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Toposequential agroforestry based land use system for soil and water conservation in sloping lands

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Abstract
Combination of suitable agroforestry systems can achieve the goal of resource conservation. In an experiment, a sloping land with 12-14 per cent slope was put under silvihortipasture and hedge-row intercropping along with water harvesting structures. Event wise runoff and soil loss was measured for the whole system. On an average agroforestry system reduced soil loss from 1.22 to 0.17 t/ha in six year period. The system was also able to increase runoff from 6.8 to 18% resulting in positive water balance in water harvesting structure created at bottom of the system which could be used as irrigation source for sustaining plantation and agricultural crops.

Keywords: Runoff, Shivaliks, Sloping land, Soil loss, Water harvesting

Introduction
Land degradation, water induced soil erosion, and declining agricultural production are intertwined with climate change in mountainous ecosystem and posing threats to their sustainable development (Bhattarai *et al*., 2009; Manandhar *et al*., 2011). Lack of appropriate management practices is also a key reason for land degradation (Chaturvedi *et al*., 2016). Soil and water loss from sloping agricultural lands not only cause reduced agricultural production but also jeopardize the natural function of hill ecosystems (Chhetri, 2011; Lenka *et al*., 2012). The Himalayan ecosystem provides a rich base for high value agriculture, forest cover, source of drinking water through network of perennial rivers, irrigation, hydro energy, wide biodiversity and tourism. Therefore, the ecological security of the Himalayan ecosystem is crucial for the livelihood of about 1.3 billion people in Asia (Anonymous, 2010). In this context, agroforestry can play an important role as it is important land use system for rural communities in hilly states (Rizvi *et al*., 2017).

Shivalik region is located between 28^0 57' 16" and 34^0 10' 48" N latitudes and 73^0 29' 24" and 80^0 14' 23" E longitudes in north-western part of India stretching from Jammu & Kashmir in north-west to Uttarakhand and it passes south-easterly through Punjab, Himachal Pradesh, Chandigarh, Haryana and Uttar Pradesh (Fig 1). The region covers an area of 3.3 million hectares (Yadav *et al*., 2015). The characteristic features of Shivaliks are undulating topography, steep slopes and easily erodible soils. Water scarcity for irrigation is one of the most critical issues constraining sustainable development of the region.

The Shivalik region is dominated by small and marginal farmers having land holding size less than one hectare. Erratic rainfall, degraded soils and poor resource base of farmers are some principal constraints affecting productivity and sustainability of rainfed farming in the region. The sloping topography can become a boon for water harvesting in Shivaliks, as the rainfall received is sufficient (average rainfall 1100 mm) but most of it is lost as runoff. The voluminous runoff on sloping topography leads to high erosive power in monsoon leading to severe soil erosion. Immediate actions are required to ensure long term sustainability of these sloping lands. A combination of agroforestry system was tried for conserving natural resource along with water harvesting for diversified production. The present paper provides the outcome of adopting toposequential agroforestry on soil and water conservation.

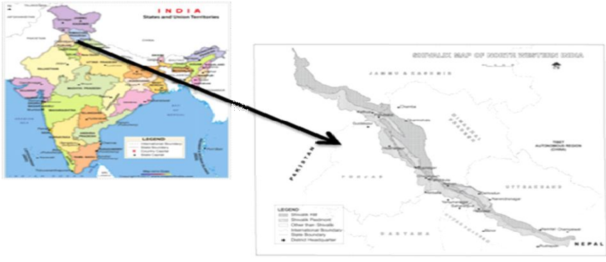

Fig 1. Shivalik region of north western Himalayas, India

Materials and Methods

Study site: The study was carried out at research farm of ICAR- Indian Institute of Soil and Water Conservation at Panchkula district of Haryana, India which is located at Shivalik Himalayan region of India. As per the USDA soil taxonomy, the soil of the study area is classified as light textured hyper thermic Udic Ustochrept (Grewal *et al*., 1996). The soil is sandy to sandy loam in texture, well drained with low water holding capacity. The area receives 1100 mm of mean annual rainfall out of which 80% occurs during the monsoon season (June to September months). The land having slope varying from 12 to 15% was selected for establishment of the system.

