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Full Research Article

Impacts of Agroforestry Systems on Soil and Nutrient Conservation in the Eastern Himalayas, India

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Abstract

In a field experiment, soil moisture, soil and nutrient losses, and surface run-off in agri-silviculture (hedgerow and alder based) and agri-horticulture (guava based) agroforestry systems (AFS) were monitored for five consecutive years (2002–2006). Soil moisture was significantly (p=0.05) higher in agri-silvi based AFS compared with sole crop field (control; without a tree). On average, soil loss was 1.97±0.19, 8.91±0.98 and 12.49±1.22 t ha^{-1}, respectively, in hedgerow, alder and guava based AFS compared to as high as 35.27±2.96 t ha^{-1} in the control plots. Mean (of all AFS systems) surface run-off was about 70% less in the plots under AFS compared with the control plots (1643.4 mm). Hedgerow based AFS was most efficient in minimizing surface run-off compared to other land use systems. Rainfall had significant positive (p<0.01) correlation with soil and nutrient loss. Significant monthly variations were also observed for nutrient loss in different AFS. Irrespective of monthly variations, organic carbon loss ranged from 1.09±0.04–1.11±0.10% in different AFS compared to 0.96±0.06% in control. Average nitrogen loss ranged from 172.0±11.45–175.08±9.43 kg ha^{-1} in various AFS as against of 169.17±12.33 kg ha^{-1} in control plots. Range of phosphorus and potassium loss was, respectively, 6.19±0.63–6.49±0.54 and 165.0±11.45–175.08±13.05 kg ha^{-1}. In control plots, loss of phosphorus and potassium was found to be 6.49±0.33 and 169.0±10.50 kg ha^{-1}, accordingly. All these systems have been reported to be ecologically and economically viable in the region.

1. Introduction

Soil erosion is one of the most common problems, responsible for land degradation throughout the world including Himalayan region of India (Borthakur, 1992). Rainfall and run-off induced soil erosion are particularly severe in humid tropics, especially from the marginal lands with steep slopes and poor soil structures (Ramakrishnan, 1992). In Eastern part of the Indian sub-Himalayas, increased level of soil erosion, hydrological imbalance and over exploitation of forest resources has resulted into reduced jhum cycle and thereby sharp decline in crop yield (Sundriyal, 2002).

The potential of using woody perennials has often been emphasized for conservation as well as production in the hilly terrain Agroforestry land use system has been found ecologically and economically viable in mountain villages including humid tropics of the Eastern Himalayas of India (Puri and Nair, 2004). Although many research reports are available on production aspect of various agroforestry systems (AFS) in the Eastern Himalayas (Bhatt et al., 2001; Bhatt and Misra, 2003; Dhyani and Tripathi, 1999; Satapathy, 2006; Jamir et al., 1998), very few findings are available on soil and nutrient losses in the plots under suitable AFS. Hence, we hypothesized that the AFS would significantly reduce soil and nutrient loss compared to control plots due to protective cover by different tree species. To test this hypothesis, the major objective of the present investigation was to evaluate soil, water and nutrient loss in the plots under different AFS as well as control plots during 2002−2006 (after one year of planting), with a minor objective to find out rainfall-run-off and rainfall-soil loss relationships in a sandy loam soil of the eastern part of the Indian sub-Himalayas.

2. Materials and Methods

2.1. Experimental site

The experimental site is located in between 25°39′–25°41′ N latitude and 91°54′–91°63′ E longitude. The altitude of the farm ranges from 900 to 950 m amsl. The climate of the area is humid subtropical with an annual rainfall of 2393.8 mm. On average, 90% of the total rainfall is received during April-October. The mean maximum and minimum temperature is 29.2 °C (June) and 6.07 °C (January), respectively. The soils of the experimental area was sandy loam, phosphorus deficient, acidic Alfisol (Majumdar et al., 2004).

About 10 ha of fallow land were taken up for rehabilitation through agroforestry interventions in the year 2001–2002. Average soil depth was ≥1.0 m and the slope percentage of the area ranged from 6.40 to 6.75. Contour bund was followed as a major tool for soil and water conservation across the slope at a vertical interval of 3 m and also for gradual conversion of hill slope into terraces (Singh, 1990).

