**Effect of geotextiles on runoff, soil loss, soil quality and vegetation in**

**sloppy lands of Western Ghats**

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**ABSTRACT**

In order to controll soil erosion and land slide, a study was conducted to compare the performance of jute geo-textiles with synthetic geo-textiles on erosion control with the objective to compare the impact of natural jute geo-textiles over the synthetic geo-textile on runoff, soil and nutrient losses, soil moisture retention and grass growth parameters. The study was conducted in two slope groups namely 60 % and 90 % and three types geo-textiles *viz* 500 GSM Synthetic Geo-textile, 500 GSM Non Woven JGT and 500 GSM Open Weave JGT were applied and one control plot without applying Geo-textiles for comparing the effect of geo-textiles. After imposing the treatments, root slips of Weeping Love Grass *(Eragrostis curvula)* which is well adopted to local climatic condition were directly planted. The results of the study on effect of various types of Jute Geo-textiles and Synthetic Geo-textiles on 60 and 90 per cent sloppy land on erosion control showed that the natural jute geo-textiles have performed with higher efficiency in controlling soil erosion. Higher runoff reduction efficiency of 41.3 % and 38.4 % was attained by open weave JGT in 60 % and 90 % slope, respectively. Similarly, maximum soil loss reduction efficiency of 86.6 % and 86.8 % was also attained by open weave jute geo-textiles under 60 % and 90 % slopes, respectively. Growth and root parameters of grass (*Eragrostis curvula)* also showed that maximum was attained by open weave jute geotextiles. Thus, the study concludes that the natural JGT is outperformed the synthetic geo-textiles and natural JGT can be effectively utilized for slope stabilization by establishing grass species. Application of open Weave JGT with grass planting is recommended for slope stabilization of degraded or landslide areas with maximum slopes of 90 percent.

**Key words:** Geotextiles, Jute, Nutrient loss, Runoff, Soil loss, Western Ghats

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Geosynthetics comprise a variety of products that largely grouped under geotextiles, geogrids, geomembranes and geocomposites found to be in immense use for many infrastructure development projects in India (Rickson, 1988). These geosynthetics plays a vital role in environmental engineering applications including pollution control, landfills and erosion control, apart from the conventional civil engineering applications. Surface coverage, roughness, water-holding capacity, wet weight and ability of increased flow depth are the unique features of geotextiles used for erosion control (Rickson, 2006). Geosynthetic structures are economical as the locally available soil or dredged material and rocks are being used as fill material in construction (Brooker and Ireland, 1965; Nagami and Yong, 2003; Deb *et al.*, 2013). Alternatively, natural fibre based Geo Textiles are being applied in slope stabilization, erosion control and road construction (Ogbobe *et al.,* 1998; Vishnudas *et al.,* 2012). Jute is one of the natural fibre geotextiles being used (Vivek *et al.,* 2019) as it is very effective in reducing soil erosion subsequently improves slope stabilization processes. Jute geotextile (JGT) which is a fabric made from jute smeared with resistant chemicals has been tried to control soil degradation in the eroding bank of Indian rivers. JGT has also been recommended as a pioneering material for controlling soil erosion where it has established itself as a potential agent (Ingold, 1994).

Many researchers successfully used JGT for slope management, soil erosion control, stabilization of earthen embankment, river and canal bank protection, strengthening of subgrade of road pavement and railway track, consolidation of soft soil etc. (Ramaswamy and Aziz, 1989; Sanyal and Chakraborty,1993; Rickson *et al.,* 2003). Abundant availability and economical choice of manufacturers and end users are additional factors which influence in application of JGT for erosion control (Ghosh *et al*., 1994). Environment-friendly nature of JGT that makes it a safe and congenial natural choice is another important factor for wide application in the area of erosion control (Mazumdar *et al.,* 1980). The open weave JGT (weft yarns) provides a series of mini barriers which act as a sort of check dams across the direction of overland flow (Sanyal, 2011). The 3-D construction of open weave JGT reduces the velocity of overland flow and opening of the fabric retain dislodged soil particles that are set to be carried away by over land flow (Choudhury and Sanyal, 2010). Open weave JGT structure with 40 to 60 percent open area provide a partial cover to the soil surface and heavy strands of JGT helps to absorb the impact of the kinetic energy of the falling rain drops. JGT has excellent drapability and can be laid out to follow the soil contours on which it is laid (Thomson and Ingold, 1986).

JGT is highly hygroscopic due to the intrinsic properties of jute fibre and its flexibility increases due to absorption of water. The uniqueness of JGT is the capacity to absorb 4.5-6 times its dry weight water because of its high cellulosic content (Rickson, 1988). It also bio-degrades within 2 to 5 years (Oosthuizen and Kruger, 1994) adding nutrients to the soil at the micro-level. Once vegetation starts growing, the role of JGT is taken over and established vegetative cover provides canopy interception to falling rain drops and protects the soil from splash detachment of soil particles (Bhattacharyya *et al.,* 2010). The fibrous root system of vegetation penetrates the soil and reinforces the slope soil and provides long term stability. JGT is preferred over other geotextiles for slope stabilization due to their additional environmental complementary support (Sanyal, 2004). Perennial grasses along with the geotextiles are more effective for stabilization of slope and reducing soil erosion (Jankauskas *et al.,* 2004).

