

1-1-2015

# Sustainable Farming versus Ethanol: A Comparison of Energy Use

Brandon John Weiland  
*University of Denver*

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Sustainable Farming versus Ethanol: A Comparison of Energy Use

A Thesis

Presented to  
the Faculty of Social Sciences

University of Denver

In Partial Fulfillment  
of the Requirements for the Degree  
Master of Arts

by

Brandon John Weiland

June 2015

Advisor: Chiara Piovani

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Author: Brandon John Weiland  
Title: Sustainable Farming versus Ethanol: A Comparison of Energy Use  
Advisor: Chiara Piovani  
Degree Date: June 2015

### **Abstract**

The subsidization of corn-ethanol has proven to not live up to the original promises made when it was promoted as gasoline additive. With research pointing to ethanol as a source of increased greenhouse gases emissions and other pollution while merely changing energy consumption, not decreasing it, an alternative that achieves the original goals of ethanol policy is sought. I propose that sustainable farming practices have the ability to decrease the United States' dependence on fossil fuels while decreasing emissions and pollution related to farming. By looking at the adoption of 3 year rotations, fertilizer banding, and zero tillage farming in Iowa, Illinois, Nebraska, and Minnesota, I find a significant decrease in energy consumption and pesticide, herbicide, and synthetic fertilizer use through decrease in field operations and conservation of soil tilth. The adoption of these sustainable practices in these four states has the ability to conserve the energy equivalent of over 1.5 billion gallons of diesel fuel per year. Current promotion of diverse cropping systems and minimal tillage through policy by the United States Department of Agriculture shows that these sustainable farming practices are applicable in other regions throughout the United States.

## **Acknowledgements**

This research would not be without the help and support of many people. Thank you to my advisor, Chiara Piovani, for allowing me to write on this subject for a course project and inspiring me to continue asking questions. Thank you to my committee members, Andrew R. Goetz, Markus Schneider, and Tracy Mott, for accepting to help me complete this project. Thank you to the Department of Economics for providing me with funding, so I was able to conduct this research. Lastly, thank you to my girlfriend and parents for their continued support through my ever changing educational pursuits.

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## **Chapter 1: Introduction**

Following the 1973 oil crisis, Brazil responded by promoting ethanol production through their Proálcool program, which was focused on phasing out fossil fuel use in support of ethanol from sugarcane. The success of this program led many other developed countries to undertake similar policy in the twenty first century. Policies implemented around the world have led to substantial biofuel production and have been warranted by beliefs that such policies will provide energy independence, a reduction in greenhouse gases, and provide income for farmers (Langeveld, et al., 2014). Examples of these policies are those in the European Union, Indonesia, and Malaysia.

Focus on agricultural development has always been a top priority in the European Union and its ethanol policy goes hand and hand with this. The EU put policy into effect in 2005 that would change the use of fossil fuels in the transportation industry to the use of biofuels and was focused on a desire to cut emissions while also finding use for their surplus of agricultural land. EU policy puts the focus of production across the EU on wheat and rapeseed biofuels with the future looking at sugar beets, both for the production of biogas and cellulosic biofuels (Langeveld, et al., 2014).

Similar focus follows biofuel production in Indonesia and Malaysia. Agricultural development has become a top priority in both countries as a way to combat high poverty rates and issues with malnutrition. In the past few years, Malaysia has seen more significant development in this area and an increase in education than Indonesia, but both



are taking steps in this direction by supporting farmers through biofuel policy. Malaysia and Indonesia are both large producers of palm oil and use it in their modest production of biodiesel. Indonesia's policy was established in 2006, but this policy was altered as palm oil replaced soybean oil as the highest consumed vegetable oil and palm oil prices became too volatile. Malaysia enacted biodiesel policy in 2006 and increased requirements for blending in 2008, but these mandates were also delayed because of the increasing demand for palm oil. (Langeveld, Dixon, and van Keulen, 2014).

Until the end of the year 2012, corn-ethanol production in the United States was subsidized at 45 cents per gallon produced under the idea that, as a gasoline additive, ethanol would aid in the reduction of greenhouse gases through a reduction in carbon emissions while supporting energy independence to the United States. There was a desire to find a new source of fuel that did not depend on foreign producers and to usher in a new wave of biofuels to move America's energy needs into the 21st century. Ethanol has been promoted in the United States as a cleaner and locally produced alternative to petroleum. This was driven by a belief that an acceptance of corn-ethanol would promote the development of other biofuels that would be more practical and cleaner in the long run. It is believed that corn-ethanol has become of extreme importance to the U.S. as it is seen as an instrument to achieve energy independence. The U.S. was subject to the pressures of energy security for the first time in 1973, when Arab countries that supplied oil to the United States protested the U.S. military support of Israel, causing an oil crisis. Since then, energy independence and security has been sought to alleviate the American energy market from outside influence while promoting price stability for consumers.

With peak oil behind the United States and possibly behind, if not fast approaching, the rest of the world and oil prices expected to rise, oil becomes an increasingly important, but scarce transportation resource<sup>1</sup>. This issue is exacerbated as the United States increases its oil consumption at the same time emergent countries, like China, also rapidly increase consumption of petroleum. BP Statistical Review of World Energy (2014) reported that from 2012 to 2013 oil usage increased in the United States by 400 thousand barrels a day and in China by an additional 390 thousand barrels. This increasing demand for transportation fuels, for many reasons, creates an increased demand for biofuels like ethanol.

With the increased acceptance of climate change as an established fact, governments and consumers looked for ways to decrease the release of greenhouse gases into the atmosphere. Ethanol was promoted as the desired replacement as transportation fuel source. Ethanol is also supported as a cleaner alternative to traditional fuels. The EPA argues that corn-ethanol is 21 percent more efficient than gasoline, and the American Coalition for Ethanol points to the reduction in greenhouse gases as a result of ethanol use of 38 million tonnes in 2013. The American Coalition for Ethanol (2014) also points out that this corn is being produced now in more efficient and sustainable ways. They state that farmers used less tilling and fertilizer in 2013 while producing 14 billion bushels of corn on 87.5 million acres. Corn-ethanol appears to be the alternative desired to wean consumers off of petroleum, and it is only believed to be a stepping stone to cleaner biofuels, such as cellulosic ethanol, which is touted as using plant waste

material and not taking crops away from food supply. Ethanol looks like the panacea to all of the fossil fuel ails until the data is analyzed.

Claims about sustainable farming in corn production do not match up with data. Although in 2010 Horowitz, Ebel, and Ueda showed that no-till farming was on the rise from 2002 into 2006, the USDA pointed out that same year that no-till farming was never as prevalent in corn production in the bulk of the Mississippi River Basin (Iowa, Illinois, Minnesota, and Wisconsin) as the rest of the United States. This includes three of the four largest corn producers in the US, Iowa, Illinois, and Minnesota, with Nebraska being excluded. Since 2006, the use of conventional tillage has increased in some states, according to USDA crop production data. According to the Cappiello and Apuzzo (2013), fertilizer use was also on the rise during this time, with an additional 1 billion pounds of fertilizer being used by American farmers between 2005 and 2010 and conservative estimates putting the increase since then at an additional one billion pounds. 14 billion bushels of corn on 87.5 million acres of land is touted by the American Coalition of Ethanol as the highest average yield ever recorded, but, at 160 bushels per acre, falls short of EPA minimum estimates of 180 bushels per acre required to reach the 21 percent increase in efficiency over traditional gasoline. Part of the issue with the efficiency of ethanol is the increased use of marginal land.

Since 2008, 5 million acres of conservation land was converted to farmland. Additionally, grazing pastures were also converted and virgin land, something that consists of natural prairies and something that the government did not anticipate happening, has been converted to farmland. The United States Department of

Agriculture estimated that in 2012 that only 38,000 acres of virgin land had been converted to fields for crops, but this does not match data that shows that since 2006 around 1.2 million acres of virgin land had been converted in Nebraska and South Dakota alone (Cappiello and Apuzzo, 2013). In 2013, Cappiello and Apuzzo pointed out that these marginal lands require higher fertilizer use to increase yields, but the conversion of virgin land into farmland also comes with the release of carbon from the ground into the atmosphere.

Claims of the decrease in greenhouse gases associated with ethanol also do not seem to match reports. In 2008, Searchinger et al. showed that in 30 years use of traditional corn-ethanol would produce twice as many greenhouse gases as traditional gasoline and, that same year, Fargione, Hill, Tilman, Polasky, and Hawthorne showed that an increase in clearing of forests and grasslands in Latin America and South Pacific Asia for biofuels would actually lead to a net increase in greenhouse gases. Mandates and subsidies create additional demands for crops, which raises prices (Headey, Malaiyandi, and Fan, 2009). As a result, Kim, Sohngen, Golub, Hertel, and Rose showed in 2010 that the increase in demand would encourage land conversion, and European and U.S. biofuel mandates would be responsible for the loss of 23 – 26 million hectares of forestland globally in the next 30 years, which would cause the release of an additional 1.2 – 1.6 billion tons of CO<sub>2</sub> when compared to 2010 levels. The increased use of fertilizer also contributes to the release of greenhouse gases, as nitrogen used as fertilizer has been linked to the release of nitrous oxide, a greenhouse gas. Corn-ethanol is

believed to be ushering in an era of new and cleaner biofuels, but the biofuel it is transitioning toward, cellulosic ethanol, is not sustainable.

Ikerd (2010) pointed out that creating biofuels from biomass and agricultural waste deprives decomposers in the soil of potential food they use to provide nutrients to crops, and that replacing 10% of the United States' fossil fuels with biofuels would deprive these microorganisms of 75% of waste energy available. Perennial grasses are better for wildlife than corn, but these grasses are not as suitable as land use prior to biofuel introduction (National Research Council, 2010). Even the goal of energy independence may mean less than it is proposed to mean.

