# Fire and the Energy Efficiency of Swidden Agriculture

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DURING THE 1960S, proponents of American agriculture frequently boasted about its high rate of productivity in contrast to the low efficiency of traditional Asian subsistence farming. They pointed out that mechanization had so greatly reduced the need for human labor that a single American farmer could feed fifty nonfarmers, thereby freeing a large labor force for productive involvement in urban industries. A traditional farmer would have to work six times as long to produce the same quantity of food (Hirst 1974:137), thus tying up masses of people in "unproductive" activity. Successful development was seen as requiring replacement of traditional labor-intensive farming systems with the American mechanized model. Throughout Asia, substitution of tractors and combines for oxen and water buffalo became synonymous with progress.

Only following the onset of the global energy crisis in the early 1970s was it belatedly recognized that while mechanized agriculture was indeed highly productive in terms of output of food per worker hour spent in farming, it was far from efficient in energy terms. American farmers might need to work only nine hours to produce 81 bushels of corn, but they consumed the equivalent of 80 gallons of gasoline in the process, giving a return of only 2.8 kilocalories of food for each kcal of fuel used (Pimentel et al. 1973:446). When all of the energy used directly and indirectly in mechanized food production is included in the calculation of energy efficiency a negative balance often appears, with a single food calorie requiring an "energy subsidy" of from 2 to 10 fossil fuel calories (Pimentel and Pimentel 1979).

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## Energy Efficiency of Traditional Agricultural Systems

The realization that energy-intensive mechanized agriculture did not necessarily provide a viable model for the development of energy-limited Asian countries aroused renewed scientific interest in traditional subsistence farming systems. Although often requiring heavy human labor inputs, many such systems appeared on initial examination to be highly efficient in energy terms, apparently yielding from 5 to 50 food calories for each calorie of work expended in farming (Leach 1976:374; Steinhart and Steinhart 1974:313). More recent analysis (Ward, Sutherland, and Sutherland 1980:571), moreover, has demonstrated that traditional farming systems based on use of draft animals may be no more energy efficient than modern mechanized systems. However, the slash-and-burn or swidden system of shifting cultivation practiced in tropical forest areas of Asia and the Pacific still appears to be particularly energy efficient, with reputed yields of 10 to 15 food calories for each calorie of human labor expended in working the system (Rappaport 1971:127; Pimentel and Pimentel 1979:38–40).

Swidden farming also has a number of ecological advantages in the difficult environmental conditions of the Asian tropical rain forest. It gives reliable yields with minimum susceptibility to pest outbreaks and, when practiced at appropriate levels of population density, causes little long-term degradation of the productive capacity of the environment. These and other positive aspects of swidden cultivation have been amply described by Barney (1970), Conklin (1957), and Geertz (1963), among many others. So well is swidden farming adapted to the humid tropics that, despite much effort, agricultural researchers have yet to perfect alternative systems having comparable social and ecological merits. In fact, the thrust of much current work is to try to improve shifting cultivation rather than try to replace it with fixed field systems (Grandstaff 1980; Greenland 1975). Swidden farming thus deserves much of the esteem in which it is currently held by ecological anthropologists (Bennett 1973, Bodley 1976). However, it does not merit the acclaim it has received as a farming system that uses energy with extraordinary efficiency.

The attribution of energy efficiency to swiddening is largely derived from Roy Rappaport's (1971) careful field study of Tsembaga slash-and-burn cultivation in the New Guinea Highlands. His comparison of human labor inputs with crop yields shows that the Tsembaga receive an average return of 16 food calories for each calorie they spend in working their fields, while under the most favorable conditions an energy output-to-input ratio of 20 to 1 is achieved, seemingly placing Tsembaga swiddening among the most energy-efficient agroecosystems known anywhere in the world (Rappaport 1971:127; Steinhart and Steinhart 1974:312, fig. 5). These favorable energy input-output ratios may be wholly misleading, however, since Rappaport failed to include the energy used in burning the field in his calculations, an oversight comparable to omitting the energy used by tractors in evaluating the efficiency of American farming.[1] As will be shown below, when the overlooked energy input of fire is taken into account the reputed energy efficiency of swidden agriculture disappears.

