Proc. Indian Acad. Sci. (Plant Sci.), Vol. 99, No. 3, June 1989, pp. 211–221.

Ecological implications of some cash crop ecosystems in north-eastern India*

ANIL KUMAR and P S RAMAKRISHNAN**†
School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110 067
**Present address: G B Pant Institute of Himalayan Environment and Development, Kosi, Almora 263 643, India

MS received 16 May 1988

Abstract. Energy and economic analysis of cash crops (coffee, tea, ginger and pineapple mixed cropping system) are contrasted with shifting agriculture under a 10-yr cycle in north-eastern India. Though ginger gave maximum monetary return, followed by tea, the output/input ratio was higher for pineapple mixed cropping system. Coffee is not successful in this area of study. Some of the cash crop systems had high energy efficiencies though the shifting agriculture had high output/input ratio of 43·5. Nutrient losses through water was high under cash crops with maximal losses under ginger; compared to shifting agriculture the losses were substantial. It is suggested that plantation crops should be sustained in the region basing it, to the extent possible, on the concept of recycling of organic wastes.

Keywords. Cash crop ecosystem; shifting agriculture; energy budget; hydrology; nutrient losses.

1. Introduction

Though shifting agriculture (jhum) is the chief land use system in the north-eastern hill region of India (Ramakrishnan *et al* 1981a, b; Ramakrishnan 1985a), the shortening of shifting agriculture cycle (time lag between two successive cropping at the same site), because of population pressure and reduction in the land area, has resulted in distortions in terms of ecology (Ramakrishnan 1985a) and economic returns to the farmer (Mishra and Ramakrishnan 1981; Toky and Ramakrishnan 1981a). Therefore, there has been attempts to have a shift in land use towards plantation and cash crops (Ramakrishnan 1985b). Shift towards plantation crops becomes particularly important when it is realized that terrace cultivation of agricultural crops have been tried from time to time as an alternative to shifting agriculture and has been rejected again and again by the jhum farmer. This is partly due to problems of terrace maintenance, soil fertility sustainability and eventual site desertification (Ramakrishnan 1984a). Introduction of plantation crops is another alternative that offers possibilities if approached correctly, particularly considering social and scientific angles (Ramakrishnan 1984b). While pineapple and ginger are traditional cash crops in the region, coffee and tea are introduction by the Soil Conservation Department on an experimental basis at Nayabunglow in Meghalaya in north-east India. The present study deals with a comparative analysis of the economic and ecological efficiencies of these plantation/cash crop systems in

*Work done at the Centre for Eco-Development, North-Eastern Hill University, Shillong 793 014, India
†To whom all the correspondence should be addressed.

Meghalaya. Such comparison compares these cropping systems with shifting agriculture under a 10-yr cycle.

One of the important reasons for shifting agriculture with a short cycle of 4–5 yr becoming untenable in the region is related to heavy losses of nutrients through run-off and percolation during the cropping season (Toky and Ramakrishnan 1981b; Mishra and Ramakrishnan 1983a). This eventually leads to an infertile soil under the short jhum cycle (Ramakrishnan and Toky 1981; Mishra and Ramakrishnan 1983b). An aspect that is considered in the present study, therefore, also pertains to nutrient losses under plantation/cash crops at Nayabunglow.

2. Study area

The present study was carried out around Nayabunglow (25°, 45′ N and 91°, 54′ E) at an altitude of 910 m in the Khasi hills of Meghalaya, about 30 km north of Shillong. The climate is typically monsoonic with more than 80% of the total annual rainfall of 180 cm occurring during May–September. The monsoon is followed by winter; March and April represent a brief dry period. The mean monthly maximum and minimum temperatures during the monsoon were 28·6 and 17·1°C respectively and for the winter they were 21·3 and 3·9°C respectively.

