Reducing Energy Inputs in the Agricultural Production System :: Monthly Review

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Oil, natural gas, coal, and other mined fuels provide the United States with nearly all of its energy needs at a cost $700 billion per year.1 Since more than 90 percent of its oil deposits have been depleted, the United States now imports over 70 percent of its oil at an annual cost of $400 billion.2 United States agriculture is driven almost entirely by these non-renewable energy sources. Each person in the country on a per capita consumption basis requires approximately 2,000 liters per year in oil equivalents to supply his/her total food, which accounts for about 19 percent of the total national energy use. Farming—that portion of the agricultural/food system in which food is produced—requires about 7 percent and food processing and packaging consume an additional 7 percent, while transportation and preparation use 5 percent of total energy in the United States.3

Global usage of oil has peaked at a time when oil reserves are predicted to last only sixty to seventy more years.4 As oil and natural gas supplies rapidly decline, there will be a greater dependence on coal as a primary energy source. Currently coal supplies are only capable of providing the United States with 50 to 100 more years of energy, although considering the environmental damage done by using coal it is not clear whether we will actually use up all the reserves.5 Keeping in mind the potential future costs and availability of fossil fuels, we will explore how agricultural production can be maintained while reducing fossil energy inputs by 50 percent.

Soil Conservation

Large quantities of soil nutrients are lost with the serious soil erosion problem in the United States. Average soil loss per hectare in the nation is now reported to be 13 metric tons per hectare per year (t/ha/yr).6 This means that an estimated 55 kilograms (kg) of nitrogen and 110 kg of phosphorus and of potassium (all essential nutrients for plants) are lost per hectare per year. To replace these nutrients requires about 880,000 kilocalories (kcal) per hectare for nitrogen and 440,000 kcal each for phosphorus and potassium per hectare per year.7 The annual total energy, just for these lost fertilizer nutrients, is 1.6 million kcal per hectare. This is about 20 percent of the total energy input that goes into producing a hectare of corn grain.8

Soil erosion rates in agriculture can be and should be reduced to 1 t/ha/yr or to the soil sustainability level.9 There are many technologies that would aid farmers to reduce soil loss levels to 1 t/ha/yr. These technologies include: better crop rotations, cover crops, grass strips along the contour of waterways, water diversion ditches, terraces of various types, no-till and other reduced tillage systems, surface mulches, contour planting, building up soil organic matter, organic agriculture techniques, and combinations of these.

Water Conservation

Irrigated crops require large quantities of water and enormous amounts of fossil energy for pumping and applying the irrigation water. A hectare of high-yielding rice requires approximately 11 million liters/ha of water for an average yield of 7 t/ha (metric tons per hectare). On average, soybeans require about 5.8 million liters/ha of water for a yield of 3 t/ha. In contrast, wheat, which produces less plant biomass than either corn or rice, requires only about 2.4 million liters/ha of water for a yield of 2.7 t/ha. Note that under semi-arid conditions, yields of non-irrigated crops such as corn are low (1 to 2.5 t/ha) even when ample amounts of fertilizers are applied.

Irrigated wheat production requires about three times more energy to produce the same amount of grain as rainfed wheat.[10] When gasoline and diesel fuel reach ten dollars per gallon, it is expected that irrigated agriculture will decline significantly in the United States

Organic agriculture and other systems that stress "feeding the soil" can, depending on soil type, increase the amount of organic matter up to as much as 6 percent compared with only about 3 to 4 percent in comparable conventional soil. This would reduce runoff during intense storms (as well as erosion), conserve water, and increase the crop yields. For example, in one study organic corn and soybeans with levels of soil organic matter of nearly 6 percent, had corn yields 33 percent higher than those of conventional corn, and soybean yields 50 percent higher than those of conventional soybeans.[11] Compared with conventional growing practices, the greater crop yields in well-managed organic systems are especially noticeable during drought years.

With many crops requiring enormous amounts of water currently being grown in dry regions, and therefore needing large amounts of energy to pump and apply irrigation water, there is a critical need to reduce water use. In the future, when oil is in short supply, it is expected that irrigation in semi-arid climates will be reduced by half and only utilized for two or three days per cropping season in order to save a crop from total loss. But even the availability of irrigation water is another concern. In some regions there is such rapid population growth that water is increasingly used for direct human and business needs, reducing the amounts available for agriculture. Another concern is that as the climate changes some drought prone areas may be subject to longer and more severe droughts. The eleven-year-long Australian drought and droughts in Northern China and in California have had serious negative effects on crop yields. Thus even more water may be needed if crops are going to continue to be grown where irrigation is only used to supplement significant rainfall.

