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Application of Potentially Important Jute Geo-textiles for Erosion Control and Slope Stabilization

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ICAR

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FOREWORD

Controlling soil erosion in sloppy lands, rehabilitation of mine dumps and landslide areas is a tedious and costly process. Engineering structures are very often used for slope stabilization and controlling soil erosion in sloppy lands which are costly and time consuming for implementation. Thus, slope stabilization using establishment of vegetation is the alternative option which can be economically adopted on large scale. However there are certain limitations which can hamper the establishment of vegetation on hill slope due to severe scour or high runoff. Hence provision of mechanical protection is essential to resist soil erosion, retaining runoff and facilitating growth of vegetation on the surface at initial stage of the vegetation establishment. Different types of natural and Synthetic Geo- textiles have been used for this purpose. Natural fibre based Jute Geo-textile is one of the material that can be used to control soil erosion and slope stabilization due to its natural water absorbing capacity which helps to conserve soil moisture and anchor soil firmly in sloppy areas. However, identification of suitable type of Jute Geo-textiles for slope stabilization is prerequisite for adopting the technology.

The ICAR – Indian Institute of Soil and Water Conservation, Research Centre, Udhagamandalam, Tamil Nadu conducted set of prototype field studies on application of Jute Geo-textiles for hill slope stabilization and quantified the effect of different types of Open Weave Jute Geo-textiles and Non Woven Jute Geo-textiles including Synthetic Geo-textiles. Results on runoff, soil loss, nutrient loss, soil moisture retention and growth parameters of vegetation grown were analyzed and reported in this technical bulletin.

I am glad that the ICAR – IISWC Research Centre, Udhagamandalam has compiled the data collected over a period of three years and has come out with the recommendations for usage of Jute Geo-textiles for slope stabilization and erosion control. I am confident that this technical bulletin will be of great help and guidance to the Jute industries, State and Central Government Organizations to apply the Jute Geo-textiles in the area of erosion control and slope stabilization.

March, 2017 (PK Mishra)

PREFACE

Erosion control and slope stabilization in hilly areas is now become a costly and tedious process since various human activities have led to land use changes which have indirectly affected the slope stability. Permanent structures are being used for slope stabilization which are costly and cannot be adopted on a larger scale. Hence growing vegetation in these areas to cover and protect the soil is the wise choice for hill slope stabilization as it is sustainable at the same time environmental friendly. However there are certain limitations which can hamper the establishment of vegetation in slopes as it is not able to resist severe scour or high runoff. Hence, some mechanical protection at initial stage of the vegetation establishment is imperative on steep slopes which resists soil erosion, retains runoff and facilitates establishment of vegetation on the surface. Different ranges of natural and Synthetic Geo-textiles have been used for this purpose. Natural fibre based Jute Geo Textile (JGT) is being effectively used in road construction and slope stabilization to some extent due to its natural water absorbing capacity which helps to conserve soil moisture and anchor soil firmly in sloppy areas.

In order to explore the possibilities for application of potentially important Jute Geo-textiles for slope stabilization and controlling soil erosion, the ICAR – Indian Institute of Soil and Water Conservation, Research Centre, Udhagamandalam, Tamil Nadu conducted set of prototype field studies on application of Jute Geo-textiles for hill slope stabilization. Effect of different types of Open Weave Jute Geo-textiles and Non Woven Jute Geo-textiles including Synthetic Geo-textiles has been evaluated. Results on runoff, soil loss, nutrient loss, soil moisture retention and growth parameters of vegetation grown were monitored for three years period, analyzed and reported in this bulletin.

We hope and look forward that this Technical Bulletin will be of immense use to the development agencies and policy makers of the State as well as Central Governments and farming community to intervene and take appropriate steps in usage of Jute Geo-textiles for slope stabilization and controlling land degradation in erosion prone fragile ecosystems.

March, 2017

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EXECUTIVE SUMMARY

Soil erosion is increasingly recognized as a problem in hilly regions which needs an effective and economic solution. Slope stabilization in hilly areas is now become a costly and tedious process since various human activities have led to land use changes which have indirectly affected the slope stability. Permanent structures are being used for slope stabilization which are costly and cannot be adopted on a larger scale. On other side, availability of area for construction of permanent structures in the road side is also a major constraint in many locations. Hence growing vegetation in these areas to cover and protect the soil is the wise choice for hill slope stabilization as it is sustainable as well as environmental friendly.

However there are certain limitations which can hamper the establishment of vegetation in slopes as it is not able to resist severe scour or high runoff and takes time to establish (Abramson et al., 1995). Without immediate, appropriate and adequate protection, slopes can suffer from severe soil erosion and instability, which in turn makes vegetation establishment extremely difficult. Thus some mechanical protection at initial stage of the vegetation establishment is imperative on steep slopes which resists soil erosion, retains runoff and facilitates establishment of vegetation on the surface. Different ranges of natural and Synthetic Geo-textiles have been used for this purpose. Apart from conventional civil engineering applications, Geosynthetics play a major role even in environmental engineering applications including pollution control, landfills and erosion control. Alternatively natural fibre based Jute Geo Textiles (JGT) are also utilized effectively in road construction and slope stabilization to some extent. Recently, coir Geo-textiles have been evaluated for slope stabilization and rehabilitation of heavy metal contaminated soils. Its natural water absorbing capacity helps to conserve soil moisture and anchor soil firmly in sloppy areas.

Keeping in view the erosion control characters of Jute Geo-textiles, two experiments were conducted to compare the performance of Jute Geo-textiles with Synthetic Geo-textiles as well as to identify the suitable Open Weave Jute Geo-textiles for hill slope stabilization with the following objectives.

1. Assess the impact of different Jute and Synthetic Geo Textiles on runoff and soil loss under various slopes.

2. Study the growth of tea and grass grown for soil binding under different Geo-textiles.

3. Evaluate the impact of Geo-textiles on soil moisture and nutrient losses.

Two sets of field experiments were conducted at the Research Farm of ICAR - Indian Institute of Soil and Water Conservation (formerly known as Central Soil and Water Conservation Research and Training Institute), Research Centre, Udhagamandalam, Tamil Nadu which represents the geographical area of Nilgiris. Effect of different types of Geo-textiles on runoff, soil loss, nutrient loss, soil moisture retention, growth parameters of tea and grass has been evaluated.

Results of three years field study on efficacy of various types of Open Weave Jute Geo-textiles namely 500, 600 and 700 GSM on slope stabilization showed that 700 GSM Open Weave JGT is more effective in reducing runoff, soil loss and nutrient loss and increasing soil moisture retention. However, plant height and growth of tea plants were better under 500 and 600 GSM JGT. Higher biomass of grass and other herbs in between tea plants was generated by 700 GSM JGT. Considering the scope of tea cultivation in sloppy regions, rehabilitation of land slide areas using tea plants, optimal moisture requirement and better plant growth of tea plants and economics, it is suggested that 500 GSM JGT will be more effective for slope stabilization with tea plants. Keeping in view of higher biomass production of grass and other herbs grown in between tea plants, 700 GSM JGT will be suitable for slope stabilization with grass.

Results of three years field study on efficacy of various types of Jute Geo-textiles and Synthetic Geo-textiles on 60 and 90 per cent slopes show that Jute Geo-textiles outperformed the Synthetic Geo-textiles in reduction of runoff and soil erosion. Among the Open Weave and Non Woven JGT, Open Weave JGT are more effective in reducing runoff, soil loss and nutrient loss and also increased soil moisture retention. Growth of the grass and root characters is vigorous in the plots covered by JGT as compared to Synthetic Geo-textiles. Application of Open Weave JGT increased the plant height, number of tillers, root density, surface area coverage and volume of soil binding in both the slope categories. The study concludes that the JGT can be effectively utilized for slope stabilization using the grass species as compared to Synthetic Geo-textiles. Open Weave JGT with grasses is recommended for slope stabilization in the degraded land having the slopes up to 90 %.

