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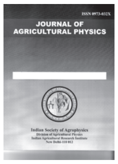

Review Article

Use of Fibrous Structures for Land Protection

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ABSTRACT

Fibrous structure can protect land through various mechanisms. The geotextile (*Bhoovastra*) is a woven/non-woven knitted structure of natural/synthetic textile fibres generally used for various geo-technical, civil engineering and soil conservation work. Organic nutrients are added to the soil with the degradation of geotextiles. Application of geotextiles, along with suitable bioengineering measures, can help control soil erosion and stabilize degraded slopes, landslides, mine spoil areas and cut slopes along road sides. Four different types of geotextile namely, Bionets, Geocells, Biomats,and Geomats are used in erosion control. Performance of geo-textiles for slope stabilization and soil erosion control is now well proven technology in developed as well as in developing countries. Extensive awareness should be created among the people about the application of geotextiles. To explore the potential of geotextile more researches are needed in this field around the world in different physiographic region.

Key words: Soil erosion, Fibrous structure, Geotextile, Land degradation, Hilly areas

Introduction

The concept of fibrous structures originates from a fibrous root system in nature which is the opposite of a taproot system. The fibrous root systems resemble a mat made out of roots when the tree has reached full maturity. This kind of mat structure can be prepared from different parts of trees like leaves and bark. These structures can be used for protection of environment polluted through soil sediments. Erosion by water contributes to landslides, endangering life and environment (Pimentel and Burgess, 2013). Fibrous structure can protect land through various mechanisms. It can protect environments in reducing emission of carbon dioxide (CO_2) which is physically protected in different aggregate size fraction. Sediments and suspended solids are detrimental to micro-flora and fauna. Fibrous structures can prevent non-point source water polluted through runoff from agricultural areas draining into rivers and thus reduces problem of eutrophication.

In Himalayan region, more than 80% agriculture area is rainfed which receives 80% rainfall (1000 mm) during rainy or monsoon season (July-September). This amount of rainfall is more than sufficient to fulfil the water requirements of major rainy season crops of paddy, maize and millets (Sharma *et al.,* 2014). Due to steep topography and heavy textured soils

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(silty clay loam, clay loam, silty loam etc.) having low infiltration rate due to eroded surface layer, this high amount of rain water goes waste as runoff and creates problems of soil erosion. Here, geo-textiles can be used as potential tool of soil erosion control and *in-situ* green water harvesting technology to raise post-rainy season crops to enhance cropping intensity of Himalayan region from 150% to 200-300%. But cost of implementation of geo-textiles like jute-geo-textile or coir geo-textiles is very high (Rs. 18,000-20,000/- ha^{-1}) and beyond reach of poor and marginal farmers of Himalayan region. Another issue is availability of these geo-textiles in remote areas of Himalayan region. Till date, information is not available on performance of geo-textiles along with practices of rainfed conservation agriculture like zero tillage, stubble retention etc. Geotextiles have been used quite extensively for erosion control and slope stabilization in the USA and Europe (Fullen *et al.*, 2011). The geotextile (*Bhoovastra*) is a woven/non-woven knitted structure of natural/ synthetic textile fibres generally used for various geo-technical, civil engineering and soil conservation work. When laid on the ground surface of affected areas and anchored with suitable devices such as wooden pegs, it provides innumerable miniature check-dams absorbing the impact and kinetic energy of falling raindrops (splash erosion) and braking the velocity of surface runoff. Geotextiles help to establish vegetation on such highly degraded lands, which cannot be stabilized by normal methods, by providing mechanical strength to land surfaces, holding the vegetation in place through its open mesh, conserving moisture and fine soil through its netting structure. In due course, the geotextile material biodegrades in about two years period by which time the vegetation is established and takes control of the soil erosion. This review highlights the types of fibrous materials used for soil protection with international evidence.