The Nilgiris hill ranges are located on the fragile environment of Western Ghats with an elevation ranging from 300 m to 2634 m above mean sea level. The Nilgiris mountainous region forms an area of 5500 sq.km and extends in three Indian States namely Tamil Nadu, Kerala and Karnataka. It is known for its rich biodiversity and source of water for major reservoirs in the plateaus. Major area of the Nilgiris is covered under natural and manmade forest (56%) followed by plantation crops (20%) like tea, coffee and remaining 24 % of area is cultivated with vegetable crops. In recent days forest and plantation crops are replaced by vegetables without adopting any soil and water conservation measures. Apart from this vertical road cutting, huge earth cut for developmental works and construction of buildings coupled with high intensity rainfall leads to mass erosion in sloppy lands. In the history of Nilgiris biosphere landslides were very rare but now becoming frequent and occurring biannually or annually in one or other parts. Landslide occurrence is periodical especially during the North-East monsoon resulting huge damages to the properties and life in the region. Keeping in view of the erosion control characters of jute geo-textiles and geographical nature of Nilgiris, a study was conducted to compare the performance of jute geo-textiles with synthetic geo-textiles on erosion control. The main objective of the study was to compare the impact of natural jute geo-textiles over the synthetic geo-textile on runoff, soil and nutrient losses and soil moisture retention.

**Materials and Methods**

**Study area**

The study was carried out at the Research Farm of ICAR - Indian Institute of Soil & Water Conservation (formerly known as Central Soil and Water Conservation Research & Training Institute), Regional Centre, Udhagamandalam, Tamil Nadu which represents the geographical area of Nilgiris and lies in between 11°24΄59΄΄ North latitude and 76°41΄11΄΄ East longitude and located 2225 m above mean sea level. The climate is sub humid subtropical with an annual rainfall of 1324.9 mm in average of 119 rainy days. It rains almost in every month of the year as it falls within the active zone of both monsoon seasons namely the south-west monsoon and the north-east monsoon. The average temperature of the study area is relatively low with the annual average temperature of 14.6º C.

**Methodology**

The experimental plot was divided into two sections of slope groups, 60 and 90 % with an intermediate transition area. In each slope groups, four plots having the dimensions of 16 m X 4 m were created with three treatments Viz., 500 GSM Synthetic Geo-textile, 500 GSM Non Woven JGT and 500 GSM Open Weave JGT and one control plot without applying Geo-textiles for comparing the effect of geo-textiles. After imposing the treatments, root slips of Weeping Love Grass *(Eragrostis curvula)* which is well adopted to local climatic condition were directly planted in the already made hole during onset of monsoon season with the spacing of 50 cm x 50 cm and firmly filled with soil. Properties of geo-textiles used in this study are presented in Table 1. The study was replicated for three years from 2013 to 2015 and hydrological parameters were monitored on time replication.

**Measurement of runoff, soil and nutrient losses and soil moisture retention**

Runoff and Soil Loss were directly measured using Multi-slot divisors developed by R.V. Geib in USA for measuring runoff and soil loss from small experimental plots were locally fabricated and installed at the outlet of each experimental plot (Harrold and Krimgold, 1943). Runoff and soil loss was measured directly for every rainfall event and added total runoff and soil loss for annual events. Soil loss was estimated by taking 1000 ml of homogenized sample from the runoff tanks and dried at 105° C and subsequent weighing of the soil samples. Soil loss (t ha-1) was calculated by multiplying the sample soil weight by total run-off volume for each event. Nutrients losses namely Nitrogen (Subbiah and Asija, 1956), Phosphorus (Bray and Kurtz, 1945) and Pottasium (Jackson, 1973) and Organic carbon (Walkley and Black, 1934) were estimated from the runoff samples as per standard laboratory procedures.

Soil moisture content was monitored using the gravimetric method at monthly intervals in three soil depths (0-15, 15-30 and 30-45 cm) to quantify the effect of different types of JGT on soil moisture retention capacity of soil. Annual runoff, soil and nutrient losses and soil moisture retention were worked out for three years period from 2013 to 2015.

**Efficiency of Geotextiles in Runoff and Soil loss Reduction**

The Runoff Reduction Effectiveness (RRE %) and Soil Loss Reduction Effectiveness (SLRE %) of different geo-textiles were evaluated using the formula of Sutherland (1998).

Where RRE (%) and SLRE (%) are Runoff and Soil Loss Reduction Efficiency of treatment i, and R and SL are Runoff and Soil Loss respectively. A higher and positive value indicates high effectiveness of geo-textiles in reduction of runoff and soil loss over control.

**Growth Parameters of Grass**

The growth parameters of weeping love grass *(Eragrostis curvula)* namely Height, Foliage lateral spread and volume of the root were observed at regular interval from planting up to three years. The height of grass was measured vertically up to the main stem from the ground level. The foliage lateral spread was measured at 2 directions perpendicular to each other the diameter and average value was calculated as follows:

FLS = (Y1 + Y2) ÷ 2

Where, FLS is average Foliage Lateral Spread

Y1, Y2 = Foliage Lateral Spread in 2 directions perpendicular to each other passing

through the main stem as vertical central axis.

The grass was uprooted by digging and the rooting depth was measured vertically down from the ground level. The lateral spread of the roots was measured at 3 directions from the main stem (central) of the grasses and the radii and average value was calculated as follows.