GLOSSARY

cc	:	Cubic Centimeter
cm	:	Centimeter
DAP	:	Days After Planting
DMP	:	Dry Matter Production
FLS	:	Foliage Lateral Spread
GSM	:	Gram Per Square Metre
g	:	Gram
Ha	:	Hectare
ICAR	:	Indian Council of Agricultural Research
JGT	:	Jute Geo-textiles
K	:	Potassium
Kg	:	Kilogram
MAP	:	Months After Planting
mm	:	Millimeter
N	:	Nitrogen
No	:	Number
OC	:	Organic Carbon
P	:	Phosphorous
RD	:	Rooting Depth of Grass
RLS	:	Root Lateral Spread
SGT	:	Synthetic Geo-textiles
t	:	Tonnes

CONTENTS

1. INTRODUCTION

Soil erosion is increasingly recognized as a problem in hilly regions which needs an effective and economic solution. Slope stabilization in hilly areas has now become a costly and tedious process since various human activities have led to land use changes which have indirectly affected the slope stability. Permanent structures are being used for slope stabilization which are costly and cannot be adopted on a larger scale. On other side, availability of area for construction of permanent structures in the road side is also a major constraint in many locations. Hence growing vegetation in these areas to cover and protect the soil is the wise choice for hill slope stabilization as it is sustainable at the same time environmental friendly. Natural vegetation on slopes is able to self-maintain, brake and dilute the kinetic energy of the rain and also provide surface roughness which slows the runoff velocity (Vishnudas *et al.,* 2006). However there are certain limitations which can hamper the establishment of vegetation in slopes as it is not able to resist severe scour or high runoff and takes time to establish (Abramson *et al.,* 1995). Without immediate, appropriate and adequate protection, slopes can suffer from severe soil erosion and instability, which in turn makes vegetation establishment extremely difficult. Thus some mechanical protection at initial stage of the vegetation establishment is imperative on steep slopes which resists soil erosion, retains runoff and facilitates establishment of vegetation on the surface. Different ranges of Natural and Synthetic Geo-textiles have been used for this purpose.

Geo-synthetics, which comprise a variety of products, largely grouped under geo-textiles, geo-grids, geo-membranes and geo-composites have been found to be of immense use in many of the infrastructure projects implemented in India. Apart from conventional civil engineering applications, geo-synthetics play a major role even in environmental engineering applications including pollution control, landfills and erosion control. Alternatively natural fibre based Jute Geo Textile (JGT) is also utilized effectively in road construction and slope stabilization to some extent. Recently, Coir Geo-textiles have been evaluated for slope stabilization and rehabilitation of heavy metal contaminated soils. Its natural water absorbing capacity helps to conserve soil moisture and anchor soil firmly in sloppy areas.

Unique properties of Jute have opened up new avenues for diversification, especially in the light of global concerns for the environment. Being agricultural produce, Jute is eco-friendly, biodegradable and has much higher CO_2 assimilation rate which increases the use of Jute in various applications in the era of environmental concern. Besides its cultivation, processing and manufacturing of by-products are pollution free and has not caused any illness to workers engaged in the job for last twenty years. Jute Geo-textiles is one such diversified products of Jute which have proved to be highly effective in addressing soil erosion and slope stabilization. JGT is hygroscopic in nature and has the unique property of absorbing water nearly from 4.5 to 6 times of its dry weight (Rickson, 1988). Due to the intrinsic property the flexibility of Jute increases and helps in effective storage of soil moisture. JGT has excellent property of drapability so it can be laid out to follow the soil contours on which it is laid (Thomson and Ingold, 1986). JGT creates a moist micro-environment around the soil surface which is conducive for rapid growth of vegetation as well as the microorganisms. Being a natural fibre it degrades in course of time (normally within 2 to 3 years) and adding nutrients to the soil at micro-level. Once vegetation starts growing, the role of JGT is taken over by it. When soil is less permeable and precipitation is heavy, soil erosion in slopes can be controlled by overland storage and prevention of detachment of soil. The lush vegetative cover established in due course of time provides canopy interception to falling rain drops and protects the soil from splash detachment. The fibrous root system of vegetation penetrates the soil and reinforces the slope and provides long term slope stability.

Open Weave JGT (weft yarns) provides a series of mini barriers (sort of check dams) across the direction of overland flow. The 3-D construction of Open Weave JGT reduces the velocity of overland flow and opening of the fabric retain the dislodged soil particles that are set to be carried away by over land flow. Open Weave JGT has around 40% to 60% open area, when laid on the slope provide a partial cover to the ground and heavy strands of JGT helps to absorb the impact of the kinetic energy of the falling rain drops.

Keeping in view of the erosion control characters of Jute Geo-textiles, two experiments were conducted to compare the performance of natural Jute Geo-textiles with Synthetic Geo-textiles as well as to identify the suitable Open Weave Jute Geo-textiles for hill slope stabilization with following objectives.

1. Assess the impact of different Jute and Synthetic Geo-textiles on runoff and soil loss under various slopes.
2. Study the growth of tea and grass grown for soil binding under different JGT.
3. Evaluate the impact of JGT on soil moisture and nutrient losses.

2. DESCRIPTION OF THE STUDY AREA

2.1. Study Area

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. This region is known for its rich biodiversity and source for major reservoirs in the plateaus. Major part of the Nilgiris is covered under forest (56%) followed by plantation crops (20%) like tea, coffee and remaining areas are covered by vegetables. Improper cultivation of annual crops without adopting soil conservation measures, vertical road cutting and huge earth cut for developmental works and construction of buildings coupled with high intensity rainfall leads to soil erosion in sloppy lands. Landslides which were rare in the history of Nilgiris biosphere are now becoming frequent and occurring biannually or annually in one or other parts of the Nilgiris. Landslide occurrence is periodical especially during the North-East monsoon resulting huge damages to the properties and life in the region. Present study was conducted 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.

2.2. Location and Relief

The experimental site - I lies in between 11°23′00.15′′ North latitude and 76°40′11.15′′ East longitude and located 2216 m above mean sea level. The experimental site - II lies in between 11°23′44.67′′ North latitude and 76°39′56.26′′ East longitude and located 2200 m above mean sea level. The experiment - I was conducted on the area having 22 % slope. The slopes of experiment - II are 60 % and 90 %.

2.3. Climate

The climate of the area can be considered as sub humid subtropical in the hilly portions of Nilgiris. The study area receives 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. However, the South West monsoon is more active, since about 4% of total rainfall of 1324.9 mm is received during the southwest monsoon in the months of June to September. The North East monsoon season brings about 26 % of the precipitation amounting to 342.9 mm of rainfall which is received during the months of October to December.

The average temperature of the study area is relatively low with the annual average temperature of 14.6^{0}C. The mean monthly maximum temperature is 16.9^{0}C which is recorded during the month of April, whereas mean monthly minimum temperature is 12.4^{0}C recorded in the month of December. Thus taking into consideration, the temperature variations of the area and the precipitation received, the climate of the hilly portion can be classified as temperate. The mean monthly relative humidity (RH) varies from 64 to 92 per cent at 07.23 hrs and 46 to 83 per cent at 14.23 hrs. The mean monthly wind velocity is 5.3 km hr^{-1}, it is highest during July (8.6 km hr^{-1}) and lowest in the month of October (3.7 km hr^{-1}).

The mean monthly evaporation is 2.9 mm day^{-1} and it is highest (4.4 mm day^{-1}) during March month. The lowest evaporation rate of 2.0 mm day^{-1} is observed in July month.

2.4. Geology and Soil

The study area was formed by Archaen, Charnockite geneiss or Nilgiris geneiss. Charnockites are a series of rocks varying from acid to ultra basic ones, the intermediate syenodiorite type being the most common Charnockites vary in texture from a coarse crystalline rock to a dark finely divided crystalline rock. The minerals present in the rock are blue quartz, plagioclase feldspars, hornblende, hypersthene and secondary minerals as garnets etc.

Study area comprised of lateritic soil which are derived from charnockites parent materials. The feldspars have lost their alkali completely by solution and are represented by white Kaolinitic clay. Most of the times this is stained with black, marking the presence of ferro-magnesium minerals like Hornblende, while throughout the mass are scattered irregular shaped grains of undecomposed Quartz. The iron from the hornblende has been oxidized and has stained the mass a deep red colour in some places and where the reduction of the iron due to back drainage occurred the soils are yellow in colour.

This chapter deals with the experimental methodology including types of jute material used, laying out of jute in the field, analytical methods used for monitoring runoff, soil loss nutrient loss and growth parameters of plants.

3. METHODOLOGY

3.1. Details of experiments

Two sets of experiments were conducted in different slopes and Geo-Textiles with tea and grass as test crops.

3.1.1. Evaluation of Open Weave JGT on slope stabilization with tea

This study was conducted in the field conditions on a uniform ground gradient of 22 %. The soil of the experimental site was sandy clay loam with low available nitrogen, phosphorous and potassium. The experimental field was divided into four uniform size plots, in which 500 GSM, 600 GSM and 700 GSM of Open Weave JGT were laid out and one plot was kept as control without JGT (Plate 1). After laying JGT in the plots, tea plants were planted in double hedge rows with spacing of 0.75 m between plants, 0.65 m between rows and 1.35 m between two double hedge rows.