3. Description of the land use systems

Coffee (*coffee arabica*) plantation was done on terraces in early sixties by Governmental agencies. The plantation was raised with a spacing of 3 × 2 m is not very successful. *Schima wallichii* and *Bauhinia purpurea* are two important shade tree species used. Average plant height of coffee is 1·5 m. Seed picking (dark reddish) is done in December–January. Pruning of the plant is done soon after. Weeding is done once, followed by application of pesticides in September–October. Inorganic fertilizer (N and P, 5 : 3) is applied twice in a year at the rate of 155 kg ha^{-1}.

Transplantion of tea (*Camellia sinensis*) was done on slopes (60 × 90 cm distance) during the year 1978 using one year old saplings. *Albizzla odoratissima* is the important shade tree species alongwith *Albizzia chinensis*, planted at distances of 3 × 5 m. Trimming of the bush at 75 cm height is done in February. Plucking of tea leaves is done during April–October, at 10-day intervals. Weeding is done 3 times during the rainy season. Apart from weedicides/pesticides applications, inorganic fertilizer (NPK, 2 : 1 : 2) is used twice in a year at the rate of 555 kg ha^{-1}. The freshly plucked tea leaves are sold at the rate of Rs 1·50 kg^{-1}.

Ginger (*Zingiber officinale*) is traditionally cultivated on terraces. After preparation of the land into ridges and furrows and after repairing the old terraces, sowing is done in April at distances of 20 × 30 cm following an application of organic manure at the rate of 720 kg ha^{-1} before crop sowing. Inorganic fertilizer (NPK, 1 : 1 : 1) is applied twice in a year at the rate of 500 kg ha^{-1}. Harvesting of the rhizome is done in December–January.

Pineapple (*Ananas comosus*) plantations are being cultivated on terraces for the last 6 years. This alongwith rhizome and tuber crops (*Colocasia antiquorum, Curcuma longa* and *Manihot esculentus*) are sown in March and harvested during the following December. Two harvests of pineapple are done from the same field, once in July–August (monsoon variety) and another in December–January (winter variety). Weeding is done twice in June and December. Weed biomass and old pineapple plant biomass are put back into the plot as organic manure.

4. Methods of study

Coffee, tea, pineapple mixed cropping system, and ginger cultivation plots were selected at Nayabunglow, in Meghalaya. In each plantation/cash crop system, 3 plots of 50 × 50 cm were identified.

4.1 *Energy and economic analysis*

Vegetation analysis in the crop systems was based on twenty 1 m^2 quadrats for herbs and twenty 10 × 10 m quadrats for shrubs and trees placed at random in each plot. The importance value indices (IVI) which is an integrated measure of relative frequency, relative density and relative basal area of the species are calculated (Curtis 1959).

Labour cost was calculated on the basis of prevailing rates (Rs 12 per day). The cost of manure, chemical fertilizer, seeds, pesticides and weedicides were calculated according to the prevailing market price. The total economic yield was converted into rupees on the basis of prevailing market prices. The economic efficiency was evaluated as monetary output/input ratio.

The labour hours expended for each activity was recorded separately. The total energy consumed was apportioned to each activity (Leach 1976), according to the relative duration on the basis of grouping, involving either sedentary, moderate or heavy work. Per hour energy expenditure was calculated as (i) 0·418 MJ for sedentary work, 0·488 MJ for moderate work and 0·679 MJ for heavy work for an adult male and (ii) 0·331 MJ for sendentary work, 0·383 MJ for moderate work and 0·523 MJ for heavy work for an adult female (Gopalan *et al* 1978). Energy input through chemical fertilizers was calculated on the basis of fossil fuel energy that is required to manufacture the fertilizer (table 1). The fossil fuel equivalents given in table 1, were used to calculate the replacement cost of organic manure in terms of fossil fuel energy. The input of energy through seed was calculated on the basis of total energy expended to produce that fraction of crop yield. For calculating the output of energy under the 4 land use systems, the total economic yield of various crops was converted into MJ of energy by multiplying with standard values of various crops as given in table 1.

