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Effect of geojute technique on density, diversity and carbon stock of plant species in landslide site of North West Himalaya

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Abstract: Mountainous regions of the globe experience landslides due to heavy rainfall and unplanned construction on slopes. Geojute is adopted globally as a landslide rehabilitation measure, but its impact on natural vegetation development is poorly understood. The present study was conducted to examine the impact of geojute application on vegetation restoration, ecology and carbon stock in a recently occurred landslide, during 2012. The results revealed that the geojute application improved the richness, diversity, density and basal area of plant species at the landslide site. Likewise, biomass production, carbon stock and carbon sequestration of plant species was observed significantly higher in geojute treatments compared to control (without geojute treatment). Moreover, significant improvement in soil moisture was recorded beneath the geojute treatments. Further, results showed that the geojute is highly effective in controlling soil erosion at the landslide site. The findings of this study revealed ecological and environmental benefits of geojute application in term of improvement in vegetation recovery processes, species diversity and

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carbon sequestration at the landslide site. The scientific outcome of this study can be helpful for planning the rehabilitation measures in landslide affected regions of the globe.

Keywords: Carbon sequestration; Erosion control; Geojute; Landslide rehabilitation; Vegetation restoration

Introduction

Over 100 million hectares of the global land are subjected to various kinds of degradation (Cai et al. 2011). In Himalaya, the continued and rapid degradation of mountains contributes to the occurrence of landslides (Marui 1988; Fiebeger 2006). A landslide is a form of mass wasting that includes a wide range of ground movements, such as rock falls, deep failure of slopes and shallow debris flows (Singh and Kumar 2018). Moreover, landslides are considered largely as an irreversible land degradation process due to their extremely slow natural rehabilitation (Nagasaka et al. 2005). Therefore, restoring such sites is extremely important to conserve soil and water resources, maintain native landscape sustainability, and to enhance plant species biomass and carbon stock (Minnemeyer et al. 2011; de MoraesSá et al. 2015; Perring et al. 2015; Sanwal et al. 2017).

Several human induced activities such as improper land use, road construction, mining, deforestation (Islam 2013; Kumar et al. 2016) and absence of conservation measures (Altieri et al. 2005) etc. accelerates land degradation that makes the Himalayan mountains vulnerable to landslides. Further, the predicted climate change is expected to result in more intense rainfall and thereby higher likelihood of landslide (Crozier 1999; Fan et al. 2017). Moreover, continued soil erosion on the landslide site resulted in changed soil physico-chemical properties (Yang et al. 2016; Zeng et al. 2004), reduced emergence, growth and development of seedlings (Juying et al. 2009; Shrivastva and Kumar 2015), and altered species richness, diversity and ecosystem succession (Krieger 2001; Wang et al. 2005; Kumar et al. 2013).

In order to rehabilitate landslide**,** soil conservation measures and afforestation are adopted successfully throughout the globe (Marui 1988; Fiebiger 2006; Karnawati 2011; Islam 2013). However, most reclamation studies have reported the poor native vegetation development in such sites (Kost et al. 1998; Torbert and Burger 2000; Rehman and Khan 2009). In this regard, mechanical measures have been considered as an important tool for ecological rehabilitation of landslide through the vegetation recovery (George et al. 2012).

For rehabilitation of landslides, geojute technology has been tested and recommended by the researchers and policy planner globally (Rickson 1988; Rickson 1992a; Khan 2012; Islam 2013). Geojute application on such sites can provide a large number of benefits, for example, reduced runoff and soil loss (Mitchell et al. 2013; Chen and Cui 2017), ameliorated soil physico-chemical properties (Thompson and Ingold 1986; Methacanon et al. 2010), increased plant species growth and biomass (Fifield 1992; Yang et al. 2000), improved carbon stock and micro-climate (Islam 2013), and greater water holding (Shao et al. 2014) and water storage capacity of the soils (Lekha 2004). Moreover, rehabilitation of landslide site enhances ecosystems services (Cao et al. 2010), landscape beauty (Fan et al. 2013), and thereby promotes regional development (Islam 2013). However, the relationship between geojute and natural vegetation development at the landslide sites requires attention due to limited quantitative data on its scientific importance and practical applications (Harper 1990; Maiti and Maiti 2015). To date, a great deal of information is available concerning the mechanisms and benefits of geojute technology (Rickson 1988; Rickson 1992a; Khan 2012; Islam 2013); however, the studies on impact of geojute on natural vegetation development are lacking, except the moderate success observed in artificial sowing or planting at such sites (Yang et al. 2016).