Plate 1. Laying out of three types 500, 600 & 700 GSM of Open Weave Jute Geo-textiles

3.1.1.1. Measurement of runoff, soil loss and nutrient loss

Multi-slot divisors were installed in the field for measurement of runoff and soil loss (Plate 2). The samples were collected from each runoff event throughout the experimental period. The total runoff collected per day in all the runoff tanks in each experimental plot was thoroughly mixed and one-litre of runoff sample was used for soil loss estimation. Another one litre of runoff sample was taken for analysis of nutrients losses namely nitrogen, phosphorous, potassium and organic carbon which are lost through runoff. Soil moisture content was monitored in all the treatments at monthly intervals to quantify the effect of different types of JGT on moisture retaining capacity of soil. Runoff, soil loss and nutrient loss were monitored for three years period from 2012 to 2014 and pooled data were analyzed and interpreted.

3.1.1.2. Growth parameters of tea plant

Growth parameters of tea plants were monitored up to two years at every two months interval after planting. Since the prime objective of applying Jute Geo-textile is to establish vegetative growth in degraded lands, biomass produced by grass and other herbs growing in between tea plants were also recorded at regular interval.

Plate 2. Runoff measuring devices installed at each plot (Multi-slot devisors)

3.1.2. Evaluation of different types of Geo-textils on slope stabilization with grass

The experiment was conducted in two slope groups namely 60 and 90 per cent. In each slope the field was divided into four plots, in which 500 GSM Synthetic Geo-textile, 500 GSM Non Woven JGT and 500 GSM Open Weave JGT were laid out (Plate 3). The fourth plot was kept as control without applying any Geo-textiles for comparing the effect of Geo-textiles. After laying out Geo-textiles in the plots, a small hole was made and the root slips of Weeping Love Grass *(Eragrostis curvula)* were directly planted in the hole during the rainy season with the spacing of 50 x 50 cm and firmly filled with soil (Plate 4).

3.1.2.1. Measurement of runoff, soil loss and nutrient loss

The runoff in each treatment was regularly measured for a period of three years by multi-slot divisors. The total runoff collected per day in all the runoff tanks in each experimental plot was thoroughly mixed and one-litre runoff sample was taken for estimation of soil loss. Similarly, nutrients losses namely nitrogen, phosphorous, potassium and organic carbon loss through runoff were also estimated. Soil moisture content was monitored at monthly intervals to quantify the effect of different types of Geo-textiles on moisture retaining capacity of soil. Runoff, soil loss and nutrient losses were monitored for three years period from 2013 to 2015 and pooled data were analyzed and interpreted.

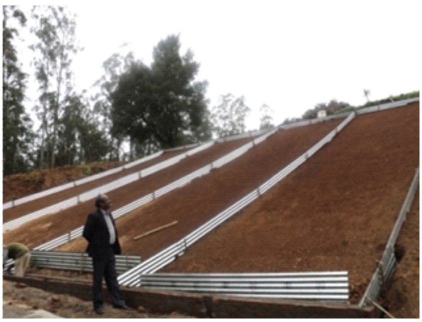

Plate 3. Photographs showing the layout of runoff plots and application of JGT

3.1.2.2. Growth parameters of grass

The growth parameters of Weeping Love Grass *(Eragrostis curvula)* were observed at regular interval from planting of grass up to three years.

3.1.2.2.1. Grass height, foliage lateral spread and volume of root

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:

$FLS = (Y_1 + Y_2) / 2$

Where, FLS is average Foliage Lateral Spread

Y_1, Y_2 = 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.

$RLS = (X_1 + X_2 + X_3) / 3$

Where, RLS = average Root Lateral Spread

X_1, X_2, X_3 = 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.

3.1.2.2.2. Volume of soil bound by the fibrous roots

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. So 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 = $\pi\ (RLS)^2(RD)$

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

3.1.2.2.3. Ground surface area protected by grass

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

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

Plate 4. Photographs showing planting of grass

4. Results and Discussion

4.1. Evaluation of Open Weave JGT on Slope Stabilization with Tea

4.1.1. Runoff and soil loss

Annual runoff and soil loss were monitored from 2012 to 2014 and the same is presented in Table 1 and Fig. 1, respectively. The runoff and soil loss from the experimental plots were high during initial year and decreased subsequently during second and third years. The decrease in runoff and soil loss in the subsequent year was due to stabilized soil, canopy and root establishment of tea plants by the application of JGT. Minimum runoff of 58.3 mm was produced under 600 GSM JGT followed by 66.6 mm in 700 GSM JGT against 140 mm of runoff in control plot during the year 2012. However, during the second year of the study, out of a total rainfall of 1142.5 mm, minimum runoff of 57.1 mm was produced by 700 GSM JGT followed by 69.5 mm by 600 GSM JGT and 85 mm by 500 GSM JGT against maximum runoff of 174.3 mm from the control plot. Similarly, minimum runoff of 30.4 mm was produced by 700 GSM JGT followed by 600 GSM (49.8 mm) and 500 GSM (79.4 mm) against maximum runoff of 169.0 mm in control plot during the year 2014. Out of three years results, runoff data of two years and the mean runoff shows that overland flow is less in the plot covered by 700 GSM JGT compared to the plots covered by 600 and 500 GSM JGT. It was also noticed that the Open Weave JGT reduced the runoff which ranged from 6.7 to 12.5 per cent.

The effect of JGT on soil erosion was also assessed and showed that the soil loss was reduced from 3.0 to 3.4 t ha^{-1} $year^{-1}$ by JGT application compared to control without any JGT. Minimum soil loss of 0.55 t ha^{-1} $year^{-1}$ was recorded in the plot protected by 700 GSM JGT followed by 600 GSM (0.65 t $ha^{-1}year^{-1}$) and 500 GSM JGT (0.98 t ha^{-1} $year^{-1}$) against mean maximum soil loss of 3.93 t ha^{-1} $year^{-1}$ in control plot.

Table 1. Rainfall and runoff under different Open Weave JGT for hill slope stabilization

Year	Rainfall (mm)	Runoff (mm)				Runoff (%)			
		500 GSM JGT	600 GSM JGT	700 GSM JGT	Control	500 GSM JGT	600 GSM JGT	700 GSM JGT	Control
2012	798.3	86.5	58.3	66.6	140.0	10.8	7.3	8.3	17.5
2013	1142.5	85.0	69.5	57.1	174.3	7.4	6.1	5.0	15.3
2014	1098.4	79.4	49.8	30.4	169.0	7.2	4.5	2.8	15.3
Mean	1013.1	83.6	59.2	51.4	161.1	8.5	6.0	5.4	16.0
CD (5%)		28.17				1.69			

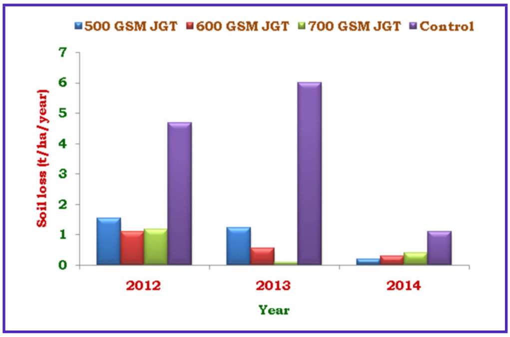

Fig. 1. Effect of various Open Weave Jute Geo-textiles on soil loss

This study confirmed that the Open Weave JGT are effective in reducing runoff and soil loss. Out of three types of JGT, the 700 GSM Open Weave JGT out performed the 500 & 600 GSM JGT in reduction runoff and soil loss in sloppy lands.

Plate 5. Rills formation in control plot (without JGT)

Table 2. Nutrient losses in runoff under different Open Weave JGT

Treatment	Year	Nutrient Loss (Kg ha^{-1})					Nutrient saved over control (%)
		N	P	K	OC	Total	
500 GSM JGT	2012	2.30	0.68	6.70	12.0	21.68	46.00
	2013	1.57	0.59	5.19	11.0	18.35	
	2014	1.40	0.12	2.40	2.0	5.92	
	Mean	1.76	0.46	4.76	8.3	15.32	
600 GSM JGT	2012	2.10	0.43	6.50	9.0	18.03	55.55
	2013	1.80	0.38	3.40	8.0	13.58	
	2014	1.00	0.23	2.00	3.0	6.23	
	Mean	1.63	0.35	3.97	6.7	12.61	
700 GSM JGT	2012	2.50	0.40	6.00	9.0	17.90	62.00
	2013	1.00	0.35	3.50	5.5	10.35	
	2014	1.00	0.10	1.00	2.0	4.10	
	Mean	1.50	0.28	3.50	5.5	10.78	
Control	2012	8.90	0.72	6.27	21.8	37.69	-
	2013	6.00	0.46	4.40	15.2	26.06	
	2014	5.50	0.36	3.50	12.0	21.36	
	Mean	6.80	0.51	4.72	16.3	28.37	

4.1.2. Nutrient loss

The major soil nutrients lost through runoff were estimated and it shows that considerable amount of nutrients were saved by JGT compare to control (Table 2). The total nutrients saved by JGT ranged from 46 to 62 per cent. However, there was no significant variation in nutrient losses observed among various Open Weave JGT.