The energy efficiencies were calculated as the output/non-solar input ratio, output/solar input ratio and output/labour hour ratio. The energy intensities: Labour input/yield ratio (min kg^{-1}) were also calculated.

All the results were compared and contrasted with shifting agriculture (jhum) under a 10-yr cycle, based on the data of Toky and Ramakrishnan (1981a, 1982).

4.2 *Nutrient losses through water*

For studies pertaining to sediment and water loss due to erosion and run-off, the loss from a confined area of 1 × 10 m was collected in large collectors and sampled

Table 1. Energy values (MJ kg^{-1} dry weight) for different components considered in the plantation/cash crop ecosystems in north-eastern India.

Items	Moisture (%)	Average energy value
Coffee seed[a]	25·7	17·03
Leafy materials[b]	46·8	13·77
Pineapple fruit[b]	50·0	2·20
Rhizome and tuber crops[b]	70·0	13·77
N[c]	–	76·90
P_2O_5[c]	–	13·95
K_2O[c]	–	9·66
Weedicides[d]	–	148·11
Pesticides[e]	–	100·00
Replacement Cost	–	—
Organic manure[f]	–	1·28

[a]Mitchell (1979); [b]Gopalan *et al* (1978); [c]Pimentel *et al* (1973); [d]Alvani and Chancellor (1975); [e]Leach and Slessor (1973); [f]Percentage of N, P_2O_5 and K_2O in organic manure was 1·3, 1·2 and 1·2 respectively.

periodically for chemical analysis. For study of percolation loss of water, zero-tension lysimeters (Buckman and Brady, 1960) were employed. Soil was cut vertically in each plot to expose the profile. A small tunnel was excavated at a depth of 40 cm (the depth to which most roots penetrate) and the lysimeter (30 × 30 × 15 cm) was placed inside it by pressing from below, the rim of the lysimeter was firmly inserted in the undisturbed soil above. The percolated water was tapped out from the lysimeter from time to time for analysis. The results are based on monthly several observations in each plot. Formaldehyde (40%) was used to stop biological activity immediately after collection.

4.3 *Soil and water analysis*

After analysing the fresh soil/water samples for NO_3-N and PO_4^{-P} soon after collection, the soil/water samples were preserved in 40% formaldehyde. Air dried soil samples were passed through 2 mm sieve and kept in glass jars for subsequent analysis. The samples were analysed by standard procedures (Allen *et al* 1974). Thus NO_3-N was estimated by phenol-disulphonic acid method and PO_4-P were estimated by molybdenum-blue method after extracting by Bray and Kurtz solution. Total nitrogen was estimated by micro-Kjeldahl method. Calcium and magnesium were analysed by EDTA titration method while potassium was analysed by flame-emission method. Soil extraction for cations was carried out with 1 M ammonium acetate at pH 7.

5. Results and discussion

5.1 *Economics and energy analysis*

Vegetation analysis of the weeds and crops done together at the peak growth period in August (table 2) showed that ginger, followed by pineapple mixed cropping had

Table 2. IVI of vegetation in different plantation/cash crop ecosystems in north-eastern India.

Species	Coffee	Tea	Pineapple mixed cropping	Ginger
Crop	89·5	95·7	75·0*	40·2
Weeds				
Ageratun conyzoides L.	18·8	40·1	43·1	95·0
Bidens pilosa Hook. f.	–	–	5·8	7·4
Borreria articularis (L f) will	20·2	64·1	81·8	80·9
Commelina nudiflora L.	11·4	12·6	5·5	11·5
Crossocephallum crepidioides (Benth) L.	6·0	–	5·3	13·7
Cynodon dactylon L.	–	–	–	5·4
Cyperus globosus All.	–	–	9·3	12·6
Eupatorium odoratum L.	36·3	–	6·0	–
Galinsoga parviflora Cav.	–	–	5·0	5·8
Imperata cylindrica P. Beauv.	–	–	5·6	–
Mimosa puldica L.	–	–	6·0	–
Panicum maximum jacq.	15·3	7·0	40·1	–
Pteridium equilinum (L) Kuhn ex Decken	9·7	8·0	–	–
Saccharum arundinaceum Hook. f.	10·9	15·9	–	–
Others	15·3	10·7	11·0	19·0
Trees				
Albizzia odoratissima Benth	–	32·8	–	–
Bauhinia purpurea L.	20·3	–	–	–
Erythrina indica L.	6·6	–	–	–
Schima wallichii (DC) Korth	6·3	–	–	–
Others	33·4	13·1	–	–

