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Efficacy of open weave jute geotextiles in controlling soil erosion and its impact on hill slope stabilization

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ABSTRACT

Slope stabilization is a tedious process since various human activities being carried out in various parts of the world have led to land use changes that has indirectly affected slope stability. Permanent structures are being used for slope stabilization which are costly and cannot be adopted in a large scale. Slope stabilization by establishing grasses with the support of Jute Geotextiles is an alternative method for stabilization of slopes in hilly areas. Set of field studies were conducted at ICAR- Indian Institute of Soil and Water Conservation (IISWC), Regional Centre, Udhagamandalam, Tamil Nadu, India with the objective to study the effect of various Jute Geotextiles (JGT) on runoff, soil loss, survival and growth of tea. Results of three years field study on efficacy of various types of open weave JGT namely 500, 600 and 700 GSM on slope stabilization showed that 700 GSM open weave JGT proved to be more effective in reducing runoff, soil and nutrient loss and increased soil moisture retention capacity of the soil. However, height and growth of tea plants were better under 500 and 600 GSM JGT. Considering the scope of tea cultivation in sloppy areas, rehabilitation of land slide areas using tea plants, optimal moisture requirement and better growth of tea plants, it is suggested that 500 GSM open weave JGT will be more effective for slope stabilization with tea plants.

Key words: Jute geotextiles, Nutrient loss, Runoff, Slope stabilization, Soil erosion, Soil loss

Hill slope stabilization is a costly and tedious process since various human activities being carried out in various parts of the world have led to land use changes that has indirectly affected slope stability. Permanent structures are being used for slope stabilization which are costly and cannot be adopted in a large scale. On the other side, area for construction of permanent structures in the roadside is not available in many locations. Application of geosynthetics for road construction and slope stabilization is recent development as geosynthetics have proved technically suitable and economically viable to improve the soil and associated materials (Ramaswamy and Aziz 1989). Application of geosynthetics in hydraulic works started in 1980 and has expanded vast in all the civil engineering infrastructures due to its functions and wide range of products. The problems in river bank protection and soil erosion due to indiscriminative man made activities are serious in many countries (Maity 1997) and geosynthetics are being globally used in river bank protection and erosion control (Sanyal and Chakraborty 1993). 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).

Erosion control approach using geosynthetics is generally preventing movement of soil particles from the bank, facilitate safe disposal of runoff and retains the silt through extraneous contraption (Sanyal 2011). 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).

Open weave Jute Geo-textile (JGT) is used to cover up the slope surface initially to control soil erosion and enhance the vegetation growth due to its coarse fibre nature, thick yarns and 3-D features. Open weave jute geotextiles provides a series of mini barriers like a check dams across the direction of overland flow. JGT has excellent drapability and can be laid out to follow the soil contours on which it is laid (Thomson 1988).

JGT has the distinctive property of absorbing water which ranges from 4.5 to 6 times of its dry weight (Rickson 1988) and helps in effecting storage of water. When soil is less permeable and precipitation is heavy, soil erosion

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in slopes can be controlled by overland storage and prevention of detachment of soil. The intrinsic property of jute fibre makes jute geotextiles hygroscopic, nature which increases its flexibility. Application of JGT creates a moist environment in soil surface which encourages rapid growth of vegetation. Jute normally bio-degrades within 1 to 2 years of adding nutrients to the soil at the micro level. Once vegetation starts growing, the role of JGT is taken over by vegetation. When vegetation is completely grown, the canopy cover provides interception to falling rain drops and protects the soil from detachment. The root system of vegetation penetrates the soil and provides long term slope stability by reinforcing nature. Jute geotextiles also add nutrients to the soil after biodegradation of the jute material (Choudhury and Sanyal 2010).

Major reasons for selecting JGT for erosion control purpose are its manifold advanteges, biodegradable nature, adding rich organic nutrients to the soil and increasing growth of vegetation. 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 which 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). Keeping in view the erosion control characters of jute geo-textiles, a study was conducted to evaluate three different types of open weave jute geotextiles for hill slope stabilization using tea plant as test crop in Western Ghat region. The objective of the study was to evaluate the impact of different open weave jute geotextiles on runoff, soil, nutrient losses, survival and growth of tea plants and biomass production of grasses grown in between tea plants.

MATERIALS AND METHODS

An experiment was conducted for a period of three years from January 2012 to December 2014 at the Research Farm of Indian Institute of Soil and Water Conservation, Regional Centre, Udhagamandalam, Tamil Nadu, India formerly known as Central Soil and Water Conservation Research and Training Institute, Research Centre. The study was conducted in the field conditions on a uniform ground gradient of 22 %. The experimental field was divided into four plots in which 500 GSM, 600 GSM and 700 GSM of Open Weave JGT were laid out. Properties of open weave jute geotextiles used in this study are given in Table 1. The selected jute Geotextiles differed in their thickness, wide width tensile strength and open area percentage. The fourth plot was kept as control plot without applying JGT for comparing effect of JGT. Tea was 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. The soil was sandy clay loam with low nitrogen, phosphorous and potassium contest. 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 a one-liter runoff sample was taken for analysis and 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 regular intervals to quantify the effect of different types of JGT on moisture retarding capacity of soil. Plant growth parameters of tea were monitored up to two years at every two months interval after planting. Runoff, soil and nutrient losses were monitored for three years period from 2012 to 2014 and pooled data were analyzed and interpreted. Since the objective of applying geo-jute textile is to promote more biomass growth in degraded lands, grass and other herbs grown in between tea plants were removed and biomass production was recorded after oven drying the material.