In a 2015 interview with Big Think, Summers stated that while Japan and Europe are dependent on the Middle East for oil it is unlikely that a drastic price difference between oil in Japan and Europe and the United States would ever arise<sup>2</sup>. This means that even if the United States were no longer a net importer of oil, they would still be vulnerable to global oil prices and could not be described as energy independent.

The fact that ethanol is proving to not live up to promises of being cleaner and more efficient than traditional gasoline creates a desire to find an alternative that can make those promises while also displacing consumption of fossil fuels.

When looking for an alternative to ethanol the desire is to find a way to promote sustainable farming, while still displacing fossil fuels and reducing emissions. The focus on sustainable farming practices is based on a desire to reduce the amount of fertilizer, pesticide, and herbicide used. Decreasing the demand for farm chemicals directly reduces greenhouse gas emissions and pollution by decreasing fuel use in shipment and

production of the chemicals, diesel use in application, and runoff in waterways linked to the Dead Zone in the Gulf of Mexico and local pollution of water resources. The objective of sustainable farming is to maintain high productivity with fewer chemical inputs. The issue becomes whether or not these farming practices exist and, if they exist, why they are not widely accepted.

The objective of this thesis is to assess how much ethanol was used in 2013 after the implementation of the Energy Independence and Security Act of 2007 and its expansion of the corn ethanol subsidy and how this energy replacement compares to the energy savings that could be made by combining a number of alternative farming practices before the implementation of the policy. It is important to look at a number of alternative farming practices in major corn ethanol producing states to get an idea of how large the potential energy savings could be. It is also important to compare the implementation of sustainable farming practices to the subsidization of corn ethanol, which was implemented to promote clean air and energy independence, to show how alternative practices can be used to solve these problems. By looking at farming practices in the four largest corn producing states - Iowa, Illinois, Nebraska and Minnesota - from 2003 to 2007, this research shows that the implementation of sustainable farming practices displaces more energy in these states than currently being replaced by ethanol. This is a particularly significant result, because, according to the US Energy Information Administration (2014), Illinois is the sixth largest consumer of ethanol in the United States, Iowa is the fifth largest consumer of energy per capita, and Nebraska is the seventh largest consumer of energy per capita. Through the elimination, rather than the

displacement, of these nonrenewable energy sources reduction in greenhouse gas emissions will be evident. The methods the empirical section of this thesis will focus on will be the implementation of a three crop rotation, no-till farming, and fertilizer banding, as looked at by Johanns, Chase, and Liebman (2012). These methods will be compared to the crop rotation, tilling practices, and average fertilizer use in these four states to show the change in consumption that can occur through an alteration in practices.

Chapter 2 discusses the background of the expansion of the subsidization of corn-ethanol through the Energy Independence and Security Act of 2007 and includes a review of existing studies that measure the impact of this subsidization. This chapter considers the stipulations surrounding the efficiencies of ethanol as an alternative fuel source and outlines how ethanol fails to meet these efficiencies. Chapter 3 presents empirical analysis showing the benefits of sustainable farming practices compared to current farming practices used in Iowa, Illinois, Nebraska and Minnesota. These energy savings will be compared to the energy replacement by ethanol while also looking at the additional environmental benefits of sustainable farming. Chapter 4 will outline the issues surrounding policy and what needs to be looked into to usher in an area of sustainable farming in Iowa, Illinois, Nebraska and Minnesota. This chapter makes a comparison between these policies and current policies in the United States that extend outside these four states and that either explicitly promote sustainable farming or similar ecological benefits as these sustainable farming practices. Chapter 5 concludes by summarizing the information from the previous chapters to explain why sustainable

farming is a better option to both conserve more energy than, and achieve the environmental goals of, corn-ethanol subsidization



## **Chapter 2: A Review of Existing Studies on Inefficiencies in Corn-Ethanol**

### **2.1 The Origin of Corn-Ethanol Subsidies**

The modern corn-ethanol subsidy, which came to an end in the twilight of 2012, began in 2007, when, in response to rising oil prices and imports, congress passed a law that required ethanol to be mixed with gasoline<sup>1</sup>. There was a desire to find a new source of fuel that did not depend on foreign producers and to usher in a new wave of biofuels to move America's energy needs into the 21<sup>st</sup> century. This was fueled by a belief that an acceptance of corn-ethanol would promote the development of other biofuels that would be more practical and cleaner in the long run. The bill demanding the fuel blending was signed by George W. Bush before the end of his second term and became the responsibility of the Obama administration to find a way to put it into effect.

Under the Obama administration, a team at the Environmental Protection Agency went to work determining how the corn-ethanol that was to be blended with gasoline would stack up when compared to gasoline. According to Cappiello and Apuzzo (2013), the EPA understood that a law that would mean billions of gallons of ethanol being blended with gasoline would also mean that the demand for corn would increase and cause the number of acres plowed to also increase, and there was also the fact that congress had ruled that there would be an exemption granted to the already existing ethanol plants that used coal and natural gas in their production processes, so these were

taken into account when they calculated how efficient corn-ethanol could be. It turned out that it was only 16 percent more efficient than gasoline, but law required it to be at least 20 percent more efficient. With ethanol producers being exempted by congress, there needed to be other changes in the assumptions about what the future of corn production would hold to make ethanol much greener than gasoline (Cappiello and Apuzzo, 2013).

Plowing new farm land releases carbon dioxide trapped underground into the atmosphere, so the more land that is plowed to meet growing demand the worse the environmental impact of ethanol. Cappiello and Apuzzo (2013) report that when the EPA originally looked at their estimates for corn production they were estimating that yields would be around 180 bushels per acre by the year 2022, but many agricultural producers thought that these predictions were too low for where genetically modified corn would lead yields. These organizations worked with the EPA to display how modified seeds would increase the yields per acre and the EPA increased their final estimate to include average yields of 230 bushels per acre in 2022 at a price of \$3.22 per bushel, pushing the benefit of corn-ethanol as being 21 percent more efficient than gasoline (Cappiello and Apuzzo, 2013). Now, over five years after these numbers were calculated, with yields holding steady around the previous average yield of 150 bushels per acre and corn prices rising to \$7 per bushel in 2013, it is completely apparent that these numbers are not supported by the current situation of corn production, but what makes the numbers so far off from the estimate?

The underperformance of yields can be attributed to two factors, an underestimation of how many acres of conservation land would be converted to farmland and an underestimation of how many farmers would see a yield penalty by continuously planting corn.

Since the Obama administration took office, 5 million acres of conservation land has been converted to farmland. This land was farmland unsuitable for farming corn, because of the quality of the soil, and was more likely to have erosion issues. The government, with the interest of creating woodlands, wetlands, and other habitats for wild animals, paid farmers \$70 per acre to keep these farms as grass, but, with corn going up to \$7 per bushel and farmers getting an average 150 bushels per acre, it is not hard to see what the best economic decision is in this situation. On top of these conservation acres being converted from grass, wetlands, and woods to farmland, grazing pastures were also converted, and virgin land, something that consists of natural prairies and something that the government did not anticipate happening, has been converted to farmland. The Department of Agriculture estimated that in 2012 that only 38,000 acres of virgin land had been converted to fields for crops, but since 2006 around 1.2 million acres of virgin land had been converted in Nebraska and South Dakota alone (Cappiello and Apuzzo, 2013).

The reason these millions of acres being converted to farmland affects average yields is the same reason why these fields were not farmed for corn or soybeans in the first place, they do not have the necessary nutrients to make for good farmland for these crops and are more suited for grasses. This has been part of the reason that there has

been an increase in fertilizer use since 2006, but the other issue is the continuous planting of corn every year.

Johanns, Chase, and Liebman (2012) at Iowa State showed both a three and four crop rotation could significantly increase yields of both corn and soybeans, while decreasing the amount of fertilizer and pesticides needed. Gentry, Ruffio, and Below (2013) at the College of Agricultural, Consumer, and Environmental Sciences at Illinois found that the yield penalty, the number of bushels lost per year from continuous corn plantation, was between 9 and 42 bushels per acre. Rabobank reported in 2012 that yields were being hurt by farmers' abandonment of crop rotations as farmers saw the average yield of corn reach only 156 bushels per acre, lower than the USDA's yield projections of 164 (as cited in Berry, 2012). Continuous corn is a product of the price of corn because farmers are able to see short term profits even though yields have fallen (National Research Council, 2010). Farmers planted over 97.4 million acres of corn in 2014, an increase in acreage for the fifth consecutive year; farmers planting continuous corn have attempted to combat this through the application of more fertilizer.

With both of these factors increasing the need for fertilizers and pesticides, which use of has increased dramatically in the last two year, for farmers to see higher yields, Cappiello and Apuzzo (2013) found that farmers in the United States have increased their fertilizer use from 2005 to 2010 by 1 billion pounds with conservative estimates putting the increase since then at another 1 billion pounds; an increase in the use of fertilizers which has large environmental costs.

## **2.2 Negative Environmental Externalities**

When fertilizers are sprayed onto crops not all of it is used by plants as nitrogen rich food as some of it gets washed away into local water ways, and as farmers plant more acres of corn, using every inch of land they can to plant, corn is being planted closer to creeks and rivers with huge environmental consequences from fertilizer run off. This is also true for pesticides, which have seen an increase in use as rootworm becomes more of a concern for farmers' crops.

Nitrogen fertilizer in a drinking supply can be poisonous, and the same goes with pesticides. Scientist Deepanjan Majumdar (2003) at India's National Environmental Engineering Research Institute showed a link between nitrate and pesticide contamination of drinkable water sources and the occurrence of a type of methaemoglobinaemia in babies that decreases their bloods' ability to carry oxygen and is often fatal. In 2013, the Des Moines Water Works saw an increase in nitrate levels in both rivers supplying drinking water to the city of Des Moines, Iowa, as the drought caused fertilizer to sit at ground level and be washed away into waterways when rains finally came. The increase of nitrate levels in both the Des Moines and Raccoon Rivers were both so large that the Water Works had to run machines to clean water supplies 24 hours a day. In Minnesota, the state government found that a decrease in the nitrate levels in the water would cost the state around \$1 billion (Cappiello and Apuzzo, 2013). In the EPA's 2004 National Water Quality Inventory, agricultural activity was cited as one of the main contributors to waterway pollution and 44% of rivers and streams, 64% of lakes, and 30% of estuaries surveyed received their lowest grade of "impaired." Some of the filtration of the nitrates

in waterways is done by bacteria natural occurring in the rivers and streams themselves, but this clearly is not enough.