*IVI of 9·6 is for rhizome and tuber crops and the rest is pineapple.

more weed intensity compared to tea and coffee. Amongst the weeds, *Borreria articularis* and *Ageratum conyzoides* were two more dominent weeds. The weed intensity in tea plantation is checked through use of weedicides and in coffee, it is biologically suppressed to some degree by the dense canopy of the coffee plants and shade trees. It may be noted that the suppression of weed growth through shading by large shrubs and trees during secondary succession after shifting agriculture (jhum) has been shown earlier (Kuswaha *et al* 1981; Toky and Ramakrishnan 1983; Swamy and Ramakrishnan 1987).

Cost of production was higher for ginger followed by tea (table 3). Energy input for tea was higher followed by ginger; pineapple mixed cropping system had minimum energy input. The major energy input for coffee, tea and ginger was inorganic fertilizer, followed by labour. Of all the inputs labour cost was the highest for tea followed by ginger. Since field preparation for tea, coffee and pineapple mixed cropping systems are done only when cultivation starts; this cost is not recurring. While tea is raised on slopes, pineapple cultivation is done on terraces. Except for the pineapple mixed cropping system, inorganic fertilizer was applied and this was minimal for coffee. Yearly seed input was required for rhizome and tuber species grown with pineapple and for ginger cultivation.

Though the economic output from ginger was higher than from other crop systems and this is followed by tea, the input for these two crops are also high (table 4). With low input into pineapple mixed cropping system and a relatively

Table 3. Cost of production (Rs ha^{-1} yr^{-1}) of different plantation/cash ecosystem in north-eastern India.

Inputs	Coffee	Tea	Pineapple mixed cropping	Ginger
1. Labour	1694 (574)	11844 (3537)	2896 (808)	8745 (2776)
(i) Field preparation	–	–	–	2200 (781)
(ii) Sowing	–	–	325 (81)	1100 (346)
(iii) Fertilizer application	525 (180)	880 (283)	–	825 (268)
(iv) Weeding	320 (99)	1320 (385)	1625 (459)	3520 (1014)
(v) Plant protection (Chemical spray)	165 (59)	220 (78)	–	–
(vi) Pruning	484 (172)	352 (125)	–	–
(vii) Harvesting	200 (64)	9072 (2666)	948 (268)	1100 (365)
2. Organic manure	–	–	–	2500 (922)
3. Inorganic fertilizer	760 (8261)	1725 (14978)	–	1375 (9958)
4. Pesticides/weedicides	500 (20)	745 (910)	–	–
5. Seed	–	–	200* (165)	6225 (190)
Total	2754 (8855)	14514 (19425)	3096 (973)	18645 (13854)

Values in parentheses are for energy input MJ ha^{-1} yr^{-1}.
*Cost of rhizome and tuber crops.

Table 4. Economic efficiencies of different plantation/cash crop ecosystems and a shifting agriculture under a 10-yr cycle in north-eastern India.