4.1.3. Soil moisture

Soil moisture in three soil depths was monitored under different Open Weave JGT applied fields during wet and dry seasons and mean data is depicted in Fig. 2. Soil moisture retention was higher in all the soil depths under all JGT applied plots than the control plot in both rainy and dry season but significance was prominent during dry season. The increased soil moisture content might be due to reduction of runoff and soil loss by JGT. Among the different JGT, soil moisture was the highest under 700 GSM JGT followed by 600 GSM JGT and 500 GSM JGT.

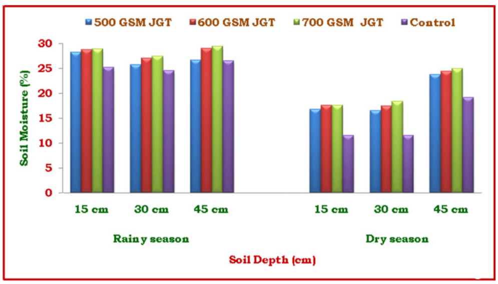

Fig. 2. Average soil moisture at different depths in wet and dry seasons

4.1.4. Soil composition and nutrient status

Soil composition of the site before and after application of various Open Weave JGT have been studied and presented in Table 3. It was found that the sand content was not significantly affected by Jute Geo-textiles before and after application. However, the difference in sand content in control plot was higher as compared to JGT applied plots. Silt content in JGT applied plots has been marginally increased whereas the silt content was decreased to the extent of 45% in control plot due to high soil loss compared to JGT applied plots. There was no significant change in clay content as the variation ranged from 1 to 3 per cent. It can be interpreted that the JGT made impact on increasing silt content by reducing sand and clay content marginally.

Nutrients build up status of soil was studied by comparing initial (January 2012) and final (December 2014) nutrient status and the same is furnished in Table 4. Soil organic carbon build up has improved in all the JGT applied plots from the initial content. The increase was 88.9, 88.1, 46.7, and 28.4 per cent in 700, 600 and 500 GSM JGT and control plots, respectively after three years. Application of JGT has increased the organic carbon build up to 87.2, 46.5 and 27.9 per cent higher in 700, 600 and 500 GSM JGT plots, respectively over the control after three years.

Table 3. Effect of Open Weave Jute Geo-textiles on soil composition

Treatment	Soil composition						Clay ratio	
	Sand %		Silt %		Clay %			
	Before	After	Before	After	Before	After	Before	After
500 GSM JGT	52.5	49.0	13.4	16.0	34.1	35.0	1.9	1.9
600 GSM JGT	53.3	49.0	13.7	15.0	32.9	36.0	2.0	1.8
700 GSM JGT	54.0	45.0	14.1	20.0	31.9	35.0	2.1	1.9
Control	53.3	60.5	13.7	7.5	33.0	32.0	2.0	2.1

Available nitrogen and phosphorus has increased marginally as compared to control plot after three years due to less nutrient losses in the JGT applied plots. Nitrogen content increased to 14.0, 13.0 and 7.4 per cent in 700, 600 and 500 GSM JGT applied plots against lowest increment of 4.5 per cent in control plot after three years. Application of 700, 600 and 500 GSM JGT has increased the available nitrogen content to 9.7, 8.5, and 2.9 per cent, respectively. Similarly the available phosphorous content increased to 18.3, 17.5 and 9.7 percent in 700, 600 and 500 GSM JGT respectively, after three years. The available potassium has recorded the negative balance under all the treatments but the reduction range was less under JGT applied plots after three years.

Table 4. Impact of Open Weave Jute Geo-textiles on building up of nutrients in the soil after three years

Treatment	Organic Carbon (g kg^{-1})		Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	Before	After	Before	After	Before	After	Before	After
500 GSM JGT	7.5	8.0	135.0	145.0	21.5	25.1	153.0	141.0
600 GSM JGT	6.7	9.4	134.0	151.0	23.2	27.1	171.0	161.0
700 GSM JGT	8.5	10.1	141.0	161.0	21.3	26.7	169.0	165.0
Control	6.7	7.1	133.0	139.0	22.5	24.1	165.0	134.0

4.1.5. Influence of JGT on growth of tea seedlings

The height of the tea plants were monitored up to two years from the date of planting and thereafter it was pruned as per regular operations.

Table 5. Growth of tea under different JGT

Treatments	Average Plant height (cm)					Leaf Area Index	DMP of grass and herbs (Kg ha^{-1})
	16 MAP	17 MAP	18 MAP	19 MAP	24 MAP		
500 GSM JGT	49.4^{a} (1.75)	50.8^{a} (2.55)	52.4^{a} (1.01)	58.7^{a} (1.9)	63.7^{a} (2.0)	2.38^{a} (0.13)	352^{c} (5.29)
600 GSM JGT	43.4^{ab} (1.66)	44.8^{a} (3.49)	48.3^{b} (1.10)	53.2^{ab} (3.02)	58.9^{ab} (1.61)	1.21^{b} (0.06)	428^{b} (10.44)
700 GSM JGT	44.5^{ab} (2.53)	45.7^{a} (2.39)	46.2^{bc} (1.01)	49.7^{ab} (2.14)	56.0^{b} (1.28)	1.10^{b} (0.05)	610^{a} (8.6)
Control	39.1^{b} (1.52)	39.06^{b} (1.52)	44.5^{c} (0.75)	50.4^{ab} (1.1)	55.6^{b} (0.8)	1.13^{b} (0.05)	156^{d} (7.8)

Note: Numbers with the same letter are not significantly different (P = 0.05). Figures in parenthesis denotes the standard error; DMP - Dry Matter Production, MAP – Months after planting

There was a significant difference in plant height at different growth stages, leaf area index after two year and dry matter production other than tea plants (weeds) compared to control plots. The highest tea plant height was achieved with 500 GSM followed by 600 GSM JGT. However, there was no significant difference among the JGT in case of plant height (Table 5). There was a significant difference in leaf area index and dry matter production among different Open Weave JGT. The highest leaf area index in tea (2.38) was observed under 500 GSM followed by 600 GSM JGT. The dry matter production other than tea was the highest with 700 GSM followed by 600 GSM. This might be due to higher soil moisture and retaining of more number of seeds. However, this higher dry matter production of grass and herbs other than tea resulted in reduction of plant height in tea. In 700 GSM plot The lowest plant growth was observed in control plots. This may be due to the lesser soil moisture and continuous washing out of seed from the plot as there was no JGT to retain the weed seeds.

Even though, the runoff, soil loss and nutrient loss were reduced by 700 GSM JGT, the growth of tea plants were affected by grass or other vegetations which is evidenced from highest dry matter production (610 kg ha^{-1}). Hence, for slope stabilization with tea plants 500 GSM Open Weave JGT may be suitable. As the dry matter production of grasses and other herbs is the highest in 700 GSM JGT, it will be suitable for slope stabilization with grass and other herbs.

Plate 6. Effects of Open Weave JGT on tea plants after three months of planting

Plate 7. Effects of Open Weave JGT on tea plants after one year of planting

Plate 8. Effects of Open Weave JGT on tea plants after two years of planting

Plate 9. Effects of Open Weave JGT on tea plants after three years of planting

4.2. Evaluation of Different Types of JGT on Slope Stabilization with Grass

4.2.1. Rainfall during the period of assessment

Rainfall from July 2013 to December 2015 was recorded and reported in Table 6.

Table 6. Monthly rainfall recorded during the assessment period

Months	Rainfall (mm)		
	2013	2014	2015
January	-	0.0	0.0
February	-	5.8	0.0
March	-	42.0	77.7
April	-	54.1	178.6
May	-	225.8	115.9
June	-	77.8	427.1
July	297.8	248.6	52.7
August	158.8	241.4	74.8
September	171.5	196.3	102.9
October	148.4	189.3	98.2
November	46.8	59.6	246.3
December	20.3	51.8	35.6
Total	843.6	1392.2	1409.8

4.2.2. Runoff and soil loss

Annual runoff and soil loss were monitored from 2013 to 2015 and the same was presented in Tables 7 and Table 8 for 60% and 90% slopes, respectively. The results showed that the runoff and soil loss was less during first year and it was in increasing trend during second year and subsequently decreased during third year. The less runoff and soil loss was during first year due to high infiltration rate as the soil was filled to make required slope. The decreasing trend during third year was due to stabilized soil, canopy and root establishment of grass. 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. 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.

