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# ECONOMIC RESTRAINTS ON REDUCED ENERGY USE IN AGRICULTURE

Lowell D. Hill
Department of Agricultural Economics
University of Illinois
Urbana, Illinois

Many of the popular suggestions for improving energy use under mechanized agriculture would result in a reduction in total food supply or they are in conflict with economic decisions. This paper examines several of these suggestions and identifies the economic limits to their implementation. The choice of food products or techniques of production must be evaluated in the context of all uses of energy. Only a market system is capable of permitting every consumer to express his preferences for the infinite array of foods and energy uses.

Recent concern over dwindling supplies of fossil fuels and inadequate supplies of food in many areas of the world, have focused attention on agriculture's role in the energy balance. Increasing the energy efficiency of food production to meet the nutritional requirements of a growing population has been given a high priority for research. The potential savings from implementing the expected research results can not be realized without recognition of the role of economics and consumer choice in the food industry. A review of the history of technological growth in agriculture shows an inherent conflict between the reduction of energy consumption and economic principles.

## I. THE ECONOMICS OF ENERGY USE

Nearly all economic activity is a process of transforming one form of energy into other more valuable forms. Agriculture is often viewed as unique among production processes because its major energy sources--air, sun, rain, and soil--are often available independent of the efforts of man. But even if these resources were free, the production of food is still a process of energy transformation--changing energy from an inedible form into an edible form. If people could digest air, soil, and crude oil we would have no need for farmers. The goal of this transformation is to find the least expensive supplies of energy to convert into a dearer form. The choice of energy sources is not technological but economic and the choices are guided by relative values of inputs and outputs. Conversion of soil, water, and labor into food is not motivated by the ratio of energy produced to the energy used but by the value of food, compared to the cost of production. In a market economy the value of food is established by its basic demand for the satisfaction of human needs and wants.

But food can be produced in many forms, by any of several processes using different combinations of energy inputs. Some of these processes are more energy efficient than others. However, the choice among these processes is not based on energy ratios but on the value of end products relative to the costs of production. Consumer choices among food items are based on their concept of value relative to the price. Farmers' choices of energy sources and enterprise combinations are explained by the returns to the resources which they control. If the producer can purchase a quantity of a certain input (e.g., fertilizer) for $1.00 and transform it into a food product (e.g., a bushel of corn) worth $3.00 by combining it with his supply of land and labor, he will do so within the limits of his physical and capital capability. Furthermore, he will select that combination of energy sources and product enterprises that provides the greatest returns for each dollar invested.

This economic principle provides an explanation of observed aggregate changes in resource use. The substitution of chemical fertilizers and fossil fuels for land and labor in agricultural production has been a response to the rate of return per dollar invested in a unit of each of these resources. For example, between 1930 and 1957 labor returns on corn belt grain farms ranged from a low of $0.24 to a high of $2.62 per hour. [10, pp. 82-84] Returns to land have also been low. Farm record data for Illinois show returns to land from agricultural production to be in the range of 4 to 6 percent on farm owners' investments.* In contrast, returns to fossil fuel energy during this period were 2 to 3 times the value of that input. [7] It is not surprising that during this period labor use decreased while fuel use increased. At a more micro level the application of an additional dollar's worth of nitrogen fertilizer on central Illinois land returned $7.23 in increased corn yield at 1964 prices, $13.35 at 1971 prices, and $8.83 at 1976 prices.** The changes in farming practices that resulted in the use of less labor, more fossil fuels, more fertilizers, more chemicals, more steel, and more of our non-renewable resources may be deplored by energy conservationists but any businessman seeking to make a profit could have made no other decision. The producer seeks to find ways to produce the largest possible amount of food by the least cost method at his disposal.

Efficiency comparisons that exclude price relationships ignore the primary function of a market--to allocate scarce resources to their most valuable uses. While 1920 agriculture used much less fossil fuel to produce a bushel of corn than 1970 agriculture [8, p. 49], 1920 techniques used much more harness leather, more steel wheeled wagons, and more husking pegs per bushel of corn production. If efficiency is measured in bushels of corn per pound of fertilizer then 1970 agriculture is inefficient relative to 1920. But if efficiency is measured in bushels of corn per acre of land, or hours of labor per bushel of corn then 1920 agriculture is the inefficient system. Both time periods, however, were economically rational in their allocation of the resources, given the prices that existed at each point in time.

