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Nitrogen budget under rotational bush fallow agriculture (jhum) at higher elevations of Meghalaya in north-eastern India

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Summary The nitrogen budge of 'rotational bush fallow' agriculture (jhum) was investigated at higher elevations of Meghalaya in north-eastern India under 15, 10 and 5 year fallow cycles (the intervening fallow period between one or two croppings on the same site). Nitrogen depletion was affected by initial stocks in the soil and vegetation compartment at the time of slash and burn as well as the rate at which this was lost during the subsequent land use. While nitrogen losses due to the burn was more severe under longer cycles compared to the 5 year cycle the losses through sediment and water was more under a 15 year cycle compared to 10 and 5 year cycles. Transfer of nitrogen from soil to the weed biomass increased with shortening of the fallow cycle. The positive role of weeds in conservation of nitrogen in their biomass and subsequent release through organic manure into the agriculture system has been highlighed. Under a short fallow cycle of 5 years, considered on a time scale of 15 years, the soil nitrogen was depleted to a very low level compared to a 15 year cycle, suggesting that a 5 year cycle as prevalent today is not viable from the point of view of nitrogen economy.

Introduction

The Khasi tribe at higher elevations of Meghalaya practise a modified version of rotational bush fallow agriculture (the entire system is locally called jhum[16]) which is distinct from the typical type[26], as described below. During cropping drastic changes occur in the nutrient status of the soil[19] partly due to heavy losses in water and sediment from steep slopes[18] during high rainfall. Since nitrogen is one of the key elements that limit crop productivity[6,12,24], an understanding of the cycling of this element in agro-ecosystems is important. Under the slash and burn system, the significance of this is even greater because of volatilization of nitrogen during the burn[2,10,15] and since fertilizer application is either not done or is minimal. It becomes even more critical with the shortening of the fallow cycle (the length of the invervening fallow period between two croppings of the same site – one cropping is done at a time under 15 and 10 year cycles and two

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consecutive croppings under a 5 year cycle before fallowing[16]), because the cropping is done at more frequent intervals starting with a lower nutrient capital as fertility recovery is inadequate[19,20]. Hence this study compares nitrogen budget under three fallow cycles of 15, 10 and 5 years between crops.

The jhum system

In its typical form, jhum in the north-eastern India consists of clearing the entire forest and burning of the dried plant biomass before growing a mixture of crops on the hilly slopes for one or two years[26]. However, in the higher elevations of the Khasi Hills of Meghalaya, jhum pattern is significantly different from its typical type[16] in that normally only the lower branches of the sparsely distributed pine trees (*Pinus kesiya*) are slashed instead of the whole tree. All the undergrowth vegetation is also slashed. Further, in the typical jhum the slash is burnt *in situ* on the steep slopes and the seeds are dibbled directly into the soil-ash complex without any preparation of the soil. In the present case, however, the dried slash is placed in parallel rows running down the slope and then covered over with a thin layer of soil forming ridges with alternating furrows. The slash on the ridges is then subjected to a slow burn. Thus, the land so prepared have elevated seed beds (ridges) and compacted furrows running down the slope. The seeds are planted only on the ridges. While fertilizer is not used in the typical jhum, in the present case both organic (pig dung and compost) and inorganic (NPK – 1:1:1) fertilizers may be used. Under a 15 year cycle no fertilizer is applied during cropping. Under a 10 year cycle, organic fertilizer alone is used at the rate of 600 kg ha^{-1} yr^{-1}. Under a 5 year cycle, organic fertilizer at the rate of 100 kg ha^{-1} yr^{-1} and inorganic fertilizer at the rate of 10 kg ha^{-1} yr^{-1} are applied.