Raw materials and processing technology of geotextile

Raw materials used for soil erosion control are mostly geotextiles. Geotextiles basically fall into five categories: woven, heat-bonded non-woven, needle-punched non-woven, knitted and fibre/soil mixing. The four main polymer families most widely used as the raw material for geotextiles are: polyester, polyamide, polypropylene and polyethylene. The major fibres used in geotextile production include polypropylene, polyethylene and natural fibres, including jute, palm mats and coconut coir. The most important factors in manufacturing geotextiles are polymer type, fibre type, fabric design and type of bonding. Polypropylene and polyester are the two most widely used polymers in geotextiles. Monofilament, multifilament, staple and slit film yarns are used in geotextile production. The biodegradable materials incorporated within geotextiles are jute, wood shavings and paper strips. Other most important materials used in India are coconut fibre. The coconut fruit fibre serves many purposes and they are longer than cotton. Coconut fibres are usually used to make ropes and matting. These are used for mattresses and for brushes. Coir, a by-product from coconut husk, has distinct properties, including strength, stiffness bulkiness, and resistance to soil moisture and microbes due to high lignin content. Raw coconut fibre products have been innovatively applied in geotextile applications in India.

Structure, properties and theories related to geotextile

Geotextiles are any textile-like material (include various mats, blankets or nets), either woven, non-woven, or extruded, used earlier mainly in civil engineering applications to increase soil structural performance. The salient properties of erosion control geotextiles are: percentage cover, geotextile-induced roughness, geotextile-water holding capacity, and weight of geotextile when wet and ability to both pond flow and increase flow depth (Rickson, 2006).

Erosion control geotextiles are made from both natural and synthetic materials in different shapes, sizes and physical characterizes. These products are classified into four groups namely, Bionets, Geocells, Biomats,and Geomats

(Rickson, 2000). Biomats are made of fibres from natural materials are held together by two lightweight mesh layers, made either from natural or synthetic materials. Geocells are honey-comb structures, manufactured by gluing together nonwoven geotextile strips or by the extrusion of high density polyethylene. Bionet are made from natural fibres of jute orcoir yarns spun into woven meshes. Geomats and Geocells are three dimensional products made from synthetic materials, but differ in their structure. Geojute is made from a natural degradable product. Enviramat is a combination of natural and synthetic products. Geocell and Enkamat are made from purely synthetic products that are non-degradable. Geojute and Enviramat were considered surface installed while Enkamat and Geoweb were considered as buried products. These geotextiles and their different characteristics were summarized in Table 1.

Natural geotextiles

Natural fibres can be sourced from plants (vegetable fibres). Vegetable fibres can be grouped into three classes, namely, bast fibres, leaf fibres and seed/fruit fibres. Bast fibres are extracted from stems. A fibre material would be suitable for geotextiles when: (i) it has reasonably good mechanical properties, and (ii) it is reasonably resistant to microbial attack. The bast fibres include jute, flax, hemp and ramie and have very high tenacity values and low extension at break (1.6-3.8%) (Banerjee, 1996). In tenacity, the leaf fibres (such as sisal, abace and henequen) are slightly stronger than jute, but weaker than the other three bast fibres. However, in extension at break they behave similarly to the bast fibres. The growth of microorganisms on vegetable fibres depends on their chemical composition. Lignin content plays an important role. In this respect alone, coir fibre with >35% lignin content stands out as extremely resistant, followed by jute (lignin content ~12%) and leaf fibres (lignin content ~10%).

Natural geotextiles can be used where vegetation is considered to be the long-term answer to slope protection and erosion control (Balan and Venkatappa Rao, 1996). They have several inherent advantages: i) they give protection against rainsplash erosion; (ii) they have the capacity to absorb water even up to 5 times their own weight; (iii) they reduce the velocity and, thus, the erosivity of runoff and (iv) they are biodegrade, adding useful mulch to the soil. Additionally, mats might help to reduce intense solar radiation, suppress extreme fluctuations of soil temperature, reduce water loss through evaporation and increase soil moisture. All these could assist in creating ideal conditions for plant growth in many circumstances. As they degrade, natural products add organic matter and nutrients to the soil. This may enhance soil microbiological activity and promote soil health, fertility and aggregate stability (Rickson, 2006). The ability of natural fibres to absorb water and degrade with time is its prime property that gives it an edge over synthetic geotextiles for slope stability applications.