Keeping above in view, the present study was conducted with the hypothesis that, application of geojute improves soil moisture regime and reduces soil loss that results in increased richness, density and biomass of plant species at the landslide site. Therefore, the objectives of the study were; (1) to assess impact of geojute application on richness, diversity, density and basal area of plant species; (2) to compute geojute influence on biomass, carbon stock and carbon sequestration of plant species, and; (3) to observe changes in the soil moisture regime and reduction of soil loss under geojute at the landslide site.

1 Material and Methods

1.1 Study area

The study was conducted in the Himalayan mountainous region of the Uttarakhand state (latitude 30°49' N; longitude 77°47'E and altitude 1600m a.m.s.l), India, during 2012 (Figure 1). The site was selected for study because of the formation of recent landslide and such landslides are common in mountainous region. The site was considered as the representative of most Himalayan landslides in term of the slope, altitude and aspect. This region is characterized by mountainous terrain having an undulating topography and steep slopes (35°). The regional climate varies from sub-tropical to sub-temperate with 1600 mm annual rainfall, most of which is received during monsoon period (June-September) and occasional snowfall during winter (Dec-Jan). The rain is received mostly in the form of intense storms and sometime occurrence of cloud bursts, which results in the occurrence of landslide. The vegetation consists of the scattered scrub and annuals. Soils at the study site belong to alluvial, entisol and inceptisols taxonomic group and gravelly sandy loam to silty clay loam texture class. Soils are slightly acidic in nature with low available nitrogen, medium to high in phosphorus and potassium, respectively.

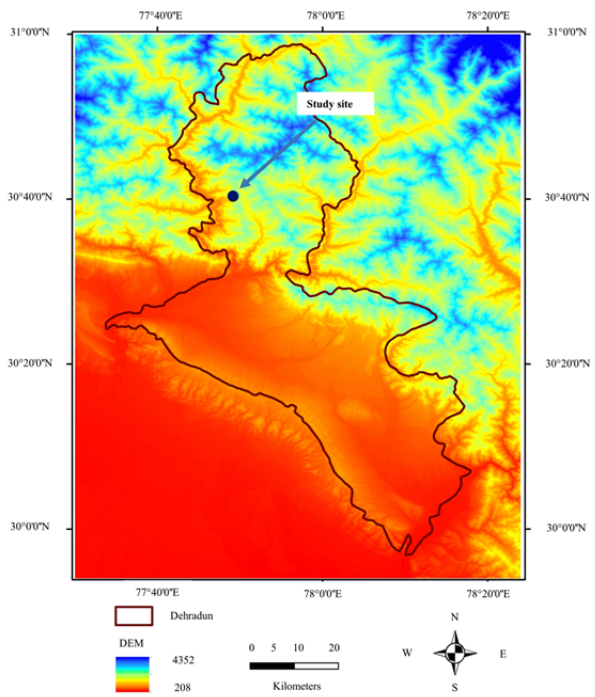

Figure 1 Location map of the experimental site.

1.2 Experimental design

The present study was conducted to assess the potential of geojute in restoration of landslide site. Initially, the experimental site was scrapped to remove protrudes and undulations caused by depression and boulders. Following this, a diversion drain was dug at the top of the landslide site to drain excess runoff, as in hilly areas and on fragile slopes runoff is the major cause of soil erosion. Further, gully plugs and stone barrier structures were executed at the landslide site to reduce soil erosion. On top of the landslide site, a trench was dug and the upper end of geojute was anchored in the trench and later re-filled with dug out soil to provide stability in geojute. Once anchored, geojute was rolled down by overlapping (approximately 20cm) adjoining widths. To make firm contact of geojute with the slope surface, wooden pegs were fixed to protect the geojute from sliding down during heavy rainfall events. In addition, a toe wall was constructed at the bottom to anchor the geojute for slope protection.