Cropping is done for only one year under 15 and 10 year cycle, but under a 5 year cycle cropping may be done for a year or two. The cycle length includes the length of the fallow period and does not include the cropping period. The crop mixture have tuber crops such as *Solanum tuberosum, Ipomoea batatus* and *Colocasia antiquorum,* cereal such as *Zea mays,* legume such as *Phaseolus vulgaris* and vegetables like *Cucurbita maxima, Cucumis sativus* and *Brassica oleracea.* Shorter cycle of 5 years have only three crop species in the mixture (cf Table 4). Weeding is done 2–3 times in a year. While a major proportion (80%) of the slashed weed is taken out of the fields to the compost pit for the preparation of manure, only a part of the weed is ploughed back into the soil. Most of the byproducts of the various crops are also removed out of the system in the same manner

Table 1. Surface soil characteristics of jhum plots (upto 7 cm depth) with SE values

	Fallow cycle (yr)		
Soil characteristics	15	10	5
Bulk density	1.09	1.09	1.10
	± 0.002	± 0.002	± 0.002
pH	5.1	5.3	5.5
	± 0.07	± 0.02	± 0.04
Organic matter (%)	3.5	3.3	2.8
	± 0.03	± 0.02	± 0.05
Total nitrogen (%)	0.26	0.26	0.21
	± 0.02	± 0.01	± 0.02

for the preparation of manure. The manure from the compost pit is subsequently used in the jhum agro-ecosystem[17].

Study site

This study was done at Shillong (25.34°N and 91.56°E) in the Khasi Hills of Meghalaya, at an elevation of 1500 meters where jhum is practised by the local Khasi tribe. The area supports sub-tropical montane evergreen pine forests with *Pinus kesiya* as the dominant species. The terrain is hilly with steep slopes (the slope angle ranging from 30°–40°). The soil is podsolic. The surface soil characteristics (Table 1) show that the soil is acidic, the acidity being more under longer cycles. Organic matter and nitrogen status of the soil declined ($P < 0.05$) with shortening of the jhum cycle. Detailed studies on soil fertility status are available elsewhere[19].

The 15 year cycle plots had at least one similar cycle prior to the present one. The 10 year plots had at least two cycles prior to this. However, it may be noted that longer cycles of 10 and 15 years have been common in the past. The 5 year cycle has been practised on the same plot for 20 years prior to which it had longer cycles. It may be noted that 5 year cycle a more recent phenomenon of the last 20 years or so. The past land use history is based upon local records by the village headmen.

Methods

Four replicate plots under three fallow cycles of 15, 10 and 5 years were identified around Shillong with similar aspects and topographic conditions. Each of the plot selected covered an area of about 2 ha. At each site, direct fall through precipitation was collected from 10 random points. Soil was also sampled at 10 random points at each site upto a depth of 40 cm. Soil sampling was done on three different occasions: (i) one day before burning the slash, in March, (ii) one day after the burn in March, and (iii) at the end of cropping period in December.

Calculations of the amount of slash burnt, organic/inorganic fertilizer used (Table 2) and materials removed from the agro-ecosystem as economic yield through crop, crop byproducts

Table 2. Quantity of slash/manure added to the jhum systems with SE values

Fallow cycle (yr)	Quantity (kg ha^{-1}) Slash	Organic manure	Inorganic fertilizer
15	4431 ± 62	–	–
10	3922 ± 87	600 ± 71	–
5 I yr crop	2979 ± 74	1000 ± 77	10 ± 0.05
5 II yr crop	–	1850 ± 79	20 ± 0.05

Dash represents absence of the item from the system.

and weed or any of these latter two components ploughed back into the system under three different fallow cycles are based on observations in 30 quadrats of 1 X 10 m size at each site.

For studies pertaining to nitrogen loss throgh sediment and run-off water, loss from a cofined area of 2 X 20 m was collected along the slope in large collectors and sampled periodically for chemical analysis. For the study of percolation loss of nitrate nitrogen, zero-tension lysimeters were employed[7]. 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 X 30 X 15 cm^3) 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 are based on four replicates at each site[18].

After analysing the fresh soil/water samples for NO_3-N soon after collection, the water samples were preserved in polythene jars for subsequent analysis. Soil and plant samples were air dried and oven dried at 80°C for 48 hours, respectively. Dried samples were ground, passed through 0.2 mm sieve and kept in glass jars for subsequent analysis. The samples were analysed by standard procedures[3]. Thus NO_3-N was estimated colorimetrically by phenol-di-sulphonic acid method and organic/total nitrogen was estimated by micro-Kjeldahl method.

