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Weed strip management for minimizing soil erosion and enhancing productivity in the sloping lands of north-eastern India

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ABSTRACT

Soil erosion and shifting cultivation are the major constraints to agriculture in the north-eastern region of India. Low acceptance of cost-intensive soil conservation technologies (e.g., terracing) calls for developing low-cost erosion control measures. Thus, a field experiment was conducted during the monsoon period of 2008 and 2009, in runoff plots on a land slope of 40% to test the hypothesis that weed cover, if properly managed, minimizes soil erosion and improves soil productivity. The treatments implemented in duplicates were: maize (*Zea mays*) under shifting cultivation (T_1), maize on contour lines (T_2), groundnut (*Arachis hypogea*) on upper and maize on lower half of treatment plot, with both on contour lines (T_3), groundnut on contour lines (T_4) and maize on contour lines with natural vegetation as buffer strips (T_5). The average sediment concentration of runoff water varied from 5.20 g L^{-1} (T_1) to 1.07 g L^{-1} (T_5) in 2008 and from 3.84 (T_1) to 0.89 g L^{-1} (T_5) in 2009. The soil loss ranged from 20.8 (T_1) to 4.7 Mg ha^{-1} (T_5), with corresponding loss of 670–147 kg ha^{-1} of SOC, 6.85–1.48 kg ha^{-1} of available N, and 2.14–0.87 kg ha^{-1} of available P. Weed strips and weed mulch on the upstream side of maize rows in T_5 led to formation of stable mini-terraces promoting better plant and root growth. This study indicates cover management involving selective weed retention can reduce soil erosion, favourably modify land slope and promotes soil productivity.

1. Introduction

Soils, apart from being a medium for plant growth, provide numerous ecosystem services (Keesstra et al., 2016), contribute to mitigating climate change effects and ensuring a healthy environment. Healthy soils with optimum soil functions are vital for sustaining food production and ensuring food and nutrition security to mankind. Soils, being the largest terrestrial carbon pool, play a critical role in sequestering atmospheric carbon and contribute to mitigating greenhouse gas emissions. However, soil erosion leading to a decline in land quality is a major global issue adversely affecting sustainable agricultural productivity (Lal, 2001; Keesstra et al., 2016; Biddoccu et al., 2016). The role of soil erosion is increasingly becoming important due to the intricate relationship between land degradation and global food security (Gessesse et al., 2015; Keesstra et al., 2016). In India, about 45% of the land area is under various forms of land degradation (Lenka et al., 2012a), with severe water erosion in the high rainfall hilly regions. As per the 2011 Indian census, the north-eastern region of India with a geographical area of 26.2 million ha, has a population of 44 million. The region accounts for 3.65% of the total population of the country as against a land share of 7.9%. About 72% of the land area in the region is hilly (Das et al., 2009). Out of the total land area, 28% has an altitude higher than 1200 m and 18% between 600 and 1200 m above mean sea level (Das et al., 2009). Being one of the most ecologically-sensitive and challenging regions of the country, it is prone to severe soil erosion, loss of fertile top soil and environmental degradation due to hilly terrain and prevailing shifting cultivation (slash and burn agriculture) practices (Singh et al., 2012; Das et al., 2014; Nath et al., 2016).

Shifting cultivation, locally known as *Jhum* cultivation, is the major form of agriculture in this region. It is an ecologically viable system of agriculture provided that the fallow cycles (replenishment phase) are long enough to maintain soil fertility and expectations of productivity are not high. However, increasing population pressure has reduced the duration of the fallow phase from 15 to 20 years to 3 to 4 years, causing significant decline in crop yield and soil fertility. Repeated use of land

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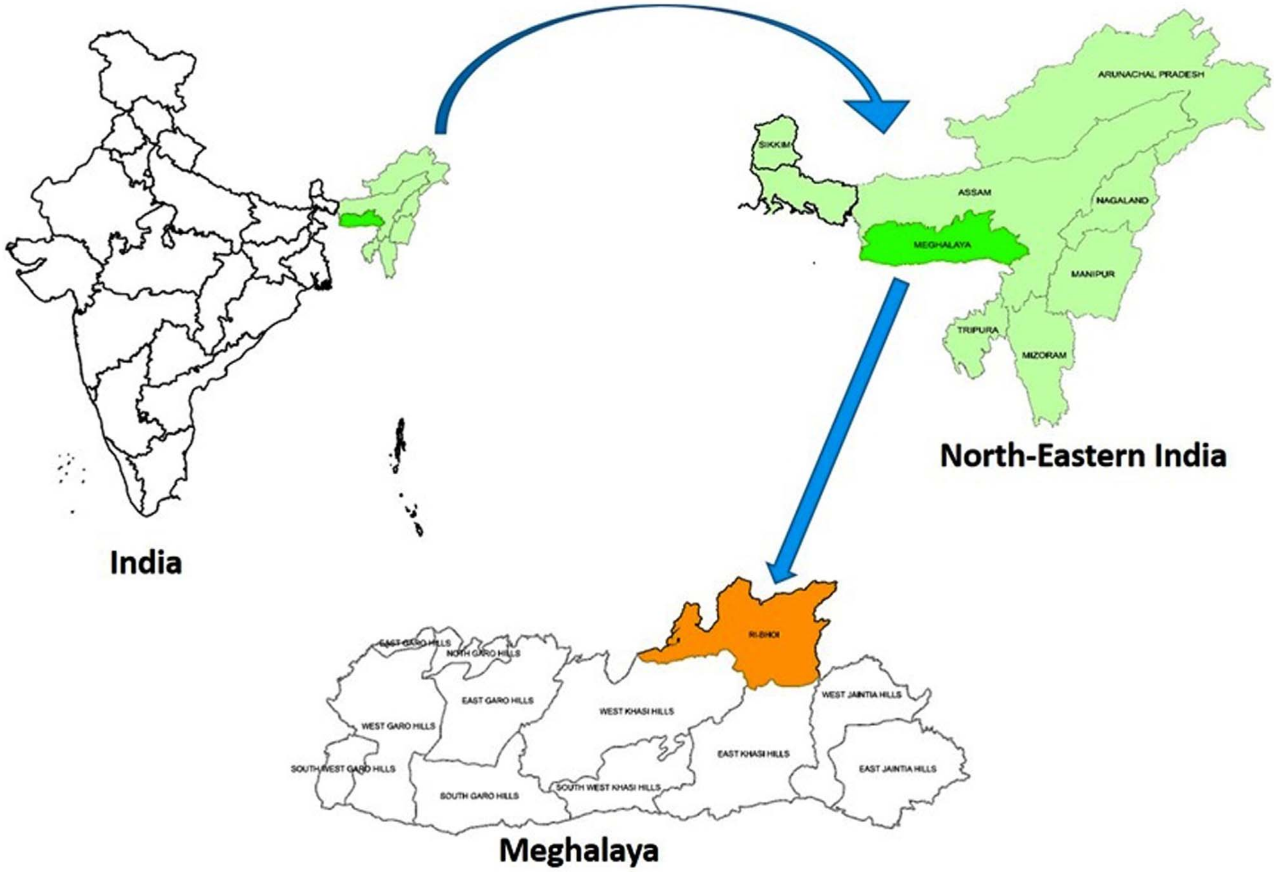