1.3 Treatment description

Four treatments comprising of three different densities of geojutes and one control (without geojute) were designed in a landslide to observe their impact on the natural vegetation development and rehabilitation of landslide. These different densities of geojutes were considered to analyze their relative effectiveness in landslide restoration. Considering above mentioned points, different densities (GSM; grams per square meter) open mesh (50% open area) geojute were selected for the study. Therefore, four treatments tested were: (i) control (without geojute); (ii) 500 GSM geojute; (iii) 600 GSM geojute; and (iv) 700 GSM geojute to observe their impact on species richness, diversity, density, basal area, biomass, carbon stock, carbon sequestration, soil moisture and soil loss at the landslide site. Each treatment was designed in a 0.1 ha area.

1.4 Composition of geojute

In order to augment the natural vegetation development and to rehabilitate landslide sites, geojutes were considered based on the recommendations by previous the researchers (Rickson 1988; Rickson 1992a; Khan 2012; Islam 2013). Biologically, geojute is a coarse natural blast fibers lying in the peripheral layer of the plant stem. It belongs to the genus Corchorus which consist of 30 species out of which *C. capsularis* (White Jute) and *C. olitorius* (Tossa Jute) are utilized for production of fibers. Jute mainly composed of α-cellulose (59%-61%), hemicellulose (22%-24%) and lignin (12%-14%).

1.5 Characteristics of geojute

The geojute was selected based on the following characteristics:

(i) Geojute increases water absorption, reduces evaporation losses, and improves water holding and the water storage capacity of soils (Lekha 2004; Li et al. 2013; Luo et al. 2013; Shao et al. 2014), which is crucial in areas where soil moisture is a limitation for the plant growth.

(ii) Geojute controls the detachment of soil particles, intercepts splashed particles, improves soil contact and reduces the leaching of nutrients in soils (Mayer and Wischmeier 1969; Rickson 1988) thereby reduces soil erosion.

(iii) Geojute increases vegetation cover, improves biomass and modifies micro-climatic conditions in degraded landslide lands (Fifled and Malner 1990; Jankauskas et al. 2008; Khan and Binoy 2012).

(iv) Biodegradable geotjute contributes organic matter to the soil, which improves its physico-chemical properties (Methacanon et al. 2010).

1.6 Vegetation measurement and analysis

To observe the natural vegetation development at the landslide site, 10 quadrate per treatment sized 1m×1m were randomly selected, during Sept. 2012. The vegetation characteristics such as number of individuals and diameter of each plant species were recorded in sample plots using procedures described by West (2009). Species richness- which is a measure of the number of species per unit area was recorded to determine the increase in number of species post geojute application at the landslide site. Density, basal area and frequency of the species were determined using the procedure elaborated by Curtis and McIntosh (1950) and Tomar et al. (2015). Total density and total basal area of plant species was determined by summing the density and basal area of all the species. Further, in order to observe the geojute influence on plant species diversity (Eq.1) and their number, the Shannon's index of general diversity was computed using the following formulae (Odum 1971):

$$H = \sum(ni/N)Log\ (ni/N) \qquad (1)$$

in which, *H*= Shannon's index of diversity, while, *ni* and *N* is the importance value of a species and total importance value, respectively.

1.7 Biomass and Carbon stock determination

The fresh shoot samples of each species were brought to the laboratory and oven dried at 60˚C to determine dry biomass for computing the above ground shoot biomass. The below ground root biomass was determined by multiplying above ground shoot biomass with a factor 0.26 (IPCC 2003). In addition, the carbon stock was determined by multiplying total biomass (above ground biomass+below ground biomass) of each species with a constant factor 0.47. The CO_2 sequestration for each treatment was estimated by multiplying the total carbon stock with a constant factor 3.67 (Petersson et al. 2012).