	Coffee	Tea	Pineapple mixed cropping	Ginger	Shifting agriculture 10-yr cycle[a]
Input	2754	14314	3096	18845	1830
Output	4560	37125	12090[b]	42435	3354
Net return	1808	22811	8994	23590	1524
Output/input ratio	1·66	2·59	3·90	2·25	1·83

[a]Toky and Ramakrishnan 1981a.
[b]Rs 9095 for pineapple and Rs 2997 for rhizome and tuber crops.

higher return from it the economic efficiency is higher. A comparison of the output/input ratio of the plantation/cash crop systems with shifting agriculture under a 10-yr cycle (Toky and Ramakrishnan 1981a, 1982) suggests that except for coffee the efficiency values are higher for the plantation/cash crop systems.

The energy efficiency (output/input ratio), considering non-solar input was maximum for pineapple mixed cropping system, but much lower than that under a 10-yr jhum cycle (table 5). If the solar energy input is involved in the calculations, tea was more efficient than shifting agriculture. The efficiency for coffee was the least. Energy output per unit labour input was maximum for shifting agriculture followed by tea plantation. Labour input per unit production was maximum for ginger and least for shifting agriculture. Yield per unit non-solar energy input was high for pineapple mixed cropping system followed by shifting agriculture.

While monetary output/input analysis is suggestive of the economic efficiency of this system, energy output/input analysis is an indication of the ecological efficiency of the system (Rappaport 1971; Ramakrishnan 1987a). Though the efficiency of the shifting agriculture system in terms of non-solar input is much higher than in all the plantation/cash crops considered have, the energy efficiency of the shifting agriculture system cannot be considered in isolation but need to be discussed in relation to land use pattern, or else energy efficiency values *per se* could lead to distorted comparisons. If land is not a limiting resource, then the greater solar input to a large area of shifting agriculture system with a large cycle could be used to offset imported energy and this would ensure harmony of the long cycle with the environment, at the same time ensuring rational returns for the farmer. The 10-yr cycle, therefore, would need a correction factor of 1/10 to make comparisons valid with other systems considered here. Thus the effective output from shifting agriculture would decrease drastically (Toky and Ramakrishnan 1982). Though the energy output from ginger is very low, the economic return is very high suggesting

Table 5. Energy (MJ) sources and efficiencies of different plantation/cash ecosystems and shifting under a 10-yr cycle in north-eastern India.

Production system	Coffee	Tea	Pineapple mixed cropping	Ginger	Shifting agriculture[a]
Input ha^{-1} yr^{-1}					
Solar incident[b]	38×10^6	33×10^6	33×10^6	33×10^6	33×10^6
Non-solar energy	8855	19425	973	13854	1302
Labour energy	574	3537	808	2776	369
	(1232)	(8616)	(1784)	(6760)	(1220)
Output ha^{-1} yr^{-1}					
Crop energy ($\times 10^3$)	8·5	18·1	17·1	33·4	56·7
Yield (kg)	496	13167	3164[c]	2425	3305
Efficiencies					
Energy output/solar input ($\times 10^{-4}$)	2·6	24·9	5·2	10·1	17·2
Energy output/non-solar input	1·01	9·41	17·6	2·4	43·5
Intensities					
Labour input/yield (min kg^{-1})	149	39	34	167	22
Yield/non-solar energy input input (kg MJ^{-1})	0·06	0·66	3·25	0·17	2·54

Labour hour expanded given in parenthesis.
[a]Toky and Ramakrishnan 1982.
[b]Spedding 1982.
[c]2290 kg pineapple fruit and 275 kg rhizome and tuber crops.

that energy efficiency has to be considered along with economic efficiency of the system for its effective evaluation. With a high inorganic fertilizer input into all plantation/cash crops, except pineapple mixed cropping system, the efficiency of these sedentary systems, have come down drastically. However, efficient recycling of resources with emphasis on organic manure would contribute to better ecological efficiency of these plantation/cash crops. Unfortunately this aspect of management has not received any attention so far, though this is important for sustainability on these highly leached weak soils of the hill slopes.