Choice of species: In the year 2010-11, about one hectare land was earmarked and was divided into three parts: upper, middle and lower. At upper part of the sloping land *Emblica officinalis* (aonla) (42 numbers) and *Melia composita* (dake) (45 numbers) were planted at a spacing of 5 X 5 m in alternative rows. *Eulaliopsis binata* (bhabbar grass) was intercropped with trees in 2012-13. Thus, the system developed was silvi–horti-pasture. In the middle portion, the sloping land was converted to terraces. On the outer edge of the terraces *Leucaena leucocephala* (subabul) was planted (95 numbers) in a liner row at spacing of one meter and was maintained as hedge with the height up to one meter. *Psidium guajava* (guava) (57 numbers) was planted in the interspaces of *Leucaena* at a distance of five meter within the row. The basic principle of agroforestry management is reducing competition (above and below ground) among the associated components. Reducing the height of the tree component automatically reduces the aboveground competition as posed by shade. Thus, leucaena and guava were maintained as hedge. Agriculture crops were grown on the terraces. At lower end of the sloping land, a farm pond of 0.12 ha meter capacity was dug up, after contour survey, to collect the runoff generated through the system (Fig 2). The water harvested was utilized for life saving irrigation to the horticultural and agricultural crops grown in the catchment area of the pond.

Measurement of runoff and soil loss: To measure runoff and soil loss gauging station was installed with automatic stage level recorder which draws graphs based on volume of flowing water passing through the weir. The weir installed was 120^0 V notch with the height of 30 cm. Time *vs.* stage relationships (height of flow of water) marked on the graphs was read and with the help of empirical formulae, the water discharge from V notch was calculated. The runoff was monitored every monsoon from the year 2010 till 2015. The water samples were collected from the runoff for each event and soil loss was determined by evaporating water from a known quantity of runoff water. The total soil loss per rainfall event was calculated as follows:

Soil loss = Total runoff volume x soil loss per liter of water

Time to peak (Tp in minutes) and peak discharge (Qp in liters per second) were also calculated during 2011 and 2015.

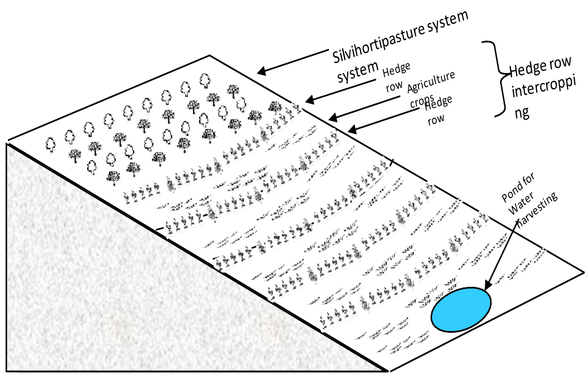

Fig 2. Line diagram showing layout of the system at research farm

Results and Discussion

Plant growth: After five years of plantation, growth and biomass of the plants were measured. It was observed that average height of *Melia composita* was higher (5.38 m) followed by *Emblica officinalis* (2.5 m). *Psidium guajava* and *Leucaena leucocephala* were maintained at a height of 1.5 and 1 m, respectively through regular pruning to convert them to hedge. Unlike height, biomass of *Leucaena leucocephala* was higher than *Emblica officinalis* (Fig 3).

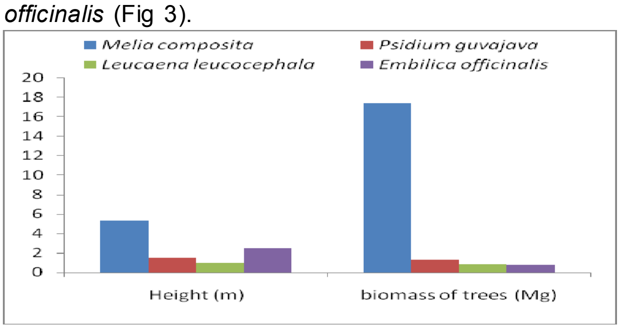

Fig 3. Height and biomass of trees after five years of plantation

Runoff and soil loss: Event wise runoff from the system was measured from the year 2010 to 2015 (Fig 4). A progressive increase in runoff was observed over the years, as depicted through the regression line in figure 4. On an average runoff increased from 6.8% in the year 2010 to 18% after five years of establishment of the system. The soil loss measured during the corresponding years was also recorded (Fig 5). The soil loss decreased with passage of time. The regression line clearly depicted the decreasing trend in soil loss as the system grew in age. On an average soil loss decreased from 1.22 t/ha in the year 2010 to 0.17 t/ha in the year 2015.