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.

Table 7. Rainfall and runoff under different Jute Geo-textiles for hill slope stabilization at 60% sloppy land

Year	Rain fall (mm)	Runoff (mm)				Runoff (%)			
		500 GSM Non Woven Synthetic Geo-textiles	500 GSM Non Woven JGT	500 GSM Open Weave JGT	Con-trol	500 GSM Non Woven Synthetic Geo-textiles	500 GSM Non Woven JGT	500 GSM Open Weave JGT	Con-trol
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 8. Rainfall and runoff under different Jute Geo-textiles for hill slope stabilization at 90% sloppy land

Year	Rain fall (mm)	Runoff (mm)				Runoff (%)			
		500 GSM Non Woven Synthetic Geo-textiles	500 GSM Non Woven JGT	500 GSM Open Weave JGT	Con-trol	500 GSM Non Woven Synthetic Geo-textiles	500 GSM Non Woven JGT	500 GSM Open Weave JGT	Con-trol
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			

Runoff data recorded in three years period and mean data shows that overland flow was 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.

The annual soil loss recorded in the plots covered by two types of Jute Geo-textiles and Synthetic Geo-textiles were compared with control plot and depicted in Fig. 3 and Fig. 4 for 60% and 90% slopes, respectively. The data showed that the 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.

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.

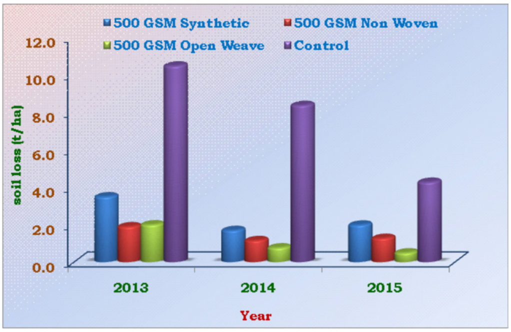

Fig. 3. Annual soil loss under different JGT for hill slope stabilization at 60 % sloppy land

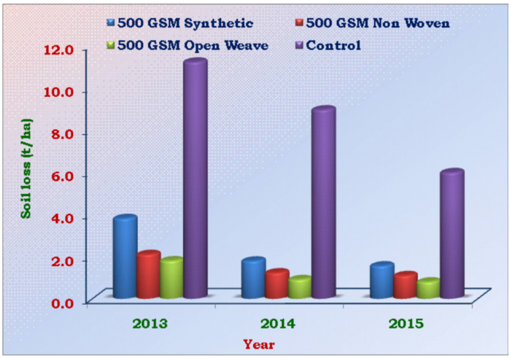

Fig. 4. Annual soil loss under different JGT for hill slope stabilization at 90% sloppy land

4.2.3. Nutrient loss

Major soil nutrients like nitrogen, phosphorous, potassium and organic carbon lost through runoff were estimated and reported in Table 9 and Table 10 for 60% and 90% slopes, respectively. As the nutrient losses are directly proportional to the soil loss, higher nutrient losses were recorded in 90% slope due to high slope and higher runoff.

Table 9. Nutrient losses in runoff under different types of JGT and Synthetic Geo-textiles in 60% sloppy land

Treatment	Year	Nutrient Loss (kg ha^{-1})					Nutrient saved (%)
		N	P	K	OC	Total	
500 GSM Non Woven Synthetic 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	14.3	27.4	

Mean nutrient loss data shows that Open Weave JGT reduced the nutrient losses as compared to Non Woven JGT and Synthetic Geo-textiles. Considerable amount of nutrients were saved by Open Weave JGT compared to Synthetic Geo-textiles and control plot. 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.

4.2.4. Soil moisture

Soil moisture in three soil depths (0 - 15 cm, 15 - 30 cm and 30 - 45 cm) was monitored under two types of JGT and Synthetic Geo-textiles applied fields in every month for three years period and mean data is furnished in Tables 11 and Table 12 for 60% and 90% slopes, respectively. Soil moisture retention was higher in all the soil depths under all JGT applied plots than the control plot in both rainy and dry season. Among the two types 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. Significant differeneces in soil moisture retention was noticed in dry season under Open Weave JGT which is due to the fact that Open Weave JGT 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.

Table 10. 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 Non Woven Synthetic 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	

4.2.5. Growth parameters of grass

4.2.5.1. Grass height

Grass height after two years of planting in 60 % slope (Fig. 5) 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). The highest plant height (125.2 cm) was observed with Open Weave JGT in 90% slope (Fig.6) which was followed by Non Woven JGT (122.2 cm).

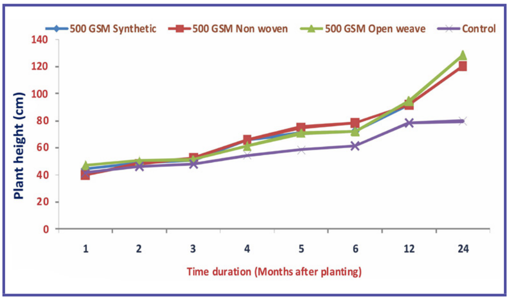

Fig. 5. Height of grass at different stages in 60% slope

Table 11. Effect of Jute Geo-textiles and Synthetic Geo-textiles on soil moisture retention in 60% slope

Treatment	Depth (cm)	Months											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
500 GSM Non Woven Synthetic 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
	15-30	18.4	17.1	17.2	21.0	25.5	30.8	22.8	25.5	28.0	25.5	29.7	20.1
	30-45	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 woven 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
	15-30	20.7	18.4	18.4	20.4	26.1	31.5	24.2	26.2	30.9	28.4	30.1	22.8
	30-45	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
	15-30	26.9	24.3	16.8	23.8	29.5	32.6	28.3	28.2	32.5	29.0	35.9	28.3
	30-45	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
	15-30	17.9	16.4	16.8	18.9	24.2	28.4	21.1	22.3	27.6	24.3	23.5	18.4
	30-45	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 12. Effect of Jute Geo-textiles and Synthetic Geo-textiles on soil moisture retention in 90% slope

Treatment	Depth (cm)	Months											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
500 GSM Non Woven Synthetic 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
	15-30	18.0	16.7	15.0	20.5	25.3	30.6	22.7	25.4	27.9	23.0	29.5	19.7
	30-45	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
	15-30	22.0	17.0	17.6	18.6	27.8	31.3	24.1	26.1	30.0	25.0	29.9	22.3
	30-45	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
	15-30	25.6	22.0	18.0	22.0	30.6	32.4	28.2	28.1	31.0	27.0	35.6	27.7
	30-45	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
	15-30	17.6	16.5	16.0	18.0	23.5	28.3	21.0	22.2	24.0	22.0	23.3	18.0
	30-45	19.8	17.7	18.1	19.1	26.1	30.7	25.3	26.2	26.0	29.0	29.9	19.8

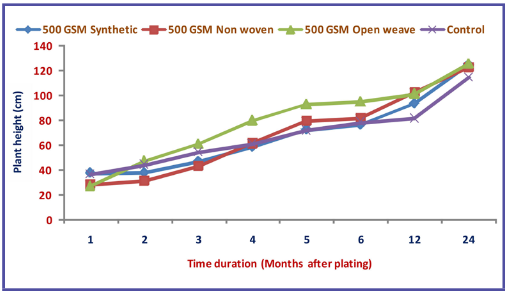

Fig. 6. Height of grass at different stages in 90% slope

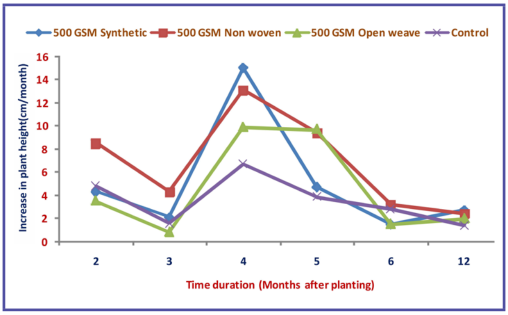

Fig. 7. Growth rate at different stages in 60% slope

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. 7 and Fig. 8). This might 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 month as the dry season commenced.