Labour requirements for tea and ginger are high throughout the year; female labour was higher than the male labour input (figure 1) unlike for coffee and for pineapple mixed cropping system. These differences are related to the agricultural operations involved at different times of the year. From this point of view pineapple mixed cropping system and coffee seem to be attractive propositions. In fact, apart from other considerations of high yield, low labour input for pineapple mixed cropping system may account for its wider acceptance as a land use system in the region.

5.2 *Hydrology and losses through water*

Run-off water was higher but percolation water was minimal under tea on the slopes ($P < 0.05$) (figure 2). The water loss through run-off and percolation under ginger was high inspite of terracing. Sediment loss too was very high under ginger ($P < 0.01$) compared to all other systems. This high loss of sediment under ginger may be due to frequent disturbances to the soil during frequent weeding operations and the harvest of the rhizome.

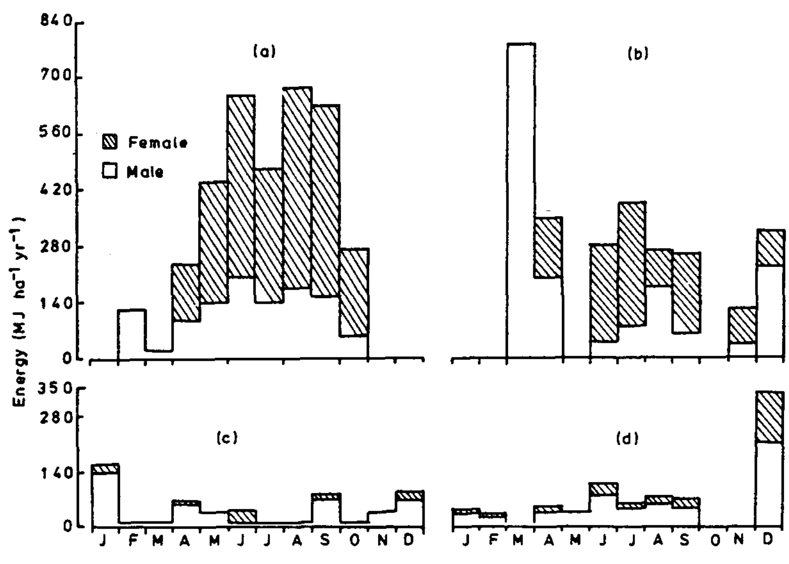

Figure 1. Monthly labour energy distribution pattern in different plantation/cash crop ecosystems in north-eastern India. (**a**) Tea; (**b**) ginger; (**c**) coffee; (**d**) pineapple mixed cropping system.

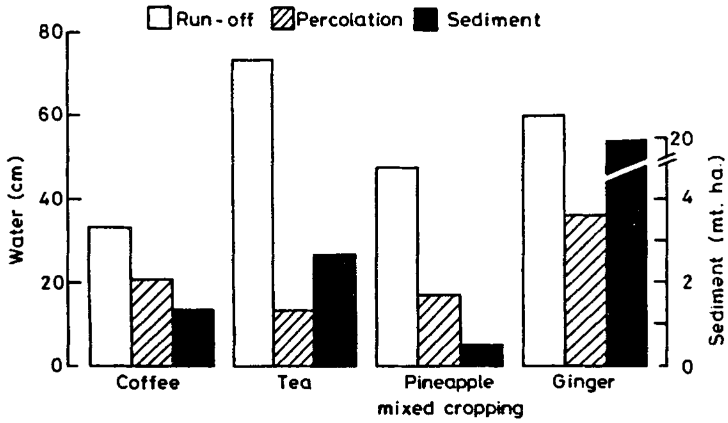

Figure 2. Annual loss of water and sediment from different plantation/cash crop ecosystem in north-eastern India.

Table 6. Total loss of nutrients (kg ha^{-1} yr^{-1}) in run-off and percolation water from different plantation/cash crop ecosystem in north-eastern India.