Conserving Vital Nutrients

As fossil fuels become scarce, costs for the production of synthetic fertilizers will rise. This economic pressure will force farmers to seek alternative sources to meet their nitrogen, phosphorus, and potassium demands. The utilization of leguminous cover crops, manure, and organic amendments from off the farm such as compost can improve soil quality and meet the production needs of the agriculture industry to reduce reliance upon energy intensive synthetic sources.

Vital Nutrients: Nitrogen is the essential nutrient needed in the largest amounts for agricultural production and is applied at a rate of 12 million tons of commercial (synthetic) nitrogen per year in the United States.[12] Though 18 million tons of nitrogen were applied in 1995 in the United States, a 300 percent increase in the price of nitrogen fertilizer over the past decade has resulted in fewer and smaller nitrogen applications, highlighting the need to explore alternative sources of this nutrient. It is of equal commercial importance to provide adequate amounts of phosphorus and potassium, the other essential elements needed in large amounts by plants to grow well and produce high yields. As will be shown below, leguminous cover crops, manure, and other organic inputs can meet the nitrogen, phosphorus, and potassium demands of food production in the United States.

Cover Crops: Conserving soil nutrients is a priority in agricultural production because this reduces the demand for fertilizers and produces high crop yields while at the same time reducing air, surface, and groundwater pollution. A crucial aspect of soil nutrient conservation is the prevention of soil erosion, as previously mentioned. Cultivation practices that build soil organic matter and prevent the exposure of bare soil are key ways to lessen soil erosion. Cover crops—planted to maintain living vegetation on the soil when commercial crops are not in the field—help protect the exposed soil from erosion after the main crop is harvested, but also take up nutrients such as nitrogen that might be lost by leaching through the soil and into the groundwater. Compared with conventional farming systems, which traditionally leave the soil bare, the use of cover crops significantly reduces soil erosion and other sources of nutrient loss.

Leguminous cover crops can also add significant amounts of nitrogen to the soil. For example, vetch, a legume cover crop grown during the fall and spring months (non-growing season), can supply all of the nitrogen needs of the following crop. Other studies in both the United States and Ghana have shown that nitrogen yields from legumes planted the season before were 100–200 kg/ha.[13] Legumes can thus provide a significant portion of the nitrogen required by most crops—and in many situations all of the nitrogen needed by the next crop. In addition, systems relying on organic amendments tend to retain more nitrogen in the soil for plants to use in subsequent years. For example, in a soil experiment at the Rodale Institute Farms in Pennsylvania, 43 percent of the nitrogen added to the organic system using legumes and manure was still there one year later compared to only 17 percent in the conventional systems.[14]

Cover crops further aid in agriculture by collecting significantly more solar energy than conventional farming systems. Cover crops added to a cropping system collect about 80 percent more solar energy than conventional crop production systems that do not use cover crops.[15] Growing cover crops on land before and after a primary crop nearly doubles the amount of solar energy that is harvested per hectare per year. This increased solar energy capture provides extra organic matter, which improves soil quality—increasing nutrient availability, providing a food supply to a diverse group of soil organisms, producing healthier plants, and helping to provide more water to the crops.

Crop Rotations: Crop rotations are beneficial to all agricultural production systems because they help control soil erosion and pests such as insects, plant diseases, and weeds. In addition, when legume cover crops are used, essential nitrogen is added to the soil for the use of succeeding crops. For example, in the Rodale study soil nitrogen levels in organic farming systems were 43 percent, compared with only 17 percent in the conventional system.[16]

Soil Organic Matter: Maintaining high levels of soil organic matter is beneficial for all agriculture and crucial to improving soil quality. Soil organic matter promotes the formation of aggregates (natural clumps of soil), which have “major implications for the functioning of soil in regulating air and water infiltration, conserving nutrients, and influencing soil permeability and erodibility” by improving the soil’s water infiltration and structure, which helps reduce erosion.[17]

Maintaining high levels of soil organic matter is a primary focus of organic farming. On average, the amount of soil organic matter is significantly higher in organic production systems than in conventional systems. Typical conventional farming systems with satisfactory soil generally have 3 to 4 percent soil organic matter, whereas organic systems soils average from 5 to 6 percent.[18] In a comparison of three cropping systems, soil carbon increased to about 28 percent in an organic system that included an animal enterprise, 15 percent in the organic system using legumes but not using animal manures, but only 9 percent in the conventional farming system.[19] Higher levels of organic matter in soils provides for high-energy efficiencies in agricultural systems.

