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Soil Fertility, Erosion, Runoff and Crop Productivity Affected by Different Farming Systems

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ABSTRACT A field study was undertaken with four farming systems (FS) such as; grasses and fodders, agro-forestry, agriculture (new farming systems) and shifting cultivation (old practice), to investigate the effect of land use on the soil properties, erosion and crop productivity on a loamy acidic Alfisol. Besides crops, the livestock were also kept and their dropping were incorporated in the respective watersheds. Soil sampling was done during first week of May every year from 0-20 cm depth, with auger. A significant increase in soil organic carbon (SOC) up to 0.99%, available P up to 17.2 mg kg^{-1}, K up to 170 mg kg^{-1} of soil, pH up to 6.3, was found after 10 years of study over their initial values of 0.46%, 2.7 kg^{-1}, 105 kg^{-1} of soil and 4.9, respectively, in the new FS. In shifting cultivation, K status increased up to three years of study and then subsequently decreased. Diethylen etriamine penta acetic acid (DTPA) extractable Zn, Mn, Fe and Cu decreased in all the farming systems. Exchangeable Al content decreased from 117 to 37 mg kg^{-1} of soil, in new FS. The study showed that about 91.1% to 99.1% rainwater could be retained depending on the vegetation cover in new FS, as against 66.3% in the shifting cultivation. New FS ameliorated the soil by decreasing exchangeable Al and Fe and enhancing soil pH. Soil and nutrient losses were significantly less and crop productivity higher in new FS compared to shifting cultivation.

Key words: *Farming systems, Shifting cultivation, Soil erosion, Soil fertility*

1 INTRODUCTION

The fertility status of soil depends on the soil's natural or inherent composition, which is a function of geological materials and soil state factors or variables. The land use systems can cause significant changes in the soil properties (Lal, 1996; Shepherd *et al.,* 2000; Dalal and Chan, 2001; Ndukwu *et al.,* 2010, Chan *et al*., 2011; Conyers *et al*., 2012; Ghazavi and Vali, 2013). Cropping systems may improve or decrease soil quality depending on the specific crop rotation, nutrient amendments, and tillage practices employed (Jokela *et al.,* 2011). The chemical changes have been found to be more rapid than the physical changes (Schipper and Sparling, 2000). In some cases, due to adverse management, human activities such as land useand farming practices can result in the deterioration of a soil that originally possessed good inherent quality (Aparicio and Costa

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2007; Coulter *et al*., 2009; Gasparatos *et al*., 2011). Therefore, the agricultural use causes modifications in the natural soil structure and soil fertility due to the addition of organic residues, which can condition its productivity (Verma and Sharma, 2008). The soil pH determines the state of availability of nutrients in the soil. Research of impacts on the soil is important to determine how soil fertility can be maintained and the land use systems improved. Shepherd *et al.* (2000) observed no change in particle size distribution and significant modifications in chemical properties in the top soil that affects agricultural productivity, while Murty *et al.* (2002) found that land use practices affect the distribution and supply of soil nutrients by directly altering soil properties and by influencing biological transformations in the rooting. For instance, cultivation of forests diminishes the SOC within a few years of initial conversion and substantially lowers mineralisation of nitrogen (Ritcher *et al.*, 2000, Jokela *et al.*, 2009; Clark and Johnson 2011). Higher SOC stocks were present in pasture-dominated land uses compared with mixed cropping (Davy and Koen, 2013). The conversion of forest to crop land has been associated with reduction in SOM content and nutrient content of the top soil (Singh and Singh, 1996) and due to various farming systems (Sharma, 2001) and subsequently, decline in productivity, since SOM content is responsible for the productivity in soils (Sanchez *et al.*, 1987, 1997). Many workers have reported the effect of crops on the forest land converted to agriculture (Motavalli and McConnel, 1998; Riezebos and Loerts, 1998; Islam and Weil, 2000). Agriculture results in differentiation of a landscape units in which soils are modified according to the type of land use (Dupouey *et al*., 2002). Shifting cultivation is the predominant land use in the study area, which has now become uneconomical with increase in population and reduction in the shifting cycle. About 59.3 t ha^{-1} of soil from a slope of 45% (Sharma and Prasad, 1995; Trinsoutrot *et al.*, 2002; Sharma and Sharma, 2005) and 170 t ha^{-1} from a slope of 70% (Singh and Singh, 1978) has been reported through runoff triggered by shifting cultivation. So, three new FS were also evaluated along with shifting cultivation, in order to replace the latter practice, which involves deforestation. Despite the forest providing important social and environmental benefits, it is increasingly threatened by accelerating rates of forest conversion and degradation (Brown and Lugo, 1990). A study was, therefore, undertaken with different FS, to assess the soil loss through erosion from the hill slopes and effect of type of vegetation cover on the soil fertility and crop productivity. While shifting cultivation is the prevalent land use in the area of study, which has become uneconomical due to increase in demographic pressure and reduction in period of shifting cycle, three new farming systems were included in the investigation to study their merit and replace shifting cultivation. The aim of this study was to assess soil use intensity effects on selected soil properties.

2 MATERIAL AND METHODS

A multidisciplinary study was conducted with four agricultural land use systems to see the effect of farming systems on the soil erosion, soil properties, runoff and resultant effect on crop productivity over ten years period. The agricultural land use systems, the slope steepness and, soil and water conservation measures undertaken are given in Table 1. The livestock included cows and their followers, pigs, goats and rabbits and were kept as per farmer's requirement in different watersheds.

Table 1 Vegetation cover in different land use systems

Farming system	Slope (%)	Crops/trees	Livestock	Soil and water conservation measures
Grasses and fodders	32	Maize *(Zea mays),* stylo grass *(Stylosanthes guianensis),* oats *(Avena sativa), Setaria* spp. *(Setaria sphaselata),* guineagrass *(Panicum maximum),* broomgrass *(Thysanolaena sphacelata),* tapioca *(Manihot esculenta),* ricebean *(Vigna umbellata)*	Cows, pigs, rabbits	Trenching/ contour bunds
Agro-forestry	33	Nevaro *(Ficus hookerii), Eucalyptus* spp. *(Eucalyptus amygdalina),* Pine *(Pinus longaeva), Phaseolus* spp., Mung bean *(Vigna radiata),* French bean *(Phaseolus vulgaris), Colocasia* spp. *(Colocasia esculenta)*	Goats, pigs	Bench terraces, half-moon terraces, contour bunds
Agriculture	32	*Phaseolus* spp., maize *(Zea mays),* Rice *(Oryza sativa),* ginger *(Zingiber officinale),* Turmeric *(Curcuma longa),* groundnut *(Arachis hypogaea),* oats *(Avena sativa),* Guineagrass *(Panicum maximum),* radish *(Raphanus sativus)*, soybean *(Glycine max)*	Cows and their followers	Bench terraces, contour bunds, grassed water-ways
Shifting cultivation	42	Mixed cropping of upland rice (*Oryza sativa),* potato *(Solanum tuberosum),* maize *(Zea mays),* mung bean *(Vigna radiata),* job's tears *(Coix lacryma)* etc.	None	None