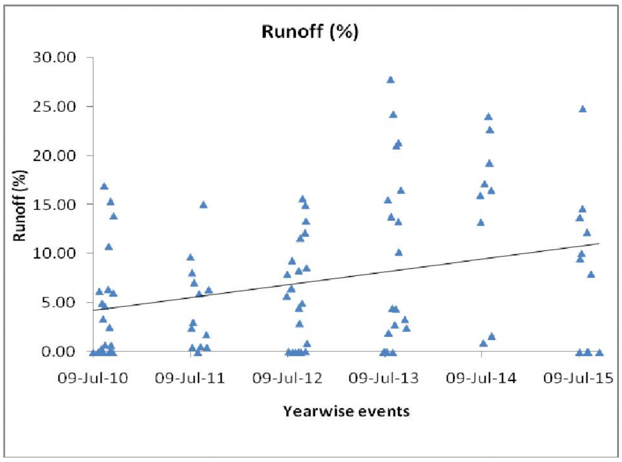

Fig 4. Event wise runoff in per cent of the rainfall

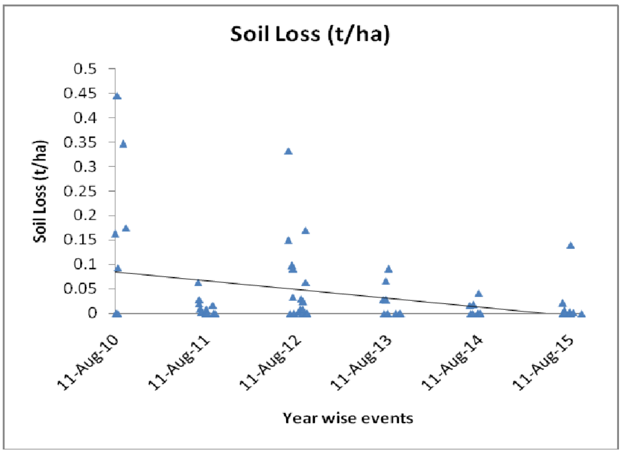

Fig 5. Event wise soil loss (t/ha)

***Time to peak (Tp) and peak discharge (Qp)*:** A land use system is categorized as effective in natural resource conservation if time taken by runoff water to reach the peak discharge from land use is increased and simultaneously the highest amount of discharge per unit time is reduced. The combination of the agroforestry land uses in sloping land was able to increase the time to peak from average 35 minutes in the year 2011 to 42 minutes in year 2015 (Table 1). The amount of average water flowing per second was 0.46 liters per second in year 2011 which decreased to 0.12 liters per second in year 2015 (Table 1). This implied that the water moved slowly and for longer period of time from the system.

Table 1. Time to peak (Tp) and peak discharge (Qp) in year 2011 and 2015

Selected storms	Rainfall (mm)	T_p (min)	Q_p (l/s)
Year 2011			
13/7/2011	32	10	0.2
15/7/2011	23	60	0.3
23/7/2011	30	25	0.2
11/8/2011	49	35	0.95
7/9/2011	36	45	0.66
Average	34	35	0.462
Year 2015			
10/7/2015	31.5	*	*
12/7/2015	19.3	37	0.05
22/7/2015	27.3	73	0.14
07/8/2015	46.2	15	0.17
23/9/2015	41.2	*	*
Average	33.1	42	0.12

*could not be computed

Decreased soil loss over a period of time is attributed to increased biomass production in the system, which led to covering the bare soil resulting in reduced soil loss. Reduction in soil loss by 58 times, in sloping lands, due to agroforestry interventions had also been reported earlier. Soil loss reduction by 4.7-22.5% was observed in Hindu Kush Himalayan region by establishing hedgerow intercropping (Patra and Fox, 2007).

Increased runoff from 6.8 to 18% was obtained which was collected in farm pond dug at the lower end of the system. In general with increased biomass in catchment area the runoff decreased. However, the intension in the present study was to collect water in the farm pond for supplemental irrigation, hence through proper channelizing the runoff water was diverted from the catchment area into the pond. This resulted in continuous water flowing from the catchment area for longer period of time as depicted through time to peak (Tp) which increased from average 35 minutes to 42 minutes with reduced discharge per unit time (Qp).

Conclusion

The toposequential arrangement of suitable agroforestry system *viz.*, silvi-horti-pasture at upper 1/3rd portion and hedgerow intercropping in middle 1/3rd portion of land with 12-14 % slope was able to reduce the soil loss from 1.22 t/ha to 0.17 t/ha. The system was also able to increase runoff from 6.8 to 18% which was collected in a farm pond at the bottom of the sloping land resulting in positive water balance. Such system with diversified plants (*Melia composita, Emblica officinalis, Psidium guajava, Leucaena leucocephala*) and farm pond conserve the soil and harvest water for its eventual utilisation.

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