Crop in Pounds per corn acre (as fed Basis)	MJ of Feed Input per Union County Corn Acre (Dry Matter Basis)
Oats	52	242
Corn	57	335
Concentrates (Wheat Bran)	0.6	2.5
Legume and Mixed Hay (Timothy and Clover)	77	561
Non-Legume Hay (Timothy)	36	277
(Average Wheat straw, Oat Straw, and Corn Stover) (Fed during Idled Months)	69	181
Total MJ/Corn Acre		**1,599**

(Bowman and Crossley 1911; Driessen 1978; Miller 1958; Morrison 1936; Myrick 1904; Walters 1916).

The amount of energy needed to feed draft animals represented a local land use that expanded or contracted based on the harvested yield per acre of each feedstuff and the size of the draft animal herd. The crops raised during the draft horse epoch depended upon the inputs of livestock manures, mechanical weed control, and crop rotation, even with the inclusion of iron and steel field implements, the crop yields were largely renewable (Table 10). About 10,000 Union County acres were devoted to raising crops to feed the draft animal herd (Table 9).

Table 9. Union County Cropland Used to Produce Draft Horse Energy for Corn Production: Average (1890-1920)

Draft Horse Feed by Crop	Draft Horse Fuel per Crop in pounds per corn acre (As fed Basis)	Average Union County Yield per crop in pounds per Acre	Required Land Use to support Draft animal feed to raise one corn Acre (Acres)	Land used to raise draft horse feed per farm (Acres)	Total Union County Cropland Used to raise Draft Animal feed (Acres to support corn production)
Oats	52	950	0.05	3.1	4,587
Corn	57	2,051	0.03	1.6	2,349
Concentrates (Wheat Bran)	0.6	NA	NA	NA	NA
Legume and Mixed Hay (Timothy and Clover)	77	3,300	0.02	1.3	1,952
Non-Legume Hay (Timothy)	36	2,840	0.013	0.7	1,070
Average Wheat straw, Oat Straw, and Corn Stover (Fed during Idled Months)	69	Not Reported	Not Reported	Not Reported	Not Reported
Total Acres					**9,958**

(Austin 1922; Bowman and Crossley 1911; Bureau of the Census 1914; Department of the Interior 1895; Miller 1958; Morrison 1936; Myrick 1904; Powers 1902; Robinson 1905; Scott 1915).

Union County averaged 83,142 acres of corn between 1890 and 1920, comprising approximately 37% of the improved land in farms during the draft horse epoch. This is close to the land cover estimate of John Fraser Hart, who found that “In 1920 only two-fifths (40%) of the cropland in four Corn Belt states was used for corn” (Hart 1986, 61).

The 9,958 acres used to produce draft horse feed were only the acres required to feed the horse teams when working the corn acres. Additional acres of crops were used to feed the draft animals when their labor was used to raise other crops, including hay, wheat, and barley. Corn production is the focus of this study; therefore, I did not include the amount of feed that draft animals consumed when producing crops other than corn in the energy analysis.

The amount of energy needed to produce an acre of corn in the study area during the draft horse epoch was more than 6,000 MJ (Table 10). I placed individual inputs into renewable or non-renewable resource categories. Solar energy was left out of the calculation because it isn’t a yield limiting factor (Transeau 1926).

Table 10. Energy Budget Analysis for Union County Corn Production: 1890-1920

Inputs	Input Amount per Corn Acre	Total Energy Inputs per corn acre (MJ)	Renewable Inputs per Acre (MJ)	Non-Renewable Inputs per Acre (MJ)
Windmill Pumped Water	63 Gallons of draft animal drinking water	2	2	
Machinery (MJ)	107	107		107
Fertilizer Application	4.5 Horse labor hours	137	137	
Fertilizer (Manure tons/acre)	2.16 tons			
Nitrogen	21.6 pounds			
Phosphorus	4.75 pounds			
Potassium	17.9 pounds			
Mixed Manure (Dry Matter Basis) (Appendix H)	648 pounds of applied manure (dry matter)	4,419	4,419	
Seedbed Preparation	16.5 horse labor hours	500	500	
Corn Seeds per Acre (Appendix I)	8.4 pounds	49	49	
Planting	2 Horse labor hours	61	61	
Cultivating	10 Horse labor hours	303	303	
Overhead (Rainy days, breakdowns, probable discing)	4.5 Horse labor hours	137	137	
Harvest	15.22 Horse labor hours	462	462	
Drying (solar and wind)	NA	NA		
Human labor hours (not included in budget total)	23			
Total Inputs (MJ per corn acre)		**6,177**	**6,071**	**107**
Percent Renewable and Non-Renewable Inputs			**98.3**	**1.7**
Renewable: Non Renewable Energy input ratio	**56.7:1**			
Corn grain yield (bushels per acre) (5.84 MJ per pound of corn)	36.2 bushels per acre (56 bushels per acre)	**11,976**		
Total input/output ratio	**1.95**			

(Austin 1922; Billings 1920; Bowman and Crossley 1911; Bureau of the Census 1914; Department of the Interior 1895; Driessen 1978; Iowa Yearbook of Agriculture 1906; Miller 1958; Morrison 1936; Myrick 1904; Pimentel and Pimentel 1996; Powers 1902; Robinson 1905; Smil, Nachman and Long 1983; Stout 1979; Third Census of the State of South Dakota 1915; U.S. Yearbook of Agriculture 1921; Victoryseeds.com Accessed April 25, 2010; Walters 1916).

Corn production was 98% renewable during the draft horse epoch (Table 10). While the approximately remaining 2% of energy inputs used in corn production were imported to Union County in the form of machinery. The number of farms increased as did the number of improved acres. Union County corn production data was not available in the literature. I adapted both national and regional information from area corn production budgets to Union County conditions. Farm management of crop pests including weeds, insects, and diseases was largely mechanical, and included tillage practices, and crop rotation.

Draft Horse Epoch Conclusion

There are several implications of geographical importance to the study area. I adjusted all the relevant corn production data I found in the literature as much as possible to the Union County environmental and technological conditions. Researchers, including Pimentel and Pimentel (1996), and Smil, Nachman, and Long II (1983), used national data to reach their conclusions regarding the energy required to produce an average acre of corn in the United States.

This thesis provides a baseline energy analysis of the historic corn production practices employed in Union County, SD. I studied the local energy flows of corn production in order to measure the changes in system sustainability over time. The years of 1920-1950, and 1950-1980 were technological bridges that led to the modern methods of corn production in the Corn Belt.

The Tractor Epoch: 1920-1950

Introduction: Tractor Technology and Land Use Change in Union County

> "The gasoline motor, adapted as it is to the use of fuel in the form of gasoline, kerosene, and alcohol, furnishes a source of power for both traction and stationary purposes that is at once economical, clean and safe, and is able to develop power from a fuel, the supply of which is practically inexhaustible…The farm tractor is rapidly becoming the horse that will do all the hard work" (Stephenson 1913, 7).

Several innovations were adopted by farmers during the tractor epoch in Union County, South Dakota, including farm tractors and hybrid corn. Tractor data wasn't collected for Union County until 1930 even though tractors were being used in the Corn Belt more than a decade earlier (Austin 1932; Reynoldson 1920).

The United States Department of Agriculture conducted a survey in 1920 of Corn-Belt farms in seven states, including Iowa (Reynoldson 1920). The survey showed that out of 191 Corn-Belt farmers, 141 had owned a farm tractor for at least a year (Reynoldson 1920). According to his map, Reynoldson collected data from Plymouth County, Iowa which lies directly to the east of the study area across the Big Sioux River (Map 4). Reynoldson (1920) found that the number of draft horses per farm began to decline after a farm tractor was purchased. However, even though a farmer owned a tractor, draft horses still provided "about 75% of the tractive work and tractors the remainder" (Reynoldson 1920). The work completed by horses on farms where a tractor was also used, largely consisted of corn cultivation, while the tractors were used in plowing and other heavy work (Reynoldson 1920).

The transition from draft animals to tractors in Union County accelerated during the tractor epoch (Figure 8; Table 11). The use of farm tractors resulted in a major land use change because Union County cropland was no longer needed to raise draft animal feed. Fossil fuels were imported from outside Union County for use in farm tractors, which then became the first major cropland substitute.

Table 11. Union County Prime Mover Profile: Tractor Epoch

	Union County Farms (Number)	Union County Horses and Mules on Farms	Union County Tractors on Farms	Farms Reporting
Year		Number	Number	
1920		10,289		
1930		9,027	638	622
1935		8,218		
1940		5,940	1,067	1,000
1945		4,347	1,394	1,218
1950		1,728	1,730	1,241
30-Year Average (County)	**1515**	**6,592**	**1,207**	
30-Year Average per Farm		**4.35**	**0.8**	

(Austin 1922; Austin 1932; United States Government Printing Office 1936; United States Government Printing Office 1946; United States Government Printing Office 1956).

The number of draft horses on Union County farms declined 83% between 1920 and 1950. The number of tractors on farms increased 63% from 1930 to 1950 (Table 11). The number of tractors on farms was not reported by the United States Department of Agriculture until 1930. The USDA also did not report the number of tractors on farms in the 1935 Census of Agriculture (Tostlebe 1954). Tractor usage continued to expand in Union County as more farmers took advantage of the labor-saving technology (Figure 18).

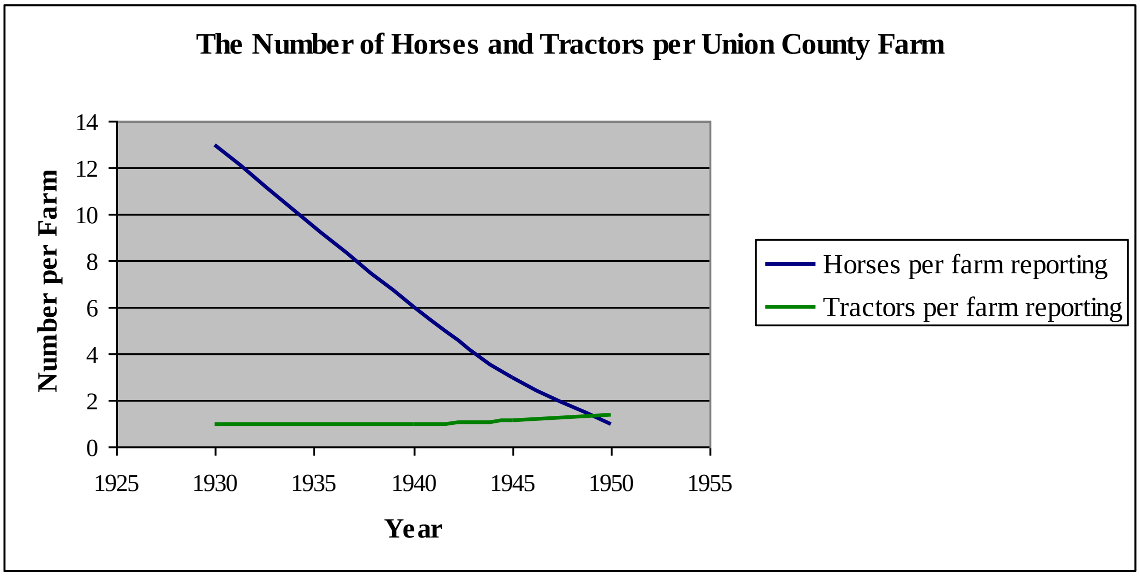


Figure 18. Union County Tractor Adoption Rate per Farm: 1920-1950

(Austin 1932; Austin 1922; Hurley 1952; United States Government Printing Office 1936; United States Government Printing Office 1946; United States Government Printing Office 1956).

Data from the University of Nebraska Tractor Test Laboratory showed that tractors used 5 types of fossil fuel during the tractor epoch, including: kerosene, gasoline, tractor fuel-distillate, diesel and liquid propane (http://tractortestlab.unl.edu/publications.htm. (Accessed 10/6/2011)). The number of tractors using each type of fuel is shown by year in order to illustrate the speed of the fuel-type transition (Figure 19). The data was also used to determine which fuel type was used the most by farmers during the tractor epoch.

A tractor fueled by kerosene was featured in a corn production study titled "Comparison of the Horse and Tractor" (Farm implement News 1916). The use of an International Harvester Mogul model 8-16 tractor was compared to the labor of an average draft horse (Farm Implement News 1916). An 8-16 tractor rating means it had 8 horsepower on the drawbar and 16 horsepower on the belt pulley (Farm Implement News

1916). I applied the data from the 1916 study to the energy budget analysis in Table 13, since it was the only one I found in the literature that compared tractor work to horse labor when producing corn prior to 1945. The 8-16 Mogul ran on kerosene, even though gasoline tractors were tested during the most years by the Nebraska Tractor Test Laboratory between 1920 and 1950, a majority of the tractors they tested before 1926 ran on kerosene (Figure 19; Nebraska Tractor Test Laboratory Accessed 10/6/2011).

Kerosene had more BTU's per gallon than gasoline or alcohol (Table 12). The conversion factors I used to convert BTU's to MJ per gallon of kerosene are listed in Appendix M.

Table 12. Fossil Fuel Energy by Type

Fuel	BTU/Lb	BTU/Gal.
Gasoline	20,462	122,770
kerosene	19,890	13,2700
alcohol	8,875	61,800

(Moyer 1914).

The type of fossil fuel used by farmers changed quickly during the tractor epoch. Tractors rapidly became more efficient as the fuel inputs changed from kerosene to gasoline, and later, diesel fuel (Figure 19).

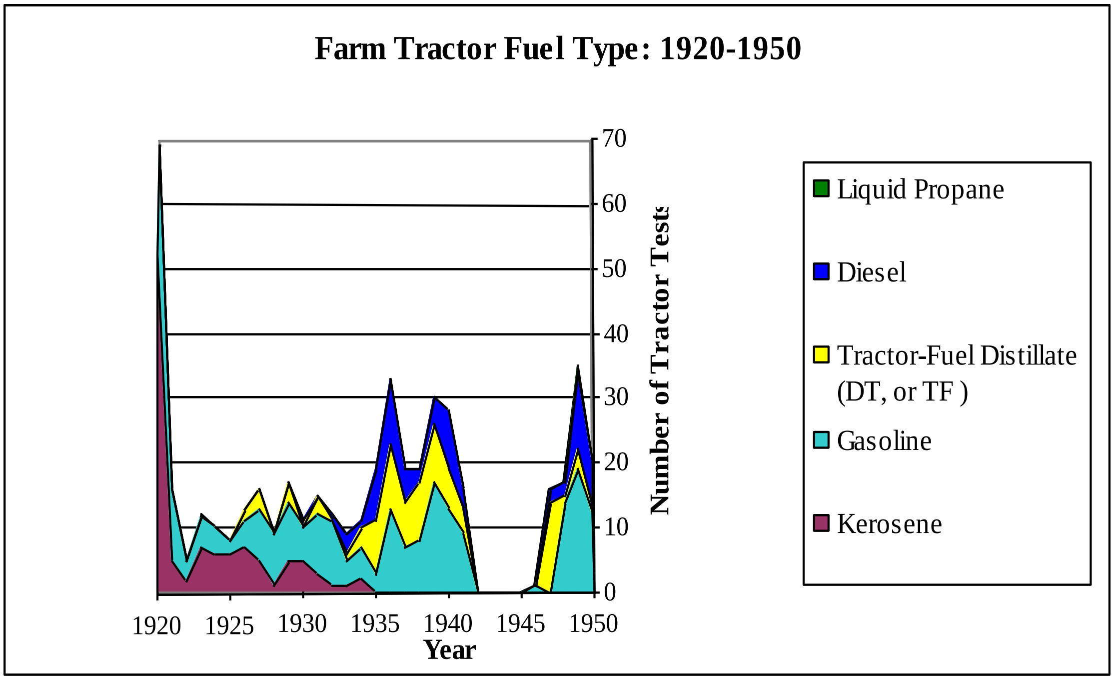


Figure 19. Tractors by Fuel Type Reported by the Nebraska Tractor Test Laboratory

The University of Nebraska did not conduct tractor tests from 1942-1945, explaining the gap in the data. (http://tractortestlab.unl.edu/publications.htm. Accessed 10/6/2011).

The number of corn acres planted in the study area increased by 40% between 1920 and 1950. The average corn yield in the study area during the tractor epoch was 35 bushels per acre. This was about 2 bushels lower than during the draft horse epoch. Climate had affected the study area during the early-mid 1930's, with rainfall being the major limiting factor for crop yields. "The drought…through the 1930's tended to desiccate most of the Great Plains and to bring extensive semiaridity to the prairie peninsula" (Borchert 1971).

The corn crop yielded about 4 bushels per acre in 1936 (South Dakota Crop and Livestock Reporting Service 1967). That was a departure from the overall average of 35 bushels per acre for the tractor epoch, and is an example of climate becoming the greatest yield limiting factor, undercutting the effects of newly introduced hybrid corn technology.

Hybrid Corn and Yield Intensification

Hybrid corn was the result of advancements in plant genetics, it was more important to corn yield increases than the farm tractor because “hybrids commonly produce yields 10% to 30% greater than the corresponding open pollinated varieties under similar circumstances” (Morrison 1947). The South Dakota Crop Improvement Association reported in 1929 that 19 varieties of hybrid corn were being grown in South Dakota test plots (Webster 1954). Hybrid corn use in Iowa increased from about 5% to 100% between 1933 and 1945 (Griliches 1960).