2.2. Experimental details

Out of the 10 ha of area, about 1.54 ha area was selected and divided into small plots, each of 500 m^2 area. In all 33 plots were made to plant 6 hedge species (*Cajanus cajan*, *Crotolaria tetragona, Desmodium rensonii*, *Flemingia macrophylla, Indigofera tinctoria* and *Tephrosia candida)*; Himalayan alder (*Alnus nepalensis*), and guava (*Psidium guajava*) cv. *Allahabad safeda* with three replications for each species in randomized block design (RBD). Hedge species were planted as a thick row on contour bunds whereas, alder and guava were planted on contours across the slope at 5×5 m^2 distance from plant to plant and row to row. While making the plots, care was taken to ensure similar slope conditions (average 6.58), soil types and exposure.

Soil samples from all the plots were collected from 0–15 cm soil depth using screw type auger, and composite samples were analyzed for soil pH, organic carbon and nutrient status with five replications. Soil pH, organic carbon and phosphorus in soil samples were estimated following the methodology suggested by Jackson (1973). Soil available potassium was measured by flame photometer and nitrogen by the Kjeldahl method. Initial values were 4.45±0.10, 1.65±0.12%, 275.0±6.50 kg ha^{-1}, 3.20±0.21 kg ha^{-1}, 297.0±5.94 kg ha^{-1}, 0.51±0.04 meq 100 g^{-1} and 0.39±0.01 meq 100 g^{-1}, respectively, to soil pH, organic carbon, available nitrogen, phosphorus, potassium, calcium and magnesium.

Plant density for hedge species ranged from 773.0±10.5–833.0±12.5 nos. $plot^{-1}$ with highest to *C. tetragona* and lowest to *T. candida*. In case of tree species, 30 seedlings were accommodated in each plot. A uniform basal dose of 500 g di-amino phosphate (DAP) and 10 kg farmyard manure (FYM) was applied in each pit (0.60×0.60×0.75 m^3) at the time of planting. Hedgerow and alder plots were treated as agri-silviculture AFS whereas, guava blocks as agri-horticulture AFS. Three plots were left for sole cropping to serve as control.

2.3. Crop cultivation

Maize (*Zea mays*) cv Vijay composite followed by mustard (*Brassica campestris*) var. M-27 and potato (*Solanum tuberosum*) var. Kufri Jyoti was intercropped in agri-silviculture and agri-horticulture AFS including in the control plots for year-round cultivation throughout the period of experiment (2002–2006). Maize was sown in last week of April in each year (distance- 0.5 m from row to row, 0.25 m from plant to plant) and harvested by last week of September. Recommended dose of N, P_2O_5 and K_2O (80:60:40 kg ha^{-1}) was applied in the maize plots. Thereafter, mustard was sown in the same plots (distance- 0.30 m from row to row, 0.10 m from plant to plant) in the second week of October and harvested in last week of December. The fertilizer dose was 60:60:40 kg ha^{-1}, respectively, of N, P_2O_5 and K_2O for the mustard crop. Potato was sown in the second week of January (distance- 0.60 m from row to row, 0.15 m from plant to plant) and harvested in the first week of March every year. Fertilizer dose to potato crop was 100:100:150 kg ha^{-1}, respectively, of N, P_2O_5 and K_2O. In each plot of guava and alder, crop productivity under 10 plants was discarded to avoid bordering effects (Puri and Nair, 2004). Economic yield ha^{-1} expressed was calculated on the basis of the yield from the entire plot (Semwal and Maikhuri, 1996).

