Impact of land use and hydrology on the soil characteristics and productivity in highland agriculture with watershed approach

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Abstract
A multidisciplinary long-term study, with seven land use systems, was undertaken to monitor the impact of land use and hydrological regimes on the changes in soil properties and crop productivity. Results showed that maximum increase of available P was found in horticulture land use, where it increased from 2.7 (initial status) to 24.9 mg P/kg soil, followed closely by agri-horti-silvi-pastoral (21.4 mg P/kg soil), agriculture (17.6 mg/kg soil) and livestock based (16.2 mg/kg soil). The build-up of available K showed a similar trend, except that highest available K in the soil was found for shifting cultivation land use during first two years of study. Continuous vegetation cover and tree plantation had an ameliorating effect in the soil and considerably improved soil fertility and crop productivity. On an average, 0.09 to 1.41 t sediment yield/ha and more than 90% of rainwater was retained *in-situ* in new land use systems as compared to 36.21 t sediment and 66.3% rainwater retention in shifting cultivation. Due to more infiltration of rainwater in the soil because of good vegetation cover, the runoff has considerably reduced, resulting in low flows to river channels and reduced sediment load in the runoff.

Key Words
Land use, hydrology, soil characteristics, highland agriculture, productivity, watershed

Introduction

The north-eastern region of India, comprising seven states, is inhabited by various tribes. It receives 2450 mm as average annual rainfall, but its indiscriminate use and mismanagement has rendered the region in a fragile state. The region is predominantly hilly. Shifting cultivation is practised in 3869 km^2 area, annually, however, the total affected area is 14,660 km^2. It has resulted in a decline in soil fertility and huge soil erosion rates in the hills and silting of river beds and floods in the plains. Land use change and its hydrological consequences have received considerable attention in hydrology. The space-time distribution of soil moisture provides a crucial link between hydrological and biophysical processes through its controlling influence on transpiration, runoff generation, carbon assimilation and water absorption by plants. It is often suggested that it is important to include changes in hydrological fluxes and soil properties in response to land use change. Hydrologists have considerable interest in land use change and its hydrological consequences, both from the perspective of field monitoring (Bosch & Hewlett 1982) and from a modelling perspective (Niehoff 2002). Studies have shown significant effects of land use change on hydrological fluxes. It is a common practice to vary only the spatial distribution of the vegetation cover when modelling the effect of land use change (Fohrer *et al.* 2002). However, in the long term, the land use change will also have an effect on soil physical properties. Several studies on tropical soils reveal an increase in bulk density when forest land is converted to pasture or crop land (Murty *et al.* 2002). The fast growing population has put pressure on the food production base and to satisfy their needs, the people have mismanaged and misused water resources (Sharma 2003; Sharma and Sharma 2008). Due to anthropogenic and natural factors like prevalence of shifting cultivation, land tenure system, free range grazing, deforestation and heavy rainfall; there has been large-scale land and environmental degradation in the region. A multidisciplinary long-term study was undertaken to monitor the impact of land use and hydrological regimes on the changes in soil properties and crop productivity as well as extent of the soil and nutrient erosion due to runoff.

Methods

To evolve eco-friendly, viable and sustainable land use systems, a multi-disciplinary, long-term study was undertaken with different land use systems (Table 1) to monitor their comparative efficacy with regard to *in-situ* retention of rain water, water yield as runoff, effect on soil constituents, loss of soil from different watersheds as well as influence of livestock on soil properties. The livestock included cows, pigs, rabbits and goats. Sediment yield from erosion was evaluated through representative gauges installed at the exit point of each land use watershed. The runoff samples, whenever it occurred, were collected in a permanently fixed small structure and representative samples were drawn for the soil content and analysis of nutrient elements. A part of the runoff samples was dried to determine the sediment yield. The watersheds slope varied from 32% to 41% and soil and water conservation measures followed were contour bunds, trenches, bench terraces, half-moon terraces and grassed water-ways (Table 1). The monitoring gauges were installed at the exit point of each watershed and the observations were recorded during different years under various rainfall regimes. The initial soil status for different parameters was determined from the soil samples collected from the study site before the start of the experiment. The sampling was done from ten sites and the analytical results were averaged. To study the nutrient build-up, five soil samples were taken from each land use and analysed for various constituents. The samples were taken in the first week of May every year after the winter crops were harvested and before sowing the summer crops. The soil samples from the horticulture and agro-forestry treatments were also taken during this time of the year. The chemical analysis of soil and runoff samples was done as per Jackson (1973).