The fallacy in comparing "efficiency" between time periods can also be demonstrated among cultures. It has been stated that U.S. rice production is very "inefficient" when compared to Chinese techniques [4, p. 524]. It is true that output per unit of fossil fuel is much lower in the U.S. than in China but Chinese agriculture is very "inefficient" in its use of labor. Efficiency can not be determined through measurement of only one of the resources essential to production. The choice in both countries is based on relative costs of resources and products, and decision makers in both cultures tend to select the least cost techniques for production.

## 2. INCREASING THE EFFICIENCY OF FOOD PRODUCTION

World food supplies will not increase as rapidly as the desire for better diets and they are unlikely to equal the minimum subsistence requirements

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*These returns are the Landlords' returns to capital and management on 260- to 339-acre farms as calculated from Illinois Farm Business Farm Management records.

**A yield increase of 12 bushel for a 25 pound increment of nitrogen was obtained at an average yield of 104 bushels per acre on Central Illinois soils. This yield response varies with soil type and level of fertilizer application. [9, p. 26] for an increasing world population. The need to increase food production in the face of shrinking supplies of fossil fuels requires that we examine alternative systems for agricultural production with lower energy requirements and the consequences of these alternatives. Inefficient use of our fossil fuels in food production will diminish our ability to feed the present population and will increase the speed of our headlong sprint on a collision course between food and population.

Several opportunities exist for increasing energy efficiency in agriculture. All of these involve an economic, social, or political cost. For purposes of evaluating their potential and assessing some of their impacts, these suggestions have been categorized under four headings: (1) reduced use of inputs, (2) input substitution, (3) development of new energy sources, and (4) changes in consumption habits.

## 2.1 Reduced Use of Inputs

Implicit in much of the writing on energy efficiency is the thought that a reduction in the quantity of fossil fuels relative to other inputs would result in a more "efficient" use of our scarce fossil fuels. The calories produced per pound of nitrogen fertilizer were much higher when application levels were low. Pounds of milk per pound of grain can be increased by reduced levels of feeding dairy cattle. These do not represent a sudden exposé of careless inefficiencies by farmers. They are rational economic decisions that illustrate a basic principle of economics. That principle is called the law of diminishing returns. The larger the quantity of any variable resource (e.g., fertilizer) applied to fixed quantities of other resources (e.g., land) the less will be the returns per unit of resource. However, so long as an additional unit of the variable returns more than its cost (in dollars or energy), it is economically efficient to use it. Returns per unit of energy can be increased by reducing the amount of energy but this will also reduce total food supplies. Experimental work with corn has provided numbers for this theoretical relationship. At application rates of 50 pounds of nitrogen per acre, each calorie of energy in fertilizer produced 9 calories of corn. At an application rate of 200 pounds of nitrogen, each calorie of energy produced only 6 calories of food. [2] Although the "energy efficiency" is decreased by nearly 1/3 at the higher application rates, the process still returns 6 calories of corn for every calorie of energy used in the production and transportation of fertilizer. In a world of food shortages it is difficult to argue that society should reduce the food supply by 6 calories in order to save 1 calorie of fossil fuel.

An increase in production per unit of fossil fuel can be obtained by reduced use of fossil fuels but only with a reduction in total output. Given the present balance of world food and population this choice does not appear to be politically or economically viable.

## 2.2 Input Substitution

Most recommendations for conservation of fossil fuels in agricultural production indicate an awareness of the need to substitute other forms of energy for the fossil fuels to be withdrawn from production. Unfortunately, many of these recommendations have ignored differences in the cost of alternative energy sources for the production of an additional unit of food. Dr. Earl Cook has estimated the cost of fossil energy on U.S. farms to be about 15 dollars per million BTU. In contrast a farm laborer earning $3.00 per hour and producing 500 BTU per hour of work costs $6,000 per million BTU. [1] The economic relationships necessary to justify such substitution require that human labor must be valued at nearly zero or the price of fossil fuels increased by a multiple of 400. The increase in energy efficiency is unequivocal in Steinhart's observation that "Hand application of pesticides could reduce energy for application from 18,000 Kcal/acre to 300 Kcal/acre." [8, p.56] The information, however, is not an adequate basis on which to recommend substitution of labor for equipment because it ignores the costs of hand spraying, and the physical magnitude of the task of spraying several million acres of corn with knapsack sprayers.