## Role of Fire in Swidden Agriculture

That the energy value of fire has been generally overlooked is not surprising in view of our relative lack of understanding of the role that burning plays in the functioning of swidden systems. Although there is agreement among ethnographers who have studied specific swidden systems in Southeast Asia that the quality of the burning largely determines the success of the crop (Barney 1970:57–59), there is no similar consensus as to why this is true. However, anthropologists, agronomists, and soil scientists have suggested at least six major beneficial effects of burning: (1) clearance of unwanted vegetation from the field; (2) alteration of soil structure, making planting easier; (3) enhancement of soil fertility by plant ashes; (4) decrease in soil acidity; (5) increase in availability of soil nutrients; (6) sterilization of soil and reduction of microbial, insect, and weed populations. Each of these suggested functions of burning in swidden agriculture will be discussed in turn below.

### *Clearance of Unwanted Vegetation from the Field*

Farmers clearing new plots in forest lands face the problem of removing large quantities of vegetation from their fields. Given the fact that tropical rain forest often has an aboveground biomass of several hundred metric tons per hectare, clearing off the fields using human muscle power alone would simply be unfeasible in any reasonable period of time. Burning can quickly solve this major problem facing the primitive farmer (Conklin 1957:71; Nye and Greenland 1960:66–67).

### *Alteration of Soil Structure*

The heat of the fire both softens the surface soil and makes it more friable, providing a suitable seed bed that can be easily planted using a wooden dibble stick (Conklin 1957: 71). If fire did not do this work the farmer would have to do it, using a hoe or other manually operated cultivation implement. However, hoe cultivation causes much more rapid breakdown of soil structure, with consequent increased vulnerability to erosion, than does the minimal disturbance of the surface caused by dibbling (Nye and Greenland 1960: 84–85).

### *Enhancement of Soil Fertility by Plant Ashes*

It is well established that in tropical rain forest ecosystems many critical nutrient elements are stored in the plant biomass rather than in the soil. For example, over ninety percent of the available phosphorus is held in the biomass (Sanchez 1976:354). Therefore, when the vegetation is burned, large quantities of nutrient-rich ashes are deposited on the soil surface, providing the newly planted crops with the equivalent of the application of several hundred kilograms per hectare of chemical fertilizer (Sanchez 1976:363–365).

It is true that much of the carbon, nitrogen, and sulphur stored in the vegetation is lost into the atmosphere in the course of burning the field but, contrary to common belief, stocks of these nutrients in the topsoil are not depleted (Nye and Greenland 1960:67–70) and incorporation of unburned charcoal and plant residues into the topsoil may somewhat increase soil carbon and nitrogen levels (Sanchez 1976:364, 368). In any case, most of the nitrogen is stored in the soil component of the ecosystem rather than in the plant materials, so that losses due to burning are not that large. Substitution of composting for burning would, of course, reduce these nutrient losses but would require greater human labor inputs, would make nutrients available only slowly and gradually rather than as a flash treatment during the critical first weeks of cereal plant germination and growth, and perhaps most important, given the acidic nature of many tropical soils, would not increase the pH value of the soil.

*Decrease in Soil Acidity*

Plant ashes are generally alkaline and cause an increase in soil pH levels of as much as three points. This decreased acidity makes existing stocks of phosphorus, potassium, and other nutrients in the soil more readily available to the crop plants (Sanchez 1976: 365–367).

*Increase in Availability of Soil Nutrients*

For reasons that are as yet only partly understood, heating of soil makes those stocks of nutrients already stored there more available to plants (Nye and Greenland 1960:71–72). According to K. T. Joseph (personal communication), the application of heat causes organic matter in the soil to release some of the phosphorous and potassium it is holding, making these nutrients available to crop seedlings.

