CHARACTERIZATION OF SOIL HEALTH UNDER DIFFERENT LAND USE PATTERN IN HILLY ECO-SYSTEM OF MEGHALAYA

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INTRODUCTION

The north-eastern hilly region of India is characterized by heavy soil erosion, loss of soil fertility and deforestation causing acute environmental degradation and severe ecological imbalance (Sachchidananda, 1989). Shifting cultivation or Slash & Burn agriculture, locally known as Jhum cultivation, is the main form of agriculture in this region. Shifting cultivation in its more traditional and cultural integrated form, is an ecological and economically viable system of agriculture as long as population densities are low and jhum cycles are long enough to maintain soil fertility (Anon, 1992). However, with changing requirements of high population pressure on land, jhum cultivation becomes very devastating in nature causing drastic decline in crop yield, loss of forest wealth, soil fertility, biodiversity and environmental degradation. In north-east India, the average annual loss of top soil, organic carbon, P_2O_5 and K_2O due to shifting cultivation were to the extent of 40900, 702.9, 0.15 and 7.5 kg per ha, respectively (ICAR, 1983). Due to shortening of jhum cycle, quite often, the secondary forests also do not get adequate time to regenerate. The repeated use of land with short jhum cycle finally converts the jhum fallows into degraded wastelands. The prevailing land tenure and ownership pattern has been viewed as the most important factor for replacing shifting cultivation in north-east. Jhum has been the way of life and integral component of the cultural ethos of the people in the north-east since time immemorial. Considering all these factors, it has never been easy to develop a viable and widely acceptable land use model that can replace shifting cultivation. However, there is an urgent need to develop alternative land use model for shifting cultivation and analyze the soil characteristics to overcome the problems of ecological imbalance for sustainable crop production.

STUDY AREA

The study area is located at Umiam in the central part of Meghalaya in *East Khasi* Hills with 25°41′21″ North latitude and 91°55′25″ East longitude and at 1080 m above the mean sea level. The climate of this region is very typical because of its steep topography and undulating physiographic condition. Maximum and minimum temperatures of this area normally ranges from 20.9 to 27.4° C and 6.7 to 18.1° C, respectively. The mean annual rainfall of this region is 2439 mm with coefficient of variation of 15.96%. About 76% of the total rainfall occurs during June to October. Mean annual evaporation from the soil is about 1099 mm. The relative humidity remains between 75 to 83% during most of the periods and the evaporation rate during March-April ranges between 4.1 and 9.0 mm day^{-1} . The soil of the area belongs to *Typic Hapludalf* and is highly acidic in reaction.

Land Use Pattern

Agriculture in north eastern hilly region is mainly of primitive type and thus agriculturally this area is far behind in development. There are various traditional agricultural systems, which are very common in sloppy and valley lands. Some of the traditional systems are:

Shifting cultivation

Shifting cultivation in this region is regarded to be the first step in the transition from food gathering or haunting to food production and believed to have originated in the Neolithic period around 7000 B.C. (Sharma, 1976). Agriculture under this system is practiced in steep slopes after removing the forest vegetation and thus is susceptible to excessive soil erosion. Besides this, washing of fertile topsoil and exposure of rocks due to soil wash as a result of shifting cultivation have been reported from Garo Hills (Goswami, 1968). Land to be brought under shifting cultivation is selected during December/January and then it is cleared by way of cutting the forest vegetation, allowing it to dry in the field, setting on fire to the dried vegetation in March/April and clearing the slope from remaining trash. All kinds of essential crops like rice, maize, tapioca, colocasia, beans, etc., are planted in intimate mixture during first year and in the second year usually rice is grown as a single crop. The lands are abandoned after 2 to 3 years of cultivation for natural build up of soil fertility and regeneration of vegetation. The farmers then select fresh site and repeat the same process of cultivation.

Bun method of cultivation

Cultivation of tuber crops and vegetables on series of beds formed on slopes is widely practiced in this region. The system locally known as 'BUN' method of cultivation, involves putting of dried vegetation mainly Khasi pine *(Pinus kesiya)* along with existing weeds like *Sataria gluaca, Imperata cylindrical, Lantana camara* in the form of raised beds along with slope, covering the same with soil collected from surrounding, burning of the covered vegetation and planting of tuber crops. When sufficient dried vegetation is not available, the beds are made of soil only. Though good crop yield is obtained, the system leads to huge soil loss.

Cultivation on slopes with contour bunds

Contour bunds as soil conservation measure are widely used on slopes for growing crops where farmers have tried to develop settled agriculture. Though the main idea of this particular measure is to convert the slopes into level benches in due course of time but the purpose is hardly served. Heavy soil losses are reported in this system due to lack of maintenance.

