ENERGY FLOWS AND SHIFTING CULTIVATION

P. S. Ramakrishnan

(Jawaharlal Nehru University, New Delhi)

INTRODUCTION

The increasing agricultural yields of the last few decades in parts of India were possible through industrialization of agriculture, involving large fossil energy subsidies, heavy fertilizer application to the soil, sophisticated chemical control measures to reduce pest and disease infestation, and above all, high-yielding crop varieties. Such agricultural systems are efficient in terms of human time and labor inputs, but are highly inefficient from an overall energy point of view, as five to ten units of fuel energy are required to produce one unit of food energy (Steinhart and Steinhart 1974). The obvious inapplicability of such systems as models of development in an energy-limited world has led to renewed scientific interest in traditional systems of agriculture and traditional rural ecosystem organization and function, as these are considered to offer greater ecological efficiencies.

In particular, shifting agriculture, variously termed as "swidden" and "slash and burn" agriculture (more popularly known in India as *jhum*) has been held up as a model of productive efficiency where five to fifty units of food energy are harvested for each unit of energy put into the system (Rappaport 1971; Steinhart and Steinhart 1974; Mishra and Ramakrishnan 1981; Toky and Ramakrishnan 1982). It has even been considered possible to have increased crop production without departing too much from this traditional system (Greenland 1975; Revelle 1976; Mutsaers et al 1981; Ramakrishnan 1985b), which has been called the most evolved system for the forested areas of the humid tropics (Conklin 1957; Carneiro 1960; Nye and Greenland 1960; Walters 1971; Ramakrishnan 1984a). This land-use system has been considered viable only when the population density is one person for every four hectares of land. At higher population levels, degradation of soil and vegetation occur due to shorter fallow periods, making this agricultural system ecologically and economically non-viable. The present paper concentrates on these aspects, with emphasis on energy flow, and looks at possible modifications in the system to restore the ecological balance that now stands distorted in the northeastern hill region of India.

THE *JHUM* SYSTEM

Jhum is an important land use in the tribal areas of India. It is extensively practiced in the northeastern hill region along with restricted valley cultivation of rice on flatlands. It is also prevalent in parts of Orissa, Madhya Pradesh, Maharashtra, Andhra Pradesh, and in the Western Ghat region of peninsular India.

Man and Land

Generally speaking, the population in most of the northeastern states slightly more than doubled in the first fifty years since the turn of the century. Similarly, it almost doubled in most states between 1951 and 1971.

In the northeast, *jhum* is estimated to have covered about 425 x 10^3 families according to 1971 census data. At a growth rate of 25 to 30 percent, this would now be about 547 x 10^3 families, likely to rise to 766 x 10^3 families by the turn of the century (North-Eastern Council 1982). If the projections given by Myers (1980) are interpreted into the northeastern situation, 0.55 million families at present have cleared about 6000 km^2 of additional forest for *jhum*, of which half would be primary forest.

The exact area under *jhum* in the northeast is not known. The area under *jhum* in 1971 (Table 1) has been determined on the basis of the average *jhum* cycle for a given state and the number of families involved. However, such an average is misleading as the length of the *jhum* cycle is dependent upon the population dispersion. Thus in Meghalaya, though the average *jhum* cycle is assumed to be a little over five years for this calculation, there are locations where the *jhum* cycle has even come down to a 0-year cycle (slash and burn of what grows during the intercropping winter fallow phase)! The data so calculated does not account for the land taken over by weeds or completely desertified, and therefore rendered useless for agriculture. Though we have identified a variety of patterns in the *jhum* system based on ecological conditions and the socioeconomic and cultural background of the tribals, what is discussed here is based on two major patterns of *jhum* in the region, studied in depth in Meghalaya. The typical *jhum*, widely practiced except for the variation in cropping pattern and the type of vegetation slashed and burnt, involves clear-cutting of the vegetation, followed by burning and subsequent cropping for a year or two on steep slopes of 30° to 40° angle without any elaborate preparation. This is exemplified by the low-elevation *jhum* system of Meghalaya (Toky and Ramakrishnan 1981a). A modified version involves selective felling of vegetation and elaborate preparation of the land, followed by a controlled burn before cropping for a year or two, as practiced at higher elevations of Meghalaya (Mishra and Ramakrishnan 1981).

The Low-Elevation System

During the winter months of December and January, the undergrowth is slashed and small trees and bamboo are felled by families (with an average size of two adults and four children) covering an area of 2.5 to 3 hectares. If the vegetation is dense and more labor for clear-cutting of the plot is required, this is done as a cooperative venture involving other families. Larger trees are often left behind along with stumps of smaller trees which help in faster regeneration of vegetation during the fallow phase subsequent to cropping.

While larger tree trunks and bamboo are taken out for construction and maintenance of huts, or even for export outside the village boundary for monetary return, some of the wood is also used for cooking fuel. Before the

Table 1: Area under *jhum* based on data of the North-Eastern Council , 1971

		Area under jhum (X 10^3 ha)			
	Geographical	Annual	% geogr.	Total	% geogr.
Arunachal	8149	92	1.13	248	3.04
Assam Hills	1535	70	4.56	498	32.44
Manipur	2236	60	2.68	100	4.47
Meghalaya	2253	76	3.37	416	18.46
Mizoram	2108	62	2.94	604	28.65
Nagaland	1649	74	4.49	608	36.87
Tripura	1067	23	2.16	221	20.71

onset of the monsoon, toward the end of March or early April, the dried slash is burnt in *situ* after making a fire line around the *jhum* plot. After repetitive burning as required, a seed mixture of cereals, legumes, vegetables, and tuber crops are sown together. The crop mixture may vary from seven to thirteen depending on the *jhum* cycle (Table 2) and is harvested sequentially from July to December as the crop matures. Often, the placement of the crop on the slope has a pattern which can be related to the photosynthetic efficiency of the crop cover in the system, and to the nutrient uptake and use-efficiency of the crops. Thus, crop species with high nutrient-use efficiency are placed at the tops of slopes while slope bottoms are a sink for nutrients washed down from the top (Ramakrishnan 1984a). The objective of the farmer is to optimize production in a situation where the nutrients are in a state of flux due to high rainfall and steep topography.

A shift toward tuber and perennial crops, rather than cereals, is noticed as a consequence of shortening the *jhum* cycle. (The length of the intervening fallow phase of natural vegetation before the same plot is cropped again.) This shift can also be related to the high nutrient-use efficiency of these crops in more infertile soil under a shorter *jhum* cycle.

The High-Elevation System

The high elevation *jhum* system is a modified version of the typical one in that the slashing of the vegetation is only partial. While the shrub and herb species in the plant community are clear-cut, only the lower branches of the sparsely distributed pine trees are cut. Elaborate ridges running down the slope are made, using the slash arranged in parallel rows and topped with a layer of soil after it has dried so that the burning is controlled. The furrows are highly compacted and act as water channels. Apart from preventing water-logging which is important for potato cultivation, the water flow through compacted furrows also helps check losses. These modifications could be partly related to the cropping pattern

Table 2: Crops grown and yield in the *jhum* plots at lower elevations in Meghalaya (after Toky and Ramakrishnan 1981a)

	Total economic yield (kg ha - 1 yr - 1)		
	30 yr	10 yr	5 yr
Grain and seed			
Oryza sativa	1161	378	66
Sesamum indicum	446	541	25
Zea mays	770	397	30
Setaria italica	193	23	9
Phaseolus mungo	10	-	-
Ricinus communis	5	-	-
(20146)	(6318)	(753)	
Leaf and fruit vegetables			
Hibiscus sabdariffa	44	139	96
Hibiscus esculentus	-	50	-
Capsicum frutescene	-	1	-
Lagenaria lencantha	140	81	-
Cucurbita maxima	62	-	-
Cucumis sativa	16	-	-
Momordia charantia	-	5	-
Musa sapientum	-	105	-
(657)	(5679)	(16182)	
Tuber and rhizomes			
Manihat esculenta	338	1352	690
Colocacia antiquorum	260	294	180
Zingiber officianalis	10	-	-
(1043)(2712)	(1556)		
Silk worm			
Cocoon (silk)	4	-	-
Pupae (without cocoon)	0.2	-	-

Total plant (Kg ha - 1 yr - 1) is given in parenthesis

and the need for conserving nutrients in the deficient acidic soil of a cold climate. Root and tuber crops such as *Solanum tuberosum*, *Ipomoea batatas*, *Colocasia antiquorum*, cereals such as rice and maize, and a few legumes and vegetable crops are all grown together in the mixtures. Under shorter *jhum* cycles, the number of crop species in the mixture is reduced.