*Sterilization of Soil and Reduction of Microbial, Insect, and Weed Populations*

Studies of burning of swidden plots in northern Thailand show that a temperature of at least 75°C is reached in the top 2 cm of the soil (Zinke et al. 1978:144). Such heating is sufficient to kill most roots, weed seeds, and insect eggs and larva in the surface soil as well as to reduce greatly the microbial population of the plot (Nye and Greenland 1960:72; Conklin 1957:71). Elimination of weed seeds is probably the most beneficial effect of this partial sterilization of the soil, as the crop plants are able to become well established before reinfiltration of the plot by new seed from external sources has time to occur. Certainly there is convincing evidence that it is the increased demand for human labor in weeding, rather than the decline of soil fertility per se, that leads to abandonment of swiddens after the harvesting of only a single grain crop. Experimental plots that have been carefully weeded have often maintained high levels of crop productivity for several successive years, but the human effort needed for weeding greatly exceeds the labor needed to clear a new plot in the forest (Janzen 1973:1215; Nye and Greenland 1960:76–80; Sanchez 1976:365–367, 383, 398).

All of the beneficial effects of burning cited above might, at least in theory, be achieved by other means. Bulldozers can clear even primary rain forest, application of chemical fertilizer can enhance soil fertility, tractor or animal-drawn plows can soften the soil for planting, and insect pests and weeds can be kept in check by chemical control methods. However, doing such work would demand greatly increased energy inputs, either from human and animal muscles or from petroleum-powered machines (Janzen 1973:1213). Since tropical forest cultivators rarely have access to sufficient supplies of such energy, they rely instead on fire to perform many of the necessary tasks of cultivation. The energy stored in the vegetation and used by the fire is thus performing useful work in the swidden agroecosystem, comparable in character to that done by the fossil fuel which powers agricultural machinery on the American farm.

## ENERGETICS OF SWIDDEN AGRICULTURE

As far as can be determined, no one has yet directly measured the energy involved in swidden burning, but it is possible to derive an approximate set of values by using published ecological data on the biomass and energy value of tropical forests.

In highland New Guinea, 12-to-13-year-old secondary forest of the sort cleared by the Tsembaga has an above-ground dry-weight plant biomass of 72.5 metric tons per hectare (Manner 1977:225, Table 1), or approximately 7 kg/m². Tropical forest vegetation is reported to have an average of 3897 kilocalories per kilogram of dry-weight material (Golley 1961:582). Therefore, if one hundred percent combustion were achieved, burning would utilize 28,250 kcal/m². Under tropical conditions, such complete combustion is improbable, so that, although the Tsembaga are reported to burn with great care, collecting and reburning any materials left after the first firing of their fields (Rappaport 1968:43), it is unlikely that more than 75 percent of the original biomass is consumed in the fire,[2] representing a total fire energy expenditure for working the swidden field of 22,188 kcal/m².

No data are available on the efficiency with which fire energy performs its work in swidden cultivation; presumably, much of the potential energy of the biomass is simply lost as heat and unburned ash particles rise in the convection column above the surface of the burning field.[3] For present purposes of calculating comparative energy efficiency of swidden versus mechanized agriculture, however, the question of efficiency of fuel use is irrelevant. What matters is only the total quantity of energy consumed in the operation of each system, not whether or not this energy is used in optimum fashion. While part of the fire energy may be misdirected, a poorly designed tractor may also deliver only a relatively small part of the petroleum energy that it consumes to the point of the plow, but its total energy cost to the operation of the system is the same per liter of gasoline as that of a more efficient model.

According to Rappaport's (1971) figures for the Tsembaga, human labor represents an input to the swidden system of 138.7 kcal/m². The caloric value of food grown in the swidden is 2416.5 kcal/m² giving an energy output-input ratio of 17.4:1, that is, approximately 16 food calories are gained for each calorie expended in working the field. If the energy represented by burning is added into the calculations, however, a radically different ratio appears. Fire energy plus human energy equals an input of 22,327 kcal/m² of swidden plot in the sort of secondary forest cleared by the Tsembaga, giving an output-input ratio of 0.11:1. It is necessary, therefore, to expend approximately 10 work calories for each food calorie yielded by swidden farming.

