# Food Production and the Energy Crisis: A Comment

The article by Pimentel *et al.* (*1*) raises serious questions concerning the energy-intensive path of agricultural development that has been followed by the developed countries of Western Europe, Japan, and the United States and that is now being adopted by a number of developing countries. Similar concerns have been expressed by Hirst (*2*) and by Steinhart and Steinhart (*3*). In addition, the Pimentel article has been cited to support more extreme conclusions than the authors themselves might espouse (*4*). Yet the evidence presented by Pimentel and his associates does not support their argument. Indeed, the data they cite indicate, if anything, that U.S. corn producers are using less than the optimum amount of energy input per unit of corn production.

The energy accounting convention adopted by Pimentel *et al.* involves an implicit assumption that a kilocalorie of energy in the form of corn is equal to a kilocalorie of energy embodied in the itemized input. If society were to adopt the assumption that energy represents an appropriate numeraire (or unit of account) for purposes of public policy and for private production and consumption decisions, the optimum (or equilibrium) level of energy input and of commodity and service output would be defined at the point where an incremental kilocalorie of energy input would produce an increment of 1 kcal of output in each line of production (whether in the form of corn or wheat, grain or meat, food or shelter, commodities or services). The general optimization (or equilibrium) principle —that the value of the marginal or incremental input should be equal to the value of the marginal product— holds, regardless of the accounting convention adopted by society in placing values on inputs and outputs.

The data presented by Pimentel *et al.* show that energy output (in the form of corn) per unit of energy input declined sharply from 1945 to 1950, and that it may have declined modestly between 1950 and 1970. Between 1964 and 1970 corn output rose by $1.31 \times 10^6$ kcal while energy input rose by $0.65 \times 10^6$ kcal. If we think in terms of an S-shaped energy input-output or energy response curve, the 1964 and 1970 observations are apparently near the inflection point. The optimum level of energy input in U.S. corn production would be the point where a line with a 45° slope (the price line consistent with the assumption that 1 kcal of input is equal in value to 1 kcal of output) is tangent to the energy response curve. At that point an increment of 1 kcal of energy input would add 1 kcal of energy output in the form of corn. Thus, even if energy accounting is accepted as an appropriate basis for decision-making, the implication of the data presented in the article is that U.S. farmers are using less than the optimum level of energy in corn production.

Energy does not, however, represent a valid numeraire for calculating the optimum level of energy input and of commodity and service production. Optimization implies a social rather than a physical evaluation of the utility of the several input components relative to each other and relative to output. Society places a higher value on a kilocalorie of energy in the form of corn (maize) than in the form of tractor fuel. And it places a higher value on a kilocalorie of energy in the form of human labor than in the form of drawbar horsepower. Indeed, energy in the form of human labor is, in the developed world, valued so highly that it is increasingly employed to perform a control function rather than as a source of direct energy input in most production processes.

Both the social accounting and energy accounting approaches still lack precision. The estimates constructed by Pimentel probably underestimate energy inputs into corn production. The price weights employed in social accounting systems are often distorted by institutional rigidities and constraints. Regardless of the precision of the measures that are available, however, the effect of using a social accounting measure that aggregates inputs on the basis of value weights is to tip the input-output price line to the right. This is because, when a social accounting system is used rather than an energy accounting system, (i) the value of inputs rises less rapidly as lower cost energy sources are substituted for higher cost energy sources (tractor fuel for labor), and (ii) a higher value is placed on the calories that are available for human consumption than the calories that are embodied in the inputs used in agricultural production. The optimum input level will therefore be to the right of the point where an input-output price line with a 45° slope is tangent to the energy response curve. The optimum level of energy input will be larger if a social accounting approach is employed than when an energy accounting approach is employed.

Hayami and Ruttan (*5*) have shown that most of the inputs associated with mechanization have represented substitutes for animal power and labor but have contributed very little to the growth of agricultural output. The growth of output over the last several decades has been accounted for primarily by inputs associated with advances in biological and chemical technology rather than mechanical technology.

It is useful, therefore, to partition the energy inputs employed in corn production into two components—that used primarily to expand the area cultivated per worker or material handled per worker (machinery, gasoline, weed killers, electricity, transportation) and that used primarily to increase output per unit area, or to prevent loss of production or product deterioration (nitrogen, phosphorus, potassium, seed, irrigation, insecticides, drying). The effect is to further weaken the implications of the Pimentel article. Between 1964 and 1970 an increase of approximately $0.14 \times 10^6$ kcal of inputs was used to save 1000 kcal of labor. The cost of saving an additional unit of labor has clearly become very expensive in terms of energy.

On the other hand, an increase of $0.5 \times 10^6$ kcal of yield-increasing inputs was associated with an increase in corn output of $1.3 \times 10^6$ kcal. The yield-increasing "green revolution" type inputs remain an extremely attractive use of energy even when energy is used as the unit of account.

Disagreement with the inferences drawn from the data presented by Pimentel *et al.* does not imply disagreement with the perspective that less energy intensive technologies should be sought. If the energy response curve can be shifted to the left it would represent a pure gain in efficiency in corn production regardless of whether an energy or a social accounting convention is adopted.