2.1 Study site and methodology

The study site is Umiam, on outskirts of Shillong city in Brahmaputra Basin of India. It is situated at 25^0 34' N latitude and 91^0 52' E longitude (Figure 1). The place is situated at 990 m above mean sea level, receiving 2230 mm of rainfall, annually and average temperature varying from 18.8 to 27.4^0C during summer and 7.0 to 18.9^0C during winter (Sharma *et al.*, 2006).The place is a remnant of an ancient plateau of pre-cambrian Indian Peninsular shield, block uplifted to its present height. It is occupied by Archean gneissic complex with acid and basic intrusive Shillong group of rocks (Sharma and Datta 2006). The soils are deep and excessively drained, fine soils on moderately slopping hills with severe erosion hazards and strong stoniness. The soils are dark brown to dark greyish brown in colour with sandy loam texture. A multidisciplinary study was conducted with four agricultural land use systems to see the effect of FS on the soil erosion, soil properties, runoff and resultant effect on crop productivity over ten years period. The agricultural land use systems, the slope % and, soil and water conservation measures undertaken are given in Table 1. The FS were selected on the basis of their significance in the area. Since almost all households keep livestock for milk and meat, the grasses/fodder system was selected, Agriculture system was included to ensure food security and, agro-forestry is thought to be suitable for the area due to sloppy lands and extent of degradation in the region. The shifting cultivation is the present common land use of the region and was kept for comparison. Each land use in the experiment has an area of one ha. The livestock included cows and their followers, pigs, goats and rabbits and were kept as per farmer's requirement in different watersheds. The monitoring gauges were installed at the outlet of each watershed and the observations on soil and nutrient loss, runoff and rainwater retained *in situ,* were determined during different years of study. The rainwater retained in a particular FS was determined by subtracting the total runoff from the amount of rainfall received by the FS area.

2.2 Sampling and laboratory analysis

The Treatments included four FS such as grasses/fodders, agro-forestry, agriculture and shifting cultivation. Soil samples were analyzed for pH, OC, available P and K, exchangeable Ca, Mg, Fe and Al and DTPA extractable Zn, Mn, Fe and Cu. The initial soil status for different parameters was determined from the soil samples collected from the study site before the start of the experiment (Table 2) and subsequently every year.

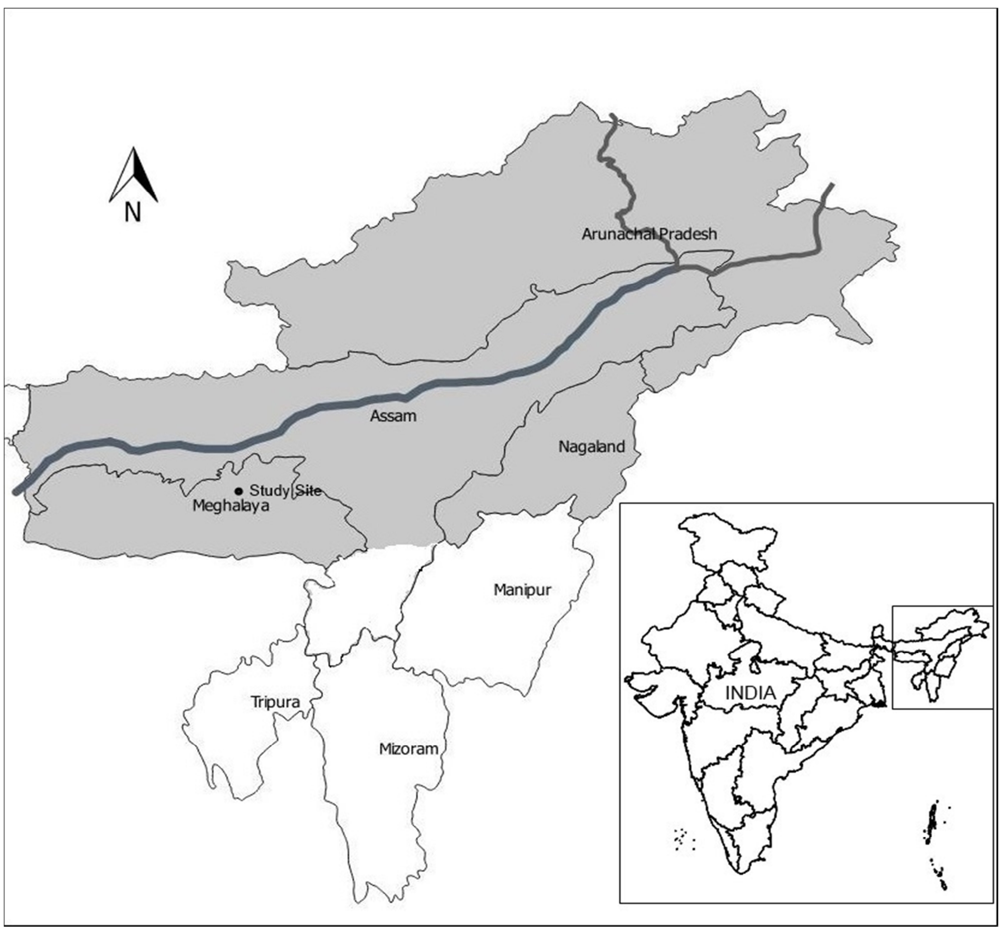

Figure 1 Study site in Brahmaputra basin in India

Table 2 Basic physico-chemical properties of the experimental soil

Parameters	Value
Sand (%)	57.30
Silt (%)	31.50
Clay (%)	11.20
Textural class	Loam
pH	4.90
SOC (%)	0.50
Available P (mg kg^{-1} of soil)	2.70
Available K (mg kg^{-1} of soil)	105.00
Exchangeable Ca (mg kg^{-1} of soil)	340.00
Exchangeable Mg (mg kg^{-1} of soil)	133.00
Exchangeable Al (mg kg^{-1} of soil)	117.00
Exchangeable Fe (mg kg^{-1} of soil)	49.00
DTTPA extractable Zn [c mol (p+) kg^{-1})]	0.12
DTTPA extractable Mn [c mol (p+) kg^{-1})]	0.51
DTTPA extractable Fe [c mol (p+) kg^{-1})]	0.39
DTTPA extractable Cu [c mol (p+) kg^{-1})]	0.02

The sampling was done from ten sites, randomly, with auger for a composite sample and the analytical results were averaged. To study the nutrient build-up, five soil samples were taken randomly from each land use andanalysed for various constituents. The samples were taken in the first week of May every year after harvest of the winter crops and before sowing of the summer crops. Soil sampling was done from 0-20 cm soil depth. These samples were routinely analysed for organic carbon (Walkley and Black, 1934), available P (Bray and Kurtz, 1945) available K and Ca and Mg (Mehlich, 1978), and exchangeable Al and Fe (Jackson, 1973). The runoff water samples were collected from monitoring gauges and analysed for soil and nutrient content. The chemical analyses of soil and runoff samples were done as per procedures mentioned by Jackson (1973). The seasonal crops were harvested after maturity and grain yield was recorded. In agroforestry system, the girth of the trees was measured for ten years at a height of 1.37m above the ground (Dhyani *et al.*, 2009). DTPA extractable zinc, manganese, iron and copper were determined as per method described by Lindsay and Norvel (1978).