Species Diversity and Stability

Mixed cropping with high species diversity ensures a high degree of stability by: high photosynthetic efficiency through a multilayered canopy organization; efficient nutrient use through a stratified root profile in the soil for the use of nutrients from all depths avoiding competition; acting as biological pest suppressant (Litainger and Moor 1976) through native species which have highly developed natural chemical defense systems (Janzen 1973) and keeping any given pest population under control through genetic diversity in the crop mixture; an efficient crop cover to conserve losses through hydrology (Toky and Ramakrishnan 1981b; Mishra and Ramakrishnan 1983a).

Once a crop species is harvested, it leaves space for the next crop at its peak growth and thus contributes to optimize resource use. A characteristic feature of the *jhum* system is the high accumulation of biomass in relation to the actual economic yield (Ramakrishnan 1984a). Such high biomass production ensures stability of the system through efficient cycling of nutrients. Without this addition of organic matter, it would become necessary to depend upon costly inorganic fertilizer that is hard to procure and of questionable effectiveness under high temperatures and rainfall of the humid tropics (Gleissman 1980; Gleissman et al 1981; Ramakrishnan 1984a). Inefficient fertilizer use is accentuated by the uneven topography of the hills and the thin and highly porous sandy soil of the mountains (Toky and Ramakrishnan 1981b; Mishra and Ramakrishnan 1983a) which result in heavy losses from the crop system (Table 3), particularly before the crop cover is established and during harvest (Fig. 1) thus contrasting with the drastic reduction in losses through hydrology from a 5 year-old fallow. In the high elevation *jhum* system, 0.6 to 0.8 kg ha^{-1} of nitrogen is ploughed back into the system through non-edible crop biomass (Table 3).

Modern agriculture considers weeds totally undesirable and, therefore, has developed technology for their total eradication from agro-ecosystems through mechanical, chemical, and biological means. However, there is growing realization that weeds to a certain extent are desirable and may play an important role in agro-ecosystem management. This "non-weeding" concept is an essential ingredient of traditional *jhum* (Saxena and Ramakrishnan 1984; Mishra and Ramakrishnan 1984) and similar systems elsewhere (Chacon and Gleissman 1982). In the *jhum* plots of northeast India, weeding is never total; the residual weed population has a role in conservation of soil and nutrients that may otherwise be lost through hydrology (Toky and Ramakrishnan 1981b; Mishra and Ramakrishnan 1983a). Even the weeds removed are put back into the *jhum* plot itself. Thus, the return of an element such as nitrogen through weed biomass recycling in a high-elevation *jhum* system may range between 0.8 to 3.5 kg ha - 1 (Table 4).

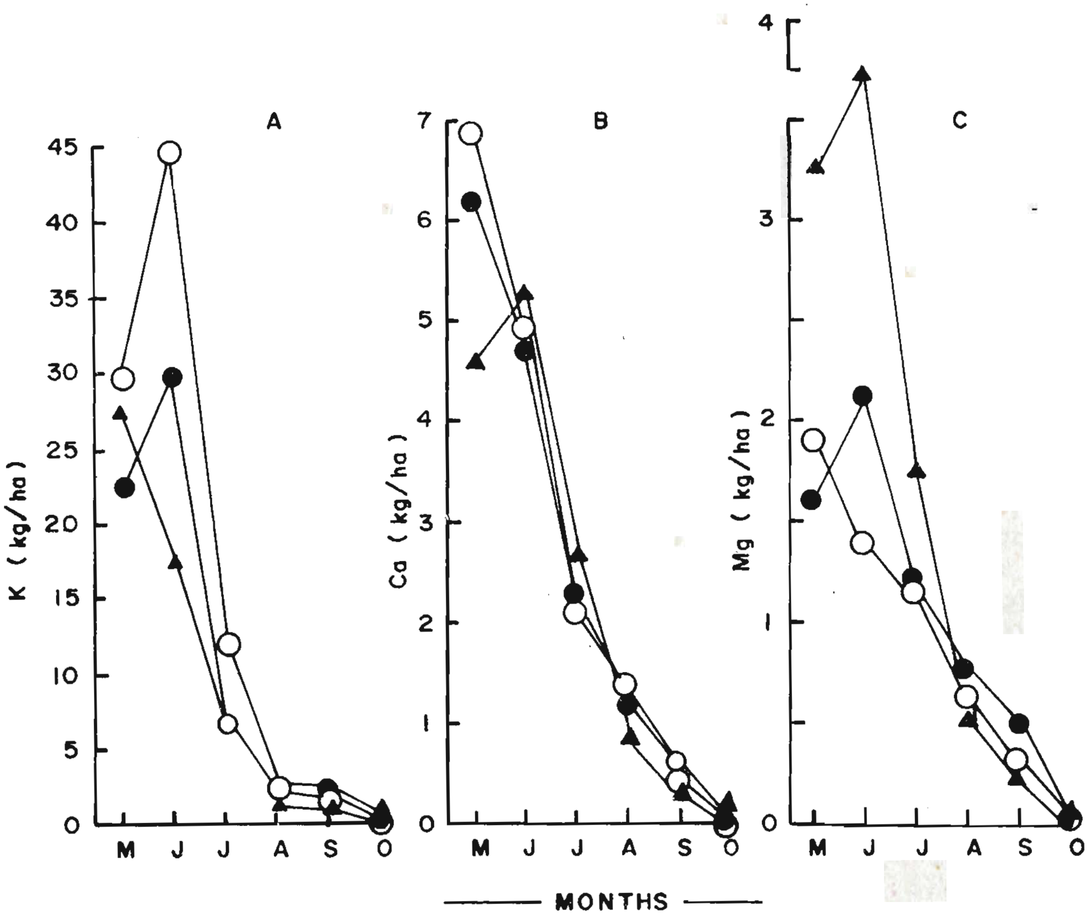


Fig. 1. Monthly loss of potassium (K), calcium (Ca) and magnesium (Mg) in percolated water during the monsoon at the time of cropping after the burn in sites under 30-(●), 10-(○), and 5-(▲) year *jhum* cycles (after Toky and Ramakrishnan 1986b)

Table 3: Nutrient losses (kg ha - 1 yr - 1) through run-off and percolation water under 10 - yr *jhum* cycle agro-ecosystem and a 5-yr fallor (after Toky and Ramakrishnan 1981 b: Mishra and Ramakrishnan 1983 a)

	10-year cycle *jhum* plot		5-yr fallow	
	Run-off	Percolation	Run-off	Percolation
Low-elevation *jhum*:				
Nitrate nitrogen	4.2	10.7	0.8	1.1
Available phosphate	1.3	0.1	0.1	0.02
Potassium	91.2	21.2	0.9	0.5
High-elevation *jhum*:				
Nitrate nitrogen	1.7	0.5	1.0	0.9
Available phosphate	0.9	0.1	ND	ND
Potassium	80.1	25.8	19.6	ND

ND - Not detectable.

Table 4: Nitrogen input: Output Budget (kg ha - 1 yr - 1) for different *jhum* systems (after Mishra and Ramakrishnan 1984)

			Fallow cycle (yr)	
	15	10	1 yr crop	11 yr crop
Inputs				
Precipitation	3.6	3.6	3.6	3.6
Slash	43.6	18.6	29.3	-
Organic manure	-	8.4	14.0	25.9
Inorganic fertilizer	-	-	0.7	1.4
Weed ploughed back	0.8	2.6	3.5	3.4
Byproducts ploughed back	0.8	0.6	0.6	0.3
Total	48.8	53.8	51.7	34.6
Outputs				
Fire	510.2	462.1	262.8	-
Sediment	119.1	128.5	172.9	176.3
Run-off	1.30	8.0	8.2	10.0
Percolation	0.9	0.5	0.8	0.7
Weed removal	4.0	13.0	17.3	16.8
Total	690.5	643.6	482.4	213.5
Net difference	641.7	589.8	430.7	178.9

Dash represents absence of that input/output from the sytem.

