Energy Use in Agriculture: Current Problems and Possible Solutions

Alex Gensch

Renewable Energy Intern

West Central Research & Outreach Center

Abstract: A lot of fossil fuels are used in modern agriculture, and their declining supply raises concerns about the sustainability of our current form of food production. Both cropping systems and swine production could benefit from renewable energy sources, as reducing fossil energy inputs is an effective way to save money and increase sustainability. By making different forms of media targeted to the general public we can educate them on how energy is used in these systems and how this can be reduced or replaced with renewable sources. These media will be valuable in creating informed consumers and raising support for sustainable agriculture.

Modern agriculture has progressed a long way since its very humble beginnings along rivers. Now, through the use of extreme energy inputs and mechanized labor, smaller groups of people are able to grow enough food to feed entire nations. This strategy developed when fossil fuel energy was abundant, making food relatively easy and cheap to produce. This created an unintentional link between food prices and energy prices which is becoming a problem in the face of rising energy prices. Higher energy prices mean farmers must either lower their inputs to cut costs, raise prices to stay in business, or suffer reduced profits. Reduced inputs can mean lower yields, and this raises concern about modern agriculture not being able to sustainably produce food for the world. The purpose of this summer internship was to help communicate information relating to energy use in cropping systems and swine production systems. This was accomplished through the production of multiple handouts and videos, and this paper is meant to be a more in-depth explanation of the information covered in other media forms.

Before discussing how energy plays a role in agriculture it is important to know what energy is. In physics energy is the ability to do work and according to the European Council energy means all forms of energy products (combustible fuels, heat, renewable energy, electricity, or any other form of energy)(Official Journal of the European Union, 2006). This creates a distinction between two different types of energy. Any energy source that can be harvested indefinitely, such as wind power, hydro power, or solar energy is considered renewable. Any energy source coming from a finite pool that recharges slower than the rate of use, such as fossil fuels, is considered non-renewable.

In 2002, the food production industry in the United States alone used about 2 quadrillion BTUs of energy, or 344 million barrel of oil equivalents (BOE) (Patrick Canning et al, 2010). This only includes the cultivation step and nothing past the farms. On a per capita level for that year all cereal product production used 199 thousand Btu (3.4% of a BOE) per US citizen, fresh dairy used 212 thousand Btu (3.7% BOE), pork used 410 thousand Btu (7.1% BOE), and beef used 562 thousand Btu (9.7% BOE). Overall, this means the US used more than one BOE of energy inputs per citizen to produce food.

Many different energy inputs go into agricultural food production. Energy inputs are separated into two categories, direct and indirect. Direct energy inputs are consumed on the farm or in the farming operation and typically include diesel, gasoline, natural gas, electricity, and liquefied propane. Indirect inputs represent energy that was employed to make something used on the farm. This could represent shipping costs of getting products to the farm, costs of building machines, or the energy that went into growing grain for animal feed or producing fertilizers and pesticides. The European Union defines

Primary Energy Consumption (PEC) as the energy consumed in an agricultural production system (within the farm limits) including the energy for the production of all indirect inputs (Official Journal of the European Union, 2006). PEC is used to calculate farm energy efficiency, which is the ratio between energy consumption and units of agricultural product. Product units are usually expressed in weight or volume units. Increasing farm efficiency, thereby lowering the importance of energy inputs, is one way to separate food prices from energy prices. Using renewable energy sources instead of fossil fuels can also help weaken this association.

The cumulative methods employed by farmers to raise crops can be described as a cropping system (*Cropping Systems and Rotations*). Many techniques are used in crop production, but they can be separated into these 5 categories: nutrient management, tilling, pest control, harvesting, and crop rotation. All of these sections have impacts on the amount of energy used in crop production and offer opportunities to reduce the amount of non-renewable energy consumed. Conventional agriculture tends to use strategies that will yield the most of the desired crop without consideration to energy intensity. In the Midwest this usually means growing corn with optional soybeans in the rotation. Cropping systems can be designed in many different ways, but systems can be generalized by whether or not they are organic.