2.4. Installation of filter type silt sampler and run-off estimation

Twenty seven numbers of filter type silt samplers were installed in suitable places to monitor soil loss from samples plots of 500 m^2 area in each land use. The design of the samplers used was modification of filter type silt sampler designed and developed by Indian Council of Agricultural Research (ICAR)-Research Complex for North Eastern Hill Region, Umiam, Meghalaya (Satapathy, 2006). The design essentially consisted of reduction in height of the sampler through the trough placed at top for ease of installation and operation. The eroded soil along with the water entered the sampler through the trough placed at top. The sample gets filtered in the central filtering cylinder and clear water flowed out through the outlet pipe at bottom. The soil retained was collected and dried to estimate soil loss from the contributing plot. Representative samples of the eroded soil collected in the filter type silter were taken for nutrient analysis. Rainfall, and maximum and minimum temperature was also recorded at experimental site besides soil moisture in each land use.

Run-off in each system was calculated by rational method (Schwab et al., 1993) as detailed below:

Q=0.0028 Cia

Where q=design peak run-off rate in $m^3 s^{-1}$; C=run-off coefficient and i=rainfall intensity in mm h^{-1} for the design return period and for a duration equal to the "time of concentration" of the area.

3. Results and Discussion

3.1. Temperature, rainfall, soil properties and Crop productivity

Monthly mean of maximum daily temperature vary from 21.75 °C in January to 29.20 °C in June. Mean temperature was consistent during June to September and decreased thereafter. Similar trend was observed in case of monthly mean of minimum daily temperature also, with values in the range of 6.07 °C in January to 20.91 °C in August (Figure 1). The mean (during the experimental period of 2002–2006) annual rainfall during was 2393.80±112.6 mm with a maximum monthly rainfall of 495.8±35.64 mm in May in all five years. On average, May month of each experimental year received almost 21% of the total rainfall, followed by July (Figure 2). On average, precipitation mainly occurred only during June to October at the experimental site. Soil organic C and nutrient (N, P and K) concentrations significantly increased in the plots under AFS compared to the initial values. After six years of planting, plots under AFS had significantly larger SOC content in the 0–15 cm soil layer than the control plots (Table 1). Significant variations were observed for soil pH also in different land use systems (Table 1). Compared with control, significantly higher, nitrogen, phosphorus, potassium, calcium and magnesium was recorded in different AFS. Although, different AFS did not exhibit significant variations for nutrients,

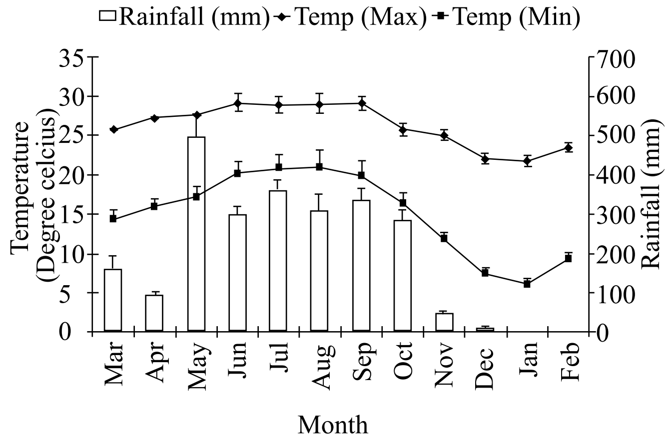

Figure 1: Rainfall, maximum and minimum temperature at experimental farm in Eastern Himalaya, India (vertical bars representing±SD)

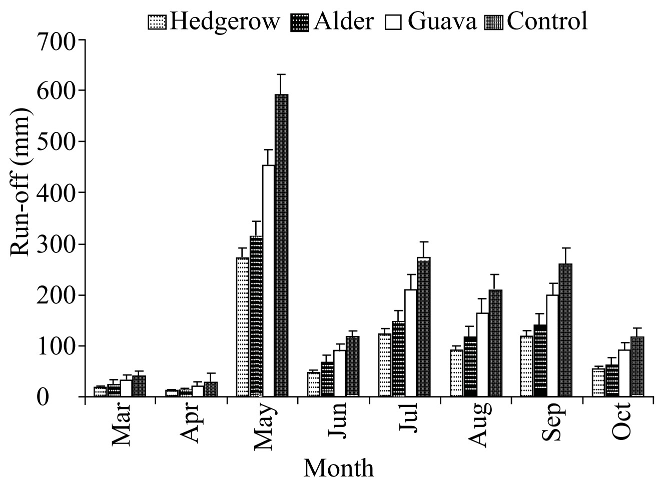

Figure 2: Mean (2004–2006) run-off in different land use systems, Eastern Himalaya, India (vertical bars representing±SD)