The logistics of producing hybrid corn made it impractical for farmers to save their own seed for planting the next year, meaning that one more input needed for corn production had to be imported to the farm. “Farmers now purchase their hybrid seed from relatively few seed growers. They do not pick seed ears from their own choice productive fields because such second-generation seed yields only an average of about 85 percent as much as first-generation seed” (Kiesselbach 1951). Hybrid corn not only yielded 20 percent more grain, but it was more resistant to pests, lodging, and drought (Kiesselbach 1951). Hybrid seeds were able to be reproduced in disparate geographical conditions including climate and soil type. For example, the variety Minnesota 13 was “identical whether the seed is produced in Nebraska, Indiana, or Missouri” (Kiesselbach 1951).

Aside from the introduction of farm tractors the convenience and reliability of hybrid corn drove the second technological transition during the tractor epoch. Farmers in the study area had been planting open-pollinated corn varieties and saving seed from their own farms to plant the next growing season, by the end of the tractor epoch in 1950, the majority of farmers in the study area were purchasing hybrid seed for planting from commercial seed producers (Griliches 1960; Webster 1954).

Tractor Epoch Energy Budget Analysis: 1920-1950

Corn producers did not substitute the tractor for all operations immediately. The corn crop was planted and cultivated using horses; and harvesting was still completed with horses. The most striking difference between the draft horse and tractor epochs was the fact that the renewable: non-renewable input ratio declined from 56.67:1 to 5:1 because fossil fuels replaced renewable draft horse feed. The overall output: input energy ratio rose from 1.95:1 to 2.14:1 mainly because of the increase in the number of MJ per pound of hybrid corn over open-pollinated varieties (Figure 20). At the same time, the average bushel of corn grain yield declined about 2 bushels per acre, mainly because of the effects of drought conditions during the 1930's.

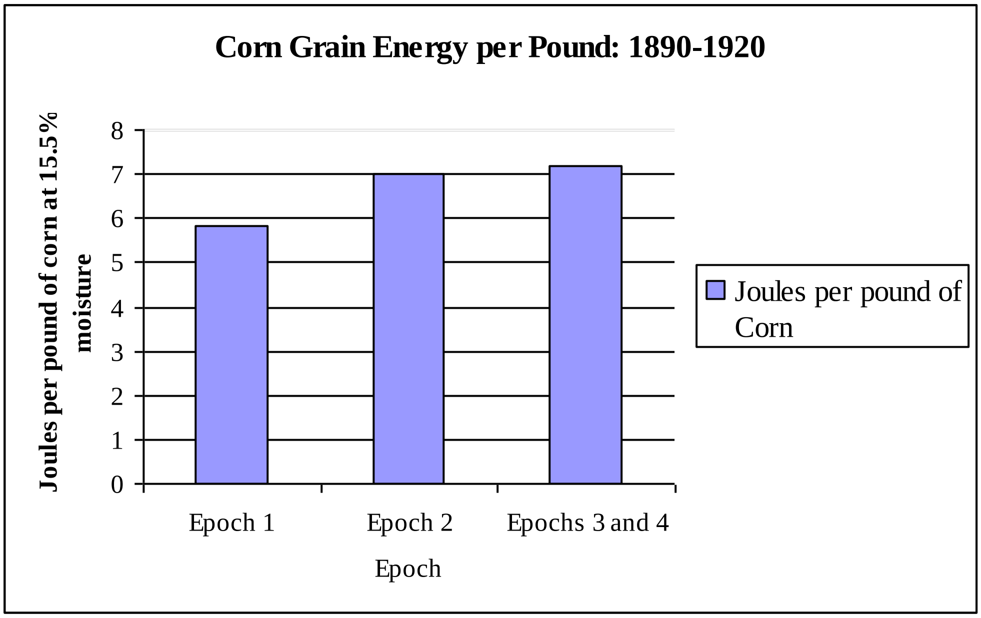


Figure 20. Change in the Amount of Corn Energy per Pound of Grain

Sources: (Myrick 1904; National Research Council 1947; National Research Council 1958).

The energy renewability of corn production during the tractor epoch exhibited a duality between renewable and non-renewable energy inputs (Table 13). Horses continued to be used for planting and cultivating because corn was still planted in hills and the tractors weren't yet set up for between-hill operation. Teams of horses also continued to be the prime movers during corn harvest operations where people still harvested the ears by hand, and especially since mechanical corn-pickers and combines were not yet reported to be used on farms (South Dakota Crop and Livestock Reporting Service 1967; Stephenson 1913; Stout 1979; United States Government Printing Office 1936; United States Government Printing Office 1946; United States Government Printing Office 1956). Other work, such as plowing, harrowing, discing, and manure spreading was done with tractors (Bowman and Crossley 1911).

Even though tractors were used, fossil energy only comprised about 16% of the total corn production energy input mix between 1920 and 1950. I used a kerosene-burning tractor for this example, although evidence shows that farmers began to use gasoline, tractor fuel distillate and diesel during the same period (Nebraska Tractor Test Laboratory, accessed 10/06/2011). Interest in electricity was making inroads to rural areas but was not reported to be distributed to Union County farms until 1945 and is not included in Table 13 (United States Government Printing Office 1956).

Table 13. Tractor Epoch Corn Production Energy Analysis including Draft Horses and Tractors	Units Per Acre	MJ per Acre	Renewable (MJ)	Non-Renewable (MJ)
Windmill Pumped Water (Appendix D)	27.2 horse labor hours	1	1	
Embodied Tractor Energy (5,000 lb. 8-16 tractor fed with kerosene fuel)	Appendix K	137		137
Implements (Same as the Draft Horse Epoch)	Appendix G	107		107
Fertilizer (Manure Tons/acre), Spread with tractor	2.16 tons	163		163
Nitrogen	10 lbs per ton			
Phosphorus	2.2 lbs P per ton			
Potassium	8.3 lbs K per ton			
Thermal Energy /equivalent dry applied manure (Total N, P, K), (Appendix K)	648 pounds of dry matter	4,419	4,419	
Plowing (8-16 tractor and 2-14 inch plows, 5.6 acres per 10 hr day)	3.1 gallons kerosene per acre	438		438
Disking and harrowing in one operation (8-16 tractor, 8 ft disk harrow w/2 section harrow, 20 acres/day)	.875 gallons per acre	122		122
Harrowing twice (8-16 Tractor, 3-section harrow, 35 acres per day)	.5 gallons per acre	70		70
Planting (Horses)	2 hrs	61	61	
Seed assumes 12,096 plants per acre (Appendix I)	8.4 pounds of seed per acre	59	59	
Cultivating-use the team and cultivator, 6 acres/day, 3 passes per season.	10 hours	303	303	
Corn Harvested from Standing Stalks with Horses	15.22 hours	462	462	
Total Inputs MJ/Corn Acre		**6,342**	**5,305**	**1,037**
Percent Renewable and Non-Renewable Inputs			84	16
Corn Renewability Factor (Renewable: Non-Renewable Input Ratio		**5:1**		
Corn Yield Bu/Acre (7.01 MJ/lb corn)	34.72	13,630		
Total Output/ Input ratio		**2.14:1**		
Total Labor per corn acre: 20 3/4 days				

(Anonymous 1918; Austin 1932; Austin 1922; Billings 1920; Bowman and Crossley 1911; Chase 1917; Farm Implement News 1916; Hurley 1952; Morrison 1936; Moyer 1914; Pimentel and Pimentel 1996; Schneider, Beeson and Lucas No Date; Smil, Nachman, and Long II 1983; South Dakota Crop and Livestock Reporting Service 1967; Stephenson 1913; Stout 1979; United States Government Printing Office 1936; United States Government Printing Office 1946; United States Government Printing Office 1956; Victoryseeds.com 2010; Walters 1916).

Farm tractors and hybrid corn weren’t the only inventions being developed for the advancement of agriculture during the tractor epoch. The national governments of Germany, Great Britain, and the United States worked to address the issue of soil fertility for decades before mined and chemically refined commercial fertilizers reached the Corn Belt after 1950 (Nelson and Parker 1990).

The Fertilizer Epoch: 1950-1980

Introduction

As early as 1300 A.D., Europe had begun to suffer from a decline in soil fertility, which diminished their food supply (Moore 2003). This prompted Europeans to expand their area of power and trade. Triggered by the voyages of Columbus, European explorers had reached the continents of North and South America, Australia, and the regions of New Zealand the Union of South Africa (Webb 1952). The consumption of trade goods from the “Great Frontier” included not only gold and silver, but food (Webb 1952). The resulting economic boom supported the population of Europe and allowed for its increased population, having reached 92 million in 1700 (Demeny 1990). The abundance of raw commodities imported to Europe supported the industrial revolution, while driving the expansion of cash-crop agriculture to Eastern Europe and the American continents (Moore 2003). It was estimated that the exploitation of the great frontier lasted 400 years, ending in approximately 1890 or 1900 (Webb 1952). The population of Western Europe rose about 320%, reaching 294 million by 1900 (Demeny 1990).

At the close of the ‘Great Frontier’ (Webb 1952), wheat was the dominant cereal grain. As such, it was coined as “the most sustaining food grain…of the peoples of Europe, United States, and British America…Australasia and parts of South America” (Crookes 1900). The farmers of the United Kingdom could only meet 25% of the nation’s wheat demand in 1899, which meant that 75% had to be imported (Crookes 1900).

Europe faced a two-pronged problem regarding their wheat supply. The expansion of wheat farming to new lands of the frontier was beginning to decrease since arable land is finite, and the lands under cultivation were losing soil fertility. Crookes (1900) noted this fact and called for an increase in wheat yields: “instead of being satisfied with an average world-yield of 12.7 bushels an acre, a moderate dressing of chemical manure would pull up the average to 20 bushels—thus postponing the day of dearth” (Crookes 1900). Producing increased yields from a fixed amount of land was possible only by amending the soil with essential plant macronutrients. These include: nitrogen, phosphorous, and potassium (Smil 2001).

The intensification of crop production in Europe between 1500 and the late nineteenth century included rotating crops, such as nitrogen-fixing legumes and applying manure to farm fields. Crop rotation and fertilizer amendments tripled wheat yields in the United Kingdom during the same period (Smil 2001). Even that yield increase wasn’t enough to make the United Kingdom able to sustainably feed its population in the event that it became cut off from international grain imports.

When studying crop yield change over time, the implications of those changes should be accounted for (Pritchard and Amthor 2005). However important it is to study the results of technological change, I think it is just as necessary to identify the drivers of those changes so that future problems can be anticipated and planned for before we are surprised. Nitrogen was identified as “the nutrient required in the largest quantity per unit of a harvested crop” (Smil 2001). At the end of the nineteenth century, the only source of plant available nitrogen that could affect agricultural outputs on a global scale was the natural store of “nitrate of soda, or Chile saltpeter” (Crookes 1900). Deposits of sodium nitrate (NaNO3) called ‘caliche’ were found in the Atacama and Tarapaca deserts of northern Chile (Lamer 1957, 44). The amount of available sodium nitrate in Chile had been the only source of fixed, or plant available nitrogen, and it was estimated that “the supply may last, possibly, fifty years, at the rate of 1,000,000 tons a year” (Crookes 1900).

The distance between mainland Germany and the nitrate resources of Chile drove the invention of a reliable source of synthetic nitrogen (Smil 2001). The natural sodium nitrate deposits in Chile were used for fertilizer as well as an input for the manufacture of explosives (Crookes 1900). Wilhelm Ostwald pointed out that foreign naval power could interrupt the imports of Chilean sodium nitrate and affect Germany’s ability to produce fertilizers and explosives (Smil 2001).

Ammonia, NH_3, “is the form all fixed nitrogen achieves and is the highest point in energy” (Gutschick 1978). Nitrogen nutrients are the only form of nitrogen that can be utilized by plants. Socolow (1999) explained that nitrogen exists molecularly in two other forms that are not plant available: N_2, or dinitrogen, is the most common form of nitrogen on Earth; however, its stability makes it an unavailable nutrient source to plant life, unless its chemical bond is broken.

There are two natural processes of nitrogen fixation in the United States: the first is biological nitrogen fixation (EPA Science Advisory Board 2011). There are two types of biological nitrogen fixation, the first occurs when N_2 is fixed by the symbiosis between rhizobial bacteria and legumes. Rhizobia are responsible for the most biological N fixed on land (Smil and Cleveland 2007). The second occurs when nitrogen bound in soil organic matter is mineralized by soil microbes (Mullen, Lenz, and Watson 2005) The second natural source of nitrogen is lightning (EPA 2011). According to EPA estimates for the U.S. in 2002, biological nitrogen fixation added 6.4 Tg N/yr and N fixation by lightning added 0.1 Tg N/yr (EPA Science Advisory Board 2011).

The earliest experimentation with commercial nitrogen production included the nitric-acid arc process and the calcium cyanamide process which both mimicked natural nitrogen fixation by lightning (Lamer 1957). Adoption of these methods on a global industrial scale was limited by their electric energy requirement. The electric arc process needed five times more energy than the calcium cyanamide process (Lamer 1957), and the calcium cyanamide process was geographically limited by access to cheap electricity (Smil 1990).

The third and most widely used way to fix atmospheric nitrogen is the synthetic ammonia process (Lamer 1957). Known as the Haber-Bosch synthesis, synthetic ammonia is produced by combining atmospheric nitrogen with hydrogen derived from "coal, coke, natural gas, or the electrolysis of water" (Lamer 1957). The Haber-Bosch synthesis occurs when "A hydrogen- nitrogen mixture reacts on the iron catalyst…at elevated temperature in the range of 400-500^0 C, and at operating pressures above one-hundred bar, and the unconverted part of the synthesis gas is recirculated after removal of the ammonia formed and replaced with fresh synthesis gas" (Appl 1997). Since Fritz Haber and Carl Bosch invented the synthetic ammonia process, there has not been a fundamental technological change in the reaction itself (Appl 1997). When discussing global production of synthetic nitrogen for fertilizer use, Smil (1990), noted that almost all modern synthetic nitrogen production is made using the Haber-Bosch synthesis and its major feedstock is natural gas (Smil 1990).

Arnulf Grubler pointed out that there are regional differences in agricultural outputs due to land productivity (Grubler 1994). The reasons for the disparity in agricultural yield outputs between production systems were caused mainly by “initial conditions, development paths pursued, and diet” (Grubler 1994, 296). He also identified that appreciable productivity gains in agricultural yields were evident in much of the world during the second half of the twentieth century, and were possible only because of the use of artificial fertilizers and higher-yielding crops (Grubler 1994).

The relationship between synthetic ammonia production and food security was identified as early as 1951 by United States Central Intelligence Agency (CIA 1951). The Central Intelligence Agency found that there are two major uses for synthetic ammonia: the first is during peacetime, for the production of nitrogenous fertilizers, and the second is the manufacture of explosives because synthetic ammonia is needed for the “manufacture of all non-atomic military explosives” (CIA 1951, 2).

The CIA noted that the synthetic ammonia production capacities of the Soviet-bloc countries were adequate for peacetime supplies in 1951, but that a relaxation of the embargo of synthetic ammonia production equipment and technology to the USSR could allow them a large enough surplus to have the ability to stockpile “explosives and food for the military forces” (CIA 1951, 9). Aside from the CIA’s observation that a direct linkage between synthetic ammonia production and a nation’s ability to stockpile food exists, Smil and Cleveland (2007) also noted that the Haber-Bosch synthesis removed the natural limits for nitrogen inputs into food production and allowed the global human population to expand because of adequate nutrition (CIA 1951, 2, 9; Smil and Cleveland 2007).

The Haber-Bosch synthesis enabled the transfer of energy from fossil fuels and mineral resources to plant available nutrients in the form of fertilizer, and then to food energy consumable by people. This drove the increased rate of crop land productivity after 1944, and it was surmised that for the first time in known history, the output of the agricultural sector climbed above the glass ceiling of the Earth's carrying capacity for humanity (Grubler 1994). "The question of what the ultimate carrying capacity of Planet Earth may be (eventually) is not the issue" (Grubler 1994, 325). The real question, as asked by Grubler (1994) was "whether humankind…will develop appropriate technologies to feed, house, and employ whatever level of global population will materialize" (Grubler 1994, 325).

Introduction to Fertilizer Use in Union County (1950-1980)

"South Dakota cannot produce cereals without depleting soils. The seriousness of such fact from the standpoint of farming and civilization cannot be overestimated" (Webster 1954, 18). The South Dakota Crop Improvement Association found that the limiting factor of increased crop production from the application of phosphates and limestone was the cost of rail transport (Webster 1954). The challenge of distance between the nodes of ammonia fertilizer production and Corn Belt farms was met by the United States fertilizer industry after WWII.

Synthetic ammonia plant expansion in the United States during the 1950's was driven by production goals set by the Federal government (Journal of Agriculture and Food Chemistry 1954). The Government issued certificates for write-offs of new plant construction to meet the production goal of 3.5 million tons set for early 1957 (Journal of Agriculture and Food Chemistry 1954).

The transportation of anhydrous ammonia from plants on the Gulf coast to mid-American farms was made economical by 800-ton capacity barges that traversed the Mississippi (Journal of Agriculture and Food Chemistry 1956). Anhydrous Ammonia producers such as Mid-South Chemical Company built break-in-bulk points where barges were offloaded onto rail cars and trucks for shipment to farm distributors (Journal of Agriculture and Food Chemistry 1956).

Union County fertilizer application rates rose by 78% between 1954 and 1974 (Table 14). The only year the use of commercial fertilizer on farms was reported for corn acres in Union County was in 1954. Whereas, 505 Union County farmers applied 2,068 tons of commercial fertilizers on 20,800 acres of corn (United States Government Printing Office 1956). This means that on average, 199 pounds of commercial fertilizer was applied per corn acre in Union County in 1954. It should be noted that the total average of 199 pounds of fertilizer per acre includes not only nitrogen, but probable applications of K_20 (potassium) and P_20_5 (phosphorous), as well (Brady and Weil 1996).