Fig. 1. Location of the study site.

with a short replenishment phase converts the shifting cultivation fallows into degraded wastelands (Lenka et al., 2012a). This requires the farmers to clear new forest areas, aggravating the loss of forest and biodiversity and creating a vicious cycle of deforestation- environmental degradation-low crop yield-poverty-more deforestation. About 80% of the area of the region is affected by moderate to severe erosion (Velayutham, 1999; Singh et al., 2012). About 59 Mg ha^{-1} yr^{-1} of soil erosion has been reported from land with a slope gradient of 45% (Sharma and Prasad, 1995; Sharma et al., 2014; Sharma and Sharma, 2005) and 170 Mg ha^{-1} from a slope of 70% (Singh and Singh, 1978). About 88.3 million tonnes of soil and about 0.5 million tonnes of plant nutrients are lost every year from the region through erosion (Sharma and Prasad, 1995).

Because of the predominantly hilly terrain, a small proportion of the cultivated lands is flat or has a low elevation gradient. These lands are situated near the valleys and are owned by richer members of the community. Thus, most of the agriculture activities are done on sloping lands. Cultivation in the hills and lands situated in the hill slopes is beset with two key problems. First, accelerated soil erosion is severe in the entire north-eastern region. Rainfall received in the region is > 2000 mm per annum, and is accompanied with torrential storms during the monsoon season (Das et al., 2014). The combined action of torrential rains during the monsoon months and the steep slope gradient results in washing away of the fertile soil and applied inputs including seeds. Secondly, walking up the slope for routine agricultural practices becomes difficult particularly during wet months.

Predominant crops in the shifting cultivation region of north-eastern India are rice (*Oryza sativa* L.), maize (*Zea mays*), potato (*Solanum tuberosum*) and ginger (*Zingiber officinales*). A modified method of shifting cultivation, known as *Bun* cultivation, is practised particularly in the Shillong plateau region, where crops are grown 'along the slope' on raised beds. These beds are formed by excavating the soil from both sides and the subsoil layers and leaving narrow channels between two beds for safe disposal of water. Because of the higher level of soil manipulation, this method is more devastating than the traditional shifting cultivation method in terms of soil erosion (Singh et al., 2012). About 0.39 million ha of the 2.28 million ha area of the Shillong plateau region is managed by shifting cultivation, and as much as 76.6 Mg ha^{-1} yr^{-1} of soil is lost under this system of farming (Satapathy, 1996).

Depending upon slope gradient, erosion control on arable lands is attempted through biological measures such as live barriers of grasses and hedges (Dass et al., 2011; Lenka et al., 2012b), surface cover of standing crops or crop residues (Lenka et al., 2012a; Das et al., 2014; Biddoccu et al., 2016; Cerdà et al., 2016) and through modification of land configuration and conservation tillage practices (Kuotsu et al., 2014; Ghosh et al., 2015). In a long-term runoff monitoring study in Italy, grass cover reduced runoff by at least 37% and soil loss was 10 times lower as compared to reduced tillage (Biddoccu et al., 2016). For highway embankment erosion control, Bakr et al. (2015) demonstrated the efficacy of surface mulch through a rainfall simulation experiment. In their experiment, the cumulative runoff loss as a percentage of the applied rainfall reduced from 90% for the tilled plot to 28% in treatments having 10 cm compost/mulch. In any case, the principle is to reduce the runoff velocity and in the long run to alter the land configuration suitably so as to reduce the slope gradient. Terracing, recommended as the best land management system for agriculture on sloping lands, is often not accepted by farmers due to high initial investment. Further, most of the sloping lands are either community lands or owned by small and marginal farmers. Thus, terracing is economically unfeasible.

Alternatively, judiciously managed natural vegetation in accord with specific crop growth stages, serves both as cover and buffer strip.

Most of the research involving conservation treatments in the remote parts of the country has been limited to flat or gently sloping lands in the valleys (Das et al., 2014; Kuotsu et al., 2014). To date, no study has been conducted in the region to compare the effectiveness of conservation measures on sloping lands. Thus, this study was undertaken to compare the effect of selected cover management techniques vis-a-vis the shifting cultivation in terms of soil and nutrient loss and crop productivity with the hypothesis that manipulating the crop and vegetation cover can moderate slope gradient, reduce soil and nutrient losses, and improve crop productivity.

