Changes in soil nutrient content under shifting cultivation in the Chittagong Hill Tracts of Bangladesh

Abdul Gafur, Ole K. Borggaard, Jens Ravnsø Jensen & Leif Petersen

Abstract

Abstract In the Chittagong Hill Tracts (CHT) of Bangladesh, shifting cultivation is an age-old practice. Usually tribal people practiced slash-and-burn agriculture in the same area with long fallow periods of 15-20 years. But, with the rapid increase of population in the hills this rotation has come down to 3-5 years, allowing insufficient time for the soils to regain their natural productivity. Although less than 5% of the hill area is used for shifting cultivation each year, 10-20 times of the additional vegetative area beyond the shifting cultivated field can be destroyed by wild fires in relation to the burning process. Thus the combined affect of such cultivation is more extensive than it is usually predicted.

The present investigation is a baseline study of the nutrient status in the topsoil and the impact of burning and subsequent runoff on changes in topsoil nutrients following land clearing and burning in a small catchment of 1 ha located on steep to very steep slopes in CHT. Analyses of topsoil samples (0-10 cm) sampled before and after burning showed significant increase in pH, exchangeable base cations (Ca, Mg, K), S, Fe, Mn and Zn but decrease in total C, exchangeable acidity, total N and available P. After having received about 2/3 of the mean anr nual precipitation, 39 ton ha^{-1} soil was lost by erosion. As these sediments were rich in most nutrients, this runoff removed up to 27% of the nutrient content in the upper 10 cm of soil. Losses of available Cu and P by erosion are especially important as the contents of these nutrients were very low before burning and were even reduced by the burning. Although the short time period of less than a year imposed some limitation on the present investigation, the results indicate that traditional shifting cultivation with a short fallow period may cause severe degradation of those soils on steep to very steep slopes in a very humid climate (~3000 mm rain per year).

Keywords

Slash-and-burn; Runoff; Erosion; Sustainability; Hill soil

Abdul Gafur: Chemistry Department, Soil Resource Development Institute, Kampsax International A/S, Dhaka-1215, Bangladesh.
Ole K. Borggaard: Chemistry Department, The Royal Veterinary and Agricultural University, 40 Thorvaldsensvej, DK-1871 Frederikberg C, Denmark.
Jens Ravnsø Jensen: Department of Agricultural Sciences, The Royal Veterinary and Agricultural University, 40 Thorvaldsensvej, DK-1871 Frederikberg C, Denmark.
Leif Petersen: Soil Resource Development Institute, Kampsax International A/S, Dhaka-1215, Bangladesh.

Geografisk Tidsskrift, Danish Journal of Geography 100: 37- 46.

Shifting cultivation, which is at the fore-front of forest exploitation in South and Southeast Asia, accounts for about 49% of deforestation (FAO, 1982). This form of agriculture is practiced all over the region, either in its traditional form by the tribal communities living in the highlands or by migrants and settlers coming from other parts of the country as a result of a lack of land, work or socioeconomic constraints. Often natural calamities including river erosion, tidal surges, cyclones, earthquakes also contribute to the migration. Traditional shifting cultivators usually practice a more complex system of slash-and-burn agriculture that is well adapted to the environment (Pimental and Heichel, 1991; Kidd and Pimental, 1992). These people live in areas with low population density where land availability permits low intensity land-use. In contrast, migrants live in areas of high population and high land pressure (Myers, 1980; Okigbo, 1984). They lack the tradition and concern for hill land and its use as they try to use the same intensive cropping systems they had been practicing in the flat lands. They not only quickly 'mine' the soil of its fertility but also leave it with little crop residues, encouraging devastating soil erosion. Most farmers use slashing and burning to remove weeds from the topsoil, destroy harmful insects, control pests and diseases and keep wild predators away, and the ashes serve as an instant source of fertilizer (Weischet and Caviedes, 1993).

The shifting cultivation system is known as 'Jhum' in Bangladesh and India, 'Kaingin' in the Philippines, 'Chena' in Sri Lanka, 'Chancar Leu' in Kampuchea and 'Ray' in Lao (FAO, 1982). Culturally, slash-and-burn agriculture has been practiced by a diverse range of societies, from unknown, isolated tribal communities to larger civilizations like the early Mayans of Central America (Dove, 1985; Hillel, 1992). It is practiced in a wide range of ecosystems ranging from forests to grassland and savanna environments (Denevan, 1981). Jhum cultivation has three prominent phases: a) land clearing and burning phase, b) cropping phase and c) fallow phase.

a. Land clearing and burning phase

Land clearing followed by burning is the most destructive land preparation system used in hill agriculture. The loss of protective plant canopy after burning may cause a sharp increase in surface soil temperatures and stimulate volatilization of C, N and S (Christanty, 1986; Crutzen and Andreae, 1990; Lal, 1987). The amount of mineral nutrients released through burning depends upon the total nutrient content in the biomass and the intensity of burning. Andriesse and Schelhaas (1987) recorded a temperature fluctuation of 200-700 °C at the soil surface during the burning of felled and dried biomass. They also observed that the temperature remains below 175°C at 1 cm depth and below 100°C at 2 cm depth. But if the biomass is piled up and burned at one place, temperature rose to 150-250°C at 5-cm soil depth. Dunn et al. (1979) reported that a moderate burn of moist biomass in which temperatures reached 530°C at the surface and 150°C at 3 cm depth, killed almost 99% of the fungi in the soil and reduced the heterotrophic bacteria by 57-93%. Burning increases pH and decreases Al concentration, which is beneficial for most crops and can be considered a significant improvement of acid soils (Ahn, 1974; Ewel et al., 1981; Sanchez et al., 1983; Christanty, 1986). Sometimes burning debris is transported to the nearby cluster of huts of the tribal people, causing fire. To avoid such catastrophe during the Jhum burning time, tribal people usually carefully guard their houses. Almost all the area of the Chittagong Hill Tracts has lost its primary vegetation through this offsite effect of fire resulting from the slash-and-burn system of agriculture.

b. Cropping phase

The choice of crops in shifting cultivation varies widely among the agroecosystems and is mainly influenced by the socioeconomic needs of the farmers and their food habits. Combination and diversity of crops (shallow or deep-rooted and fibrous or tap rooted) grown in Jhum influence soil mining and erosion. Diversified rooting systems of the crops means soil nutrients are taken by these crops from different depths of the soil profile but tap rooted crops enhance erosion. Tillage may improve the soil conditions in the beginning of the growing season but may also disrupt the soil surface, destroy aggregates and increase the surface area exposed to rain and wind erosion. This may increase the runoff and soil loss (Lal, 1987). Soil organic matter declines during the cropping season resulting in decreased CEC, increased acidity, reduced nutrients levels (especially N and P), degradation of soil structure, increased bulk density and hence, reduced porosity and aeration and lowered water infiltration capacity (Ahn, 1974). Removal of soil nutrients by the harvested crop adds to the decrease of soil fertility.

c. Fallow phase

Fallow can be viewed as a weed management strategy and as an amelioration of soil conditions for future cropping periods (Van Wambeke, 1992). The success of fallow depends on the past degradation of the soil, nature and kind of the succession community and the length of the fallow period. Too short a fallow period may result in fertility depletion up to a point where the land would be abandoned (Zinke et al., 1978). During fallow, nutrients taken up by the plants are stored in the vegetation until they are partly released to the soil after burning. Natural bush growth is considered the most effective type of fallow regeneration for nutrient recycling and biomass accumulation because it consists of many plant species with different types of root systems (Young, 1989). In areas of intense land use pressure, as in CHT of Bangladesh, longer periods of fallow may not be possible and the agroecological system may not be sustainable and therefore will eventually break down.