Crop rotation can be used to reduce requirements for commercial fertilizer, but the total grain production cannot be maintained without an increase in land in crops. The use of the simple corn, small grain, legume rotation as a substitute for continuous corn would require 3 acres of land to maintain every 1 acre of corn. Assuming that all the present small grain, hay and rotation pastures would be worked into the rotation scheme, Illinois would require an additional 15.1 million acres in cropland just to maintain the total corn acreage of 10 million acres. An expansion of this magnitude would require expensive and extensive land reclamation, clearing, drainage, and irrigation--clearly not an alternative for saving energy.

It has also been suggested that the substitution of mechanization for animal power in the United States between 1940 and 1973 has reduced the efficiency of agriculture and conversely a return to draft animals would solve some of our energy shortage. The amount of feed required to maintain the draft animals is indicated in USDA statistics which show that 42 million acres of crop land were used for feed for draft animals in 1940. [11, p. 7] Even at a modest corn yield of 50 bushel per acre, over 2 billion bushel of corn would be withdrawn from food production in order to provide the hay and oats needed for animal power. Such a substitution among inputs is obviously unacceptable on any criteria except minimum fuel use. The emphasis on crop yield per acre or per energy unit detracts from the more important goal of increased total food production.

There are opportunities for substituting replaceable forms of energy for the scarce fossil fuels. The most rapid response is obtained from changes in price relationships. Increased prices of fertilizer lower the relative profitability of corn compared to soybeans. The lower cost of diesel fuel compared to gasoline provided much of the incentive for a rapid increase in the number of diesel tractors with the accompanying increase in energy efficiency. Higher prices for grain drying fuel have also encouraged farmers to delay corn harvest to decrease the fuel needed for drying despite increased field losses and delays in fall plowing. These are only a few examples of the many opportunities for substitution among inputs to reduce the consumption of fossil fuels. All are dependent on an economic stimulus or at least the removal of a negative stimulus for their adoption. Present price relationships encourage continuation of the trend toward a more energy intensive agriculture and the inescapable result of lower energy efficiency.

### 2.3 Development of New Energy Sources

The idea of substitution among existing inputs can be extrapolated to inputs and technologies not yet known or available. Only a few of the many possible examples will be mentioned.

The efficiency of plants in converting sunlight into food is quite low. Although incident radiation energy on Illinois during a year averages 1250 BTU per square foot per day, a 130 bushel/acre corn crop extracts only .6 percent of this energy. At the peak of the growing season photosynthetic efficiency is only about 3-4 percent. [3] Research is needed to develop techniques for capturing a higher proportion of the tremendous quantities of energy delivered by the sun and converting this into food.

### 2.4 Changes in Consumption Habits

The calorie content of an average diet in the United States has been estimated to be nearly 50 percent greater than the calories consumed in the less developed countries. Even worse, because of the meat that is included in the U.S. diet, a total of 5,280 calories of plant material is required to produce the 3,000 calories of food products. These widely publicized comparisons have encouraged numerous suggestions for sharing U.S. food supplies with needy nations. Most of the suggestions such as meatless diets, increased grain shipments overseas, and selective export restrictions are inadequate solutions to the short-run problem of food shortages because they ignore the difficulty of transportation and distribution of large quantities of food grains; they ignore the effect that a drastic decline in meat consumption would have on the economic incentive for production of grain; they incorrectly assume that the corn not fed to livestock would be readily consumed by people who have eaten rice or wheat for generations; they consider only calories as a measure of nutrition.

These comparisons have led to many suggestions for changing consumption patterns for the United States. However, comparisons on the basis of calories can be misleading because nutritional requirements include more than just calories. Consequently, attempts to compare food products on the basis of the calories produced per calorie of energy used in production may lead to errors from a nutritional point of view. Corn meal or wheat flour cannot be substituted for fresh fruits and vegetables even though it requires much less energy to produce a calorie in grain than a calorie in vegetables. Although production of a calorie in the form of meat requires many times the energy for production of a calorie of grain the comparison is not valid since meat is seldom if ever consumed for its caloric content.

Comparisons among food products to identify the efficiency of one form relative to another also overlook the convenience factor that heavily influences consumer preferences. A raw potato, a live chicken, and a basket of unshelled peas are not good substitutes for a TV dinner in the mind of a working housewife. The energy in the form of fossil fuels required to produce, process and market the two meals is irrelevant to most consumers.

Comparison of caloric levels can also be misleading because of differences in palatability, dietary habits, or culture. A baked potato is not an acceptable substitute for a potato chip even though the energy cost per calorie is much less.