LAND USE AND ECONOMIC EFFICIENCY

A sweeping statement often made is that the *jhum* system is not economically viable and therefore should be abandoned in favor of settled terrace cultivation on hill slopes. Lack of reliable data has hindered looking at this problem in a systematic way. Available studies have not defined parameters such as *jhum* cycle, crop mixtures, or conversion values used for calculation when comparing different crops in terms of rice yield, as rice was only one of the crops in the mixture. It is therefore not surprising to find rice yield values as low as 190 kg/ha (Borthakur et al 1978) and as high as 1200 kg/ha on the other extreme (Misra 1976). Therefore, comparative estimates of yields under different *jhum* cycles at low and high elevations and evaluation of this land use vis-a-vis sedentary farming, such as terrace and valley cultivation (Toky and Ramakrishnan 1981a; Mishra and Ramakrishnan 1981), become meaningful.

The actual yield for individual crop species was obtained for 30-, 10-, and 5-year *jhum* cycles for the low-elevation *jhum* system (Toky and Ramakrishnan 1981a) and for 15-, 10-, and 5-year cycles for the high elevation *jhum* system (Mishra and Ramakrishnan 1981), making it possible to compare economic input and output (Table 5). A few conclusions from this study were: a longer *jhum* cycle gives better yield than a short cycle; a 10-year *jhum* cycle is economically viable; though terrace cultivation gives as much return to the farmer as *jhum* under a 10-year cycle, a major fraction of input for the former is through inorganic fertilizer while labor is the chief input into *jhum*.

Though terrace cultivation provides annual sustained yield, the life of terraces in the region often is not more than six to eight years, partly due to wash-out by heavy rains, damage to the soil, and high weed potential, leading to eventual desertification. Valley cultivation of rice has the advantage of sustained yield without the need for additional input of fertilizers as the valleys hold the nutrients washed down from the hill slopes.

When one compares *jhum* of the low elevation with the high-elevation system (Table 6), one finds that the net return from the *jhum* plot under a 10-year cycle is about six times more for the high elevation system. This is related to the better returns from potato cultivation, emphasized here at the expense of cereals, both under long and short *jhum* cycles.

The main advantage of the *jhum* system is that it meets the diverse needs of the tribal farmer, such as cereals, vegetables, tubers, and even fibre from the same plot, allowing self-sufficiency if the yields are maintained under a *jhum* cycle of 10 years or more. Besides, mixed cropping is an "insurance policy" in that some crops are likely to give good returns even if there is partial or complete failure of others.

ENERGY RELATIONS

Jhum in the northeastern hill region of India has survived chiefly because of the high energy efficiency of the system associated with longer *jhum* cycles where the only energy input is human

Table 5: Monetary Input-Output (Rs. ha - 1 yr - 1) into *Jhum* Terrace and Valley Agro-ecosystems (after Toky and Ramakrishnan 1981a)

	Jhum (year) 30	10	5	Terrace	Valley Crops I
Input	2616	1830	896	2542 (4544)	4843
Output	5586	3354	1690	3658	3565
Net gain/loss	2970	1524	794	1116 (-886)	722
Output/Input	213	1.83 (0.80)	1.88	1.43	1.14

Table 6: Monetary Input-Output Analysis of *Jhum* under a 10-yr Cycle at Lower and Higher Elevations of Meghalaya (after Toky and Ramakrishnan 1981a; Mishra and Ramakrishnan 1981)

	Low-elevation *Jhum*	High-elevation *Jhum*
Input	1830	3842
Output	3354	14171
Net gain	1524	10329
Output/Input	1.83	3.9

labor provided by the farmer from within the family unit. According to Rappaport (1971), the Tsembaga people of the New Guinea highlands obtained an average of sixteen units of food energy for each unit of human energy employed during farming; this may increase to twenty under more favorable conditions. Others have reported equally high or even higher efficiency values with input/output ratios of up to 54 (Lewis 1951; Norman 1978; Uhl and Murphy 1981).

Input/Output Patterns

Most studies, however, do not mention the length of the *jhum* cycle or its relationship to energy efficiency. The present study of three *jhum* cycles gives different energy input and output patterns and overall efficiency values. Labor, the only input into the *jhum* system, is highest under a 30-year cycle and lowest under a 5-year cycle, with a 10-year cycle falling in between. Of all agricultural operations, slashing vegetation involves the highest energy expenditure ranging from over half of the total input under 30- and 10-year cycles to 16 percent under a 5-year cycle. This is because of the presence of larger species--shrubs, bamboo, and trees--under longer cycles, compared to predominantly herbaceous vegetation under a 5-year cycle. Labor input for weeding increased with shortening of the *jhum* cycle due to increased weed potential under shorter cycles (Saxena and Ramakrishnan, 1984). The labor input into thrashing and shelling is higher under a 5-year cycle due to the emphasis placed by the farmer on tuber crops at the expense of cereals.

The highest energy output in the form of economic yield per hectare for cereals was obtained under a 30-year cycle; this declined drastically with the shortening of the cycle. However, the energy output through vegetable, tuber, and rhizomatous crops was higher under 5- and 10-year cycles than under a 30-year cycle (Fig. 2).

When one compares *jhum* with valley cultivation of rice, the major input is for land preparation (with an energy expenditure of 55 percent) followed by weeding. Fertilizer is the major input for terrace cultivation, accounting for 82 percent of the total input into the system; clearing vegetation and terrace preparation are chiefly restricted to the first year (Table 7). As maximum input of energy for valley cultivation is for land preparation, it is efficient from the land-use point of view.

Energy output under terrace cultivation, obtained through grain and seed crops, was about one-third of that under a 30-year *jhum* cycle, although energy output through leaf and fruit vegetables, tubers, and rhizomes was higher than that under *jhum* (Table 8). Valley cultivation with two crops annually gave almost the same energy yield as 10- or 30-year cycles.

The labor energy input pattern of male and female workers of *jhum* under a 5-year cycle and terrace and valley cultivation was studied in the high-elevation *jhum* system (Fig. 3).

The findings would essentially hold true for many tribal communities; more than 65 percent of the total work is done by the female members of the family. However, the work done by males and females for the initial slashing of undergrowth is similar. Slashing larger trees, if any, is done by males. While preparation of land into ridges and furrows along with burning and seed sowing is an exclusively female operation, weeding and maintenance of the plot is almost equally shared between male and female members. Transport of harvest and sale is exclusively done by males while other operations such as sowing, weeding, field maintenance, and harvesting are mostly done by females.

The energy distribution pattern over a year (Fig. 4) shows uniform distribution of labor for *jhum* allowing time for other activities such as valley cultivation and for animal husbandry and domestic activities in the village. Terrace cultivation, requires heavy input of labor for land preparation. One of the main advantages of *jhum* is that