Increased soil organic matter also provides the soil with an increased capacity to retain water. As organic matter increases more stable aggregates are formed, more water can infiltrate into the soil (instead of running off the field) during intense storms, and more water can be stored in soils for plants to use later. The large amount of soil organic matter and water present in the organic systems is considered the major factor in making these systems more drought resistant.

Furthermore, the 110,000 kg/ha of soil organic matter in an organic corn system could sequester 190,000 kg/ha of carbon dioxide. This is 67,000 kg/ha more carbon dioxide sequestered than in the conventional corn system, and is the amount of carbon dioxide emitted by ten cars that averaged twenty miles per gallon and traveled 12,000 miles per year.[20] The added carbon sequestration benefits of organic systems have beneficial implications for reducing global warming.

Manure: In 2007, the 100 million cattle, 60 million hogs, and 9 billion chickens maintained in the United States produced an estimated 20.3 million metric tons of nitrogen. This nitrogen, most of which is produced by cattle, could potentially be used in crop production (see table 1). The collection and management of this manure nitrogen requires special attention. Approximately 50 percent of the nitrogen is lost as ammonia gas within 24 to 48 hours after defecation, if the animal waste is not immediately buried in the soil or placed in a lagoon under anaerobic conditions.21 The liquid nutrient material in the lagoon must be buried in the soil immediately after it is applied to the land, or again a significant portion of the nitrogen will be lost to the atmosphere. Because cow manure is 80 percent water, this manure can only be transported a distance of about 12 kilometers before the energy return is negative. Manure resources along with other organic materials can be stored as compost. Yet, the problem with storing manure and other wastes in compost is that nearly 75 percent of the nitrogen in the compost is lost during the year.

Table 1. Livestock numbers and manure and nitrogen produced per year in the United States

Livestock	Number (millions)	Manure produced per head kg/yr	Manure (millions of tons)	N produced per head (kg)	Total N (millions of tons)
Cattle	100	10,000	1,000	273.0	27.0 (8)*
Hogs	60	1,230	74	62.0	3.7
Chickens	9,000	31	28	0.1	8.6
Total					20.3

Total = 20.3 million metric tons of nitrogen per year.

* The quantity of manure collected for use.

Source: D. Pimentel, et al., "Reducing Energy Inputs in the U.S. Food System," *Human Ecology* 36 (4) (2008): 459-71.

An estimated 70 percent of cattle manure is dropped in pasture or rangeland and is not included in this analysis. Using this estimate, the amount of nitrogen theoretically collected for use per year is 18 million metric tons of nitrogen (see table 1).22

Conserving nutrients will be crucial to farmers in a world of high fertilizer costs. In addition, practices that center on building and conserving soil integrity can greatly improve energy efficiency in food production systems. The use of manure, cover crops, composting, and conservation tillage can contribute to such energy reductions and allow farmers to produce food with significantly less energy.

The separation of large concentrations of animals (in factory farms and feedlots) from where their feed is produced has resulted in a huge energy cost as well as significant pollution. Crop farms, shipping their products significant distances to concentrated animal production facilities, must purchase commercial fertilizers to produce the corn and soybeans that the animals are fed because of the lack of recycling of nutrients from manure back to the land. At the same time, large quantities of nutrients accumulate on factory farms and are especially a problem when they are concentrated in relatively small areas—for example, poultry on the Delmarva Peninsula and hogs in North Carolina—for the convenience of corporations that need large numbers of animals near slaughter facilities. Thus nutrients accumulate at the animal production facilities at the same time that nutrients are depleted on crop farms located far from where the manure is produced.

Through regulatory action and market-based incentives livestock manure could be moved away from industrial scale, pollution generating concentrated animal feeding operations and back into integrated livestock and crop production farms where manure can be successfully incorporated in appropriate quantities into the soil. Regulatory actions and incentives could also encourage the agricultural practice of crop rotation, the use of cover crops, and reduced pesticide application, all of which would result in increased energy savings. Of course, a more ecologically sound solution would be to raise animals more humanely and on the farms that produce their feed. This would allow for efficient nutrient cycling to occur.