This is the background of the present study aimed at showing the effect of Jhum cultivation on the nutrient status, soil loss and hence the sustainability of this agroecosystem. The investigation comprises:

- (a) Inventory of the nutrients stored in the soil after 5 years of fallow.
- (b) Nutrient input-output in topsoil following burning of slashed vegetation.
- (c) Indication of nutrient loss in the initial stage of the Jhum cycle.

Materials and Methods

Description of the study area

The field experiment was conducted at the Soil Conservation and Watershed Management Research Center (SCWMRC), Banderban, CHT, Bangladesh (Fig. 1). Hill

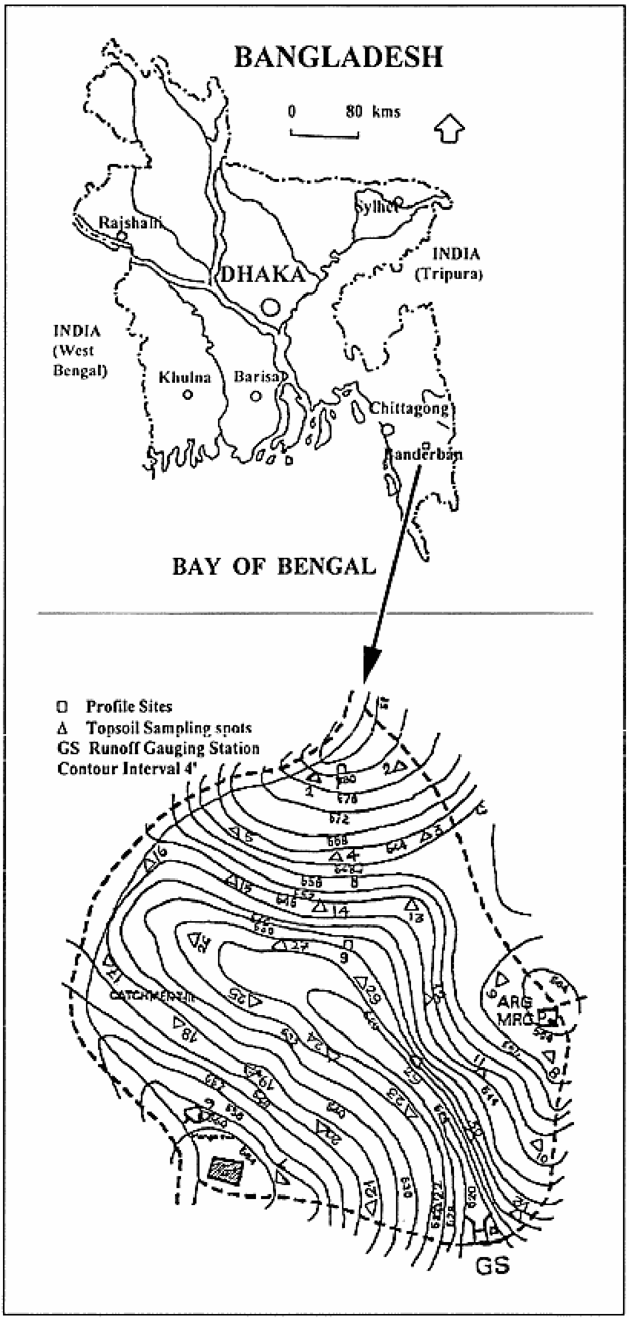

Figure 1: Location and Contour Map of the Experimental Site.

lands occupy nearly 1.7 million hectares, i.e. 12% of the total area of Bangladesh. These hills lie mainly in Khagrachari, Rangamati and Banderban districts and partly in Old Chittagong, Sylhet, Mymensingh and Comilla districts. The hills of Bangladesh are part of Hindu Kush-Himalayan mountain ecosystem and are considered to belong to the youngest mountain chains in the world. They are composed of low-grade metamorphic and sedimentary rocks of Mio-Pliocene to Early Pleistocene age, aligned approximately North-Northwest to South-Southeast with some transverse faults. Most of these hills are closely dissected, mainly with steep to very steep slopes, ranging up to an altitude of 1000 m. They consist of unconsolidated, semi-consolidated and consolidated beds of sandstones, siltstones, shales and some conglomerates, folded into a succession of pitching anticlines and synclines (RSS Report of CHT, 1975). As a result of a high silica content in the prevailing geological material, the majority of the soils in the region is inherently acidic and have rather low nutrient status. The only macronutrient that is generally abundant is potassium as a consequence of the dominance of mica minerals in the region (ICIMOD, 1998). The hilly regions of Bangladesh receive the highest annual rainfall (2,500-3,750 mm) in the country. Most of the rainwater drains out of the hills through numerous creeks, streams and rivers. Previously these hills were covered with dense tropical rain forest.

Site selection, cultural practices, sample collection

The experimental site is situated on a closely dissected medium high hill (150-180 m above MSL) and constitutes a small watershed unit of about one ha. Average soil temperature within 100 m of the experimental site varied from 24.5 to 34.8, 22.9 to 34.9, 22.9 to 30.8 and 23.4 to 30.6 °C at the soil depths of 5, 10, 30 and 50 cm respectively (3 years average recorded in 1997 to 1999).

Previously tribal farmers used this area for shifting cultivation with varying rotation periods of 10-15 years. Now the rotation period has been reduced to 3-5 years. After the last Jhum in 1993, the site was left fallow for 5 years and was covered with secondary forest like shrubs, climbers, thickets and grasses. In January 1998, profile samples were collected from top, middle and lower slope (Fig. 1) of the hill and analyzed for texture and nutrient status.

To assess the change in nutrient content in the topsoil by slashing and burning, the surface soil was sampled two times, one in middle of March 1999, immediately after slashing the vegetation and the other in middle of April 1999, immediately after burning the in-situ slashed materials.

In the beginning of March 1999 a tribal family comprising 3 members was engaged to practice shifting cultivation on the site following their traditional way of cultivation. They were assured that they would not be influenced or biased to do anything beyond of their normal and traditional Jhum practice. Close monitoring of all the tillage operations conducted by the farmer family were recorded and taken into account during the entire study period.