2.3 Statistical analysis

All the results were statistically analysed for comparison among treatments by the method suggested by Goulden (1960). Variance analysis was done for assessing farming system impact on various soil quality parameters at 5% level of significance. Since the data on soil erosion under different treatments do not conform to assumptions of normality, the Box-Cox transformation method (Box & Cox 1964, Dettinger 2004) was used for bringing the population to normal or Gaussian distribution.

3 RESULTS

3.1 Soil erosion and nutrient loss

Soil erosion from different farming systems is shown in Figure 2. Our findings showed that the average soil loss due to erosion was 36.20 t ha^{-1} in shifting cultivation on a 42% slope of the watershed. The soil and nutrient erosion was significantly ($p = 0.05$) affected by FS and amount of rainfall received. Maximum annual soil loss varied from 0.04 to 0.24 t ha^{-2} in agriculture, 0.09 to 0.29 t ha^{-1} in grasses/fodders, 0.28 to 0.76 t ha^{-1} in agroforestry and 26.69 to 44.99 in shifting cultivation farming system with annual rainfall varying from 1992 to 2770 mm (Figure 2). About 90% of rainwater was retained in new land use systems as against 66.3% rainwater retention in shifting cultivation.

There were large differences in soil erosion due to runoff and, so, 1/5 root of the data was used to show the values in the figure (Box and Cox 1964). Maximum *in-situ* infiltration was 39.3% of rainfall in grasses/fodders land use and minimum (8.2%) in shifting cultivation. The average loss of soil nutrients varied significantly due to various FS (Table 3). Maximum average loss of N, P and K was 7.4, 0.9 and 4.5 kg^{-1} in shifting cultivation, respectively, whereas; the loss of these nutrients in other farming systems was far below. Maximum loss of Mn, Zn, Ca and Mg was found in shifting cultivation and minimum in grasses/fodders land use (Table 3).

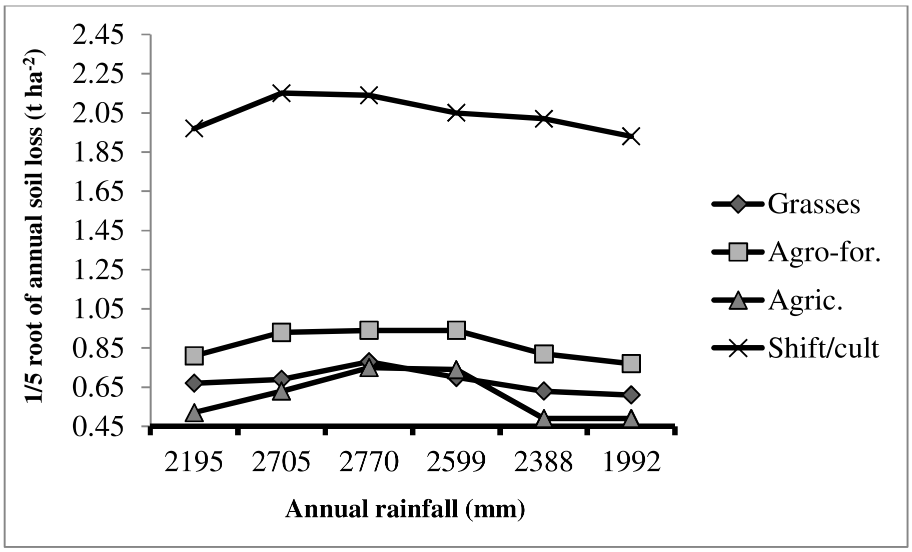

Figure 2 Annual soil erosion from various farming systems as affected by the amount of rainfall.CD (p = 0.05); Rainfall 0.11, FS 0.09, Rainfall x FS 0.32

Table 3 Loss of nutrients from different land uses (average values)

Variables	Grasses/ fodders	Agro-forestry	Agriculture	Shifting cultivation	CD (p = 0.05)
N (kg ha^{-1})	0.09	0.42	0.37	7.4	0.42
P (kg ha^{-1})	0.02	0.07	0.06	0.9	0.05
K (kg ha^{-1})	0.07	0.29	0.27	4.5	0.23
Mn (g ha^{-1})	6.16	18.20	17.10	92.5	5.21
Zn (g ha^{-1})	4.28	11.60	12.06	62.0	3.82
Ca (g ha^{-1})	0.02	0.23	0.18	0.6	0.03
Mg (g ha^{-1})	0.01	0.12	0.10	0.5	0.02

3.2 Soil properties

Different FS had a significant influence on various soil characteristics (Figures 3, 4 and 5). The SOC, available P and K and exchangeable Ca increased significantly in the new land use systems compared to shifting cultivation. The OC increased up to 0.97% in grasses and fodders, 0.99% in agroforestry, 0.95% in agriculture and decreased to 0.40% in shifting cultivation FS over its initial status of 0.46% over a period of 10 years (Figure 3a). The OC remained almost stagnant in forestry land use upto 4^{th} year but it showed a progressive increase subsequently. In shifting cultivation, the OC changed from initial value of 0.46% to 0.65% in 3^{rd} year, however, it decreased subsequently. It was observed that the soil pH, in the new land uses, increased from 4.9 to 6.3, that is from highly acidic (below critical level of 5.5) to moderately acidic conditions over the years (Figure 3b). Increase in soil pH was up to 6.3 in agro-forestry system, followed by 6.2 in grasses/fodders and 6.1 in agriculture land use. In shifting cultivation, a non-significant increase in soil pH was found up to 2^{nd} year of study but it decreased subsequently, finally stabilizing at the initial level. The available P content of the soil did not show any significant increase up to 3^{rd} year of study in new farming systems, rather, initially, there was a slight increase in the shifting cultivation (Figure 3c). After third year, the available. P content of soil increased significantly in all the new systems over the initial status, with maximum increase in agriculture, followed by grasses/fodders and agroforestry. The available P increased from 2.7 to 17.2 mg P kg^{-1} of soil in agriculture followed by grasses/fodders (2.7 to 16.2 mg P kg^{-1} of soil). Like P, the buildup of available K was significant in the new farming systems (Figure 3d). Interestingly, the available K was highest in shifting cultivation during the first (160 mg K kg^{-1} of soil) and second year (146 mg K kg^{-1} of soil) of study. The available K was subsequently reduced in shifting cultivation and was a little below the initial soil status (105 mg K kg^{-1} of soil), at the end of ten years of study. However, it continued to increase in other farming systems, highest being 170 mg K kg^{-1} of soil in agriculture followed by 165 and 158 mg kg^{-1} of soil in grasses/fodders and agroforestry farming systems.