RLS = (X1 + X2 + X3) ÷ 3

Where, RLS = average Root Lateral Spread

X1, X2, X3 = root lateral spread in 3 directions from the main stem (central)

Volume of the root was measured by water displacement method. Root mass density was calculated by dividing the volume by the root dry weight and expressed in gram/cc of soil volume.

**Soil conservation properties of grass**

Grasses are shallow rooted and it is assumed that fibrous roots bind the soil in cylindrical shape. It is because more lateral spread of the roots provides umbrella for the soil beneath up to the maximum rooting depth. Hence, formula of volume of cylinder is used for calculating the volume of soil bound by the roots as follows:

Formula adopted for the volume of soil bound by roots = π (RLS)2(RD)

Where RLS = root lateral spread (radial form from the main stand of grass); And RD = rooting depth of grass

The ground surface area protected by grass foliage against direct raindrop effect is calculated using the formula to calculate the area of circle (A = 2πd/4) as follows:

Protected ground surface area = 2π (FLS) /4

Where FLS is foliage lateral spread (taking as diameter passing through the main stand of the grass) and d is diameter.

**Results and Discussion**

**Runoff and soil loss**

Runoff and soil loss data showed less during the initial and increased during second year then subsequently decreased during third year. The less runoff and soil loss during the first year (2013) is due to high infiltration rate as the soil was filled to make required slope for the experiment. The fact of decreasing trend during third year was (2015) due to stabilized soil, canopy and root establishment of grass (Fullen and Booth, 2006). Minimum runoff of 59.4 mm was produced under 500 GSM Open Weave JGT followed by 66.9 mm in 500 GSM Non Woven JGT against 83.9 mm of runoff in control plot during the year 2013 in 60 % sloppy land (Table 2). However, during the second year of the study, out of a total rainfall of 1392.2 mm, minimum runoff of 125.6 mm was produced by 500 GSM Open Weave JGT followed by 149.8 mm by 500 GSM Non Woven JGT and 178.6 mm by 500 GSM Synthetic Geo-textiles against maximum runoff of 215.1 mm from the control plot. Similarly, minimum runoff of 72.4 mm was produced by 500 GSM Open Weave JGT followed by 500 GSM Non Woven JGT (86 mm) and 500 GSM Synthetic Geo-textiles (105.8 mm) against maximum runoff of 154.1 mm in control plot during the year 2015. Application of geo-textiles on bare soils is generally reduce the runoff volume (Sutherland, 1998) and the same was confirmed in the present study.

The runoff data recorded in 90 % sloppy land shows that minimum runoff of 69.5 mm was produced under 500 GSM Open Weave JGT followed by 78.9 mm in 500 GSM Non Woven JGT against 98.5 mm of runoff in control plot during the year 2013 . However, during the second year of the study, out of a total rainfall of 1392.2 mm, minimum runoff of 185.1 mm was produced by 500 GSM Open Weave JGT followed by 197.8 mm by 500 GSM Non Woven JGT and 221.2 mm by 500 GSM Synthetic Geo-textiles against maximum runoff of 253.6 mm from the control plot. Similarly, minimum runoff of 77.1 mm was produced by 500 GSM Open Weave JGT followed by 500 GSM Non Woven JGT (92.6 mm) and 500 GSM Synthetic Geo-textiles (124 mm) against maximum runoff of 186.3 mm in control plot during the year 2015 (Table3 ).

Runoff data recorded in three years period and mean data shows that overland flow is less in the plot covered by 500 GSM Open Weave JGT compared to the plots covered by Non Woven JGT and Synthetic Geo-textiles. It was also noticed that the Open Weave JGT reduced the runoff from 3.0 to 6.5 per cent in 60 % slope and 3.5 to 7.7 per cent in 90 % slope (Fig 1 and Fig 2). The application of geo-textiles on soil is effective in reducing runoff by altering the shear stress partitioning of overland flow on hill slopes (Thomson, 2001).

Both the Jute and synthetic geo-textiles produced lower annual soil loss rates than the control. In 60 % slope, soil loss was reduced by Open Weave JGT from 3.8 to 8.5 t ha-1 year-1 compared to control plot. Minimum mean soil loss of 1.1 t ha-1 year-1 was recorded in the plot covered by 500 GSM Open Weave JGT followed by 500 GSM Non Woven JGT (1.4 t ha-1 year-1) and 500 GSM Synthetic Geo-textiles (2.4 t ha-1 year-1) against maximum soil loss of 7.7 t ha-1 year-1 in control plot. Similar fact of decreased soil loss by geo-textiles with perennial grass was reported by Jankauskas *et al.*(2008).

Similarly, in 90 % slope, mean minimum soil loss of 1.2 t ha-1 year-1 was recorded in the plot covered by 500 GSM Open Weave JGT followed by 500 GSM Non Woven JGT (1.5 t ha-1 year-1) and 500 GSM Synthetic Geo-textiles (2.4 t ha-1 year-1) against maximum soil loss of 8.7 t ha-1 year-1 in control plot. Least soil loss in jute geotextiles covered plots proved the importance of natural fibre based geo-textiles in soil conservation. Jana *et al.* (2016) also reported that the soil loss reduction due to application of 500 GSM JGT was the tune of 99.4 %. The effectiveness of the Jute geotextiles in reducing the soil erosion is attributed to their great drapability which refers to its attachment to the soil especially when wet (Álvarez-mozos *et al.,* 2013; Bhattacharyya *et al.,* 2010).