From the 1 ha catchment, 31 composite samples from the depth of 0-10 cm were collected following the contour lines (Fig. 1). In a long dry spell of 7 months (October, 98 to April, 99), the surface soil cracked down to ~10 cm. Assuming that the fire will affect it and the ash will enter the crack and influence the soil characteristic down to the bottom of the crack, 0-10 cm sampling depth was chosen. From each 25 cm x 25 cm sampling spot, topsoil from 3 to 4 spots were collected in a bucket, pulverized and mixed thoroughly. During sampling, all the sampling sites were marked with a recognizable earth mark so that the sites could be easily identified even after burning the slashed materials. Approximately 1 kg soil was collected from each sampling site. As the site has a very complex sloping pattern ranging from 20-150 % and the soils are shallow to moderately deep in nature, sampling was performed following the contour lines maintaining horizontal distance of 19-20 m and vertical interval of 6-7 m.

On the upper, middle and lower parts of the slope, pits were excavated, profiles described and soil samples collected. Profile descriptions were made according to FAO (1990) guidelines. As the profiles were all very similar, except for depth to parent rock, only one profile description is presented here.

Description of the upper profile

Location: SCWMRC, Banderban (22°10' N, 92° 11' E).
Altitude: 176 m above MSL.
Landform: Closely dissected, medium and low hills.
Site: Upper part of rounded hill with 30-40 % slope.
Parent material: Tertiary shale.
Drainage: Well drained.
Land use: Fallowed Jhum (5 years) with secondary forest, shrubs, climbers, thickets and grasses.
Soil classification: Typic Haplohumult (Soil Taxonomy), Haplic Alisol (FAO), Endoleptic Luvisol (WRB).

Comments: Worm casts and forest litter occurred on the mineral soil surface. Partially weathered, broken rock fragments were common throughout the profile but the amount increases with depth. Almost unweathered shales and sandstone were present at a depth of 75 cm, which can be considered as the lithic contact of the profile.

A (0-3 cm): Very dark gray (10 YR 3/1) moist, clay loam; weak fine and medium granular structure; sticky, plastic, friable moist, hard dry; many very fine to medium interstitial pores; frequent fine to coarse roots; common, medium and coarse, flat and angular, fresh or slightly weathered rock fragments; irregular wavy boundary.

E (3-15 cm): Dark yellowish brown (10 YR 4/4) moist; clay loam; weak medium to coarse subangular blocky breaking easily to moderate fine and very fine angular blocky; sticky, plastic, friable to firm moist; broken to continuous, thin to moderately thick, dark grayish brown cutans along the pores and root channels; many very fine to medium interstitial pores; frequent fine to coarse roots; common, medium and coarse, flat and angular, fresh or slightly weathered rock fragments; clear smooth boundary.

Bt (15-45 cm): Yellowish brown (10 YR 5/6) moist, clay; weak medium to coarse subangular blocky breaking easily to moderate fine and very fine angular blocky; sticky, plastic, friable to firm moist; broken, thin to moderately thick, dark grayish brown cutans along the pores and cracks; many very fine to medium interstitial pores; frequent fine to coarse roots; common hard brownish iron oxide nodules; common, medium and coarse, flat and angular, fresh or slightly weathered rock fragments; clear smooth boundary.

C (45-75 cm): Yellowish brown (10 YR 5/6) moist, clay; massive; sticky, plastic, friable to firm moist; no detectable cutans; common very fine to medium interstitial pores; frequent fine to medium roots; common hard black manganese oxide and few brownish iron oxide nodules; common, medium and coarse, flat and angular, fresh or slightly weathered rock fragments.

Runoff and rainfall gauging station

An automatic runoff gauging station, constructed with 90 V notch, stilling tank and 4 m^3 sized upstream debris tank was in operation at the site to monitor runoff and sediment loss (Fig. 2). Runoff samples (known volume) were collected during each rainfall event and were filtered for sediment and water estimation. In the beginning of the monsoon when the rain did not continue for a long time, the tank could be emptied after every rainstorm. Afterwards, most of the time the debris tank was full of runoff sediment and the samples were collected from the running water at the downstream point of the notch. When runoff decreased, suspension in the debris tank was mixed thoroughly and the volume measured. From this composite suspension a known volume was sub-sampled, and oven-dried at 105°C for dry soil mass measurements. Part of the sub-samples was air-

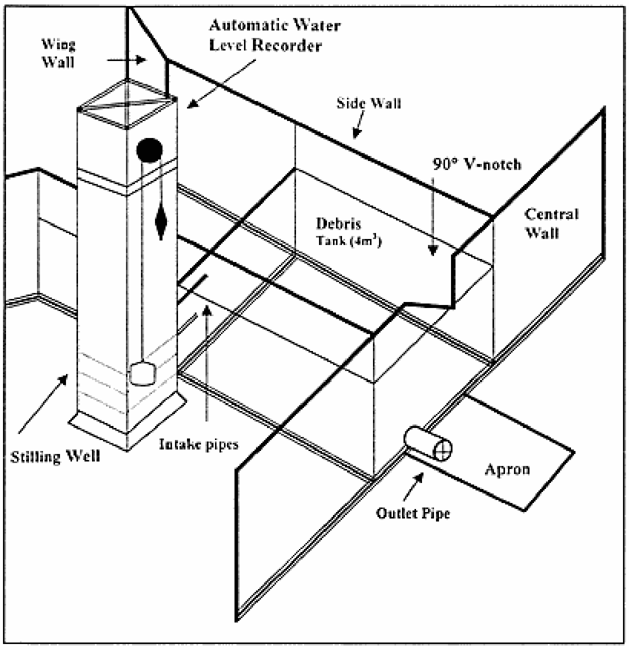

Figure 2: Design of the Gauging Station at the Jhum Cultivated Site in the Soil Conservation and Watershed Management Research Centre, Banderban, Bangladesh.

dried, grounded, sieved through 2 mm sieve and used for laboratory analyses. In this study, out of 174 runoff events only 5 remarkable event samples were analyzed and compared with the in-situ soil. Every 0.2 mm rainfall was recorded by an automatic rain gauge installed at the study site. Peak intensity (I_{max}) was determined from each 0.2 mm rainfall reading and converted to an hourly rate.

Chemical analyses

Soil samples from the soil profiles, topsoils collected before and after burning and runoff sediment samples collected at the gauging station were air-dried and sieved through a 2 mm sieve. Profile samples were analyzed for texture, pH, total C and N, exchangeable base and acidic cations and CEC at pH 7. Topsoils (0-10 cm taken before and after burning) and runoff samples were analyzed for pH, total C and N, exchangeable acidity, Ca, Mg and K and extractable P, S, Cu, Fe, Mn and Zn.

Soil texture was determined by sieving and hydrometer measurement after dispersion in sodium pyrophosphate, pH 10.

Soil pH was determined in a 1:2.5 soil in 0.01 M $CaCl_2$ suspension using Metrohm pH meter with a combination glass electrode.

Total C was determined by a LECO C-200 Carbon analyzer (Tabatabai and Bremmer, 1970).

Exchangeable acidity was measured by extraction with 1 M KCl and titration with 0.02 NaOH (Coleman et al., 1959). Exchangeable bases were extracted by one extraction with 1 M ammonium acetate (NH_4Ac) at pH 7. In the clear extract K and Na were determined by flame emission spectroscopy (FES), while Ca and Mg were determined by atomic absorption spectroscopy (AAS) after adding $LaCl_3$ solution to the extract.