1.8 Soil loss and moisture estimation

The wooden erosion pegs sized 1cm in diameter and 30cm in length (5 numbers in each treatment) containing measuring scale were installed in the landslide site to determine changes in soil levels (depth) for estimating the sheet erosion as per the procedure outlined by Godfrey et al. (2008). To supplement erosion pegs, rill formation was also observed and later analyzed to determine the relative severity of rill erosion at the landslide. Rills were categorized into four classes, ie., no rill, slight rill, moderate rill, high rill, severe rill and very severe rill based on depths and specification elaborated by Saadat et al. (2014). The soil moisture (0-15cm depth) was determined under each treatment by gravimetric method.

1.9 Statistical analyses

The Tukeys HSD (honest significant difference) was performed in conjunction with one-way ANOVA with five replications in a randomized block design to detect mean differences between the treatments for various parameters. The SPSS 16.0 software was used for statistical analysis and significance among the treatments was tested at 5% level of significance.

2 Results and Discussion

2.1 Species richness

Species presence and their distribution were observed non uniform in different geojute treatments and in control at the landslide site. In three geojute treatments, number of species recorded was ranged from twelve to seventeen, while only four species were recorded in control. Moreover, species richness was recorded higher in 700 GSM density geojute compared to control (F=28.05, df=3, 12, P<0.05; Table 1). In absolute terms, species richness in 700 GSM, 600 GSM and 500 GSM treatments was recorded higher by 30%, 25% and 20%, respectively, compared to control. Among geojute treatments, higher density geojute contributed to increased species richness compared to the lower density geojute.

Overall, present findings explained that the geojute application increased species richness and the reduction in geojute density resulted in declined species richness at the landslide site. Moreover, in control least species richness was recorded compared to the geojute treatments. The increased species richness beneath geojute clearly indicated soil water induced seedlings emergence. In general, geojute created favorable physico-chemical and biological conditions in the soils as a consequence of soil and water conservation that improved the species richness in such lands. Likewise, Islam (2013) observed that the lower runoff and soil loss in geojute treatments resulted in the reduced species seed removal which contributed to increased species richness at landslide sites compared to without geojute treatment (Control). In China, Yang et al. (2016) reported the increased species richness post geojute application along the highway slopes. Similarly, Zhang et al. (2014) summarized that the reduction in soil loss contributed to the increased plant species survival (98 percent) in loess plateau of China. In general, increase species richness as a consequence of geojute application eventually contributes to the improved ecosystem structure and function of landslide sites (Singh et al. 2012).

Table 1 Species richness (mean, n=5) and Shannon diversity index under different geojute treatments (GSM=gram per square meter)

	Species richness (no.)	Shannon diversity index
Control	4.0^{c}±1.0*	0.59
500 GSM	12.0^{b}±3.0*	1.06
600 GSM	15.0^{ab}±3.0*	1.15
700 GSM	17.0^{a}±2.0*	1.20

Notes: Letter ($^{a-c}$) indicates significant differences at 5 % level of significance (P<0.05); *Value (±) indicates standard deviation of mean.

2.2 Species diversity

The influence of geojute was observed on species diversity at the landslide site. Geojute application at the landslide site contributed to increased species diversity. Species diversity was observed greater in higher density geojute compared to the lower density geojute and control (Table 1). Moreover, species diversity in 700 GSM was observed higher by 4%, 13% and 103% compared to 600 GSM, 500 GSM and control, respectively. Likewise, species diversity in 600 GSM and 500 GSM was computed 95% and 80% higher, respectively, compared to control. The results demonstrated that the geojute application improved species diversity in landslide site. The favourable conditions created for plant growth beneath geojute contributed to the increased species diversity (Jankauskes et al. 2012). Indeed, geojute resulted in high water absorption (Lou et al. 2013), reduced evaporation losses (Li et al. 2013) and improved water storage capacity of the soil (Lekha 2004) that resulted in enhanced species diversity at the landslide site. Moreover, geojute application created favorable micro-environment for seedling emergence and growth that might have improved the species diversity (Thompson and Ingold 1986). Davies et al. (2006) and Yang et al. (2016) have also reported potential of geojute in improving the plant species diversity in such lands. Indeed, improvement in species diversity as a consequence of geojute application contributes to enhanced vegetation diversity, which promotes the long term stability to landslide ecosystems.