Organic farming is a strategy different than conventional agriculture with the potential to lower certain energy inputs and still produce similar amounts of products. It is defined as an “approach to producing food and fiber that maintains and enhances the productive capacity of a farm’s soils by relying on ecological processes and cycles adapted to local conditions rather than the use of chemical inputs” (IFOAM 2009). The largest and most readily measured differences between conventional and organic farming are associated with the energy required to manufacture, ship, and apply pesticides and nitrogen-based fertilizers used for nutrient management (David Pimental, 2006). In organic crop systems this involves not using any synthetic pesticides or fertilizers. Manure is used instead of anhydrous ammonia, and if the manure is produced on sight this offers a multitude of benefits; no costs are associated with the production of animal waste, and no shipping costs are necessary to get it to the farm. Environmental benefits also exist for using manure; instead of the nitrogen and carbon in the waste entering the atmosphere as greenhouse gasses (GHG) they can be reincorporated into the soil.

Instead of using herbicides for weed control, mechanical weeding strategies are employed. One pass of a cultivator and one pass with a rotary hoe would cost approximately 300,000 kcal/ha. However, with herbicide weed control (6.2 kg/ha of herbicide), plus the sprayer application, this would total about

720,000 kcal/ha (David Pimental, 2006). However, herbicides usually only require one application while mechanical methods will likely have to be repeated throughout the growing system as weed growth requires.

Another significant factor affecting the amount of energy inputs needed for a cropping system is the soil organic matter (SOM) of the farmland. Organic matter comes from organic material, which is anything that used to be alive and is now resting in or on the soil (*Soil Organic Matter*). This includes plant residue like roots, leaves, and stalks, and other life-forms like micro-invertebrates and insects. Once this material has broken down to a stable, or resistant, state of decomposition it is considered SOM and can supply the necessary nitrogen, phosphorous, and sulfur (N, P, and S) for plants . Generally, the top 6” of soil is where the most organic matter is found and weighs about 2 million pounds. It takes about 10 times more material than matter to complete this process, so in order to get 1% more SOM 200,000lbs of organic material need to be left with the soil.

SOM in part controls the amount of water that can be held by the soil, thus lowering the amount of added water that is necessary. 1% more SOM is reported to increase the water holding capacity of a field by 4%. Higher SOM also means more vital nutrients are available to plants, which lowers the amount of supplemental N and P that must be added through fertilizers. A 1% increase in SOM in the top 6” of an acre is reported to contribute to the release of 10-20 pounds of N, 1-2 pounds of P, and 0.4-0.8 pounds of S over a year (*Soil Organic Matter*). SOM and water content are also involved in how much soil is lost to erosion, which can help preserve the necessary materials for plant growth. Farms managed under organic systems at the Rodale Institute that used manure and cover crops had higher levels of soil carbon (C) and N than conventional systems; soil carbon increased 25% and nitrogen increased about 10% in 22 years (Pimental and Hepperly, 2005). These differences between the SOM content in organic and conventional farms makes a difference every year, but it is especially noticeable during drought years. Throughout the 30-year Farming Systems Trial at the Rodale Institute, during times of drought organic systems for corn and soybean had yields that were 30% and 50% higher respectively than conventional systems during times of drought (*The Farming Systems Trial*).

There are many ways to help control the SOM levels of farmlands to encourage stronger yields. Tests can be done on soil to determine current levels and help plan techniques to raise them. Applying man-made fertilizers is the quickest way to add the needed nutrients to the field in an absorbable state and is what most conventional farms choose to drive their production. Crop rotation and tillage and harvesting practices can also affect the amount of SOM in fields. Harvesting practices are usually determined by what crops are intended for sale; if corn silage is sold as feed or bedding it cannot be left in the field as organic material. Tillage practices and crop rotations on the other hand, can easily be modified within cropping systems.

Almost universally, rotating between crops leads to better yields than growing a monoculture, like continuous corn. The energy balances for corn and soybeans were higher in rotated systems than in continuous systems (Rathke et al, 2007). The use of legumes and other cover crops in rotations is a well proven way to increase nutrient cycling into farm soil and increase yields, which explains why almost 100 million acres in the United States are planted in a 5 year corn-corn-soy-corn-soy rotation (Pimental and Hepperly, 2005). Leguminous crops fix nitrogen at their roots, and after harvesting these nutrients remain to break down in the soil. Small grain cover crops like wheat and oat grown before winter can provide useful feed to livestock operations, but more importantly the plant structure prevents erosion that farrow fields would typically experience and adds carbon to the soil.