Table 1. Description of various land use system.

Land Use System	Crops/Trees grown	Soil and water conservation measures	Major land capability classes	Soil texture	Average slope (%)	Area (ha)
Livestock based fodder agriculture	*Stylosanthes sp, Setaria sp.* *Pennisetum purpureum* *Panicum maximum* *Avena sativa etc.*	Contour bunds + bench terraces + grassed waterways	V II_e	C1	32.0	1.39
Food agriculture	*Zea mays.L, Glycine max. L,* *Oryza sativa. L,,Marihot esculenta. C* *Colocasia esculenta. L* *Pisum sativum, Brassica juncea. etc.*	Contour bunds + bench terraces + grassed waterways	V II_e	C1	32.4	0.64

Agroforestry	*Alnus nepalenesis, Parkis roxburghii* *Gmelina arborea, Micheliaoblonga* + agricultural crops	No conservation measures	V II_e	C1	32.18	2.94
Natural forest	*Pinus kesiya, Thysanolaena agrostis* *Seasonal weeds like,* *Setaria gluaca,Lantana camara* *Imperata cylindrical*	No conservation measures	V II_e	C1	45.9	1.03
Shifting cultivation	*Zingiber officinails, Curcuma longa,* *Colocasia esculenta.L* *Zeya mays.L, Oryza sativa.L*	No conservation measures	V II_e	C1	38.2	1.65

Modified agriculture system

A brief description about the various farming systems was given in Table 1. The different agro-forestry systems (AFS) were *Arboretum* (mixed multipurpose tree species) + annual agricultural crops; Khasi mandarin *(Citrus reticulate* Blanco.) + annual agricultural crops; Assam lemon *(Citrus lemon* L.) + annual agricultural crops; Silvi-horti-pastoral [alder *(Alnus nepalensis*) + pineapple *(Ananus squennsa* L.) + fodder grasses] and multistoried AFS [alder + tea *(Camellia sinensis*) + black pepper + annual agricultural crops]. The tree species in *arboretum* system included *Alnus nepalensis, Parkia roxburghii, Prunus cerasoides, Michelia oblonga, Gmelina arborea, Cryptomeria japonica, Symingtonia populnea* and *Pinus kesiya*. The fodder species in the Silvi-horti-pastoral system were stylo *(Stylosanthes guyanensis*), guinea *(Panicum maxicum*), setaria *(Setaria sphacelata*) and local grass *(Imperata cylindrical*). Annual agricultural crops grown in different systems were turmeric *(Curcuma longa* L.), colocasia [*Colocasia esculenta* (L.) Schott.], paddy *(Oryza sativa* L.), ginger *(Zingiber officinale* Rosc.), maize *(Zea mays* L.), soybean [*Glycine max* (L.) Merr.], groundnut *(Arachis hypogaea* L.) *etc.* Natural forest is mainly dominated by *Pinus kesiya* along with *Schima wallichii, Lagerstroemia speciosa* and *Bambusa pallida*.

Table 2. Effect of land use factors on soil physico-chemical properties.

Soil properties	Reserve forest	Land use factor (L)*			
		Phase I (>10)	Phase II (5-10)	Phase III (2-5)	Phase IV (<2)
Sand (%)	42.50	44.75	46.90	51.65	61.15
Silt (%)	33.45	34.10	33.50	31.15	23.50
Clay (%)	24.05	21.15	19.60	16.70	15.35
B.D (Mg m^{-3})	0.98	1.15	1.11	1.13	1.20
pH	4.55	4.85	4.80	5.10	5.00
Organic C (%)	3.32	2.33	2.09	1.42	1.18
Available N (Kg ha^{-1})	478.50	447.00	425.00	342.50	300.00
Available K (Kg ha^{-1})	11.85	9.80	8.30	6.00	5.50
Available P (Kg ha^{-1})	301.50	283.50	259.00	184.5	171.50

MWD (mm)	3.75	3.24	2.85	1.52	1.11
Dispersion ratio	0.112	0.172	0.182	0.224	0.282
Macro aggregates (>0.25mm)	74.24	65.65	61.44	48.38	36.26
Macro aggregates (<0.25mm)	3.62	5.25	7.62	10.43	14.67

*L=(C+F)/C, Where L=Land use factor, C=cropping period and F=Fallow period, in years.