2.3 Density and basal area

The different plant species were compared for density and basal area at the landslide site. Overall, cumulative plant density was observed higher for *Galium asperifolium* compared to the rest of the species (Table 2). Overall, our results explained that different geojute density significantly affected plants density (F=17.08, df=3, 12, P<0.05) and basal area (F=560.61, df=3, 12, P<0.05) at the landslide site. Both these parameters were recorded higher in 700 GSM followed by 600 GSM, 500 GSM treatments, while, their least value was recorded in control. Moreover, mean species density was observed 7.82, 3.62 and 2.13 times more in 700 GSM compared to 600 GSM, 500 GSM and control, respectively (Table 3). Likewise, the mean basal area was recorded higher in 700 GSM (71.45 m^2 ha^{-1}) followed by 600 GSM (68.45 m^2 ha^{-1}), 500 GSM (60.76 m^2 ha^{-1}) and control (19.82 m^2 ha^{-1}), in decreasing order (Table 3).

Our results illustrated that *Galium asperifolium* was observed as the dominant species in term of density at landslide site. The favorable environment created after geojute application in landslide site might have resulted in the dominance of *Galium asperifolium*. Overall, results explained that the geojute application enhanced species density and basal area at the landslide site.

Table 2 Effect of geojute on species density (mean, n=5). (GSM=gram per square meter)

Species	Control	500 GSM	600 GSM	700 GSM
Aegeratum conyzoides	-	80700^{d}	274000^{a}	60100^{e}
Aerva lanata	-	171550^{a}	36610^{kl}	13560^{j}
Ajuga bracteosa	-	-	-	20050i
Anaphalis contorta	-	52450^{gh}	34250^{kl}	9110^{j}
Artemisia indica	-	130400^{b}	94000^{c}	-
Artemisia roxburghiana	-	-	123800^{b}	180500^{a}
Atylosias carabaeoides	131452^{ab}	20350^{j}	-	-
Bidens biternata	-	40250^{i}	5250^{m}	50150^{g}
Bothriochloa pertusa	-	-	37050^{jk}	110150^{b}
Celebrookia oppositifolia	-	-	123717^{b}	77250^{c}
Dichanthium annulatum	-	54360^{g}	-	-
Digitaria adscendens	-	50650^{h}	124154^{b}	70400^{d}
Galium asperifolium	150146^{a}	60250^{f}	54460^{f}	180750^{a}
Gomphrena celosioides	-	-	-	30150^{h}
Oxalis corniculata	-	-	74850^{e}	-
Polygonum capitatum	-	80360^{d}	83750^{d}	55120^{f}
Rumex hastatus	22125^{c}	96800^{c}	44150i	60230^{e}
Sida cordifolia	-	70400^{e}	42640^{ij}	80540^{c}
Tagetes minuta	-	-	34150^{i}	110800^{b}
Thymus linearis	-	-	-	70150^{d}
Verba cumthapsus	110658^{b}	-	-	58300^{ef}

Notes: Letter ($^{a-l}$) indicates significant differences at 5% level of significance (P<0.05).

Table 3 Total density and total basal area of plant species under different geojute treatments

Treatments	Total density (no. ha^{-1})	Total basal area (m^3 ha^{-1})
Control	414381.0^{d}±7500^{*}	19.82^{c}±1.88^{*}
500 GSM	908520.0^{c}±13100^{*}	60.77^{b}±3.32^{*}
600 GSM	1185531.0^{b}±18600^{*}	68.43^{a}±3.74^{*}
700 GSM	1237310.0^{a}±20500^{*}	71.45^{a}±4.52^{*}

Notes: Letter ($^{a-d}$) indicates significant differences at 5% level of significance (P<0.05); *Value (±) indicates standard deviation of mean.