Table 1: Selected soil (0–15 cm) characteristics of the experimental site, Meghalaya, India as affected by different land use systems after five years of their adoption

Soil parameters	Agroforestry systems			Control (without tree)
	Agrisilviculture (hedgerow based) AFS	Agrisilviculture (alder based) AFS	Agrisilvi culture (guava based) AFS	
Soil pH	4.61±0.10[a]	4.76±0.09[ab]	4.92±0.14[b]	4.99±0.11[b]
Organic carbon (%)	3.42±0.21[a]	2.97±0.19[a]	2.94±0.26[a]	1.91±0.16[b]
Available nitrogen (kg ha^{-1})	485.0±23.50[a]	562.0±46.54[a]	492.0±37.32[a]	400.0±28.11
Available phosphorus (kg ha^{-1})	7.39±0.41[a]	4.48±0.31[c]	5.60±0.28[b]	3.50±0.31[d]
Available potassium (kg ha^{-1})	392.0±23.54[a]	403.0±28.32[a]	362.0±31.39[a]	291.0±16.85[b]
Exchangeable				
Calcium (meq 100 g^{-1})	1.96±0.11[a]	1.57±0.13[b]	2.11±0.10[a]	0.65±0.09[c]
Magnesium (meq 100 g^{-1})	0.71±0.07[a]	0.55±0.08[a]	0.63±0.07[a]	0.38±0.04[b]

Means (n=3) followed by the same lower case letters within a row are not significantly ($p<0.05$) different; Organic C was oxidizable soil organic C determined following Walkley and Black (1934).

highest build up of SOC (3.42±0.21%), P (97.39±0.41 kg ha^{-1}) and mg (0.71±0.07 kg ha^{-1}) was recorded in agri-silvi system (hedgerow based) compared to others. Nitrogen and potassium was recorded highest in alder based system (562.0±46.54 kg ha^{-1} and 403.0±28.32 kg ha^{-1}, respectively) whereas, Ca was highest (2.11±0.10 meq 100 g^{-1}) in agri-horti system. Phosphorus content differed significantly between different land use systems including control. Significantly higher crop yield was recorded in control plots compared to AFS. Between systems, maize yield was significantly higher in agri-horticulture AFS than agri-silvi system. Similar was the trend in potato yield. Mustard yield was also significantly higher in agri-horti system compared to agri-silvi system (alder based). Crop yield in both the agri-silvi systems, however, did not differ significantly. Compared to control, maize, mustard and potato yield was, respectively, 20.2, 19.7 and 10.9% low in agroforestry land use (Table 2).

3.2. *Soil loss under different land use systems*

Significant monthly variations were also observed for soil loss in different land use systems (Table 3). Hedgerow system was found most suitable to reduce the soil loss, followed by agri-silvi (alder based) and agri-horticulture AFS. Compared to control, woody perennials checked the soil loss by 94.4, 74.7 and 64.6%, respectively, when hedgerow, alder and guava was intercropped. Soil loss in control plots was 35.27±2.96 mg ha^{-1}. Among various months, soil loss was found maximum in the May (range 0.51±0.012–9.41±0.67 mg ha^{-1}), which was directly related to the amount of rainfall.

3.3. *Impacts of agroforestry systems on run-off yield*

Significant monthly variations were recorded for run-off in each land use. On average, run-off was highest in May, followed by July in each system including control. Total run-off was, however, 745.66±81.76, 897.74±94.98 and 1270.57±135.83 mm $annum^{-1}$, respectively, in hedgerow and alder based agri-silvi, and agri-horti AFS compared to 1643.4±176.70 mm in control plots. On average, *in situ* moisture conservation was highest (68.85±4.54%) in hedgerow, followed by alder based agri-silvi (62.49±7.50%) and agri-horti AFS (53.01±8.90%), respectively, compared to 31.3±2.67% in control plots . Significant positive correlation was recorded between rainfall and run-off in all the land use systems.