The exchangeable Ca content of soil was also found to increase in the new land uses, more prominently in agro-forestry FS. It shows that tree plantation and fall of litter (leaves with petioles) had affected the increase in Ca content of the soil (Figure 4a). The Ca content of soil increased in all the new land use systems and varied between 540 and 578 mg kg^{-1} of soil after 10 years of experimentation. While, it almost stabilized in different land uses, a progressive increase was observed in agroforestry land use even after 10 years. However, the exchangeable Ca content of soil did not change significantly in the shifting cultivation land use. Exchangeable magnesium content of soil also increased significantly in different farming systems except shifting cultivation (Figure 4b).

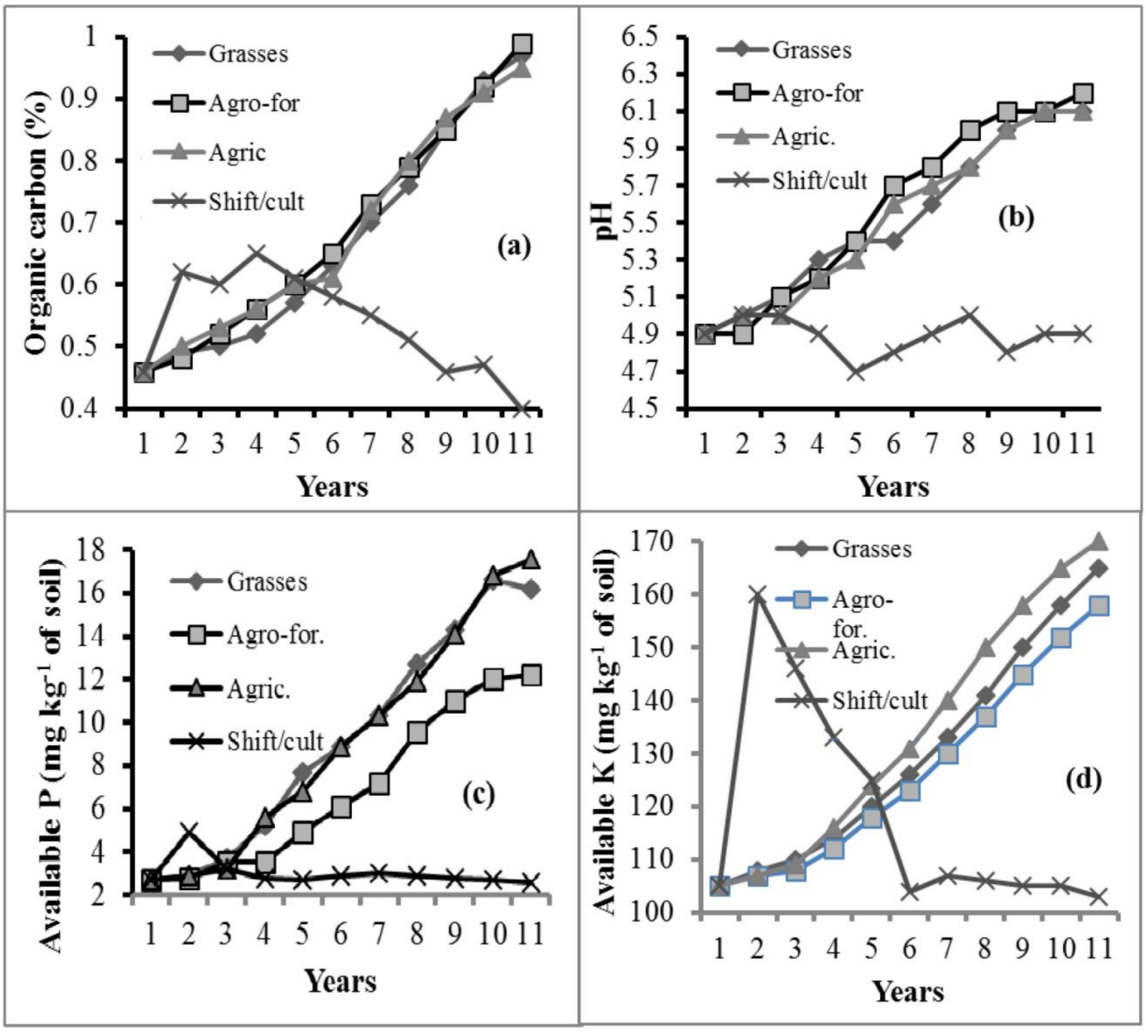

Figure 3 Effect of farming systems on the (a) organic carbon, (b) pH, (c) Available P and(d) available K CD (p = 0.05); OC (FS 0.015, Years 0.024, FS x Years 0.072; pH (FS 0.13, Years 0.020, FS x Years 0.62); Av. P (FS 0.28, Years 0.45, FS x Years 1.30); Av. K (FS 4.6, Years 7.3, Av. K x FS 21.0)

Maximum increase was in grasses/ fodders farming system, where it increased from 133 to 403 mg MJ kg^{-1} of soil. The experimental soil had exchangeable Al concentrations of almost toxic amounts, but continuous cropping in the new land use systems ameliorated the soils to large extent (Figure 4c). Maximum decrease in exchangeable Al content was from 117 to 37 mg Al kg^{-1} of soil in the grasses and fodders based farming system followed by agroforestry and agriculture land uses. The grasses and forest trees had more ameliorating effect and reduced the toxicity of Al. Changing trend in exchangeable Fe content of soil is shown in Figure 4d. It decreased significantly from initial value of 48.2 to an average of 17.9 mg exchangeable Fe kg^{-1} of soil in the new farming systems. A non-significant decrease in soil Fe content was observed in shifting cultivation also (4d).