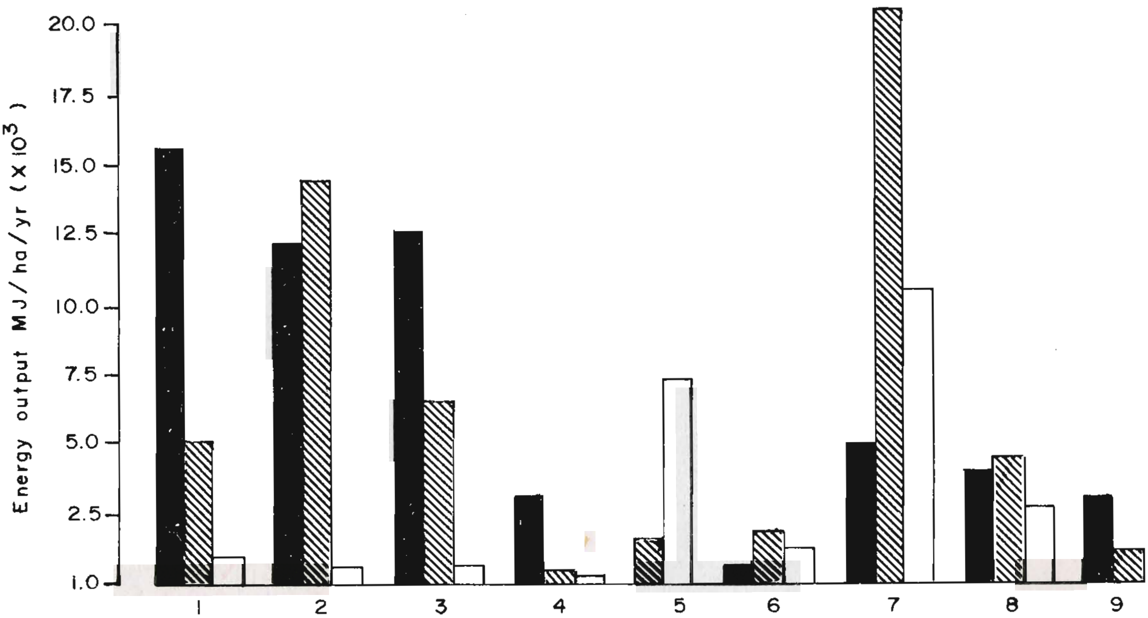


Fig. 2: Comparison of energy outputs from various crops under 30-, 10-, and 5-year *jhum* cycles. Dark column, 30-year cycle. Hatched column, 10-year cycle. Open column, 5-year cycle. 1. *Oryza sativa* 2. *Sesamum indicum* 3. *Zea mays* 4. *Setaria italica* 5. *Musa sapientum* 6. *Hibiscus sabdariffa* 7. *Manihot esculenta* 8. *Colocasia anticuorum* 9. *Cururbits* (after Toky and Ramakrishnan 1982).

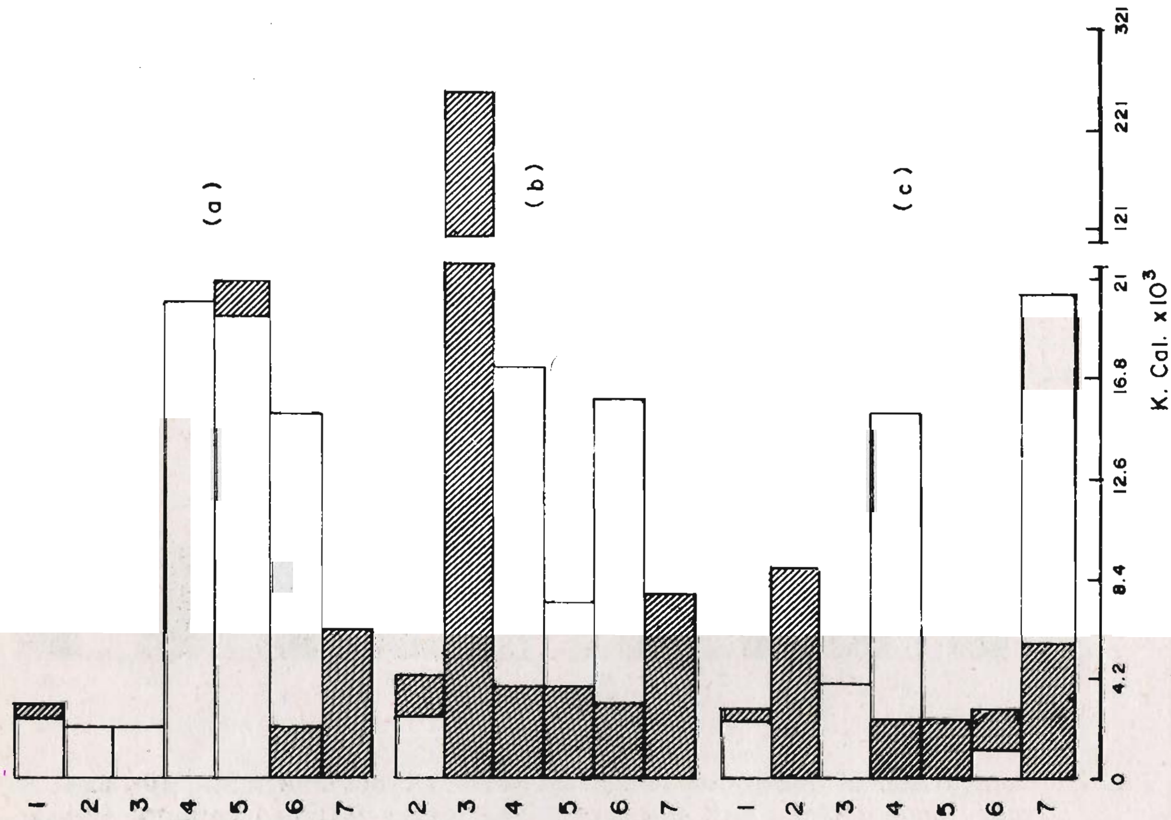
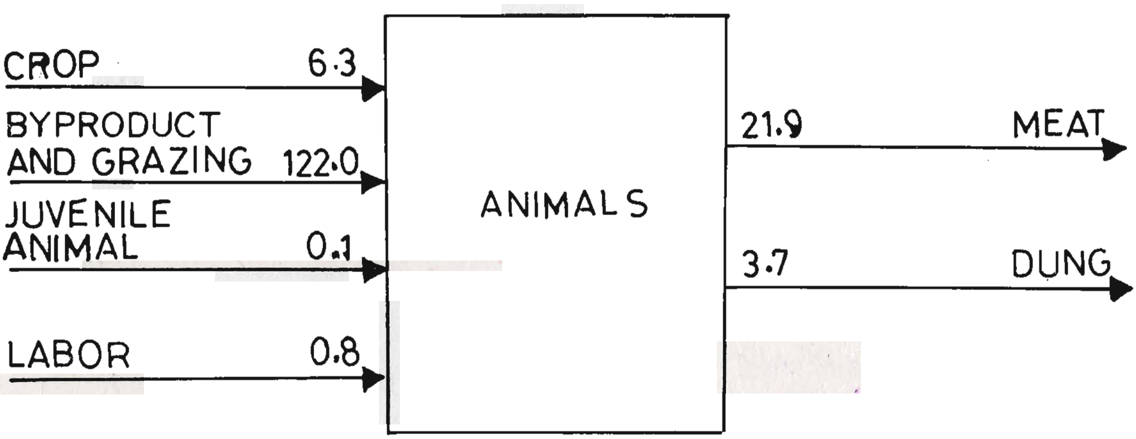


Fig. 3: Allocation pattern of labor between male and female members of the family under different agricultural system (a, 5-year *jhum* cycle; b, terrace cultivation; c, valley cultivation). Hatched column, male labor; open column, female labor. 1. clearing the vegetation 2. land preparation 3. burning 4. seed sowing 5. weeding and field maintenance 6. harvesting 7. transportation 8. threshing and milling (Mishra and Ramakrishnan 1981)



Output : Input ratios

Meat (+ byproduct + grass) = 0.17

Meat (- byproduct + grass) = 3.04

Meat + dung = 0.20

Fig. 4 Energy input-output pattern and efficiency ratios:

Animal husbandry subsystem. Unit = MJ x 10^3 (after Mishra and Ramakrishnan 1982)

Table 7: Energy Input (MJ ha - 1 yr - 1) for Agriculture under Different *Jhum* Cycles and Terrace Cultivation (after Toky and Ramakrishnan 1982)

Agricultural Operation	Energy Input (MJ ha - 1 yr 1) *Jhum* Cultivation 30-yr cycle	10-yr cycle	5-yr cycle	Terrace Cultivation
Labour Input (total)	1615	1148	494	984 (1478)
Clearing under storey Vegetation	274	331	78	293
Felling trees and Bamboos	583	319	-	(595)
Collection of Debris and Burning	51	35	5	(140)
Terrace Preparation	-	-	-	(759)
Dibbling, Broadcasting and Transplantation	40	43	43	41
Hut Construction	23	24	24	
Weeding	63	76	87	44
Guarding the Field from Wild Animals	71	70	64	86
Rearing Caterpillars	123	-	-	110
Harvest	187	198	173	276
Transportation	21	13	8	24
Threshing	77	25	5	41
Shelling	128	42	7	69
Seed Input	24	15	16	202
Fertilizer	-	-	-	5323
Total Energy Input into the System	1665	1181	510	6509 (8003)

Figures in the Parenthesis indicate Values for the First Year of Terrace Cultivation

Table 8: Energy Outputs (MJ ha - 1 year - 1) under Terrace Cultivation (after Toky and Ramakrishnan 1982)

	Crops Species	Energy Output (MJ ha - 1 year - 1)
	Oryza sative	13024
	Senamum indicum	545
Grain and seed crops	*Zea mays*	2347
	Phaseolus mungo	114
	Ricinus communis	208
	Musa sapientum	2686
	Hibiscus sabdariffa	1245
Leafy and Fruit Vegetables	*Cucurbita mixima*	1418
	Momordica charantia	142
	Phaseolus vulgaris	224
	Manihot esculenta	19639
Tuber and Rhizome Crops	*Colocasia anticuorum*	1351
	Zingiber officinalis	330
	Curcuma longs	245
	Cocoon (silk)	80
	Pupae (without cocoon	4

it provides leisure time for the farmer.