**Runoff and Soil Loss Reduction Efficiency of geo-textiles**

The runoff and soil loss reduction efficiency of all the geo-textiles were low in initial years due to less vegetation establishment and more runoff. The mean runoff reduction efficiency (RRE) showed the efficiency of open weave JGT was higher followed by Non woven JGT when compared to Synthetic geo-textiles, the same was the trend in soil loss reduction efficiency (SLRE). Maximum RRE of 41.3 % and 38.4 % was attained by open weave JGT in 60 % and 90 % slope, respectively. Similarly, maximum SLRE of 86.6 % and 86.8 % was observed under 60 % and 90 % slope, respectively (Table 4). Increased RRE and SLRE is due to higher inﬁltration process of JGT by absorbing more water and support the erosion control and reduce the overland ﬂow (Beven, 2011; Jana *et al.,* 2016).

**Nutrient loss**

Nutrient loss in runoff is directly proportional to volume of runoff and soil erosion. Major soil nutrients like nitrogen, phosphorous, potassium and organic carbon lost through runoff were estimated under 60 % and 90 % slope and mean data is furnished in Tables 5 and 6, respectively. Among the geotextiles, Open Weave JGT was more effective in reducing the nutrient losses as compared to Non Woven JGT and Synthetic Geo-textiles and considerable amount of nutrients were saved by Open Weave JGT. The Open Weave JGT saved 68.6 % total nutrients in 60 % slope and 55.7 % in 90 % slope from the loss through runoff compared to the plot without JGT. These results confirmed the hypothesis that natural geotextiles are very effective in soil erosion control and vegetation establishment (Davies *et al.,* 2006).

**Soil moisture retention**

The application of Jute geotextile on sloppy land increases moisture retention in the soil at various depths and the data is presented in Tables 7 and 8. The soil moisture content in different soil depths (0 - 15 cm, 16 - 30 cm and 31 - 45 cm) is higher under all JGT applied plots than the control plot in both rainy and dry season. Among the two types of JGT, the soil moisture retention was highest under 500 GSM Open Weave JGT followed by 500 GSM Non Woven JGT and 500 GSM Synthetic Geo-textiles. Similar significant differences in soil moisture retention was noticed in dry season under Open Weave JGT which is due to the fact that it checked the velocity of flowing water, increased the time of concentration and allowed higher infiltration into the soil consequently reduced the runoff and soil loss (Manivannan et al., 2018). Several earlier investigations showed the higher moisture retention capacity by the application of the different types of geotextile due to gyroscopic property of jute textile (Jankauskas at al., 2012; Rahul Adhikary and Ravi Sankar 2018.).

**Growth parameters of grass**

Grass height after two years of planting in 60 % slope (Fig. 3) was the highest (128.4 cm) under 500 GSM Open Weave JGT which was followed by 500 GSM Non Woven JGT (120.4 cm) and Synthetic Geo-textiles (119.8 cm). The highest plant height (125.2 cm) was observed with Open Weave JGT in 90% slope (Fig. 4) which was followed by Non Woven JGT (122.2 cm). The growth rate of grass was higher in case of Non Woven JGT in 60 % slope and Open Weave JGT in case of 90 % slope (Fig. 5 and Fig. 6). This may be due to the optimum growing condition provided in terms of better soil and moisture conservation. The growth rate of grass under different treatments were the highest during the fourth month after planting and started declining from the six months as the dry season commenced.

In 60% slope, number of tillers per clump of grass was the highest (163.5 cm) in Open Weave JGT (Fig. 7) which was followed by Non Woven JGT (155.3 cm). However, the highest tiller numbers were observed under Synthetic Geo-textiles and it was on par with other JGT treatment. The least tiller number was observed under the control treatment. In 90% slope, the highest tiller number was observed under Open Weave JGT (Fig. 8) after one and two year of planting. The less number of tillers observed under Synthetic compared to Open Weave JGT may be due the mechanical resistance given by the synthetic materials for tillering. The least tiller number was observed under control. Biomass produced was the highest in 500 GSM Open Weave JGT after one year (3.84 t ha-1) and two years (10.7 t ha-1) after planting, which was followed by 500 GSM Non Woven JGT and Synthetic Geo-textiles which were on par with each other (Table 9). In 90% slope the highest biomass was observed under Open Weave JGT after one year (11.16 t ha-1) and two years (35.3 t ha-1) after planting which was followed by Non Woven JGT and Synthetic Geo-textiles. Similarly, grass and other herbs produced higher biomass of in between tea when covered with open weave jute geo-textiles in 22% slope (Manivannan et al.,2019). The lowest biomass at one and two year after planting was observed under control.

The surface area protected by the grass was more under 500 GSM Open Weave JGT followed by 500 GSM Non Woven JGT due to higher plant height compared to Synthetic Geo-textiles and it was the least in case control plot without any Geo-textiles. In 90 % slope, there was clear-cut trend among various Jute Geo-textiles. The highest value for surface area protection (16733 cm2) was recorded in 500 GSM Open Weave JGT because of higher tiller number and foliage lateral spread. Surface area protected by the grass was the least in case of control.