In 1945 a California economist published a minimum cost diet, meeting all nutritional requirements. This diet would also use much less production and processing energy than the present diets of most Americans. However, housewives have not been very enthusiastic about the suggested diet of 535 pounds of wheat flour, 107 pounds of cabbage, 13 pounds of spinach, 134 pounds of pancake flour, and 25 pounds of pork liver.

The fallacy of comparing countries, diets, or food items on the basis of calories illustrates a fact that everyone recognizes with a moment's reflection. In developed countries, food is a form of entertainment, a business function, a social amenity, a psychological escape or a form of peer acceptance. Only rarely is it used primarily as a source of nourishment to meet biological requirements. Caloric content, or even the more general criterion of nutritional content, is seldom the basis on which food is purchased. There is a very limited market for nutrition and no market for calories as such. A select committee of the U.S. Senate has released a study showing that improved diets could reduce medical problems and the grocery bill at the same time for the average American family. They also reported that Americans are now consuming an average of 27 gallons of soft drinks per person per year. Meanwhile, the price of low calorie foods is rising more rapidly than the full calorie counterpart. Caloric measures of efficiency are of little value to consumers.

In the longer run, a recommended shift in U.S. consumer diets as a solution to world food shortage has an additional fallacy: current food production is only a minute part of the total question of energy allocation. Food cannot be separated from other choices of energy use. Forcing a choice between meat and grain consumption while ignoring other important uses of energy ignores the relationship between food and fuel. Adequate food supplies are possible on a world wide basis if sufficient fossil fuels are provided to use the available land and solar energy. Current world food shortages could be eliminated if present supplies of fossil fuels were used for food production rather than for production of other consumer goods.

Conservation of fossil fuels in transportation, in households, or in industry provide the same potential as reduced beef consumption for increasing food supplies to be distributed to hungry nations. Reduction of meat consumption has a popular appeal, and it provides an element of self sacrifice among an over-fed population but it is not the most effective approach to a goal of relieving widespread famine on either a long-run or short-run basis. The solution lies in an economically rational use of our total energy supply and an allocation of this supply among all the choices available to consumers.

## 3. THE ROLE OF CONSUMER CHOICE IN ENERGY USE

Economists have long debated the issue of consumer sovereignty. For the most part it is still unresolved but recent consumerism activity suggests that the consumer still has considerable "free will" in his decisions and he is not adverse to making his wishes known through boycotts or shifts in purchase patterns.

As a basic philosophy the market system has allowed consumers to choose between beer and coke, chicken and pork, and cake mixes and "bake it from scratch." Recommendations that agriculture shift from products with a high ratio of energy input per calorie, to products with a low energy input, either visualizes a new social order in which consumer preferences are legislated or incorrectly assumes that consumer preferences do not influence the allocation of resources into their highest value use.

If the intent is to legislate consumer preferences in order to reduce energy consumption, then careful thought should be given as to whose value judgments are to provide the basis for the "acceptable" market basket of goods.

The criterion on which certain food items such as meat have been selected for elimination in the interest of energy conservation is not clear. There are several foods whose ratios of energy output per unit of input are lower than poultry and not significantly different from beef--especially when one considers that some of the energy input to meat is not suitable for direct human consumption. (Table 1)

On the basis of caloric efficiency, corn production under mechanized agriculture ranks very low. However, a comparison with other food products quickly demonstrates that calories produced per unit of energy in unprocessed green beans are much lower. Frozen cauliflower is even less "efficient." The comparison of a broader range of food products on the basis of total energy consumed in processing and manufacturing, suggests other candidates where reduced consumption would have as great an effect on energy consumed with less effect on nutritional levels. (Table 2)

Table 1. Ratios of Crop Calorie Content to Fuel and Electrical Energy Input in Crop Production.[a]

| Commodity | Ratio |
|---|---|
| Barley | 6.609 |
| Corn | 3.250 |
| Wheat Flour | 5.363 |
| Green Beans (raw) | .545 |
| Green Beans (canned) | .288 |
| Strawberries (raw) | .461 |
| Broccoli (raw) | .246 |
| Tomatoes (canned) | .167 |
| Cauliflower (frozen) | .123 |

[a] Values for all commodities include energy requirements up through the first stage of processing.