The energy output/input ratio was high under all *jhum* cycles. It was much lower under terrace cultivation. Because of higher labor input for land preparation under valley cultivation, the efficiency ratio was lower, although the energy output was closer to 30- and 10-year *jhum* cycles. However, this system is superior to terrace cultivation. The main point of difference in energy input between terrace and other land use systems is qualitative in that the former depends heavily upon fossil fuel energy while all others are labor-intensive. (Table 9)

Energy in Relation to Land Use

The comparative energy efficiency of the *jhum* cycles cannot be considered in isolation but needs to be discussed in relation to land-use patterns. Energy efficiency values per se could lead to a distorted comparison for different *jhum* cycles (e.g. a *jhum* site cropped once in five years as compared to once in every 10 or 30 years). What has been discussed is indicative of the trade-off between land area and energy input. If land is not a limiting factor, then the greater solar energy input to a larger area of the *jhum* system with a longer cycle could be used to offset imported energy and this would ensure harmony of the long cycle with the environment, and at the same time ensure rational returns to the farmer. However, with increase in population pressure and decrease in land area available for *jhum*, due to environmental degradation with permanent weedy communities of arrested succession or even extreme

Table 9: Energy Ratios in Agricultural Systems - *Jhum*, Terrace and Valley Cultivation (after Toky and Ramakrishnan 1982)

Agricultural System	Energy (MJ ha - 1 yr - 1) Input	Output	Output/Input ratio
Jhum 30-yr Cycle	1665	56766	34.1
Jhum 10-yr Cycle	1181	56601	47.9
Jhum 5-yr Cycle	510	23858	46.7
Terrace	6509	43602	6.7
	(8003)		(5.4)
Valley - I and II Crops	2843	50596	17.8

desertification (Ramakrishnan et al 1981), land is in short supply, resulting in very short *jhum* cycles of four to five years. In such a situation, the longer the *jhum* cycle, the larger the land area needed. However, the effective output per hectare would decrease due to a correction factor depending upon the *jhum* cycle. Thus for the 30-, 10-, and 5-year *jhum* cycles at lower elevations of Meghalaya (Toky and Ramakrishnan 1982), the effective output per hectare would decrease due to a correction factor of 1/30, 1/10, or 1/5 so there is an effective output of 1892.2, 5660.1, or 4771.6 MJ per hectare. On this basis, a 10-year *jhum* cycle is the most efficient in terms of energy ratio and land use.

Energy Efficiency of a Semi-Industrial Agricultural System

Terrace cultivation, suggested as an alternative to *jhum*, involves labor for terracing in the first year, along with continued heavy input of fertilizers. This makes it inefficient from energy and economic viewpoints, although the output is only slightly less than that under a 10-year *jhum* cycle when the land re-use pattern is not considered, as evident at lower elevations (Toky and Ramakrishnan 1982)

This system is comparable to more modern Indian agricultural systems, where nine units of food energy are harvested for each unit of fossil fuel energy put into the system (Mitchell 1979), and better than most Western agricultural systems, where the yield is one or two units of food energy per unit of energy input (Spedding 1975; Spedding and Walsingham 1976; Leach 1976; Pimental and Pimental 1979). Apart from energy efficiency, the system is not stable; even if soil erosion is checked to some extent by terracing, infiltration losses would still prove heavy (Ramakrishnan et al 1981a; Toky and Ramakrishnan 1981b).

Furthermore, heavy input of fertilizer in such a high-rainfall region may result in serious environmental problems. In the ultimate analysis, this form of land use has not found much favor with local populations. In fact, the life of the terraces themselves often is not more than six to eight years.

General Considerations

If one considers that the 4 to 5-year *jhum* cycle now prevalent in the northeastern hill region is untenable from the point of view of energy and land use, and if it is further realized that terracing is neither ecologically nor economically viable as an alternative to *jhum*, the only alternatives seem to be to have cereal cultivation under a 10-year *jhum* cycle (which is not feasible under present conditions of pressure on land) or to confine cereal cultivation to valleys, which does not demand any fertilizer input and permits a dependable good return on a sustainable basis and also has fairly high energy efficiency. The main limitation of valley cultivation, however, is that imposed on it due to topography. Hence, this system of land use may have to be supplemented by a minimum cycle period of 10 years for *jhum*, assuming that *jhum* has to be retained as a land-use practice. It is in this context that alternative land-use strategies become important, with cereal cultivation confined to valleys or restricted under 10-year *jhum* cycles. It may be profitable to consider horticultural and plantation crops on hill slopes as a limited alternative to controlled *jhum* with a 10-year cycle, since these have been a success on an experimental scale in this region.

In the wider context of Indian agriculture, it should be possible to replace use of imported chemical fertilizers by local resources based on bio-fertilizers using available manpower most effectively (for example, small-scale irrigation projects) for stability of agricultural production. With the large majority of rural households composed of small and marginal farmers, more emphasis on agricultural technology based on local natural resources, rather than a total shift to that chiefly based on chemical fertilizers, seems to be appropriate.

ENERGY BUDGET AND VILLAGE ECOSYSTEM FUNCTION UNDER *JHUM*

The industrialized societies of today face reduced flexibility owing to their strong dependence on petroleum and other fossil fuel-based products, becoming scarce and costly. The way many societies have evolved in the past, in harmony with low levels of energy supply, may provide clues as to how modern societies could adapt to the limitations imposed by energy scarcity. In a study of a typical Khasi village ecosystem under *jhum* at higher elevations of Meghalaya, the relationship between food and energy, inputs into the food production system, energy flow through primary and secondary food production units, energy needs for cooking and the manner in which they are met, and cost-benefit analysis of village functions are examined (Mishra and Ramakrishnan 1982). Such analyses of energy flow patterns through various compartments of a society adapted to low-energy inputs are few (Rappaport 1971; Odum 1971; Leach 1976).

In the village ecosystem at Sethliew in northeast India, *jhum* and valley cultivation are the two major land uses, apart from fallow land under natural vegetation. Closely associated with the *jhum* agricultural system is swine husbandry. Animal husbandry systems are closely interlinked with shifting agriculture in traditional societies the world over.

While this animal husbandry practice may not be efficient elsewhere, as with the Tsembaga farmers in the New Guinea highlands (Rappaport 1971) who raise a single a pig over a 10-year period with only 1.5 percent return on the food energy as pig meat energy (Pimental and Pimental 1979), the practice in India is more efficient (Fig. 5). The demands on the Khasi farmer are lighter and the animals feed chiefly on vegetable waste as they browse and on cheap feeds such as poor quality tubers unfit for human consumption. The cost of rearing is further lowered for Khasi farmers as their pigs are slaughtered every year rather than once in 10 years as under the Tsembaga system.

