

Energy use in agriculture: an overview

David Pimentel and Marcia Pimentel

For over a million years, starting with the hunter-gatherers, humans have found ways to secure their food from the Earth's land. Much of the world's agriculture was, and still is, carried out by hand. Once fossil energy supplies started to become available about 200 years ago, industrialized agricultural production began to develop. Although the current industrialized agricultural systems based on high fossil inputs are relatively productive, their sustainability is questionable because the world agricultural environment is being degraded severely by soil erosion, salinization and water pollution; fossil energy resources, essential for making fertilizers, pesticides, farm machinery and for powering irrigation, are non-renewable; and vital energy resources of oil and natural gas supplies will be depleted in 35 to 40 years.

Humans have long been dependent on sustainable agricultural systems for their survival. Today, the rapidly growing human population and the diminishing resources of fertile land and fossil energy present major problems. The supplies of various grains – staples that make up more than 80 percent of the world's food – have been declining since 1984. To meet the basic food needs of our expanding human population, a productive, sustainable agricultural system must be developed and population growth controlled. Based on the analyses of various agricultural systems, we should study the efficient use of all energy sources and learn to preserve land, water, and biological resources essential to a sustainable agriculture in the future.

Based on previous studies, this article reviews the energy inputs and outputs of different maize production systems. The evolution from sustainable, low-input systems to high-input systems with questionable sustainability is examined. High-input systems can be made more sustainable by learning from traditional systems and adopting a number of agronomic practices that make more efficient use of, and conserve available resources on the farm.

Solar energy: the basis for life

Plants possess the unique capability to capture solar energy and convert it into biomass. The success of agricultural production can be measured by the amount of solar energy that is captured and converted into food per unit land area as a result of manipulating plants, land, water, and other resources. Agricultural success can be enhanced by finding ways to intensify the utilization of solar energy through the use of human, animal, and other energy sources.

To produce and harvest sufficient food, farmers must manipulate the natural ecosystem and contribute energy with their own hands, draught animals, tools and mechanization, and/or chemicals.

Slash-and-burn agriculture

One of the major factors that caused humans to move from hunting and gathering to slash-and-burn agricultural production was the continual expansion of their population. This required a higher and more dependable yield than was possible with hunter-gatherer systems.

Early slash-and-burn agriculture, with a 20-year rotation, was sustainable. A minimum of two hectares were required to produce food for one person – or up to ten hectares for a family of five. This system required about ten hectares of uncultivated land to provide sustainable food supply from about one cultivated hectare of land. The cultivated hectare of land could be used for about two years before the nutrients were depleted. The land then had to be set aside for a 20-year fallow period to restore the nutrients and productivity of the soil.

Typical slash-and-burn agriculture requires only three additional energy inputs: human labour, simple tools and maize seed. The tools, axe and hoe, can be produced using charcoal, making the system fully independent of fossil fuels. Slash-and-burn agriculture is very energy-efficient: About 1144 hours of manpower and 10.4 kg/ha of maize seed are required to produce about 1944 kg/ha of maize. By calculating these energy inputs and outputs in terms of kcal, it can be estimated that for each unit of energy put into the system, around 8.4 units are produced (see references for more detailed calculations). However, increasing populations and a shortage of arable land are major constraints to using this technology sustainably.

Draught-animal agricultural system

If some of the 1144 hours of human labour in the slash-and-burn system are replaced with about 200 hours of ox power per hectare, then the human labour input can be reduced to 380 hours/ha. The feed needed to supply the ox for about 200 hours of work is 150 kg of maize concentrate and 300 kg of forage. The concentrate consumed by the ox is derived from the 1944 kg of maize produced per hectare and reduces the net yield. In addition, the ox consumes forage from two hectares of pasture on marginal land. About 20 percent (2000 kg) of the dung produced by the ox is applied to the maize land to improve fertility, and the remaining dung ensures the continued productivity of the pasture. Human wastes from the family of five are also applied to the maize land.

In this system, maize is grown in rotation after a legume green-manure crop such as clover or vetch, and this increases the land requirement by one hectare. The legume provides the minimum nitrogen needs (60 kg/ha) of the maize, helps control soil erosion and adds organic matter to the soil.

For each unit of energy put into the system, 4.1 units of energy are produced. The minimum amount of land needed to keep this system sustainable is about four hectares. While this is less than the ten hectares required for the slash-and-burn system, it is still land extensive.

Draught-animal agroforestry system

This agroforestry system is similar to the draught-animal system in terms of labour, ox power, machinery, and seeds. The difference is that maize is now intercropped with the leguminous tree *Leucaena*, alternating two rows of maize with two rows of trees. Maize is planted at twice the density on half of the cultivated area used in the draught-animal system, and a similar yield of 1944 kg/ha is assumed.