Table 2: Crop productivity (mg ha^{-1}) in different agroforestry systems during 2004–2006, Meghalaya, India

Agroforestry systems	Mean (of three years) yield (mg ha^{-1})		
	Zea mays	*Brassica campestris*	*Solanum tuberosum*
Agrisilviculture (hedgerow)	1.64±0.069[a]	0.61±0.010[b]	15.14±0.146[a]
Agrisilviculture (alder)	1.61±0.057[a]	0.59±0.017[b]	15.60±0.231[a]
Agrihorticulture (guava)	1.68±0.095[a]	0.62±0.017[b]	16.45±0.340[ab]
Control (without tree)	2.06±0.075[b]	0.76±0.013[a]	17.65±0.265[b]

Between columns, means followed by the same lowercase letter are not significantly (p<0.05) different

3.6. *Carbon and nutrient loss through run-off water*

Significant seasonal variations were observed for organic carbon loss in different AFS including control (Figure 3). During the period of May-August, organic carbon loss was highest (range 10.0–16.0%) in all the plots including control. Carbon loss was significantly higher in AFS compared to control. Similar to organic carbon, significant seasonal variations were found in nutrient loss in all the systems. Inter-comparing nutrient loss between systems, no significant variations were observed, however, maximum nitrogen (175.08±9.43 kg ha^{-1}) and potassium (175.08±11.20 kg ha^{-1}) loss occurred in alder based AFS. Phosphorus loss was, however, highest in agri-horticulture and control plots (6.49±1.24 kg ha^{-1}). Rainfall had significant (p=0.01) positive correlation with organic carbon and nutrient loss in all the systems including control.

3.7. *Soil moisture*

Soil moisture had significant (p<0.01) monthly variations in each land use. On average, soil moisture was high during May–August and decreased during winter months (Figure 3). Hedgerow system retained maximum moisture (31.4%, irrespective of monthly variations) into the soil, followed by alder (29.4%) and guava (27.7%). Compared to control plots, hedgerow and alder plots had significantly higher moisture percentage. However, no significant variations were recorded for moisture content between systems.

3.8. *Crop productivity and biomass input*

Agroforestry land use has been found efficient for soil conservation and minimizing surface run-off in Eastern Himalayan region. Crop productivity observed in the present investigation was within the range as reported by Bhatt et al. (2001) for maize and mustard, and Dhyani and Tripathi (1999) for maize in selected AFS in Meghalaya, India. Productivity of maize and potato was significantly (p=0.05) higher in guava blocks compared to agri-silvi AFS, indicating favourable growth of light demanding food crops in the understory of guava. Bhatt and Mishra (2003) also recorded higher crop yield in agrihorticulture AFS than agrisilvi system in Meghalaya, which supports the present findings.

Owing to short gestation period, high survival percentage and quick growth along an elevational transect (200–1650 m

Table 3: Mean (during 2004–2006) annual soil loss under different agroforestry systems in Meghalaya, India

Months	Soil loss (mg ha^{-1})			Control (without tree)
	Agrisilviculture (hedgerow based) AFS	Agrisilviculture (alder based) AFS	Agrisilvi culture (guava based) AFS	
March	0^{b}	0.42±0.011^{ab}	0.73±0.004^{a}	1.37±0.17^{a}
April	0^{c}	1.26±0.09^{b}	1.56±0.013^{b}	3.52±0.23^{a}
May	0.51±0.012^{c}	3.23±0.10^{b}	4.07±0.103^{b}	9.41±0.67^{a}
June	0.27±0.006^{c}	1.94±0.113^{b}	2.35±0.081^{b}	6.74±0.49^{a}
July	0.22±0.004^{d}	0.83±0.008^{c}	1.50±0.065^{b}	5.02±0.38^{a}
August	0.20±0.007^{d}	0.54±0.006^{c}	1.09±0.034^{b}	3.68±0.31^{a}
September	0.43±0.013^{c}	0.41±0.005^{c}	0.84±0.021^{b}	3.17±0.29^{a}
October	0.34±0.011^{b}	0.28±0.003^{b}	0.35±0.012^{b}	1.64±0.26^{a}
November	0^{b}	0^{b}	0^{b}	0.72±0.11^{a}
December	0	0	0	0
January	0	0	0	0
February	0	0	0	0
Total	1.97±0.19^{d}	8.91±0.98^{c}	12.49±1.22^{b}	35.27±2.96^{a}
'r'	0.91**	0.70**	0.77**	0.86**