At Sethliew, the domestic subsystem has low energy efficiency (Fig. 6) with food and fuel for cooking being two inputs into this subsystem, which generates manpower used for agriculture and animal husbandry. Fuel for cooking is an important need of the domestic subsystem, more than half of which is imported from outside the village ecosystem. One of the consequences of shortening the *jhum* cycle (Ramakrishnan et al 1981a) has been rapid depletion of the fuelwood resources of the region. This is aggravated due to low-efficiency fuelwood energy utilization in the developing world (Leach 1976) where the per capita consumption of energy for cooking is considered to be over two and a half times more than in the West. (Table 10)

Table 10: Annual Fuel Consumption for Cooking in the Village Ecosystem (after Mishra and Ramakrishnan 1982)

Category	Quantity kg	Energy Equivalent (MJ)
Firewood	5033	86276
Rice husk	328	6032
Total		92308 (92033)

Value in Parenthesis is the standard requirement.

In the Sethliew village ecosystem, about 70 percent of the protein yield is of plant origin and the rest is of animal origin. Rice, the staple diet of the people, along with maize, accounted for over 70 percent of the total food energy and about 67 percent of the protein consumed by humans. Pork, the only form of meat consumed, accounted for about 13 percent of the food energy (Table 11).

Results suggest that the high energy efficiency and energy balance of the village ecosystem as exemplified at Sethiew are adversely affected in villages under shorter *jhum* cycles and in areas where there is degraded land under arrested weed stage of succession (Saxena and Ramakrishnan 1984) or in desertified sites as at West Khasi Hills District in Meghalaya. The self-sufficiency of the village ecosystem

Table 11: Annual Food and Protein Consumption in the Village Ecosystem (after Mishra and Ramakrishnan 1982)

Category	Food Quantity (kg)	Energy Equivalent (MJ)	Protein Equivalent (kg)
Solanum tuberosum	88.96	1288	4.16
Colocasia antiquorum	43.30	629	4.23
Ipomoea batatus	360.00	5965	15.59
Zea mays	342.80	5685	44.02
Oryza sative	2567.00	42538	213.57
Phaseolus vulgaris	10.78	169	2.55
Cucurbitus maxima	28.00	430	6.00
Pork	112.50	8560	93.49
Total		65264 (67383)	383.61 (321.20)

Values in Parentheses are the Standard Requirements

also is adversely affected.

These studies also show that the village ecosystem function in the northeastern hills varies in relation to ecological conditions and social and cultural factors. A variety of lesser-known plants of food value are used by the different tribes. These are either cultivated in their *jhum* plots or collected wild.

These food plants supplement carbohydrates and proteins obtained through conventional crops. Apart from a variety of leafy ferns used in the Mokochung District in Nagaland, the Naga tribes use two weedy species: *Ghetum montanum* and *G. gnemon.* The Khasis in Meghalaya cultivate at least two important lesser known crop species in their *jhum* plots, namely *Pesilla ocimoides* and *Flemingia vestita.* When one realizes that by the turn of the century, conventional food resources may have to be supplemented by new sources to feed the increasing world population of which a large proportion would be in the underdeveloped world of the tropics, this ethnobiological study becomes urgent.

ENERGY, ENVIRONMENT, AND DEVELOPMENT

Self-sufficiency in food is the chief concern of any developing society. A variety of strategies to make *jhum* viable in terms of food yield could be designed. While longer *jhum* cycles of

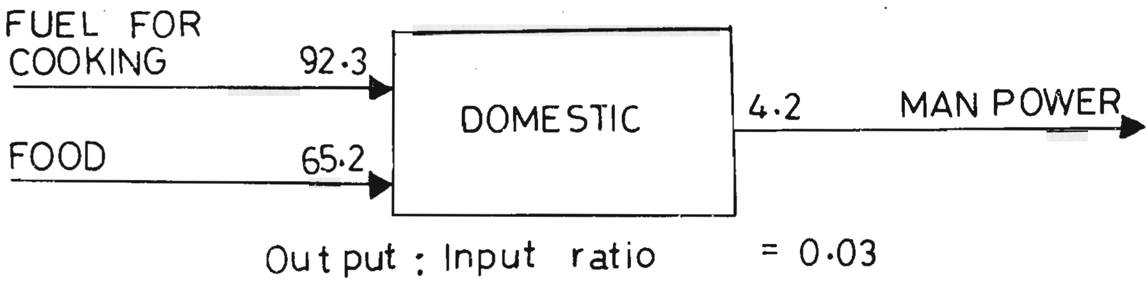


Fig. 5: Energy input-output pattern and efficiency ratios: Domestic subsystem. Unit= MJ x 10 (Mishra and and Ramakrishnan 1982)

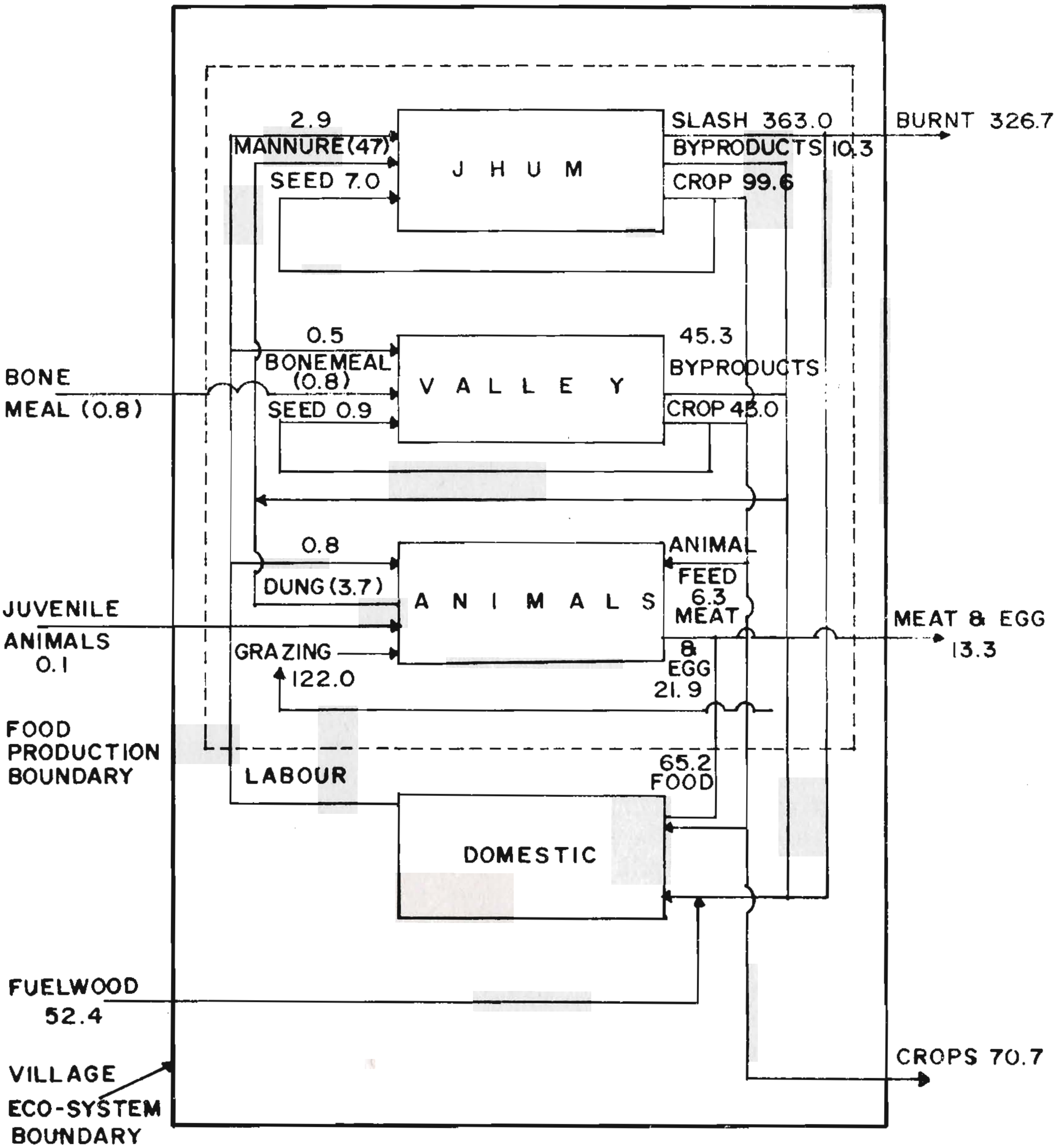


Fig. 6: Energy flow model for the village ecosystem at Sethliew.