Hall et al. (2009) looked into how much nitrate was taken up by waterways in 2008, and they found at that time that the ability of waterways to filter out nitrates from fertilizers was decreasing, with only 16% of the nitrate being filtered out natural by bacteria. Donner and Kucharik (2008), at the University of British Columbia and the University of Wisconsin, respectively, predict that with this decrease in the effectiveness of filtration of our nations waterways could lead to a 34 percent increase in the level of nitrogen pollution in the Mississippi River by 2022, and this will have a devastating ecological impact on an area of the Gulf of Mexico known as the “dead zone.”

The dead zone is an area in the Gulf that is inhabitable to many aquatic animals as nitrogen rich fertilizers provide the necessary nutrients for cyanobacteria to grow at a faster than normal rate. These cyanobacteria are not a food source for many forms of aquatic animals and instead decompose in the water. These dead zones, created by the overgrowth of cyanobacteria and their decomposition, form a habitat low in oxygen and unsuitable for fish, crustaceans, and zooplankton. As a result, these animals die from a lack of oxygen in the water or are less likely to be able to reproduce. The Gulf of Mexico’s dead zone, on average, has doubled every year of the past two decades. Some of the issues with agrichemicals are not as obvious or easy to measure.

While agrichemicals and emissions remain a main source of fresh water pollution, the fact that many of these sources are not included in the Clean Water Act makes regulation impossible. The measurement of these nonpoint sources is difficult because

damages can differ by the areas where pollution occurs. Although these sources are listed as nonpoint, they still limit the ability to achieve the goals stated by the Clean Water Act (Kling, 2011). Agricultural nutrients runoff is not the only way fresh water sources are being impacted.

Increased ethanol production has led to the over pumping of aquifers, clear cutting of forests, and edge tillage<sup>2</sup> (Conca, 2014). While the over pumping of aquifers impacts fresh water sources directly, clear cutting and edge tillage can impact waterways through soil erosion. Edge tillage goes against research that has shown the benefits of prairie buffer zones. The conversion of 10% of fields to prairie can conserve 95% of the sediment that ends up in water ways as a result of soil erosion (as cited in Eller, 2014a). Prairie strips would take less than an acre away from farmland from crop production in 71% of the 11% of Iowa farms it is recommended on (as cited in C. Doering, 2015). The sediment from soil erosion reduces the depth of waterways, which directly impacts aquatic life. Soil erosion also increases the cost of water treatment while damaging bridges, roads, railways, and other buildings. In 1995 the estimated cost of these damages was \$8 billion (Pimentel et al., 1995). Water quality is also impacted through ethanol production.

Ethanol production requires large quantities of water for biochemical and thermochemical conversions. This becomes an issue in water strained regions as ethanol production is expected to remain regional into the future (National Research Council, 2010). These impacts on water are not the only negative externalities of an increase in the production of ethanol; air quality is also being impacted.

Kristie Boering, a chemistry professor at UC Berkeley, with the aid of researchers around the world, showed, without a doubt, that the increasing use of fertilizers since the 1940s has caused an increase in nitrous oxide in the atmosphere, a gas that is considered to be part of the group of greenhouse gases causing global warming and destroying the ozone layer. Boering and her colleagues analyzed data to find a common link between a nitrogen isotope in fertilizer and nitrous oxide in the air. Nitrous oxide is a byproduct of fertilizer use as the microbes in soil convert nitrogen into nitrous oxide (as cited in Sanders, 2012). The nitrous oxide released from the production of crops that rely extensively on synthetic nitrogen fertilizers negates any benefits of replacing fossil fuels (Crutzen, Mosier, Smith, and Winiwarter, 2008). The greenhouse gas emissions are not just linked to the use of them on fields, though.

The production of nitrogen fertilizers actually uses natural gas and contributes to the emissions of greenhouse gases. According to the Soil Conservation Council of Canada (2001), the production and shipment of 1 lb. of nitrogen fertilizer releases around 1.68 lbs. of CO<sub>2</sub> into the atmosphere. Nitrogen is not the only fertilizer that leads to greenhouse gas emissions, and, looking at all fertilizers, A. Lappé (2010) estimates that the production and distribution of fertilizers makes up 1.5% to 2% of the total global warming effect of emissions. The application of fertilizer on crops is a large consumer of energy as well. Johanns, Chase, and Liebman's 2012 research into crop rotation mentioned earlier also delved into energy use for different crop rotations. They showed that the energy use for corn in a two crop cycle was 5.83 million BTU with 61% of the energy use coming from fertilizer use, whereas, in 3 and 4 crop rotations, the energy use



for corn was 2.45 million BTU with 17% from fertilizers and 2.63 million BTU with 25% from fertilizers, respectively. This means that, for these crops, the average consumption of fuel also increases. The two crop cycle was found to have used the energy equivalent of 25.43 gallons of diesel fuel per acre, while a three crop rotation only used 10.15 gallons per acre and a four crop rotation used 10.80 gallons per acre. Through the moving away from typical crop rotations, farmers increase their consumption of energy and the consumption of diesel fuel, the burning of which is believed to lead to an increase in greenhouse gases (Johanns, Chase, and Liebman, 2012). Data based on energy consumption associated with corn production and ethanol production has led many to question whether or not the predictions about the energy benefits of ethanol could be misreported.

Patzek, at UC Berkeley, questioned the findings by others who put the energy return to ethanol between .9 and 1.5 the energy consumed in its production. Patzek noticed that in many of the calculations conducted by other researchers that there were energy costs that were not being attributed to the production of corn and ethanol. Patzek went to work trying to account for energy costs that he believed others missed, including the fuel used in the production of corn seed and fertilizers, fuel consumption from transportation, and water and waste water costs. With all of these new costs being attributed to the production of corn-ethanol, the net energy lost is 65% by the time ethanol is used as energy, making it seem like not a very green alternative to gasoline (Patzek, 2004). By comparison, the energy return on investment for oil and gas in the United States was 11:1 for domestic and 12:1 for imports in 2007 (Hall, Lambert, &

Balogh, 2014). Pimentel et al. (2008) does not believe that ethanol could make an actually impact on fossil fuel consumption in the United States since the conversion of all the corn produce would only replace 7% of total oil consumption in the US. Pimentel also estimates that if all the solar energy collected by plants could be converted to fossil energy that it would only replace half of the energy used each year. If only farms and commercial forests are considered this number only is one sixth (as cited in Ikerd, 2010). In comparison, sugarcane is a better source of energy. Twice as much energy can be obtained per acre than corn, but sugarcane is not the answer either (de Gorter & Taylor, 2010). Bioenergy is an inefficient use of land, as sugarcane only turns .5% of solar radiation into sugar and only .2% of solar radiation is converted to ethanol. In Iowa, corn only turns .3% of radiation into biomass, and only .15% to ethanol. The higher energy conversion efficiencies of photovoltaic systems make them better for land use efficiency (Searchinger & Heimlich, 2015).

Also, unlike gasoline, corn-ethanol can currently only be transported by trucks, trains, or barges, which also leads to the higher consumption of fuel associated with corn-ethanol. Corn-ethanol's highly corrosive nature means that it cannot be moved by pipelines and makes it dependent on these forms of transportation that require high consumption of fossil fuels. Ethanol's properties limit it as a large scale fuel source because of its damaging effects on steel and rubber (Jarrell, 2013). The transportation of feedstocks to, and ethanol from, processing facilities is expected to continue to stay expensive even with future technological innovations because processing facilities are expected to stay small and numerous. Increased consumption of ethanol will lead to an

increase in the number of processing facilities, which will each have their own externalities (National Research Council, 2010).

The myriad of uses of fossil fuel in the production process, from the corn seed to the final step of putting ethanol into an automobile, has an environmental effect in this country, and the inputs into production are also damaging water and air quality at home, but what impact is corn-ethanol production having overseas?

Lappé, an earth scientist at Stanford, looked into the overseas impact of corn-ethanol production in the United States. Lappé found that with increase demand for corn, and a larger portion of corn being used for ethanol than food and cattle feed – which two thirds of the corn grown in the United States used to go to – is the cause for the increased deforestation of the rainforest in Brazil (G. Lappé, 2011).

Corn is a private good which is both rival and excludable. This means that when corn is used in the production of ethanol it can no longer be used to meet the demands for the food supply. In the year 2000, 90% of corn produced in the United States went to directly food or to feed animals and only 5% went to ethanol. In the year 2013, 40% of the United States' corn went to ethanol and 45% went to feed (Conca, 2014). This is an issue since the United States produces forty percent of the world's corn supply and, with a larger demand coming from fuel, the world's food supply must be made up elsewhere (G. Lappé, 2011).

According to Laurance et al. (2001) of the Smithsonian Tropic Research Institute, Brazil is the world's second largest producer of soybeans and as corn crops in the United States increased by 19 percent from 2006 to 2014, soybean crops decreased by 16

percent, meaning that production needed to be made up elsewhere. The decrease in supply of soy, with the increase in price of corn, caused the price of soy, and soy fed livestock, to increase. With a decrease in supply which did not meet demand, and an increase in the price of soybeans, Brazil took up larger soybean production, but at the cost of rainforest that was chopped down, or burnt, to provide more farmland, and the destruction may be worse than originally believed.