Input and output of total nitrogen for each of the fallow cycles were calculated on the basis of the amount of that particular input/output and the concentration of nitrogen in it. The amount of nitrogen 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 dry weight of soil to the total volume it occupies in the field) was determined from the air dry mass of a known field volume of soil. The soil was removed using a core sampler.

Calculations of the amount of nitrogen loss due to fire are based on the difference of that present in the soil upto a depth of 40 cm between the pre-burn (a day before the burn) and post burn (a day after the burn) stages: (Nitrogen in pre-burn soil pool + addition through slash) – (Nitrogen in the post-burn soil pool) = Loss of nitrogen due to fire (Table 3).

Results

The nitrogen budget in the pre-burn and the post-burn stages are shown in Table 3. At both these stages, the soil pool under 10 and 15 year fallow cycles had higher quantities of nitrogen compared to a 5 year cycle. Further, the addition of nitrogen through slash increased with increase in the fallow cycle. Nitrogen declined sharply soon after the burn. The loss of nitrogen through fire markedly increased with increase in the fallow cycle.

The quantity of nitrogen in the crop biomass (which includes both

Table 3. Loss of nitrogen (kg ha^{-1}) through fire with SE values

	Quantity of nitrogen (kg ha^{-1})				
Fallow cycle (yr)	Pre-burn soil pool (a) (X 10^3)	Addition through slash (b)	Total in soil pool before burning (a + b (X 10^3)	Post-burn soil pool (c) (X 10^3)	Loss (a + b)−(c)
15	7.68 ± 0.11	43.6 ± 0.6	7.73 ± 0.11	7.22 ± 0.11	510.2 ± 14
10	7.74 ± 0.09	38.6 ± 0.9	7.78 ± 0.09	7.32 ± 0.13	462.1 ± 22
5	6.40 ± 0.12	29.3 ± 0.7	6.43 ± 0.13	6.17 ± 0.10	262.8 ± 16

Table 4. Nitrogen content (kg ha^{-1}) of the crop biomass with SE values

	Fallow cycle (yr)			
			5	
Crop items	15	10	I yr crop	II yr crop
Solanum tuberosum	28.2 ± 0.4	19.6 ± 0.4	13.5 ± 0.2	8.2 ± 0.1
Edible	25.3	17.6	12.0	7.2
Non-edible	2.9	2.0	1.5	1.0
Ipomoea batatus	2.7 ± 0.1	1.0 ± 0.02	–	–
Edible	2.7	0.9		
Non-edible	< 0.1	0.1		
Colocasia antiquorum	0.3 ± 0.01	0.3 ± 0.01	–	–
Edible	0.2	0.2		
Non-edible	0.1	0.1		
Zea mays	1.3 ± 0.04	1.6 ± 0.04	1.7 ± 0.02	0.2 ± 0.02
Edible	0.7	0.9	1.0	0.1
Non-edible	0.6	0.7	0.7	0.1
Phaseolus vulgaris	0.4 ± 0.02	0.2 ± 0.02	–	–
Edible	0.2	0.1		
Non-edible	0.2	0.1		
Cucurbita maxima	9.7 ± 0.1	8.2 ± 0.1	–	–
Edible	8.6	8.1		
Non-edible	0.1	0.1		
Cucumis sativus	0.1 ± 0.01	0.1 ± 0.01	–	–
Edible	0.1	0.1		
Non-edible	< 0.1	< 0.1		
Brassica oleracea	2.4 ± 0.1	0.9 ± 0.1	5.1 ± 0.1	1.6 ± 0.1
Edible	2.2	0.8	4.8	1.5
Non-edible	0.2	0.1	0.3	0.1
Grand total	44.1 ± 0.5 (0.8)	31.9 ± 0.5 (0.6)	20.3 ± 0.6 (0.6)	10.0 ± 0.4 (0.3)
Edible	40.0 ± 0.5	28.7 ± 0.5	17.8 ± 0.5	8.8 ± 0.4
Non-edible	4.1 ± 0.1	3.2 ± 0.1	2.5 ± 0.2	1.2 ± 0.2

Values within parenthesis refer to the part of non-edible crop ploughed back into the soil.
Dash represents absence of that crop from the system.