An 8 year study was conducted in Iowa to test the effects that crop rotation diversity and nutrient management strategies can have on yields and energy balances of typical corn-soy rotations (Davis et al, 2012). Three rotations were tested: a typical 2 year corn-soy rotation, a 3 year corn-soy-small grain + red clover rotation, and a 4 year corn-soy-small grain +alfalfa-alfalfa rotation. The small grain was triticale in the first three years and oat in the following five years. The two year system was managed with typical amounts of fertilizer (80 kg of N/ha), and the more diverse systems were given less synthetic nitrogen (16 and 11 kg/ha for the 3 and 4 year systems respectively) and supplementary manure. Herbicide use was also reduced in the more diverse systems: 1.9 kg/ha for 2 year, 0.26 kg/ha for 3 year, and 0.20 kg/ha for 4 year. Yields for corn and soybeans were higher in the more diverse systems by about 4% and 9% respectively.

A main concern for farmers considering diversifying a crop rotation is loss of profit from less frequent harvesting of the main cash crop, but when profit was calculated for the three systems including net returns to land and management (i.e. nutrient benefits to land and crop sales) there was no difference in profitability between the systems (Davis et al 2012). This is very significant considering the more diverse crop rotations used less energy intensive agrichemicals. If less energy inputs are required to produce the same level of crops the energy balances are higher in the more diverse systems. Designing a crop rotation that has multiple crops growing every year also offers financial protection to farmers from damaged crops or low market prices. The diverse systems studied had less variance in mean profitability even though they had more variance in mean crop mass harvested. Farmers may also want to consider changing their tillage practices to help improve energy efficiency.

The tilling of fields is meant to accomplish three things: weed control, burial of crop residue, and preparation of seed bed (*Cropping Systems and Rotations*). There are three generic types of tillage: conventional, reduced or conservational, and no-till. Conventional tillage, also known as moldboard tillage involves multiple trips across the field to plow, disk, cultivate and plant. This accomplishes burying around 90% of the crop residue, which leaves a black soil top that will warm faster in spring. Reduced tillage leaves around 50% of crop residue above ground and no-till leaves around 90%, which helps reduce soil erosion. Tillage practices also contribute to the addition of C and N to the soil (Al-Kaisi et al 2005). When comparing no-till to chisel plow, a conservation tillage method, increases of around 15% for C and N were reported for no-till strategies while maintaining similar yields. No-tillage and strip tillage resulted in 14.7% and 11.4% increases for soil C and N respectively, compared to moldboard tillage. No-tillage practices also had the highest energy balances for corn-soy rotations (Rathke et al, 2007).

The United States' food production system involves more than just crop production. Each year, around 100 million pigs are raised for market in the US (*Hogs and Pigs Final Estimates 2003-2007*). Corn, a common crop in the Midwest, is used primarily to feed livestock, providing an estimated 70% of livestock feed (David Pimental, 2006). When raising livestock there are two different types of energy inputs put towards the animals; there is the energy put into making their feed, and the energy that is used to maintain the breeding herd. General maintenance costs don't vary much between conventional and organic farming, but the production strategy of the animal feed type can make a significant difference in energy input.

Swine production systems include more than just the growth and performance of pigs. There is a large supporting infrastructure that consumes energy to raise pigs for market. This infrastructure includes the housing for the swine, facility management, feed production and preparation, and manure management. A recent analysis of swine production systems in the U.S. was performed to examine how alternative pig systems compare to more conventional strategies in terms of energy balances for market pigs (Lammers et al, 2011). This is the most recent LCA on swine production and no other recent reports were found that contained energy use statistics. Therefore, all information relating to swine production presented henceforth will be from this report unless specifically cited. This report analyzed typical production systems that grew crops on site to be used for swine feed. Pig manure was recycled into the fields in all systems, and any extra crops were exported. All energy exports were counted against energy inputs. Two different crop rotations, three phased diets, and two feed formulation strategies were all investigated to determine the amount of energy needed to raise a pig in each strategy. The crop rotations were corn-soy-corn-soy etc. and corn-soy-corn-oat etc. The diets were a traditional corn-soybean meal (SBM), a more diverse oat-SBM, and an enhanced corn-SBM with biofuel co-products like dried distiller grains (DDGs) and crude glycerin. The two different formulation strategies were simple and complex. The simple strategy provides adequate nutrition through traditional feedstuffs like corn, SBM, and mono-calcium P. Complex diets have added synthetic l-lysine, which is an amino acid, and the exogenous enzyme phytase. The simple strategy was applied to the oat-SBM and the complex strategy was applied to traditional corn-SBM and the co-product feed.