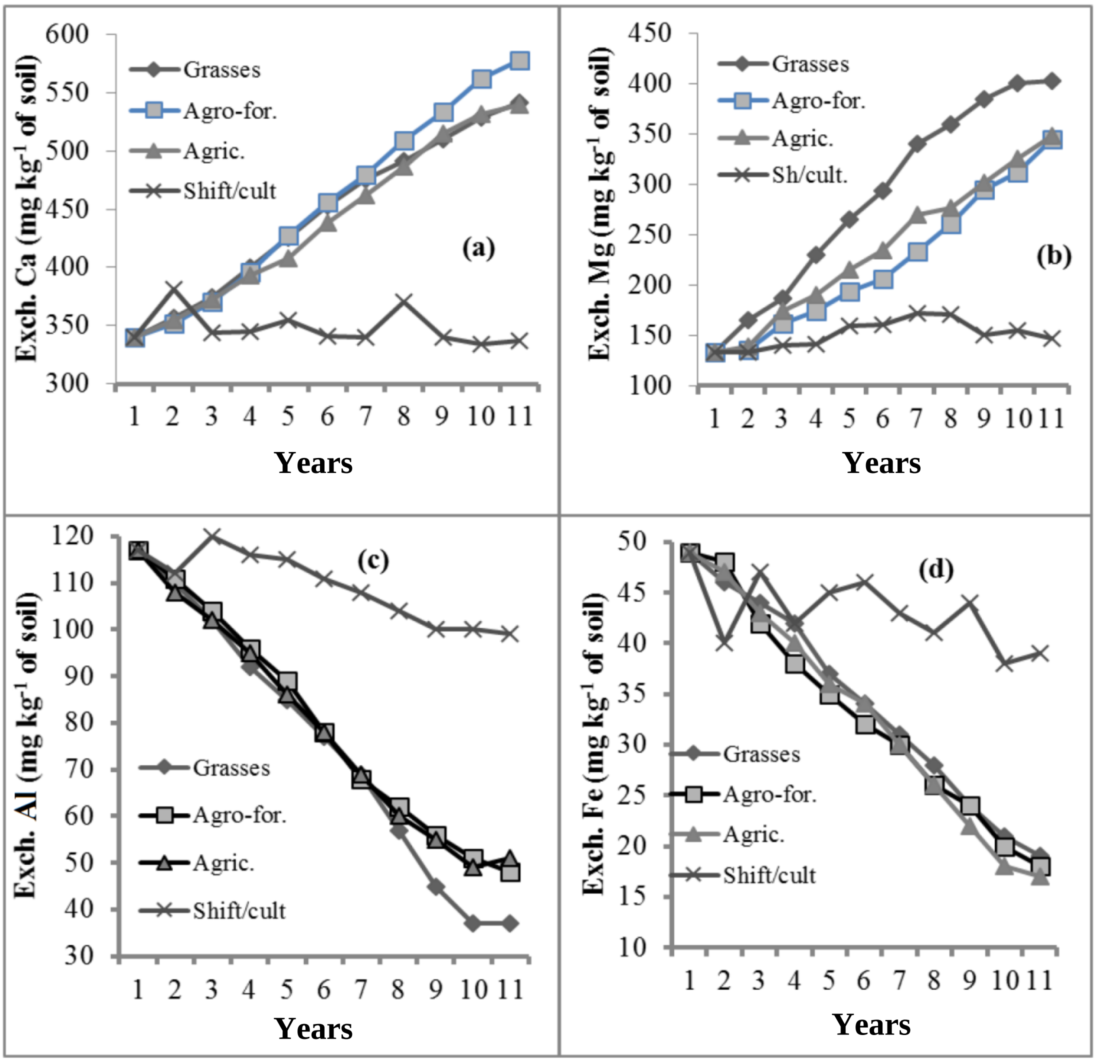

Figure 4 Effect of farming systems on exchangeable (a) Ca, (b) Mg, (c) Al and (d) Fe
(CD ($p = 0.05$); Exch.Ca (FS 7.8, Years 12.3, FS x Years 35.1); Exch. Mg (FS 6.5, Years 10.3, FS x Years 29.3); Exch. Al (FS 2.8, Years 4.4, FS x Years 12.6); Exch. Fe (FS 1.5, Years 2.3, FS x Years 6.7)

3.3 DTPA Extractable Micronutrients

The DTPA extractable zinc decreased significantly in all the farming systems with maximum decrease from 0.12 Cmol (p+) kg^{-1} to 0.06 Cmol (p+) kg^{-1} of soil in agroforestry farming system during 10 years period (Figure 5a). Contrary to Zn, a different behaviour was observed in Mn content of soil (Figure 5b). The vales of DTPA extractable Mn decreased initially up to five years but, subsequently increased in all the farming systems except shifting cultivation, where the Mn remained almost stagnant. The DTPA extractable Mn decreased from initial value of 0.51 to an average value of 0.39 Cmol (p+) kg^{-1} of soil in three farming systems during 10 years of study, compared a non-significant decrease to 0.48 Cmol (p+)

kg^{-1} of soil Mn in shifting cultivation. A significant decrease in DTPA extractable Fe (Figure 5c), as it decreased from initial value of 0.39 Cmol (p+) kg^{-1} of soil to an average value of 0.30 Cmol (p+) kg^{-1} of soil in new FS, whereas; there was no significant decrease in shifting cultivation. The DTPA extractable Cu decreased from initial value of 0.017 Cmol (p+) kg^{-1} of soil to 0.012 Cmol (p+) kg^{-1} of soil (Figure 5d), however, the values remained constant after 5 years of initial decrease in agriculture land use.

3.4 Runoff

The base and surface flows contributed towards runoff from the watersheds. The runoff varied significantly among different FS (Table 4). Highest runoff was 34.1% of rainfall in shifting cultivation, followed by 9.6% in agroforestry, 0.9% in agriculture and 0.1% in grasses and fodders. Maximum rainwater was retained in the grasses/fodders farming system and minimum in the shifting cultivation. It showed that about 91.1% to 99.1% rain-water can be retained in different FS depending on the vegetation cover in new land use systems, as against 66.3% in the shifting cultivation. Due to more infiltration of rainwater in the soil because of good vegetation cover, the runoff considerably reduced in new land use systems, resulting in low flows to river channel and reduced sediment load in the runoff. There was significant reduction in runoff in farming systems other than shifting cultivation due to sufficient vegetation cover. This increased the soil moisture content. The enhancement of soil moisture was beneficial for the winter crops when there are no or insufficient rains. The interactional effect of amount of rainfall and farming systems was highly significant. Deforestation in shifting cultivation has resulted in land degradation, soil infertility and water scarcity in the study region because the natural water cycle has been upset. The runoff water goes untapped instead of infiltrating to recharge aquifers and cause huge soil erosion, putting the ecology of the region in peril. About 88.3 million tones of soil and about 0.5 million tones of crop nutrients are lost every year through erosion (Sharma and Prasad, 1995). There have been marked changes in soil fertility in the region due to faulty agricultural practices, like shifting cultivation.

