ENERGY USE IN PRODUCTION OF FOOD, FEED, AND FIBER

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Summary

Energy inputs are critical to agricultural production and the increased use of fossil fuel based energy resources has become increasingly important, particularly in developed countries and increasingly in the developing countries. Even though agriculture requires only a very small percentage of all the fossil fuel resources used in the world, long-term sustainability of global agricultural production will require renewable alternative energy resources. Just after the oil embargo of 1973 there was significant research to document the energy flows and requirements in a number of agricultural production systems. Also there was a substantial effort in some countries to develop conservation strategies and alternative renewable energy systems for production agriculture. There are many systems that can provide on-farm energy resources from renewable sources. Solar energy, wind and small-scale hydro systems can provide on-farm as well as off-farm energy resources. Biomass is a resource being used at an increasing rate but still at only a minute portion of its total potential. The derivation of useful energy from waste materials by direct burning, gasification or anaerobic digestion with recycling of the nutrients can replace a substantial portion of current consumption of fossil fuel. Agriculture also has a potential to provide energy to other segments of society, particularly from biomass-based systems. These include biogas from anaerobic digestion and liquid fuels such as ethanol and biodiesel.

1. Introduction

Agricultural productivity has increased with increased use of energy from a variety of sources. Increasing use of inputs to production agriculture of fertilizer, irrigation and pesticides all require commensurate increases in the use of energy. Mechanization of agricultural tasks increases human productivity and improves the timeliness and quality of many operations and also relies on energy inputs. Increasingly the energy for all of these inputs to the agricultural production system has been derived from fossil fuels, particularly in the developed countries and increasingly in the developing countries. The requirements of fossil fuel based energy resources for post farm operations including processing, transportation, storage, wholesale and retail distribution and home storage and cooking far exceed production energy requirements in developed production systems.

The energy requirements for production agriculture, less than 3% of global energy use, represent a small portion of the demand for fossil fuels, but are a critically important input to the food, feed and fiber production system. Interest in reducing the dependence on fossil fuel for agricultural production increased dramatically just after the oil embargo of 1973. Many studies were undertaken to quantify the relationships involved in energy flows in various farming systems. Research and demonstration projects focused on reducing dependence on fossil fuel by conservation and replacing fossil fuel resources with solar energy and other renewable alternative sources.

Many renewable energy strategies such as solar thermal energy systems and electrical generation systems such as photovoltaic, wind and small-scale hydro can make a contribution to on-farm as well as off-farm applications. In addition there are possibilities to generate on-farm energy requirements from on-farm sources such as agricultural wastes and other biomass derived energy sources that are particularly effective fossil fuel replacement strategies as the resource is near the place of application.

Beyond the use of farm derived energy sources to meet on-farm energy requirements there are additional opportunities for agriculture to contribute to off-farm energy needs, particularly through biomass derived fuels. Biogas from anaerobic digestion and liquid fuels including ethanol and biodiesel can meet a substantial portion of global energy requirements on a sustainable basis. In order for this to occur the technologies developed must be based on consideration of all aspects of the production and utilization systems. Not only must the energy flows meet all needs on a renewable basis but ultimately all materials must be recycled to achieve long term sustainability.

2. After the 1973 Oil Embargo

As a result of the oil embargo of 1973 and the resultant supply shortages and price increases there was a significant interest in all topics related to dependence on fossil fuel resources. This led to research on a wide variety of energy related topics which included studies of the requirements for energy for food production, the possibilities to reduce dependence on fossil fuel by conservation and alternative energy sources. Also interest grew in the possibilities for agriculture to become a source of energy supply for other societal energy requirements. Many papers, articles and books were produced over the following decade on these topics, three of which are selected as sources for examples in the following discussion.

Energy flows in a variety of food production systems are analyzed by Pimentel in

Pimentel and Hall (1984). The gathering of nuts in a hunter-gatherer society is analyzed assuming the inputs are all the energy requirements of one gatherer for his collection and transport of the nuts and his daily maintenance energy requirement for other activities and sleep. His total daily energy requirement of 2 680 kcal enabled him to produce 1.75 kg of shelled nuts with a food energy content of 10 500 kcal. Thus the ratio of food energy collected to energy expended is 3.9:1, but significantly all the energy input is human. Another case presented is for Maize production in Mexico using only manpower but includes the energy to produce the tools, (axe and hoe) and the corn seeds for a hectare yielding 1 944 kg of grain. The total energy inputs of 642 338 kcal result in 6 901 200 kcal of food energy produced for a ratio of 10.74:1. In another case example on less productive land with animal power replacing much of the human labor 941 kg of grain are produced from 770 253 kcal total energy inputs and 3 340 550 kcal food output for a ratio of 4.34:1. Clearly the relationship here would have been improved if the land had been more productive. Pimentel points out that the second study was on land that had been cropped for years with a reduction in soil fertility. Significantly the substitution of animal power for human power can enable the use of forage crops for the animal rather than food items normally required for people.

For two additional scenarios for a hectare of maize production in the United States Pimentel uses one case for mechanized production including the use of fertilizer, pesticides, drying and transportation. In the second case he assumes horses replace fossil fuel powered equipment. For both the yield of 7 000 kg per hectare of grain produces a food energy output of 24 500 000 kcal. In these cases the energy input for fertilizers and herbicides and LP gas for drying totaled 4 759 250 kcal per hectare, almost half of which was for nitrogen fertilizer. The total inputs were 6 958 250 kcal per hectare for the mechanized system and 7 219 200 kcal per hectare for the horse based system for output/input ratios of 3.5:1 and 3.4:1 respectively. While there was not much difference in total energy input it is highly significant to note that the human effort was 120 man hours and 70 000 kcal human energy per hectare for the horse based system vs. only 12 man hours and 7 000 kcal for mechanization.