Table 2. Total Energy Used for Heat and Power in Processing and Manufacturing of Selected Agricultural Products (millions of kilowatt equivalent).

| Commodity | Energy Use |
|---|---|
| Meat products | 32,308 |
| Frozen fruits and vegetables | 7,657 |
| Sugar | 31,899 |
| Beverages | 29,151 |
| Roasted coffee | 2,511 |
| Cigarettes | 3,335 |
| Agricultural chemicals | 17,617 |
| Farm machinery | 11,320 |

Source: [12]

For example, the processing of sugar utilizes almost as much energy as the processing of meat. Coffee and cigarettes, offering no nutritional value, together require almost as much energy as the entire frozen fruits and vegetables industry. Beverages utilize more energy than the manufacture of agricultural chemicals and farm machinery combined. Before central planners can optimally allocate energy resources among alternative uses in agricultural production, they must develop allocation criteria that encompass more than just calories and allow for a range of consumer preferences broader than the traditional definition of food. To restrict the use of fuel for drying grains while permitting--even subsidizing--the production and drying of tobacco is inconsistent with a goal of national nutrition and health, or caloric efficiency. Whose value judgments are to be used in determining that feed and food should be reduced by restricting energy for drying grain while continuing to use more fuel in drying tobacco than is used for rice, peanuts, sorghum and soybeans combined?

Steinhart and Steinhart raise questions as to the appropriateness of frost free freezers and kitchen appliances in an energy conscious society. It is not clear why these are less desirable than TV's and electric golf cars. These examples are given only to illustrate the danger of legislating consumer preferences. Necessities are often defined to be the products I buy--luxuries are the products that other people buy. This is especially true when we recognize that food choices cannot be made independently of all uses of land and energy. Fertilizer--the basic ingredient for increasing food supplies in the U.S. and the world--is in short supply due to lack of natural gas. At the same time millions of gallons of natural gas are used for generating electricity and for other industrial and consumer uses. We cannot simply choose between beef and bread. We must extend this choice to "instant on" TV units, recreational vehicles and every use that is made of land, labor and fossil fuels. They all compete for energy supplies capable of providing food and alleviating starvation no less than the beef animal.

There is no satisfactory system for allocating products among people, and resources to the production of different products, except a market price--permitting people to express their preferences by the dollars they are willing to spend. A rationing system that substitutes coupons for dollars reflects dissatisfaction with distribution of wealth--it does not indicate a failure of the market system.

## 4. RESEARCH NEEDED FOR IMPROVED ALLOCATION OF ENERGY RESOURCES

There are two basic problems facing every individual, firm, community, country, or society: (1) how to obtain a greater supply of resources, and (2) how to allocate these resources among alternative products and production processes. The allocation of resources is especially important because it not only affects the kind and quantity of goods available for consumption, but the efficiency with which limited resources are converted into goods and services desired by society or individuals.

While the allocation is often considered to be an individual decision, society develops the rules by which these choices are made. For example, a national policy of cheap fossil fuels has been largely responsible for a rapid shift to mechanized agriculture in the United States. It is therefore important to understand not only the allocation process of individuals, but the economic and political organization that constrains or alters the range of individual choices in allocating energy.

The research should focus on two aspects of the allocation question: (1) the optimum allocation of energy, and (2) the process by which the available resources are to be allocated. The first requires an analysis of production technologies available for the production of the given mix of food products. Research questions include whether total food production could be increased by different combinations of resources or production techniques, and what kinds of additional energy use could provide the greatest increase in food at minimum cost. Research should also be focused on shifts of energy use from production of non-food products to food production. This question of priorities in the use of limited energy supplies leads into the second group of research issues--the allocation process. In a competitive economic system, market prices provide the criterion by which energy is allocated to different uses. However, every country has found it necessary to supplement or circumvent the market mechanism to varying degrees. The role of incentives in production, the procedures for determining priorities, and the techniques for implementing and enforcing priorities differ widely among countries. The degree to which the needs and wants of society are met under these alternative systems should be evaluated.

The research approach to the problems of determining the optimum allocation of energy and comparing techniques for allocation should be coordinated with the collection of an inventory of energy supplies and uses in selected countries. Aggregate resource use by type and source of energy and by type and quantity of products should be carefully documented. The effect that reallocation of energy and the application of alternative techniques would have on total food production should be quantified under several alternative assumptions. The allocation mechanism in each country should also be carefully analyzed with special attention to methods of altering the allocation of energy within the existing cultural and political environment to better meet the needs of society.

The results of the research would be directed toward policy decisions in energy use priorities, as well as guidelines for individual firms in their allocation decisions. Research institutions in each of the countries selected for analysis should be heavily involved in describing and analyzing energy use and allocation procedures. An understanding of the political and cultural criteria affecting allocation would be an especially important contribution of the researchers in cooperating countries.

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