Values within parentheses refer to the replacement cost in terms of fossil fuel. Unit = MJ x 10 3 (Mishra and Ramakrishnan 1982).

10 years or more are both ecologically and economically viable, one way of taking the pressure off the land is to diversify economic activities. Encoraging horticulture/plantation crops, intensifying valley cultivation through modern inputs, and improving animal husbandry are some possibilities. Even with the current short 5-year cycle, introduction of identified legumes and non-leguminous trees and shubs during the fallow phase could ensure reasonable recovery of the soil fertility depleted during the cropping phase, making such a cycle more productive. A tree line around *jhum* plots would also check nutrient losses that occur through wind and hydrology during the cropping phase itself (Toky and Ramakrishnan 1981b; Mishra and Ramakrishnan 1983a). Apart from improving the *jhum* system itself, a tree line would provide fuelwood energy, a major fraction of which has often to be imported from outside the village at present. An examination of the native species with fast growth rates that could be exploited for such a social forestry program has been undertaken (Ramakrishnan et al 1982). The introduction of identified native trees during the fallow phase as part of the social forestry system for the tribal communities could contribute to their energy needs (Ramakrishnan 1984b 1985a,b). Such an acceleration of the fallow phase regrowth of secondary successional plant communities (Toky and Ramakrishnan 1983a; Mishra and Ramakrishnan 1983c) would help speed fertility recovery processes (Ramakrishnan and Toky, 1981; Toky and Ramakrishnan 1983b; Mishra and Ramakrishnan 1983b,d). Energy-efficient stoves for cooking would further contribute to the village ecosystem function from an energy viewpoint.

Agroforestry systems with fast-growing native tree species, along with a variety of crops, could meet the food, fodder, and fuelwood needs of the people. Cash crops with horticulture/plantation crops either as part of the agroforestry system or apart from it, could encourage an export-oriented economy which should be secondary only to self-sufficiency of the village ecosystem in hill areas. Improvements on valley land agro-ecosystems through better crop varieties and management techniques could increase cereal production and considerably augment the *jhum* system. Improved animal husbandry practices are other possibilities for supplementing food energy and meeting protein needs. High technology of low magnitude for semi-processing of the produce of rural areas is possible. Semi-processing of tea, coffee, or rubber could be organized for a cluster of villages before transport to city centers for final processing.

Nowhere is the interlinkage between energy and environment so evident as in the tribal societies of the northeast (Ramakrishnan 1985a). The distortions brought about in tribal societal functions due to deforestation could be corrected through revegetation strategy using native species (Boojh and Ramakrishnan 1982a, b, c, 1983; Ramakrishnan and Shukla 1982; Ramakrishnan et al 1982; Shukla and Ramakrishnan 1984a, b, 1986; Ramakrishnan 1985b).

Public intervention for development should be first to design development packages suited to a given ecological zone after these are identified. These packages should be implemented with people's participation, by taking advantage of the cooperative spirit ingrained into traditional societies. Apart from providing acceptable technology that is in accord with the value system of the tribals, the government agencies can act as catalysts for providing the organizational base both for production and marketing.

REFERENCES

Boojh, R., and P. S. Ramakrishnan.
1982a *Growth Strategy of Trees Related to Successional Status.I Architecture and extension growth.* Forest Ecol. Manage. 4:355-374.

Boojh, R. and P. S. Ramkrishnan.
1982b. *Growth strategy of trees related to successional status. II. Leaf dynamics.* Forest Ecol. Manage. 4: 375-386.

Boojh, R and P. S. Ramakrishnan.
1982c. *Growth and architecture of two altitudinal populations of Schima wallichii.* Proc Indian Natl. Sci. Acad. B 48: 534-545.

Boojh, R. and P. S. Ramakrishnan.
1983 *Sacred groves and their role in environmental conservation.* In: Strategies for Environmental Management, Souvenir Vol. Dept. Sci. & Environ, Govt. U.P., Lucknow pp. 608

Borthakur, D. N. Singh, A. Awasthi, R. P. and R. N. Rai.
1978 *Shifting cultivation in the north eastern region.* In: Resources, Development and Environment in the Himalaya Region. Dept. Sci. and Tech, Govt. of India. pp. 330-342.

Carneiro, R. L.
?190 Slash and burn agriculture: *A closer look at its implications for settlement patterns.* In: Men and Cultures (ED. A.F.C. Wallace), Philadelphia.

Conklin, H. C.
1957 *Hanunoo agriculture*, FAO Forestry Development Paper No. 12, FAO, Rome, 109 pp.

Gleissman, S. R.
1980 *Some ecological aspects of traditional agricultural practices in Tabasco,* Mexico. Applications for production, Biotica, 5, 93-104.

Gleissman, S. R., E. R. Garcia, and A. M. Amador.
1981 *The ecological basis for the application of traditional agricultural technology in the management of tropical agroecosystems.* Agro-Ecosystems, 7, 173-185.

Greenland, D. J.
1975 Bringing the Green Revolution to the *Shifting cultivator.* Science 190, 841-844.

Leach, G.
1976. *Energy and Food Production.* Guildford, IPC Science & Technology Press. 137.pp

Lewis, O.
1951 *Life in a Mexican Village: Tepoztlau restudied.* University of Illinois Press. Urbana, 512 pp.

Misra, B.
1976 *A positive approach to the problem of shifting cultivation in eastern India and a few suggestions to the policy makers* (EDs. B. Pakem, J.B. Bhattacharjee, B. B. Dutta and B. Dutta-Ray) In: Shifting Cultivation in North-East India, N. E India Council. Social Sci. Res., Shillong, pp. 80-91.

Mishra, B. K. and P. S. Ramakrishnan.
1981 *The economic yield and energy efficiency of hill agro-ecosystem at higher elevations of Meghalaya in north-eastern India.* Act Oecologica/Oecol. Applic. 2: 369-389.

Mishra, B. K. and P. S. Ramakrishnan,
1982 *Energy flow through village ecosystem with slash and burn agriculture* in *north-eastern India.* Agric. systems, p: 57-72.

Mishra, B. K. and P. S. Ramakrishnan.
1983a *Slash and burn agriculture at higher elevations in north-eastern India.* I. Sediment, water and nutrient losses. Agric. Ecosys Environ. 9: 69-82.

Mishra, B. K. and P. S. Ramakrishnan.
1983b *Slash and burn agriculture at higher elevations in north-eastern India. II Soil fertility changes.* Agric. Ecosys Environ 9. 83-96.

Mishra, B. K. and P. S. Ramakrishnan.
1983c *Secondary succession subsequent to slash and burn agriculture higher elevations of north-east India.* I. species diversity, biomass and litter production. Acta Oecologica/ Oecol. Applic. 4: 237-245.

Mishra, B. K. and P. S. Ramakrishnan.
1983d *Secondary succession subsequent to slash and burn agriculture at higher elevations of north-east India. II. Nutrient cycling.* Acta Oecologic/Oecol. Applic. 4: 237-245.

Mishra, B. K. and P. S. Ramakrishnan.
1984 *Nitrogen budget under rotational bush fallow agricultural (Jhum) at higher elevations of Meghalaya in north- eastern India.* Plant Soil. 80: 237-246.

Mitchell, R.
1979 *The Analysis of Indian Agro-ecosystems.* Interprint, New Delhi, India, 180 pp.

Mutsaers, H. J. W. P. Mbonemboue, and M. Boyomo.
1981 *Traditional food crop growing in the yaounds area (Cameroon). Part I.* Synopsis of the system. Agro Ecosystems, 6, 273-287.

Norman, M. J. T.
1978 *Energy inputs and outputs of subsistence chopping systems in the tropics.* Agro-Ecosystems, 4, 355-366.

Nye, P. H. and D. J. Greenland.
1960 *The Soil under shifting cultivation. Technical Bulletin No. 51,* Commonwealth Bureau of soils, Harpenden, 156 pp.

Odum, H.
1971 *Environment, Power and Society.* Wiley-Interscience, New York, 331 pp.