Means followed by the same lowercase letters within a row are not significantly (p<0.05) different. 'r' represents correlation coefficient computed between rainfall and soil loss (**indicates significant at (p<0.01)

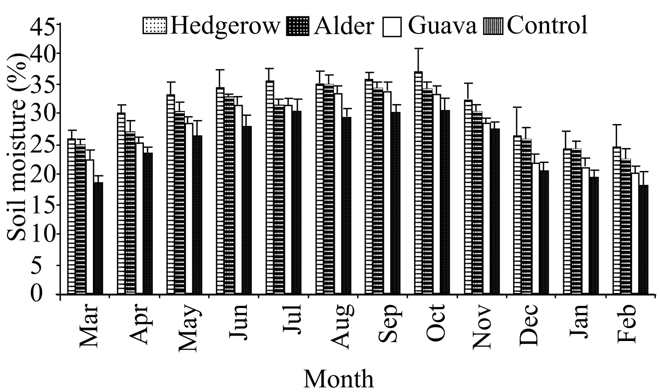

Figure 3: Soil moisture percentages in different land use systems, Eastern Himalaya, India (vertical bars representing±SD)

amsl), *C. cajan*, *C. tetragona*, *D. rensonii*, *F. macrophylla*, *I. tinctoria* and *T. candida* hedge spp. could be successfully introduced for biomass augmentation, soil fertility buildup and soil conservation in Eastern Himalayas (Jamir et al., 1998; Sundriyal and Jamir 2005). Pruned biomass yield of hedge spp. ranged from 4.70±0.47–19.50±0.69 t ha^{-1} (Laxminarayana et al., 2006), which was well within the range as reported by Sundriyal and Jamir (2005) for the same species. Among various species, *C. cajan* and *T. candida*, respectively, had lowest and highest biomass yield. pruned biomass yield of 16.0–20.0 t ha^{-1} in *L. leucocephala* in fertile humid environments, which also supports the present findings. All the species also had high nitrogen concentration (range 3.29±0.14–3.86±0.13%), which might be due to fixation of atmospheric nitrogen, mineralization of organic matter and subsequent accumulation in the foliage. On average, hedge spp. added 20.0−80.0, 3.0−14.0 and 8.0−38.0 kg ha^{-1} yr^{-1}, respectively, of nitrogen, phosphorus and potassium in the soil. Although seed was the main source of propagation in all the hedge spp., however, *F. macrophylla* could also be multiplied successfully through branch cuttings (personal observations of authors). Below ground biomass yield was also recorded high (≥40.0%) in *F. macrophylla* compared to other spp., indicating its adaptability under harsh environmental conditions (Bhatt et al., 2006).

3.9. *Selected soil properties*

Significant variations were recorded for soil characteristics between different land use systems. There was significant increase in soil nutrients after three years of plantation compared to initial nutrient status. Although organic carbon and potassium status in soils of agroforestry land use was high, phosphorus and magnesium had low status. Nitrogen and calcium status was medium in agroforestry land use including control (Jackson, 1973). However, nutrient status of the soils was well within the range as reported by earlier workers for agroforestry systems in acid Alfisols of Meghalaya, India (Majumdar et al., 2004; Majumdar and Venkatesh, 2006).