According to the Berenguer et al. (2014), much of the devastation to the rainforest associated with the removal of trees through logging and burning is larger than previously thought. Much of the destruction of the rainforest could not be captured through satellite imagery, which gave the impression that much more of the rainforest was intact. A recent team of researchers working on the issue went to Brazil and found that the issue with the impact farming is having on the rainforest is not just about deforestation, but also about degradation of the rainforest, which was not accurately measured using satellite imagery.

The researchers also acknowledge that it is hard to measure degradation from the ground, and, although they believe the loss of carbon associated with degradation makes up 40% of the carbon loss associated with the destruction of the rainforest in Brazil, they currently cannot say for sure how severe the losses are (Berenguer et al., 2014). These severe losses in land quality are not just something happening in Brazil, but are also happening in the American heartland.

The Food and Agriculture Organization of the United Nations (1993) points to improper land use and farming techniques, such as moving farming onto marginal lands

and inadequate crop rotation, to causing land degradation in agricultural areas. The National Resources Conservation Services at the USDA saw this as being such an extreme issue surrounding the increase in grain prices as a result of ethanol subsidies that they released a pamphlet out to Wisconsin farmers in 2007. As a concern shared by multiple agencies, what are the consequences of these actions that have been associated with corn-ethanol subsidization?

These inadequate farming practices can lead to increased erosion, with an increased loss of nutrient-rich topsoil. This increased erosion does not only make farmland less productive, but also leads to an increased amount of sediment in waterways, which makes it difficult for wildlife to flourish in the streams and rivers it is washed into. The loss of nutrients also contributes to the previously described higher demand in fertilizers and pesticides, and the increased erosion pushes more of these chemicals into waterways and allows them to soak into groundwater sources, polluting them with phosphorous, nitrogen, and pesticides (USDA National Resources Conservation Services, 2007).

The increase in prices of both soybeans and corn are not only causing deforestation and degradation in the rainforest and land and water degradation in the United States, but are having other negative consequences, since, as mentioned earlier, corn is also a major contributor to the food supply.

### **2.3 Non-Environmental Negative Externalities**

The increase in demand for corn has brought the price per bushel of corn higher than the EPA could predict. With corn hovering around \$7 per bushel in 2013, the price

changes have a large impact on food production in the United States and around the world, as an increase in the supply of ethanol means a decrease in the supply of corn for food.

The decrease in supply of corn to the world market from the United States from an increase in demand for ethanol can be attributed to famines around the world in 2010 and 2011, in countries that saw poor crop yields of their own, and also as the cause of the 2008 commodity price spike. These factors are also attributed to the riots that were sparked in many parts of the world during this same time (G. Lappé, 2011). This is because biofuels disproportionately impact developing areas.

Meeting current or future biofuels mandates would significantly increase prices of fuel crops by 2020, which would decrease global GDP and cause a significant reduction in the food supply in developing countries (Timilsina, Beghin, van der Mensbrugge, and Mevel, 2010). Even ushering in a second wave of ethanol from corn stover would lead to increased prices as a result of increased demand (National Research Council, 2010).

Higher corn prices also have an effect on the food supply in the United States, since corn is used in many of the foods consumed in the United States and since such a large portion of the corn produced in this country goes to livestock feed. Senators Toomey and Feinstein introduced a bill in February 2015 to repeal the ethanol mandate because they believe the continuation of the mandate would lead to an increase in the price of corn and, subsequently, food (Barron-Lopez, 2015). The future of food may be in trouble without the price increase associated with ethanol production.

Currently, the United States and Canada are the only major grain exporters, but this may be coming to an end. The United States is expected to cease exportation in 2025 to meet growing domestic demand. In 2006 there were 1.8 acres of land per person to grow food, with a requirement of 1.2 acres for current nutritional standards, but, with current growth rates, there will only be .6 acres per person by 2050. This situation may be exasperated by the decline in production of oil and natural gas and by ethanol mandates (Pfeiffer, 2006). The price and growing population is not the only way food is being compromised.

In 2011, the Department of Agriculture approved the use of a type of corn that would produce an enzyme that would make it easier to convert the corn to ethanol. This enzyme was normally added by the ethanol plants, but there is a belief that the corn producing the enzyme itself will cut down on the energy and water consumption of ethanol plants. This sounds like a good proposal when looking at the possible energy return of ethanol described early, but this one strain of maize, according to its producer, Syngenta, could completely compromise food production.

Cross pollination with corn designated for food crops can compromise the food produced with that corn. Cross pollination is not the only way food could be compromised by this new corn hybrid. Syngenta's own research showed that one kernel of this new corn amongst 10,000 kernels destined for food would compromise the food processed. This would have large economic impacts for food producers, from recalls to disruption of exports.

## **2.4 Corn-Ethanol as Fuel**

Corn-ethanol was subsidized as fuel to help aid the U.S. in its movement toward energy independence and reduction in greenhouse gases. The American Coalition for Ethanol (2014) believes that U.S. corn-ethanol production could reduce oil imports by one third and that corn-ethanol use could reduce greenhouse gases by 35%-46%, but this data misses issues what make corn-ethanol different from petroleum as a fuel.

Part of the reason corn-ethanol differs from petroleum as a fuel is because of the fact that when used to fuel motor vehicles it creates a reduction in fuel efficiency. According to the U.S. Department of Energy (2009), this drop in fuel economy for using a 10% mixture of corn-ethanol may be anywhere from three to five percent when compared with pure gasoline, and the loss in fuel efficiency associated with corn-ethanol only gets worse as the percentage of the fuel mixture that is corn-ethanol increases . The higher consumption of fuel associated with corn-ethanol is not just tied to its lower efficiency, but is also tied to corn-ethanol's corrosive nature that requires it to be transported by trucks, trains, or barges and to be more dependent on fossil fuels (Jarrell, 2013). The corrosive nature of corn-ethanol does not just change the way it is shipped, but also damages engines it is used in (Van Hoesen, 2015). Using ethanol as fuel also appears to not reduce greenhouse gas emissions when compared to fossil fuels.

Wallace (2009) reports that the EPA's attorneys admitted in 1995 that ethanol would increase smog. Taylor (2009) gives evidence that while ethanol reduces carbon monoxide, it actually increases the emission of hydrocarbons, nitrogen oxides, acetaldehyde, formaldehyde, ethylene, and methanol, all of which have been associated



with increased smog in urban areas and the detrimental health effects associated with that smog.

Corn-ethanol not only increases the use of fossil fuels in its production and through non-sustainable farming techniques associated with its subsidization, but it also increases the use of fossil fuels and increases greenhouse gas emissions through its main role as an alternative source of energy.

## **2.5 Conclusion**

Corn-ethanol is unable to live up to the standards that allowed it to initially be subsidized. The number of environmental and non-environmental externalities associated with ethanol and its inefficiencies as a fuel source mean that it will never create energy independence for the United States and it will meet the EPA standards for efficiency as a fuel or in reducing emissions when compared to petroleum. Other methods for achieving these goals need to be considered and this leads to looking at the energy conservation possibilities of sustainable farming practices.

## **Chapter 3: Empirical Analysis of the Energy Conservation Possibilities of Sustainable Farming**

### **3.1 Introduction**

In 2012, Johanns, Chase, and Liebman looked at the energy use and economic return of different crop rotation practices by using data collected from the Iowa State University Extension and Outreach Marsden Research Farm. This research was conducted to address variable energy costs through a comparison of 2 year (GMO corn and soybeans), 3 year (non-GMO corn, soybeans, and oats), and 4 year rotations (non-GMO corn, soybeans, oats, and alfalfa) from 2006 – 2011. This research can be tied to the 2012 study conducted by Davis, Hill, Chase, Johanns, and Liebman from 2003 to 2011, in which they investigated ways cropping diversity could benefit the ecosystem stating that “[m]ost crop production systems in the United States are characterized by low species and management diversity, high use of fossil energy and agrichemicals, and large negative impacts on the environment” (p. 1). In Johanns, Chase, and Liebman’s 2012 research they found a drop in energy consumption from a 2 year to 3 and 4 year crop rotations. When considering energy consumption, the researchers did not consider storage, handling, and hauling past the original removal of the crop. The three and four year rotations also saw a change in application of fertilizers, insecticides, and herbicides through banding, which lead to a decrease in overall usage of these agrichemicals. Also,

during the 3 and 4 year rotations, manure from an available livestock operation was used as a fertilizer source instead of commercial fertilizers. Even though manure was used, the manure was assessed for nutrient content to compare it to the cost of using commercially available fertilizers. Energy use was separated into five categories to assess which consumed the most energy. The five categories are the following: seed, grain drying, field operations, pesticides, and fertilizers. The researchers point out that seed looks at seed production and grain drying was separated to show how energy intensive the process can be. Field operations were fuel requirements for field operations excluding fertilizer and pesticide application, which were given their own categories. Fertilizer use was averaged over the time period to give a perspective into long term energy requirements, and the energy use in pesticides were based on active ingredient in application.

Assessing these methods of farming, and the decreased agrichemical and energy use associated with them, will allow for the calculation of energy savings at a multi-state level and the comparison of these energy savings to the amount of ethanol used throughout these states in 2013.

### **3.2 Methodology & Data**

Figure 1 shows the energy usage Johanns, Chase, and Liebman (2012) observed for each rotation. It can be seen that there is a drop in energy usage from the 2 year rotation to the 3 and 4 year rotations. Figure 1 also illustrates how the energy usage was partitioned into different areas of farm practices. By looking at Figure 3.1, it becomes apparent that fertilizer application drops significantly from the 2 year rotation to the 3 and

4 year rotations. In the 2 year rotation, fertilizer application uses more energy than the total energy use in either the 3 year rotation or the 4 year rotation.

Table 1 looks at energy use by category, taking the information in Figure 1 and showing what percentage of energy use in each rotation a category consumes. It can be seen that fertilizer use drops drastically from taking up 61% of all energy use in the 2 year rotation to only taking up 17% and 25% of energy use in the 3 year and 4 year rotations, respectively. It can also be seen that after the implementation of 3 year and 4 year rotations that field operations becomes the chief consumer of energy.