Element	Coffee	Tea	Pineapple mixed cropping	Ginger
NO_3^{-N}	3·03 ± 0·18	6·61 ± 0·12	1·05 ± 0·08	6·10 ± 0·35
	(3·80 ± 0·17)	(2·20 ± 0·14)	(2·28 ± 0·13)	(8·38 ± 0·44)
PO_4^{-P}	0·59 ± 0·05	2·56 ± 0·15	0·61 ± 0·04	1·68 ± 0·07
	(0·22 ± 0·02)	(0·30 ± 0·02)	(0·19 ± 0·01)	(1·0 ± 0·05)
K	22·01 ± 0·96	54·67 ± 1·61	15·15 ± 0·68	41·03 ± 1·57
	(9·45 ± 0·35)	(5·90 ± 0·35)	(3·80 ± 0·22)	(15·86 ± 1·20)
Ca	10·83 ± 0·64	26·0 ± 1·36	8·01 ± 0·40	12·94 ± 0·56
	(3·84 ± 0·77)	(3·0 ± 0·21)	(2·33 ± 0·12)	(6·56 ± 0·40)
Mg	8·97 ± 0·41	36·94 ± 1·95	6·32 ± 0·40	10·86 ± 0·49
	(2·33 ± 0·11)	(4·55 ± 0·25)	(1·62 ± 0·17)	(5·58 ± 0·35)

Values in parentheses are for percolation losses.

The high run-off loss of nutrients under tea is largely due to heavy input of fertilizer that is washed out (table 6). The loss under pineapple mixed cropping system was minimal, partly because of the terracing and partly due to use of organic manure alone in preference to inorganic fertilizer. A higher nutrient load in percolation water under ginger is due to a lossened surface soil under frequent disturbances. This would also explain high losses through sediment ($P < 0·05$) under ginger compared to all others (figure 2). Pineapple mixed cropping system had least losses through sediment.

In earlier studies on shifting agriculture system done on slopes of 30–40° angle, it was shown that percolation losses of nutrients from the system could be substantial going up to as much as 50% of the total (Toky and Ramakrishnan 1981; Mishra and Ramakrishnan 1983a). With terracing under mixed cropping with pineapple or under ginger the percolation losses of nitrogen, phosphorus and potassium could vary from 1/3 to as high as two times of the run-off loss. Even in coffee and tea plantations the losses could be substantial. This would seem to suggest that a multiple cropping system with a vertically layered crop mixture as in home gardens (Maikhuri 1987) may be more appropriate to conserve nutrients in the system in the humid tropics.

6. Conclusions

A major disadvantage of plantation/cash crop systems such as tea and ginger is the heavier labour input that often necessitates labour employed from outside. This is often costly and may also have implications of import of labour from outside the region. Under the given socio-economical and socio-political framework in which the traditional societies operate, it may be desirable to stabilize shifting agriculture (jhum) with a 10-yr cycle or even redevelop shifting agriculture under a 5-yr cycle so as to ensure self-sufficiency of the village ecosystem wherever possible (Ramakrishnan 1987b). It may not be desirable to consider plantation/cash crop systems at this stage, that can not be handled by the family unit, with labour coming exclusively from within the family. It is in this context a mixed land use pattern which considers redeveloped shifting agriculture alongwith small units of plantation/cash crops for a family organised on a co-operative basis (Ramakrishnan 1984b) become relevent. In terms of managing these plantation systems, it is important to consider the possibilities of lesser dependance upon inorganic fertilizer. Emphasis on recycling of organic residues from the village ecosystem is important as this is an ecological concept on which traditional societies are based.

Acknowledgement

This study was supported by the Department of Environment and Forests, New Delhi through a research grant.