The effective cation exchange capacity (ECEC) was calculated as the sum of NH_4Ac extractable cations and 1 M KCl extractable acidity.

For CEC measurement, the samples were percolated with a solution containing 0.9 M sodium acetate and 0.1 M sodium chloride adjusted to pH 7.0, excess salt was removed by washing with 96% ethanol and subsequently the adsorbed sodium was exchanged by percolating with 1 M NH_4Ac (Van Reeuwijk, 1995). In the percolate, exchanged sodium was quantified by FES.

Total N was determined by the Kjeldahl digestion, distillation and titration with 0.05 M NaOH. Extractable P was determined by the Bray and Kurtz method (Olsen and Dean, 1965). Available S (sulphate) was extracted by calcium phosphate ($Ca(H_2PO_4)_2$) and measured by turbidimetry in the clear extract (Johnson and Fixen, 1990).

Concentrations of Cu, Zn, Mn, and Fe were analyzed by AAS after extracting the soil samples with DTPA (Martens and Lindsay, 1990). All analyses were done in duplicate.

Results and Discussions

Soil characteristics and classification

Morphologically all the soil profiles look alike with similar colours, textures and horizon descriptions. The main difference between the three profiles is the depth to the parent rock. The texture of the soils shows that the A and E horizons are clay loams or sandy clay loams, while the B and C horizons are clays (Table 1). The clay enrichment of the B horizons fulfills the requirements for an argillic horizon. The pH is low in all horizons with a slight decrease from upper to lower soil layer. The somewhat higher pH in the A horizons undoubtedly results from base cation uptake by the vegetation (pumping) and released through burning. The burning is probably also responsible for the rather weak structure in the A horizons, despite their appreciable contents of organic carbon (Table 1). The C/N ratios

Table 1: Texture and chemical composition of the soil samples collected from shifting cultivation in the Chittagong Hill Tracts, Bangladesh.

Horizon/	Clay(%)	Silt(%)	Fine Sand(%)	C.Sand(%)	pH	Total C	Total N	Exchangeable Cation (cmol(+) kg^{-1})					
Depth(cm)	<2μm	2-50μm	50-250μm	>250μ	$CaCl_2$	%	%	Ca	Mg	K	Na	ECEC	CEC(pH 7.0)
Profile 1: Upper part of hill													
A(0-3)	39	29	2	30	5.3	3.30	0.26	9.72	3.16	1.00	0.06	13.94	17.86
E(3-15)	36	30	3	31	4.4	1.46	0.16	3.78	2.25	0.19	0.04	6.29	13.50
Bt(15-45)	50	26	3	22	4.2	1.03	0.13	2.16	2.10	0.16	0.04	4.56	12.20
C(45-75)	42	29	4	25	4.1	0.55	0.09	1.21	0.85	0.13	0.06	2.38	12.92
Profile 2: Middle part of hill													
A(0-4)	36	33	2	29	4.8	2.72	0.22	4.73	2.83	0.86	0.03	8.46	16.14
E(4-16)	38	33	2	27	4.3	1.77	0.17	3.13	1.88	0.40	0.03	5.48	13.15
Bt(16-47)	51	29	2	18	4.1	1.12	0.12	1.67	1.17	0.24	0.05	3.25	12.74
C1(47-75)	49	33	3	14	4.0	0.78	0.11	0.93	0.72	0.18	0.03	2.03	12.53
C2(75-100)	41	41	6	11	4.0	0.56	0.10	0.90	0.84	0.17	0.03	2.13	12.93
Profile 3: Lower part of hill													
A(0-4)	37	36	2	24	4.9	3.32	0.29	5.62	3.30	0.79	0.03	9.74	16.57
E(4-15)	31	45	3	21	4.3	1.47	0.16	3.12	2.06	0.40	0.05	5.67	14.14
Bt(15-33)	50	34	3	13	4.1	1.03	0.14	2.13	1.56	0.24	0.05	4.10	14.51
C(33-55)	49	35	3	13	4.1	0.87	0.13	1.52	1.21	0.20	0.03	3.12	15.75

are about 10, indicating favorable conditions for organic matter mineralization and good availability of released N. The content of exchangeable

(and available) Ca, Mg and K is fairly high especially in the A horizons, while exchangeable Na is low suggesting favorable plant growth conditions. Accordingly, the sum of base cations is seen to almost equal ECEC indicating low amounts of exchangeable Al.

Like pH, the base saturation (the percentage of base cations to CEC at pH 7) is seen to decrease with increasing soil depth leading to a base saturation of less than 50% in the Bt and C horizons. Consequently, the soils will be Ultisols according to the Soil Taxonomy system (Soil Survey Staff, 1997). At the subgroup level they key out as Typic Haplohumults. Allocation into the FAO-Unesco system (FAO-UNESCO, 1990) leads to Alisols as CEC at pH 7 of the Bt clay fraction exceeds 24 cmol(+) kg^{-1} (e.g. 12.20*100/50 = 24.4 cmol(+) kg^{-1} in the upper profile). Moreover, with ochric epipedons the soils are Haplic Alisols at the soil unit level of the FAO-Unesco system. A low Al saturation and hence absence of so-called alic properties, the soils will not be Alisols in the recently launched, WRB system (ISSS-ISRIC-FAO, 1998), but they key out as Luvisols. At the second level they are Endoleptic Luvisols in the WRB system as they have hard rock between 50 and 100 cm from the soil surface.

Effects on nutritional status

Due to strong alkalinity of ashes (Armando et al., 1996), burning increased soil pH significantly at 5% level, whereas in the runoff samples the increase was significant at 1% level (Table 2). Runoff samples have more than one unit higher pH values than the source material. The amount and magnitude of change in soil chemical properties are influenced by the chemical composition of the ash and the mineralogy of the soil. In strongly acidic soils, input of large amounts of alkali and base cations (Ca, Mg, K) from ash can cause significant increase of pH and ECEC. However, as leaching and crop harvest removal take place during the subsequent cropping cycles, the soil will become acidified again because of the loss of the base cations from the soil exchange complex. Such pH reversion may also take place during the fallow phase when a major portion of the exchangeable bases are being taken up by the fallow vegetation (Juo and Manu, 1996).

The content of total carbon and nitrogen decreased significantly after burning which is in agreement with results of many other investigations (Ewel et al., 1981; Andriesse and Schelhaas, 1987; Hölscher et al., 1997; Brand and Pfund, 1998). In an experiment with burning rice straw, Nagarajah and Amarisiri (1977) found that 700° C temperature was reached at the surface and 300-400 C in the centre of the heap, causing losses of 93% of N and 20% of K. With increasing temperatures, C disappears faster than N (Andriesse and Schelhaas, 1987). Brand and Pfund (1998) recorded a loss of 98% C and 95% N through slash-and-burn of a 5-year old fallow.