Table 14

Commercial Fertilizer Distribution in Union County from 1950-1978				
Year	1954	1969	1974	1978
Number of Farms	646	592	609	549
Acres on Which Used	39,347	82,048	122,395	125,418
Tons	3,632	8,749	14,330	
Pounds per Acre Applied	185	213	234	

Sources: (Bureau of the Census 1984; Bureau of the Census 1977; United States Government Printing Office 1967; United States Government Printing Office 1956).

The Union County commercial fertilizer application rate measured in pounds per acre in the study area increased by 26% from 1954 to 1974. The number of acres receiving commercial fertilizer increased 211% between 1954 and 1974. The total average amount of commercial fertilizer applied per acre was 210.62 lbs/acre (Table 14).

The primary energy inputs for corn production during the fertilizer epoch were A): Sunlight and B): Fossil Fuels. Sunlight is needed for photosynthesis, while fossil fuels were used for commercial fertilizer production and to power farm machinery. "If fertilizers are used, they become part of the cost of production…If the fertilizers are derived from fossil sources (e.g. natural gas) then the gains of sustainability become partially compromised" (Cassedy 2000, 79).

Corn Production in Union County during the Fertilizer Epoch (1950-1980)

Harvest technology dramatically changed farm labor activities in corn grain farming in the Western Corn Belt after 1900, but the adoption rate of the mechanical corn-picker was relatively slow. Patents on corn harvesting machinery exist as far back as the 1850's, but only about 3,000 corn picker-huskers were produced in 1920 (Bogue 1983). Most of these mechanical corn pickers were horse-drawn; in 1927 a member of the press reported that approximately half of the corn crop in Northwestern Iowa Counties was harvested by farmers using this technology (Bogue 1983). Data on corn pickers wasn't reported by the United States Department of Agriculture until 1950 (Hurley 1952).

Reynold Wik (1980), made a similar observation when writing about the combined harvester. He noted that Midwestern farmers were isolated from the mechanical innovations taking place in other states. Given that the combine was developed in California during the 1870's, combines were not used in South Dakota before 1925 (Wik 1980). There was one important fact about combine use in the

Midwest; many believed that combines couldn’t be used there successfully because the grain didn’t dry quickly enough in the field (Wik 1980).

When farmers used a mechanical corn-picker to harvest their crop, the resultant product was a corn cob with kernels still attached (Bogue 1983). Corn drying technology did not change during the draft-horse and tractor epochs in the Corn Belt. Corn grain was dried on the ear after being loaded into an on-farm corn crib built out of wood with slats that allowed for natural airflow through compartmentalized stacks of grain on the cob to facilitate drying (Hart 1986).

There were 797 corn-pickers and 326 grain combines on farms in Union County in 1950. The ability to harvest shelled grain created the need for artificial drying. Corn cribs were replaced by cylindrical bins made of corrugated steel that generally had an internal drying mechanism that allowed the grain to be dried while in storage (Hart 1986).

Corn grain needs to be stored at 13-14% moisture content (Smil, Nachman and Long II 1983). Grain drying technology during the fertilizer epoch underwent an energy transition which included a switch from the sustainable method of solar-driven natural air drying, to three fossil fueled methods. Those were “high temperature and high-air-flow dryers; medium-temperature and medium-air-flow in-storage bin drying; and low-temperature in-bin drying (Smil, Nachman and Long II 1983). County level data for the adoption of grain dryers or bins is not available for Union County. However, the rate of change in the number of on farm corn-pickers when compared to that of grain combines is a good indicator of grain bin and dryer use (Figure 21).

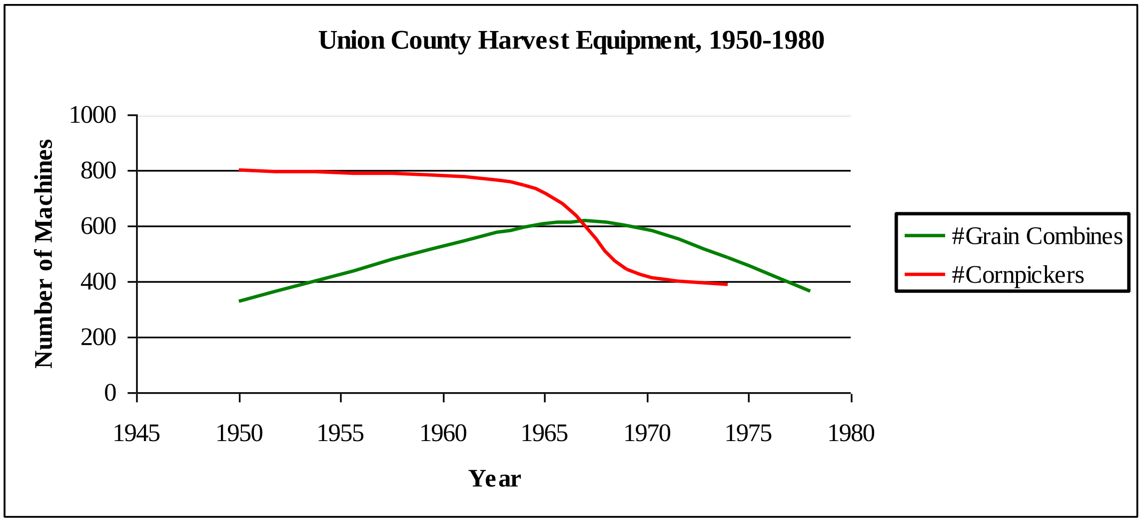


Figure 21. Harvest Equipment Use, 1950-1980

Sources: (Bureau of the Census 1984; Bureau of the Census 1977; United States Government Printing Office 1967; United States Government Printing Office 1956).

The data available from the Bureau of the Census (1977) for 1974 listed grain combines differently than the other Census data years in the fertilizer epoch. The 1974 survey reported the numbers of grain and bean combines, self propelled as well as “other cornpickers and picker-shellers” (Bureau of the Census 1977). The result of the change in data definition resulted in fewer farms reporting self-propelled combines for 1974, as well as fewer farms reporting combines (Bureau of the Census 1977). However, 539 farms had an inventory of 600 corn heads for combines in 1969 (Bureau of the Census 1977). Therefore, I left out the number of self-propelled combines reported for the 1974 Census of Agriculture and took an average of the farms reporting and number of combines on farms for the years 1969 and 1978 (Figure 21).

The changes in tractor technology available to Union County farmers during the fertilizer epoch drove the changes in fuel type used for corn production. This was important because there are differences in the amount of energy when considering gasoline, liquid propane, kerosene, and diesel fuel (Figure 22).

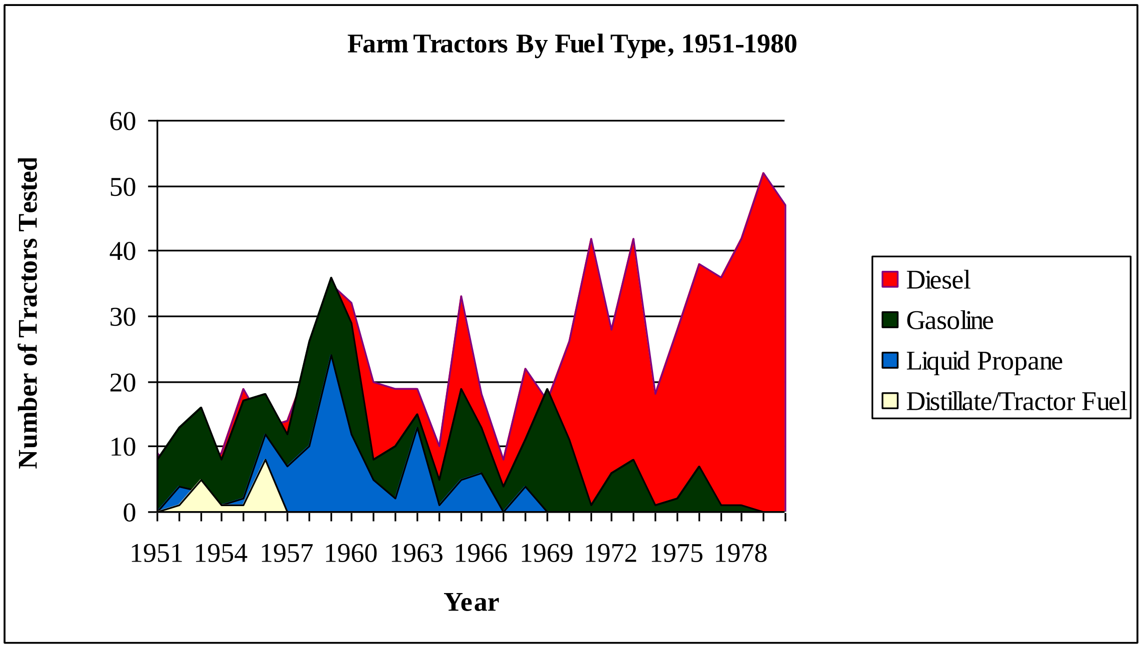


Figure 22. Farm Tractor Numbers by Fuel Type, 1951-1980

Source: Nebraska Tractor Test Laboratory, accessed 10/06/2011. (http://tractortestlab.unl.edu/publications.htm).

The data from the Nebraska Tractor Test laboratory showed that after 1980, all tractors submitted for testing were powered by diesel fuel (Nebraska Tractor Test Laboratory. Accessed 10/06/2011). This affected the energy efficiency of corn production because the "replacement of gasoline-fueled tractors, combines, and trucks by diesel-fueled ones reduced energy consumption by an average of 21 percent for identical tasks" (Smil, Nachman, and Long II 1983).

Another major change in corn production was the advancement of planting techniques. The departure from draft horse technology meant that no longer did corn for grain have to be planted in hills on a 40x40 inch grid, resulting in a population of 10,000-11,000 plants per acre. Now, corn plants could be set closer together in rows (Smil, Nachman, and Long II 1983). The corn plant population increased 66% per acre between 1945 and 1974, assuming an average of 1440 seeds per pound (Smil, Nachman and Long II 1983). This increase in plant population allowed for a higher yielding crop per acre, largely thanks to genetic improvements by the seed corn industry to perfect hybrids that could produce grain in spite of crowded conditions (Smil, Nachman, and Long II 1983). As the number of corn plants per acre increased, the fertilizer epoch brought an average 2% decline in corn acres per farm as compared to the tractor-epoch (Tables 13, 16).

Farm operators in the study area continued to adjust their field operations when new technologies became available. Major advancements after 1950 included chemical applications to control insect and weed infestations in addition to fertilizer amendments (Pimentel and Pimentel 1996, Smil, Nachman and Long II 1983). Even though herbicides were available, farmers still mechanically controlled weeds between the rows with cultivation, and treated the weeds within the rows with herbicide applications.

The difference in energy efficiency due to farm location within the Corn Belt is illustrated by the estimated amounts of diesel fuel burned during field operations in the Corn Belt from three studies (Table 15). This data shows the common field operations used in different areas of the Corn Belt: with Aldrich, Scott and Leng’s (1975) data from Illinois, and Griffith and Parsons (1983) study, “Energy Requirements for Various Tillage-Planting Systems” looked at Indiana corn production, and the data reported by the South Dakota Office of Energy Policy (1981) originated from Iowa State University.

Table 15. Field Operations in Corn Production and Gallons of Diesel Fuel Consumed per Corn Acre (1950-1980)

	Aldrich, Scott, and Leng (1975) Gallons of Diesel Fuel/Acre	Griffith and Parsons (1983) **Moderate Draft Soils**	SD Office of Energy Policy (1981)	SD Office of Energy Policy (1981)
Conventional tillage		Gallons Diesel/acre		
Shred Cornstalks		0.75	0.6	
Disk Stalks	0.43	0.45	0.45	
Moldboard plow	1.75	1.85	1.9	
Chisel plow	0			
Disk	0.51	0.55	0.65	
Apply NH3	0.36	0.7	0.55	(NH3 30 in rows)
Field Cultivate	0.43	0.6	0.75	
Plant	0.32	0.5	0.5	Planter w/fertilizer attachment
Apply herbicide (listed as no-till)	0.3			
Spray Fertilizer		0.2		
Spray Pesticides		0.15	0.07	Trailer type sprayer
Rotary Hoe	0.24	0.25	0.15	
Cultivate	0.32	0.35	0.45	(Sweep Cultivator)
Harvest	1.1		1.6	Corn Combine
Total	**5.76**	**6.35**	**7.67**	

(Aldrich, Scott, and Leng 1975; Griffith and Parsons 1983; South Dakota Office of Energy Policy 1981).

The total gallons of diesel fuel per acre varied by 1.91 gallons, or 33% between the high and low energy use estimates (Table 15). Given that the available mix of tractors during the fertilizer epoch burned gasoline, diesel fuel, and liquid propane, I included an estimate of the amount of energy used per corn acre using a mix of those three fuels Smil, Nachman and Long II). Smil, Nachman and Long II (1983) presented the inputs used in an acre of corn production in the Corn Belt in different ways. I based the data analysis (Table 16) on the fertilizer inputs, manure inputs, and pounds of machinery used per acre, averaging their estimates for the years 1950-1974 (Smil, Nachman and Long II 1983).

A table titled, “Estimated Inputs and Variable Costs for Grain Corn in North Central and West Central Iowa in 1970”, (Smil, Nachman and Long II 1983), was the basis for the seed and lime inputs (Appendix N; Table 16). Another table titled, “Energy Analysis of U.S. Corn Production 1974” (Smil, Nachman and Long II 1983), was the basis for the herbicide, insecticide, and drying energy variables in my analysis (Appendix N). Smil, Nachman and Long II (1983) also reported energy inputs for irrigation and transport in their analysis. I did not include irrigation data for the fertilizer epoch because USDA figures for irrigated corn acres were not available for the study area until after 1980. I chose not to include the energy for transport because that is outside of the organizational boundary for this study.

Electricity had reached 1341 Union County farms by 1950 (US Government Printing Office 1954). I calculated the average amount of electricity used per corn acre from Pimentel et. al. (1973) by averaging their numbers for the electricity energy input for corn production for the years 1950-1970. The electricity used by farmers for corn production in the study area is 30% renewable because of the hydropower on the Missouri River, the remaining 70% of East River Electric Cooperative’s energy is purchased from Basin Electric (http://www.eastriver.coop/energy/powersupply.htm, Accessed January 30, 2012). Basin Electric traditionally generates electricity from coal, fuel oil, and natural gas, however; during the past 20 years, 16% of Basin Electric’s generation capacity is from renewable resources, such as recovered energy, wind, and biogas (http://www.eastriver.coop/energy/powersupply.htm, Accessed January 30, 2012).

Union County farmers have been concerned about increasing the corn yield per acre over time. The draft horse and tractor epochs had average yields of 36.6, and 34.7 respectively, while the average acre yield of the fertilizer epoch increased to 57.2 bushels per acre. The yield increases were due to several factors, including changes in planting technology, the use of herbicides and pesticides for better weed and insect control, and the application of commercial fertilizer.

There was a slight increase in the amount of energy contained in a pound of corn. The total MJ/lb of corn during the tractor epoch was 7, with 7.17 MJ/lb reported for the year 1958 by the National Research Council (1958). This increase could be due to better plant nutrition, plant genetics, sampling techniques, or environmental factors. The use of nonrenewable inputs surpassed renewable inputs during the fertilizer epoch by 60% (Table 16). The average Union County corn yield increased about 61% when compared to the tractor epoch.

Table 16. Fertilizer Epoch Energy Budget Analysis 1950-1980	Units/Acre	MJ/Acre	MJ/Acre Renewable	MJ/Acre Non-Renewable
Prime Mover	Tractor and Combine			
Implements and Equipment	25.74 pounds	995		995
Manure	1.59 Tons	3,252	3,252	
—Nitrogen (Manure)	15.9 Pounds			
—Phosphorous (Manure)	3.5 Pounds			
—Potassium (Manure)	13.19 Pounds			
Nitrogen (Commercial)	50.8 Pounds	1,388.4		1,388.4
Phosphorous (P2O5)	30 Pounds	300		300
Potassium (K2O)	48 Pounds	152.64		152.64

Lime	0.15 Tons	27.9		27.9
Seeds/Acre	20,966 seeds = 14.56 Pounds	75.27	75.27	
Herbicides	1.65 Pounds	165		165
Insecticides	0.308 Pounds	31		31
Fuel (Mix Gasoline, LP, and Diesel Fuel) (All Operations)	1,526 MJ	1,526		1,526
Drying	LPG	809		809
Electricity (Hydroelectric and fossil)	675.29 MJ	675.29	202.59	472.7
Labor	Hours			
Total Inputs MJ/Corn Acre		**9,397.29**	**3,529.86**	**5,867.64**
Percent Renewable and Non-Renewable Inputs			37.56	62.44
Corn Renewability Factor (Renewable: Non-Renewable Input Ratio)		.60:1		
Corn Yield Bu/Acre (7.17 MJ/lb corn)	57.21 Bushels	**2,2971**		
Total Output/Input ratio (MJ)		2.44:1		

Sources (Aldrich, Scott and Leng 1975; Energy Information Administration 2011; Morrison 1936; Bureau of the Census 1984; Bureau of the Census 1977; US Government Printing Office 1967; US Government Printing Office 1956; Pimentel et.al. 1973; Smil, Nachman and Long II 1983; South Dakota Crop and Livestock Reporting Service 1967).