Figure 1 considers energy consumption in terms of millions of BTU per acre, but energy consumption can also be illustrated through diesel fuel equivalents considered in gallons per acre. As Johanns, Chase, and Liebman (2012) describe, “[t]his represents the energy consumption in an easily recognizable form, even though not all energy usage was associated with diesel fuel” (p. 4), and, because it is easily recognizable, diesel fuel equivalents in terms of gallons per acre will be used from here forward<sup>1</sup>. Energy usage by rotation in terms of diesel fuel equivalents can be found in Table 2. It can be seen that differences in energy use were the largest between 2 year and 3 year rotations, with energy savings equivalent to 15.27 gallons of diesel fuel per acre. Using the energy savings in 3 year rotations, an evaluation of crop rotations is the next step to find possible energy savings where corn production is the highest.

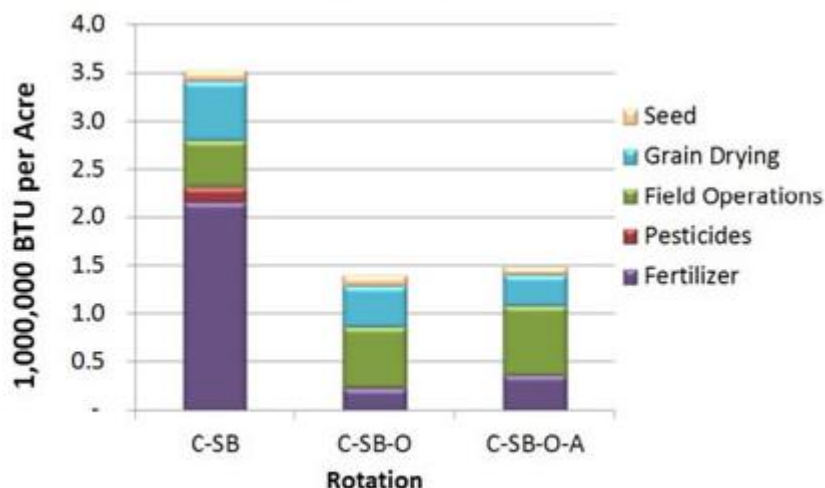


Figure 1 Distribution of Energy Inputs by Selected Energy Categories, 2006-2011. Reprinted from Johanns, A.M., Chase, C., & Liebman, M. (2012) Energy and economic returns by crop rotation. Retrieved from <http://www.extension.iastate.edu/agdm/crops/html/a1-90.html>

	GMO	Non-GMO	
	C-SB	C-SB-O	C-SB-O-A
Seed	3%	8%	6%
Grain Drying	17%	30%	21%
Field Operations	14%	44%	47%
Pesticides	5%	1%	1%
Fertilizer	61%	17%	25%

Table 1 Percent of Energy Use by Category. Reprinted from Johanns, A.M., Chase, C., & Liebman, M. (2012) Energy and economic returns by crop rotation. Retrieved from <http://www.extension.iastate.edu/agdm/crops/html/a1-90.html>

	2yr	3yr	4yr
Diesel Fuel Equivalents (gal/acre)	25.43	10.16	10.80

Table 2 Energy Usage by Rotation in Diesel Fuel Equivalents. Reprinted from Johanns, A.M., Chase, C., & Liebman, M. (2012) Energy and economic returns by crop rotation. Retrieved from <http://www.extension.iastate.edu/agdm/crops/html/a1-90.html>

Research by Boryan, Craig, and Willis (2008) at the USDA National Agricultural Statistics Service identified crop rotations in Iowa, Illinois and Nebraska, the three largest corn producers, over the period of 2003 – 2007 as a percentage of total cropland in each state. In this research four types of crop rotations were identified: 1) Corn (2003), Soy (2004), Corn (2005), Soy (2006), Corn (2007), 2) Soy (2003), Corn (2004), Soy (2005), Corn (2006), Soy (2007), 3) Continuous Corn (2003 – 2007), and 4) Four Years of Corn and One Year of Another (2003 – 2007). These rotational patterns made up 59% of cropland in Iowa, 49.5% of cropland in Illinois, and 43.4% of cropland in Nebraska. These numbers do not paint a clear picture of crop production in these states.

Although this data shows particular crop rotations, it leaves out millions of acres of corn and soybeans produced during this period. This data also does not clearly express crop production in these states since the percentages come from total cropland, which includes land for grazing animals and orchards, vineyards, and other crops that are not part of rotations and are continuously produced. Annual crop production data from the USDA portrays actual production in these states more accurately.

Annual crop production data in Iowa shows corn and soybeans making up over 92% of the principal crops planted during this time while constituting over 22.8 million acres of land. In Illinois an average of around 21.5 million acres were planted, which constituted over 92% of all principal crops in the state over these years. In Nebraska, just

fewer than 70% of the principal crops planted were corn and soybeans at an average of over 13 million acres during this period. Illinois makes it the clearest why these numbers may not be helpful in describes all crop rotations in these states (USDA, 2014). With Illinois having 26.7 million acres of cropland, the 49.5% that fall into these rotations would only account for just over 13.2 million acres, which is around 8 million less acres than the actual acres planted in the state. The production on those other 8 million acres needs to be described to understand production and cropping patterns<sup>2</sup>.

In figuring out how crop rotations were implemented in these states, the fact that the states in question consistently planted around the same percentage of acres to corn and soybeans can be interpreted as a sign that few farmers were including a third crop into their rotations. Using this idea, the next step is to look at how acres in these states were planted in prior years during this period to estimate what percentage of farmers were using 2 crop rotations or continuous planting. 2 crop rotations are not considered to be solely rotations 1) or 2) as described by Boryan, Craig, and Willis (2008). These descriptions are made to highlight that this land was not in a 3 year or 4 year crop rotation during this period. This estimate was calculated by using data on total acres of individual crops in two years, corn in 2005 and soybeans in 2006, and how many acres of these crops were either soybeans or corn the prior year and what percentage of the total acres in the given year this constituted.

Table 3 shows how many total acres were planted to corn and what was planted on the same acres the year prior in Iowa, Illinois, Nebraska, and Minnesota during 2005.

Table 4 shows soybean how many total acres were planted to soybeans and what was

planted on the same acres the year prior in Iowa, Illinois, Nebraska, and Minnesota during 2006. The column titled, “Percentages of Acres,” in both tables represents the percentage of acres that were corn and soybeans the prior year.

	Total	Previously Corn	Previously Soybeans	Previously Either	Percentage of Acres
Iowa	12802.748	3368.09	9272.876	12640.966	98.74%
Illinois	12100.265	2976.74	8870.421	11841.61	97.86%
Nebraska	8501.575	2518.936	4654.01	7172.946	84.37%
Minnesota	7297.875	1666.175	5212.82	6878.995	94.26%

Table 3 2005 Corn Production in 1000 Acres. Adapted from USDA Economic Research Service (2014), Agricultural resource management survey. Retrieved from <http://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/arms-data.aspx>

	Total	Previously Corn	Previously Soybeans <sup>3</sup>	Previously Either	Percentage of Acres
Iowa	10149.98	9938.491	*	9938.491	97.92%
Illinois	10100.1	9386.534	*	9386.534	92.94%
Nebraska	5050.089	4717.67	*	4717.67	93.42%
Minnesota	7350.149	6311.565	*	6311.565	85.87%

Table 4 2006 Soybean Production in 1000 Acres. Adapted from USDA Economic Research Service (2014), Agricultural resource management survey. Retrieved from <http://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/arms-data.aspx>

Using the percentage of acres that were planted to corn and soybeans the prior year for the four states given, it is possible to make conservative estimates of the percentage of crops in either 2 crop corn or soybeans rotations or in continuous crop rotations. Combining the estimates of acres planted to 2 crop or continuous crop rotations with the energy usage described by Johanns, Chase, and Liebman (2012) allows for the calculation of potential energy savings<sup>4</sup>.



Based on this analysis, Table 5 shows the percentage and number of acres planted that were not in 3 year or 4 year rotations in Iowa, Illinois, Nebraska, and Minnesota. This gives a yearly average of 62.406 million acres in Iowa, Illinois, Nebraska, and Minnesota not planted to 3 year or 4 year rotations from 2003 to 2007. Given that it was previously shown that the switch from a 2 year rotation to a 3 year rotation could save the energy equivalent of 15.27 gallons of diesel fuel per acre, the switch to 3 year rotations in these 4 states would save the energy equivalent of nearly 953 million gallons of diesel fuel per year. This is not the only area that energy could be saved using the methods described by Johanns, Chase, and Liebman (2012).

	% of Acres	Total Acres (Million Acre)
Iowa	92%	20.976
Illinois	90%	19.35
Nebraska	80%	10.4
Minnesota	80%	11.68

Table 5 2003 – 2007 Acres not in 3 Year or 4 Year Rotations.

In their research, Johanns, Craig, and Liebman (2012) saw a decrease in energy used to apply fertilizers, herbicides, and pesticides through use of a 3 year crop rotation and the practice of banding<sup>5</sup>. These decreases in energy use in application were tied to a decrease in overall usage of fertilizers, herbicides, and pesticides. In evaluating energy conservation, only nitrogen use in corn will be considered. Nitrogen is used most in corn production to produce optimum yields and is the most energy intensive among fertilizers since it uses natural gas both as an energy source in production and to create ammonia, a necessary ingredient in its production (Sawyer, Hanna, & Petersen, 2010).

Johanns, Chase, and Liebman (2012) saw the use of banding in the 3 year rotation decrease the average nitrogen fertilizer use to 2.39% of the 2 year rotation's average for corn, from 140.9 lbs/acre in the 2 year rotation to 3.32 lbs/acre in the 3 year rotation. Sawyer, Hanna, and Petersen (2010) showed that, for a 2 year rotation of corn and soybeans, an application of 125 lbs/acre of nitrogen used the diesel fuel energy equivalent of 13.3 gallons in production with an additional 1.9 gallons used in transport and application. Only energy use for production is considered since energy use in application was previously accounted for when calculating the energy savings of 3 year rotations. This value should be considered a conservative estimate as continuous corn needs more nitrogen to reach desired yields, which comes with increased energy use in production, transportation, and application.