3.10. *Run-off and soil loss*

Significant (p<0.05) monthly variations were recorded for soil and nutrient loss in all the AFS and control plots with higher values during May–July, which coincides with amount of rainfall. Similar was the trend for soil moisture percentage. Significant positive ($p<0.01$) correlation was recorded between rainfall and soil loss in all plots under AFS including control. Similar was the trend for rainfall and nutrient loss. In general, nutrient loss followed the pattern of volume of soil loss. Agroforestry land use minimized the soil loss by 78.0% (with highest–94.4% in hedgerow agrisilvi system) compared to sole crop fields. Thus, hedgerows were more effective in arresting displaced soil in crop field than the trees because of their closer planting and weed growth in the inter-row spaces providing more or less a continuous vegetative barrier. In an earlier study, Sundriyal and Jamir (2005) also reported that soil loss was minimized by 80% in hedgerow plots in humid tropics of India. *Leucaena leucocephala* hedgerow and *Eucalyptus* hybrid, has also been reported to minimize soil loss by 71.2 and 81.2%, respectively, in maize-wheat cropping system in western Himalaya (Narain et al., 1998). Present findings are also in agreement with these observations.

Jhum cultivation has caused severe environmental degradation in Eastern Himalaya (Ramakrishnan, 1992). Soil loss in first year of cropping in jhum field has been reported to be 47.0 t ha^{-1} yr^{-1}, which increased to 147.0 and 174.0 t ha^{-1} yr^{-1} in second and third year, respectively (Borthakur, 1992). Compared to western Himalayan region, soil loss in first year jhum field itself has been found to be 8.0 ton higher (Narain et al., 1998). In order to minimize soil loss, agroforestry land use could be adopted in jhum areas.

Significantly higher ($p<0.01$) *in situ* moisture conservation was also recorded in agroforestry land use systems compared to control plots. Large intense rainfall events with high antecedent moisture content in soils generated most of the run-off from the respective land use systems. Hedgerow planting, followed by alder was most effective in retaining annual rainfall, which may be attributed to the high infiltration rates maintained by its high leaf litter fall. Rainfall amount, intensity, duration and frequency of occurrence might have caused considerable variation in stream flow as no consistency in run-off was recorded (Sundriyal 2002). Most of the times, precipitation was too small or too infrequent to generate stream flow. It was also found that even when the antecedent soil moisture was abnormally high, heavy rains resulted in negligible amount of direct run-off.

Based on the run-off and soil losses, land use systems can be ranked in the order of agrisilviculture (hedgerow)>agrisilviculture (alder)>agrihorticulture (guava)>control. In an earlier study, Satapathy (2006) also recorded minimum surface run-off in agrihortisilvipastoral (20.0%) and agrisilviculture (28.0%) AFS in Meghalaya, India, which support the present findings. Narain et al. (1998) reported that contour paired rows of *L. leaucocephala* in maize based cropping system could reduce run-off by 41% in foothills of Western Himalaya. A similar trend was reported by Konig (1992) from Butare (Rwanda) using leguminous hedgerows of *Calliandra calothyrsus* and *Leucaena leaucocephala* at 28% sloping land.

Throughout the North Eastern Himalayan region, many agroforestry systems have already been developed by integrating *A. nepalensis*, e.g., alder-large cardamom plantations in Sikkim (Sharma et al., 1994), multistoried AFS with alder-black pepper-turmeric/ginger in Meghalaya and Manipur (Bhatt et al., 2001), alder based indigenous farming system developed under Nagaland empowerment of people through economic development (NEPED) project in Nagaland (Bhatt et al., 2006). All these systems have been reported to be ecologically and economically viable in the region. In case of present study, this pioneer species minimized soil loss by 74.70%. Guava though new introduction in the region, is gaining popularity since last two decades either for orchard development or in home garden throughout the North East (Yadav et al., 2006). Soil loss was minimized by 64.6% in guava block compared to sole crop field.

4. Conclusion

Owing to short gestation period and wide ecological amplitude, hedge species like *C. cajan*, *C. tetragona*, *D. rensonii*, *F. macrophylla*, *I. tinctoria* and *T. candida* besides *A. nepalensis* has a potential for some improvement in traditional land use systems, e.g., shifting cultivation in order to minimize soil and nutrient loss, *in situ* moisture conservation, apart from biomass augmentation.

5. Acknowledgement

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