**Rooting characters**

The highest root depth of 46 cm was recorded under Open Weave JGT after one year of planting in 60% slope, which was followed by Non Woven JGT (Table 10). However root lateral spread (37.6 cm) and volume of soil bind by the root (130956 cc) was the highest under Non Woven JGT and it was on par with Open Weave JGT. In 90% slope, the highest root lateral spread (40.3 cm) and volume of soil bind by the root (188686 cc) was observed under Open Weave JGT followed by Non Woven JGT which was on par with each other. In 60% slope two years after planting the highest root depth was observed in case of Open Weave JGT followed by Non Woven JGT (Table 11). The volume of soil bind by the root was more under Open Weave JGT due to higher root lateral spread (49 cm). The root volume and root weight was higher under Open Weave and Non Woven JGT which were followed by Synthetic Geo-textiles. In 90% slope, the highest root depth (34 cm) was observed in Non Woven JGT which was followed by the Synthetic Geo-textiles. However, the volume of soil bind (391073 cc) by the root was more under 500 GSM Open Weave JGT due to the higher root lateral spread (62 cm) which was followed by 500 GSM Non Woven JGT (359140 cc) and Synthetic Geo-textiles. Overall, the root and growth characters in 500 GSM Open Weave and Non Woven JGT were better as compared to Synthetic Geo-textiles.

The results of the study on effect of various types of Jute Geo-textiles and Synthetic Geo-textiles on 60 and 90 per cent sloppy land on erosion control showed that the natural jute geo-textiles have performed with higher efficiency in controlling soil erosion. Among the Open Weave and Non Woven JGT, Open Weave JGT is more effective in reducing runoff and soil loss, nutrient loss and also increased soil moisture retention and plant growth parameters. Higher runoff reduction efficiency of 41.3 % and 38.4 % was attained by open weave JGT in 60 % and 90 % slope, respectively. Similarly, maximum soil loss reduction efficiency of 86.6 % and 86.8 % was also attained by open weave jute geo-textiles under 60 % and 90 % slopes, respectively. Maximum surface area protected by the grass was obtained under 500 GSM Open Weave JGT followed by 500 GSM Non Woven JGT due to higher plant height compared to Synthetic Geo-textiles and it was the least in case control plot without any Geo-textiles. Growth and root parameters of grass (*Eragrostis curvula)* also showed that maximum was attained by open weave jute geotextiles. Thus, the study concludes that the natural JGT is outperformed the synthetic geo-textiles and natural JGT can be effectively utilized for slope stabilization by establishing grass species as compared to Synthetic Geo-textiles. Open Weave JGT with establishment of grasses is recommended for slope stabilization in the degraded land having the slopes up to 90 %.

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**TABLES:**

**Table 1. Properties of Jute Geo-textiles Evaluated for Erosion control**

|  |  |  |
| --- | --- | --- |
| **Specifications** | **Jute Geotextile Evaluated** | |
| Weight (GSM) at 20% M.R | 500 GSM Open weave JGT | 500 GSM non woven JGT |
| Width (cm) | ≥ 122 | 150 |
| Thickness (mm) | 4.5(±10%) | 4 |
| Wide Width tensile strength (KN/m) MD×CD | ≥ 6.5×6 | 4 × 5 |
| Elongation at break (%) MD X CD | ≤ 10 ×10 | 3.5 × 7 |
| Open area (%) | 50-65 | Nil |
| Water holding capacity (%) on dry weight | 450-500 | 250-300 |

**Table 2. Rainfall and runoff under different Geo-textiles for hill slope stabilization at 60 % sloppy land**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Rainfall (mm) | Runoff (mm) | | | | Percentage of runoff | | | |
| 500 GSM Synthetic Non Woven Geo-textiles | 500 GSM Non Woven JGT | 500 GSM Open Weave JGT | Control | 500 GSM Synthetic Non Woven Geo-textiles | 500 GSM Non Woven JGT | 500 GSM Open Weave JGT | Control |
| 2013 | 843.6 | 78.2 | 66.9 | 59.4 | 83.9 | 9.3 | 7.9 | 7.0 | 10.0 |
| 2014 | 1392.2 | 178.6 | 149.8 | 125.6 | 215.1 | 12.8 | 10.8 | 9.0 | 15.5 |
| 2015 | 1409.8 | 105.8 | 86.0 | 72.4 | 154.1 | 7.5 | 6.1 | 5.1 | 10.9 |
| Mean | 1215.2 | 120.9 | 100.9 | 85.8 | 151.0 | 9.9 | 8.3 | 7.1 | 12.1 |
| CD (0.05%) | | 31.61 | | | | 1.71 | | | |

**Table 3. Rainfall and runoff under different Geo-textiles for hill slope stabilization at 90 % sloppy land**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Rainfall (mm) | Runoff (mm) | | | | Percentage of runoff | | | |
| 500 GSM Synthetic Non Woven Geo-textiles | 500 GSM Non Woven JGT | 500 GSM Open Weave JGT | Control | 500 GSM Synthetic Non Woven Geo-textiles | 500 GSM Non Woven JGT | 500 GSM Open Weave JGT | Control |
| 2013 | 843.6 | 90.2 | 78.9 | 69.5 | 98.5 | 10.7 | 9.4 | 8.2 | 11.7 |
| 2014 | 1392.2 | 221.2 | 197.8 | 185.1 | 253.6 | 15.9 | 14.0 | 13.3 | 18.3 |
| 2015 | 1409.8 | 124.0 | 92.6 | 77.1 | 186.3 | 8.8 | 6.6 | 5.5 | 13.2 |
| Mean | 1215.2 | 145.1 | 123.1 | 110.6 | 179.5 | 11.8 | 10.0 | 9.0 | 14.4 |
| CD (0.05%) | | 36.46 | | | | 2.04 | | | |