Table 6 provides the average number of pounds of fertilizer that were applied per acre of corn in Iowa, Illinois, Nebraska and Minnesota in 2005 while also illustrating the number of acres these averages were applied to in each state. This data can be used to evaluate how much energy can be saved through the implementation of banding practices.

	Average N applied (lbs/acre)	% of Acres Applied	Total Acres (1000 Acre)	Acres Applied
Iowa	141.242	91.44%	12802.798	11707.01
Illinois	149.459	99.08%	12100.265	11988.82
Nebraska	132.48	98.81%	8501.575	8400.151
Minnesota	134.4	96.37%	7297.875	7032.597

Table 6 2005 Nitrogen Application for Corn Production 2005 Corn Production in 1000 Acres. Adapted from USDA Economic Research Service (2014), Agricultural resource management survey. Retrieved from <http://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/arms-data.aspx>

Table 6 shows that the implementation of banding in fertilizer application would need only an average of 3.32 lbs/acre of nitrogen and would decrease average fertilizer use in all four states by more than 125 lbs/acre. This would mean that there would be more than a 13.3 gallons/acre diesel fuel energy equivalent savings through the implementation of this technique. By converting to banding in nitrogen fertilizer application these four states would save over 520 million gallons of diesel fuel energy equivalent. Implementation of banding and 3 year rotations can lead to large energy savings. An additional technique could also help increase energy savings.

In 2010, the USDA's Economic Research Service released a report stating that no till farming with corn was considerably less prevalent in Iowa, Illinois, and Minnesota than elsewhere. The USDA's Natural Resources Conservation Services also reported in 2005 that implementation of no till farming from conventional tillage farming could save at least 3.5 gallons of fuel per acre. Looking at principal crop production during the time period in Iowa, Illinois, Nebraska, and Minnesota with conventional tillage practices will give an idea of fuel savings in these states.

Principal crop production in Iowa had over 2.2 million acres in conventional tillage, in Illinois over 4.5 million acres were in conventional tillage, in Nebraska over 1.4 million acres were in conventional tillage, and in Minnesota over 5.5 million acres were in conventional tillage (Horowitz, Ebel, & Ueda, 2010). With nearly 13.8 million acres of land in these four states using conventional tillage conservative fuel savings of at least 3.5 gallons per acre would save over 48 million gallons of fuel in these states.

### **3.3 Results**

In Iowa, Illinois, Nebraska, and Minnesota, through the implementation of 3 year rotations, fertilizer, pesticide and herbicide banding, and no tillage farming, a conservative estimate of energy savings equivalent to over 1.5 billion gallons of diesel fuel per year could be achieved. In 2013, Iowa, Illinois, Nebraska, and Minnesota consumed less than 965 million gallons of ethanol (EIA, 2014a). Not only is more energy conserved through sustainable farming practices, but this energy would be removed from consumption; ethanol simply replaces another energy source without decreasing energy consumption. The 1.5 billion gallons of diesel fuel equivalent per year is a conservative calculation for a number of reasons.

The reason this number is conservative is because continuous corn is more energy intensive and not all farmers planting two crops are using 2 year rotations. The decrease in use of phosphorus, potash, herbicides, and pesticides would lead to additional energy savings through the decreased production and transportation of these materials. Farmers that do not use conventional tillage are not necessarily using zero tillage, and no tillage for these farms could save more energy. Diesel fuel continues to be the greatest expense on Iowa farms and even switching from conventional tillage to reduced tillage can reduce fuel expenses and equipment depreciation (Peterson, 2012). Lastly, other practices can aid these procedures and decrease the need in fertilizers and pesticides. An example is the intercropping winter wheat and red clover, which 2006 research from Gibson, Singer, Barnhart, and Blaser states could provide subsequent corn with the replacement of

nitrogen equivalent to 80 lbs/acre, further decreasing the need for nitrogen production and conserving more energy.

### **3.4 Conclusion**

Davis et al. (2012) showed that when compared to conventional systems using 3 year and 4 year crop rotations would result in farmers seeing similar, if not greater, grain yields, mass of harvested products, and profits. While they suppressed weeds effectively in all cropping systems, the freshwater quality in diverse, multi-year rotations experienced toxicity two orders of magnitude lower than conventional systems.

Lamberton (2012), writing in response to Davis et al. (2012), stated that actual increases in yields were 4% for corn and 9% for soybeans and the herbicide toxicity of freshwater 200 times lower in diverse cropping systems. Also, changing from conventional to more diverse cropping patterns, unlike using herbicide tolerant or Bt crops, will not stimulate resistant weeds and will continue to stifle pest levels while producing high yields<sup>6</sup> (Mellon, 2012).

In response to questions surrounding the 2012 research by Davis et al., the Leopold Center for Sustainable Agriculture (2012), which funded their research, highlighted that these diverse cropping systems work with both GMO and non-GMO crops without penalizing yields and that the diverse cropping systems actually grant farmers more flexibility in their choice of seeds. Along with this, the Leopold Center (2012) pointed out that these cropping systems would be able to address apprehensions surrounding herbicide tolerant plants, pesticide tolerant insects, climate change, and quality of rural life while being able to work across regions with different sets of diverse

plants. 3 year and 4 year rotations have been recognized as answers to weed resistance while reducing the need for herbicide by 88% (Davis et al., 2012). Using herbicides and pesticides could control the pest and weed problem, but there is the increased risk of decreased yields through the phytotoxic effect (Hennessy, 2006). Herbicides no longer have any impact for some plants. There are nearly twenty weeds in Iowa that have been identified as herbicide resistant. Palmer amaranth, one of the herbicide resistant crops identified, has the ability to cut corn and soybean yields by 67%. These potential losses have led to increased use of herbicides, even though crop rotations have been proven effective at decreasing Palmer amaranth's ability to spread (Eller, 2014b). Integrating livestock operations into cropping systems through the use of manure as fertilizer, along with decreasing the amount of herbicides and pesticides used, not only lowers input costs for farmers, but also benefits the environment.

Herbicides, pesticides, and synthetic fertilizer can impact wildlife, fish, pollinators, and humans through water pollution, toxicity and cancer causing chemicals. An issue with herbicides and pesticides is that they impact non-targets and result in resistance in their targets (Leopold Center for Sustainable Agriculture, 2012). Using cattle manure and nitrogen fixing through intercropping red clover and alfalfa resulted in decreased use of synthetic nitrogen by 80 – 87% (Lamberton, 2012). The highest suggested synthetic nitrogen fertilizer rates for corn come after planting corn the year prior, and these high fertilizer rates still are unable to reproduce the yields of planting corn after soybeans or alfalfa. Even the occasional planting of soybeans cannot produce the results of diverse cropping systems, as continuous corn and second and third year

corn after soybeans have similar yield and require the same amount of nitrogen (Mallarino, 2006). A 30 year study, starting in 1962, of nitrogen applications found that average nitrogen recovery in crops in the United States was 49 – 51% and that the residual nitrogen left in the soil led to a high potential for soil acidity (Barak, 1997). While a decrease in the use of herbicides, pesticides, and synthetic fertilizers can benefit soil and water quality, so can diverse crop rotations themselves.

Pimentel et. al (1995) ranked soil erosion as one of the most serious risks facing global cropland, but crop rotations can benefit. Diverse cropping patterns can help combat soil erosion and degradation while preserving soil moisture (Campbell et. al, 1990). Reduced tillage also has the ability to help preserve soil moisture and soil quality, which all aids soil tilth (Peterson, 2012). In research by the Environmental Working Group (EWG), they found that in April, May, and June 2014 Iowa farms lost 15 million tons of topsoil, and in an interview, senior vice president for agriculture and natural resources at EWG, Craig Cox stated that using reduced tillage or no tillage, and by changing fertilizer application, has been proven to prevent topsoil losses, but has not been used by enough farmers (as cited in C. Doering, 2014). A diverse set of crops in 3 year and 4 year rotations can also decrease topsoil loss during severe weather (Lamberton, 2012). Results would not be immediate, as the amount of sediment and agrichemicals in waterways is dependent on the cropping history of the land, making more immediate adoption even more important (National Research Council, 2010). Windblown particles can cause problems through siltation, which can decrease the value of amenities and pollute rivers and reservoirs that are used for drinking water, which can require

government action and funds to clean. The more varied landscapes associated with diverse cropping systems can reduce the risk of flooding, which also can require government funds (Pimentel et al., 1995). Although the results seen by Davis et al. (2012) were based in Iowa, they are not unique to the area and imply similar benefits elsewhere.

A 16 year study in Minnesota, starting in 1989, researched how yields were impacted by different input systems on 2 year corn and soybean rotations and 4 year corn, soybean, alfalfa, and oats rotations. The input systems were zero external input (ZEI), low external input (LEI), high external input (HEI), and organic input (OI). Oat yields stabilized and were highest with LEI, HEI, and OI. Alfalfa had highest yields with LEI, HEI, and OI during the first 8 years, but yields were highest with OI during the second 8 years. Corn had maximum yields with HEI in the 2 year rotation and LEI, HEI, and OI in the 4 year rotation. Corn yields from the 2 year to 4 year rotation showed no difference when both in HEI systems. Soybean yields were 7% higher with 4 year rotations and highest with LEI and HEI. Corn and Soybean yields were 7% and 16% higher in the 2 year HEI system than in the 4 year OI system, but both systems had the same net return. This research confirms that diverse cropping systems can see similar, if not greater, yields from using diverse cropping patterns while reducing inputs and achieving similar returns (Coulter et al., 2011). Research outside the United States also points to similar results.