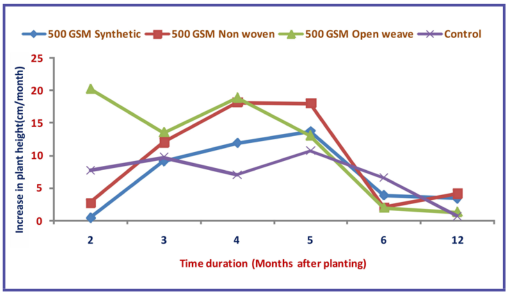

Fig. 8. Growth rate at different stages in 90% slope

4.2.5.2. Tillers

In 60% slope, tillers per clump of grass was the highest (163.5) in Open Weave JGT (Fig. 9) which was followed by Non Woven JGT (155.3) 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. 10) after one and two year of planting. The less number of tiller observed under Synthetic compared to Open Weave JGT might be due the mechanical resistance given by the synthetic materials for tillering. The least tiller number was observed under control

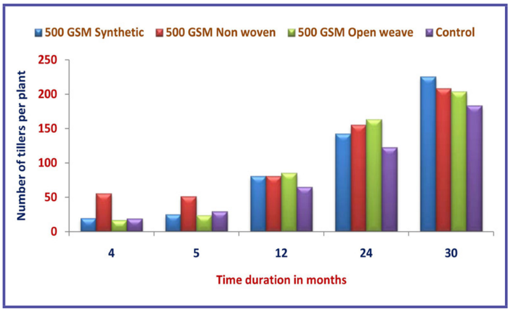

Fig. 9. Number of tillers per clump of grass in various growth stages in 60% slope

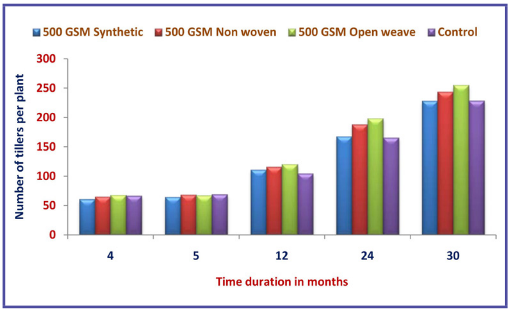

Fig. 10 Number of tillers per clump of grass in various growth stages in 90% slope

Table 13. Biomass, foliage spread and surface area protection given by the grass

Treatments	Biomass after one year (t ha^{-1})	Biomass after two year (t ha^{-1})	Foliage lateral spread after one year (cm)	Foliage lateral spread after two year (cm)	Surface area protected by grass after one year (cm^2)	Surface area protected by grass after two year (cm^2)
60% slope						
500 GSM Non Woven Synthetic GT	3.54^{ab}	9.6^{bc}	69.7^{bc}	133^{a}	3813^{bc}	13886^{a}
500 GSM Non Woven JGT	3.62^{ab}	10.7^{ab}	78.2^{ab}	135^{a}	4800^{ba}	14307^{a}
500 GSM Open Weave JGT	3.84^{a}	11.2^{a}	86.2^{a}	142^{a}	5833^{a}	15829^{a}
Control	3.12^{b}	8.6^{c}	58.1^{c}	106^{b}	2649^{c}	8820^{b}
90% slope						
500 GSM Non Woven Synthetic GT	10.3^{ab}	31.2^{a}	109^{ab}	129^{bc}	9331^{ba}	13063^{bc}
500 GSM Non Woven JGT	10.5^{ab}	32^{a}	116^{a}	138^{ba}	10659^{ba}	$14950b^{a}$
500 GSM Open Weave JGT	11.16^{a}	35.3^{a}	118^{a}	146^{a}	10935^{a}	16733^{a}
Control	9.16^{b}	29.6^{b}	105^{b}	115^{c}	8659^{b}	10382^{c}

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

4.2.5.3. Biomass, foliage spread and surface area protected by grass

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 13). 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 and all these three treatments are on par with each other. 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 cm^2) was recorded in 500 GSM Open Weave JGT because of higher tiller number and foliage lateral spread. It was followed by 500 GSM Non Woven JGT and it was on par with Open Weave JGT. Surface area protected by the grass was the least in case of control.

4.2.5.4. Rooting characters

One year after planting, in 60% slope, the highest root depth of 46 cm was recorded under Open Weave JGT which was followed by Non Woven JGT (Table 14). 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 15). The volume of soil bind by the root was more under Open Weave JGT due to higher root lateral spread (49 cm). The higher value of root volume and root weight also was higher under Open Weave and Non Woven JGT which were followed by Synthetic Geo-textiles. The values for root characters and volume of soil bind by the root were the least under the control plot.

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 performing better as compared to Synthetic Geo-textiles.

Table 14. Root growth of grass under different treatments and slopes after one year

Treatments	Root depth (cm)	Root lateral spread (cm)	Root weight / plant (g)	Root volume (cc)	Root mass density (g cc^{-1})	Volume of soil bind by the root (cc)
60% slope						
500 GSM Non Woven Synthetic GT	23.0^{c}	31.8^{ab}	5.2^{ab}	32^{ab}	0.16^{a}	72802^{b}
500 GSM Non Woven JGT	29.5^{b}	37.6^{a}	6.0^{a}	35^{a}	0.16^{a}	130956^{a}
500 GSM Open Weave JGT	46.0^{a}	30.1^{ab}	5.8^{a}	35^{a}	0.17^{a}	130864^{a}
Control	26.0^{bc}	26.5^{b}	4.8^{b}	30^{b}	0.14^{b}	57332^{c}
90 % slope						
500 GSM Non Woven Synthetic GT	31.0^{b}	26.6^{b}	5.9^{bc}	35^{b}	0.15^{ab}	68873^{b}
500 GSM Non Woven JGT	39.0^{a}	35.6^{a}	6.6^{ab}	45^{a}	0.19^{a}	155200^{a}
500 GSM Open Weave JGT	37.0^{a}	40.3^{a}	7.7^{a}	50^{a}	0.19^{a}	188686^{a}
Control	33.0^{b}	24.8^{b}	4.8^{c}	25^{c}	0.13^{b}	63730^{c}

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

4.2.5.5. Vegetation index as influenced by slope and different JGT

In 60% slope, the frequency of *Eragrostis curvula* was 100% and the density was 4 m^2 as this grass was planted as part of experiment with the spacing of 50 x 50 cm. The frequency and density of other plants were not noticed in the synthetic and Non Woven JGT as it did not allow other plants to emerge because it covered the soil completely (Table 16). As the time advance, presence of other plants also was observed in case of 500 GSM Non Woven JGT (Table 18). In Open Weave JGT and control plots, apart from the planted *Eragrostis curvula* grass, frequently observed grasses are *Eupatorium*, *Cystisuss coparius* and Sonchus oleraceus. The density of plants other than planted *Eragrostis curvula* grass was 8 m^2 in case of 500 GSM JGT and 6 m^2 in case of control during the first year. As the time advanced, apart from these plants, other plants like *Poa annua, Helichrysum wightii* and *Bidens pillosa* were also emerged with the frequency of 25 to 50%. The density of plants other than planted *Eragrostis curvula* grass was increase in the range of 4 to 24 m^2 due to decomposition of JGT. The same trend was also observed in case of 90% slope with increased frequency and density of *Pennisetum clandestinum* grass.

Table 15. Root growth of grass under different treatments and slopes after two year

Treatments	Root depth (cm)	Root lateral spread (cm)	Root weight / plant (g)	Root volume (cc)	Root mass density (g cc^{-1})	Volume of soil bind by the root (cc)
60% slope						
500 GSM Non Woven Synthetic GT	32^{ba}	42^{bc}	13.8^{ba}	51^{a}	0.27^{ba}	177247^{b}
500 GSM Non Woven JGT	32^{ba}	45^{ba}	16.2^{a}	55^{a}	0.29^{ba}	200292^{ba}
500 GSM Open Weave JGT	38^{a}	49^{a}	18.0^{a}	58^{a}	0.31^{a}	286487^{a}
Control	29^{b}	38^{c}	10.0^{b}	42^{b}	0.24^{b}	131490^{b}
90 % slope						
500 GSM Non Woven Synthetic GT	33.6^{a}	50^{b}	15.5^{b}	52^{b}	0.30b^{a}	263760^{b}
500 GSM Non Woven JGT	34.0^{a}	58^{a}	22.3^{a}	55^{ab}	0.41^{a}	359140^{a}
500 GSM Open Weave JGT	32.4^{a}	62^{a}	24.6^{a}	62^{a}	0.40^{a}	391073^{a}
Control	31.6^{a} (1.49)	48^{b} (1.20)	12.4^{b} (1.23)	48^{b} (2.64)	0.26^{b} (0.019)	228612^{b}

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

4.3 Cost of JGT applications

Out of different types Jute Geo-textiles, cost of Open Weave Jute Geo-textiles is cheapest in the market followed by Non Woven Jute Geo-textiles and Synthetic Jute Geo-textiles. Cost of application including JGT cost with 500 gsm Open Weave Jute Geo-textiles with tea seedlings will be Rs. 3,35,000/ per ha and Rs. 3,38,000/ per ha for 700 gsm Open Weave Jute Geo-textiles with planting of grass.