2. Materials and methods

2.1. Study site

The field experiment was conducted at the Research Complex of the Indian Council of Agricultural Research (ICAR) for the North-Eastern Hill (NEH) region, Umiam, Meghalaya (Fig. 1). The study site comes under the mid-tropical hill zone ecoregion and is located at 25°41′21″ North latitude and 91° 55′ 25″ East longitude, and at an altitude of 1010 m above sea level. Average annual rainfall received at the study site is 2390 mm with a coefficient of variation of 16%. Of this, 80% is received between the 17th to 42nd meteorological weeks (last week of April to 2nd week of October). The mean monthly maximum temperature ranges from 10.6 °C (during December) to 27.4 °C (during August) and mean monthly minimum temperature ranges from 6.5 °C (during January) to 20.8 °C (during July). Relative humidity varies between 75 and 83% during most of the year. Soils of the study area are classified as *Typic Paleudalfs* with loam to clay loam texture and pH of 5.4–6.2. The area used for the experiment was under fallow for the five years prior to the study.

2.2. Experimental treatments

The experiment was conducted for two consecutive crop years during 2008 and 2009 in runoff plots with different surface cover treatments. The treatments taken in duplicates were: maize (*Zea mays*) under shifting cultivation (T_1), maize sown on contour lines (T_2), ground nut (*Arachis hypogea*) on upper and maize on lower half of treatment plot, with both sown on contour lines (T_3), groundnut on contour (T_4) and maize on contour lines with weed cover as buffer strips (T_5). Maize was planted for the first time in the 1st year of the experiment after five years of fallow. A total of 10 runoff plots were laid out on land with a slope gradient of 40%. The dimensions of each plot were 22.0 m long and 1.85 m wide. The width of each plot was chosen keeping in view the fact that in hilly regions with land slopes of more than 40%, establishing experimental plots at the same location and same aspect is difficult. Two adjacent plots were separated by inserting high density polyethylene (HDPE) sheets. These sheets were inserted 30 cm below and 30 cm above ground on all four sides to prevent seepage flow and lateral movement of water from one plot to another (Plate 1). The farmers' practice of shifting cultivation, *i.e. Bun* method (T_1) involved four bunds, each with 10.5 m length, 0.7 m width and 0.4 m height above the soil surface. Two bunds were made on the upper portion of the treatment plot and two were on the lower portion. These bunds were prepared up and down the slope at an inter-channel distance of 0.5 m. For the treatment involving weed retention (T_5), 20-cm weed-free strips were prepared across the slope at 60 cm intervals. Maize was seeded on the 20-cm weed-free strips after loosening the soil. Weeds were allowed to grow in the inter-strip space for up to 20 days after sowing (DAS), after which manual weeding was done and the weed biomass was spread close to the upstream side of the base of the maize plants. After the first weeding at 20 DAS, two more manual weedings were done at 40 and 60 DAS and the weed biomass was retained on the soil surface as mulch near the upstream side at the base of the maize plants (Fig. 2). This treatment was designed to minimize the risks of severe erosion by intense rain storms which are common features of this region during the rainy season.

Plate 1. Runoff plots and segregation of runoff plots through High Density Poly Ethylene sheets.

2.3. Crop management

As test crops, maize (cv. Vijaya composite) and groundnut (*Arachis hypogaea* L.) (cv. ICGS – 76) were sown following the treatment details as mentioned above at a row spacing of 60 cm and 30 cm, respectively and at plant – plant spacing of 15 cm for both the crops. In the 2008 season, crops were sown on 08th July and harvested on 01st September. In the 2009 crop season, maize was sown on 13th May, groundnut on 20th May and both crops were harvested on 05th September. The recommended agronomic practices including the rate of fertilizer, plant to plant spacing and weeding were followed in all the treatments. As tillage on such high slopes is difficult, hence, maize and groundnut were planted after pulverizing the top of 10 cm soil with small farm tools, as practiced by local farmers.

2.4. Observations taken

Baseline soil properties were determined before initiation of the experiment following standard methodologies (Table 1). The soil samples in nine replicates were analysed for soil pH (1:2.5 soil to water suspension using a pH meter), soil organic carbon (SOC) content by Walkley and Black method, $KMnO_4$ oxidizable N as plant available N, available P (Bray – I method) and available K content (using 1.0 N NH_4 acetate extractant) following Jackson (1973). During the growing period, measurements were made for soil penetration resistance, runoff, soil loss and nutrient loss as measured in terms of sediment and nutrient concentration of runoff water. Soil penetration resistance (SPR) was measured using a hand held cone penetrometer (Eijelkamp) during different crop growth stages for 0–10 cm depth. The SPR measurements were made at near field capacity moisture conditions. Nine penetrometer readings were taken from each plot with three each from the lower, middle and top portions of the treatment plots. The nine readings of a plot were averaged to represent a particular treatment.

2.5. Plant and root biomass at harvest

Biomass and grain yields of maize and groundnut were recorded at harvest by oven drying at 65 °C for 48 h. Root weight and root length were measured at harvest and only for maize crop by extraction of soil cores of 10 cm diameter and 13 cm height from near the maize plant. From each plot, six root samples were collected with two each in the upper portion, middle and lower portion of the treatment plot. Root samples were carefully cleaned with gentle shaking in small trays filled with water and then primary and secondary roots were separated. The

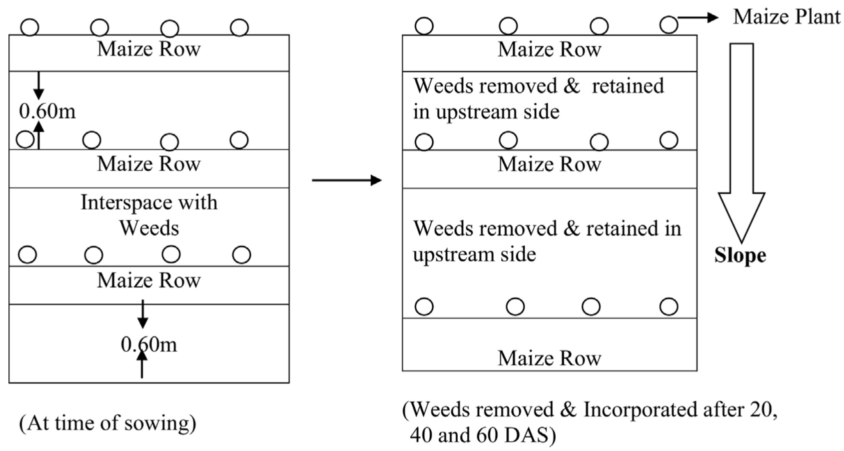


Fig. 2. Schematic illustration of the cover management treatment involving retention and management of natural vegetation for reducing the soil erosion risks.

