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Cation budget under terrace agroecosystem in Meghalaya in north-east India

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Abstract. Cation budgeting was done under 4- and 12-year old terraces at higher elevation of Meghalaya (960 m) in north-east India. Cation addition occurred after burning the biomass arising from the weed and the crop residue prior to cropping. While nutrient removal through weeds was more under 12-year old terrace than under 4-year old one, the reverse was true for that removed by crop. Nutrient deficit, particularly potassium, was obvious under 12-year old terrace. Decline in soil fertility and increase in weed potential are implicated in the reduced crop yield.

Keywords. Terrace; cation budget; biomass; soil fertility.

1. Introduction

Slash and burn agriculture (jhum) is the chief land use of the north-eastern hill region (Ramakrishnan *et al* 1981; Ramakrishnan 1985) and this agricultural activity is the chief one in other areas of the humid tropics elsewhere (Nye and Greenland 1960; Ruthenburg 1976). In recent times, the slash and burn agriculture cycle (the length of the fallow period before the land is again cleared for cropping) has become extremely short (4 to 5 years) due to increased population pressure and reduced land area (Mishra and Ramakrishnan 1981; Toky and Ramakrishnan 1981a). One of the suggested alternatives has been settled farming on terraces, though this has not found acceptance by the people. However, in some selected areas where the soil is sufficiently deep and well formed, terracing has been continually practised over some time, largely by the immigrant Nepalis as at Nayabunglow, in Meghalaya in north-east India. Among the many factors that contribute to the large-scale rejection of this alternative land use system (Patnaik 1988), nutrient supply to the agroecosystem is an important one. Under terrace system the slash of the weed biomass and crop residue arising from the previous cropping is slashed and burnt which results in release of cations in one single flush. However, under continuous cropping on the terraces cations are depleted through heavy leaching. Of all the cations, the loss of potassium, is most pronounced as shown in our studies in north-east India (Toky and Ramakrishnan 1981b; Mishra and Ramakrishnan 1983; Swamy and Ramakrishnan 1988) and also shown by others (Nye and Greenland 1960). In terraced plots, even though surface run-off would minimized, nutrient leaching would still be a major carrier under the high rainfall condition in north-east India. Therefore the present paper considers the budgeting of cations under terraces maintained for 4 and 12 years under continuous cropping, by the Nepalis. The objective is to calculate the role of cations in the sustenance of this land use system by the immigrant Nepalis alone in this region.

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2. Study area

The study area at Nayabunglow is located about 30 km north of Shillong (25° 45″ N and 91° 54″ E) at an altitude of about 960 m, in the Khasi hills of Meghalaya. The precambrian rocks are represent by gniess, schists and granites. The soil is a red sandy loam of laterite origin. The pH ranged from 5 to 6. The angle of slopes ranged from 20°–40°.

The climate of the area can be divided into 4 more or less marked seasons, (i) the monsoon season of heavy rainfall during May–September, (ii) a transitional period of low rainfall during October–November, (iii) a winter season during December–February and (iv) a windy dry summer during March–April. The average rainfall during the study period was 1800 mm. The average maximum and minimum temperatures during the monsoon season were 28·6 and 17·1°C respectively, and during the winter periods these were 21·3 and 4°C respectively.

3. Description of agroecosystem

3.1 *Terrace agroecosystem*

Terrace cultivation resembels slash and burn agriculture (jhum) in that some slash burning is done followed by mixed cropping. The weed biomass produced between December–March when the land is fallowed is slashed and the weed residue and the crop residue from the previous croppings are burnt before crop introduction in April. On younger terrace, two croppings are done in a year, a mixed cropping between April–August followed by monocropping of *Eleusine coracana*. In older terraces, mixed cropping alone is done. Organic manure is applied at the rate of 2550 kg $ha^{-1} yr^{-1}$ before crop sowing in April. *Zea mays*, *Vigna sinensis*, *Phaseolus vulgaris* and *Cucurbita maxima* are sown simultaneously followed by sequential harvesting, as the crop matures, between August and December. Hand hoeing is done to remove weeds that pose a problem. This weed biomass gets recycled into the plots.

4. Methods

Terrace plots of 4- and 12-yr old (each with 3 replicates) were identified at Nayabunglow 30 km north of Shillong at an elevation of 960 m, in Meghalaya in north-east India. While selecting the plots, similar aspect and topographic conditions were ensured. Direct fall through precipitation was collected from 10 random points in each plot. Soil sampling up to a depth of 40 cm was done by using a core sampler at 15 random points on each plot at 3 times during the year: (i) a day before burning the slash prior to cropping, (ii) a day after the burn and (iii) at the end of cropping.

The slash (weed and crop residues) and organic manure are uniformly spread out in each plot. In order to calculate the amount of slash burnt and the organic manure input into the agroecosystem, ten 1 m^2 quadrats were randomly laid in each plot; values represent the mean of these 10 observations in each replicate plot.