Table 1. Vegetation cover, livestock and soil and water conservation measures in different land use systems

Land use	Slope (%)	Crops / Trees	Livestock	Soil conservation measure
Fodders	32.0	*Zea mays*, *Stylosanthes guyanensis, Avena sativa, pisum sativum*, *Setaria sphaselata, Panicum maximum, Thysanolaena sphacelata*	Cows, pigs, rabbits	Contour bunds,trenches, grass water-ways
Forest	38.0	*Alder nepalensis, Albziia lebbeck, Acacia auriculiformis*	None	None
Agro-forestry	32.2	*Ficus hookerii, Eucalyptus amygdalina, Pinus longaeva, Ananas comosus*, *Phaseolus spp., Psidium guajava*	Goats, rabbits	Contour bunds
Agriculture	32.4	*Phaseolus spp., Raphanus sativus, zea mays*, *Oryza sativa, Zingiber officinale, Curcuma longa, Arachis hypogaea, Avena sativa*, *Panicum spp.* on risers	Cows	Contour bunds, bench terraces grass water- ways
Agri-horti-silvi-pastoral	41.8	*Phaseolus spp*., *Carica papaya*, *Citrus spp., Zingiber officinale, Solanum spp., Alder nepalensis, Ficus hookerii,Psidium guajava*	Pigs, goats	Contour bunds half-moon terraces, grass water-ways
Horticulture	53.2	*Prunus persica, Pyrus communis, Citrus spp., Citrus lemon, Psidium guajava* vegetables	None	Same as above
Shifting cultivation	45.0	Mixed cropping	None	None

Results

Soil properties

During the ten year study, there was a substantial build-up of available P over the initial status in all the new land use systems as compared to the shifting cultivation, in which the available P status remained constant (Figure 1). The maximum increase was found in the horticulture land use, where it increased from 2.7 to 24.9 mg P/kg soil, followed closely by agri-horti-silvi-pastoral (2.7 to 21.4 mg P/kg soil), agriculture (2.7 to 17.6 mg P/kg soil) and livestock based (2.7 to 16.2 mg P/kg soil). 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 (Sharma and Tripathy 1999). 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. Maximum decrease in exchangeable Al content was from 117 mg Al/kg soil to 30 mg Al/kg soil in the livestock based land use system followed by forestry land use where it decreased up to 40 mg Al/kg soil (Figure 1). The grasses and forest trees had more ameliorating effect and reduced the toxicity of Al. Like P, the build up of available K was significant in the new land use systems.

Interestingly, the available K was highest in the shifting cultivation during the first (160 mg K/kg soil) and second year (146 mg K/kg soil) of study. This could easily be attributed to the burning of forest vegetation in the shifting cultivation at the beginning of the study. The available K was subsequently reduced in shifting cultivation and was a little below the initial soil status (105 mg K/kg soil), however it continued to increase in other land use systems, highest being 185 mg K/kg soil in the horticulture land use. The Ca content of soil was also found to increase in the new land uses, more prominently in forestry and agro-forestry land uses. It shows that tree plantation and fall of litter (leaves with petioles) had affected the increase in Ca content of the soil. Similar trend was observed in pH increase where it increased from 4.9 to 6.3 in forestry and 6.2 in agro-forestry land uses.