Table 5. Nitrogen content (kg ha^{-1}) of the weed biomass with SE values

	Fallow cycle (yr)			
			5	
Weed items	15	10	I yr crop	II yr crop
Ageratum conyzoides	–	0.8 ± 0.2	1.2 ± 0.1	1.2 ± 0.1
Dicranopteris linearis	0.8 ± 0.2	2.2 ± 0.1	1.9 ± 0.1	1.7 ± 0.1
Erigeron linifolius	0.4 ± 0.05	0.4 ± 0.05	2.5 ± 0.2	3.0 ± 0.1
Eupatorium adenophorum	0.3 ± 0.05	1.0 ± 0.05	1.2 ± 0.05	1.3 ± 0.05
Galinsoga parviflora	–	1.2 ± 0.05	0.6 ± 0.05	0.7 ± 0.05
Hypochaeris radicata	0.2 ± 0.05	0.7 ± 0.1	0.6 ± 0.05	0.6 ± 0.05
Imperata cylindrica	0.6 ± 0.05	4.1 ± 0.2	6.1 ± 0.3	6.1 ± 0.25
Oxalis latifolia	1.1 ± 0.05	1.8 ± 0.1	3.4 ± 0.1	1.9 ± 0.2
Plantago major	0.3 ± 0.05	0.5 ± 0.1	0.7 ± 0.1	1.3 ± 0.1
Pteridium equilinum	1.1 ± 0.05	2.9 ± 0.2	2.6 ± 0.1	2.4 ± 0.2
	4.8 ± 0.5 (0.8 ± 0.2)	15.6 ± 0.8 (2.6 ± 0.1)	20.8 ± 0.05 (3.5 ± 0.2)	20.2 ± 0.4 (3.4 ± 0.2)

Values within parentheses refer to the part ploughed back into the soil.
Dash represents absence of that weed in the system.

above and below-ground biomass) declined with the shortening of the fallow cycle (Table 4). A major fraction of nitrogen is taken up by *Solanum tuberosum* which is emphasized more in the crop mixture. About 1/7 to 1/10th of the total nitrogen is present in the non-edible component of the crop.

Among the weeds the different fern species, *Imperata cylindrica, Oxalis latifolia, Erigeron linifolius* and *Eupatorium adenophorum* are important in storing nitrogen in their biomass (Table 5). A pronounced increase in nitrogen content in the weed biomass was observed with shortening of the fallow cycle. About 1/6th of the nitrogen is ploughed into the soil at the time of cropping.

Table 6 indicates some major aspects of the input : output nitrogen budget for the three fallow cycles. Though slash is shown as an input, the nitrogen through this source gets volatilized along with that from the surface soil which is accounted as an output through fire. Organic manure forms a major input for 10 and 5 year cycles but inorganic fertilizer is not a significant input except for a small fraction of the total under a 5 year cycle. The crop byproducts ploughed back decreased with shortening of the fallow cycle. The component ploughed back through weed increased with decrease in fallow cycle. This pattern is also reflected in the amount lost through crop and weed removal. Apart from that lost through fire a major loss from the system is through sediment and run off.

The net change in nitrogen pool in the soil sub-system is shown in Table 7. This shows that the quantity of nitrogen is much lower under

Table 6. Nitrogen input : output budget (kg ha^{-1} yr^{-1}) for different jhum systems

	Fallow cycle (yr)			
			5	
	15	10	I yr crop	II yr crop
Inputs				
Precipitation	3.6	3.6	3.6	3.6
Slash	43.6	38.6	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	13.0	8.2	8.9	10.0
Percolation	0.9	0.5	0.8	0.7
Weed removal	4.0	13.0	17.3	16.8
Crop removal	43.3	31.3	19.7	9.7
Total	690.5	643.6	482.4	213.5
Net differences	641.7	589.8	430.7	178.9

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

Table 7. Net change of nitrogen (10^3 kg ha^{-1} yr^{-1})

	Fallow cycle (yr)			
			5	
	15	10	I yr crop	II yr crop
Soil pool before burning	7.68	7.74	6.40	5.98
Soil pool at the end of cropping	7.04	7.15	5.98	5.60
Net difference	0.64	0.59	0.42	0.18

a 5 year fallow cycle compared to other cycles, both before the burn and at the end of cropping. During second year of cropping done only in the 5 year cycle, there was a lower nitrogen capital at both these stages. The net loss from the system during one cropping was more under longer cycles than under a 5 year cycle.