The analysis used a cradle-to-gate approach that included energy used one step before the farm gate. For example, the fossil fuel energy used to synthesize L-lysisine and the enzyme phytase is included, but the energy used in building the equipment and facility necessary for these processes are not included. Previous reports by Lammers and others did not include these types of inputs, and as such this new report is more accurate in terms of energy efficiency according to the EU definition. All parts of the swine production system were thus incorporated into the analysis, including energy used in heating the barns and energy used in food production. Energy balances were calculated for different combinations of confinement strategy, feed, and formulation strategy. Confinement strategies had little effect on energy balance overall, while feed type and strategy were influential to the energy balance. In general, the corn-soybean meal had the highest energy balance and the oat feed and coproduct diet had lower energy balances.

The baseline system for this study used conventional confinement strategies, a corn-soy rotation, and complex corn-SBM feed. It produced 15,600 pigs annually and was found to require 744.6 MJ or 6.19 gallons of gas equivalents (GGE) per 136-kg market pig. Full swine production facilities, also called farrow-to-finish operations, use multiple types of barns as their pigs grow. Pigs are born in heated farrowing crates and are moved to a heated nursing facility after weaning. Later they are moved to larger grow-finish buildings. These typically house 1,200 animals in pens of 30-60 animals. For conventional confinement all of these buildings are sealed to the outside and require mechanical ventilation and temperature control. The entire floor is slatted concrete which allows for liquid manure collection. Sow gestation takes place in buildings similar to finishing barns, except the sows are given individual gestation stalls. Approximately 25% of the energy used in these conventional systems goes to the operating costs of the facilities, such as ventilation and temperature control.

The alternative system uses farrowing and nursery facilities similar to the conventional system, but grow-finish pigs and gestating sows are housed in bedded hoop barns. The hoops barns are 21.9 by 9.1 m Quonset-shaped structures, and are left open to the outside environment. This means there is no mechanical ventilation or temperature control in these hoop barns, but the animals now require cornstalks or other plant material for bedding and more feed than the conventional confinement strategy. This solid floor means that manure recovery can only be done by cleaning out the barn and composting the material. Without counting the net energy in feed, but still counting the energy used in cultivation, the hoop barn system used about 3% less energy and produced about 10% less GHGs.

Heating is added to both types of systems for the nursing pigs, but some swine systems are experimenting with reduced nocturnal temperature (RNT) regimens. This involves lowering the nursery barn temperature at night enough to save energy without hurting the performance of the pigs. Recent studies suggest that heating and electricity use could be reduced by 29% and 19% respectively (Johnston et al, 2011). Even without the RNT techniques hoop barn-based alternative use 64% less energy to operate, but require bedding and 2.4% more feed. Importantly, sows housed in group pens in hoop barns gave birth to 7% more live pigs on average than sows gestated in individual stalls and the housing type for gestation did not influence pre-weaning mortality.

The most energy-intensive part of making pig feed is the production of synthetic nitrogen for crop production. The amount of nitrogen lost in manure systems varies, but since manure contains nutrients vital to plant growth more research into efficient manure recycling is necessary to reduce energy inputs from synthetic fertilizers. This analysis assumed 25% loss from liquid manure storage and 2% loss in application. For solid manure this analysis assumed passive composting, no turning of material, and a 40% reduction in material mass. A total of 50% nitrogen loss was assumed throughout storage and application. This means that if 100Kg of N in liquid manure are injected directly into the fields about 73.5kg are available to crops in the first year. For compost manure only about 50% of the nitrogen would make it to the field, and 60% of this would be available the first year after application and the other 40% would be available the second year. Thus, if there was originally 100kg of N in the composted manure, about 50kg would be available to the crops over the next two years. Different composting strategies will have different effects on the amount of nitrogen that makes it back into the field.