The nutrient input into the agroecosystem was then quantified. Nutrients removed through crop thinning, crop uptake, weed uptake and recycling through weeds ploughed back into the system were all based on 10 random observations in each plot, using 1 m^2 quadrats.

For studies pertaining to cation losses through sediment and run-off water, loss from a confined area of 1×10 m was collected in large collectors and sampled periodically for chemical analysis. For the study of percolation loss of cations, zero tension lysimeters (Buckman and Brady 1960). In each of the 3 replicate plots, 15 lysimeters were placed at random to obtain the mean. Soil was cut vertically at each site 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 $30 \times 30 \times 15$ 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 observations were based on 5 replicates in each plot. A few drops of 40% formaldehyde was added to the samples to stop biological activity immediately after collection.

The amount of nutrients present in the soil pool (kg ha^{-1}) was calculated to a depth of 40 cm using soil bulk density estimates calculated for each site, at depths of 0–7, 7–14, 14–28 and 28–40 cm, considered separately. Bulk density or volume weight (the quotient of the over dry weight at 105°C of the soil to the total volume it occupies in each field) was determined from the air dry mass of a known field volume of soil.

The soil was air dried and plant samples were oven dried at 60°C for 48 h, powdered and passed through 0·2 mm sieve and stored in glass jars for subsequent analysis by procedures given by Allen *et al* (1974). Plant samples were wet digested with triple acids (perchloric acid, nitric acid and sulphuric acid) and soils were extracted with 1 M ammonium acetate solution at pH 7. Thus calcium and magnesium were estimated by EDTA titration and potassium by flame emission method.

While calculating the nutrient budget between the pre-burn and the post-burn stages, nutrient addition through weed/crop residues during the intervening fallow period that were burnt were considered. Calculations of the amount of nutrients (potassium, calcium and magnesium) gained due to slash burning are based on the differences of that element present in the soil up to a depth of 40 cm between pre-burn (a day before burn) and that present in the soil a day after the burn. Input and output of elements for each plot were calculated on the basis of the amount of that particular input/output and the concentration of the element in it.

5. Results

Potassium and magnesium in the pre-burn and post-burn soil were markedly higher ($P < 0{\cdot}005$) under 12-yr old terrace than under 4-yr old terrace (table 1). Addition of cations through weed residue was more under 12-yr old terrace than under 4-yr old one. Addition through crop residue before the burn was not very different in 4- and 12-yr old terraces. The net gain of potassium and magnesium in the post-burn soil pool was more under 4-yr old terrace than under 12-yr old one and the reverse was true for calcium ($P < 0{\cdot}01$).

During the first cropping, more cation was immobilised by the weeds and more addition occurred through them under 12-yr old terrace than under 4-yr old one

Table 1. Gain of cations through fire (kg ha^{-1}) under terrace agroecosystem in north-east India.

	Terrace age (yr)					
	4			12		
	Potassium	Calcium	Magnesium	Potassium	Calcium	Magnesium
Pre-burn soil pool	510 ± 25·1	2122 ± 150	792 ± 43·1	982 ± 34·1	1385 ± 57·6	1086 ± 47·8
Addition through						
Weed residue	23 ± 2·4	10 ± 1·1	13 ± 1·07	38 ± 3·1	26 ± 1·6	27 ± 2·5
Crop residue	57 ± 5·6	39 ± 3·02	32 ± 2·9	53 ± 3·1	36 ± 2·5	32 ± 2·5
Post-burn soil pool	797 ± 49·04	2272 ± 141·5	1043 ± 37·83	1155 ± 58·9	1581 ± 32·16	1308 ± 26·52
Net gain	207	101	205	82	134	165

(table 2). However, the proportional contribution through grasses was more ($P < 0·01$) under 4-yr old terrace than under 12-yr. During the second cropping on 4-yr old terrace, the cation recycled through weeds originated from the previous cropping season. Further, during the second cropping, the proportional contribution by grass species was more ($P < 0·01$) than through dicots.

Total nutrient removal by edible and non-edible components of crop species was higher ($P < 0·01$) under 4-yr old terrace than under 12-yr old one (table 3). If the second cropping done under 4-yr old terrace is excluded the reverse was found to be the case. *E. coracana* under 4-yr old terrace removed a larger proportion of potassium during the second cropping season than other species of the first cropping phase. Removal of nutrients through non-edible component for a given species was significantly higher ($P < 0·01$) than through edible parts.

The input/output pattern for cations is given in table 4. While there was a net gain of potassium under 4-yr old terrace, there was loss under 12-yr old one; the reverse was true for calcium. Magnesium gain was more or less similar under 4- and 12-yr old terraces. In general, the input and output totals were more under 4-yr old terrace than under 12-yr.