**Table 4. Runoff and Soil Loss Reduction Effectiveness of different Geo-textiles at 60% and 90% sloppy land**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Year** | **500 GSM Synthetic Non woven Geo textiles** | | **500 GSM Non woven JGT** | | **500 GSM open weave JGT** | |
| **60 % slope** | **90 % slope** | **60 % slope** | **90 % slope** | **60 % slope** | **90 % slope** |
| **RRE %** | | | | | | |
| 2013 | 6.79 | 8.43 | 20.26 | 19.90 | 29.20 | 29.44 |
| 2014 | 16.97 | 12.78 | 30.36 | 22.00 | 41.61 | 27.01 |
| 2015 | 31.34 | 33.44 | 44.19 | 50.30 | 53.02 | 58.62 |
| Mean | 18.37 | 18.22 | 31.60 | 30.73 | 41.28 | 38.36 |
| **SLRE %** | | | | | | |
| 2013 | 66.67 | 66.07 | 81.90 | 81.25 | 80.95 | 83.93 |
| 2014 | 79.76 | 79.78 | 85.71 | 86.52 | 90.48 | 89.89 |
| 2015 | 53.49 | 73.33 | 69.77 | 81.67 | 88.37 | 86.67 |
| Mean | 66.64 | 73.06 | 79.13 | 83.15 | 86.60 | 86.83 |

**Table 5. Nutrient losses in runoff under different types of JGT and Synthetic Geo-textiles in 60 % sloppy land**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Year** | **Nutrient Loss (kg/ha)** | | | | | **Nutrient saved (%)** |
| **N** | **P** | **K** | **OC** | **Total** |
| **500 GSM Synthetic Non Woven Geo-textiles** | 2013 | 29.9 | 0.1 | 3.3 | 5.7 | 39.0 | **17.8** |
| 2014 | 11.6 | 0.1 | 3.1 | 3.1 | 17.9 |
| 2015 | 4.5 | 0.1 | 3.1 | 3.0 | 10.7 |
| Mean | 15.3 | 0.1 | 3.2 | 3.9 | 22.5 |
| **500 GSM Non woven JGT** | 2013 | 16.2 | 0.2 | 4.8 | 3.2 | 24.4 | **43.4** |
| 2014 | 7.8 | 0.1 | 3.4 | 2.2 | 13.5 |
| 2015 | 3.8 | 0.1 | 2.6 | 2.1 | 8.6 |
| Mean | 9.3 | 0.1 | 3.6 | 2.5 | 15.5 |
| **500 GSM Open Weave JGT** | 2013 | 10.1 | 0.1 | 2.4 | 1.9 | 14.5 | **68.6** |
| 2014 | 3.5 | 0.1 | 1.5 | 1.6 | 6.7 |
| 2015 | 2.5 | 0.1 | 1.3 | 0.7 | 4.6 |
| Mean | 5.4 | 0.1 | 1.7 | 1.4 | 8.6 |
| **Control** | 2013 | 8.3 | 0.1 | 5.8 | 18.3 | 32.5 | **-** |
| 2014 | 7.8 | 0.1 | 5.5 | 14.9 | 28.3 |
| 2015 | 7.5 | 0.1 | 5.0 | 8.9 | 21.5 |
| Mean | 7.9 | 0.1 | 5.4 | 42.1 | 27.4 |

**Table 6. Nutrient losses in runoff under different types of JGT and Synthetic Geo-textiles in 90 % sloppy land**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Year** | **Nutrient Loss (kg ha-1)** | | | | | **Nutrient saved (%)** |
| **N** | **P** | **K** | **OC** | **Total** |
| **500 GSM Synthetic Non Woven Geo-textiles** | 2013 | 27.3 | 0.1 | 5.0 | 6.3 | 38.7 | **20.5** |
| 2014 | 11.6 | 0.1 | 3.2 | 5.5 | 20.4 |
| 2015 | 6.0 | 0.1 | 3.0 | 5.1 | 14.2 |
| Mean | 15.0 | 0.1 | 3.7 | 5.6 | 24.4 |
| **500 GSM Non woven JGT** | 2013 | 21.4 | 0.1 | 3.4 | 5.8 | 30.7 | **38.0** |
| 2014 | 10.8 | 0.1 | 3.4 | 3.9 | 18.2 |
| 2015 | 3.8 | 0.1 | 2.5 | 1.8 | 8.2 |
| Mean | 12.0 | 0.1 | 3.1 | 3.8 | 19.0 |
| **500 GSM Open Weave JGT** | 2013 | 18.9 | 0.1 | 2.6 | 4.7 | 26.3 | **55.7** |
| 2014 | 3.5 | 0.1 | 1.6 | 4 | 9.2 |
| 2015 | 2.1 | 0.1 | 1.5 | 1.7 | 5.4 |
| Mean | 8.2 | 0.1 | 1.9 | 3.5 | 13.6 |
| **Control** | 2013 | 20.7 | 0.2 | 10 | 14.1 | 45.0 | **-** |
| 2014 | 12.7 | 0.1 | 5.3 | 9.4 | 27.5 |
| 2015 | 10.9 | 0.1 | 2.8 | 5.8 | 19.6 |
| Mean | 14.8 | 0.1 | 6.0 | 9.8 | 30.7 |