Possible improvements to swine systems include better matching of diets to the thermal environment of the pig facility and a better understanding of the optimal genetics of pigs housed in hoop barns. This could lead to hoop-barn systems needing the same amount of food, or even less than conventional systems. More research into manure storage and composting strategies could provide the alternative system with more access to sources of vital nutrients that don't come from the fossil-fuel dependent production of fertilizer. This could lead to better yields and less fertilizer application, in turn leading to higher energy efficiency. Renewable energy also has many potential applications for swine production. Solar energy can be used to replace electricity from the grid or for heating purposes. Wind turbines can also create significant amounts of electricity. Methane digesters can be added to liquid manure systems to create fuel that can be used in heating or electricity generation. Geothermal heat pumps (GHPs) can also be used to save energy on heating and cooling by capitalizing on the relatively constant temperature of the soil. GHPs are reported to save 30-70% on heating and cooling costs in residential settings (Michael L'Ecuyer et al 1993).

The West Central Research and Outreach Center is responsible for more than just doing research. Sharing these results and educating the public is also a crucial part of their mission. In order to help this I made multiple handouts and videos to help explain how energy is used in cropping systems and swine production, and how these fossil sources can be either reduced or replaced with renewable energy supplies. My media were targeted to the general public for multiple reasons. It is important that people know what work is being done here at the center and what improvements have been made. Educating the public can also address their desire to know more about where their food comes from and help to stimulate support for sustainable agriculture.

The video on swine production systems will cover some of the material presented in this paper, but is meant to be a more general overview of the current state of systems and what is being done to improve efficiency. A handout was also made to be a summary of the video that can easily be distributed to interested citizens. Given the topic of the video it will be geared to a general public audience, and as such it will stay away from specifics of how much energy goes into parts of the production infrastructure. Instead of listing specific numbers, a pie chart made from the Lammers report will explain the relative percentages of energy use parts of swine production. This first video will not deal with differences between confinement strategies as this is likely above the interest level of the general public.

This video is important for multiple reasons. Firstly, it highlights certain improvements that have already been made at the WCROC, which helps to show that our work is leading to progress. Relatedly, it helps to address the growing public concern over sustainable food production by explaining the current problem in agricultural production and then offering possible solutions. This video helps to portray swine production as a dynamic and improving industry.

A handout was made for cropping systems, and was targeted to the general public while still trying to offer useful information to farmers. It was designed to help people start thinking about what changes could be made to cropping systems to raise efficiency. The information is presented without judgment or bias, while still trying to point out the possibility of sustainable agriculture. Hopefully this handout will create interest amongst the public and farmers for what changes could do to energy use and profitability.

To go along with the cropping handout I made a similar video. Currently the video is still being produced. Collecting footage for different parts of cropping systems is difficult, because we have to know when field operations are taking place and try to set up equipment quickly without interfering with any work. Given the timing of field work, some footage has not been collected yet. As such the video is still a work in progress but I have written a script and will be putting together a draft version that could be updated with more video later.

I also made a video about the Wind to Ammonia plant that is meant to be a simple explanation of what the plant is, why we have it, and how it works. The importance and the current energy intensive problem of nitrogen fertilizers are mentioned, and then the video explains how wind power generates the hydrogen and nitrogen for production. A simplified diagram and moving molecules are used to demonstrate the reaction process without dealing with the chemistry behind it. I believe this video is very suited to show to groups visiting the plant, or to anyone who is curious about green hydrogen and ammonia production.

Another large part of my internship was organizing and making templates and tutorials. These are meant to help anyone making media in the future. I made tutorials for PowerDirector 11 and Photoshop to help people make templates and use the ones already created. I also have a collection of images that may be useful, including molecules and logos for the University and Research Center. My partner and I also designed a new handout template. This will ensure that any handouts created at the Center can be compiled and look consistent. We are also planning on making a collection of all the handouts created this summer.