The renewable to nonrenewable energy input ratio was .60 MJ worth of renewable inputs for every MJ of non-renewable inputs. The total energy input/output ratio for the fertilizer epoch was 2.44, up from 2.17 during the tractor epoch, and 1.95 in the draft horse epoch.

Corn production became more efficient over time when farmers adopted technologies and inputs from non-renewable resources, which in-turn changed applicable cultural practices. Mechanization and fossil fuel usage lowered labor requirements, and by 1950 were used on 100% of corn production field operations.

The increase in land productivity per acre during the fertilizer epoch in the Corn Belt was unprecedented in world history. Researchers have determined that it wasn't until after 1950 that agricultural land productivity increased faster than the rate of human population growth (Grubler 1994).

Introduction to the Biotechnology and Precision Agriculture Epoch: (1980-2010)

The 2011 South Dakota Corn Yield winner was a Union County farmer, who produced a conventionally tilled, non-irrigated corn grain yield of 266.52 bushels per acre, he also raised the highest yielding corn crop in South Dakota in 2010, at 266.88 bushels per acre (http://www.sdcorn.org/documents/publications/2011SDcycResults.pdf, Accessed February 4, 2012). The second highest South Dakota Corn Yield Contest winner, also from Union County raised a 255.66 bushel per acre crop in 2011 (http://www.ncga.com/uploads/useruploads/ncyc2010.pdf, Accessed February 4, 2012). The first and second place winners planted an average of 35,250 plants per acre with the winner using Pioneer hybrid 34F07, HX1LLRR2, while the second place contestant planted a DeKalb hybrid, DKC59-35 (http://www.ncga.com/uploads/useruploads/ncyc2010.pdf, Accessed February 4, 2012).

The acronym for Pioneer hybrid 34F07, HX1LLRR2 means that the seed has added genetic traits from applied biotechnology. These include strengths such as "stalk and root strength, stress emergence, drought tolerance and resistance to anthracnose stalk rot, gray leaf spot, and northern leaf blight (Pioneer.com Accessed February 16, 2012). The second part of the acronym, HX1LLRR2, is dissected so that HX1 stands for the Herculex® I Insect Protection Gene "which provides protection against European Corn Borer, southwestern corn borer, black cutworm, fall armyworm, western bean cutworm, lesser corn stalk borer, sugarcane borer, and suppresses corn earworm" (Pioneer.com Accessed February 16, 2012). The LL stands for gene resistance to the herbicide Ignite; while the RR2 stands for the Roundup Ready Corn 2 gene and that the crop is resistant to applications of Roundup herbicide (Pioneer.com Accessed February 16, 2012).

The acronyms for corn hybrid seeds are company specific. The DeKalb DKC59-35 hybrid contains the VT3 trait. The Asgrowanddekalb.com website (Accessed February 16, 2012), has a trait selection program where farmers can pick the biotechnology gene traits they want to use on their farm, and the results will give them several hybrid choices. The VT3 trait means the crop is a 109-day maturity corn that is suited to a medium to high planting rate, and has very good seedling growth, excellent root strength, very good stalk strength, greensnap, harvest appearance, dry down, and test weight (DeKalb 2010). The VT3 trait designation also means the crop has genetic resistance to the following diseases: Northern Corn Leaf Blight, Southern Corn Leaf Blight, Gray Leaf Spot, Eye Spot, Common Rust, Southern Rust, Anthracnose Leaf Blight, Anthracnose Stalk Rot, Stewart's Leaf Blight, and Goss's Wilt (DeKalb 2010). The hybrid is also resistant to herbicide family types including growth regulators, sulfonylureas, and isoxasoles (DeKalb 2010).

Researchers have estimated that the average yield increase of the United States corn crop due to biotechnology for the 2006 crop year was 5% (Brookes et. al. 2010). However, that does not mean that the crop needs 5% less fertilizer; the gene manipulation of biotechnology raised the pest and disease resistance of corn plants.

Biotechnology is produced by laboratory scientists for sale to the end user. Precision agriculture is a technology that is practiced on farms in the study area. Also known as site specific farming, precision agriculture uses "spatial information technology such as the global positioning system and geographic information systems to make precise management decisions in cropping systems" (Koch and Khosla 2003).

Precision technology seems to be in its adoption era at present. The U.S. Economic Research Service has reported that yield monitors have been adopted by 40-45% of corn grain farmers while the use of variable rate application technology by the same farmers was only 12% (Schimmelpfennig and Ebel 2011). Meanwhile, the adoption rate of biotech corn seed by U.S. farmers was 88% in 2011 (Cornejo 2011).

Union County Corn Production: 1980-2010

Manure application in the Corn Belt changed as the specialization of farms increased. Available data for the percentage of United States corn acres in the top 10 producing states that received a manure application in 1987 was 16%, and by 1995, manure applications had fallen to 14% (Anderson and Magleby 1997).

Corn acres receiving manure were down to 11.6% by 2005 (Macdonald et.al. 2009). The specialization of Corn Belt farms can be attributed to the adoptive expansion of commercial fertilizer use. External input use allowed for the geographical decoupling of livestock as a necessary part of the value-added process, and the farmers no longer had to rely on livestock sales for the majority of their income.

Soybeans took the place of livestock on many cash grain farms in the Corn Belt because they gave the farmer another cash crop. Soybeans became the highest earning U.S. feed grain export after 1966 (Rahe 1970). The soybean adoption rate on Union County farms increased steadily between 1960 and 2000 (Figure 23).

The beginning of the Precision Agriculture and Biotechnology Epoch in Union County was no different than the rest of the Corn Belt as far as the change to cash grain farming was concerned. "By 1982 the pattern had changed completely. Livestock predominated in only a handful of counties, mainly around the margins of the Corn Belt." (Hart 1986, 64).

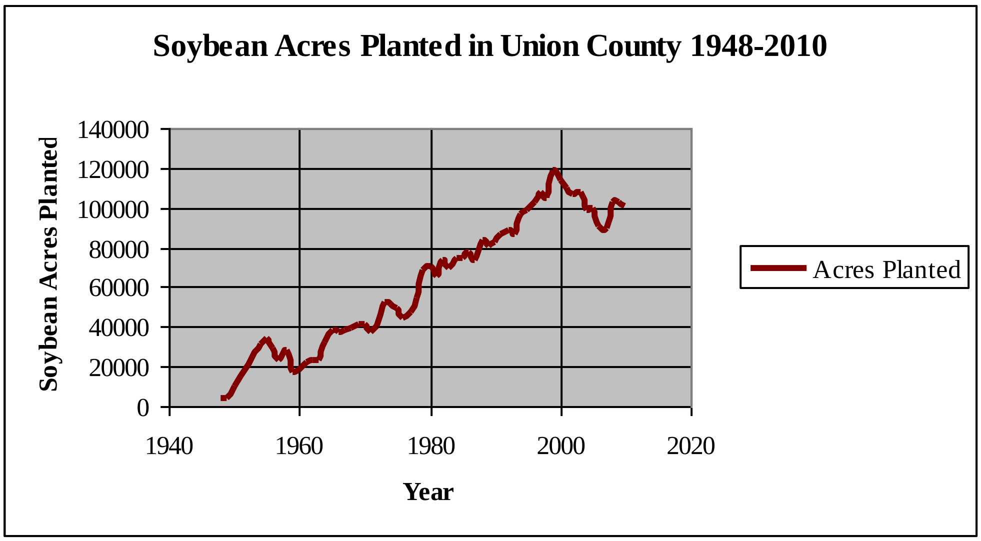


Figure 23. **Union County Soybean Acres Planted: 1948-2010**

Adapted from: (Bureau of the Census 1984; Bureau of the Census 1977; Bureau of the Census 1967; Bureau of the Census 1956; South Dakota Crop and Livestock Reporting Service 1967; and (http://www.nass.usda.gov/Statistics_by_State/South_Dakota/index.asp (Accessed March 3, 2012).

Soybeans further displaced the need for livestock manure on each farm because the soybean is a legume, and is able to fix atmospheric nitrogen into the soil (Hart 1986). This helped drive farm business specialization in the Corn Belt, creating the 'cash grain' farm, where livestock were now absent from the farmstead (Hart 1986).

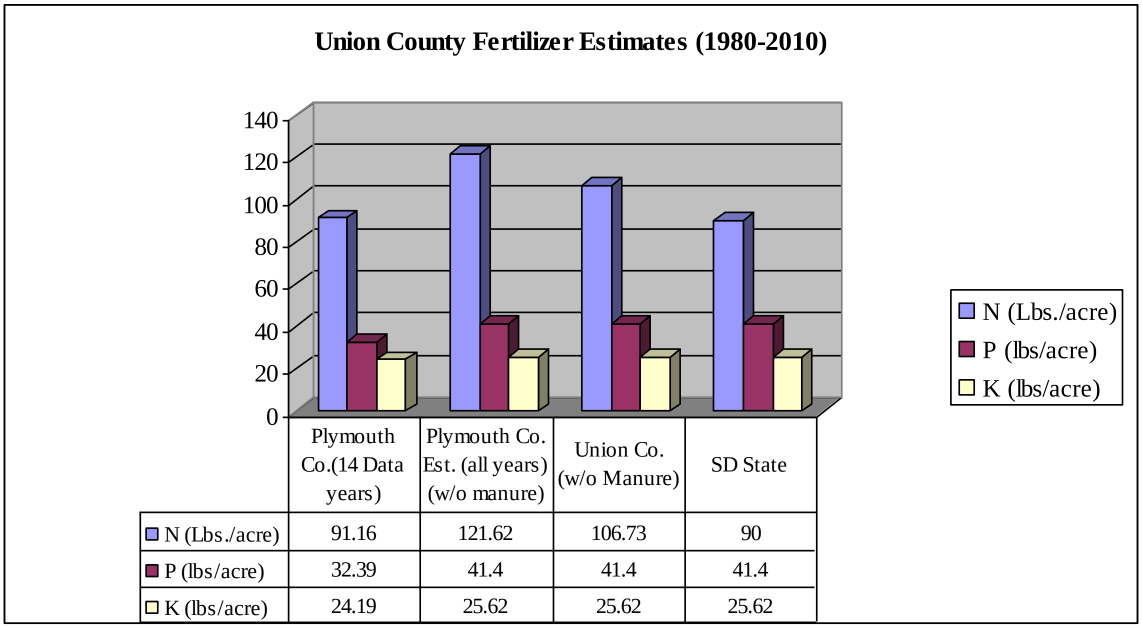
The amount of fertilizer applied per acre continued to increase during the Precision Agriculture and Biotechnology Epoch. The increase in fertilizer use allowed for an increase in land cover intensification on cropland planted to corn. The average population of corn plants per acre was 20,996 during the fertilizer epoch (Smil, Nachman and Long II 1983, 144). Corn plants seeded per acre rose to an average of 30,000 plants during the precision agriculture and biotechnology epoch, a 43% increase (Duffy 2011).

The available USDA county-level fertilizer application data for the study area during the precision agriculture and biotechnology epoch was not applicable to this analysis. Commercial fertilizer data published by the United States Department of Agriculture after 1980 for Union County was reported as the number of farms reporting, acres covered, and total dollars spent, and not tons applied (Bureau of the Census 1984; Census of Agriculture 1989, 1992, 1999, 2002, 2004, 2009). Therefore, because of the lack of quality county-level data, I applied the county level fertilizer data from Plymouth County, Iowa, to the study area. I only had access to data for the years 1980-1996, and data was not readily available for 2 of those years, leaving 14 years worth of fertilizer distribution data for Plymouth County, Iowa. The Iowa fertilizer distribution data is the amount of fertilizer by grade and tons distributed in Iowa counties (Cochran 1997). I assumed that each ton of fertilizer distributed within Plymouth County, Iowa, was applied to Plymouth County cropland. I estimated the remaining missing data years from 1997-2010 by calculating the total average corn yield in bushels per acre, and multiplied that number by 1.2 pounds of nitrogen (Figure 25).

Research agronomists recommend applying 1.2 pounds of nitrogen per bushel of expected corn grain yield (Reitsma, et.al. 2008). The average corn grain yield per acre during the precision agriculture and biotechnology epoch in Union County was 122.28 bushels per acre. Multiplying the (122.28 bushels of average yield x 1.2 lb N/bushels =

146.73#N - 40 lbs/bushel) = 106.73 pounds of nitrogen applied per corn acre. The 40 pounds subtracted from the total is the legume credit of nitrogen from the soybean crop assuming a corn-soybean rotation (Reitsma et.al. 2008). A comparison of the total nitrogen, phosphorous, and potassium applied per acre in the study area including the estimated amount of actual fertilizer applied per acre assuming that farmers used the nitrogen credit from the soybean crop is presented in Table 17.

Even though it was estimated that Corn Belt farmers applied an average of about 16 pounds of manure per acre, I did not include that variable in Figure 24 (Smil, Nachman and Long II 1983). I used a more recent source for the precision agriculture and biotechnology epoch energy analysis in Figure 24, which reported that 12.8% of U.S. corn acres receive a manure application (Macdonald et. al. 2009). Union County estimates were adjusted from Plymouth County, Iowa data to reflect actual corn yield.



	Plymouth Co.(14 Data years)	Plymouth Co. Est. (all years) (w/o manure)	Union Co. (w/o Manure)	SD State
N (Lbs./acre)	91.16	121.62	106.73	90
P (lbs/acre)	32.39	41.4	41.4	41.4
K (lbs/acre)	24.19	25.62	25.62	25.62

Figure 24. Union County Fertilizer Use Estimates: 1980-2010

Adapted from: (Census of Agriculture 1989, 1992, 1999, 2002, 2004, 2009; Cochran 1986, 1987a,1987b, 1988a, 1988b, 1989a, 1989b, 1990a, 1990b, 1991a, 1991b, 1992a, 1992b, 1993, 1995a, 1995b, 1996a, 1996b, 1997, 1998; Lounsberry 1980, 1981a, 1981b, 1982a, 1982b, 1983a, 1983b, 1984a, 1984b, 1985, 1986; Reitsma, et. al. 2008; Smil, Nachman, and Long II 1983; US Bureau of the Census 1984; United States Department of Agriculture. National Agricultural Statistics Service 1993, 1994, 1995, 1996, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008 (http://www.nass.usda.gov/Statistics_by_State/Iowa/Publications/County_Estimates/index.asp; (Accessed March 3, 2012)); and http://www.nass.usda.gov/Statistics_by_State/South_Dakota/index.asp (Accessed March 3, 2012)).

The Iowa Department of Agriculture data agreed with the USDA survey data for commercial fertilizer application in South Dakota (Figure 24). Aside from increased fertilizer usage, Union County farmers irrigated 19,000 acres of cropland, which wasn't reported by the USDA for Union County until after 1980 (US Bureau of the Census 1984; 1989; Census of Agriculture 1992, 1999, 2002, 2004, 2009).

The average yield for irrigated corn was about 151 bushels per acre, while the non-irrigated corn acres averaged a yield of 119 bushels per acre. The irrigated corn acres, however, elevated the total average bushel per acre corn yield on all acres by approximately 4 bushels per acre. The difference between the non-irrigated bushel yield of about 119 bushels per acre and the total average reported acres planted for corn grain in the study area between 1980 and 2010 was about 122 bushels per acre. This translated to a percentage increase total average yield in the study area of about 3%. I left the irrigation energy input out of the analysis because of its nominal impact on the total overall average acre yield, and because irrigation was not widely used in Union County during the prior 3 epochs. I did, however, report the amounts of energy output for the total average, irrigated average, and non-irrigated average yield at the end of the energy budget for this period to point out the difference in output (Figure 25).

Irrigated corn lands accounted for approximately 17% of the average number of all corn acres planted in the study area between 1980 and 2010 (Figure 25). Irrigation allowed farmers to expand corn production to soils where water is a greater limiting factor to yield, while the usage of other inputs such as commercial fertilizers and pesticides on the irrigated acres remained the same. Pimentel and Pimentel (1996) noted that just over 16 percent of the total United States corn acreage is irrigated. They also reported that "producing an acre of corn using irrigation requires more than 3 times the energy than producing the same yield under rain-fed conditions" (Pimentel and Pimentel 1996).

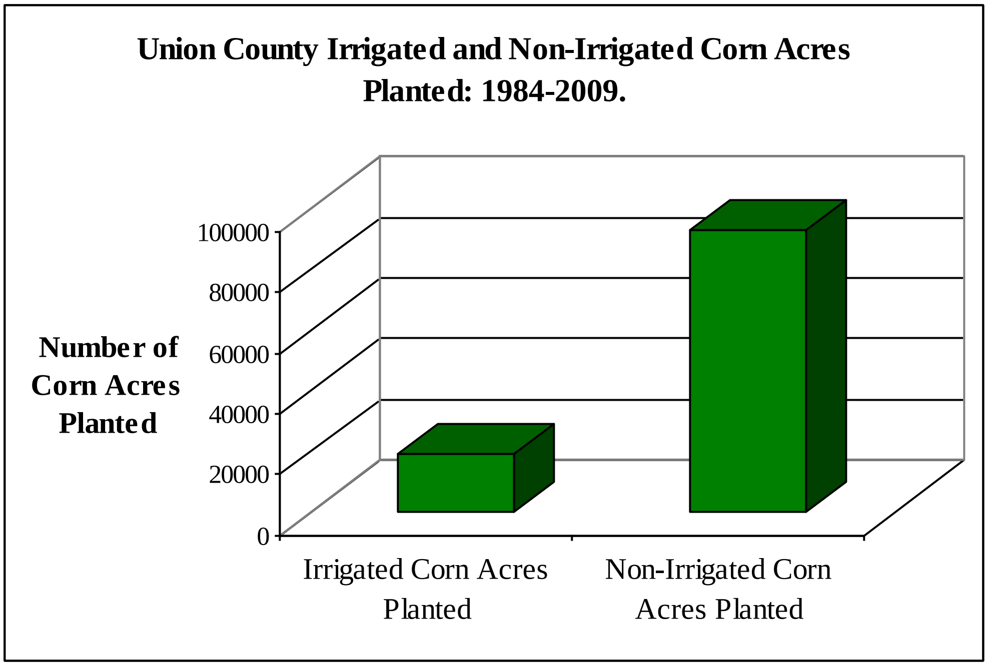


Figure 25. Irrigated and Non-Irrigated Corn Acres Planted in Union County: 1984-2009

Sources: (Bureau of the Census 1984, 1989; Census of Agriculture 1992, 1999, 2002, 2004, 2009; United States Department of Agriculture. National Agricultural Statistics Service. 2012. http://www.nass.usda.gov/Statistics_by_State/South_Dakota/index.asp (Accessed March 3, 2012).