From the sample cases discussed above it is clear that the use of fossil fuels in the production of man's basic food energy requirements has increased land productivity and the productivity of human labor. One of many interesting and useful charts and tables presented by Stout (1979), p 66, is an overview of the flow of energy in the United States food system to produce 1 kcal of human food. The consumption of 1 kcal of food is composed of 0.38 kcal from animal products and 0.62 kcal from vegetal products. To generate this consumption the total potential food, feed and fiber produced in the field represents 16 kcal of basic energy. Of this amount, 3.9 kcal remains in the field as crop residue 1.1 kcal represents food exports and nonfood items including cotton and tobacco. Of the remaining 11 kcal that enter the food chain 1.2 kcal move directly towards human consumption but 0.5 kcal become processing byproducts that move to animal consumption and an additional 0.08 kcal are waste resulting in the final 0.62 kcal consumed as vegetal products. The remaining 9.8 kcal of the 16 kcal produced plus the 0.5 kcal from processing waste are fed to livestock. Of this energy 5.3 kcal finally reside in the manure produced by the livestock and waste. The remaining energy is used by the animals for their metabolism and for the 0.38 kcal final human consumption.

This chart also indicates the non-solar energy inputs to produce the 16 kcal of food, feed and fiber that ultimately result in human consumption of 1 kcal. The on-farm consumption of energy for field production totals 1.39 kcal and on farm livestock operation plus feed manufacturing an additional 0.4 kcal. Food processing requires 1.3 kcal and the transportation of food an additional 0.9 kcal. The energy required by the wholesale and retail distribution system is 1.0 kcal and food preparation from 2 to 5.7 kcal. The total on-farm energy consumption of 1.79 kcal per kcal of food energy produced is an output/input ratio of 0.56. This ratio for the entire food system is less than 1/6 that of mechanized corn production discussed above, a consequence of the high dependence on animal based food production.

It is important to note that there have been a large number of analyses of energy flow in the food systems of a number of countries and for a variety of circumstances. In many cases these analyses are presented to support a particular proposed strategy for change in the food production system or allocation of scarce resources in society or change in human behavior that might result in greater efficiencies of energy conversion from the inputs to the food system relative to the energy content of the food consumed. An argument is often made for changing human diet to reduce or eliminate foods derived from animals thereby substantially improving the efficiency of conversion of energy from that in food and feed produced to human calorie intake.

Pimentel in Pimentel and Hall (1984) pp 18-19 presents an example of such a discussion. The three high protein diets presented include a pure vegetarian diet, a non-vegetarian diet and one, a lacto-ovo vegetarian diet that includes eggs, milk and milk products. Each diet is to provide a total of 3 300 kcal and at least 80 g of protein with over 100 g of protein in the animal protein diet. The fossil fuel inputs required to support these are a high of 33 900 kcal for the animal protein diet to 9 900 kcal for the all-vegetarian diet with the lacto-ovo diet in between requiring 18,900 kcal.

In times of a shortage of resources rationing is often used to allocate resources to high priority items and the most visible rationing strategy for many during the oil embargo was a scheduling system for the purchase of fuel for automobiles. Given the relatively low percentage of global energy required for production agriculture, 2.5% in Table 2, and the importance of food production for humans it would be reasonable to argue that production agriculture should receive all the energy resources required. It is significant to note that in highly developed countries this percentage is even lower, i.e. 1.1% for North America. In the discussion above it is noted that in the United States for example, the energy requirement for food processing and transportation exceeds the total for all on farm food production. The energy consumed in the marketing of food and the energy required for storage and food preparation far exceeds that required for production. Thus there is much greater potential for reducing societies dependence on fossil fuel in these areas of the food system than in on farm food production.

A typical example of the efforts to organize information related to energy requirements for agriculture and find ways to reduce dependence on fossil fuel resources was a conference held on the topic of agriculture and energy reported in a conference proceedings edited by Lockeretz (1977). In addition to studies on energy use in various production systems there were focused programs on specific areas that require substantial energy inputs such as: tillage, irrigation, fertilizer, crop drying and livestock production. Also covered were topics including the potential for alternative energy systems, the special needs in developing countries and topics on policy.

More recent and increasingly thorough production system energy requirements for various agricultural systems have focused on environmental as well as energy sustainability in many cases. An example of a comprehensive system analysis quantifying all the required energy flows is a study of the energy flow relationships of Asian rice systems (Chancellor 2002). The complete system presented is composed of 12 major entities with 53 linkages representing energy and materials flows. Special emphasis is given to the issues of sustainability related to the nitrogen and water cycles so critical to rice production. The potential to replace all or part of the energy derived from fossil fuels with renewable resources, such as the biomass waste materials, in a number of the linkages are presented. The study concludes that with the advances in knowledge and technology and advances in understanding about energy relationships, there is the possibility that agriculture could not only supply increased yields, but also strengthen its position as a supplier of its own energy as well as of energy to the general economy.

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Biographical Sketch

David Mears is Professor of Bioresource Engineering at Rutgers University where he has concentrated his teaching and research in recent years in the engineering aspects of controlled environment agriculture. The Rutgers University group focused on Horticultural Engineering was intimately involved in a number of energy conservation measures resulting in potential savings of 90% for commercial greenhouses relative to average 1970’s requirements. He has long been interested in the relationships between production agriculture and energy and has maintained that through involvement in a wide range of projects from the late 1950’s to the present.