Remarkable increases in exchangeable base cations after burning were recorded in the study (Table 2). The increases in Ca, Mg and K after burning were equivalent to approximately 234, 55 and 20 kg ha^{-1}, respectively (bulk density = 1.15 ton m^{-3} for the 0-10 cm layer), which is in agreement with the results of Salacedo et al. (1997). Such increases in the base cations are definitely an advantage if the fertility could be retained in the in-situ soils.

An important observation in this study regarding the removal or addition of nutrients following slash-and-burn was, however, that runoff resulted in a lowering of most nutrients which were just increased by fire and ash addition. It became clear when the nutrient stock of the source material (before burning samples) was compared with that after-burning and with runoff samples. Table 2 shows that Ca, Mg and K were 4.31, 2.04 and 0.42 cmol(+) kg^{-1} in the after-burning sample and 7.87, 2.70 and 0.85 cmol(+) kg^{-1} in the runoff samples compared to 3.29, 1.80 and 0.34 cmol(+) kg^{-1} respectively in the source material. This shows that any soil gains of these nutrients from burning are severely reduced by the runoff.

The data indicated that exchangeable acidity, i.e. mainly exchangeable Al, was reduced markedly with the significant increase of all the exchangeable cations (Table 2). The initial decrease of exchangeable Al might have beneficial effect on plant growth. These beneficial effects for crop growth have been well established by Nye and Greenland (1960), Seubert et al. (1977), Stromgaard (1984) and Andriesse and Schelhaas (1987).

The proportion of exchangeable Al to total cations (Al saturation) is considered a better parameter than exchangeable Al concentration to indicate the potential toxicity of Al to plants (Lopes and Cox, 1977). In this study Al saturation was 22% (Ex.Acidity.*100/ECEC) in the source material, which decreased to 16% after burning. This value can be considered suitable for most crops as the critical level of Al saturation is 20-40% for most crops (Marschner, 1995).

Phosphorus is frequently limiting for crop production in tropical upland agroecosystems (Sanchez, 1976). According to Olsen and Dean (1965) a phosphorus content of less than 3 mg kg^{-1} determined by the Bray and Kurtz method is very low. Therefore, as available P is only about 1 mg kg^{-1} (Table 3), the content of available phosphorous in the soils studied is very low and the content becomes even lower after burning. Available phosphorus decreased significantly (25%) after burning, while it showed remarkable increase of about 228% in the runoff samples. Continued losses of phosphorous in runoff water will of course increase the phosphorous deficiency problem of these soils. Available sulphur increased significantly in the after-burn soil (24%) but decreased dramatically in the runoff samples (23%). Due to large variability between samples, this decrease is, however, not significant (Table 3). Although the content increases to 8.1 mg kg^{-1} after burning, available sulphur in these soils is rather low as compared with the critical level of 10 mg kg^{-1} (Johnson and Fixen, 1990).

The extractability, and hence critical level of the micronutrients, copper, iron, manganese and zinc is strongly dependent on the method of extraction (and soil type) but for the DTPA method used, the critical levels can be approximated as follows: 1 mg Cu kg^{-1}, 5 mg Fe kg^{-1}, 0.5 mg Mn kg^{-1} and 0.5 mg Zn kg^{-1} (Martens and Lindsay, 1990). A comparison between these figures and those in Table 3 shows that the Fe and Mn contents of the soil investigated are well above the critical limits, while the Cu and Zn contents are at or close to the critical levels. Continued removal of these micronutrients in runoff water will inevitably induce micronutritional deficiency as the runoff sediment is enriched in these elements (Table 3).

Rainfall and runoff

Runoff and soil loss monitoring started just after the onset of rain, which occurred on 5th May 1999, about 20 days after burning the slashed material. Sowing of seeds was completed on the 5th of June 1999. Before the emergence of the crops, i.e. until 15th June 1999, the area received 707 mm of rain, of which 12% of the rainwater (84 mm) was lost as surface runoff, eroding 2.7 ton ha^{-1} soil from the catchment. Throughout this period the hill slope was bare, being covered by sparsely emerging weeds and new seedlings and was therefore very susceptible to water erosion. This condi-

Table2: *Total C and N, pH and exchangeable cations of the soil material before burning ($n=31$), after burning ($n=31$) and in runoff samples ($n=5$). In parenthesis the numbers are kg ha^{-1} for the top 10 cm soil having a bulk density of 1.15 Mg m^{-3}.*

Parameter/treatment	Depth (cm)	pH	Total C (%)	Total N (%)	Ex.Aci.	Ca	Mg	K	ECEC
							(cmol kg^{-1})		
Before burning (n=31)	0-10	5.16	2.31 (26565)	0.18 (2063)	1.53 (158)	3.29 (757)	1.80 (414)	0.34 (78)	
After burning (n=31)	0-10	5.31	2.19 (25185)	0.16 (1892)	1.25 (129)	4.31 (991)	2.04 (469)	0.42 (98)	8.02
Runoff Sample (n=5)	Composite	6.26	n.m.	n.m.	n.m.	7.87	2.7	0.85	-
Change after burning (% and significance)		*	-5 *	-8 *	-18 *	31 *	13 *	26 *	15 *
Enrichment ratio after burning		1.03	0.95	0.92	0.82	1.31	1.13	1.26	1.15
Change in runoff sediment (% and significance)		**	-	-	-	139 *	50 **	152 *	-
Enrichment ratio in runoff sediment		1.21	-	-	-	2.39	1.50	2.52	-

n.m.: not measured
*: $P < 0.05$; ** $P < 0.01$

Table3: Plant available phosphorus, sulphur and micronutrients of the soil material before burning (n=31), after burning (n=31) and in run-off samples (n=5). In parenthesis the numbers are kg ha^{-1} for the top 10 cm soil having a bulk density of 1.15 Mg m^{-3}.

Parameter/treatment	Depth (cm)	P	S	Cu	Fe	Mn	Zn
		(mg kg^{-1})					
Before burning (*n*=31)	0-10	1.1 (1.3)	6.5 (7.5)	1.08 (1.24)	77 (89)	37 (43)	1.14 (1.31)
After burning (*n*=31)	0-10	0.8 (0.9)	8.1 (9.3)	1.02 (1.17)	93 (107)	49 (56)	1.24 (1.43)
Runoff Sample (*n*=5)	Composite	3.6	5.0	1.35	172	156	1.66
Change after burning (% and significance)		-25 *	24 *	-6. NS	20 ***	31 *	9 *
Enrichment ratio after burning		0,8	1.2	0.9	1.2	1.3	1.1
Change in runoff sediment (% and significance)		228 NS	-23 NS	25 NS	123 *	319 **	46 NS
Enrichment ratio in runoff sediment		3.3	0.8	1.2	2.2	4.2	1.5

NS: non significant; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$

tion prevailed until the crop cover was well established. Until 10th August 1999, out of 2121 mm rainfall, 602 mm or 29% was removed by runoff. Within this period the site experienced 39 ton ha^{-1} soil loss. Although the time period covers only a quarter of a year, more than two thirds of the annual precipitation is received during this period. Therefore, the annual soil loss will not much exceed the measured 39 ton ha^{-1}.