The energy budget analysis for the Precision Agriculture and Biotechnology Epoch shows that the nonrenewable resource inputs applied to corn production had increased to about 91% (Table 17). I assumed an average of 12.8 percent of this acreage received a manure application (Macdonald et.al. 2009). I counted the energy from the manure application in the renewable column, even though it is reasonable to assume that the livestock feed ration included a portion of non-renewably produced grains and mineral supplements.

The most striking result of this epoch's analysis is that the renewable: non-renewable energy input ratio was .09:1, meaning that for each renewable MJ of input used to produce an acre of corn, 11 non-renewable MJ of inputs were also applied. The total overall efficiency ratio is a measurable increase over the energy efficiency ratio of the Fertilizer Epoch. The energy efficiency ratio of the total corn grain production outputs: total inputs for the 1980-2010 epoch was 6.7:1: while the same number during the Fertilizer Epoch was 2.44:1, a 274 percent increase in the overall efficiency of corn production between epochs. The 2.44:1 input/output ratio increase in the overall production efficiency of raising an acre of corn between 1950 and 2010 is lower than Pimentel and Pimentel's estimate of a recent 2.5: 1 kcal output/kcal input ratio for U.S. corn production (1996, 115). However, their research included an input of gasoline in addition to diesel fuel and included transportation costs as well. I did not include transportation costs and assumed a 100% use of diesel fuel instead of gasoline in the energy budget for 1980-2010. The data for the field operations analysis in Table 17 is listed in Appendix 0.

Table 17. Corn Production Energy Analysis: 1980-2010

	Input Unit	MJ/Acre	Renewable (MJ)	Non Renewable (MJ)
Prime Mover	Tractor and Combine			
Implements and Equipment (1950-1974 Smil, Nachman, and Long II 1983)	Embodied Energy (25.74 Pounds)	995		995
Manure (x12.8 % of corn acres covered)	0.2 Tons per Acre	416	416	
Nitrogen (Manure) (1950-1974 avg S,N, L 1983)	2.04 Pounds per Acre			
Phosphorous	0.448 Pounds per Acre			
Potassium	1.68 Pounds per Acre			
Commercial Nitrogen	106.73 Pounds per Acre (25.08 MJ/lb Bhat et.al. 1994)	2,677.18		2,677.18
Phosphorous (P2O5)	41.4Pounds per Acre	414		414
Potassium (K2O)	25.62 Pounds per Acre	81.47		81.47
Lime	0.15 Tons	27.9		27.9
Seeds/Acre 30,000 seeds/acre=20.83 lbs * 7.17 MJ/lb	20.83 Pounds per Acre	149.35		149.35
Herbicides	1.65 Pounds per Acre	165		165
Insecticides	0.308 Pounds per Acre	31		31
Shred Cornstalks	0.75 Gallons of Diesel 147.7MJ/Gallon	110.77		110.77
Disk Stalks	0.45 Gallons of Diesel	66.47		66.47
Moldboard Plow	1.85 Gallons of Diesel	273.25		273.25
Disk	0.55 Gallons of Diesel	81		81
Apply NH3	0.7 Gallons of Diesel	104		104
Field Cultivate	0.6 Gallons of Diesel	88.62		88.62
Plant	0.5 Gallons of Diesel	73.85		73.85
Spray Pesticides	0.15 Gallons of Diesel	22.16		22.16
Rotary Hoe	0.25 Gallons of Diesel	37		37
Cultivate	0.35 Gallons of Diesel	51.7		51.7
Harvest	1.6 Gallons of Diesel	236.32		236.32
Drying (.05 gallons/ lpg per bushel) (21.05 mj/lb) (lb/gallon 4.2) (EIA 2011)	6.11 LPG (Gallon/Acre)	540.85		540.85
Electricity	MJ/Acre	675.29	202.59	472.7
Labor	3.09 Hours			
Total Inputs MJ/Corn Acre			618.6	6,699.59
Corn yield Bu./Acre	122.28 Bushels (7.17MJ/lb)	49,097.9		
Non-Irrigated Corn Yield Bu./Acre (1984-2009)	118.68 Bushels (7.17MJ/lb)	47,652.4		

Irrigated Corn Yield Bu./Acre (1984-2009)	151.39 Bushels (7.17MJ/lb)	6,0786.1		
Percent Renewable and Non-Renewable Inputs			8.45%	91.54%
Corn Renewability Factor (Renewable: Non-Renewable Energy Input Ratio)			.09:1	
Corn Yield Bu/Acre (7.17 MJ/lb corn)	122.28	49,097.9		
Total MJ Inputs per Acre		7,318.19		
Total Output/Input ratio (MJ)		6.7:1		

Adapted from: (Anderson and Magelby 1997; Bhat. et. al. 1994; Census of Agriculture 1992, 1999, 2002, 2004, 2009; Cochran 1986, 1987a,1987b, 1988a, 1988b, 1989a, 1989b, 1990a, 1990b, 1991a, 1991b, 1992a, 1992b, 1993, 1995a, 1995b, 1996a, 1996b, 1997, 1998; Duffy 2011; Griffith and Parsons 1983; Energy Information Administration 2011; Lounsberry 1980, 1981a, 1981b, 1982a, 1982b, 1983a, 1983b, 1984a, 1984b, 1985, 1986; Macdonald. et.al 2009;; Pimentel and Pimentel 1996; Reitsma, et. al. 2008; Smil, Nachman, and Long II, 1983; United States Department of Agriculture. National Agricultural Statistics Service 1993, 1994, 1995, 1996, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, http://www.nass.usda.gov/Statistics_by_State/South_Dakota/index.asp (Accessed March 3, 2012; US Government Printing Office 1984, 1989)).

Union County farmers continued to adopt new and emerging technologies to their corn production activities. The results of the energy budget analysis show that as farmers applied increasing amounts of nonrenewable energy inputs to their corn crops, overall yields continued to increase. Land use intensification of cropland used for corn production continued to rise as farmers planted more plants per acre and the total corn acreage in the study area expanded. One driver of the expansion of corn lands in the study area is the emerging ethanol industry in the northwestern Corn Belt (Graesser 2008). South Dakota is home to the largest ethanol producer in the world. Poet Biorefining owns 4 ethanol production facilities in southeastern South Dakota alone (http://www.poet.com (Accessed March 4, 2012). According to Iowacorn.org (Accessed 8/07/2011), over 30 percent of the entire United States corn crop is now purchased as feedstock for the ethanol fuel industry.

CHAPTER 5. CONLCUSIONS AND IMPLICATIONS

The sustainability of the United States corn crop has changed since 1890 due to a series of primary energy transitions away from renewable input technologies. The rate of technological advancement and adoption of new technologies by farmers was largely due to United States agricultural policies. The United States Department of Agriculture was established by Congress in 1862, "the aim of the Department has been two-fold: first, scientific, developing a scientific knowledge of every phase of agriculture; second, educational, conveying this knowledge to all the people" (Davis 1909, 102). Agricultural policies "have been used to increase farm income directly or indirectly by improving efficiency of production" (Buller 1972, 20). Improvements to the efficiency of crop production as part of governmental policies had two goals: the first was "increasing the amount produced per unit of input; and the second was "decreasing year to year variability in production" (Buller 1972, 21). The agricultural policy of boosting the input/output efficiency of crop production increased corn yield in bushels per acre in Eastern Kansas between 1932 and 1965 by 66% due to "fertilizer use, fallow, and research" (Buller 1972, 26).

Historically, renewable energy inputs used to produce corn in the Corn Belt mostly originated on the farm. Since then, mechanical tractors replaced draft animals between 1890 and 1950, and nitrogen fertilizers produced using the Haber-Bosch synthesis of ammonia production replaced renewable livestock manures and crop rotations with non-renewable, fossil based energy. Other non-renewable inputs used to produce corn in included hybrid corn seeds, mineral fertilizers, chemical pesticides, and natural gas used in grain dryers.

The energy budget method was used to identify and measure the changes to corn production in Union County, South Dakota between 1890 and 2010. The required inputs and outputs of corn grain farming were reduced to a common unit of measure of MJ per acre. This allowed for direct comparisons of different corn production systems during four technological epochs involving a total of 120 years of corn cropping. The four technological epochs of corn production in Union County were The Draft Horse Epoch (1890-1920); The Tractor Epoch (1920-1950); The Fertilizer Epoch (1950-1980); and The Precision Agriculture and Biotechnology Epoch (1980-2010).

The energy budget method was modified in order to place renewable and non-renewable energy inputs in separate categories. This was done with the goal of understanding the energy sustainability of modern corn production. Results of the energy budgets for all four epochs are presented here as the energy renewability ratios of renewable to non-renewable energy inputs compared as percentages over time (Figure 26).

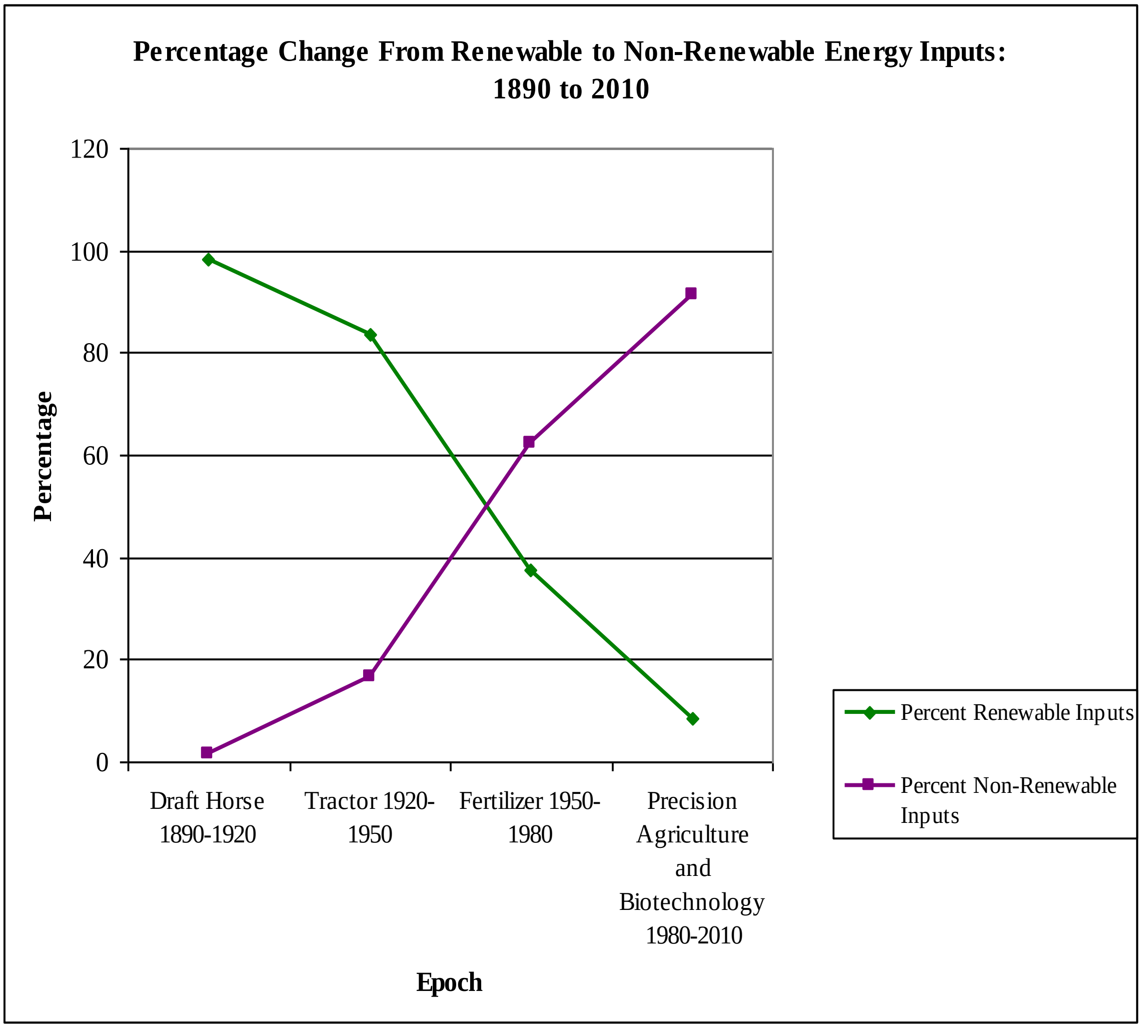


Figure 26: Percentage Change from Renewable to Non-Renewable Inputs: 1890-2010

Sources: (Table 10; Table 13; Table 16; Table 17).

The energy renewability ratio is used to point out how much fossil energy is used in the corn production system specific to each epoch in this thesis. The results of this study are startling. The energy renewability ratio of the draft horse epoch was 57:1; meaning that for each MJ of non-renewable inputs, 57 MJ of renewable energy inputs were applied to an acre of corn land. The energy renewability ratio of corn production during the precision agriculture and biotechnology epoch was .09:1, which means that for each MJ of managed renewable inputs, just over 11 MJ of non-renewable resources were applied to every acre of corn (Figure 27).

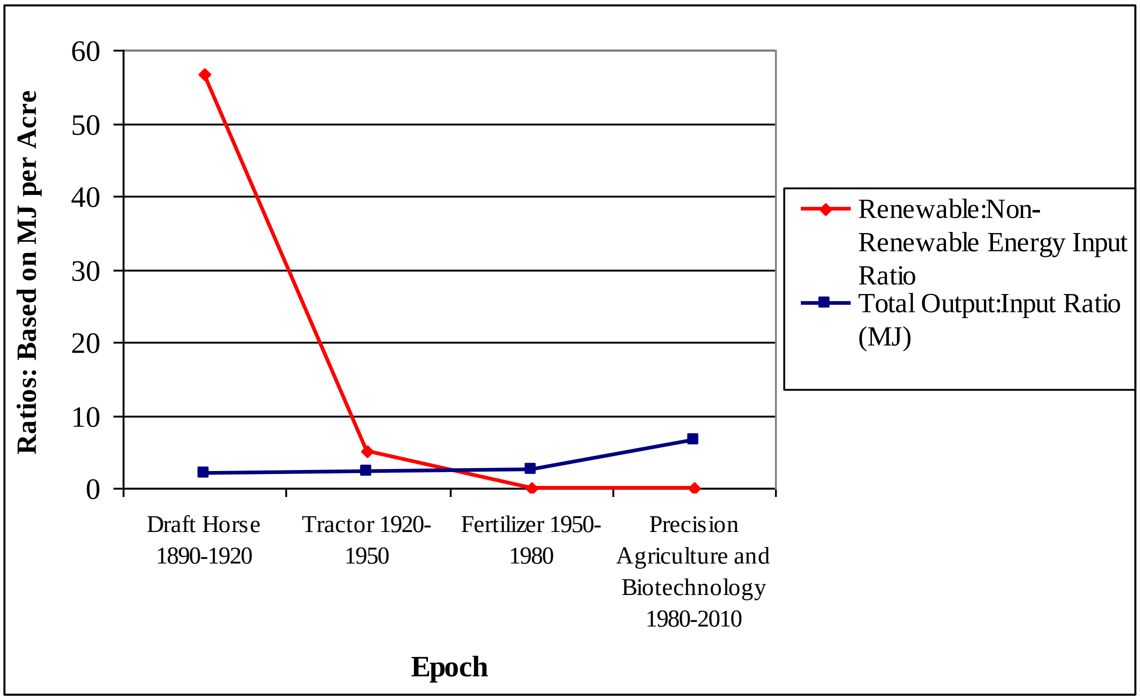


Figure 27. Renewable: Non-Renewable and Input: Output Energy Ratios Comparing The Corn Production Systems Used in Union County from 1890-2010

Sources: (Table 10; Table 13; Table 16; Table 17).

The corn grain yield increased from about 37 bushels per acre in the draft horse epoch to an average 122 bushels per acre in the precision agriculture and biotechnology epoch. This increase was due to the use of hybrid corn, chemical pesticides, and fertilizer inputs produced from mining and fossil fuels. Additionally, farm tractors and self-propelled combines cut the amount of time needed for land cultivation and harvest activities. The total energy used to raise an acre of Union County corn increased 53% between the draft horse and fertilizer epochs, and then declined 34% while the total harvested yield increased (Figure 28).