References

Allen S E, Grimshaw H M, Parkinson J A and Quarnby C 1974 *Chemical analysis of ecological materials* (Oxford: Blackwell)

Alvani P K and Chancellor W J 1975 Energy requirements for wheat production and use in California; *Am. Soc. Agric. Eng.* paper No. 75, p 1557

Buckman H O and Brady N C 1960 *The nature and properties of soils.* (New York: Macmillan)

Curtis J T 1959 *The vegetation of Wisconsin: an ordination of plant communities* (Wisconsin: University of Wisconsin Press)

Gopalan C B, Ramasastri V and Balasubramanian S C 1978 *Nutritive value of Indian foods* (Hyderabad: National Institute of Nutrition)

Kushwaha S P S, Ramakrishnan P S and Tripathi R S 1981 Population dynamics of *Eupatorium odoratum* in successional environments following slash and burn agriculture; *J. Appl. Ecol.* **18** 529–535

Leach G 1976 *Energy and food production* (Guildford: IPS Science and Technology Press)

Leach G and Slesser M 1973 *Energy equivalents of network inputs to food processing processes,* (Glasgow: Strathclyde University)

Maikhuri R K 1987 *Studies on tribal village ecosystem function in north-eastern hill region of India,* Ph.D thesis, North-Eastern Hill University, Shillong

Mishra B K and Ramakrishnan P S 1981 The economic yield and energy efficiency of hill agro-ecosystems at higher elevations of Meghalaya in north-east India; *Acta Oecol./Oecol. Appl.* **2** 369–389

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

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

Mitchel R 1979 *The analysis of Indian agro-ecosystem* (New Delhi: Interprint)

Pimental D, Hurd L E, Bellotti A C, Forster M J, Oka I N, Sholes O D and Whitman R J 1973 Food production and the energy crisis; *Science* **182** 443–449

Ramakrishnan P S 1984a The science behind rotational bush follow agriculture system (jhum); *Proc. Indian Acad. Sci.* (*Plant Sci.*) **93** 379–400

Ramakrishnan P S 1984b Let the tribals decide what they want; *Sci. Age* **2** 8–11

Ramakrishnan P S 1985a Tribal man in the humid tropics of the north-eastern; *Man India* **65** 1–32

Ramakrishnan P S 1985b Jham Cultivation — Prospects for developing countries; *Sci. Technol. Dev. ISCU COSTED* **9** 1–5

Ramakrishnan P S 1987a Energy flows and shifting cultivation; in *Rural energy planning for the Indian Himalaya* (eds) T M V Kumar and D R Ahuja (New Delhi: Wilay-Eastern) pp 247–276

Ramakrishnan P S 1987b Role of tree architecture in agroforestry; in *Agroforestry for rural needs* (eds) R K Khosla and D K Khurana (Solan: Indian Society Tree Scientists) pp 112–131

Ramakrishnan P S and Toky O P 1981 Soil nutrient status of hill agro-ecosystem and recovery pattern after slash and burn agriculture (jhum) in north-eastern India; *Plant Soil* **60** 41–64

Ramakrishnan P S, Toky O P, Mishra B K and Saxena K G 1981a Slash and burn agriculture in north-eastern India; in *Fire regimes and ecosystem properties* (eds) H A Money, J M Bonnickser, N L Christensen, J E Lotan and W A Reiners (Honolulu: USDA For Serv Tech. Rep. WD 26) pp 507–584

Ramakrishnan P S, Toky O P and Mishra B K 1981b Jhum—an ecological assessment; in *Int. Soc. Trop. Ecol.* Souvenir volume (eds) A singh and P Wali, pp 570–576

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

Swamy P S and Ramakrishnan P S 1987 Weed potential of *Mikania micrantha* H.B.K. and its control in fallows after shifting agriculture (jhum) in north-east India; *Agric. Ecosyst. Environ.* **18** 195–204

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

Toky O P and Ramakrishnan P S 1981b Run-off and infictration losses related to shifting agriculture (jhum) in north-eastern India; *Environ. Conser.* **8** 313–321

Toky O P and Ramakrishnan P S 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. Syst.* **9** 143–154

Toky O P and Ramakrishnan P S 1983 Secondary succession following slash and burn agriculture in north-eastern India I. Biomass, litter fall and productivity; *J. Ecol.* **71** 735–745