Table 1
Initial soil properties of the experimental site in the 0–15 and 15–30 cm soil layers.

Soil property	0–15 cm	15–30 cm	Methodology used
Soil pH (1:2.5)	[a]5.44 ± 0.44	5.46 ± 0.41	1:2.5soil: water suspension, pH meter
Organic carbon ($g\ kg^{-1}$)	26.2 ± 3.2	20.6 ± 2.8	Walkley and Black method
Available N ($kg\ ha^{-1}$)	335.5 ± 38.8	285.4 ± 22.6	$KMnO_4$ oxidizable (Jackson, 1973)
Available P ($kg\ ha^{-1}$)	16.5 ± 2.4	13.6 ± 1.0	Bray – I
Available K ($kg\ ha^{-1}$)	214.1 ± 10.2	207.9 ± 7.8	NH_4 acetate extractant (Jackson, 1973)

[a] Values are mean ± standard deviation based on nine replicate measurements.

root length of the freshly collected root samples was measured directly by laying out each piece of root on a graph paper. The root length density, i.e., the length of roots per unit volume of soil, was computed by taking the ratio of measured root length to the volume of soil core used for root sampling (soil volume in this case was 1020 cm^3). The oven dry root weight was obtained by drying the root samples in a hot air oven at 65 °C for 48 h.

2.6. Maize equivalent yield (MEY)

The crop yield in the treatments was expressed in terms of maize equivalent yield (MEY). The MEY was computed by considering the minimum support price fixed by the Government of India for maize and groundnut crops for the years of study and as per the following formula:

$$MEY = \frac{Priceofgroundnut}{Priceofmaize} \times Grainyieldofgroundnut(quinatals/\text{ha})$$

2.7. Measurement of runoff and sediment concentration of runoff water

The daily rainfall data were collected from the Meteorological Observatory installed by the India Meteorological Department (IMD), using a standard rain gauge, located about 500 m from the experimental plot. Triangular weirs were installed towards the downstream side of each runoff plot for measuring the runoff generated from each plot. The runoff generated was collected in containers placed in a trench beneath the flume. One container of 500 l capacity was connected at the rim to another container of the same capacity. Although the station regularly receives heavy rains, very high intensity rain storms causing spill over were not recorded during the experimental period. Sediment concentration of runoff water was measured during the experimental period on days receiving rainfall of > 12.5 mm.

The runoff water collected in the container was thoroughly stirred, and one litre of sample was collected from the middle of the container for determining the sediment concentration of runoff water. The runoff sample was allowed to settle and the clear supernatant liquid was decanted. The remaining suspension was transferred to a glass petridish, and dried in a hot air oven at 65 °C till a constant weight. The measured sediment concentration of runoff water was expressed in grams per litre ($g\ L^{-1}$) and the soil loss in each event was computed from sediment concentration and the runoff volume. The sediment samples collected during the entire crop season were mixed, dried in a hot air oven at 65 °C and ground to pass through a 2.0 mm sieve. Moisture correction was made by drying a portion of the sediment sample at 105 °C for 48 h. The sediment samples were analysed for soil organic carbon (SOC) content (Walkley and Black method), $KMnO_4$ oxidizable or available N, available P (Bray – I method) and available K content (using NH_4 acetate extractant) following Jackson (1973).

2.8. Statistical analysis

For yield and root growth related traits, combined analysis of variance (ANOVA) across two years were performed to test the significance of year (Y), treatment (T) and Year × Treatment (YT) using SAS MIXED procedure (SAS V9.4). Residual variances of individual year were modelled into combined analysis. Year wise analysis of variance was also performed to test the significance of treatments. Least square means and multiple comparisons for treatments were also estimated. For sediment and nutrient loss through runoff, year wise analysis of variance was performed using general linear model (SAS GLM Procedure) (SAS V9.4) and the least square means and multiple comparison tests for treatments were estimated.

3. Results

3.1. Sediment concentration in runoff samples

The event wise rainfall and sediment concentration data during the experiment period of 2008 and 2009 crop years are shown as Fig. 3A and B, respectively. The number of runoff events in 2008 was lower than those in 2009. A total of 19 and 21 runoff events (with ≥12.5 mm rainfall per day) were observed in the first and second crop year, respectively. The sediment concentration averaged over all the cover management treatments was 3.28 $g\ L^{-1}$ in the first year as compared to 2.66 $g\ L^{-1}$ in the 2nd crop year. The higher sediment concentration in the 1st year might be due to higher soil disturbance in the 1st year for the initial land preparation.