From the analytical results of the runoff samples (Tables 2 and 3) it is clear that the materials washed out from the catchment were richer in almost all plant nutrients than the soil from which they were originally derived. Since 39 ton ha^{-1} of soil material is removed in runoff water by about 2/3 of the annual precipitation, lower limits for the removal of nutrients can be estimated by multiplying the soil loss with the nutrient content of the runoff sediments. Accordingly, the annual losses per ha are at least: 61 kg Ca, 13 kg Mg, 13 kg K, 0.14 kg P, 0.20 kg S, 0.05 kg Cu, 6.7 kg Fe, 6.1 kg Mn and 0.065 kg Zn corresponding to 8% Ca, 3% Mg, 17% K, 11% P, 27% S, 4% Cu, 8% Fe, 14% Mn and 5% Zn of the nutrient content before burning. A comparison between these losses and the gains following burning shown in Tables 2 and 3 suggests that except for Cu and P the increases of the nutrients in the top 10 cm of the soil following burning exceed the runoff losses. On the other hand, the calculated losses are annual minimum values and do not account for losses by runoff and crop removal in the following years before the next burning. In the nearby catchment, having similar landscape under 5 years fallowed Jhum, approximately 10 ton ha^{-1} of nutrient-enriched sediment was removed by runoff during the same time period (Gafur, unpublished results). Moreover, the runoff losses of Cu and P, although small, seem crucial, because the contents of these essential nutrients were very low before burning and decreased even further after burning.

Conclusions

Shifting cultivation as practiced in the Chittagong Hill Tracts of Bangladesh was found to have a serious impact on the plant nutritional status of the soil. The burning caused substantial losses of C, N, P and S from the soil, whereas the content of other plant nutrients (Ca, Mg, K, Fe, Mn and Zn) present as ash components increased. Increased amounts of base cations resulted in pH increase and exchangeable Al decreases after burning. As a result of severe runoff from the bare soil after burning, substantial amounts of the nutrients gained were lost by runoff. Thus, after having received about 2/3 of mean annual precipitation in one year, up to 27% of the nutrient content in the upper 10 cm of soil was lost along with 39 ton ha^{-1} of soil material. The loss of Cu and P by erosion is important as the contents of these nutrients were very low before burning and were even reduced by the burning. Although the short time period of less than one season places limitation on the present investigation, the results indicate that traditional slash-and-burn with a short fallow period may cause severe degradation of the soil in the region.

Acknowledgements

This study has been carried out at the Soil Conservation and Watershed Management Research Center, Banderban, Bangladesh. The authors are grateful to the Ministry of Agriculture and the Director of Soil Resource Development Institute, Government of the People's Republic of Bangladesh for permitting them to conduct the experiment at the research center of SRDI, Banderban. Most of the laboratory analyses were carried out at the Regional Laboratory of SRDI, Comilla. The authors gratefully acknowledge the financial support from DANIDA and SRDI. Thanks are due to the referees for valuable suggestions to an earlier draft.

References

Ahn, P.M. (1974): Some observations on basic and applied research in shifting cultivation. FAO Soils Bull. 24: 123-154.

Andriesse, J.P. and Schelhaas, R.M. (1987): A monitoring study on nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia. III. The effects of land clearing through burning on fertility level. Agric. Ecosyst. Environ. 19: 311-332.

Armando S. N. Lessa., Darwin W. Andersen. and Jackie O. Moir. (1996): Fine root mineralization, soil organic matter and exchangeable cation dynamics in slash and burn agriculture in the semi-arid northeast Brazil. Agric. Ecosyst. Environ. 59: 191-202.

Brand, J. and Pfund, J.L. (1998): Site-and watershed-level assessment of nutrient dynamics under shifting cultivation in eastern Madagascar. Agric. Ecosyst. Environ., 71: 169-183.

Christanty, L. (1986): Shifting cultivation in tropical soils: patterns, problems and possible improvements. 226-240 in: G.G. Marten (Ed.), Traditional Agriculture in Southeast Asia. Westview Press, Boulder, CO, pp.

Coleman, N.T., Weed, S.B. and McCracken, R.J. (1959): Cation-exchange capacity and exchangeable cations in Piedmont soils of North Carolina. Soil Sci. Soc. Am. Proc.23: 146-149.

Crutzen, P.J. and Andreae, M.O. (1990): Biomass burning in the tropics: impact on atmospheric chemistry and biogeochemical cycles. Science, 250: 1669-1678.

Denevan, W.M.(1981): Swiddens and cattle versus forest: the imminent demise of the Amazon rain forest reexamined. Pp 25-44 in: V.J. Sultive, N. Altshuler and M. D. Zamora (Ed.): Where Have All the Flowers Gone? Deforestation in the Third World,Studies in Third World Soci eties. Collage of William and Mary, Williamburg, VA.

Dove, M.R. (1985): Swidden Agriculture in Indonesia: The Subsistence Strategies of the Kalimantan Kantu. Mouton, Berlin.

Dunn, P.H., De Bano, L.F. and Eberlein, G.E. (1979) Effects of burning on chaparral soils.II. Soil microbes and nitrogen mineralization. Soil Sci. Soc. Am. J. 43: 509-514.

Ewel, J., Berish, C., Brown, B., Prince, N. and Raich, J.(1981): Slash-and-burn impact on a Costa Rican wet forest site. Ecology 62: 816-829.

FAO (1982): Conservation and Development of Tropical Forest Resources. FAO Forestry Paper, 37. FAO, Rome.

FAO (1990): Guidelines for Soil Description. Food and Agriculture Organization of the United Nations, Rome.

FAO-UNESCO (1990): Soil Map of the World, Revised Legend. World Soil Resources Report 60, FAO, Rome.

Hillel, D., (1992): Out of the Earth: Civilization and the Life on the Soil. University of California Press, Berkeley, CA.

Hölscher D., Ludwig B., Moller R. F. and Folster H. (1997): Dynamic of soil chemical parameters in shifting agriculture in Eastern Amazon. Agric. Ecosyst. Environ. 66: 153-163.

ICIMOD (1998): Inherent Parent Materials of NHK Soils, Newsletter no. 32. p: 3.

ISSS-ISRIC-FAO (1998): World Reference Base for Soil Resources. (Deckers, O.C. Nachtergaele, Oldeman L.R. and Brinkman R., J.A., (Eds.)). World Soi Resources Report 84 International Society of Soil Science (ISSS),International Soil Reference and Information Centre (ISRIC) and Food and Agricultural Organization of the United Nations,Rome.

Johnson, G.V. and Fixen, P.E. (1990): Testing soils sulfur, boron, molybdenum, and chlorine. In: Soil Testing and Plant Analysis (Ed. Westerman, R.L.). 3rd Edition. Soil Science Society of America, Madison, .

Juo, A.S.R. and Manu, A. (1996): Chemical dynamics in slash-and-burn agriculture. Agric. Ecosyst. Environ. 58: 49-60.

Kidd, C.V. and Pimental, D. (Eds.), (1992): Integrated Resource Management: Agroforestry for Development. Academic Press, San Diego.