Likewise, higher density geojute improved the species density and basal area compared to the lower density geojute and control. Rather, plants density and basal area is determined by the quantity of water and nutrient conserved in the soils and their availability to plants (Hishe et al. 2017). Greater soil and water conservation and more nutrient availability in higher density geojute contributed to the improved species density and basal area in such sites (Yang 2016). By and large, creating congenial soil environment through geojute application provide stress free environment, which resulted in improved species density and basal area (Harper 1990; Khan and Binoy 2012). For example, Fifield (1992) summarized the important role of geojute in plant growth improvement at landslide site. In general, the increased plant species density and basal area as a consequence geojute application contributes to increased vegetation covers that can rapidly ameliorate such lands (Ran et al. 2013).

2.4 Biomass and Carbon stock

The different density geojute significantly (F=768.80, df=3, 12, P<0.05) affected species biomass and carbon stock and CO2 sequestration at the landslide site (Figure 2). Geojute application increased biomass and carbon stock in order of 700 GSM >600 GSM >500 GSM> control. Mean biomass and carbon stock were ranged from 0.89 t ha^{-1} and 0.42 t ha^{-1} in control to 3.33 t ha^{-1} and 1.58 t ha^{-1} in 700 GSM, respectively. Moreover, geojute application improved carbon stock that contributed to the greater CO_2 sequestration at landslide site. Indeed, mean CO_2 sequestration was recorded higher in 700 GSM (5.81 t ha^{-1}) compared to 600 GSM (4.99 t ha^{-1}), 500 GSM (3.80 t ha^{-1}) and control (1.54 t ha^{-1}), in decreasing order.

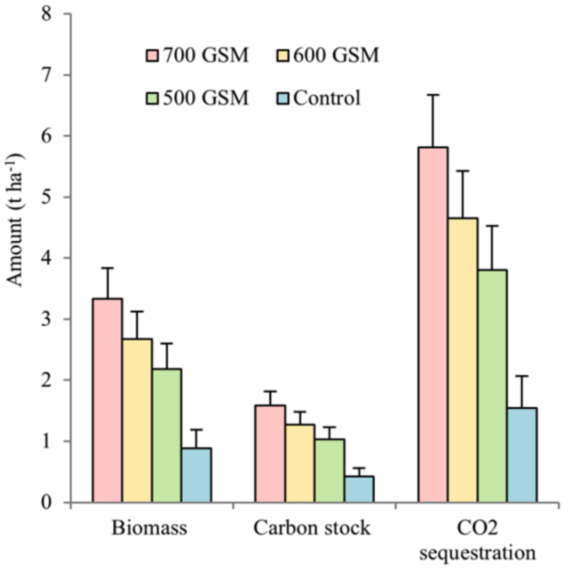

Figure 2 Effect of geojute treatments on biomass, carbon stock and CO_2 sequestration (mean, n = 5) at landslide site (GSM = gram per square meter).

The results explained that greater biomass, carbon stock and CO_2 sequestration were observed in higher density geojute treatments compared to the lower density geojute and control. In contrast, greater soil loss in control treatment resulted in reduced biomass production and carbon stock of plant species. Moreover, soil loss reduces soil fertility that resulted in the lower CO_2 sequestration by the plants. This indicates that lesser soil loss in geojute treatments contributed to improved plant biomass and carbon stock compared to control. Likewise, reduction in soil carbon stock due to erosion and degradation has also been reported by researchers throughout the globe (Chaplot et al. 2009; Olson 2010; Polyakov and Lal 2004; Olson et al. 2016). Nevertheless, greater biomass production and carbon stock in such sites contributes to climate change mitigation globally through enhanced CO_2 sequestration (Franzluebbers, and Doraiswamy 2007; Singh 2012).