For all rainfall events, sediment concentration was significantly

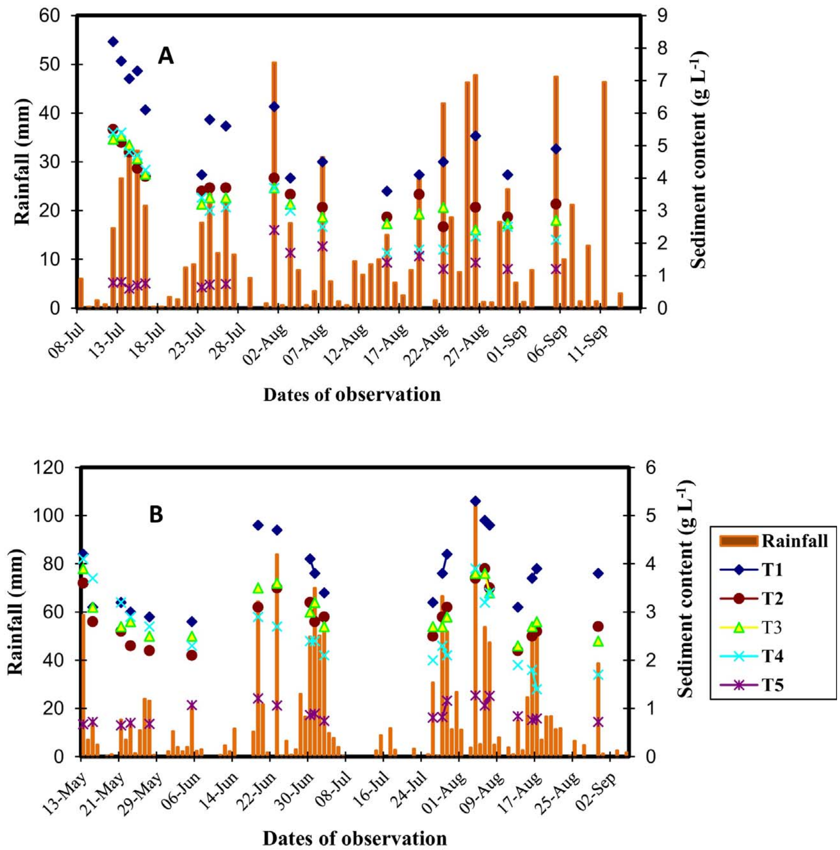


Fig. 3. Daily rainfall and sediment concentration of runoff water in rainy days with rainfall of more than 12.5 mm in the (A) 2008 and (B) 2009 crop seasons (T_1: Shifting cultivation, T_2: Maize on contour, T_3: Ground nut on upper and maize on lower half, T_4: Groundnut on contour, T_5: Maize on contour with weed cover).

higher under T_1 than for other cover management treatments in both the study years (Fig. 4). Significantly lower sediment concentration was observed under T_5 treatment. The sediment concentration ranged from 5.20 g L^{-1} under T_1 to 1.07 g L^{-1} under T_5 (Fig. 3A) during the first year compared with 3.84 g L^{-1} under T_1 to 0.89 g L^{-1} under T_5 for the second year (Fig. 3B). Despite the difference between the treatments, the magnitude of sediment concentration was also a function of the total amount of rainfall for the event. The multiple pair wise comparison test indicated the sediment concentration to be in the order of $T_1 > T_2 \approx T_3 > T_4 > T_5$ in both crop years (Fig. 4). The sediment concentration in the T_1 treatment was 3.8 times higher than that for the best treatment (T_5) in the first and 3.3 times in the second crop year.

3.2. Soil and nutrient loss

The soil and nutrient loss data averaged over the two years' experiment period is shown in Table 3. Significantly higher loss of soil and nutrients was observed under T_1 followed by other treatments and significantly lower soil and nutrient losses were observed in the T_5 treatment (Tables 2 and 3). The soil loss ranged from 20.8 Mg ha^{-1}(T_1) to 4.7 Mg ha^{-1} (T_5), with corresponding losses of 147–670 kg ha^{-1} of SOC, 6.85–1.48 kg ha^{-1} of available N, 2.14–0.87 kg $ha^{-1}$of available P and 7.91–1.71 kg ha^{-1} of available K. The treatments were in the order of $T_1 > T_2 \approx T_4 > T_3 > T_5$ in terms of soil and nutrient loss. The combined ANOVA over the two years of experiment showed non-significant interaction effect of year and treatment in case of available P and available K loss (Table 2) whereas the effect was significant for soil loss, SOC and available N loss ($P < 0.05$). Thus, the soil conservation efficacy of the T_5 (weed retention) treatment was significantly higher than that of the T_3 (upper half maize and lower half groundnut) treatment followed by T_2 (maize on contour) and/or T_4 (groundnut cover) treatment.

3.3. Formation of terraces across the slope

Over time, the growing of crops across the slope led to formation of mini-terraces ~ 35 cm wide (Plate 2). However, terraces were formed only in plots with maize as the test crop but not in those under groundnut. Secondly, the number of stable terraces was the highest in T_5, having maize with weed retention treatment (Table 4). The number of stable terraces ranged from 9 in T_3 to 12 in T_2 and 26 in T_5 treatment.

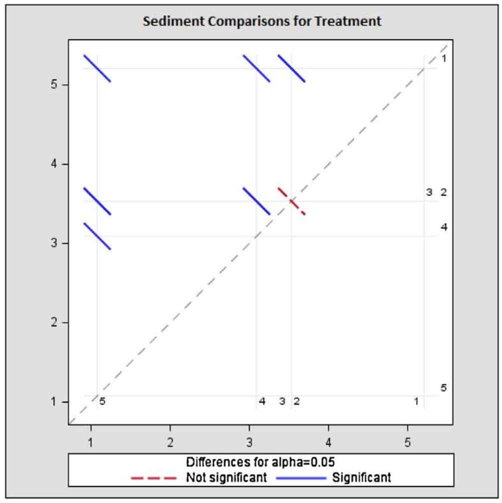
3.4. Soil penetration resistance

Soil penetration resistance (SPR) measured at different days after sowing indicated significantly ($p = 0.01$) lower values under T_1 than in other treatments during both years of study (Table 2, Fig. 5). The SPR in the T_1 treatment gradually increased due to settling of soil as observed from higher values in the later dates of measurements and in the 2nd year of study. The SPR values ranged from 0.30 MPa under T_1 to 1.93 MPa under T_5 treatment at the first measurement date in the 1st crop season. On an average, the SPR was relatively higher under T_2 in both the crop years. Averaged over measurement dates of the 1st crop year, the SPR value in the T_1 treatment was lower by 3.1–3.4 times as compared to the average values under other treatments. In the 2nd crop year, the T_1 treatment was lower by 2.0–2.3 times. Though the SPR values in the T_2 treatment were relatively higher than T_3, T_4 and T_5 treatments but all the treatments except T_1 were statistically at par with one another.