Competition between the *Leucaena* and maize is reduced by cutting the tree back to an 8-cm stump before the maize is planted. Each year the trees produce 4500 kg/ha of biomass. >>

>> Of this total biomass, about 2500 kg of leaves and small twigs are worked into the soil, effectively applying about 60 kg/ha of nitrogen, similar to the amount of nitrogen added in the draught-animal system. Planting *Leucaena* on the contour, plus mulching with 2500 kg of leaves and twigs, limits soil erosion to an estimated one ton/ha/year. The remaining 2000 kg of *Leucaena* are harvested as stems for fuelwood. By providing about 80 percent of the fuelwood needs of one family, this system has an advantage compared with the previous draught-animal system.

Similar to the draught-animal system, feed and forage for the ox requires two hectares of marginal land and reduces the net maize harvest. To help maintain phosphorus and potassium fertility of the cultivated hectare, about 20 percent of the ox dung is applied to the maize crop. The leguminous tree roots supply some phosphorus and potassium from deep in the soil, and human wastes are also recycled.

For each unit of energy put into the system 4.1 units are produced, comparable to the draught-animal system. Although the total land area needed to keep this system sustainable is three hectares, less than the four hectares needed for the draught animal system, it is still relatively land extensive. The agroforestry system, however, has the added benefits of providing some fuelwood and improving soil quality by limiting soil erosion.

Intensive maize production

The energy flow in tractor-powered agriculture, typical of the United States and other industrialized nations, is distinctly different from that of all the hand- and draught animal-powered agricultural systems analysed. Labour input is dramatically reduced to only ten hours per hectare, which is very low compared with all the hand-powered systems discussed.

Table 1. Average energy inputs for producing a hectare of maize in the United States, 1997

Input	Quantity	Energy (kcal) x 1000
Labour	10 hr	444
Machinery	55 kg	1300
Fuel		
Gasoline	40 litres	320
Diesel	75 litres	750
Nitrogen	160 kg	2400
Phosphorus	75 kg	227
Potassium	96 kg	155
Lime	426 kg	135
Seeds	21 kg	540
Insecticides	3 kg	300
Herbicides	8 kg	800
Irrigation	16 % (irrigated)	1750
Drying maize	4000 kg	800
Electricity	100 000 kcal	100
Transport	350 kg	97
Total		10118
Maize yield	8000 kg	28800
Output/Input Ratio		2.8 / 1

(After Pimentel et al. 1999)

A significant increase in fossil energy input is needed to build and run the machines that reduce labour input and to produce fertilizers and pesticides. In 1997, the total energy inputs (mostly fossil fuels) required to produce one hectare of maize in the United States averaged about ten million kcal, or the equivalent to 1000 litres of oil (see Table 1). Based on U.S. production, the total costs of these inputs average approximately US\$550/ha.

Under favourable moisture and soil nutrient conditions, maize is one of the most productive food/feed crops. Intensive maize production yields more than 8500 kg/ha. Because of the high energy inputs only 2.8 units of energy are produced for each unit of energy put into the system.

Often overlooked in the assessment of agricultural production systems are the diverse environmental costs that accrue over time. These costs are significant, especially for intensive, highly mechanized systems. Taken together, these environmental damages would add at least US\$300/ha to the cost of intensive maize production.

Even if we ignore these economic costs related to soil erosion and degradation of other local resources, the contemporary maize production system in the USA is of questionable sustainability compared with the less technologically developed systems discussed earlier. The major difficulties associated with the intensive system are the high economic costs of production; dependence on non-renewable energy resources; serious environmental resource degradation; and instability of crop yields.

Making intensive maize production more sustainable

Numerous agricultural technologies already exist that, if implemented, will make intensive maize production more sustainable and ecologically sound than it is today. These technologies would reduce chemical inputs, reduce soil erosion and rapid water runoff, and make more effective use of livestock manure for fertilizer on the farm.

The first step in achieving sustainable maize production is to implement a crop rotation system. A suitable crop for rotation with maize is soybean, because it will not only eliminate the corn rootworm problem, but will also reduce diseases in both maize and soybeans and reduce weed problems that typically plague conventional maize production. It is also more profitable than producing either crop alone. In particular, the elimination of the corn rootworm problem increases maize yield by about eight percent and makes costly insecticides unnecessary. Because soybeans produce their own nitrogen through the assistance of microorganisms, the application of nitrogen fertilizer is also unnecessary.

To make effective use of the grain produced in a diversified farming system, livestock are often included. Effective use of farm manure reduces pollution of ground and surface waters, adds nutrients to the soil, and enhances soil organic matter while reducing soil erosion. Planting a cover crop like winter vetch further reduces soil erosion and water runoff, reduces weed problems, and adds needed nitrogen to the soil. Although using a cover crop requires additional labour and costs for the legume crop seed, the payoff is significant. The total labour increase might be 20 - 25 percent, but this would be more than compensated by the higher yields and higher price for the organic produce that result.