3.5 Crop yield and economics

About 3 to 4 times higher yield was recorded in all the farming systems compared to shifting cultivation, where it was much below the optimum level. The cost/benefit ratio was found to be highest (2.12) in grasses/fodders farming system, followed by agriculture (1.96) and agroforestry (1.83). The shifting cultivation was found to be an uneconomical practice with a cost/benefit ratio of 0.63 (Table 5).

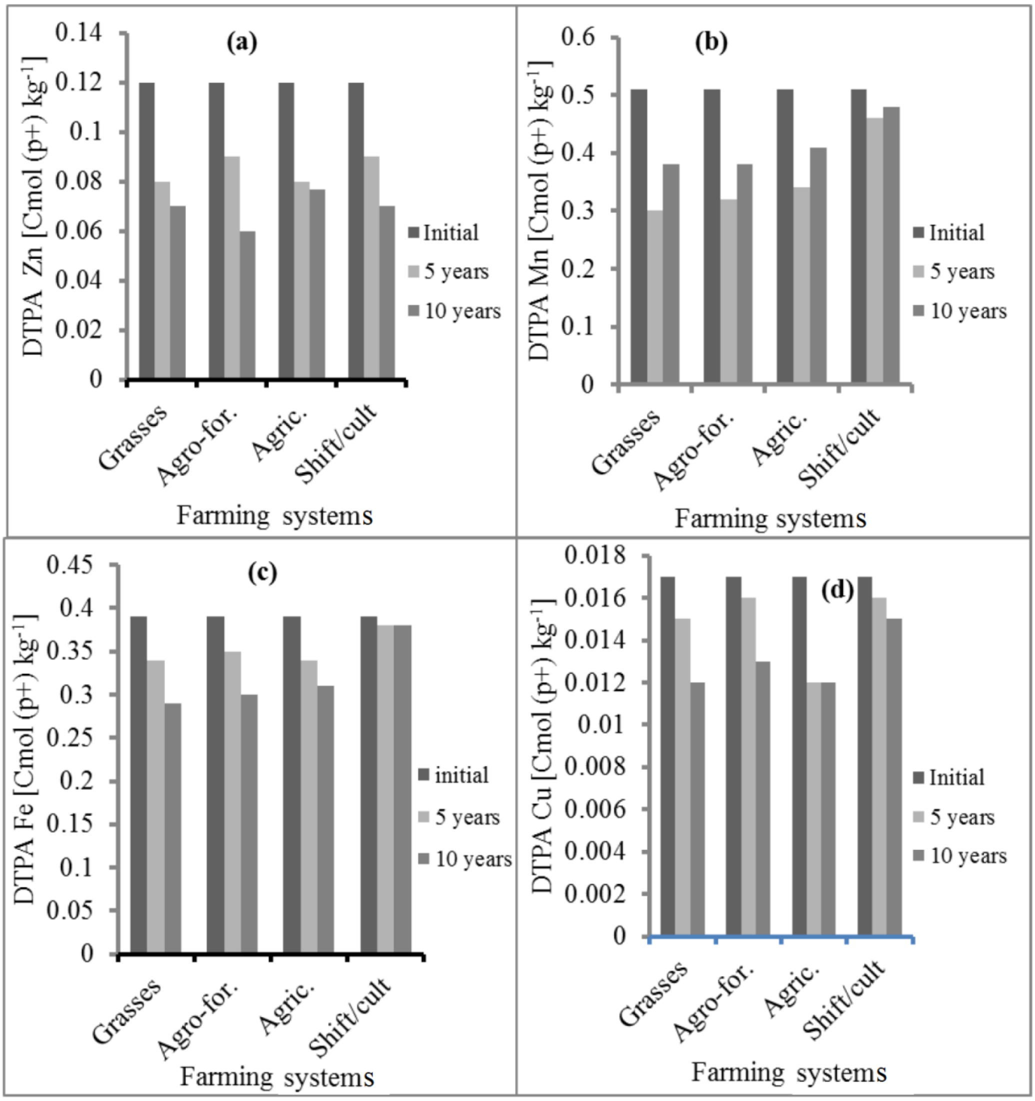

Figure 5 Effect of land use on DTPA extractable (a) Zn, (b) Mn, (c) Fe and (d) Cu (CD ($p = 0.05$); Zn 0.0035, FS 0.0041, Zn x FS 0.0101; Mn 0.011, FS 0.013, Mn x FS 0.032; Fe 0.025, FS 0.029, Fe x FS 0.072; Cu 0.0015, FS 0.0017, Cu x FS 0.0043)

Table 4 Effect of farming systems on runoff from different watersheds

Variables	**Farming systems**			
	Grasses/ fodders	**Agro-forestry**	**Agriculture**	**Shifting cultivation**
Total runoff (mm)	14.0	433.3	20.9	835.3
Percent of rainfall	0.6	9.6	0.9	34.1
In situ rainwater retention (%)	99.4	90.4	99.1	65.9

Table 5 Average annual yield and economics of different land use systems

Land use	Crop	Yield (t ha^{-1})	Land use	Crop	Yield (t ha^{-1})
Grasses/ fodders	Maize	35.6	Agriculture	French bean	8.2
	Rice bean	18.2		Soybean	2.4
	Oats	44.6		Radish	26.7
	Guinea grass	25.1		Maize grain	3.3
	Setaria sphaselata	36.7		Low land rice	3.5
	Tapioca tubers	5.1		Ginger	12.2
	Stylo grass	26.2		Turmeric	20.5
Agro-forestry	*Ficushookerii*	1.1		Groundnut	5.2
	Eucalyptus	1.4		Guinea grass	21.6
	French bean	12.5		*Thysanolaena sphacelata*	19.4
	Pulse crop	1.8	Shifting cultivation	*Coixlacryma*grains	1.5
	Colocasia	2.2		Upland rice	0.6
	Mungbean	2.6		Potato	5.7
				Maize grains	0.9
				Mungbean	0.8