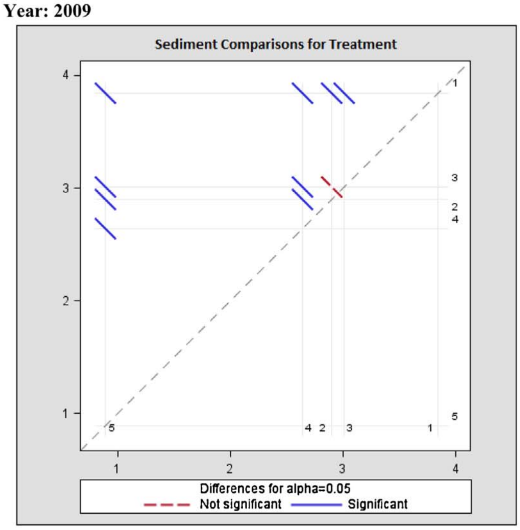
3.5. Root growth parameters

The cover management treatments showed a significant effect (Table 2) on the root weight of maize in both years (Table 5, Plate 3). The combined ANOVA indicated the main effects of both 'year' and

Year: 2008



Year: 2009



In the above Diffograms, X and Y axis represents mean values of 5 treatments (1, 2, 3, 4 and 5). Significant difference between any two treatment means is represented with blue color line and non-significant difference by red color line.

Fig. 4. Diffogram showing multiple comparison of treatment means for sediment concentration in the (A) 2008 and (B) 2009 crop seasons (T_1: Shifting cultivation, T_2: Maize on contour, T_3: Ground nut on upper and maize on lower half, T_4: Groundnut on contour, T_5: Maize on contour with weed cover).

Table 2
Significance of differences of Least Square Means between ‘Year’ and ‘Treatments’.

Factor	Root weight	RLD	MEY	Soil loss	SPR	SOC loss	Available N loss	Available P loss	Available K loss
Year	*	NS	NS	*	*	*	*	NS	NS
T1-T2	**	**	**	**	**	**	**	*	**
T1-T3	NS	*	**	**	**	**	**	*	**
T1-T4	–	–	**	**	**	**	**	**	**
T1-T5	**	**	**	**	**	**	**	**	**
T2-T3	*	NS	*	**	NS	*	*	NS	*
T2-T4	–	–	**	NS	NS	NS	NS	NS	NS
T2-T5	**	**	*	**	NS	*	**	*	**
T3-T4	–	–	*	*	NS	*	*	NS	NS
T3-T5	**	**	NS	**	NS	**	**	*	*
T4-T5	–	–	NS	**	NS	*	**	*	**

RLD: Root Length Density; MEY: Maize Equivalent Yield; SPR: Soil penetration resistance; SOC: Soil organic carbon; *Significance at p = 0.05; **Significance at p = 0.01; NS = Not significant; T_1: Shifting cultivation, T_2: Maize on contour, T_3: Ground nut on upper and maize on lower half, T_4: Groundnut on contour, T_5: Maize on contour with weed cover.

Table 3
Effect of conservation treatments on soil and nutrient loss (average of two years).

Treatment	Soil loss ($Mg\ ha^{-1}\ yr^{-1}$)	Nutrient loss ($kg\ ha^{-1}\ yr^{-1}$)			
		Organic carbon	Available N	Available P	Available K
T1	[a]20.8 ± 3.2	670 ± 52	6.85 ± 2.14	2.14 ± 0.86	7.91 ± 2.04
T2	11.2 ± 1.6	345 ± 47	3.71 ± 1.44	1.75 ± 0.71	4.17 ± 1.63
T3	8.3 ± 2.6	292 ± 45	3.04 ± 0.82	1.54 ± 0.52	2.98 ± 0.54
T4	10.9 ± 1.2	400 ± 55	3.78 ± 1.10	1.52 ± 0.68	3.62 ± 0.88
T5	4.7 ± 1.5	147 ± 33	1.48 ± 0.76	0.87 ± 0.54	1.71 ± 0.72

T_1: Shifting cultivation, T_2: Maize on contour, T_3: Ground nut on upper and maize on lower half, T_4: Groundnut on contour, T_5: Maize on contour with weed cover.
[a] Values are mean ± standard deviation.

Plate 2. Conservation treatment of contour sowing with retention of weed biomass resulting in formation of mini-terraces.

Table 4
Effect of cover management treatments on modification of land slope as assessed through formation of mini-terraces.

Treatment	After 1st crop season		After 2nd crop season	
	Total terraces	Stable terraces#	Total terraces	Stable terraces
T1	–	–	–	–
T2	15	12	15	15
T3	12	9	15	11
T4	–	–	–	–
T5	28	26	30	28

#Stable terraces of 35 cm width.
T_1: Shifting cultivation, T_2: Maize on contour, T_3: Ground nut on upper and maize on lower half, T_4: Groundnut on contour, T_5: Maize on contour with weed cover.

'treatment' to be significant at the 5% level of significance. Root growth in the 2nd crop year was significantly higher because of a better root growth environment in the form of levelled terraces. The root weight varied from 1.96 g $plant^{-1}$ under T_1 to 7.57 g $plant^{-1}$ under T_5 in the first crop year, and from 2.24 g $plant^{-1}$ to 8.85 g $plant^{-1}$ under the same treatments in the 2nd crop year (Table 5). In both the years, the root weight was significantly higher in T_5 as compared to other treatments, with the lowest being under T_1. The poor root growth of maize under T_1 was attributed to severe erosion caused by a loose soil structure and lower soil strength as indicated by low SPR values under the *bun* method of cultivation. Across the two study years, the root weight under T_5 was about 3.8 times higher than that under the T_1 treatment.