Nutrient status both before burn and after cropping was higher ($P < 0·01$) under 12-yr old terrace than under 4-yr old one, the exception being calcium (table 5). A net loss in calcium under 4-yr old terrace and a similar loss for potassium under 12-yr old terrace were noted, while others showed a net gain at the end of cropping.

6. Discussion

Terrace cultivation introduced as an alternative land use to replace jhum is largely practised by non-tribal immigrant Nepalis in this region. Apart from the input of organic fertilisers such as cow dung and compost, for terrace cultivation slash and burn operation associated with shifting agriculture (Nye and Greenland 1960; Spencer 1966; Ruthenburg 1976; Ramakrishnan 1984) is also done. However, the slash is largely the crop and weed residues from the previous cropping season. While massive losses of nitrogen are associated with the burn, a substantial increase in exchangeable cations occurred after the burn. Though the budget up to 40 cm depth of the soil profile was done, the changes that occurred due to the burn was

Table 2. Contribution through weed (kg ha^{-1}) during cropping under terrace agroecosystem in north-east India.

	Terrace age (yr)							
	4				12			
	Biomass	Potassium	Calcium	Magnesium	Biomass	Potassium	Calcium	Magnesium
First cropping								
Weed biomass	2050 ± 31·8 (741 ± 20·7)	32 ± 3·1 (10 ± 0·9)	20 ± 1·8 (6·2 ± 0·3)	23 ± 1·9 (8 ± 0·7)	2759 ± 151·6 (255 ± 9·2)	44 ± 2·3 (5 ± 0·4)	37 ± 2·8 (2 ± 0·2)	43 ± 2·0 (3 ± 0·3)
Weed recycled during cropping	548 ± 8·7 (167 ± 3·8)	8 ± 0·3 (3 ± 0·1)	6 ± 0·2 (2 ± 0·1)	7 ± 0·2 (2 ± 0·2)	1009 ± 12·6 (143 ± 4·7)	15 ± 0·9 (2 ± 0·2)	12 ± 0·4 (1 ± 0·09)	13 ± 0·9 (1·2 ± 0·03)
Second cropping								
Weed slash ploughed in prior to second cropping	1503 ± 29·6 (574 ± 23·2)	23 ± 3·5 (7·4 ± 0·9)	14 ± 1·7 (5 ± 0·3)	16 ± 1·8 (6 ± 0·7)	—	—	—	—
Weed biomass	1038 ± 22·6 (628 ± 19·1)	17 ± 1·2 (7·1 ± 0·4)	11 ± 0·7 (5·2 ± 0·3)	12 ± 0·9 (5·4 ± 0·2)	—	—	—	—

Values in parantheses are for grasses.

Table 3. Cation removal (kg ha^{-1}) through edible and non-edible crop biomass under terrace ecosystems in north-east India.

	Terrace age (yr)											
	4						12					
	Potassium		Calcium		Magnesium		Potassium		Calcium		Magnesium	
Grains and pulses												
*Zea mays**	7·8	(42·4)	11·5	(34·6)	17·8	(37·1)	11·8	(49·3)	12·43	(27)	15·5	(23·8)
Eleusine coracana	18·9	(49·1)	33·1	(37·1)	16·6	(36·1)	—	—	—	—	—	—
Vigna sinensis	0·02	(0·9)	0·02	(0·34)	0·02	(0·6)	0·02	(2·02)	0·012	(0·5)	0·02	(0·8)
Phaseolus vulgaris	0·18	(0·7)	0·2	(0·26)	0·28	(0·5)	—	—	—	—	—	—
Total	26·9	(93·1)	44·82	(72·3)	34·7	(74·3)	11·8	(51·3)	12·44	(27·5)	15·6	(24·5)
Leafy and fruit vegetables												
Momordica dioica	0·03	(0·4)	0·02	(0·2)	0·03	(0·02)	0·013	(1·3)	0·01	(0·45)	0·02	(0·4)
Cucurbita maxima	1·38	(0·2)	0·03	(1)	0·05	(0·01)	2·5	(0·2)	0·04	(0·04)	0·05	(0·06)
Hibiscus sabdariffa	0·009	(0·03)	0·005	(0·004)	0·01	(0·02)	—	—	—	—	—	—
Total	1·4	(0·6)	0·06	(0·3)	0·09	(0·06)	2·5	(1·4)	0·05	(0·5)	0·1	(0·5)
Tuber and rhizomes												
Ipomoea batatus	—	—	—	—	—	—	—	(1·6)	—	(0·3)	—	(0·4)
Colocasia antiquorum	—	—	—	—	—	—	—	(0·2)	—	(0·003)	—	(0·1)
Total	—	—	—	—	—	—	—	(1·8)	—	(0·3)	—	(0·5)
Grand total	28·3 ± 2·8	(93·7 ± 6·7)	44·9 ± 4·6	(72·6 ± 7·3)	34·8 ± 3·3	(74·4 ± 6·9)	14·3 ± 1·6	(54·5 ± 4·7)	12·5 ± 0·7	(28·3 ± 1·2)	15·6 ± 1·1	(25·5 ± 1·6)

Values in parantheses are for non-edible component.
*Grown as a 2nd crop of the mono cropping system.