Reduced Pesticide Use: Currently, more than 500,000 kg of pesticides are applied annually in U.S. agriculture.23 Certified organic farming systems do not apply synthetic pesticides. Weed control is, instead, achieved through crop rotations, cover crops, and mechanical cultivation. Avoiding the use of herbicides and insecticides improves energy efficiency in corn/soybean production systems. For example, in organic farming, one pass of a cultivator and one pass of a rotary hoe use approximately 300,000 kcal/ha of fossil energy. Herbicide weed control (including 6.2 kg of herbicide per hectare plus sprayer application) requires about 720,000 kcal/ha or about twice the amount of energy used for mechanical weed control in organic farming.24 In addition, there are a reported 300,000 non-fatal pesticide poisonings per year in the United States, and pesticides in the diet have been shown to increase the odds of developing cancer.25

Labor and Draft Horses

Raising corn and most other crops by hand requires about 1,200 hours of labor per hectare (nearly 500 hours per acre).26 Modern mechanization allows farmers to raise a hectare of corn with a time input of only 11 hours, or 110 times less labor time than that required for hand-produced crops.27 Mechanization requires significant energy for both the production and repair of machinery (about 333,000 kcal/ha) and the diesel and gasoline fuel used for operation (1.4 million kcal/ha). About one-third of the energy required to produce a hectare of crops is invested in machine operation.28 Mechanization decreases labor significantly, but does not contribute to increased crop yields.

Table 2. Energy inputs and costs of corn production per hectare in the United States and potential for reduced energy inputs

	Average Corn Production		Reduced Energy Inputs	
Inputs	Quantity	kcalx × 1000	Quantity	kcal × 1000
Labor	11.4 hrs	462	15 hrs	608
Machinery	18.0 kg	333	10 kg	185
Diesel	88.0 L	1,003	60 L	684
Gasoline	40.0 L	405	0	
Nitrogen	155.0 kg	2,480	Legumes	1,000
Phosphorus	79.0 kg	328	45 kg	187
Potassium	84.0 kg	274	40 kg	130
Lime	1,120.0 kg	315	600 kg	169
Seeds	21.0 kg	520	21 kg	520
Irrigation	8.1 cm	320	0	0
Herbicides	6.2 kg	620	0	0
Insecticides	2.8 kg	280	0	0
Electricity	13.2 kWh	34	34 kWh	34
Transport	146.0 kg	48	75 kg	25
Total		7,470		3,542
Corn yield 9,000 kg/ha		31,612		

Source: D. Pimentel, et al., "Reducing Energy Inputs in the U.S. Food System," *Human Ecology* 36 (4) (2008): 459-71

The reduced energy inputs in table 2 resulted from the following:

- Smaller tractors
- Less diesel and gasoline used
- Legumes used to produce nitrogen instead of commercial nitrogen
- Less phosphorus, potassium, and lime were applied, because soil erosion was controlled
- No irrigation employed
- No insecticides and herbicides applied

- Fewer goods were transported to the farm for use

Organic corn production requires mechanization. Economies of scale are still possible with more labor and the use of smaller tractors and other implements. Reports suggest that equipment quantity and size is often in excess for the required tasks. Reducing the number and size of tractors will help increase efficiency and conserve energy.29

Hydrogen is the fuel most looked to as a substitute for diesel and gasoline. However, hydrogen is relatively expensive in terms of the energy used to produce, store, and transport it. About 4.2 kcal of energy is required to produce 1 kcal of hydrogen by electrolysis.30 Diesel and gasoline, in contrast, require 1.12 kcal of oil to produce 1 kcal worth of fuel.

Another proposal has been to return to horses and mules. One horse can contribute to the management of 10 hectares (25 acres) per year.31 Each horse requires 0.4 ha of pasture and about 225 kg of corn grain. Another 0.6 ha of land is necessary to produce the roughly 1,200 kg of hay needed to sustain each animal. In addition to the manpower required to care for the horses, labor is required to drive the horses during tilling and other farm operations. The farm labor required per hectare would probably increase from 11 hours to between 30 and 40 hours per hectare using draft animal power. An increase in human and animal labor as well as a decrease in fuel-powered machinery is necessary to decrease fossil fuel use in the United States food system.

Conclusion

Based on this assessment of agricultural production technologies and possible changes in agricultural technologies, in most cases the adoption of these practices would lead to an approximate 50 percent reduction of energy inputs in agricultural production. At the same time agriculture would become more environmentally sound, as natural resources are conserved, nutrients are cycled better on the farm, less runoff and erosion would occur, and the use of chemical toxins are reduced.

Also of Interest:

Streaming audio interview with David Pimentel courtesy of *Against The Grain*

Trouble with the streaming audio? Download the .mp3 for offline listening: Pimentel “Energy Use” interview

Notes

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