Soil Physico-chemical behaviour under shifting cultivation

In general, shifting cultivation practices deteriorate the soil fertility due to huge soil loss of about 2-200 t ha^{-1} yr^{-1} (Singh and Singh, 1978). A minimum period of 10 to 15 years is very much essential to maintain the soil fertility for sustainable crop production (Singh *et al.*, 2003). According to them, C & N in the soil may be among the most limiting factors for plant growth after a forest is cut and then burned. Mishra *et al.* (2003) reported that only fallow periods under shifting cultivation is not enough for consideration of the restoration capacity of soil. The proper ratio of cropping and fallow should be considered for sustainable *Jhum* cultivation. In this regard, they found that the bulk density was also affected by *jhum* cycle and showed maximum value of 1.27 Mg m^{-3} in phase IV (1:1) among the various phases of jhum cycle (Table 2). This could be ascribed as more soil erosion and disintegration of soil particles as a result of very narrow ratio of cropping and fallow period under phase IV. On the other hand, the corresponding values were restored gradually in the soil of phase III (1:3), II (1:5) and I (1:10) due to the recycling of more biomass under wider ratio of cropping and fallow periods. Mean weight diameter (MWD) also decreased from 3.75 mm in reserve forest to 1.11 mm in phase IV soil and the micro and macro aggregates ranged from 3.62 to 14.67 and 36.26 to 74.24%, respectively. The data (Table 2) on the erodibility factors showed that land use factor of <5 as in phase IV and III had higher values of 0.31 and 0.28, respectively, against the lower value (0.03) under reserve forest. Poor build up and deterioration in soil health was observed in phase III (2-5 land use factor). Therefore, a minimum 1:4 years of cropping and fallow periods, respectively could be suitable cycle under *jhum* cultivation for resilience of soil in this agro-climatic region.

Nutrient status after burning under Bun system

Bun farming is a form of shifting cultivation. Burning of grasses during Bun cultivation caused an increase in pH and exchangeable bases whereas organic carbon and exchangeable A1 content reduced. Increase in pH was the result of an increase in bases (Ca, Mg and K) after burning of biomass and subsequent enrichment of these bases (Venkatesh *et al.,* 2001). Organic carbon content in soils drastically reduced as a result of burning by rapid loss of organic matter due to oxidation of un-humified materials. Nye and Greenland (1964) also reported rapid loss of organic matter in the first year of shifting cultivation cycle in Tripura soils. Available N, P, K and S in the soil were also increased due to burning during the first year. Available Fe, Zn and Cu decreased by 16.4, 35.4 and 15.2 %, respectively, due to burning in bun cultivation (Table 3). This might be due to increase in soil pH after burning and possibly increased adsorption of late two cations by A1, Fe and Mn oxides. The increase in Mn content to more than four fold on burning may be attributed by conversion of Mn_2O_3 to MnO. Considering the critical limits of 4.5, 2, 0.6 and 0.2 mg kg^{-1} for available Fe, Mn, Zn and Cu, respectively, all the soils were adequate in micronutrients (Venkatesh *et al.*, 2003). The bun system also helps in maintaining aerobic condition in root zone area. Probably this is the reason that the systems are very popular during rainy season and mostly vegetables, potato, ginger and turmeric are cultivated by this method of cultivation.

Table 3. Effect of burning under Bun cultivation on soil physico-chemical properties.

Land Use System	Slope portion	pH (1:2)	Org. C (g/kg)	Available nutrients(Kg/ha)				Available micronutrients (mg/kg)			
				N	P	K	S	Fe	Mn	Zn	Cu
Bun 1st	Top	4.6	21.7	413.95	6.85	213.40	12.12	21.7	7.4	1.02	0.85

year (before burning	Middle	4.6	23.9	472.92	9.38	272.40	13.75	27.6	4.8	1.00	0.65
	Bottom	4.9	25.6	542.16	16.52	373.75	16.00	19.3	5.5	0.86	0.55
Bun 1st year (before burning	Top	5.0	16.9	794.69	22.08	392.12	21.50	21.1	26.0	0.68	0.46
	Middle	5.1	21.9	808.33	29.13	487.50	30.27	23.4	25.4	0.55	0.85
	Bottom	5.7	20.0	846.47	39.80	706.80	28.75	12.9	25.3	0.63	0.47
Bun 2nd year	Top	4.8	24.5	394.00	8.28	261.70	7.62	21.4	12.9	0.84	0.63
	Middle	4.5	26.8	430.14	8.06	291.20	9.37	20.0	7.6	0.64	0.61
	Bottom	5.1	24.5	445.40	16.36	336.80	12.50	20.7	7.8	0.81	0.59
Bun 3rd year	Top	4.6	24.1	437.79	8.28	162.65	9.62	32.0	9.9	0.82	0.89
	Middle	4.7	26.3	467.62	10.22	176.60	10.06	20.0	8.0	0.87	0.59
	Bottom	4.8	24.4	478.67	16.15	194.80	15.62	27.2	4.9	0.82	0.47