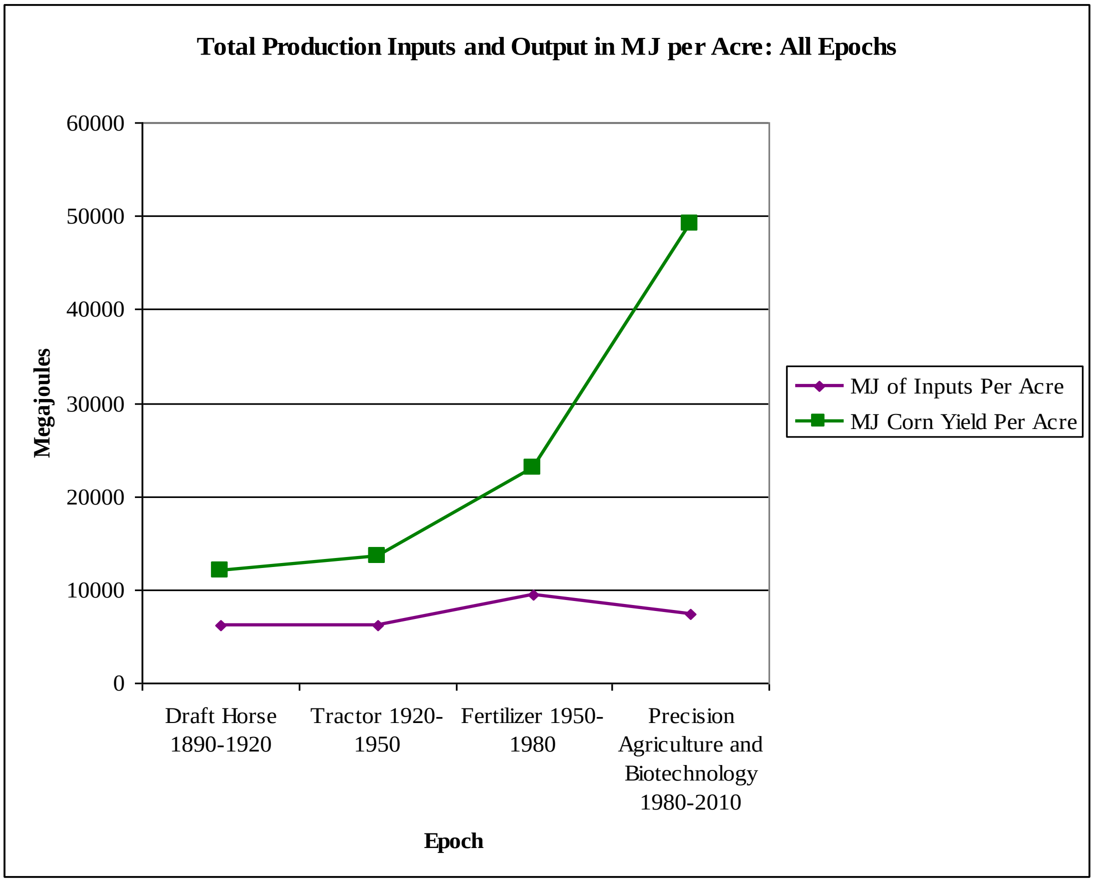


Figure 28. Total Production Inputs and Output in MJ per Acre: All Epochs.

Sources: (Table 10; Table 13; Table 16; Table 17).

The application of fossil inputs to corn production drove land use intensification in Union County. The change in land use intensification can be understood by looking at the increase of corn plants per acre from 12,096 during the draft horse epoch to a total of 30,000 plants per acre during the precision agriculture and biotechnology epoch (Figure 29).

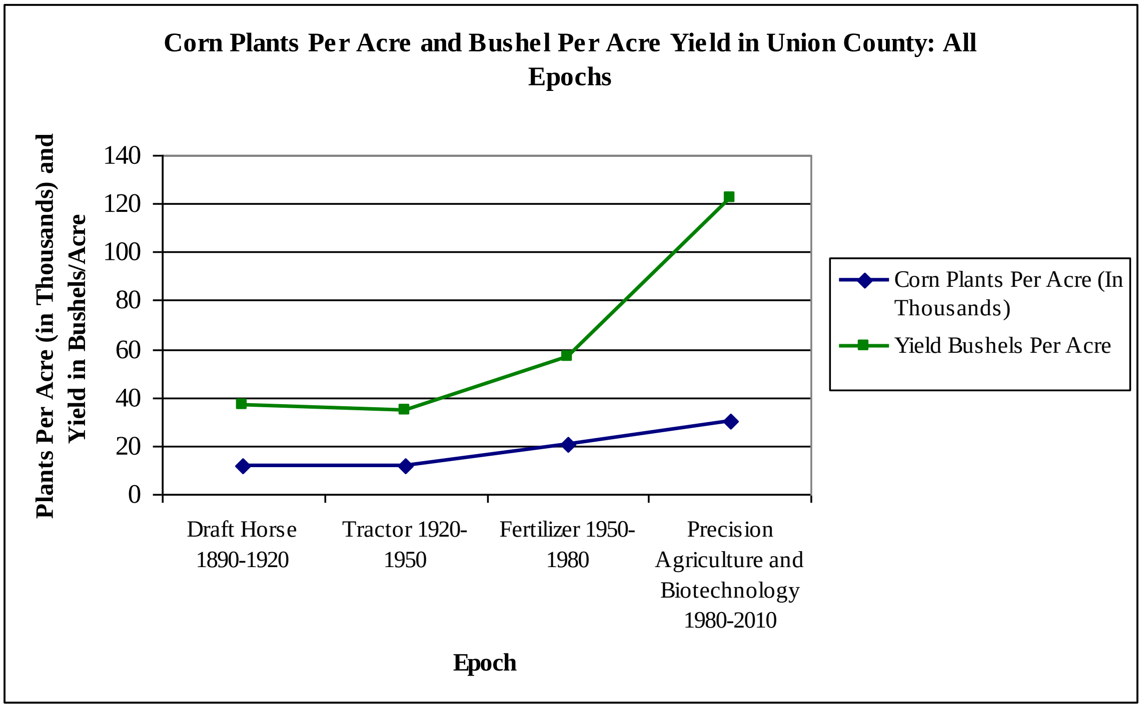


Figure 29. Corn Plants Per Acre (Thousands) and Bushel Yield Per Acre

Sources: (Table 10; Table 13; Table 16; Table 17).

What are the implications of raising corn grain using non-renewable resources?

Sources of energy commonly defined as renewable, are not always so because all or some of the feedstock energy may be non-renewable. For example, a non-renewable fertilizer input converted into a kernel of corn grain becomes digestible by animal and human populations. The yield of the Zea mays world annual crop depends upon the plant available fossil energy produced from non-renewable resources that have been mined from the Earth’s crust. The ability of the earth to sustain the current human population is limited by the actual finite amount of accessible natural gas and coal because they are the feedstock of the Haber-Bosch ammonia synthesis process (Smil 2001).

South Dakota State University research agronomists recommend that farmers apply 1.2 pounds of synthetic nitrogen per expected bushel of corn grain during each crop year (Reitsma, et. al. 2008). Other research supported the fact that ammonia fertilizer produced from the Haber-Bosch synthesis is responsible for the current level of crop yield from much of the world's croplands, including Union County (Smil 2001, 155; Figure 30).

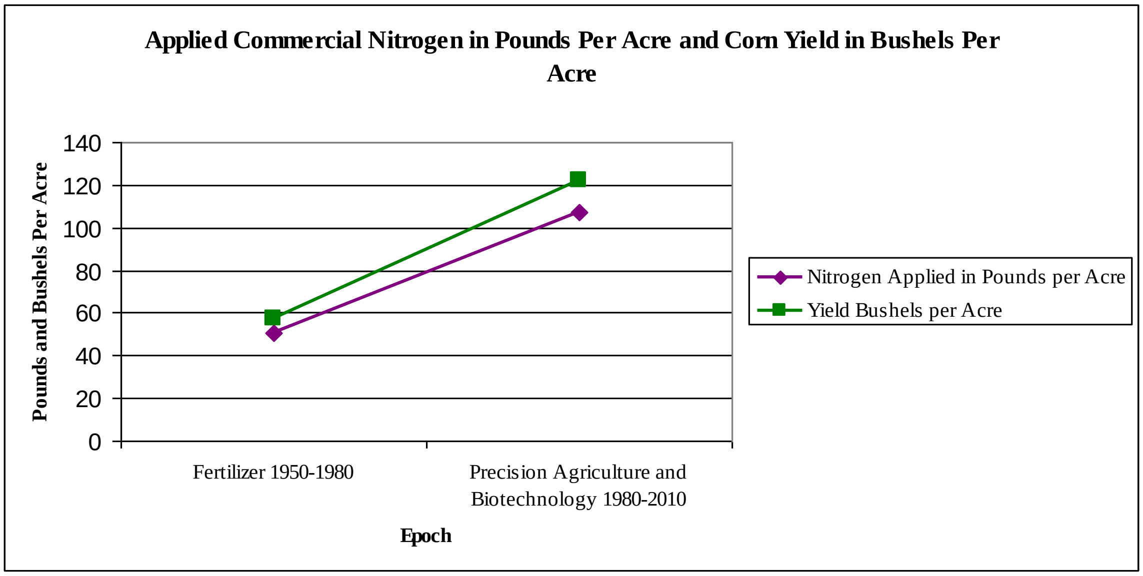


Figure 30. Applied Nitrogen and Corn Yields: 1950-2010

Sources: (Table 10; Table 13; Table 16; Table 17).

Synthetic nitrogen produced by the Haber-Bosch synthesis is chemically known as NH3, or anhydrous ammonia. After 1950 the main energy feedstock of the Haber-Bosch synthesis process was natural gas. The hydrogen in the NH3 originates from the natural gas input (Smil, 2001). The need for inexpensive natural gas feedstock for nitrogen fertilizer was investigated by the General Accounting Office in 2003 for a report to the Congressional Committee on Agriculture, Nutrition, and Forestry. The report described that:

> "Natural gas is a key feedstock in the manufacturing of nitrogen for which there is no practical substitute. Manufactured nitrogen-also known as anhydrous ammonia-is used as a fertilizer itself and is also the primary building block used to manufacture all other nitrogen based fertilizers" (United States General Accounting Office 2003, 3).

It has been noted that modern corn ethanol as well as other energy from biomass is a renewable and sustainable source of energy (National Renewable Energy Laboratory 2002). They also assumed that biomass and corn ethanol production begins with the harvested plant-based materials (National Renewable Energy Laboratory 2002). The decision by the National Renewable Energy Laboratory (2002) to leave the fossil fuels and additional finite energy inputs needed to raise plant-based material out of their study, ignored the actual renewable resource status of the corn production system. Since 1890, cropland planted to corn has been transformed from a primary source of renewable energy to a node in the fossil food energy supply chain that transforms fossil fuel and finite resources into digestible energy for human and animal consumption.

There are two viewpoints applicable to the future of nonrenewable energy usage in the corn production supply chain. The egocentric view is a short-term outlook that assumes unlimited fossil fuel supplies or readily available substitutes (Hannon, Ruth, and DeLucia 1994, 134). The egocentric viewpoint is convenient, however, it is generally accepted that natural gas is essential to ammonia fertilizer production. An alternative outlook includes "a very long time horizon, fossil and nuclear fuels will be exhausted…and…no new technologies will be available to supply energy from finite resource stocks" (Hannon, Ruth, and DeLucia 1994, 134).

The future sustainability of current average corn grain yield should continue to be researched from a local to global scale viewpoint, for example, a local viewpoint places the problem in the context of human action, and the global viewpoint connects the result of human activity to the scale of the entire ecosphere (Gasto et.al. 2009).

Adopting long-range sustainable management strategies from a global viewpoint will allow U.S. farmers to continue to produce enough cereal grain to support the increasing world population. According to a report by the United Nations, “between 1950 and 1985, cereal production outstripped population growth, increasing from around 700 million tons to over 1,800 million tons, an annual growth rate of around 2.7 percent” (United Nations 1987, 101). Smil (2006) wrote that about forty percent of the world’s population is alive because of the invention and use of synthetic nitrogen fertilizer (Smil 2006). Farmers in the United States have become dependent upon input supplies imported from outside of their counties of residence. There has been an “evolving relationship of corporations to individual farmers” (Walsh 1975, 533). A supplier-farm customer supply chain has developed where one dealer “can sell and service machinery and supply fertilizer, pesticides, fuel, and animal biologicals according to the farmer’s special needs” (Walsh 1975, 533).

The current corn production system in the Unites States Corn Belt is producing a largely unsustainable yield from finite fossil energy sources. If the corn grain yield levels produced by U.S. farmers during the Precision Agriculture and Biotechnology epoch are to continue into the future, then the planning stages for cereal grain yield sustainability should begin soon. Further research is needed by geographers, agronomists, engineers, scientists, and policy makers who can find ways to address the issue of energy inputs vs. food security sustainability for future generations. The time to act is now.

APPENDICES

Appendix A. Conversion Factors, Definitions, and Units of Measurement

Appendix A. Table 1. Conversion Factors

Units	Multiply by	Equals (Units)	Source
calories	0.003968	British thermal units	(Stout et. al. 1979)
calories	4.184	joules (or watt-seconds)	(Stout et. al. 1979)
calories (food unit)	1,000	Calories (1 Kilocalorie)	(Stout et. al. 1979)
kilograms	2.2046	pounds	(Stout et. al. 1979)
Horsepower hours	2,546.14	British thermal units	(Harding and Willard. 1917, 10; Stout et. al. 1979)
British thermal units "(Btu_{th}) th means thermochemical btu, which is based on the thermochemical calorie, cal_{th}, whereas: cal_{th} = 4.184 J exactly" (National Institute of Standards and Technology. 2008. Appendix B.8. Accessed July 29, 2013. http://physics.nist.gov/Pubs/SP811/footnotes.html#f09)	1,054,350 E+03	joules	(National Institute of Standards and Technology 2008; Stout et. al. 1979)

Definitions (These terms and definitions are generally accepted by the scientific community)

As-fed Basis

"Feed analyses reports often state results based on the feed's natural state (i.e., including water) and/or on a dry matter basis. The term "As-fed Basis" is used to alert the reader that the analytical results of a feed sample are based on its natural state including water. That means it is affected by the sample's moisture level before drying. This may also be referred to by the terms "As-is Basis" or "As-Received Basis." When comparing two or more analyses, it is generally best to utilize the data from the "Dry Matter Basis" rather than the "As-fed Basis" unless you are mixing a ration for feeding"
(Saha et.al. 2010).

Concentrates

"Concentrates refer to animal feeds that are rich in energy and/or protein but low in fiber, such as corn, soybean meal, oats, wheat, molasses, etc"
(Saha et.al. 2010).

Dry Matter

"Dry matter represents everything contained in a feed sample except water; this includes protein, fiber, fat, minerals, etc. In practice, it is the total weight of feed minus the weight of water in the feed, expressed as a percentage. It is determined by drying the feed sample in an oven until the sample reaches a stable weight"
(Saha et. al. 2010).

Dry Matter Basis

"Dry matter basis indicates the nutrient levels in a feed sample based on its dry matter content (i.e., excluding its water content). This is also referred to as "Dry Basis," "Dry Results" or "Moisture-free Basis." As there is considerable variation in the water content of forages, excluding the water or expressing the nutrient levels on a dry matter basis eliminates the dilution effect of the water, thereby providing the essential common basis for direct comparison of the nutrient content across different forages"
(Saha et. al. 2010).

Dry Matter Intake

> "Dry matter is the amount of (or prediction of the amount of) dry matter consumed by the animal and is a central concept to any discussion of animal nutrition. Typically, intake increases as the digestibility of the forage increases. However, anti-quality components such as tannins and alkaloids in feeds and forages may decrease intake. Scientists have consistently observed that as the percent of neutral detergent fiber (NDF) increases in the feed, animals consume less (i.e. DMI is less). This relationship, along with estimates of NDF digestibility, is used to estimate DMI for grasses and legumes" (Saha et.al. 2010).

Forage

"Forage refers to plants or plant parts other than separated grains fed to or grazed by domestic animals. Forage may be fresh, dry or ensiled (e.g., pasture, green chop, hay, haylage"
(Saha et. al. 2010).

Gross Energy

> "Gross energy refers to the total energy in a feed before accounting for losses due to normal digestive, metabolic and productive functions. It is determined by measuring the amount of heat produced when a feed is completely oxidized in a bomb calorimeter. It is not a very useful measure since the gross energy in most common feeds is about the same, but they do not result in similar animal performance. For example, GE in oat grain = GE in oat straw"
> (Saha et.al. 2010).

Ration

> "Ration refers to the 24-hour feed allowance for an individual animal"
> (Saha et.al. 2010).

Roughage

> "Roughage refers to bulky and coarse feed high in fiber (greater than 18 percent crude fiber) but lower in energy than most concentrates. For example, forage, hay, silage, and haylage are sometimes called roughage"
> (Saha et.al. 2010).

Weight Conversions

> “While it is common and beneficial to compare nutrient profiles on a dry matter basis, producers must work with and mix feed on an as-fed basis. For example, a ration may be formulated on a dry matter basis, but the actual feed ingredients must me mixed on an as-fed basis. It’s also common to evaluate dry matter intake as an indicator of health and performance, but the feed that is placed in the bunk may contain from 10 to 50 percent water. When feeds are expressed on a dry matter basis, all water is removed. While the nutrients are very concentrated, the total weight is light (small) in absence of water. When water is added back or as feed expressions are converted from a dry matter to an air-dry or as-fed basis, the weight should increase or become heavier. For simple weight conversions, multiply or divide by the associated as-fed dry matter percentage, expressed as a decimal. Multiplication by a percentage less than 100 expressed as a decimal will result in a smaller number, which is expected when converting weights from an as-fed (water included) to a dry matter (water removed) basis. To convert weights from a dry matter to an as-fed basis, divide by the as-fed dry matter percentage value, expressed as a decimal” (Saha et. al. 2010).