**Table 7. Impact of Jute Geo-textiles and Synthetic Geo-textile on soil moisture retention in 60 % slope**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Soil depth (cm)** | **Soil moisture (%)** | | | | | | | | | | | |
| **January** | **February** | **March** | **April** | **May** | **June** | **July** | **August** | **September** | **October** | **November** | **December** |
| 500 GSM Synthetic Non Woven Geo-textiles | 0-15 | 15.2 | 14.6 | 13.5 | 14.2 | 21.5 | 28.4 | 20.6 | 21.2 | 24.6 | 21.4 | 24.2 | 17.3 |
| 16-30 | 18.4 | 17.1 | 17.2 | 21.0 | 25.5 | 30.8 | 22.8 | 25.5 | 28.0 | 25.5 | 29.7 | 20.1 |
| 31-45 | 23.9 | 21.3 | 19.3 | 23.2 | 30.0 | 32.4 | 26.7 | 29.7 | 32.0 | 32.2 | 34.2 | 26.0 |
| 500 GSM Non Oven JGT | 0-15 | 18.6 | 16.6 | 14.2 | 16.4 | 23.2 | 29.3 | 22.6 | 22.9 | 26.1 | 24.2 | 28.2 | 20.0 |
| 16-30 | 20.7 | 18.4 | 18.4 | 20.4 | 26.1 | 31.5 | 24.2 | 26.2 | 30.9 | 28.4 | 30.1 | 22.8 |
| 31-45 | 26.5 | 24.1 | 20.9 | 23.8 | 31.2 | 33.6 | 29.7 | 34.6 | 34.0 | 33.6 | 36.4 | 28.1 |
| 500 GSM Open Weave JGT | 0-15 | 22.5 | 20.4 | 12.6 | 17.0 | 26.6 | 30.4 | 24.2 | 24.7 | 28.1 | 26.8 | 33.1 | 24.8 |
| 16-30 | 26.9 | 24.3 | 16.8 | 23.8 | 29.5 | 32.6 | 28.3 | 28.2 | 32.5 | 29.0 | 35.9 | 28.3 |
| 31-45 | 28.1 | 26.4 | 18.7 | 30.0 | 32.9 | 35.1 | 32.1 | 36.0 | 36.2 | 34.3 | 38.6 | 31.7 |
| Control | 0-15 | 14.6 | 14.1 | 12.6 | 13.0 | 18.1 | 26.2 | 19.5 | 19.9 | 22.3 | 20.0 | 21.4 | 15.9 |
| 16-30 | 17.9 | 16.4 | 16.8 | 18.9 | 24.2 | 28.4 | 21.1 | 22.3 | 27.6 | 24.3 | 23.5 | 18.4 |
| 31-45 | 18.3 | 18.3 | 18.7 | 21.3 | 26.5 | 30.9 | 25.5 | 26.4 | 30.4 | 31.1 | 31.1 | 20.6 |

**Table 8. Impact of Jute Geo-textiles and Synthetic Geo-textile on soil moisture retention in 90 % slope**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Depth (cm)** | **Soil moisture (%)** | | | | | | | | | | | |
| **January** | **February** | **March** | **April** | **May** | **June** | **July** | **August** | **September** | **October** | **November** | **December** |
| 500 GSM Synthetic Non Woven GT | 0-15 | 14.8 | 14.5 | 13.9 | 13.8 | 21.4 | 28.3 | 20.5 | 21.1 | 24.5 | 21.3 | 24.1 | 16.9 |
| 16-30 | 18.0 | 16.7 | 15.0 | 20.5 | 25.3 | 30.6 | 22.7 | 25.4 | 27.9 | 23.0 | 29.5 | 19.7 |
| 31-45 | 23.3 | 21.0 | 19.1 | 23.5 | 30.3 | 32.2 | 26.5 | 29.5 | 30.0 | 30.0 | 32.8 | 25.0 |
| 500 GSM Non woven JGT | 0-15 | 18.1 | 16.8 | 14.0 | 16.3 | 23.8 | 29.2 | 22.5 | 22.8 | 26.0 | 23.0 | 28.1 | 19.8 |
| 16-30 | 22.0 | 17.0 | 17.6 | 18.6 | 27.8 | 31.3 | 24.1 | 26.1 | 30.0 | 25.0 | 29.9 | 22.3 |
| 31-45 | 25.9 | 23.9 | 20.5 | 22.0 | 31.0 | 33.4 | 29.5 | 34.4 | 31.0 | 29.0 | 34.9 | 27.0 |
| 500 GSM Open Weave JGT | 0-15 | 23.0 | 20.0 | 16.1 | 16.8 | 26.3 | 30.2 | 24.1 | 24.6 | 28.0 | 25.0 | 32.9 | 24.6 |
| 16-30 | 25.6 | 22.0 | 18.0 | 22.0 | 30.6 | 32.4 | 28.2 | 28.1 | 31.0 | 27.0 | 35.6 | 27.7 |
| 31-45 | 27.8 | 23.0 | 24.0 | 29.5 | 33.4 | 34.9 | 31.9 | 35.8 | 34.0 | 32.0 | 37.1 | 30.4 |
| Control | 0-15 | 13.9 | 13.6 | 12.3 | 12.9 | 18.0 | 26.1 | 19.4 | 19.8 | 22.2 | 19.9 | 21.3 | 15.7 |
| 16-30 | 17.6 | 16.5 | 16.0 | 18.0 | 23.5 | 28.3 | 21.0 | 22.2 | 24.0 | 22.0 | 23.3 | 18.0 |
| 31-45 | 19.8 | 17.7 | 18.1 | 19.1 | 26.1 | 30.7 | 25.3 | 26.2 | 26.0 | 29.0 | 29.9 | 19.8 |