Table 1 Properties of open weave Jute Geotextiles used in the study

Construction	500 GSM Open weave JGT	600 GSM Open weave JGT	700 GSM Open weave JGT
Width (cm)	>122 cm	>122 cm	>122 cm
Ends × Picks / dm	6.5 × 4.5	8 × 7	8 × 8
Thickness (mm)	4.50	5.25	5.50
Wide width tensile strength (KN/m) MD × CDE	>6.5 × 6	>12 × 6	>14 × 7
Elongation-at-break (%) MD × CD	<10 × 10	<10 × 10	<10 × 10
Open area (%)	50-65	45-50	40-45
Water holding capacity (%) on dry weight	450-500	450-500	550-600

RESULTS AND DISCUSSION

Runoff and soil loss

Annual runoff and soil loss were monitored from 2012 to 2014 and the same are presented in Table 2 and Fig 1, respectively. The results show that the runoff and soil loss were high during initial year and it was in decreasing trend during second and third year. The decreasing trend during second and third year was due to stabilized soil, canopy and root establishment of tea plants. 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 85.0 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 (59.2 mm) and 500 GSM (83.6 mm) against maximum runoff of 169.0 mm in control plot during the year 2014. Out of three years runoff data, two years data and mean data shows that overland flow

Table 2 Effect of different open weave jute geotextiles on runoff

Year	Rainfall (mm)	Runoff (mm)				Percentage of runoff to rainfall			
		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 (P=0.05)		28.17				1.69			

was less in the plot covered by 700 GSM JGT compared to the plots covered by 500 and 600 GSM JGT. It was also noticed that the open weave jute Geotextiles reduced the runoff ranges from 6.7 to 12.5%.

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/year by JGT application compared to control without any JGT. Minimum soil loss of 0.55 t/ha/year was recorded in the plot protected by 700 GSM JGT followed by 600 GSM (0.65 t/ha/year) and 500 GSM JGT (0.98 t/ha/year) against mean maximum soil loss of 3.93 t/ha/year in control plot which shows that 75 % soil loss was reduced by 500 GSM JGT. Jana *et al.* (2016) also reported that the soil loss reduction due to application of 500 GSM JGT was the tune of 99.4 %.

It can be confirmed from this study that the open weave jute geotextiles are effective in reducing runoff and soil loss. Out of three types of JGT, the 700 GSM open weave jute geo-textile out performed the 500 and 600 GSM jute geotextiles in reducing runoff and soil loss.

Nutrient loss

Major nutrients moved with runoff namely nitrogen, phosphorous, potassium and organic carbon were estimated and reported in Table 3. It shows that considerable amount of nutrients were saved by jute geotextiles compared to control plot. It was observed that the total nutrients saved by jute Geotextiles ranged from 46 to 62%. However, there was no significant variation in nutrient losses observed among various open weave jute geo-textiles.

Soil moisture

Soil moisture in three soil depths was monitored under different jute geotextiles 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. Visible differences in soil moisture retention was noticed in dry season which might be due to the fact that jute geo textiles checked the velocity of water, increased the time of concentration and increased the infiltration consequently reduced the runoff and soil loss. Among the different jute geo textiles, the soil moisture was the highest under 700 GSM JGT followed by 600 GSM JGT and 500 GSM JGT.

Soil composition and nutrient status

Soil compositions of the site before and after application of various open weave jute Geotextiles were studied and are presented in Table 4. It was found that the sand content was not significantly affected by JGT as there was no significant variation in the sand content during before after application of JGT. However, the difference in sand content in control plot was higher as compared to JGT applied plots. Silt content in JGT applied plots was 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 not much change in clay content as the variation ranged from 1 to 3%. It can be interpreted that the JGT made impact on increasing silt content due to reduced soil loss.