Table 16. Vegetation index monitored in December 2014

Treatments	Frequency	Density (No m^{-2})
60% slope		
500 GSM Non Woven Synthetic GT	*Eragrostis curvula* (100%)	*Eragrostis curvula* (4)
500 GSM Non Woven JGT	*Eragrostis curvula* (100%	*Eragrostis curvula* (4)
500 GSM Open Weave JGT	*Eragrostis curvula* (100%) *Cystisuss coparius* (50%) *Eupatorium galandulosum* (50%) *Sonchus oleraceus*(25 %)	*Eragrostis curvula* (4) *Cystisuss coparius* (4) *Eupatorium galandulosum* (2) *Sonchus oleraceus*(2)
Control	*Eragrostis curvula* (100%) *Eupatorium galandulosum* (50%) *Sonchus oleraceus* (50 %)	*Eragrostis curvula* (4) *Eupatorium galandulosum* (2) *Sonchus oleraceus*(4)
90% slope		
500 GSM Non Woven Synthetic GT	*Eragrostis curvula* (100%)	*Eragrostis curvula* (4)
500 GSM Non Woven JGT	*Eragrostis curvula* (100%)	*Eragrostis curvula* (4)
500 GSM Open Weave JGT	*Eragrostis curvula* (100%) *Eupatorium galandulosum* (50%) *Pennisetum clandestinum* (75%) *Helichrysum wightii* (50%	*Eragrostis curvula* (4) *Eupatorium galandulosum*(8) *Pennisetum clandestinum* (6) *Helichrysum wightii* (2)
Control	*Eragrostis curvula* (100%) *Eupatorium galandulosum* (50%) *Pennisetum clandestinum* (75%) *Helichrysum wightii* (50%)	*Eragrostis curvula* (4) *Eupatorium galandulosum*(8) *Pennisetum clandestinum* (10) *Helichrysum wightii* (4)

Table 17. Vegetation index monitored in March 2015

Treatments	Frequency	Density (number m^{-2})
60% slope		
500 GSM Non Woven Synthetic GT	*Eragrostis curvula* (100%)	*Eragrostis curvula* (4)
500 GSM Non Woven JGT	*Eragrostis curvula* (100%) *Eupatorium galandulosum* (25%)	*Eragrostis curvula* (4) *Eupatorium galandulosum*(2)
500 GSM Open Weave JGT	*Eragrostis curvula* (100%) *Cystisuss coparius* (50%) *Eupatorium galandulosum* (50%) *Sonchus oleraceus*(50 %)	*Eragrostis curvula* (4) *Cystisuss coparius* (4) *Eupatorium galandulosum*(4) *Sonchus oleraceus*(3)
Control	*Eragrostis curvula* (100%) *Eupatorium galandulosum* (50%) *Sonchus oleraceus* (50%) *Helichrysum wightii* (25%) *Bidens pillosa* (25%)	*Eragrostis curvula* (4) *Eupatorium galandulosum*(5) *Sonchus oleraceus*(3) *Helichrysum wightii* (1) *Bidens pillosa* (2)
90% slope		
500 GSM Non Woven Synthetic GT	*Eragrostis curvula* (100%)	*Eragrostis curvula* (4)
500 GSM Non Woven JGT	*Eragrostis curvula* (100%)	*Eragrostis curvula* (4)
500 GSM Open Weave JGT	*Eragrostis curvula* (100%) *Eupatorium galandulosum* (50%) *Pennisetum clandestinum* (75%) *Helichrysum wightii* (25%)	*Eragrostis curvula* (4) *Eupatorium galandulosum* (10) *Pennisetum clandestinum* (4) *Helichrysum wightii* (2)
Control	*Eragrostis curvula* (100%) *Eupatorium galandulosum* (75%) *Pennisetum clandestinum* (75%) *Helichrysum wightii* (50%)	*Eragrostis curvula* (4) *Eupatorium galandulosum*(10) *Pennisetum clandestinum* (7) *Helichrysum wightii* (5)

Table 18. Vegetation index monitored in September 2015

Treatments	Frequency	Density (No m^{-2})
60 % slope		
500 GSM Non Woven Synthetic GT	*Eragrostis curvula* (100%)	*Eragrostis curvula* (4)
500 GSM Non Woven JGT	*Eragrostis curvula* (100%) *Eupatorium galandulosum* (25%) *Poa annua* (25%)	*Eragrostis curvula* (4) *Eupatorium galandulosum*(2) *Poa annua* (2)
500 GSM Open Weave JGT	*Eragrostis curvula* (100%) *Cystisuss coparius* (50%) *Poa annua* (50%) *Eupatorium galandulosum* (50%)	*Eragrostis curvula* (4) *Cystisuss coparius* (3) *Poa annua* (4) *Eupatorium galandulosum*(6)
Control	*Eragrostis curvula* (100%) *Poa annua* (75%) *Eupatorium galandulosum* (25%) *Sonchus oleraceus*(50 %) *Helichrysum wightii* (25%) *Bidens pillosa* (25%)	*Eragrostis curvula* (4) *Poa annua* (8) *Eupatorium galandulosum* (2) Sonchus oleraceus(3) *Helichrysum wightii* (3) *Bidens pillosa* (8)
90% slope		
500 GSM Non Woven Synthetic GT	*Eragrostis curvula* (100%)	*Eragrostis curvula* (4)
500 GSM Non woven JGT	*Eragrostis curvula* (100%)	*Eragrostis curvula* (4)
500 GSM Open Weave JGT	*Eragrostis curvula* (100%) *Poa annua* (50%) *Eupatorium galandulosum* (50%) *Pennisetum clandestinum* (75%) *Helichrysum wightii* (50%)	*Eragrostis curvula* (4) *Poa annua* (6) *Eupatorium galandulosum*(8) *Pennisetum clandestinum* (6) *Helichrysum wightii* (6)
Control	*Eragrostis curvula* (100%) *Poa annua* (75%) *Eupatorium galandulosum* (25%) *Pennisetum clandestinum* (75%) *Helichrysum wightii* (50%)	*Eragrostis curvula* (4) *Poa annua* (8) *Eupatorium galandulosum*(6) *Pennisetum clandestinum* 10) *Helichrysum wightii* 6)