4 DISCUSSION

4.1 Soil erosion and nutrient loss

The quality of any soil depends in part on the soil's natural or inherent composition, which is a function of geological materials and soil state factors or variables (Jenny 1980, Anderson 1988, Gangopadhayay *et al*. 1990, Olowolafe 2002 and Romanaya and Roviro 2009). In some cases, due to adverse management, human activities such as land use and farming practices can result in the deterioration of a soil that originally possessed good inherent quality. Therefore, the agricultural use caused modifications in the natural soil structure, which conditioned its productivity (Karlen 2006, Aparicio *et al.*, 2007, Coulter *et al.*, 2009, Jokela *et al*., 2009, Aziz *et al.*, 2011). Mean values of soil loss showed highly significant differences between shifting cultivation and other three farming systems, while there were no significant differences among the farming systems other than shifting cultivation. There were significant differences in soil erosion due to the amount of rainfall received as well as interactional effect of rainfall and the farming systems. The increase and variation in the soil and nutrient loss because of erosion with runoff was due to variation in the amount of rainfall received during different years (Figure 2) and the type of vegetation cover in the farming system (Table 3). The results corroborate the findings of Trinsoutrot *et al.* (2002) and Sharma and Sharma 2005, who found that the runoff is impacted by the nature and extent of vegetation cover and amount and intensity of rainfall received. The vegetation type and density is mainly influenced by the amount of rainfall and human interventions, besides other climatic factors like temperature (Malo and Nicholson 1990, Vanacker *et al*., 2005). They reported a strong linear relationship between the normalized difference vegetation index (NDVI) and rainfall. The soil and nutrient loss was found to be further impacted by the slope of the watershed, besides rainfall and vegetation cover. In the present study, the soil loss was highest from the shifting cultivation. It was due to the reason that vegetation cover was scarce in this land use and slope was more compared to other farming systems. The nutrient loss was mainly because of soil erosion as part of soil solution and as particulate matter. The relationship between soil erosion and nutrient erosion was highly significant (r= 0.963) (Table 3). Interactional effects of rainfall and vegetation cover were significant because the amount of rainfall influenced the vegetation and quantum of vegetation, in turn, impacted *in-situ* retention of more rainwater, reduced runoff and, hence, reduced loss of soil and nutrients through erosion.

4.2 Organic carbon

Different farming systems had a significant influence on various soil constituents (Figures. 3, 4 and 5). The SOC, available P and K and exchangeable Ca increased significantly in the new farming systems compared to shifting cultivation. This was due to the reason that the biomass produced in shifting cultivation was too little to make a significant change in soil properties. Use and management of organic waste/residues is currently an important global issue for attaining sustainability in agricultural production systems. However, knowledge about the decomposition characteristics and nutrient release pattern of added organic materials in subtropical soils and their interaction with inherent soil properties are lacking (Khalil *et al.,* 2005). In the present study, the SOC and nutrient soil status increased significantly in the new land use systems due to continuous addition of nutrients through the crop residues, organic wastes as well as dung and urine of livestock kept in different farming systems and incorporation of this material into the soil. The addition of OM to agricultural soil (with or without chemical fertilizers) is important for replenishing the annual C losses and for improving both the biological and chemical properties of the soils (Goyal *et al.*, 1999, Trinsoutrot *et al.,* 2002). This can be achieved from the plant biomass that is usually removed from the agricultural field and from the extensive use of animal manure with improved management approaches. The residue bound-nutrients can be available to the plants in a considerable amount over time. As such, information on the timing and method of adding organic matter, particularly with respect to its decomposition and nutrient release pattern for a specific soil is vital towards generating effective management strategies. These may reduce the use of chemical fertilizers while offering better crop return and less environmental degradation. The application of organic wastes, such as animal manure to soil is a current environmental and agricultural practice for maintaining soil organic matter, reclaiming degraded soils and supplying plant nutrients. There is degradation of wastes which contain a high percentage of soluble organic carbon in the soil leading CO_2 production immediately after their addition to soil (Marstorp, 1996 and Chan *et al.,* 2010). In the present study, the addition of OC on the forest land use was very low during the initial years of study as the trees were small and addition of litter was negligible. However, subsequently after about five years of plantation, with increase in canopy of trees and addition of more forest litter, the organic carbon in the soil increased. Davy and Koen (2013) also reported significant correlations between SOC and a range of climatic, topographical, and soil physico-chemical variables at both the catchment and sub-regional scale. Soil physico-chemical and topographical factors play an important role in explaining SOC variation and should be incorporated into models that aim to predict SOC sequestration across agricultural landscapes. The results obtained corroborate our findings.

4.3 Soil properties

Certain edaphic and agronomic factors related to soil physical and chemical properties govern fertility status of the soil (Braver *et al.* 1978, Landon, 1999), others such as soil aggregate stability (Bremner and Mulvaney 1982), soil moisture availability and general quality equally contribute. All the measured soil chemical properties varied under the influence of the type of vegetation cover and the livestock kept in. Soil pH, available P and K, exchangeable Ca, Al and Fe showed a significant change in their values over a period of 10 years. Variations in soil properties under similar agro-ecological zone may be as a result of parent materials, landscape position, land use and cultural practices (FAO 1990), topography, vegetation are among these factors. In shifting cultivation, a non-significant increase in soil pH was found up to 2nd year of study but it decreased subsequently, finally stabilizing at the initial level. The available P content of the soil did not show any significant increase up to 3 years of study in new farming systems, rather, initially, there was a slight increase in the shifting cultivation (Figure 3). After 3rd year of study, the available P content of soil increased significantly in all the new farming systems over the initial status, with maximum increase in agriculture and grasses and fodders systems. The increase in available soil P may be attributed partly to the increase in soil pH under new land use systems from 4.9 to 5.4 and partly due to application of phosphoric fertilizers in these land uses (Holford 1997, Sharma and Tripathy 1999). With increase in soil pH, more P was added to the labile pool, thereby increasing its availability. The decrease in Fe and Al content in the soil was also favourably good as their initial soil content was slightly toxic to the plants. The experimental soil had exchangeable Al and Fe concentrations of almost toxic amounts, but continuous cropping in the new land use systems ameliorated the soils to large extent (Figure 3c, 3d). Due to the strong acidity (pH< 5.5), these soils contained Al in the exchangeable form. That resulted from the higher degree of weathering of rock constituent minerals. The nature vegetation and the organic wastes as well as incorporation of dung and urine of the livestock kept in the respective farming systems, showed an amelioration effect causing significant reduction in exchangeable Al in all the new land uses except shifting cultivation. The results obtained corroborate the findings of Singh and Das (1990) and Tiessen *et al.* (1994). Kauffmann *et al.*(1998) reported that in such soils, a large part of the plant nutrients and about 90 per cent of the capacity of the soil nutrient retention depends on soil organic matter. Thus acidity problems will occur in the top soil and Al toxicity problems in the sub-soil. Soil fertility then depends on the organic matter supply by the natural vegetation and the nutrient cycling (Juoand Mani, 1996). In cropped fields, exposure of the soil surface to heavy rains brings about erosion, rapid decomposition and mineralization of soil organic matter, and intense leaching of nutrients. Burning and ploughing lead to the destruction and rapid decomposition of soil organic matter and reduce the contribution of organic and microbial processes to nutrient cycling (Juo and Mani, 1996, Knicker *et al.* 2005, Neff *et al*. 2005). However, the fertility status depends on the inevitable loss of soil nutrients in crop harvest and additional losses by leaching and runoff. The sudden increase in K in shifting cultivation could easily be attributed to the burning of forest vegetation in the shifting cultivation at the beginning of the study. Rostamabadi *et al*. (2013)reported that plantations affect the soil properties.