Units of Measurement

> “1,000 Calorie (cal) = 1 Kilocalorie (Kcal)
> 1,000 Kcal = 1 Mega calorie (Mcal)
> Therefore, 1 Mcal = 10^6 cal”
> (Saha et.al. 2010).

Appendix B. Estimated Draft Horse Feed Use per Union County Farm

A study was done on the average yearly cost of keeping horses on Corn Belt farms considering all crops, not just corn production. (Morrison 1936). Morrison based his analysis on these variables: 137 crop acres per farm; 6 work horses per farm; and 691 hours of work per horse (Morrison 1936, 474).

The Union County variables for the draft horse epoch based on Census data were 152 acres per farm, 6.4 work horses per farm, 767 horse labor hours of work per horse. The calculation: 152 acres per farm / 137 acres per farm = 110.9 % more acres per farm in Union County than in Morrison’s (1936) example. Therefore, the number of horse labor hours increased, as did the amount of concentrated feeds consumed by the working horses, and the number of acres used to produce the feedstuffs also increased. This analysis was conducted to reflect the actual conditions inside the study area of Union County, South Dakota (Appendix B. Table 1).

Appendix B. Table 1. Total Estimated Draft Horse Feed Use per Union County Farm

Type of Feed	Morrison's Estimate: lbs Feed/yr/Horse	Union County Estimated pounds of feed/yr/Horse (Morrison's variable X 110.9%)
Oats, lbs	1,565	1,737.13
Corn, lbs	1,730	1,920.27
Other Concentrates, lbs (Wheat Bran)	18	19.98
Legume and Mixed Hay, lbs (Timothy and Clover)	2,260	2,508.57
Non-Legume Hay, lbs (Timothy)	1,060	1,176.58
Straw and Stover, lbs total: Likely Used in Union County: (Average Wheat straw, Oat Straw, and Corn Stover) (Fed during Idled Months)	1,640	1,820.38

(Austin 1922; Morrison 1936; Miller 1958; Robinson 1905; Scott 1915; Department of the Interior 1895; Powers 1902; Bureau of the Census 1914).

The months draft animals spent on grass and stubble pastures in the study area were modified from estimates made by Morrison (1936), because the number of labor hours per horse was higher in Union County than in Morrison's (1936) estimate. Therefore, since the amount of time the draft animals were at work was higher in the study area, the amount of time spent on pasture by the draft horses was inversely less.

The number of Union County months on grass pasture was calculated as follows:

(691 horse labor hours) / (767 horse labor hours) = .90 * (100) = 90%

(.90) * (4.4 months on grass pasture) = 3.96 months on grass pasture annually.

The time spent grazing corn stalk and stubble pasture in the study area was calculated in the same way. (.90) * (1.7 months pastured) = 1.53 months spent by draft horses on corn stalk and stubble pasture in Union County on an annual basis (Appendix B. Table 2).

Appendix B. Table 2. Estimated Time on Pasture per Draft Horse

	Morrison's Estimate: lbs Feed/yr/Horse	**Union County Estimated pounds of feed/yr/Horse (Morrison's variable X 90%)**
Grass Pasture, Months (Land use)	4.4	3.96
Corn Stalk and Stubble Pasture, Months (Land use)	1.7	1.53

(Austin 1922; Morrison 1936; Miller 1958; Robinson 1905; Scott 1915; Department of the Interior 1895; Powers 1902; Bureau of the Census 1914).

Appendix C. Draft Horse Feedstuff Consumption per Farm in MJ

The data collection methodology for each epoch included finding data specific to each epoch in order to maintain historical accuracy. The data for the draft horse feed was mostly collected from the draft horse epoch (Myrick 1904) with data for the likely types of hay fed in the study area from a more recent source (Miller 1958). Definitions of terms can be found in Appendix A.

The calculation to convert from pounds of dry matter fed to kilocalories per pound to MJ per pound was as follows: (pounds of feed on a dry matter basis) per horse. Converting from kilocalories to MJ required the following equation: (kilocalories per year per feed (dry matter basis) per horse) * .004184 = MJ per feed fed on a dry matter basis per horse per year. The results show the amount of energy in the dry matter consumed annually by one draft horse (Appendix C, Table 1).

Appendix C. Table 1. Energy per Feedstuff to Support one Draft Horse per Year

Feedstuff	**Pounds of Feed per Draft Horse in Union County (Dry Matter Basis)**	**Kcal/lb**	**Kcal/year (Dry Matter Basis) per Horse**	**MJ/ year (Dry Matter Basis) per Horse**	**Author Date**
Oats, lbs	1,737.13	1,248	2,167,935	9,071	Myrick 1904, 361
Corn, lbs	1,920.27	1,568	3,010,991	12,598	Myrick 1904, 361
Other Concentrates, lbs (Wheat Bran)	19.98	1,111	22,198	93	Myrick 1904, 361
Legume and Mixed Hay, lbs (Timothy and Clover)	2,508.57	2,007	5,034,695	21,065	Miller 1958
Non-Legume Hay, lbs (Timothy)	1,176.58	2,110	2,482,594	10,387	Miller 1958, 512
Wheat Straw		739.98			Myrick 1904, 360
Oat Straw		834.93			Myrick 1904, 360
Corn Stover		677.66			Myrick 1904, 360
Straw and Stover, lbs total: Likely Used in Union County (Average Wheat straw, Oat Straw, and Corn Stover) (Fed during Idled Months)	1,820.38	**750.85**	1,366,830	5719	Myrick 1,904, 360
Total			12,242,574	58,933	

(Austin 1922; Bureau of the Census 1914; Department of the Interior 1895; Miller 1958; Morrison 1936; Myrick 1904; Powers 1902; Robinson 1905; Scott 1915)

Appendix D. Windmill Energy Used to Pump Water for Draft Horse Consumption in Union County

Appendix D. Table 1. Windmill Energy Generation

"Capacity of Windmills Under a Wind Velocity of Sixteen Miles Per Hour, Rated in Equivalent Horsepower and Gallons of Pumped Water"

Diameter of Wheel	Equivalent horse-power	Revolutions per minute	Gallons of water raised per minute to an elevation of: 25 ft	50 ft	75 ft	100 ft	150 ft	200 ft
8.5 feet	.04	70 to 75	6.16	3.02	-	-	-	-
10 feet	.12	60 to 65	19.18	9.56	6.64	4.75	-	-
12 feet	.21	55 to 60	33.94	17.95	11.85	8.48	5.68	-
14 feet	.28	50 to 55	45.14	22.57	15.30	11.25	7.81	5.00
16 feet	.41	45 to 50	64.60	31.65	19.54	16.15	9.77	8.07
18 feet	.61	40 to 45	97.68	52.16	32.51	24.42	17.48	12.21
20 feet	.78	35 to 40	124.95	63.75	40.80	31.25	19.28	15.94

(Walters 1916).

Calculations include the following:

In order to water one draft horses per farm, 4,380 gallons needed to be pumped annually. Each farm windmill had to water approximately 6 draft horses per farm per year (4,380 * 6 = 26,280 gallons). Finding the amount of MJ required to pump water for an average farm required several conversions. I used the variable for a 10 ft wheel pumping water from a depth of 50 ft.

(26,280 gallons / year / 9.56 gallons per minute) = 2748.95 minutes

(2,748.95 * .12 horsepower / minute) = 329.87 horsepower of wind energy used to pump water for 6 horses per farm per year. I converted the amount of horsepower to MJ:

(329.87 hp / 8,760 hrs per year) = .03765 horsepower per hour

(.03765 hp / hr * 2,546.14) = 95.88 British thermal units

(95.88 Btu's * 1,054.35) = 101,089.44 joules

(101,089.44 joules / 1,000,000) = .10109 MJ per hour

(.10109 MJ per hour * 8,760 hours) = 885.5484 MJ to pump water for 6 draft horses per farm per year.

(885.5484 MJ / 26,280 gallons / year = .0336 MJ per Gallon of water pumped.

Appendix E. Union County Draft Horse Labor per Acre of Corn Production

The amount of time spent to produce a corn crop varied among regions and sometimes from county to county inside the Corn Belt. Examples of these differences were found in several county level corn production budget surveys printed by the Iowa Department of Agriculture (Mueller 1906); Bowman and Crossley (1911); Billings (1917); and Leighty et.al. (1922). Appendix E, Table 1 shows the time it took to complete each step in the corn production process per acre when the data was analyzed and applied to Union County.

Appendix E. Table 1. Estimated Union County Draft Horse Labor per Acre of Corn Production

Union County Corn Production (Basis of 1 corn Acre, assume 10 hour day)	Number of Horses	Number of People	Operating Hours per Corn Acre Per Person	Total Horse Labor Hours per Corn Acre
Hauling manure 6 days*12 loads/day=72 loads/40 acres=1.8 loads/acre* 1.2 tons/load=2.16 tons/acre	3	1	1.5	4.5
Breaking stalks with harrow	3	1	0.5	1.5
Plowing 2 1/2 acres/day	3	1	4	12
Harrowing twice before planting (20 acres/day)	3	1	1	3
Planting (10 acres per day)	2	1	1	2
Cultivating (6 acres per day), 3 times over	2	1	5	10
rainy days, breakdowns, and probable discing	3	1	1.5	4.5
Total Pre-Harvest Labor Hours			14.5	37.5
Husking and Cribbing (Harvest and storage)	2	1	8.19	15.22
Total Labor Hours			22.69	52.72

Data compiled from various accounts published in (Billings 1917, 12.; and Bowman and Crossley 1911).

I used data from the following source tables to derive a reasonable estimate for the probable corn production methods used by Union County farmers. A study conducted by the United States Department of Agriculture in Chester County, Pennsylvania noted:

> "In order to determine the amount of labor in man-days and horse-days necessary to perform any operation, it is necessary to know the crew, that is the number of men and horses, the number of acres covered in a 10-hour day, or the number of tons or loads handled in the same period of time, and the average length of the work day. If these data are in tons or loads, by knowing the capacity of the wagon, the rate of application, and the yield of the crop, the acreage covered can be obtained" (Billings 1917, 11).

Appendix E. Table 2. Horse Labor Applied to Manure Spreading

This data taken from: "Crews and duty of machinery in plowing and preparation of soil (average of 165 farms, Billings 1917).

Operation	Men (Crew)	Horses (Crew)	Acres covered in 10 hour day	Days per acre (Man) 10 hour day	Days per acre (Horse) 10 hour day
Manuring [1] 12 loads, 14.4 tons	1	2	1.44	0.7	1.4
Manuring [1] 14 loads, 16.8 tons	2	2	1.68	1.19	1.19
Manuring [2] 14 loads, 16.8 tons	3	2	1.68	1.79	1.19

[1] With manure spreader, 10 tons per acre
[2] Spread by hand.
(Billings 1917).

A 1911 survey study by Bowman and Crossley provided an economic analysis of the cost of growing corn. They included data from the Iowa Counties of Buena Vista, Linn, and Iowa, which is shown here in (Appendix E Tables 3, 4, 5).

Appendix E. Table 3. The Cost of Growing Corn on 40 Acres in Buena Vista County, Iowa

Basis of 40 Acres, Yield 40 bushels per acre	Days, Man and Team	$3.00 cost of a day's work, man and team
Hauling Manure	6	
Breaking Stalks with Harrow	2	
Plowing (2.5 acres per day)	16	
Harrowing twice before planting (20 acres per day)	4	
Cultivating (6 acres per day), 3 times over	20	
For rainy days, break downs and probable discing	6	
Total ($3.00 per day)	60	$180.00
Seed corn (8 bushels) at $1.00 per bushel		$8.00
Use of tools, $1.00 per day for corn planter (4 days)		$4.00
50 cents per day for harrow, cultivator, and plow (44 days)		$22.00
Breakage, hire of extra horses, use of manure spreader		$8.00
Interest on wages at 8 percent for 6 months		$8.88
(Neither rent nor husking paid in advance) Rent		$3.25 per acre
Husking (3.5 cents per bushel, 1600 bu.		

(Bowman and Crossley 1911, 226).

> "Twenty acres of corn stalk ground. This ground should be disced and harrowed; then plowed, following the plow with the harrow, disced crosswise to furrow and harrowed; planted and harrowed at least three times before it comes up; then cultivated four times. With good seed on good average ground, corn raised this way should yield from 60 to 90 bushels per acre. This makes the ground disced twice, plowed once, harrowed six times, planted and cultivated four times, or in other words, 40 acres disced, 20 acres plowed, 120 acres harrowed, 20 acres planted and 60 acres cultivated" (Bowman and Crossley 1911, 227).

Appendix E. Table 4. The Cost of Growing Corn in Linn County, Iowa

1 man and 3-horse plow, nearly 3 acres per day for 7 days, at $4.00 per day	$28.00
1 man and 3 horses harrow 30 acres per day for 4 days at $4.00 per day	$16.00
1 man and 3 horses disc 20 acres per day for 2 days, at $4.00 per day	$8.00
1 man and 2 horses plant 20 acres in 1 ¼ days	$4.00
1 man and 2 horses cultivate 8 acres per day for 10 days, at $3.00 per day	$8.00
3 bushels tested seed corn at $3.00 per bu.	$9.00
Rent on 20 acres at $5.00 per acre	$100.00
For picking and cribbing at 5 cents per bushel, figuring 60 bushels per acre	$60.00
Wear on machinery	$10.00
Total	$265
A yield of 1200 bushels for $265.00	

(Bowman and Crossley 1911, 227).

Appendix E. Table 5. The Cost of Growing Corn in Iowa County, Iowa

"Forty acres of Sod Plowed in Spring of 1906"

Nine loads of manure per acre, 40 days for 1 man and 3 horses at $3.50 per day	$140.00
Plowing sod (40 acres) 2 men and 3 teams, 8 days	$56.00
Discing 3 times, 1 man and 2 teams, 6 days	$35.00
Harrowing four times, 2 teams, 6 days	$30.00
Planting, 1 man and team, 2 ½ days	$7.00
5 ½ bushels seed corn at $2.50 per bushel	$13.75
Cultivating five times, 1 man and team, 30 days	$90.00
Husking, 70 bushels per acre, or 2800 bushels at 3 cents per bushel	$84.00
Rent	$125.00
Total	$580.75

(Bowman and Crossley 1911, 227).

Madison County, Iowa

"Cost of Producing A Bushel Of Corn in Madison County"

> "To get close estimates it will be necessary to follow the routine of raising corn. If the land has been in corn the previous year the stalks must be disposed of. A man with a three horse harrow can cover forty acres in a day, and going over it twice would cost 20 cents per acre. Raking twelve acres per day would cost 30 cents per acre. Discing before plowing 85 cents per acre. Plowing $1.25 per acre. On an average one half of the plowed land must be disced before planting, at a cost of 15 cents per acre. Harrowing twice, 25 cents per acre. Seed corn 15 cents per acre. Planting 25 cents per acre. Two harrowings after planting 25 cents per acre. A team can cultivate in the neighborhood of seven acres per day at a cost of $3.25 or 45 cents per acre. Three cultivations $1.35. Husking costs at least 4 cents per bushel" (Mueller 1906, 715).

Appendix E. Table 6. The Cost of Growing Corn in Madison County, Iowa

Rent	$4.60
Breaking Stalks	.20
Raking and burning	.30
Discing before plowing	.35
Plowing	1.25
Discing after plowing	.15
Harrowing	.25
Seed	.15
Planting	.25
Harrowing	.25
Cultivating	1.35
Husking 45 bushels at 0.4	1.80
Total cost per acre	$10.80
Per bushel	.23

(Mueller 1906, 715).

The data from Mueller (1906) was only used in Table 6 to show differences in the steps of corn production. I used the data from Linn County corn production budget for the Union County study because it listed the number horses used during each field operation. I used the manure application data from the Buena Vista County production budget because it was in close proximity to Union County (Figure 17), and it listed the amount of time to spread manure on 40 acres of corn land, while the Iowa County production data reported the number of loads of manure spread per acre it did not list the amount in tons of manure per load. Therefore, as shown in Appendix E, Table 1, I used the data from Billings (1917) to substitute for manure spreading operations in the Union County corn production budget for the 1890-1920 draft horse epoch. This was 12 loads of manure per acre and 14.4 tons of manure per acre spread which divides out to 1.2 tons of manure per load. The number of horses to haul manure according to Billings (1917) was 2. The Iowa County, Iowa data by Bowman and Crossley (1911) listed that 1 man and 3 horses were used to spread manure, so instead of the 2 horses listed by Billings (1917), I applied 3 horses to the manure hauling operations for Union County. Therefore, based on the available data, it took a Union County farmer 6 days to spread 12 loads per day using 1 man and 3 horses pulling a manure spreader across 40 acres of cropland used for growing corn which equates to: Hauling manure 6 days*12 loads/day=72 loads/40 acres=1.8 loads/acre* 1.2 tons/load=2.16 tons/ acre.

The 2.16 tons per acre of manure applied is the figure I used in Appendix H with Smil, Nachman, and Long II's (1983) estimates regarding the nutrient make-up of manure used to fertilize crops. Those results are shown in Table 10 of this thesis.

Appendix F. Draft Horse Energy Consumption used to Produce One Acre of Corn

This appendix shows the analysis used to convert pounds of feed intake by one draft horse when performing the required labor for one acre of corn. The results show that 1,599 MJ of feed were consumed per corn acre, per horse (Appendix F. Table 1).