Introducing forage crops, which include alfalfa, into crop rotations in the Northern Great Plains in Canada has been shown to provide higher grain yields, suppress



weed populations, increase the quality of soil, provide better habitats for wildlife, and reduce energy requirements. Reduced tillage was introduced with these cropping systems and shown to benefit yields in semi-arid regions by helping maintain soil moisture while preserving soil quality (Entz et al., 2002). Farmers on the Canadian prairie also notice the benefits of introducing forage crops into their rotations. 67% of farmers in semi-arid regions reported increased yields, with higher increases in wetter areas. 83% noticed a decrease in weeds after forages, and this was while many were using fewer herbicides (Entz, Bullied, and Katep-Mupondwa, 1995). Benefits of diverse crop rotations are also identified in Asia and Europe.

Diverse crop rotations have been identified as ways to increase farm labor employment opportunities and exports in South Asia (Joshi, Gulati, Birthal, and Tewari, 2004). In the European Union, diverse cropping patterns are believed to be essential in the sustainable management of natural resources, and the same benefits to ecosystem have been identified as in the United States and Canada. 3 year and 4 year rotations with crops from diverse botanical families and minimal tillage are recommended in the European Union (Mudgal et al., 2010). With diverse cropping systems helping the environment, conserving energy, and potentially protecting government funds, why are more farmers not implementing crop rotations?

Mellon (2012) suggests that it is farmers who are not interested in changing because they continue to accumulate profits. Mellon (2012) highlights that farmers' choices are based on government funding through subsidies, research agendas, crop insurance, and farmer education, which leads farmers to use simple rotations while

relying on agrichemicals. The Leopold Center (2012) believes that the fact that there are no price signals, market structures, or policies currently in place to support diverse crop rotations is an issue suppressing widespread implementation, but they believe that early adopters could usher in a new era of policies no different than the Conservation Reserve Program or the Conservation Security Program. The issue both Mellon and the Leopold Center look at is the need for new policies.

## **Chapter 4: Policy Implications of Energy Conservation from Sustainable Farming**

### **4.1 Introduction**

Diverse cropping systems present, for many farmers, a new way of running on farm operations, and the fact that they are able to see similar, if not greater, profits through these systems as conventional systems may not be compensation enough to convince farmers to change. Just as Kurkalova, Kling, & Zhao (2006) saw when looking at getting farmers to adopt conservation tillage, there are uncertainties surrounding changing practices and farmers risk aversion and irreversible sunk investments may deter adoption of sustainable practices . Farmers will need to be compensated for the uncertainties, and subsidies will need to play a role in overcoming adoption premiums.

Reasons for non-adoption would need to be taken into account to design subsidies that compensated correctly for the adoption premium. This applies both to changes in crop rotations and changes to tillage practices. Kurkalova, Kling, and Zhao's 2006 research on subsidization for adoption of conservational tillage would need to be re-evaluated for current markets and to include no tillage, which can provide additional environmental gains with additional fuel savings. There would not be an issue switching away from solely producing corn and soybeans since all of the crops in diverse 3 year and 4 year crop rotations have food market values. Farmers will react to profit signals, so the only way diverse cropping systems would cause a negative economic reaction would be if the government does not place value on the environmental and energy independence

goals that it used to promote the subsidization of corn ethanol. The subsidies put into place to promote diverse cropping patterns and achieve societal goals would be similar to those currently in place for the Conservation Reserve Program (CRP) and the Conservation Security Program (CSP). While alfalfa and small grains perform the task of being price savers and profit stabilizers, more than money makers, markets for these goods currently consist of them being sold or used as feed, sold for human consumption, or used as green fertilizer, but additional markets would also need to be established to give additional incentive to change operations (Leopold Center for Sustainable Agriculture, 2012). The use of alfalfa or small grains as animal feed can be a substitute for corn and, as a result, negate any decreases in corn production resulting from diverse cropping systems. With the United States being an importer of oats based on mass achieved in other regions and diverse cropping systems being better adapted to a variety of GMO and non-GMO crops, it is unrealistic to believe that a variety of oats that would achieve higher average mass would not be possible to create and add into cropping rotations to aid in oats grown in Iowa, Illinois, Nebraska, and Minnesota finding market share. The subsidization of diverse crop rotations and zero tillage and the establishment of markets for small grains and alfalfa are not just ways to incentivize farmers, but are also ways to correct for distorted energy and agricultural markets created by the US Federal Government.

Ethanol has seen promotion for 30 years by the Federal Government in the form of subsidies for production and infrastructure and tax breaks. While the direct subsidization of ethanol production ended, the Federal Government continues to support

corn-ethanol. Continued support for ethanol includes tax breaks and the Renewable Fuel Standard, which mandates production. Tax breaks include the Master Limited Partnership, which was altered to include the transportation and storage of alternative fuels in 2008 and grants access to a lower cost of capital. This lower cost of capital allows the building and operation of low-return assets, while still attracting investors through sufficient returns. Alternative Fuel Vehicle Refueling Property Credit is another tax break favoring ethanol, along with biodiesel, as it grants access to a 30% tax break to facilities that dispense certain alternative fuels. This was expected to end in 2013, but was still available for the 2014 financial year and is expected to be continued. These tax breaks essentially subsidize infrastructure while simultaneously picking which alternative energy source will come out on top. This support contributed to the expansion and overproduction of ethanol while leading to distorted markets (Taxpayers for Common Sense, 2014). Diverse cropping patterns and no till farming need subsidization to overcome the market distortions caused by the Federal Government's promotion of corn through ethanol policy. Even if the United States still values ethanol as part of their solution for achieving their environmental goals while relying less on foreign energy, subsidizing diverse cropping patterns will not have an impact.

Ethanol consumption is expected to peak by 2020 while ushering in cellulosic biofuels from switchgrass and, as a result, cropping systems should follow suit (EIA, 2012). Although, ethanol is set to lead to cellulosic biofuels, focusing on them as liquid based fuel may not be the correct solution. Instead of focusing on fuel for combustion engines, bioelectricity appears to be the better choice.

## 4.2 Additional Policy Areas

Campbell, Lobell, and Field (2009), while focusing on how bioenergy could maximize land-use efficiency, found that bioelectricity, when compared to cellulosic ethanol, produced an average of 81% more transportation kilometers. This would mean that a small sports utility vehicle powered by bioelectricity would be able to go 14,000 miles while an internal combustion engine would only be able to go 9000 miles on the energy produced by an acre of switchgrass (Carnegie Institution, 2009). This increase in range is achieved while offsetting 108% more emissions per unit of cropland than cellulosic ethanol, preventing the release of 10 tons of CO<sub>2</sub> per acre more than internal combustion engines. (Campbell, Lobell, and Field, 2009; Carnegie Institution, 2009). A contributing factor is the inefficiencies in use of energy by internal combustion engines, with average efficiencies for gasoline engines only being 15%, diesel engines being 20%, and electric vehicles being around 80% (Sandalow, 2009). Shifting to fully electric vehicles may not be immediately necessary either, and it is not the only advancement that can decrease fuel consumption.

A shift to plug-in hybrid electric vehicles (PHEV) has the potential to decrease oil imports by 52%. These decreases in oil imports come without a major change in the United States' electrical infrastructure, as there is currently available capacity for 84% of cars and light trucks to go 33 miles per day (National Research Council, 2010).

Autonomous cars may be just as important. In a 2014 interview, Brad Templeton, a consultant on Google's self-driving car, stated that the energy efficiency of driverless cars would be so high that they would not just replace cars currently on the market, but

would also replace trains and busses in major metropolitan areas<sup>1</sup> (Big Think, 2014). The government can aid in accelerating the adoption and production of autonomous cars by avoiding restrictive regulation and hindering policies that can limit the function of these vehicles. It is not just future technology that promises to save fuel; freight shipped by trains is also more energy efficient than that shipped by heavy trucks. Heavy trucks consume over 11.6 times as much energy BTU per short ton mile when compared to rail (Oakridge National Laboratory, 2014). Promotion of bioelectricity, electric vehicles, PHEV cars and light trucks, autonomous smart cars, and freight transported by rail should be a higher priority than ethanol for the United States if its goals are to improve environmental health while decreasing dependence on foreign energy. Completely moving away from combustion engines would not happen overnight, but there are ways that internal combustion engines could be improved in the meantime.

The climate change benefits of replacing petroleum with ethanol are nonexistent, and a cheaper, more effective method for reducing emissions would be to increase emission standards on vehicles while also raising Corporate Average Fuel Economy (CAFÉ) standards (Charles et al., 2013). Otto Doering (2006) pointed out in 2006 that a 10% increase in CAFÉ standards would save 14 billion gallons of fuel while only costing 1/3 of an ethanol subsidy to save the same amount. Although there are worries about increased miles driven as a result of increased fuel economy, research by The National Research Council (2002) showed that CAFÉ standards resulted in a 7% decrease in emissions. There may be another issue with the categories for vehicles within the CAFÉ standards that has only started to develop in recent times.

In 1979, the year after the CAFÉ standards were established, light-trucks only made up 9.7% of the market, but, by 2001, light-trucks made up 47% of the market (US Department of Transportation, 2011). This number continues to grow, as the 2015 prediction is for light-trucks to make up 56% of market share (Finlay, 2015). It must go along that many of these vehicles classified as light-trucks, which includes pickup trucks, vans, SUVs and CUVs, are being used as passenger vehicles, while having different fuel efficiency standards than cars. According to the Alternative Fuels Data Center (2014), average annual mileage for light-trucks was almost 4000 miles more than cars while consuming 43.7% more energy. An improvement in standards for all vehicle categories would help, but also a reevaluation of standards and regulations surrounding light-trucks also needs to be taken into account to end in energy consumption and greenhouse gas emissions. While CAFÉ standards are currently in place in the United States, so are policies that can promote sustainable farming practices.