3.6. Root length density (RLD)

The root length density (RLD) ranged from 0.36 under T_1 to 1.08 cm cm^{-3} under the T_5 treatment during the first year compared with 0.39 and 1.28 cm cm^{-3}, respectively, for the second (Table 5). Over the two study years, RLD under T_5 was 3.0–3.3 times higher than

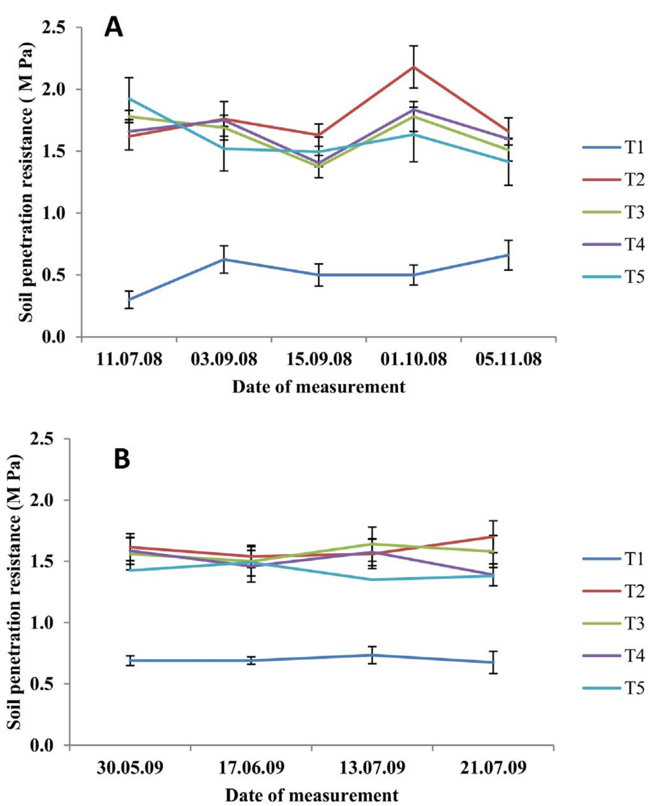


Fig. 5. Soil penetration resistance under different treatments at different measurement dates in the (A) 2008 and (B) 2009 crop seasons (T_1: Shifting cultivation, T_2: Maize on contour, T_3: Ground nut on upper and maize on lower half, T_4: Groundnut on contour, T_5: Maize on contour with weed cover).

Table 5
Effect of soil cover management on maize root growth and maize equivalent yield.

Treatments	Oven dry root weight (g/plant)		Root length density (cm/cm^3)		Maize equivalent yield (Quintals/ha)	
	Year – I	Year – II	Year – I	Year – II	Year – I	Year – II
T1	[a]1.96 ± 0.29	2.24 ± 0.21	0.36 ± 0.05	0.39 ± 0.06	6.22 ± 0.66	8.85 ± 1.04
T2	3.47 ± 0.22	4.04 ± 0.34	0.74 ± 0.04	0.74 ± 0.05	14.5 ± 0.75	15.05 ± 2.11
T3	2.58 ± 0.30	3.12 ± 0.24	0.56 ± 0.06	0.65 ± 0.04	16.7 ± 0.94	18.45 ± 2.14
T4	–	–	–	–	20.35 ± 2.12	20.38 ± 1.56
T5	7.61 ± 0.51	8.85 ± 0.62	1.08 ± 0.06	1.28 ± 0.04	16.71 ± 1.74	18.83 ± 2.02

T_1: Shifting cultivation, T_2: Maize on contour, T_3: Ground nut on upper and maize on lower half, T_4: Groundnut on contour, T_5: Maize on contour with weed cover.
[a] Values are mean ± standard deviation.

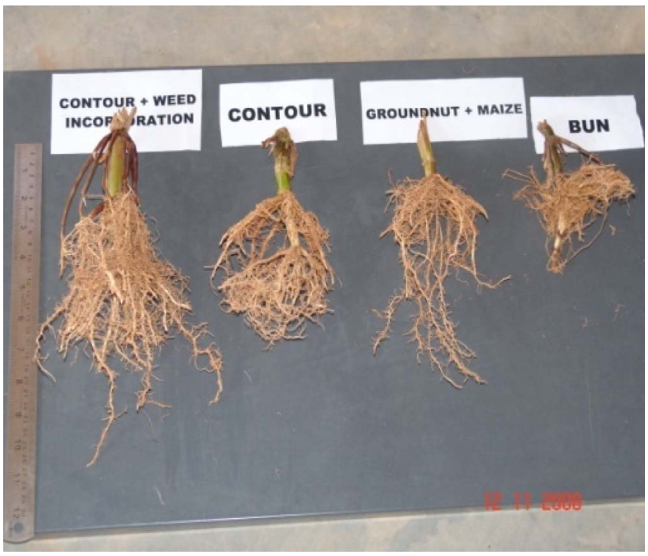


Plate 3. Maize plant roots under specific cover management treatments.

that for the T_1 treatment. The combined ANOVA (Table 2) showed a significant effect of cover management treatments. However, the effects of year (P = 0.21) and the year × treatment interaction were non-significant (P = 0.60). Across both seasons, RLD was significantly higher for T_5 and significantly lower under T_1 than other treatments (Table 2). However, RLD under T_2 and T_3 were statistically at par with one another.

3.7. Maize equivalent yield

The maize equivalent yield (MEY) ranged from 0.62 under T_1 to 2.04 Mg ha^{-1} under T_4 treatment in the first year compared with 0.89 and 2.04 Mg ha^{-1}, respectively in the 2nd (Table 5). Across the years, the MEY ranged from 0.75 Mg ha^{-1} under T_1 to 2.04 Mg ha^{-1} under T_4. The highest MEY under the T_4 treatment was due to a higher minimum support price of groundnut as compared to maize and also due to a better performance of groundnut on the sloping lands of the region. The difference of least square means from the combined ANOVA indicated T_4 and T_5 to be statistically at par with one another (P = 0.051). The combined ANOVA (Table 2) showed a significant effect of cover management treatments ($P < 0.0001$). However, the effects of year (P = 0.08) and the year × treatment interaction were non-significant (P = 0.75), indicating similar trend of differences between treatments in both years. Across both years, the MEY under T_4 was 2.3–3.2 times higher and that for T_5, 2.1–2.7 times higher than that of T_1.