Table 4. Input/output patterns for cations ($kg\,ha^{-1}$) under terrace agroecosystems in north-east India.

	Terrace age (yr)					
	4			12		
	Potassium	Calcium	Magnesium	Potassium	Calcium	Magnesium
Inputs						
Precipitation	4·1	7·4	7	4·1	7·4	7
Addition through fire	207	101	205	82	134	165
Thinned crop biomass	6·8	4·1	3·8	5·01	2·0	1·8
Weeds ploughed back during						
First crop	23·4	14·4	15·9	14·6	12·2	13
Second crop	8·3	5·9	7·1	—	—	—
Organic manure	16·6	10·2	9·1	14·1	8·7	7·7
Total (a)	266 ± 12·0	143 ± 6	248 ± 8·1	120 ± 6·3	164 ± 8·1	195 ± 15·4
Outputs						
Sediment	2·1	3·6	4·1	5·1	4·6	5·1
Run-off	20	7·1	8·1	19·3	13·3	6·1
Percolation	7·9	2·7	2·5	6·1	3·1	3·4
Weed removal during						
First crop	31·7	20·3	23·0	44·3	36·8	43
Second crop	16·8	10·8	11·9	—	—	—
Crop removal during						
First crop	60·8	51·3	60·3	73·8	42·8	43
Second crop	68·0	70·2	53	—	—	—
Total (b)	207 ± 13·2	166 ± 11·3	163 ± 8·3	149 ± 9·9	101 ± 10·9	101 ± 8·4
Net differences (a–b)	+ 59	− 23	+ 85	− 29	+ 63	+ 94

Table 5. Net change in nutrients ($kg\,ha^{-1}\,yr^{-1}$) under terrace agroecosystem in north-east India.

	Terrace age (yr)					
	4			12		
	Potassium	Calcium	Magnesium	Potassium	Calcium	Magnesium
(a) Soil pool before burning	510 ± 25·1	2122 ± 150	792 ± 43·1	982 ± 34·1	1385 ± 57·6	1086 ± 47·8
(b) Soil pool at the end of the cropping	552 ± 50	1473 ± 50·5	1307 ± 57·7	643 ± 45·0	1670 ± 120·3	1547 ± 30·1
(a–b) Net difference	42	649	574	339	285	461

confined only to the first 0–7 cm layer. All the increase that occurred in the soil pool could not be accounted by the input through ash. Obviously, mobilization of cations into the exchange pool after the burn may be an important factor and may be related to increased cation exchange capacity of the soil and the consequent interchange between non-exchangeable to exchangeable forms due to burning (Stromgaard 1984).

With a higher weed potential on older terraces, the biomass recycled through this component of the agroecosystem is two times more under a 12-yr old terrace than under 4-yr old one, during the first cropping. During the second cropping under 4-yr old terrace, the weed slash from the previous cropping phase is just ploughed in and not subjected to burn. If this is considered together with the weed biomass put back during the first cropping phase, the weed recycled becomes more under 4-yr old terrace than under 12-yr old one. Because of higher weed potential of the site under 12-yr old terrace, the nutrient removal by the weed population was generally more compared to 4-yr old one, inspite of two croppings under the latter situation. In contrast to this, crop removal of cations was markedly higher under 4-yr old terrace than in the older one.

The above discussed differences between the two terrace systems when considered along with nutrient losses related to hydrology (where losses were more under older terraces because of poor physical quality of the soil) the input was higher than the output for a labile element such as potassium under a 4-yr old terrace. This may be related to drastic decline in the nutrient status of the soil under continuous cropping (Asamoa 1980; Cowgill 1961; Sanchez 1976) which results in decline in crop production. The negative value for calcium under 4-yr old terrace may be related to high uptake by *E. coracana* during second cropping.

The results presented here suggests that continuous cropping on terraces apart from adversely affecting soil fertility also results in increased weed potential of the site, both of which contribute to reduced crop yield. However, at Nayabunglow, the soil is deep and well developed and therefore terraces can be sustained over a long time period but with sustained input of organic manure particularly cow dung which the Nepalis alone can afford because they maintain cattle. Tribal farmers are unable to maintain terraces in the absence of organic manure availability. They prefer to do shifting agriculture instead. However, elsewhere in the region where the soil is poorly developed terrace farming is not viable (Ramakrishna 1984) inspite of availability of organic manure.

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