Draft horse feed per crop in pounds per corn acre worked (as fed basis) = (((pounds of feed per crop fed annually (Dry Matter Basis) / 198.01 draft horse days on feed) / Dry Matter percentage as decimal point (i.e. 89% = .89))* 5.272 draft horse labor days per corn acre worked).

The equation for column 2 is as follows: MJ of feed input per horse, per day = ((MJ/ year (Dry Matter Basis) per feed, per Horse) / (198.01 days on feed) = MJ per feedstuff per Horse, per 10 hr Day); whereas: (MJ of feedstuff per Horse, per 10 hr day) *(5.272 Horse Labor Days/ Corn Acre) = Feed input per Union County Corn Acre worked per feedstuff in (MJ).

Appendix F. Table 1. The Feed Inputs Consumed per Draft Horse, per Corn Acre: Converted From Pounds to MJ

Draft Horse Fuel by Crop (1 Horse)	**Draft Horse Feed per Crop in Pounds per corn acre, as fed**	**MJ of Feed Input per Union County Corn Acre Worked (Dry Matter Basis)**
Oats	52	242
Corn	57	335
Concentrates (Wheat Bran)	0.6	2.5
Legume and Mixed Hay (Timothy and Clover)	77	561
Non-Legume Hay (Timothy)	36	277
(Average Wheat straw, Oat Straw, and Corn Stover) (Fed during Idled Months)	68.55	181
Total MJ of feed input per Corn Acre		1,599

(Bowman and Crossley 1911; Driessen 1978; Miller 1958; Morrison 1936; Myrick 1904; Walters 1916).

Appendix G. Implements and Machinery Estimates for the Study Area: 1890-1920

Appendix G. Table 1. The Amount of Non-Renewable Energy Used per Corn Acre in Mexico Using Traditional Methods

"Commercial energy required for maize production by traditional methods in Mexico"

Quantity/ha	Energy/ha (10^6 joules)
173 x 10^6	173

(Stout 1979, 41).

Appendix G. Table 2. Draft Oxen Energy Used for Corn Production in Mexico

"Energy requirements for traditional corn production with draft oxen in Mexico"

Inputs	Quantity/ha	Kcal/ha
Labor	383 hours	197,245
Ox	198 hours	49,5000
Machinery	41,400 kcal	41,400
Seeds	10.4 kg	36,608
Total		77,0253
Outputs		
Corn yield	942 kg	334,0550
Protein yield	85 kg	
kcal output/kcal input		4.34:1

(Pimentel and Pimentel 1996, 113).

Finding the embodied energy in the weight of machinery pulled by draft horses based on the amount of embodied energy in the weight of the machinery pulled by oxen engaged in corn farming required the following calculations:

173 x 10^6 joules / 2.47 acres per hectare = 70.04 MJ/ acre. Based on data by Stout (1979).

198 ox hours to produce a hectare of corn / 2.47 acres per hectare = 80 ox hours per corn acre. Based on data by Pimentel and Pimentel (1996).

52.72 draft horse labor hours to produce an acre of corn in the study area (Appendix E, this thesis).

80 ox hours per acre / 52.72 draft horse hours per acre = 1.52 ox hours for each horse labor hour.

70.13 MJ per acre of embodied equipment energy (oxen) per acre * 1.52 ox hours to horse hours per acre = 106.59 (Rounded to 107) MJ of machinery per corn acre using draft horses.

Appendix H. Manure Energy Applied per Acre (MJ): 1890-1920

Manure value per ton (MJ) "Assuming the nutrient contents of 6 percent Nitrogen, 1 percent Phosphorus, and 4 percent (potassium) K (Smil, Nachman and Long II 1983, 191).

Appendix H. Table 1. Manure Energy Applied per Corn Acre

"Manure Applications to Corn and Their Thermal Energy and Nutrient Energy Cost Equivalents, 1945-1974" (Table 6.16 in Smil, Nachman and Long II 1983).

Year	Manure Applied to Corn (kg per acre) Fresh weight	Manure Applied to Corn (kg per acre) Dry weight*	Thermal Energy Equivalent** (MJ/acre)
1945	1,450	220	3,300
1950	1,450	220	3,300
1954	1,220	185	2,775
1959	1,210	180	2,700
1964	1,600	240	3,600
1969	1,630	245	3,675
1974	1,580	240	3,600

* Assumed to be 15 percent of the fresh weight
** Assumed to be 15 MJ per kg of dry manure

Appendix H. Table 2. The Chemical Make-Up of Farm Manure

Chemical make-up of mixed fresh farm manure per ton

Nitrogen	Phosphorus	Potassium
10 pounds	2.2 pounds	8.3 pounds

(Morrison 1936, 416, 417).

Finding the amount of manure energy in MJ per corn acre applied in Union County required the following: Manure energy (MJ/acre) on a dry matter basis = (2.16 tons per acre applied manure (Appendix E) * 15 percent dry matter) = (.324 tons * 2000 pounds per ton) = (648 pounds dry matter applied per acre).

(15 MJ per kilogram / 2.2 pounds per kilogram) = 6.82 MJ per pound of manure dry matter * (648 pounds of manure (dry matter) applied per acre) = 4419 MJ of manure energy applied per corn acre.

Appendix I. Corn Seeds Planted per Acre. 1890-1920 average, also used for the Tractor Epoch

Number of seeds per pound = (Reid's Yellow Dent corn at 90 seeds per ounce) * (16 oz per pound) = 1,440 seeds per pound.

(1440 seeds per pound * 8.4 pounds of seed corn planted per acre) = 12, 096 corn plants per acre.

Data from (Bowman and Crossley 1911; and victoryseeds.com).

Appendix J. Data for The Tractor Epoch Energy Analysis

Data taken from "A Comparison of the Horse and Tractor" (Anonymous 1916). The figures are based on conditions found on 160 acre farms, assuming a ten hour workday.

> "Field with an Oil Tractor on a 160-acre Farm…Let us suppose that this farmer sold four horses at an average price of $150. These four horses would bring $600, almost enough to buy a kerosene burning tractor rated at 16 h. p. on the belt and 8 h. p. on the drawbar. What would be the same work cost when done by this tractor? In the first place, the tractor will do all of the operations mentioned above with the exception of planting and cultivating the corn, and perhaps operating the side delivery rake, and for this work and other light horse jobs we have kept two horses and the colt (Anonymous 1916).
>
> 50 Acres of Corn Land.
>
> Plowing: 8-16 tractor and two 14-inch plows, 5.6 acres per day…9 days
> (If pulling three 14-inch plows, 8.4 acres per day, six days)
>
> Disking and Harrowing in one operation: 8-16 tractor, 8-foot disk harrow with 2-section peg, 20 acres per day…..2 ½ days.
>
> Harrowing twice: 8-16 tractor with a 3-section harrow, 35 acres per day…3 days
>
> Planting: use the team and planter
>
> Cultivating: use the team and cultivator
>
> Harvesting: 8-16 tractor and corn binder,
> 8 acres per day….6 ½ days.
>
> Total…..20 ¼ days" (Anonymous 1916).

The tractor used in the "Comparison of the Horse and Tractor" (Anonymous 1916), was an 8-16 kerosene burning tractor. The Tractor Field Book (1916, 19), included the mechanical descriptions of several tractors, including an 8-16 Mogul farm tractor.

The description listed the measurements of the Mogul tractor in inches and gallons, while the weight of the tractor is the shipping weight of the machine in pounds.

> The "International Harvester CO. of America, Chicago model (Mogul 8-16. p.; d.b.; 16 b. h.p.; 1 cyl; 4 wheels; 2 drivers; speed 2; 400 r.p.m.; pulley 20x 10; front wheels 36 x6; drivers 54 x 10; tank, kerosene 19; length 135; width 56 height 61; weight 5000; price $725; distributing houses in all leading cities" (Anonymous 1916, 19).

"a tractor which will require 15 to 20 gallons of low grade kerosene…per day" I averaged this estimate and used the average amount of 17.5 gallons of kerosene burned in corn production operations on the average Union County farm per day.

Appendix K. Tractor and Implement Energy for the Tractor Epoch: 1920-1950

Energy in implements and equipment: 108 MJ/ kg (Smil, Nachman, and Long II 1983, 60).

Implements were the same amount of energy as in the draft horse epoch

Therefore: (108 MJ / kg) / 2.2 lbs. / kg = 49.09 MJ per pound.

The embodied energy in an 8-16 Mogul tractor by weight = (49.09 MJ/ lb) * 5,000 lb. = 245,450 MJ (Anonymous 1916; Smil, Nachman, and Long II 1983, 60).

The number of cropland acres on an average Union County farm during the Tractor Epoch = 178.86. I divided the amount of energy embodied in a Mogul 8-16 tractor ((245,450 MJ) / 178.86 = 1372.30 MJ / Acre)/ (10 yr estimated useful life of the tractor (Schnitkey and Lattz 2005)) = 137.23 MJ

Schnitkey and Lattz. 2005. American Society of Agricultural Engineers estimated a 10 year tractor life to calculate depreciation with a 36% salvage value at the end.

Appendix L. Spreading Manure with 8-16 Tractor

Pulling Manure Spreader With 8-16 Tractor in Heavy Soil (Chase 1917, 144).

Nebraska Tractor Test No. 267—Time required per load: loading 11’ 38”; going to field 3’ 41”; unloading, 5’ 25”; returning from field 7’ 29”. Gallons kerosene used per load, .645; water used per load, 1.2 gallon. Rate of travel with spreader = 2.26 mi. per hour; rate of travel spreading = 2.19 mi per hour.

‘ = minutes

“ = seconds

The estimated number of MJ used per acre in manure spreading operations = .645 gallons of kerosene per load * 139.92 MJ per gallon of kerosene = 90.25 MJ per load * 1.8 loads per acre = 162.45 MJ per acre applied.

Appendix M. The Amount of Energy Consumed by an 8-16 Kerosene Burning Tractor per Hour

Appendix M. Table 1. The Energy in Kerosene, Gasoline, and Alcohol in British Thermal Units

"Calorific Values for Kerosene, Gasoline, and Alcohol."

Fuel	Sp.Gr.	B.T.U. per Lb.	B.T.U. per Gal.
Gasoline	0.72	20,462	122,770
Kerosene	0.80	19,890	132,700
Alcohol	0.86	8,873	61,800

Source: (Moyer 1914, 570).

These energy figures were reported in British Thermal Units. Converting from B.T.U.'s to MJ required the following:

B.T.U. per gallon of kerosene = 132,700 / 3.968 (conversion factor from B.A. Stout 1979) *4184 = 139,923,587.4 joules * 10^{-6} = 139.92 MJ per gallon of kerosene

The gasoline conversion required the same equation: B.T.U. per gallon of gasoline = 122770 / 3.968 * 4,184 = 129,453,044.4 joules * 10^{-6} = 129.45 MJ per gallon of gasoline.

Appendix N. Tractor Epoch Energy Budget Analysis Data

Appendix N. Table 1. Corn Production Inputs for 1945-1974, from Smil, Nachman, and Long II (1983)

"Table 10.1 Summary of Quantities and Energies, 1945-1974 (All energies in MJ/Acre; Quantity is denoted by Q, energy by E)

Year (19)	45	45	50	50	54	54	59	59	64	64	69	69	74	74
Productive Factor	Q	E	Q	E	Q	E	Q	E	Q	E	Q	E	Q	E
Labor* (hours)	23		16		12		8		7		6		5	
Animal feed++	67		45		26		17		0		0		0	
Machines (kg/acre)	45	437	68	636	95	872	117	1010	140	1147	154	1234	140	1,071
Fuel	*	1479	*	1742	*	1943	*	1944	*	1990	*	1760	*	1526
Seeds++ (kg/acre)	3.5	-	3.4	-	3.4	-	3.9	-	4.2	-	4.9	-	5.8	-
Nitrogen (kg/acre)	1.6	158	3.2	294	7.2	612	11.4	901	22.4	1611	46.4	3065	46.2	2818
Phosphorus (kg/acre)	1.7	7	2.2	13	3.3	30	4.4	53	6.4	89	11.1	244	10.9	240
Potassium (kg/acre)	1.9	13	2.7	19	5.6	39	7.2	50	9.5	66	20.8	146	20.7	145
Liming Materials (kg/acre)	59	53	79	55	50	20	64	13	82	16	89	18	73	15
Herbicides (kg/acre)	0	0	0.04	9	0.07	15	0.14	31	0.18	40	0.55	121	0.75	165
Insecticides (kg/acre)	0	0	0.02	4	0.02	4	0.03	7	0.11	24	0.15	33	0.14	31
Irrigation		33		36		68		112		203		403		740
Drying		15		17		24		85		214		479		809
Transport		50		72		112		140		202		325		321
Sum of Energies**		2245		2897		3739		4346		5602		7828		7881

+ Labor is listed only for sake of completeness: it is not included in energy totals.
++Energy costs of seeds and feed are calculated implicitly in computations of energy intensity I; see text and tables 11.2 and 11.4
*Diesel Fuel, gasoline, and LPG in changing proportions (see Chapter 4).
**Sum of energies is same as quantity E_{aoi}. See text" (Smil, Nachman amd Long II 1983, 127).

The energy estimate I used for the amount of energy supplied by machinery per acre was averaged from the "Machines (kg/acre)" variable. (Smil, Nachman, and Long II 1983). This calculated out to 995 MJ per acre, and that is what I used to represent the embodied machinery variable for the fertilizer and tractor epochs.

The other data supplied in Smil, Nachman and Long II (1983) used in my energy analysis included information specific to north and west central Iowa (Appendix N. Table 2).

Appendix N. Table 2. Inputs used to Produce Corn in North and West Central Iowa

Category	Unit	Quantity	Pounds per acre	My calculation (MJ/Lb) (Using energy figures from Table 10.1 above)	Total MJ/Acre
Labor	Hour	3.09			
Custom Hire	Dollar				
Seed 20,966 plants per acre	Bushel	0.26	14.56	5.17	75.27
Nitrogen	Pound	113	113	27.72	3,132.36
Phosphorous	Pound	30	30	10	300
Potassium	Pound	48	48	3.18	152.64
Lime	Tons	0.15	300	0.093	27.9
Fuel	Dollar				
Insecticide	Dollar			100.64	
Herbicide	Dollar			100	
Hail Insurance	Dollar				
Interest	Dollar				
Harvest Costs	Diesel fuel (gallons0	1.6		1.6	147.7* 1.6=236. 32MJ
Labor	Hour	1.97			

"Estimated Inputs and Variables for Grain Corn in North Central and West Central Iowa in 1970"

(Smil, Nachman, and Long II 1983, 144).

The amount of fuel energy used to produce one acre of corn in Union County was quoted from the estimate by Smil, Nachman, and Long II (1983) (Appendix N. Table 3).

Appendix N. Table 3. Energy Used in Corn Production: 1974

"Energy Analysis of U.S. Corn Production 1974" Quantities per acre, Energy in MJ per acre

	Quantities	Energy (MJ/Acre)	(My Conversion) MJ per lb.	MJ per Acre
Labor	Hours			
Machinery	Kg	1,071	41.61	1,071
Fuel (average mix Diesel, Gasoline, and liquid propane)	L	1,526		1,526
Seeds (1974)	Kg	66	5.17	66
Nitrogen	Kg	2,818	27.72	2,818
Phosphorous	Kg	240	10	240
Potassium	Kg	145	3.18	145
Liming Materials	Kg	15	0.093	15
Herbicides	Kg	165	100	165
Insecticides	Kg	31	100.64	31
Irrigation		740		740
Drying		809		809
Electricity				
Transport		321		

(Smil, Nachman, and Long II 1983).

Appendix 0: Precision Agriculture and Biotechnology Epoch Energy Analysis Data

The data for this epoch's energy analysis was largely taken from Griffith and Parson's (1983) study on energy consumption regarding various tillage systems. They supplied a comparison of tractor fuel use in low, moderate, or high draft soils. Given the average soil types of Union County, I used the variables for their moderate draft soils in my energy budget; they used diesel fuel in their study (Appendix 0, Table 1).

Appendix O. Table 1. Gallons of Diesel Consumed per Field Operation in a Moderate Draft Soil

Field Operation	Moderate soil draft rating: moderate (gallons per acre)
Shred Cornstalks	0.75
Subsoil Chisel, 14 inches	2.1
Moldboard Plow, 8 inches	1.85
Chisel, 8 inches	1.25
Offset disk	0.95
Field cultivate plowed ground	0.60
Tandem disk plowed ground	0.55
Tandem disk, second trip	0.5
Tandem disk cornstalks	0.45
Harrow, spring tooth	0.40
Harrow, spike tooth	0.35
Apply NH3, no-till ground	1.05

Apply NH3, Plowed ground	0.70
Field cultivate and plant	1.05
Strip Rotary till and plant	0.95
Plant, wheel track	0.65
Plant, conventional	0.50
Plant, till	0.50
Plant, no-till	0.50
Cultivate, disk hiller	0.40
Cultivate, sweeps	0.35
Cultivate, rolling tines	0.35
Rotary hoe	0.25
Spray fertilizer	0.2
Spray pesticides	0.15

(Griffith and Parsons 1983).

Fuel requirements given are averages of tests conducted over a wide range of soils. The actual fuel requirements for a particular field operation in a particular soil type may vary as much as 25% or more from the values shown here. Soil types associated with the draft ratings include Low—sands and sandy loams; Moderate—loams and silt loams. High—clay loams and clays" (Griffith and Parsons 1983).

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