4. Discussion

Erosion-induced soil and nutrient losses are major constraints to agricultural productivity in the sloping farm-lands. Use of cover crops and surface barriers such as contour hedgerow intercropping are cost effective technologies to minimize the erosion risk (Sudhishri et al., 2008; Lenka et al., 2012b; Tao et al., 2012; Biddoccu et al., 2016). Results presented herein indicate the erosion mitigation potential of weed cover management as compared to the traditional shifting cultivation (Tao et al., 2012; Gholami et al., 2013). The most visible impact in terms of reduced soil loss, plant root growth and crop yield was observed in the T_5 treatment with retention of weed biomass, live and subsequently the uprooted weed biomass put across the slope in the upstream side of the plant root. Retention of live and uprooted weed biomass, apart from reducing the runoff velocity, also filters sediments from runoff water (Lenka et al., 2012b; Cerdà et al., 2016). During the initial stage of maize growth, live weed biomass protected against rainfall erosivity on steep land and enhanced plant growth. Subsequently, at 20 DAS, weeds biomass was removed and retained on the surface as mulch. The retention of uprooted weed biomass provided surface cover, which coupled with the binding effect of maize roots, proved an effective barrier and led to the formation of stable terraces. Thus, soil erosion was significantly lower under T_5 than that in other treatments for all runoff events in both years (Tables 2 & 3, Figs. 3 & 4). This trend is also evident from the average sediment concentration which was more than 4.0 times higher in T_1 than that in T_5 (Fig. 3). On sloping lands, therefore, selective weed retention can be a cost effective strategy for control of soil erosion and nutrient loss. Similar observations have also been reported for an olive (*Olea europaea)* grove established on land with slope gradient of 13%, in which the highest runoff and soil loss were observed in the weed-free treatment (Gomez et al., 2009). In a long term runoff monitoring study in Italy, grass cover reduced runoff by at least 37% as compared to management by tillage. The sediment yield varied from 1.8 to 20.7 Mg ha^{-1} yr^{-1} for grass cover and reduced tillage treatment, respectively (Biddoccu et al., 2016). The efficiency of surface mulch in controlling soil loss, runoff and phosphate loss has also been reported by Bakr et al. (2015), where the runoff loss as a percentage of the applied rainfall was reduced from 90% for the tilled plot to 28% in treatments having 10 cm compost/mulch.

Research data on runoff and erosion have been reported for live vegetative barriers of different grass species and live contour hedgerow barriers of different shrub species (Gomez et al., 2009; Dass et al., 2011; Lenka et al., 2012b; Tao et al., 2012). For sloping land (12–46% slope), Tao et al. (2012) reported reduction in runoff by 57%, 94% and 95% under contour hedgerow intercropping with maize + soybean, maize + alfalfa and maize + *Hemerocallis citrina*, as compared to maize only. Inclusion of grass filter strips enhanced the conservation effectiveness of hedge rows of Gliricidia in a high rainfall region of eastern India. In comparison with the control, these hedge rows reduced runoff and soil erosion by 30%, while sequestering soil organic carbon at the rate of 0.35–1.35 Mg ha^{-1} yr^{-1} (Lenka et al., 2012b). Conservation effectiveness of hedgerow barriers can be better than that of stone and soil dike terraces (Shen et al., 2010).

The alternate cover treatments also promoted better root growth and produced higher crop yield than that under T_1 treatment (Table 5). On average, the root weight of maize under T_5 was 3.8 times higher and the RLD about 3 times higher than that under T_1 in both years primarily because of lower soil erosion. The contrary effect is also possible. The better root growth environment in the T_5 treatment due to weed and mulch cover in the inter-strip spaces might play a vital role in promoting soil aggregation and reducing erosion which led to formation of terraces (Tisdall and Oades, 1982; Gyssels et al., 2005). Because of the high runoff potential of the sloping lands as in the case of the experimental plot, the role of plant roots seems to be additive to the action of the vegetation cover (Gyssels et al., 2005). Lower root growth, poor crop yield and high sediment loss under T_1 were also caused by loosening of soil during bunding (Fig. 5).

In addition to reducing soil erosion, mulching also enhances agronomic productivity (Aggarwal and Sharma, 2002). Mulching with weed biomass in conjunction with minimum tillage and strips of grass barrier reduced soil erosion and runoff by 51% and 45%, respectively, on a gently sloping land in the Indian sub-Himalayas (Ghosh et al., 2015). Applying mulch at the rate of 4 Mg ha^{-1} decreased water runoff by 58%, soil erosion by 72% and nutrient loss by 60% while also increasing the grain yield of maize (Kukal et al., 1993).

A judicious manipulation of weed cover controls soil erosion and nutrient loss (Francia et al., 2006), and leads to formation of phytogenic mounds (Abu-Zreig et al., 2004) by the barrier action and resulting deposition of sediments towards the upstream side of the strips of vegetative barriers (Zuazo and Pleguezuelo, 2008). In the present study, terrace formation across the slope was caused by the binding action of plant roots. Further, incorporation of weed biomass in soil in the vicinity of the plant rows enforced the action and thus resulted in the maximum formation of stable terraces under the T_5 treatment. Reduction in erosion is also due to increase in shear strength of the soil, which is a measure of the cohesiveness of soil particles and resistance of the soil mass to shearing forces exerted by forces of gravity, moving fluids and mechanical loads (Zuazo and Pleguezuelo, 2008). The binding action of plant roots in this study was reinforced by the live weed biomass and the weed mulch, which led to the formation of terraces and reduction of effective land slope in the T_5 treatment. The better plant growth reinforced shear strength of the soil– root matrix (Anderson and Richards, 1987), which was higher than the separate values of the soil or the roots (Simon and Collison, 2001; Zuazo and Pleguezuelo, 2008).

5. Conclusion

The data presented indicated the soil and nutrient losses were lower and maize yield higher under the cover management treatment with selective and controlled weed retention. A discriminative retention of weed cover also changed land slope gradient and formation of bio-terraces. Of the cover management methods, selective weed retention is a cost-effective management strategy for conserving soil, water and plant nutrients on sloping lands of areas under shifting cultivation in the north-eastern region of India. Being a simple and low cost technology, it can be adopted by farmers of hilly regions of tropical and sub-tropical parts of the world experiencing similar soil erosion problems.

Conflict of interest

Authors declare no conflict of interest in the paper.

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