By and large, the DTPA extractable Zn, Mn, Fe and Cu decreased during the study, particularly in new farming systems (Figure 4a, 4b, 4c and 4d). This was due to the fact that increase in crop productivity removed these micronutrients from the soil in relatively large amounts but were not replenished from outside source. Increase in the level of crop yields and use of high analysis fertilisers aggravate the deficiency of micronutrients in many soils (Kakmak 2002), and their deficiency in soils has been identified as a major constraint productivity of major field crops (Katyal and Agarwal, 1982;Alloway 2008). Kakmak (2002) reported that intensive cultivation of high yielding cultivars with heavy applications of N, Pand K fertilizers has led to the occurrence of micronutrient deficiencies in many countries. Due to complex and dynamic nature of the soil, the applied micronutrients may become immobile even under adequate supply.

4.4 Runoff

The extent of thickness of vegetation cover in the farming systems affected the runoff from the watersheds (Table 4). Soil moisture content is a significant factor in determining how much runoff will occur from a site (Mingguo *et al*. 2007). Moist soils are more prone to runoff losses than drier soils. The grasses and fodders farming system had the maximum vegetation cover and therefore, showed maximum rainwater retention, while shifting cultivation showed the opposite due to sparse vegetation. In agroforestry farming system, the canopy of the trees was less up to about 5 years of study and, hence, yielded more runoff than other two farming systems. Low runoff from the farming systems is expected to result in low flows and sedimentation to the river channels, which could cause reduced incidences of floods in the plains in the long run. The results obtained corroborate the findings of Loch (2000) and Mingguo *et al*. (2007). Loch (2000), Dunjo *et al*. (2004) and Sriwongsitanon and Taesombat (2011),established the role of vegetation in reducing runoff from the agricultural lands.

4.5 Crop productivity

Nutrient inputs in crop production systems have come under increased scrutiny in recent years because of the potential for environmental impact from inorganic fertilizers. There was progressive increase in crop productivity in all the farming systems except the shifting cultivation (Table 5). This was because of the addition of chemical fertilizers in these farming systems as well as incorporation of the livestock manure of the animals kept in the respective land use systems. The increase in the crop yields with the addition of native soil deficit nutrients has been reported by many workers across the globe (Katyal and Agarwal, 1982; Halford, 1997; Sharma and Tripathy, 1999; Islam and Weil, 2000; Stewart*et al.,* 2005;Malhi, *et al.,* 2006;Ali,*et al*., 2008;Sharma and Sharma, 2009; 2010). Shifting cultivation was an acceptable land use when the population was low and the needs were meagre. About five decades ago, the shifting cycle was 25 to 30 years. The land used to get enough time for rejuvenation of vegetation for burning in the practice which was the reason behind this age old practice for addition of required nutrients. However, with increase in population, the shifting cycle has got reduced to 2 to 7 years and the land get sparse vegetation for burning and, hence, reduced soil fertility.

5 CONCLUSION

Shifting cultivation is the prevalent land use in the study area as the region occupying 255,090 km^2 area, is predominantly hilly. The practice is associated with substantial soil and nutrient erosion. The practice was acceptable when the population was less and shifting cycle was 25 to

30 years. But with fast population increase, the shifting cycle has come down to 2 to 7 years. The land does not get enough time for rejuvenation of vegetation, required for burning in the system to enhance soil fertility for optimum crop productivity. The study shows that the introduction of new eco-friendly and sustainable farming systems will be of great importance in arresting soil erosion, improving soil fertility and enhancing crop productivity on the hill slopes. Different FS had great influence on soil properties and helped in ameliorating the soil pH. The study also reveals that the farming system could be selected based on productivity, slope and needs of the community.

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اثر سیستم‌های مختلف کشاورزی بر حاصل‌خیزی خاک، فرسایش، رواناب و تولید محصول

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چکیده به منظور بررسی اثر کاربری اراضی بر ویژگی‌های خاک، فرسایش و تولید محصول، مطالعه‌ای صحرایی با چهار سیستم کشاورزی شامل چمن-علوفه، آگروفارستری، کشاورزی (سیستم جدید کشاورزی) و کشت متغیر (سیستم قدیمی) در یک خاک آلفی‌سول اسیدی با بافت لومی انجام گردید. در محل انجام پژوهش علاوه بر محصولات کشاورزی، دام نیز نگهداری می‌شده و لذا فضولات آن‌ها نیز در آبخیزهای مربوطه رها می‌شود .نمونه‌برداری خاک در هفته اول ماه می هر سال از عمق ۰-۲۰ سانتی‌متر و با مته انجام شد. پس از ۱۰ سال مطالعه افزایش قابل توجهی در کربن آلی خاک تا۰/۹۹ درصد، فسفر قابل دسترس تا ۱۷/۲ میلی‌گرم بر کیلوگرم، پتاسیم تا ۱۷۰ میلی‌گرم در کیلوگرم از خاک و pH تا ۶/۳ نسبت به مقادیر اولیه آن‌ها به‌ترتیب ۰/۴۶، ۲/۷، ۱۰۵و ۴/۹ در سیستم جدید کشاورزی مشاهده شد. در کشت متغیر، پتاسیمتا سه سال اول دوره مورد مطالعه افزایش و سپس کاهش یافت. اسید استیک Diethylene triamin epenta (DTPA)، روی قابل استخراج، منگنز، آهن و مس در تمام سیستم‌های کشاورزی کاهش یافت. در سیستم جدید کشاورزی محتوای آلومینیوم قابل تبادل از ۱۱۷ به ۳۷ میلی‌گرم در کیلوگرم از خاک کاهش یافت. این مطالعه نشان داد که در سیستم جدید کشاورزی حدود۹۱/۱ تا۹۹/۱ درصد از آب بارانمی‌تواند بسته به پوشش گیاهی حفظ شود در حالی‌که این مقدار در کشت متغیر۶۶/۳ درصد است. سیستم جدید کشاورزی خاک را با کاهش آلومینیوم قابل تبادل و آهن و هم‌چنین افزایش pH بهبود بخشید. در سیستم جدید کشاورزی در مقایسه با کشت متغیر، هدررفت خاک و مواد مغذی به‌طور قابل توجهی کم‌تر و بهره‌وری محصول بالاتر بود.

کلمات کلیدی: حاصل‌خیزی خاک، سیستم‌های کشاورزی، فرسایش خاک، کشت متغیر