The high fertilizer prices that have prevailed in national and world markets since mid-1973 are primarily a result of shortages in plant capacity to produce fertilizer rather than a reflection of a fundamental shift in energy supply-demand relationships (*6*). Nevertheless, there remains the question, in times of shortage in plant capacity to produce yield-increasing inputs, of how such inputs should be optimally allocated among farms throughout the world. One effect of the "green revolution" has been to provide Indian and Philippine farmers with more efficient response curves—similar to those available to farmers in the United States, Western Europe, and Japan. Because of restricted access to fertilizer, however, Indian farmers are operating further down (to the left) on their input response curves than farmers in developed countries. There can be little doubt that the optimum allocation of fertilizer during the present period of stress would result in greater use of fertilizer in India and other poor countries, even at the expense of lower use in the United States and other more developed countries.

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**References**

1. D. Pimentel, L. E. Hurd, A. C. Bellotti, M. J. Forster, I. N. Oka, O. D. Sholes, R. J. Whitman, *Science* **182**, 443 (1973).
2. E. Hirst, *ibid.* **184**, 134 (1974).
3. J. S. Steinhart and C. E. Steinhart, *ibid.*, p. 307.
4. "Pointing the way to more rational use of Energy," *Times* (London), 9 January 1974.
5. Y. Hayami and V. W. Ruttan, *Agricultural Development: An International Perspective* (Johns Hopkins Press, Baltimore, 1971), pp. 43–63.
6. G. F. Donaldson, "Issues relating to the fertilizer situation: A seminar report," Agricultural Development Council–International Bank for Reconstruction and Development Fertilizer Seminar, Princeton, N.J., 23 to 25 May 1974.

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Ruttan appears to read his own conclusion into our data and then criticizes the conclusion. In his first paragraph, Ruttan states that "the evidence presented by Pimentel and his associates does not support their argument" (that U.S. corn production is uneconomical). This is not our conclusion but Ruttan's conclusion. We clearly stated that in spite of a 24 percent decline in corn kilocalorie yield per fuel kilocalorie from 1945 to 1970, the 2.8 to 1 ratio was economically profitable for U.S. corn producers. However, we did question whether this return would be economical for less developed nations.

Furthermore, Pimentel *et al.* (*1*), recognizing the rapid use of valuable environmental resource (fuel), suggested that fuel prices might rise fivefold over 1970 prices. If fuel prices rose this much, then we explicitly stated that a "return of 2.8 kcal of corn per 1 kcal of fuel input may then be uneconomical."

In his comment, Ruttan also questions our (*1*) using the "implicit assumption that a kilocalorie of energy in the form of corn is equal to a kilocalorie" of fossil fuel. Thermodynamically and ecologically (energy accounting) a kilocalorie of corn *is* equal to a kilocalorie of fuel. Economically a kilocalorie of corn has greater price value than a kilocalorie of fuel, but prices are subject to change. The apparent difficulty with Ruttan's argument is that he desires to equate the laws of thermodynamics and ecology with those of economics.

For example, an estimated 2043 $\times 10^6$ kcal of solar energy input plus $2.9 \times 10^6$ kcal of fossil energy input were required to produce $8.2 \times 10^6$ kcal of corn grain (*1*). Hence, by ecological energy accounting about 250 kcal of fuel and solar energy were necessary to produce 1 kcal of corn product. By economic accounting, the 250 kcal (fuel and light) have a lower price than a corn kilocalorie; therefore, the value of the product (corn) is greater than the input of energy. Hence, the operation is economically profitable.

Understanding the relation between ecological and economic principles has several important benefits as suggested by Georgescu-Roegen (*2*) and Boulding (*3*). For example, ecological accounting of energy inputs and outputs of an agroecosystem provides greater understanding of the interrelations and mechanisms underlying various crop production alternatives. By using this information and assigning current or projected prices for input fuel kilocalories and output corn kilocalories, sound economic accounting results. Hence, combining ecological and economic information significantly strengthens our overall decision-making processes.

I agree with Ruttan that fossil fuel will have to be used to increase food production for the world population of 4 billion humans expected in the coming year and 7 billion expected within the next 25 years. With most of the arable land of the earth already in production, the only means of increasing production will be to intensify production on the available arable land using fossil fuel inputs. These inputs should be those that primarily increase food production (that is, fertilizer) and not those agricultural inputs that save labor (that is, heavy machinery).

Finally, the major thrusts of Pimental *et al.*'s article were to emphasize that (i) large quantities of fossil energy are used in U.S. agriculture (using corn model), and "green revolution" agriculture requires similar large inputs of fuel; and (ii) fossil fuel energy is a finite environmental resource, and as it becomes scarce its price value will significantly increase. If the data of our ecological energy accounting are correct and the economic assumption is sound, then we should anticipate substantial changes in world agriculture and our way of life as fossil fuel shortages intensify.

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**References and Notes**

1. D. Pimentel, L. E. Hurd, A. C. Bellotti, M. J. Forster, I. N. Oka, O. D. Sholes, R. J. Whitman, *Science* **182**, 443 (1973).
2. N. Georgescu-Roegen, in *Growth, Limits and the Quality of Life*, W. Burch and F. H. Bormann, Eds. (Freeman, San Francisco, 1974).
3. K. E. Boulding, in *The Control of Environment*, J. D. Roslansky, Ed. (North-Holland, Amsterdam, 1967), pp. 41–57.

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