Lal, R. (1987): Tropical Ecology and Physical Edaphology. Willey, Chiechester.

Lopes, A.S. and Cox, F.R. (1977): A suvey of the fertility status of surface soils under 'cerrado' vegetation in Brazil. Soil Sci. Soc. Am. Proc. 4: 742-747.

Marschner, H. (1995): Mineral Nutrients of Higher Plants. Academic Press, London.

Martens, D.C. and Lindsay, W.L. (1990): Testing soils for copper, iron, manganese, and zinc. Pp. 229-264 in: Westerman, R.L.(Ed.), Soil Testing and Plant Analysis 3rd Edition, Soil Science Society of America, Madison.

Myers, N. (1980): Conversion of tropical Moist Forests. National Academy of Sciences, Washington, DC.

Nagarajah, S. and Amarisiri, S.L. (1977): Use of organic materials as fertilizers for lowland rice in Sri Lanka. 97-104 in: Organic Matter Studies. Proc. Symp. Braunschweig, 1976. International Atomic Energy Agency, Vienna.

Nye, P.H. and Greenland, D.J. (1960): The soil under shifting cultivation. Technical Communication 51, Commonwealth Bureau of Soils, Harpenden, UK.

Okigbo, B.N. (1984): Shifting cultivation in tropical Africa: definition and description. Pp. 18-36 in: A.H. Bunting and E. Bunting (Eds.): The Future of Shifting Cultivation in Africa and the Task of Universities, Proc. Int. Workshop on Shifting Cultivation: Teaching and Research at the University Level. Ibadan, Nigeria. FAO, Rome.

Olsen, S.R. and Dean, L.A. (1965): Phosphorus. Pp. 1035-10901 in: Black, C.A., (Eds.). Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties. American Society of Agronomy, Madison.

Pimentel, D. and Heichel, G.H. (1991): Energy efficiency and sustainability of farming systems. Pp.113-123 in: R. Lal and F.J. Pierce (Eds.), Soil Management for Sustainability. Soil and Water Conservation Society, Ankeny, IA.

Reconnaissance Soil Survey (RSS) Report on Chittagong Hill Tracts (1975): SRDI Staff, Dhaka, Bangladesh.

Salacedo, I.H., Tiessen, H. and Sampaio, E.V.S.B. (1997): Nutrient availability in soil samples from shifting cultivation sites in the semi-arid Caatinga of NE Brazil. Agric. Ecosyst. Environ. 65: 177-186.

Sanchez, P.A. (1976): Properties and management of soils in the tropics. John Wiley and Sons, New York.

Sanchez, P.A., Villachica, J.H. and Bandy, D.E. (1983): Soil fertility and dynamics after clearing a tropical rainforest in Peru. Soil Sci. Soc. Am. J. 47: 1171-1178.

Seubert, C.E., Sanchez, P.A., and Valverde, C. (1977): Effect of land clearing on crop performance in an Ultisol of the Amazon Jungle of Peru. Trop. Agric. (Trinidad), 54: 307-321.

Soil Survey Staff (1997): Keys to Soil Taxonomy. 7th Edition, Pocahontas Press, Blackburg.

Stromgaard, P. (1984): The immediate effect of burning and ash-fertilization. Plant Soil, 80: 307-320.

Tabatabai, M.A. and Bremmer, J.M. (1970): Use of the Leco automatic carbon analyzer for total carbon analysis of soils. Soil Sci. Soc. Am. Proc. 34: 608-610.

Van Reeuwijk, L.P. (Ed.), (1995): Cation Exchange Ca pacity. Pp 9,1- 9,8 in: Procedures of Soil Analyses, Fifth Edition. International Soil Reference and Information Centre, Wageningen, The Netherlands.

Van Wambeke, A.(1992): Soils of the Tropics: Properties and Appraisal. McGraw-Hill, New York.

Weischet, W., Caviedes, C. N. (1993): The persisting Ecological Constraints of Tropical Agriculture. Longman, Essex.

Young, A. (1989): Agroforestry for Soil Conservation. International Council for Research in Agroforestry and CAN International, Wallingford, UK.

Zinke, P.J., Sabhasri, S. and Kunstadter, P. (1978): Soil fertility aspects of the Lua' fallow system of shifting cultivation. Pp. 134-159 in: P. Kunstadter, E.C. Chapman and S. Savhasri (Eds.): Farmers in the forest: Economic Development and Marginal Agriculture in Northern Thailand. East-West Center, Honolulu.

Table3: Plant available phosphorus, sulphur and micronutrients of the soil material before burning (n=31), after burning (n=31) and in runoff samples (n=5). In parenthesis the numbers are kg ha^{-1} for the top 10 cm soil having a bulk density of 1.15 Mg m^{-3}.

Parameter/treatment	Depth (cm)	P	S	Cu	Fe	Mn	Zn
		(mg kg^{-1})					
Before burning (*n*=31)	0-10	1.1 (1.3)	6.5 (7.5)	1.08 (1.24)	77 (89)	37 (43)	1.14 (1.31)
After burning (*n*=31)	0-10	0.8 (0.9)	8.1 (9.3)	1.02 (1.17)	93 (107)	49 (56)	1.24 (1.43)
Runoff Sample (*n*=5)	Composite	3.6	5.0	1.35	172	156	1.66
Change after burning (% and significance)		-25 *	24 *	-6. NS	20 ***	31 *	9 *
Enrichment ratio after burning		0,8	1.2	0.9	1.2	1.3	1.1
Change in runoff sediment (% and significance)		228 NS	-23 NS	25 NS	123 *	319 **	46 NS
Enrichment ratio in runoff sediment		3.3	0.8	1.2	2.2	4.2	1.5

NS: non significant; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$

tion prevailed until the crop cover was well established. Until 10th August 1999, out of 2121 mm rainfall, 602 mm or 29% was removed by runoff. Within this period the site experienced 39 ton ha^{-1} soil loss. Although the time period covers only a quarter of a year, more than two thirds of the annual precipitation is received during this period. Therefore, the annual soil loss will not much exceed the measured 39 ton ha^{-1}.

From the analytical results of the runoff samples (Tables 2 and 3) it is clear that the materials washed out from the catchment were richer in almost all plant nutrients than the soil from which they were originally derived. Since 39 ton ha^{-1} of soil material is removed in runoff water by about 2/3 of the annual precipitation, lower limits for the removal of nutrients can be estimated by multiplying the soil loss with the nutrient content of the runoff sediments. Accordingly, the annual losses per ha are at least: 61 kg Ca, 13 kg Mg, 13 kg K, 0.14 kg P, 0.20 kg S, 0.05 kg Cu, 6.7 kg Fe, 6.1 kg Mn and 0.065 kg Zn corresponding to 8% Ca, 3% Mg, 17% K, 11% P, 27% S, 4% Cu, 8% Fe, 14% Mn and 5% Zn of the nutrient content before burning. A comparison between these losses and the gains following burning shown in Tables 2 and 3 suggests that except for Cu and P the increases of the nutrients in the top 10 cm of the soil following burning exceed the runoff losses. On the other hand, the calculated losses are annual minimum values and do not account for losses by runoff and crop removal in the following years before the next burning. In the nearby catchment, having similar landscape under 5 years fallowed Jhum, approximately 10 ton ha^{-1} of nutrient-enriched sediment was removed by runoff during the same time period (Gafur, unpublished results). Moreover, the runoff losses of Cu and P, although small, seem crucial, because the contents of these essential nutrients were very low before burning and decreased even further after burning.