Discussion

Depending upon the rotational bush fallow agriculture involving low or high intensity burn which in turn depends directly upon the quantity of the slash under different fallow cycles, nitrogen status of the soil pool would vary[1,19,21]. The decline in the amount of nitrogen in the soil pool after fire, also reported by other workers[27,28] could be attributed to the conversion of organic nitrogen to volatile forms during the pyrolysis[2,10,15]. The greater loss due to volatilization of nitrogen with increase in the length of the fallow cycle may be attributed to the higher intensity burn under longer cycles.

Since jhum is practised on steep slopes of the hills, heavy losses of nitrogen would occur during cropping period through sediment and water[18]. These losses chiefly occur during the initial phase of cropping, before plant cover is established. With the development of plant cover, the nutrients including nitrogen gets tied up and conserved in the crop biomass. The byproducts of the crops provide organic manure for the crops either directly or via the compost pit of the village ecosystem[17]. The crop byproducts ploughed back into the system is more under longer fallow cycles as the crop biomass is more[13].

Weeds as an important component of agro-ecosystem has started receiving attention in recent times[4,5,9,23] and their nutrient conservation role has been recognised[8]. The transfer of nitrogen from the crop to the non-crop (weed) compartment, then back again, becomes a potentially important mechanism for optimum utilization of this labile element. Besides, weeds also help in checking nutrient losses through run-off and percolation water[18]. The frequent weeding done during cropping followed by this biomass being ploughed back into soil[13] or being used for compost which eventually comes back into the system as organic manure[17] provides such a mechanism. The weed component ploughed back increase with the shortening of the fallow cycle due to severe weed problem associated with short cycles[22,25]. The use of weeds in this manner but with least interference on the crop would provide tropical agriculture of the future much greater degree of integrated management capability, what the farmers in the traditional tropical agro-ecosystems have developed for centuries[12,13,14].

The net difference between input and output from the jhum plots ignores at least three aspects: nitrogen fixation, mineralization and denitrification. While the net difference is likely to change, the conclusions may not be different had these aspects been included. When the overall pattern for inputs is considered it is seen that the farmer tries to compensate for lesser input under a short 5 year cycle through application of manure/fertilizer. The net change in the nitrogen pool suggests that the shortening of the fallow cycle results in a lower nutrient capital at the pre-burn stage as well as at the end of the cropping period. Greater loss under longer fallow cycles may however be related to the larger amount of nitrogen stored in the soil pool and the vegetation compartment at the time of slashing[20]. The loss of nitrogen from the 5 year cycle plots is higher only if the values are put on a time scale of 15 years: these then would lose three times more than that from a plot under a 15 year cycle and twice that from a plot under a 10 year cycle.

If the plots under 5 year fallow cycles now, had longer fallow cycles preceeding the 20 year period, for which land use history is available, then the system seems to have lost, in terms of initial capital, about 1.28×10^3 kg of nitrogen ($7.68-6.40 \times 10^3$ kg) during the last 20 years. Thus while 15 or 10 year fallow cycles are long enough to restore the original status in the soil before the next cropping, it seems unlikely that about 600 kg of nitrogen lost (the difference between the nitrogen capital before and after two croppings) could be restored under a 5 year cycle. One of the important disadvantages of the 5 year cycle lies in the reduced nitrogen capital with which the agro-ecosystem has to operate due to increased frequency of fire and cropping with too short a fallow phase. An aspect which comes out is the useful role of weeds (the non-weed concept of Gleissman[9]), under traditional agricultural systems as the present one, particularly enhanced under a 5 year fallow cycle due to greater recycling of nitrogen through this component of the agro-ecosystem.

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