The figures used here to calculate energy efficiencies are no better than rough approximations at best but, even if the estimate of the energy value of burning is considerably overstated, the basic conclusion that swidden agriculture is not a highly energy efficient system of food production remains unchanged. Swidden farming is just as dependent on an energy subsidy to achieve high production with low input of human labor as is modern mechanized farming. The fact that this subsidy comes in the form of tree trunks rather than barrels of petroleum is irrelevant to the assessment of energy efficiency.[4]

Regardless of its source, the availability of energy is a critical limiting factor for the maintenance of the productivity of the agricultural system, and thus a determinant of the size of the human population that can be supported on a long-term basis. In the case of swidden farming, increasing population densities can easily exhaust the available supplies of high quality stored energy, and this normally leads to a shortening of the fallow period during which the forest regenerates. Plots are cut again before sufficient energy has accumulated in the vegetation to ensure an adequate burn to do the work necessary to achieve high productivity. Unless yields are to decline precipitously, more and more human labor must be substituted for the work formerly done by the fire in cultivating, fertilizing, and weeding the land.[5] Such intensification is evident today in many areas of tropical Asia.

The swidden farmer, just as much as the industrial farmer, is feeling the pinch of the energy crisis. At current use rates, Southeast Asian swidden farmers may well run out of trees to burn before Western farmers run out of gas for their tractors.[6]

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## Notes

[1]Referring to this failure to consider the energy input from fire, Henry T. Lewis (1977:45–46, n.2) commented that "given the fascination which the control and flow of energy has had for many writers of the 'Michigan School' [of cultural ecologists], this lack of interest is perhaps paradoxical. Rappaport, for instance, makes only two very minor notations regarding the burning of swidden fields in his study of 'ritual-ecology' in New Guinea. . . . The possibility of measuring the B.T.U.s involved in the transformation of plant communities, domesticated or otherwise, would seem to be of fundamental importance to understanding energy expenditures."

[2]In the Amazonian rain forest, stems compose 61 percent of the above-ground organic matter while leaf matter, branches and twigs, lianes and epiphytes, standing dead wood, dead wood of litter layer, and fine litter compose 39 percent of the total (Klinge et al. 1975:116–117). As many of the smaller stems would burn completely in any moderately successful firing of the plot and even large trunks are usually partly consumed, the above estimate of 75 percent combustion is probably conservative.

[3]In northern Thailand, burning of a 95-hectare swidden reportedly produced a column of smoke and ash rising 10,000 to 20,000 feet (Zinke et al. 1978:136).

[4]It can be argued that energy use in swidden farming is qualitatively different than in mechanized farming since the former relies on the renewable energy of trees whereas the latter draws down nonrenewable fossel fuel stocks. Such reasoning provides an unfortunate example of how rigid linguistic dichotomies can distort thought about natural phenomena. Whether an energy resource is renewable or not is simply a function of the rate at which the resource is used in comparison to the rate at which it can be replaced. If forests are cut and burned at a faster rate than allowed for by their natural regeneration then they become a nonrenewable energy source for all practical purposes. Conversely, if fossil fuels are used at a lower rate than they are being replaced by geological processes then they represent a renewable resource. That this may be the case with regard to petroleum is suggested by H. T. Odum (1975:7), who points out that the estimated rate of deposition of organic matter in the biosphere is of the same order of magnitude as the world's present oil use rate. Of course, only some fraction of

this organic material is transformed into fossil fuel, so that current use rates are certainly not sustainable for very many more years.

[5]Malaysian aborigine swidden farmers appear to be well aware of the relationship between fire and human labor demands. A Temuan woman whom I observed struggling to dig out a heavy growth of weeds in a field that had been burned after only a three-year fallow period remarked that, "if the fire does not eat them then there are many weeds."

[6]In Thailand, foresters estimate that between 18 and 30 trees are being cut down for every tree replanted, so that the area of the nation's land under forest has shrunk from 58 percent to 38 percent in just 17 years, with total deforestation predicted within 30 to 40 years (Borsuk 1977:4).

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