#### **4.3 Current Sustainable Farming Policies in the United States and Abroad**

While this research only focused on the benefits in Iowa, Illinois, Nebraska, and Minnesota, the Leopold Center for Sustainable Agriculture (2012) states that the benefits of crop rotations can be seen in other areas of the United States. It has been shown that similar benefits to those highlighted by Davis et al. (2012) have been seen in Canada, the European Union, and Southern Asia. There are also currently policies in place, both in the United States and the European Union, that promote sustainable farming practices, including crop rotations, while looking to achieve similar environmental benefits as 3 year rotations, fertilizer banding, and zero till practices.



In the United States farmers are compensated by federal funds to leave lands fallow through CRP. The goal of CRP, as stated by the National Sustainable Agriculture Coalition (2014), is to promote the reduction of soil erosion, improvement of water quality, and reduction of damages by floods. These environmental goals are also achieved through the promotion of 3 year crop rotations and no till practices. Another part of the United States' platform is CSP, which promotes 5 year funding for conservation practices with the possibility of re-enrollment. CSP increases the amount paid when conservation is increased and it directly promotes crop rotations.

Farmers and ranchers enrolling in CSP must establish that they currently meet or exceed the threshold of standards set to improve long term sustainability for 2 or more resource concerns, or they must demonstrate that they will at the end of the contract. CSP began promoting soil health crop rotations in 2015, and this extended resource-conserving crop rotations described by the program in the years prior. The resource-conserving crop rotations include cover crops, forages, or green manures that reduce the inputs required in crop production. Farmers looking to qualify under the soil health crop rotations must have resource-conserving crops grown for two consecutive years and annual crops must be followed by cover crops. CSP also promotes the conservation of soil and the increase in soil quality through conservation tillage (National Sustainable Agriculture Coalition, 2015). This program directly promotes crop rotations while supporting a reduction in external inputs on farmland. While this does not necessarily guarantee diverse cropping systems or that a farmer will not produce corn in three of the five years under contract, with the other two being the mandatory resource-conserving

crops, it does show that the intent of the United States to promote nationwide programs that achieve similar environmental and resource goals as those that can be achieved by diverse cropping systems, fertilizer banding, and zero tillage. Similar practices are promoted through policy in the European Union.

In the European Union, the Common Agriculture Policy (CAP) includes the section on Good Agricultural and Environmental Conditions, which promotes crop rotations where applicable and as defined by Member States (MS). Germany and Ireland both conduct soil analyses and recommend crop rotations in certain situations. France and Luxembourg promote the production of at least 3 crops in a single year to increase plant diversification and the United Kingdom promotes rotations that improve the organic material in soil. Crop rotations also are included under the Rural Development area of CAP and are aimed at improving the environment and the countryside.

Under the Rural Development policy there are additional Agri-Environmental Measures, and these measures aim to protect the environment through sustainable farming. Farmers adhering to this policy voluntarily select measures for 3 years as prescribed by their MS. In certain regions these have included crop rotations. In Austria, crop rotations were sought to increase yields through the promotion of crop rotations, and 84% of farmers saw an increase within two years. Greece used crop rotations as a method to decrease nitrate pollution, and Portugal promoted traditional crop rotations to protect wild bird populations. Crop rotations were encouraged across the European Union as a way to reduce pesticide and nitrogen use (Mudgal et al., 2010). The promotion of crop rotations throughout different MS shows that diverse cropping patterns

can be used while trying to achieve a varied set of goals across different regions, which shows that policy supporting crop rotations could be made applicable nationwide in the United States.

#### **4.4 Conclusion**

Sustainable farmer practices of diverse crop rotations and zero tillage have the possibility of actually achieving the original goals of ethanol subsidization. These goals are achieved through decreasing farm operations, diverse crop rotations, and zero tillage, and they decrease emissions, water and land pollution, and energy consumption, completely removing it from use, not simply replacing it as ethanol does. Since profits for different cropping systems are similar, it may seem like there is no incentive for policy to change farmers cropping systems. The reality is that this is myopia. In the short-term, current cropping systems that use higher amounts of herbicides, pesticides, and synthetic fertilizers may seem efficient, but this is only because long term environmental health and weed and insect resistance are not accounted in the economics of farming operations correctly.

The United States government already supports nationwide programs through CRP and CSP that support and provide similar environmental and resource-conserving goals as diverse cropping patterns and zero tillage farming. A promotion of different crops by region would make a program that endorses both diverse cropping and zero till practices applicable to districts in the United States outside of Iowa, Illinois, Nebraska, and Minnesota and would increase nationwide energy conservation. Crop rotation and zero tillage policies could be included into the CSP 5 year contracts, which would give

farmers enough time to cycle through one three year or four year rotation and continue to see benefits as they start their second planting of their chosen rotation.

## **Chapter 5: Conclusion**

Throughout this thesis, reasons why ethanol, both corn-ethanol and cellulosic ethanol, are not viable present and future energy sources was discussed. While these studies indicate that ethanol does not live up to the original promises promoted by the EPA of decreasing the United States' dependence on fossil fuels and reducing greenhouse gas emissions, the focus of this thesis was to find other methods of decreasing energy consumption and pollution. What was found was that the adoption of diverse crop rotations, fertilizer banding, and zero tillage in Iowa, Illinois, Nebraska, and Minnesota could decrease consumption by the energy equivalent of just over 1.5 billion gallons of diesel fuel per year. Unlike ethanol, which simply replaces fossil fuels, this energy would be completely removed from consumption. These sustainable farming practices also decrease farm inputs which decreases the pollution of soil and fresh water sources. These sustainable farming practices achieve the goals original set forth by the EPA in its promotion of ethanol and, based on United States policies that promote minimal tillage and diverse cropping patterns, are applicable in regions outside the four states analyzed.

The USDA's Conservation Stewardship Program promotes resource-conserving practices that include, but are not limited to, minimal tillage and diverse cropping rotations. As a nationwide program, the Conservation Stewardship Program shows that policies supporting diverse cropping systems, fertilizer banding, and no till practices are

applicable outside Iowa, Illinois, Nebraska, and Minnesota. These sustainable farming practices also attain similar goals to those promoted by USDA through Conservation Stewardship Program and the Conservation Reserve Program, which indicates that these practices are suitable additions to United States policy. The sustainable farming practices of 3 year and 4 year crop rotations, fertilizer banding, and zero tillage are appropriate additions to the Conservation Stewardship Program and fit into the program's 5 year contract structure.

## Notes

### Chapter 1: Introduction

1. In the United States, peak oil was predicted Hubbert to occur, and did occur, in 1970. In 1997, Campbell and Laharrère at Petroconsultants predicted world production of oil to peak in 2010. Although optimistic predictions do not agree with this, there are issues with production data. Supply and discoveries are often delayed to encourage investment. Many companies decreasing the size of their exploration crews in the early 2000s is cited as a sign that peak oil is fast approaching or has already passed (Pfieffer, 2006). The emphasis on oil as a transportation resource is related to the use of ethanol as a transportation resource.
2. <http://bigthink.com/videos/larry-summers-on-the-fall-of-oil-prices>

### Chapter 2: A Review of Existing Studies on Inefficiencies in Corn-Ethanol

1. Although the subsidization of corn-ethanol at 45 cents per gallon produced was ended in 2012, ethanol continues to be subsidized through tax incentives and production mandates.
2. Edge tillage is the planting of row crops up to the edge of the field.

### Chapter 3: Empirical Analysis of the Energy Conservation Possibilities of Sustainable Farming

1. It should also be noted that while not all of the energy being used is diesel fuel or gasoline, the majority of the fuel is from nonrenewable resources. In Iowa in 2007, diesel and gasoline made up 53% of energy consumed. Another 24% came from propane, fuel oil, kerosene, and motor oil and 2% came from natural gas. The additional 21% of energy used came from electricity (USDA, 2007). The majority of the electricity used, for the four states listed, was produced by coal. Nuclear is the second highest source for electricity after coal in Illinois, Nebraska, and Minnesota. The second highest source for Iowa is renewables (EIA, 2014b).
2. In finding a way to describe crop rotations in these states it was decided that Minnesota should also be included in these numbers since it is the fourth largest producer of corn and third largest producer of soybeans during this period.

3. Data on previous years' soybean production was not statistically significant because of small sample sizes and was not considered.
4. The estimate of the percentages of corn and soybean operations in 2 crop or continuous crop production in these four states is based on previous crops harvested as reported by the Agricultural Resource Management Survey conducted by the USDA (2014). Along with looking at the number of acres previously planted to corn or soybean as shown in Table 3 and Table 4, the data also looked at the number of acres previously planted to small grains and other crops. In Iowa, Illinois, and Nebraska the number of acres of corn in 2005 and 2010 planted to small grains the year prior was too small to be statistically unreliable. The number of acres planted to other crops prior to corn in both 2005 and 2010 in Iowa, Illinois, and Nebraska were also statistically unreliable. The numbers for both small grains and other crops were statistically unreliable for Iowa, Illinois, and Nebraska prior to soybean production in 2006 and 2012. Only in Minnesota was the number of acres of small grains in the year prior to soybean production in 2006 statistically reliable. The number of acres of small grains the year before 2012 soybean production was, again, statistically unreliable, as were other crops for both years. Also, in 2005, the number of acres of small grains before corn production was statistically unreliable. The number of small grains before corn production in 2010 was also statistically unreliable. Other crops were statistically unreliable in years prior to 2005 and 2010 corn production (USDA, 2014). The fact that the production of small grains and other crops the year before the planting of corn and soybean crops was consistently statistically unreliable combined with the number of acres that were corn and soybean crops in the years prior led to the estimation of the percentage of acres in 2 crop or continuous crop rotations.
5. Banding is the application of fertilizer placed underground near the seed.
6. This should not imply that farmers are unable to plant herbicide tolerant or Bt crops in their diverse cropping rotations.

#### **Chapter 4: Policy Implications of Energy Conservation from Sustainable Farming**

1. <http://bigthink.com/big-think-xfinanace/autonomous-cars-101-with-brad-templeton>



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