The modifications of the system to be more organic and sustainable can increase maize yield slightly to 9200 kg/ha,

while at the same time providing a 30 - 50 percent reduction in energy inputs. This would reduce the total cost of maize production, including the additional labour, by 30 - 40 percent. Were the environmental benefits to be included in this equation, the total costs would be further reduced.

Table 2. Energy efficiency in different maize production systems

Agricultural system	Energy output/input ratio
Slash-and-burn	8.4:1
Draught animal	4.1:1
Agroforestry	4.1:1
Industrialized maize	2.8:1
"Improved sustainability" intensive maize	4.8:1

(Based on calculations presented in Pimentel et al. 1999)

Employing appropriate crop rotations, use of livestock manure, and a ridge-till rotation system reduces soil erosion from about 15 ton/ha/year to less than one ton/ha/year, equal to the soil reformation rate under most agricultural conditions. Furthermore, soil and water conservation technologies are reported to increase maize yields by 10 - 15 percent, even under intensive agricultural systems that usually experience moderate to severe soil erosion.

Conclusion

When considering the energy inputs and outputs of a particular agricultural system, it becomes clear that energy efficiency can be greatly improved when the flow of energy through the system is understood. Energy provided by fossil fuels such as oil and natural gas are non-renewable and therefore exhaustible. Most modern, industrialized agricultural systems that depend on fossil fuels are energy-inefficient and in the longer term, unsustainable. Current reports of oil and natural gas shortages project more serious shortages in the future, suggesting that intensive agricultural production should adopt more energy-conserving, ecologically sound and sustainable practices. In addition to conserving fossil energy, sound agricultural practices must place priority on using renewable energy, and conserving soil, water and biological resources.

David Pimentel and Marcia Pimentel. College of Agriculture and Life Sciences, 5126 Comstock Hall, Cornell University, Ithaca, New York 14853-0901, USA. Email: dp18@cornell.edu

This article is based on information from:

- Pimentel D., Pimentel M. 1996. **Food, energy and society.** Niwot, CO, Colorado University Press.

- Pimentel D., Pimentel M., Karpenstein-Machan, M. 1999. **Energy use in agriculture: an overview.** CIGR Electronic Journal, <http://www.agen.tamu.edu/cigr/>

Planting to catch more sunlight

Reddy Naganagouda, Zhu Shuijin and V.C. Patil

Today, conventional agricultural systems depend on high energy inputs to be productive – making their sustainability questionable. One way to increase production more sustainably may be to improve the amount of solar energy that is captured by the cultivated plants and transformed into biomass. This can be achieved with a variety of agronomic practices; some are common in traditional agriculture and some are presently being developed by scientific research. For example, the amount of solar energy captured by crops on a particular field can be increased by changing planting dates to extend the season or to allow for more crops in different development stages; by rotating or mixing crops; or by changing the distribution of crops in the field.

Intercropping

Intercropping in many different forms can optimize the utilization of resources such as nutrients and water, as well as increasing the amount of solar energy intercepted per unit area of land, resulting in increased total biomass production. In intercropping, two or more crops are grown together either mixed or in rows. These crops must be complementary in terms of utilization of soil nutrients, water and sunlight. It may be useful, for example, to combine tall and short crops, plants that root deeply with shallow-rooted plants, crops with a broad leaf cover with those having a narrow canopy, and early with late maturing crops or crop varieties. Because of the complementary way the crops utilize important resources, the productivity of these systems is high. Common intercropping systems in China and India include sorghum with green gram, onion with chilli and cotton (traditional cultivars), pigeon pea with sorghum, sugarcane with cabbage and maize with soybean. The intercropping of cotton

with sunflower or cotton with castor are new research recommendations, which are now being adopted in the rain-fed cotton areas of Karnataka state, India.

Combined row planting

Two or more rows of a particular crop are planted closer than usual, while leaving more space in between these groups of rows. Plants in the rows experience more competition and as a reaction, they develop more roots and leaves. At the same time the wider spaces between the groups of rows improves aeration and allows interception of more sunlight by the increased number of leaves. The number of rows that can be planted together depends on the particular characteristics of each crop: for cotton or pigeon pea, no more than two rows should be planted together. For maize, three rows can be planted at short distances, while for vegetables, more rows may be combined.

High density planting with a dwarf crop variety

This technique is widely practiced in Chinese cotton growing areas of Xinjiang, and is also a common practice for rice and wheat. High density planting, combined with the smaller size of the plants, helps to rapidly achieve a closed leaf cover and to intercept more of the sunlight reaching the field. It should be noted, however, that high density planting may require more inputs like water and fertilizer to be able to reach maximum productivity.

Reddy Naganagouda and Zhu Shuijin. Dept. of Agronomy, Zhejiang University, Hangzhou 310029, PR China. Email: reddy_zju@yahoo.com.cn and shjzhu@zju.edu.cn

V.C. Patil. Professor & Head, Dept. of Agronomy, University of Agricultural Sciences, Dharwad 580005, India. Email: vcpatiluasd@yahoo.com