**Table 9. Biomass, foliage spread and surface area protection given by the grass**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Treatments | Biomass after one year (t/ha) | Biomass after two year (t/ha) | Foliage lateral spread after one year (cm) | Foliage lateral spread after two year  (cm) | Surface area protected by grass after one year (cm2) | Surface area protected by grass after two year (cm2) |
| 60% slope | | | | | | |
| 500 GSM Synthetic non woven GT | 3.54ab | 9.6bc | 69.7bc | 133a | 3813bc | 13886a |
| 500 GSM Non woven JGT | 3.62ab | 10.7ab | 78.2ab | 135a | 4800ba | 14307a |
| 500 GSM Open Weave JGT | 3.84a | 11.2a | 86.2a | 142a | 5833a | 15829a |
| Control | 3.12b | 8.6c | 58.1c | 106b | 2649c | 8820b |
| 90% slope | | | | | | |
| 500 GSM Synthetic non woven GT | 10.3ab | 31.2a | 109ab | 129bc | 9331ba | 13063bc |
| 500 GSM Non woven JGT | 10.5ab | 32a | 116a | 138ba | 10659ba | 14950ba |
| 500 GSM Open Weave JGT | 11.16a | 35.3a | 118a | 146a | 10935a | 16733a |
| Control | 9.16b | 29.6b | 105b | 115c | 8659b | 10382c |

***Note: Numbers with the same letter are not significantly different (P = 0.05). Figures in parenthesis denotes the standard error***

**Table 10. Root growth of grass under different treatments and slopes after one year**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Treatments | Rootdepth (cm) | Root lateral spread (cm) | Root weight / plant | Root volume (cc) | Root mass density (gm/cc) | Volume of soil bind by the root (cc) |
| 60% slope | | | | | | |
| 500 GSM Synthetic non woven GT | 23.0c | 31.8ab | 5.2ab | 32ab | 0.16a | 72802b |
| 500 GSM Non woven JGT | 29.5b | 37.6a | 6.0a | 35a | 0.16a | 130956a |
| 500 GSM Open Weave JGT | 46.0a | 30.1ab | 5.8a | 35a | 0.17a | 130864a |
| Control | 26.0bc | 26.5b | 4.8b | 30b | 0.14b | 57332c |
| 90 % slope | | | | | | |
| 500 GSM Synthetic non woven GT | 31.0b | 26.6b | 5.9bc | 35b | 0.15ab | 68873b |
| 500 GSM Non woven JGT | 39.0a | 35.6a | 6.6ab | 45a | 0.19a | 155200a |
| 500 GSM Open Weave JGT | 37.0a | 40.3a | 7.7a | 50a | 0.19a | 188686a |
| Control | 33.0b | 24.8b | 4.8c | 25c | 0.13b | 63730c |

***Note: Numbers with the same letter are not significantly different (P = 0.05). Figures in parenthesis denotes the standard error.***

**Table 11. Root growth of grass under different treatments and slopes after two year**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Treatments | Root depth (cm) | Root lateral spread (cm) | Root weight / plant | Root volume (cc) | Root mass density (gm/cc) | Volume of soil bind by the root (cc) |
| 60% slope | | | | | | |
| 500 GSM Synthetic non woven GT | 32ba | 42bc | 13.8ba | 51a | 0.27ba | 177247b |
| 500 GSM Non woven JGT | 32ba | 45ba | 16.2a | 55a | 0.29ba | 200292ba |
| 500 GSM Open Weave JGT | 38a | 49a | 18.0a | 58a | 0.31a | 286487a |
| Control | 29b | 38c | 10.0b | 42b | 0.24b | 131490b |
| 90 % slope | | | | | | |
| 500 GSM Synthetic non woven GT | 33.6a | 50b | 15.5b | 52b | 0.30ba | 263760b |
| 500 GSM Non woven JGT | 34.0a | 58a | 22.3a | 55ab | 0.41a | 359140a |
| 500 GSM Open Weave JGT | 32.4a | 62a | 24.6a | 62a | 0.40a | 391073a |
| Control | 31.6a (1.49) | 48b (1.20) | 12.4b (1.23) | 48b (2.64) | 0.26b (0.019) | 228612b |

***Note: Numbers with the same letter are not significantly different (P = 0.05). Figures in parenthesis denote the standard error.***

**Figure Caption**

Fig. 1. Effect of different Geo-textiles on annual soil loss under 60 % sloppy land

Fig. 2. Effect of different Geo-textiles on annual soil loss under 90 % sloppy land

Fig. 3 Height of grass at different stages in 60% slope

Fig. 4 Height of grass at different stages in 90% slope

Fig. 5 Growth rate at different stages in 60% slope

Fig. 6 Growth rate at different stages in 90% slope

Fig. 7 Number of tillers per clump of grass in various growth stages in 60% slope

Fig. 8 Number of tillers per clump of grass in various growth stages in 90% slope