Impact of integrated farming systems on soil productivity

The alternative systems (Integrated farming systems) to shifting cultivation were developed in ICAR Research Complex in 1983. After almost 17 years, the soil pH decreased in most of the farming systems except in agriculture, agri-horti-silvi-pastoral systems, maximum decrease being in forestry and shifting cultivation (Table 4). The organic carbon enrichment under shifting cultivation might be due to continuous growth of broom grass (pasture). Maximum accumulation of exchangeable Ca^{2+} was noted under agriculture system. Exchangable Mg^{2+} showed a decreasing trend in all the systems except in agriculture, agri-horti-silvi-pastoral and livestock based farming systems. Highest accumulation of exchangeable K in agri-horti-silvi-pastoral system may be attributed by the nature of species and variation in the quantity of fertilizer inputs. There was substantial build up of available N in soils under all the systems. The rise in available P in agriculture, livestock based system could be due to heavy and continuous dressing of cowdung litter for long period. Available K increased in all the systems except in livestock based farming system. The overall fertility build up followed the trend as agriculture > agri-horti-silvi-pastoral > livestock based farming system (Majumdar *et al.*, 2002). These results are supported by the findings of Singh et al. (2003). However, Das *et al.* (1997) recommended that livestock based or horticulture farming systems could be the alternative to shifting cultivation on sloppy land under mid to low altitude condition in Meghalaya. According to them, horticulture system ameliorated acid Alfisols by reducing the A1- toxicity followed by livestock based farming system, while organic matter build up was highest by the livestock based system (1.63%) followed by agro-forestry system (1.6%).

Table 4. Effect of different farming system on soil properties and available nutrients status of soil.

Soil properties	Livestock based system	Forestry system	Agriculture system	Agri-horti-silvi-Pastoral system	Shifting cultivation
pH (1:2.5)	4.65(4.90)	4.41(4.90)	5.03(4.90)	4.92(4.90)	4.76(5.20)
Organic Carbon(%)	2.70(1.71)	2.87(1.62)	2.66(1.60)	2.97(18.2)	3.42(1.90)
Exch. K [cmol(p+)/kg]	0.248(0.18)	0.274(0.18)	0.359(0.15)	0.417(0.19)	0.326(0.19)
Exch. Ca [cmol(p+)/kg]	1.68(1.18)	0.59(0.90)	3.61(1.10)	2.11(1.20)	1.57(1.16)
Exch. Mg [cmol(p+)/kg]	0.65(0.47)	0.30(0.50)	2.29(1.80)	1.45(1.20)	0.38(1.16)
Exch. Al	1.25	1.53	0.46	0.90	1.30

[cmol(p+)/kg]					
Available N (ppm)	221.1	253.8	233.3	220.3	251.1
Available P (ppm)	18.3	5.1	19.5	16.6	2.0
Available K (ppm)	97.1	109.5	135.1	162.7	130.8
Available S (ppm)	6.2	9.3	15.5	19.9	14.8

Figures in parenthesis indicate the initial values at the start of the project.

Soil hydro-physical behaviour and erodibility index under different models of agro-forestry