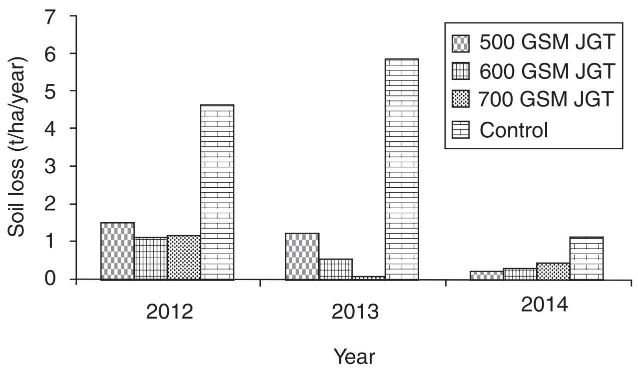

Fig. 1. Effect of various open weave JGT on erosion control

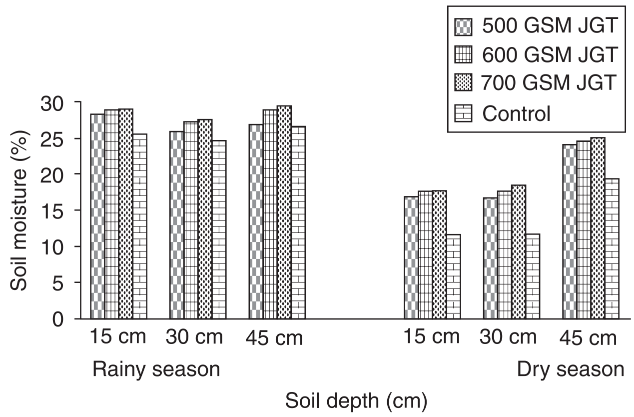

Fig. 2. Average soil mosiutre at different depths in wet and dry seasons

Table 3 Nutrient losses in runoff under different open weave jute geotextiles

Treatment	Year	Nutrient loss (kg/ha)					Nutrient saved over control plot (%)
		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	8.33	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	

Table 4 Effect of open weave jute geotextiles on soil composition

Treatment	Texture						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

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 5. Soil organic carbon build up improved in all the JGT applied plots from the initial carbon content. The increase was 88.9, 88.1, 46.7, and 28.4% in 700, 600 and 500 GSM JGT and control respectively after three years. Application of jute Geotextiles increased the organic carbon build up to 87.2, 46.5 and 27.9% higher in 700, 600 and 500 GSM jutes respectively over the control after three years.

Available nitrogen and phosphorus increased marginally as compared to control plot after three years due to less nutrient losses in the JGT applied plots. Nitrogen content increased to 14.2, 13.0 and 7.4% in 700, 600 and 500 GSM JGT applied plots against lowest increment of 4.5% in control plot after three years. Application of 700, 600 and 500 GSM JGT increased the available nitrogen content to 9.7, 8.5, and 2.9%, respectively compared to control.

Table 5 Impact of open weave jute geotextiles on building up nutrients in the soil

Treatment	Nutrient status							
	Organic carbon (%)		Available nitrogen (kg/ha)		Phosphorous (kg/ha)		Potassium (kg/ha)	
	Before	After	Before	After	Before	After	Before	After
500 GSM JGT	0.75	1.10	135.0	145.0	21.5	25.1	153.0	141.0
600 GSM JGT	0.67	1.26	134.0	151.0	23.2	27.1	171.0	161.0
700 GSM JGT	0.85	1.61	141.0	161.0	21.3	26.7	169.0	165.0
Control	0.67	0.86	133.0	139.0	22.5	24.1	165.0	134.0

Table 6 Effect of open weave jute geotextiles on growth parameters of tea

Treatment	Average plant height (cm)					Leaf area index	DMP (kg/ha) of grass and herbs
	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)

Numbers with the same letter are not significantly different (P = 0.05). Figures in parenthesis denotes the standard error; DMB - Dry matter production, MAP – Months after planting

Similarly, 700, 600 and 500 GSM JGT had increased available phosphorous to 18.3, 17.5 and 9.7 respectively, after three years. The available potassium recorded the negative balance under all the treatments but the reduction range was less under jute applied plots after three years.

Growth of tea seedlings as influenced by JGT

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. 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 and it was followed by 600 GSM JGT. However, there was no significant difference among the Jute geotextiles in case of plant height (Table 6). There was a significant difference in leaf area index and dry matter production within the jute geotextiles also. The highest leaf area index in tea (2.38) was observed under 500 GSM and it was followed by 600 GSM JGT. The dry matter production of plants other than tea was the highest with 700 GSM followed by 600 GSM. The highest dry matter production of weeds in 700 GSM may be due to higher soil moisture content and retaining of more number of seeds. Enhancement of vegetation growth by gotextiles was also been reported elsewhere by Rickson *et al.* (2006).

However, this higher dry matter production of herbs other than tea resulted in reduction of plant height in tea. 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 jute geo-textiles, the growth of tea plants were affected by grass or other vegetations which is evidenced from highest dry matter production (610 kg/ha). Hence, for slope stabilization with tea plants, 500 GSM open weave jute geotextiles may be suitable. As the highest dry matter production grasses and other herbs recorded were highest in 700 GSM JGT, 700 GSM JGT will be suitable for slope stabilization with grass and other herbs.

Conclusions

Prototype field study on efficacy of various types of open weave jute geotextiles namely 500, 600 and 700 GSM on slope stabilization showed that 700 GSM open weave JGT proved to be more effective in reducing runoff and soil and nutrient losses, and increasing soil moisture retention. However, plant height and growth of tea plants were better under 500 GSM JGT. Considering the scope of tea cultivation in sloppy areas, rehabilitation of landslide areas using tea plants, optimal moisture requirement and better plant growth of tea plants, it is suggested that 500 GSM jute geotextiles will be more effective for slope stabilization with tea plants. Higher biomass of grass and other herbs in between tea plants was generated by 700 GSM jute geo-textiles, thus 700 GSM jute geotextiles is recommended for slope stabilization with grass species.

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