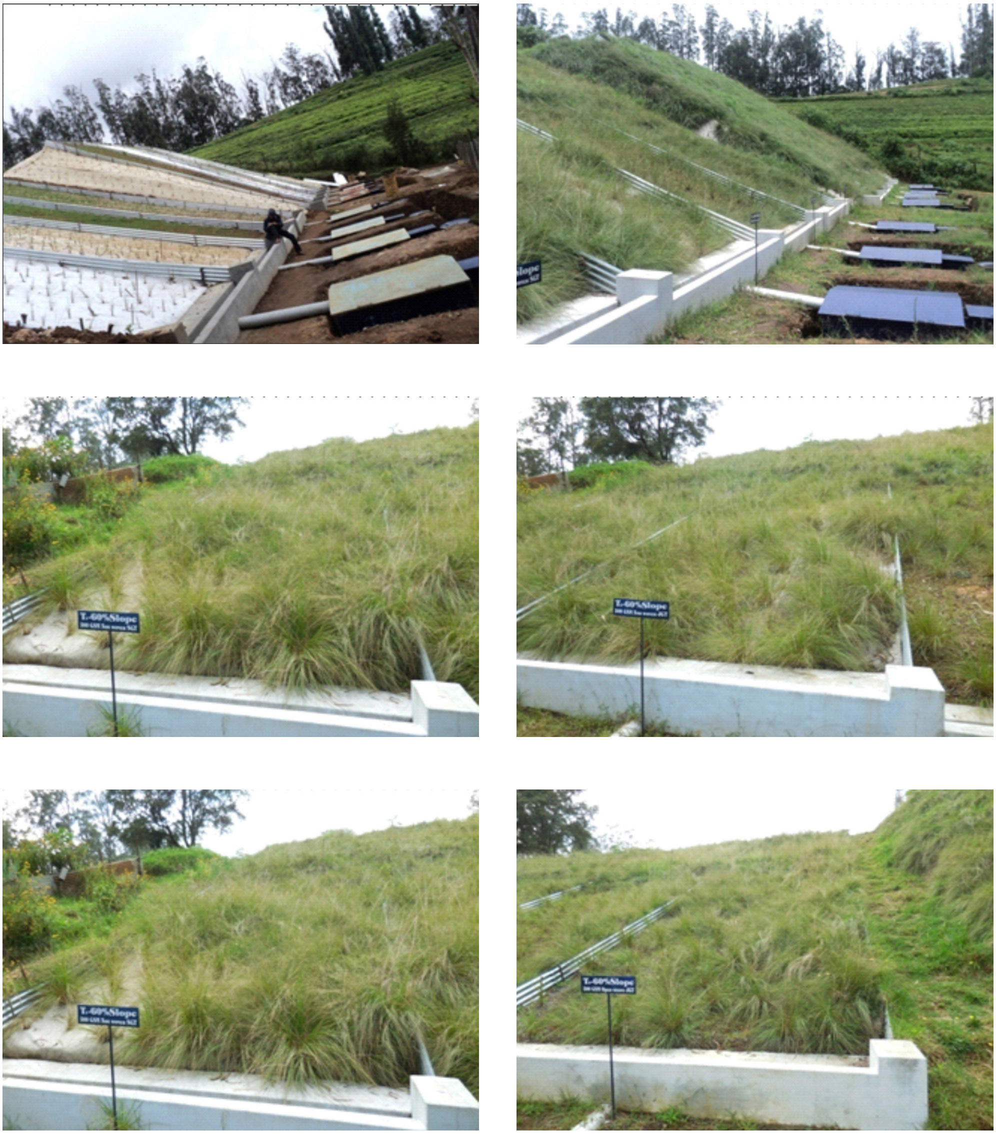

Plate 10. Photographs showing establishment of grass at various stages in 60% slope

Plate 11. View of the grass establishment during final monitoring period in 60% slope

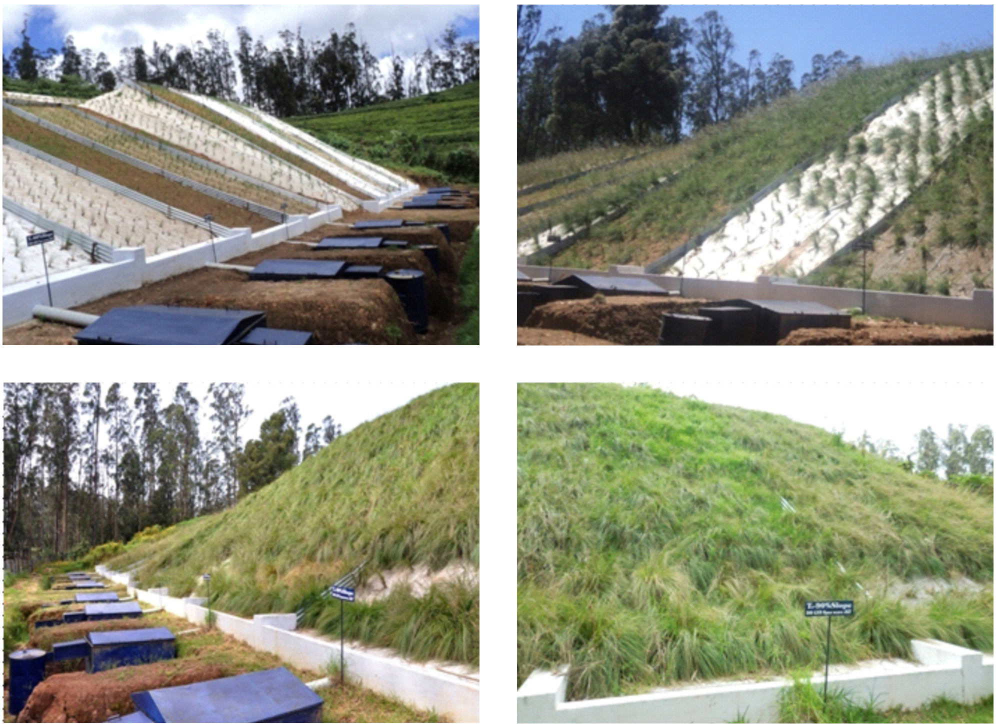

Plate 12. Photographs showing establishment of grass at various stages in 90% slope

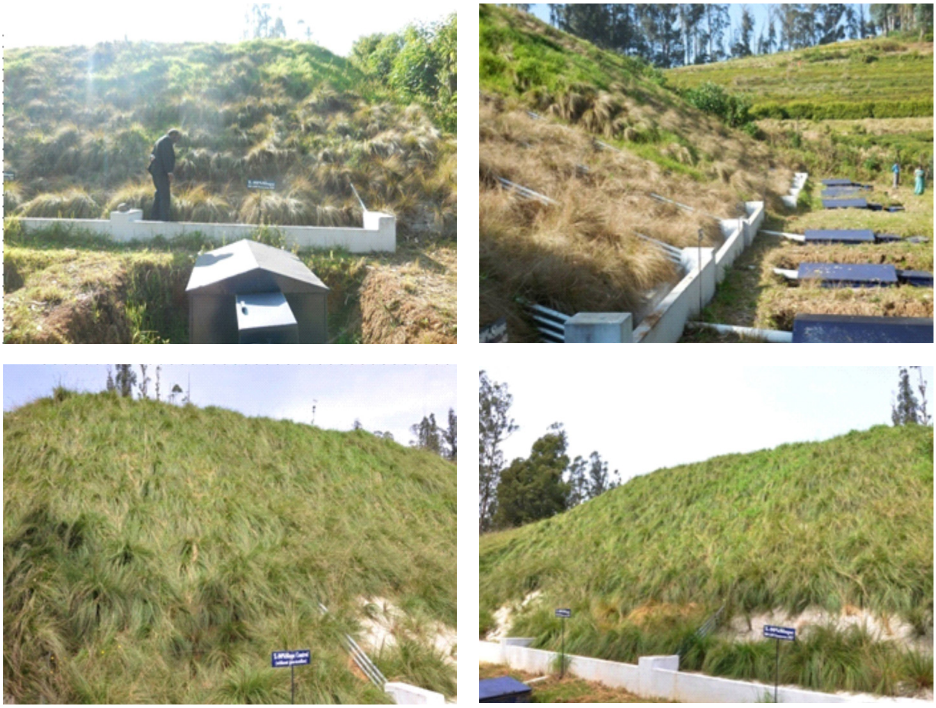

Plate 13. View of the grass establishment during final monitoring period in 90% slope

Table 19. Economics of different Jute Geo-textiles

Type of Geo-textiles	Specification	Cost of application with grass		Cost of application with Tea	
		(Rs m^{-2})	(Rs ha^{-1})	(Rs m^{-2})	(Rs ha^{-1})
Open Weave Jute Geo-textiles	500 GSM	25.50	2,55,000	33.50	3,35,000
	600 GSM	31.25	3,12,500	39.25	3,92,500
	700 GSM	33.80	3,38,000	41.80	4,18,000
Non Woven Jute Geo-textiles	500 GSM	42.00	4,20,000	50.00	5,00,000
Non Woven Synthetic Geo-textiles		86.14	8,61,400	94.14	9,41,400

5. CONCLUSIONS

5.1. Evaluation of Open Weave JGT for Slope Stabilization with Tea

Results of three years field study on efficacy of various types of Open Weave Jute Geo-textiles namely 500, 600 and 700 GSM for slope stabilization on 22% sloppy land showed that 700 GSM for Open Weave JGT is more effective in reducing runoff and soil loss, nutrient loss and increasing soil moisture retention. However, plant height and growth of tea plants were better under 500 and 600 GSM JGT. Higher biomass of grass and other herbs in between tea plants was generated by 700 GSM JGT. Considering the scopes of tea cultivation in sloppy regions, rehabilitation of land slide areas using tea plants, optimal moisture requirement and better plant growth of tea plants and economics, it is suggested that 500 GSM JGT will be more effective for slope stabilization with tea plants. Keeping in view of higher biomass production of grass and other herbs growing in between tea plants, 700 GSM JGT will be suitable for slope stabilization with grass.

5.2. Evaluation of Different Types of Geo-textiles for Slope Stabilization with Grass

Results of three years field study on efficacy of various types of Jute Geo-textiles and Synthetic Geo-textiles on 60 and 90 per cent slopes show that Jute Geo-textiles outperformed the Synthetic Geo-textiles in reduction of runoff and soil erosion. Among the Open Weave and Non Woven JGT, Open Weave JGT are more effective in reducing runoff and soil loss, nutrient loss and also increased soil moisture retention. Growth of the grass and root characters is vigorous in the plots covered by JGT as compared to Synthetic Geo-textiles. Application of Open Weave JGT increased the plant height, number of tillers, root density, surface area coverage and volume of soil binding in both the slope categories. The study concludes that the JGT can be effectively utilized for slope stabilization as compared to Synthetic Geo-textiles. Open Weave JGT with grasses is recommended for slope stabilization in the degraded land having the slopes up to 90%.

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