Pimental, D. and M. Pimental.
1979 *Food, Energy and Society.* Edward Arnold, London, 165pp.

Ramakrishnan, P. S.
1984s *The Science behind rotational bush fallow agriculture systems (Jhum)* Proc. Indian Acad. Sci. (Plant Sci) 93: 379-400.

Ramakrishnan, P. S.
1984b *Let the tribals decide what they want.* Science Age, 2,8-11.

Ramakrishnan, P. S.
1985a *Tribal man in the humid tropics of the north-east*, Man in India, 65: 1-32.

Ramakrishnan, P. S.
1985b *Jhum Cultivation-Prospects for developing countries. Science Technology and Development* (COSTED) 9, 1-3.

Ramakrishnan, P. S. and O. P. Toky.
1981 *Soil nutrient Status of hill agro-ecosystems and recovery pattern after slash and burn agriculture (Jhum) in north-eastern India.* Plant Soil, 60:41-64.

Ramakrishnan, P. S. and R. P. Shukla.
1982 *On the relation among growth strategies, allocation patern, productivity and successional status of trees of a sub-tropical forest community.* In: P.K. Khosla Ed.) Improvement of Forest Biomass. Indian Soc. Tree Scientists, Sohan, India pp. 403-412.

Ramakrishnan, P. S.,O. P. Toky. and R. K. Mishra.
1981a *Slash and burn agriculture in north-eastern India.* In: H. Mooney. T.M. Bonuicksen, N.L. Christensen. J.E. Lotan and W.A. Weiners (Eds.) Fire Regime and Ecosystem Properties. USDA. Forest Serv. Gen. Tech. Rept., W.O. 26, Washington, D.C.

Ramakrishnan, P. S. , O. P. Toky, and R. K. Mishra.
1981b *Jhum - an ecological assessment.* In: Souvenir, Silver Jubilee Symp. Internat. Soc. Trop. Ecol, Bhopal, India, pp. 41-49

Ramakrishnan, P. S, R. P. Shukla, and R. Boojh.
1982 *Growth strategies of trees and their aplication in forest management. Curr. Sci. 51: 448-455.*

Rappaport, R. A.
1971 *The flow of energy in an agricultural society.* Sci. Am 225, 117-132.

Revelle, R.
1976 *Energy use in rural India. Science*, 192, 969-975.

Saxena, K. G. and P. S. Ramakrishnan.
1984 *Herbaceous vegetation development and weed potential in slash and burn agriculture (Jhum) in N.E. India.* Weed Res. 24: 135-142.

Shukla, R. P. and P. S. Ramakrishnan.
1984a *Leaf dynamics of tropical trees related to successional status.* New Phytol, 97:697-706

Shukla, R. P. and P. S. Ramakrishnan.
1984b *Biomass allocation strategies and productivity of tropical trees in relation to successional status.* J. Ecol. 74 (in press).

Spedding, C. R. W.
1975 *The Biology of Agricultural Systems.* Academic Press, London.

Spedding, C. R. W. and J. M. Walsingham.
1976 *The production and use of energy in agriculture.* J. agric. Economics, 27,19-30.

Steinhart, J. S. and C. E. Steinhart.
1974 *Energy use in the US food System*, Science, 184, 307-316.

Toky, O. P. and P. S. Ramakrishnan.
1981a *Cropping and yields in agricultural systems of the north-eastern hill region of India.* Agro-Ecosystems, 7: 11-25.

Toky, O. P. and P. S. Ramakrishnan.
1981b *Run-off and infiltration losses related to shifting agriculture in north-eastern India. Environ, Conserv.* 8:313-321.

Toky, O. P., and P. S. Ramakrishnan.
1982 *A comparative study of the energy budget of hill agro-ecosystems with emphasis on the slash and burn system (Jhum) at lower elevations of north-eastern India.* Agric. Systems, 9, 143-154.

Toky, O. P., and P. S. Ramakrishnan.
1983a *Secondary succession following slash and burn agriculture in north-east India.* I. Biomass, litterfall and productivity. J. Ecol. 71: 735-745.

Toky, O. P., and P. S. Ramakrishnan.
1983b *Secondary succession following slash and burn agriculture in north-eastern India.* II. Nutrient cycling, J. Ecol. 71: 747-757.

Uhl, C., and P. Murphy.
1981 *A comparison of productivities and energy values between slash and burn agriculture and secondary succession in the Upper Rio Negro region of the Amazon Basin.* Agro-Ecosystems, 7, 63-83.

Walters, R. F.
1971 *Shifting cultivation in Latin America,* FAO Forestry Development Paper No. 17, FAO, Rome, 305 pp.

APPENDIX - 1

Energy Calculations

Solar energy, which is the primary source of energy, and the slash burnt during shifting cultivation, do not enter into calculations for energy efficiency of this agro-ecosystem as these are considered to be 'free' inputs and no special effort goes into obtaining them. The input of energy through seeds was calculated on the basis of the total energy expended to produce that fraction of the crop yield. Total food energy consumed was apportioned to each activity (Leach, 1976)[1] according to relative duration on the basis of grouping involving either sedentary, moderate or heavy work. Per hour energy expenditures of 0.418 MJ for sedentary work, 0.488 MJ for moderate work and 0.679 MJ for heavy work for an adult man and 0.331 MJ for sedentary work, 0.383 MJ for moderate work and 0.523 MJ for heavy work for an adult woman were used to calculate the labour energy 2 input into the system (Gopalan et.al. 1978). The energy values for economic yield of crops were estimated after burning the samples in a bomb calorimeter. Energy input through organic manure was calculated on the basis of their replacement cost (pig dung, 1.32; goat dung, 2.0; fowl dung, 4.78; dung + vegetable manure, 1.46; bone meal, 5.87 MJ Kg_{-1})

For the estimation of the annual meat production, the weight gained by each category of animal at the time of slaughter was calculated and the values thus obtained were connected using a dressing percentage (Ranjhan, 1977) 3 of 75, 56 and 70 for pig, lamb and fowl respectively. Using the energy values of 4. 937, 4.560 and 7,238 MJ Kg^{-1} for goat meat, chicken and eggs, respectively (Gopalan et. al, 1978)and 17.121 MJ Kg^{-1} for pork (Ranjhan, 1977) the energy equivalent of secondary production through animal husbandry was calculated. The estimation of the feed/fodder consumed by livestock was based on the daily rations given to the animal and their energy values. For calculation of browsing by the animals it was assumed that the energy equivalent for this would be equal to the value obtained after subtracting the energy value of the actual feed consumed from their standard food energy requirement (Ranjhan, 1977).

The fuelwood energy calculations for the domestic sub-system were based on the value of 17.142 MJ Kg^{-1} for slash, calculated using a bomb colorimeter. Estimation of the actual amount of food/fuel consumed by humans was based on actual observations, and the energy equivalents.

---

1. Leach, 1976 (as in references)

2. Gopalan, C.B. , Ramasastri, V. and Balasubramanim v. 1978. Nutritive value of Indian foods. Natl. Inst. Nutrition, Hyderabad and the input through inorganic fertilizer is based on production cost (N, 76.99; P_2O_5, 13.95; K_2O, 9.67 MJ kg^{-1})

3. Ranjham, S.K. 1977.Animal Nutrition and feeding practies in India.Vikas Pub. House Pvt. Ltd., New Delhi.
of all the items consumed were calculated using their respective energy values. For calculatingthe theoretical food energy requirement of humans, the energy consumption scale suggested by Gopalan et al (1978): (one adult male, 1 unit; one adult female, 0.9 unit; children aged 5-7 years, 7-9 years and 9-12 years, 0.6, 0.7 and 0.8 units respectively), was used for conversions into units. This was then multiplied by the food energy equivalent of an adult (one unit) of 10.042 MJ day 1 (Gopalan et al, 1978). The values of food energy thus obtained (nutritive values) were then corrected to the heat of combustion by multiplying with the coefficient of 1.149 (Mitchell, 1979). To find the energy equivalent of fuelwood needed per day for cooking purposes it was assumed that the potential energy required for one adult man (one unit) would be 15.759 MJ (Mitchell, 1979).

4. Mitchell, 1979 (as in references)