Different agro-forestry systems were developed here to find out the alternative systems of shifting cultivation. A general increase in bulk density values was observed with soil depth in all the agro-forestry systems, ranging from 0.94 to 1.19 Mgm^{-3} (Table 5). The decrease in bulk density in natural forest, multistoried AFS and silvi-horti-pastoral systems can be related to the effect of relatively high organic carbon content (1.23 to 2.70%) due to heavy litter fall and their subsequent decomposition in the soil profile. Mean weight diameter (MWD) remained higher in the surface soils in all the systems probably due to the presence of high amount of A1 and Fe oxides, organic carbon and clay content in the soil. The macro aggregates decreased and micro aggregates increased with soil depth owing to higher percentage of organic matter content in surface soil. The lower values of soil aggregates under Khasi mandarin, Assam lemon and arboretum systems could be ascribed as more disintegration of soil structure due to different agricultural operations in comparison to natural forest, multistoried AFS and silvi-horti-pastoral systems, maintaining intensive vegetative cover throughout the year. Higher values of dispersion ratio were noted under Khasi mandarin system (0.048) as compared to that in natural forest (0.025). The volume of residual pores (<0.5 µm) was maximum in natural forest (57.93%) followed by multistoried AFS (52.87%), indicating it's higher capacity to retain soil moisture. The maximum reduction in transmission pores under Khasi mandarin system (16.12%) by 46% as compared to natural forest (30.12), indicated the downward movement of water is restricted, facilitating run-off. This might be due to disintegration of soil aggregates by various tillage practices for annual agricultural crop production. Soil biota influence soil properties through formation of stable aggregates, development of organo-mineral complexes by improving macroporosity and continuity of pores from surface to the subsoil, increase the water transmission and reduce run-off (Lal and Hawksworth, 1991). The low erosion ratio values in silvi-horti-pastoral and multistoried AFS (3.07 and 3.06, respectively) showed that these systems were most suitable for soil and water conservation in hilly ecosystem. This could be ascribed as the effect of heavy litter fall, which might have increased the cohesiveness in the soil system after decomposition and also binds the soil tightly in lower horizons by their deep root systems. Available water content in different systems varied marginally throughout the soil profile. Multistoried AFS (25.30%) and silvi-horti-pastoral (24.23%) systems had the slightly lower values of available water in relation to natural forest (26.94%). Significant variation in available water capacity may be attributed to the differences in quantity, nature of colloidal materials present, pH and pore size distribution among the various systems. Data on saturated hydraulic conductivity values (Table 6) revealed that there was almost 5 folds reduction in Ksa values under Khasi mandarin system (0.38 $X10^{-4}$ ms^{-1}) as compared to that of natural forest (1.84 $X10^{-4}$ ms^{-1}), might be due to high disintegration of aggregate. Irrespective of soil characteristics, the rate of unsaturated hydraulic conductivity, K(θ), and water diffusivity, D(θ), invariably decreased with decrease in their water content. (Saha *et al.*, 2003).

Table 5. Effect of various agro-forestry systems on soil physical properties.

System	Bulk densit	MWD	Aggregate size	Pore size distribution (%)	Dispersio	Erosion ratio	Erodibility factor

	y (Mg m^{-3})	(mm)	Macro aggregate (>0.25cm)	Micro aggregate (<0.25cm)	>50 µm	0.5-50 µm	<0.5 µm	n ratio		
Arboretum	1.13	2.42	53.91	6.16	18.66	40.00	41.34	0.041	3.95	0.20
Khasi Mandarin	1.19	2.42	51.48	5.81	16.12	43.64	40.24	0.048	4.46	0.31
Assam Lemon	1.19	1.97	50.94	5.22	19.51	38.50	41.99	0.045	4.26	0.30
Alder+Pineapple+Fodder	0.98	2.43	55.06	6.25	21.94	34.95	43.11	0.033	3.07	0.26
Alder+Tea+Black pepper	0.97	2.65	56.32	6.37	20.08	27.95	52.87	0.039	3.06	0.18
Natural forest	0.94	3.13	60.78	6.87	30.12	11.95	57.93	0.025	2.16	0.05

Table 6. Effect of different agroforestry systems on hydrological behaviour of soil.

System	ϴ at 0.3 bar (%) (V/V)	ϴ at 15 bar (%) (V/V)	Available water (%) (V/V)	Moisture equivalent (%)	ϴs (%) (V/V)	Hydraulic Conductivity (ms-1 X10-4)
Arboretum	44.18	20.83	23.35	39.78	54.47	0.50
Khasi Mandarin	43.26	21.73	21.53	39.04	52.91	0.38
Assam Lemon	42.53	20.76	21.77	37.83	55.24	0.53
Alder+Pineapple+Fodder	42.21	17.98	24.23	39.67	55.83	0.72
Alder+Tea+Black pepper	40.79	15.49	25.30	34.00	56.01	0.77
Natural forest	39.58	12.64	26.94	37.20	61.28	1.84

CONCLUSION

As sustainability of the land resource base has become great concern in recent years, regenerative agricultural technologies for the sustainable development of hilly areas in respect of soil, water and nutrient management must integrate socio-economic issues and bio-physical processes. So, the priorities for hilly agriculture for sustained productivity and soil health should combine the following points:

- Integrated farming system approach for soil fertility management based on land use systems on watershed basis.
- Restoration of highly degraded land suffering from soil erosion and chemical degradation by agro-forestry, horticulture and pasture plantation crops.
- Soil conservation and agricultural production no longer should be regarded as separate activities. It must be an integral part of agriculture development and should start with improved farming systems.

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