Agriculture is a growing and changing industry, and there are a lot of improvements that could still be made with regards to energy efficiency. More research needs to be done, but there is already promising data coming from organic farming, alternative livestock, crop management, and renewable energy research. With more research into these areas it is very possible for the US to lower its energy use and dependence on fossil fuels and make progress towards more sustainable agriculture. Through education efforts at the WCROC and other places the public will become more knowledgeable about how food is produced and support for sustainable agriculture will increase.

Energy in Agriculture works cited

Al-Kaisi, Mahdi M., Xinhua Yin, and Mark A. Licht. "Soil Carbon and Nitrogen Changes as Affected by Tillage System and Crop Biomass in a Corn–soybean Rotation." *ScienceDirect*. Applied Soil Ecology, Nov. 2005. Web. 10 June 2014.

"Cropping Systems and Rotations." *Corn Agronomy*. University of Wisconsin, 1 Feb. 2006. Web. 30 June 2014. <http://corn.agronomy.wisc.edu/Management/L001.aspx>.

Davis, Adam S., Jason D. Hill, Craig A. Chase, Ann M. Johanns, and Matt Liebman. "Increasing Cropping System Diversity Balances Productivity, Profitability and Environmental Health." *PLOS ONE*. PLOS ONE, 10 Oct. 2012. Web. 01 July 2014.

"Document 32006L0032." *EUR-Lex*. Official Journal of the European Union, 27 Apr. 2006. Web. 04 June 2014. <http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32006L0032>.

International Federation of Organic Agriculture Movements (IFOAM). 2009. Frequently asked questions. Bonn, Germany. www.ifoam.org/sub/faq.html

Johnston, Lee, Michael Brumm, Steve Moeller, Stephen Pohl, Marcia Shannon, and Robert Thaler. *Reducing Energy Consumption in Swine Nurseries with Reduced Nocturnal Temperature*. Rep. Minnesota Pork Board, 30 Sept. 2011. Web. 2 July 2014.

Lammers, P.J., M.D. Kenealy, J.B. Kliebenstein, J.D. Harmon, M.J. Helmers, and M.S. Honeyman. “Energy Use in Pig Production: An Examination of Current Iowa Systems.” *Journal of Animal Science.* The American Society of Animal Science, Nov. 2011. Web. 20 May 2014

"The Farming Systems Trial: Celebrating 30 Years." *Rodale Institute*. Rodale Institute, n.d. Web. 4 June 2014. <http://rodaleinstitute.org/our-work/farming-systems-trial/farming-systems-trial-30-year-report/>.

Pimental, David. “Impacts of Organic Farming on the Efficiency of Energy Use in Agriculture.” *The Organic Center* (2006): n. pag. *Organic Valley Coop.* Efficiency of Energy Use SSR. Web.

Pimental, David, Paul Hepperly, James Hanson, David Douds, and Rita Seidel. "Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems." *BioScience* 55.7 (2005): 573-82.*BioScience*. Oxford Journals, 2005. Web. 30 June 2014.

Rathke, G. W., B. J. Wienhold, W. W. Wilhelm, and W. Diepenbrock. "Tillage and Rotation Effect on Corn–soybean Energy Balances in Eastern Nebraska." *Soil and Tillage Research* 97.1 (2007): 60-70. *ScienceDirect*. Web. 10 June 2014.

USA. EPA. Office of Air and Radiation. *Space Conditioning: The Next Frontier*. By Michael L'Ecuyer, Cathy Zoi, and John S. Hoffman. EPA, Apr. 1993. Web.

USA. USDA. Agricultural Statistics Board. *Hogs and Pigs Final Estimates 2003-2007*. USDA Mann Library Cornell, Mar. 2009. Web.

USA. USDA. ERS. *Energy Use In The U.S Food System*. By Patrick Canning, Ainsley Charles, Sonya Huang, Karen R. Polenske, and Arnold Waters. USDA ERS, Mar. 2010. Web. 28 May 2014.

USA. USDA. NRCS. *Soil Organic Matter- Soil Quality Kit- Guide for Educators*. N.p., n.d. Web. 2 June 2014. <http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053264.pdf>.