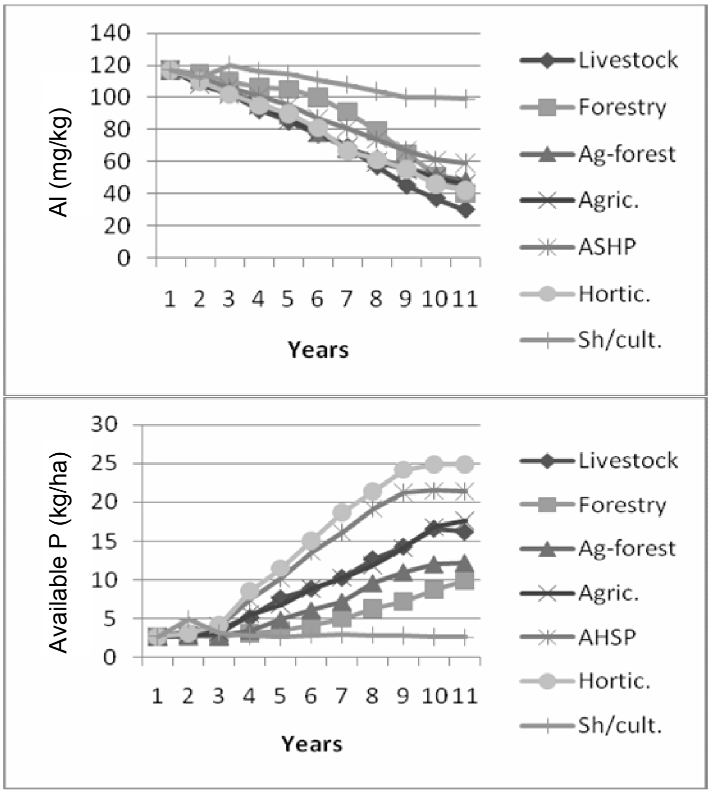

Figure 1. Change in Al and available P content of soil under various land use systems over the years.

Table 2. Effect of land use, rainfall and their interactions on groundwater recharge and sediment yield.

Land use	Rainfall (mm)						
	2195	2705	2770	2599	2288	1992	Mean
	Groundwater Recharge (mm) and Sediment Yield (t/ha) (in parentheses)						
Livestock based	738 (0.14)	1212 (0.16)	1294 (0.28)	1101 (0.18)	835 (0.10)	555 (0.09)	956 (0.16)
Forestry	426 (0.60)	729 (1.15)	746 (1.41)	663 (1.31)	477 (0.70)	338 (0.65)	563 (97.2)
Agro-forestry	560 (0.35)	954 (0.70)	984 (0.75)	870 (0.74)	633 (0.37)	459 (0.27)	742 (0.53)
Agriculture	731 (0.04)	1219 (0.09)	1289 (0.24)	1102 (0.22)	831 (0.04)	570 (0.03)	957 (0.11)
Agri-horti-silvi-pastoral	679 (0.20)	1134 (0.37)	1198 (0.36)	1021 (0.36)	769 (0.18)	526 (0.11)	888 (0.26)
Horticulture	516 (0.65)	897 (1.01)	914 (1.24)	815 (0.80)	590 (0.70)	420 (0.51)	692 (0.82)
Shifting cultivation	152 (29.50)	260 (45.80)	274 (44.99)	231 (36.10)	168 (34.19)	125 (26.69)	202 (36.21)
Mean	543 (4.47)	915 (7.04)	957 (7.04)	829 (5.67)	615 (5.18)	426 (4.05)	

Soil erosion and water yield

The results showed that on average, 0.09 to 1.41 tonnes of sediment yield ha^{-2} and more than 90% of rainwater was retained *in-situ* in new land use systems as against 36.21 tonnes of sediment and 66.3% rainwater retention in shifting cultivation (Table 2). Due to more infiltration of rainwater in the soil because of good vegetation cover, the runoff has considerably reduced, resulting in low flows to river channel and reduced sediment load in the runoff. Maximum *in-situ* infiltration was 39.3% of rainfall in livestock land use and minimum (8.2%) in shifting cultivation. This shows reduction in surface and base flows in new land uses due to sufficient vegetation cover. The enhancement of soil moisture was beneficial for the winter crops when there are no or little rains. The interactional effect of amount of rainfall and land uses was highly significant, while maximum soil loss was 44.99 t/ha in the shifting cultivation during the year when rainfall was 2770 mm and minimum, 0.09 t/ha in livestock based land use when annual rainfall was 1992 mm.

Crop productivity

The crop yield increase in new land uses was, on average, 2.6, 2.3, 2.1, 2.7, 3.2, 3.1, 1.9, 2.3, 2.5 and 3.7 times higher in case of rice, maize, ginger, turmeric, radish, sweet potato, pine-apple, citrus, guava and grasses/fodders, respectively, over the yields from the shifting cultivation.

Conclusion

Shifting cultivation is an age-old practice of land use. It was alright when the population was small, the food requirements were limited, and the shifting cycle was 25 to 30 years. Within this long period, the forest vegetation used to be sufficient to burn and add enough nutrient to sustain soil fertility to get optimum productivity. However, with increases in demographic pressure, the shifting cycle has come down to 2 to 10 years. The land does not have enough time for the rejuvenation of vegetation. The soil fertility is on the decline, the productivity is low and the system has become uneconomical. Furthering the woes, the high rainfall received in the region and mismanagement of rainwater has resulted in extreme soil erosion through runoff in the hills and silting of river beds and floods in the valley areas. The new land use systems tried are soil health friendly, highly productive, eco-friendly and sustainable and need to be popularized to replace shifting cultivation, reduce soil erosion, judicious management of rainwater as well as improve soil health, productivity and quality of life of the people.

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