2.5 Soil moisture

The different geojute significantly (F=7.69, df=3, 12, P<0.05) affected soil moisture at the landslide site. Mean soil moisture under 700 GSM, 600 GSM, 500 GSM geojute was recorded 28%, 21% and 6% higher, respectively, compared to control (Figure 3). In addition, soil moisture under 700 GSM geojute was recorded 20% and 5% higher compared to 600 GSM, 500 GSM geojute, respectively. The results demonstrated that higher density geojute contributes to improved soil moisture compared to lower density geojute and control at the landslide site. The greater interception, absorption and storage of water by geojute contributed to increased soil moisture (Lou et al. 2013). This is due to fact that geojute improved contact with soil surface that reduced runoff and evaporation losses and increased water infiltration in the soils (Islam 2013). For example, Lekha (2003) observed a 22 percent increase in soil moisture beneath coir mat covered slopes compared to non-covered slopes. Moreover, increased soil moisture beneath geojute has also been reported by previous researchers (Vishnudas et al. 2006; Li et al. 2013; Shao et al. 2014). This indicates that the better soil moisture beneath geojute creates favorable soil physico-chemical properties that expedite plant growth which helps in rapid vegetation recovery at the landslide sites.

2.6 Soil loss

The erosion pegs status showed no visible change in soil levels (depth) in control and as well as in geojute treatments. This is due to fact that the sheet erosion was not observed in landslide site, because of the removal and subsequently equal deposition of soil around the erosion pegs. In contrast, slight to high rill formation was observed in control treatment, while, no rill formation was observed in geoute treatments (Table 4).

Overall, results illustrated that geojute is highly effective in controlling soil erosion at landslide site. The reason was that, the geojute prevents detachment of soil particles, intercepts splashed particles, improves soil contact and reduces leaching of nutrients from the soils (Rickson 1988). Moreover, greater water infiltration post geojute application improved soil moisture that reduced runoff and soil loss at the landslide site. For instance, Rickson (1992b) and Mitchell et al. (2003) have reported higher soil loss in sites that were without geojute compared to the geojute treated sites. In general, geojute techniques have great potential in conserving soil and water resources that contributes to long term ecosystem stability and services in landslide sites.

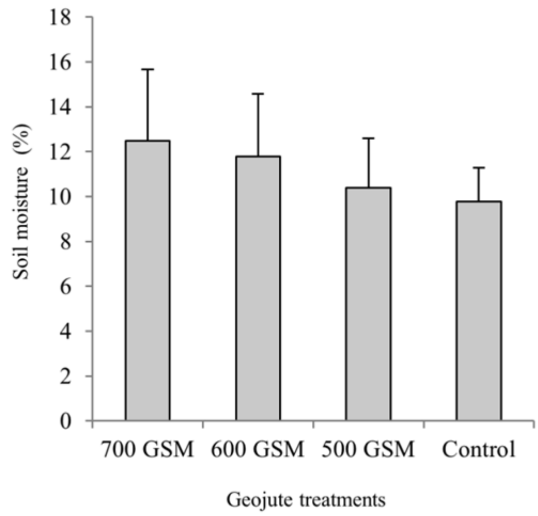

Figure 3 Variation in soil moisture content (%) (mean, n = 5) under different geojute treatments (GSM = gram per square meter).

Table 4 Effect of geojute on rill formation at landslide site

Treatments	No rill	Slight rill	Moderate rill	High rill	Severe rill	Very severe rill
Control	x	✓	✓	✓	x	x
500 GSM	✓	x	x	x	x	x
600 GSM	✓	x	x	x	x	x
700 GSM	✓	x	x	x	x	x

3 Conclusions

Results from present study demonstrated that geojute application successfully improved species density and basal area, which promoted the greater biomass production and carbon stock and thereby the higher CO_2 sequestration in landslide site. Moreover, geojute application improved the soil moisture regime, while reduced the soil loss, which resulted in the improved vegetation growth, species richness and diversity in such site. In general, the research demonstrates that geojute technology has the great potential to reduce soil erosion and improve the productivity of the extremely degraded landslide site. Further, the present study provides important information on improvement in vegetation characteristics post geojute application and can be useful for planning rehabilitation measures on similar landslide sites. Moreover, future studies on the impact of improved geojute technology should be initiated for sustainable management and utilization of landslides through growing ecologically and commercially important tree species.

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