Conclusions

Shifting cultivation as practiced in the Chittagong Hill Tracts of Bangladesh was found to have a serious impact on the plant nutritional status of the soil. The burning caused substantial losses of C, N, P and S from the soil, whereas the content of other plant nutrients (Ca, Mg, K, Fe, Mn and Zn) present as ash components increased. Increased amounts of base cations resulted in pH increase and exchangeable Al decreases after burning. As a result of severe runoff from the bare soil after burning, substantial amounts of the nutrients gained were lost by runoff. Thus, after having received about 2/3 of mean annual precipitation in one year, up to 27% of the nutrient content in the upper 10 cm of soil was lost along with 39 ton ha^{-1} of soil material. The loss of Cu and P by erosion is important as the contents of these nutrients were very low before burning and were even reduced by the burning. Although the short time period of less than one season places limitation on the present investigation, the results indicate that traditional slash-and-burn with a short fallow period may cause severe degradation of the soil in the region.

Acknowledgements

This study has been carried out at the Soil Conservation and Watershed Management Research Center, Banderban, Bangladesh. The authors are grateful to the Ministry of Agriculture and the Director of Soil Resource Development Institute, Government of the People's Republic of Bangladesh for permitting them to conduct the experiment at the research center of SRDI, Banderban. Most of the laboratory analyses were carried out at the Regional Laboratory of SRDI, Comilla. The authors gratefully acknowledge the financial support from DANIDA and SRDI. Thanks are due to the referees for valuable suggestions to an earlier draft.

References

Ahn, P.M. (1974): Some observations on basic and applied research in shifting cultivation. FAO Soils Bull. 24: 123-154.

Andriesse, J.P. and Schelhaas, R.M. (1987): A monitoring study on nutrient cycles in soils used for shifting cultivation under various climatic conditions in tropical Asia. III. The effects of land clearing through burning on fertility level. Agric. Ecosyst. Environ. 19: 311-332.

Armando S. N. Lessa., Darwin W. Andersen. and Jackie O. Moir. (1996): Fine root mineralization, soil organic matter and exchangeable cation dynamics in slash and burn agriculture in the semi-arid northeast Brazil. Agric. Ecosyst. Environ. 59: 191-202.

Brand, J. and Pfund, J.L. (1998): Site-and watershed-level assessment of nutrient dynamics under shifting cultivation in eastern Madagascar. Agric. Ecosyst. Environ., 71: 169-183.

Christanty, L. (1986): Shifting cultivation in tropical soils: patterns, problems and possible improvements. 226-240 in: G.G. Marten (Ed.), Traditional Agriculture in Southeast Asia. Westview Press, Boulder, CO, pp.

Coleman, N.T., Weed, S.B. and McCracken, R.J. (1959): Cation-exchange capacity and exchangeable cations in Piedmont soils of North Carolina. Soil Sci. Soc. Am. Proc.23: 146-149.

Crutzen, P.J. and Andreae, M.O. (1990): Biomass burning in the tropics: impact on atmospheric chemistry and biogeochemical cycles. Science, 250: 1669-1678.

Denevan, W.M.(1981): Swiddens and cattle versus forest: the imminent demise of the Amazon rain forest reexamined. Pp 25-44 in: V.J. Sultive, N. Altshuler and M. D. Zamora (Ed.): Where Have All the Flowers Gone? Deforestation in the Third World,Studies in Third World Soci eties. Collage of William and Mary, Williamburg, VA.

Dove, M.R. (1985): Swidden Agriculture in Indonesia: The Subsistence Strategies of the Kalimantan Kantu. Mouton, Berlin.

Dunn, P.H., De Bano, L.F. and Eberlein, G.E. (1979) Effects of burning on chaparral soils.II. Soil microbes and nitrogen mineralization. Soil Sci. Soc. Am. J. 43: 509-514.

Ewel, J., Berish, C., Brown, B., Prince, N. and Raich, J.(1981): Slash-and-burn impact on a Costa Rican wet forest site. Ecology 62: 816-829.

FAO (1982): Conservation and Development of Tropical Forest Resources. FAO Forestry Paper, 37. FAO, Rome.

FAO (1990): Guidelines for Soil Description. Food and Agriculture Organization of the United Nations, Rome.

FAO-UNESCO (1990): Soil Map of the World, Revised Legend. World Soil Resources Report 60, FAO, Rome.

Hillel, D., (1992): Out of the Earth: Civilization and the Life on the Soil. University of California Press, Berkeley, CA.

Hölscher D., Ludwig B., Moller R. F. and Folster H. (1997): Dynamic of soil chemical parameters in shifting agriculture in Eastern Amazon. Agric. Ecosyst. Environ. 66: 153-163.

ICIMOD (1998): Inherent Parent Materials of NHK Soils, Newsletter no. 32. p: 3.

ISSS-ISRIC-FAO (1998): World Reference Base for Soil Resources. (Deckers, O.C. Nachtergaele, Oldeman L.R. and Brinkman R., J.A., (Eds.)). World Soi Resources Report 84 International Society of Soil Science (ISSS),International Soil Reference and Information Centre (ISRIC) and Food and Agricultural Organization of the United Nations,Rome.

Johnson, G.V. and Fixen, P.E. (1990): Testing soils sulfur, boron, molybdenum, and chlorine. In: Soil Testing and Plant Analysis (Ed. Westerman, R.L.). 3rd Edition. Soil Science Society of America, Madison, .

Juo, A.S.R. and Manu, A. (1996): Chemical dynamics in slash-and-burn agriculture. Agric. Ecosyst. Environ. 58: 49-60.

Kidd, C.V. and Pimental, D. (Eds.), (1992): Integrated Resource Management: Agroforestry for Development. Academic Press, San Diego.

Lal, R. (1987): Tropical Ecology and Physical Edaphology. Willey, Chiechester.

Lopes, A.S. and Cox, F.R. (1977): A suvey of the fertility status of surface soils under 'cerrado' vegetation in Brazil. Soil Sci. Soc. Am. Proc. 4: 742-747.

Marschner, H. (1995): Mineral Nutrients of Higher Plants. Academic Press, London.

Martens, D.C. and Lindsay, W.L. (1990): Testing soils for copper, iron, manganese, and zinc. Pp. 229-264 in: Westerman, R.L.(Ed.), Soil Testing and Plant Analysis 3rd Edition, Soil Science Society of America, Madison.

Myers, N. (1980): Conversion of tropical Moist Forests. National Academy of Sciences, Washington, DC.

Nagarajah, S. and Amarisiri, S.L. (1977): Use of organic