Table 1. Properties of different geotextiles material used in erosion control

Product	Material characteristics	Geotextile area (%)	Open area (%)	C Factor	Type
Enviramat	Wood chips in photodegradable	94	6	0.154	Biomat, surface installed
Geojute	100% jute woven mesh(natural),degradable	54	46	0.126	Biomat, surface installed
Enkamat	3D Polyethylene mesh (synthetic), non-Degradable	40	60	0.257	Geomat, buried
Geoweb	3D honeycomb high density polyethylene (synthetic),non-degradable	1	99	1.032	Geomat, buried

Source: Morgan and Rickson (1985); Rickson (2000, 2013)

Jute is fast becoming the market leader in natural geotextiles and is being promoted for its economic advantages in terms of cheaper costs and availability compared with other natural fibres. Even in the field of erosion control, geojute has many limitations, primarily because its strength and durability are too limited for harsh applications, such as steep slopes, higher altitude slopes or waterways. Coir, made from coconut (*Cocos nucifera*) husk, has the highest tensile strength of any natural fibre and retains much of its tensile strength when wet. Jute fibres exhibit moderately high modulus of rupture as well as high tenacity and very low elongation at break. Coir fibres behave exactly in the opposite manner, namely moderately low modulus of rupture, low tenacity and very high elongation at break (Banerjee, 1996). Palm-mat geotextiles constructed from the leaf of *Borassus aethiopum* (Black Rhun Palm of West Africa are termed Borassus mats. Geotextile palm-mats constructed from the leaf of *Mauritia flexuosa* (Buriti Palm of South America) are called Buriti mats (Fullen *et al.,* 2006). The Buriti fibre is known as 'hemp' in Barreirinhas Municipality (Maranhão State, Brazil), and for its attainment the sprouts are collected from young leaves-called 'eye'.

Not many theories were generated out of state-of-the art research on using fibrous materials for soil conservation. Bhattacharyya (2009) valuated that plots under buffer strips (area coverage ~10%) of Borassus mats were as effective as completely covered plots in the United Kingdom. Mat-cover also conserved the soil chemical properties, improved soil aggregation and soil organic matter. Results from UK, China, Thailand, Vietnam, Lithuania, Belgium, South Africa, Hungary and Brazil suggested that these mats are very effective (37-95%) in reducing soil erosion (Bhattacharyya *et al*., 2011). Results in the UK indicate soil loss in the Borassus completely-covered plots was about 99% less than bare soil. Soil and water loss under Borassus completely-covered plots, permanent grass plots and buffer strip plots of both Borassus and Buriti mats were similar. Except Borassus completely-covered plots, all plots significantly ($P<0.05$) increased topsoil (0-5 cm) bulk density and decreased aggregate stability (Bhattacharyya *et al*., 2011).Buffer strips were more effective in trapping fine particles than Borassus completely-covered plots. No treatments had significant ($P>0.05$) effects on pH, soil organic matter, total soil C and N changes. Plots with Borassus mats significantly ($P<0.05$) increased total P and decreased total Ca. Treatments had no significant effects on changes in total S, Mg, Zn, Cu, Fe, Mn, Mo and Cl concentrations. This is probably the first work on evaluation of soil properties after using biological geotextiles (Bhattacharyya *et al*., 2011).

Completely covering bare soils with bio-geotextiles would not be economically viable despite their higher effectiveness in different agro-climatic conditions. Bunch and Lopez (1999) revealed that for farmers to accept soil conservation technologies, which are to be sustained, it must be combined with a technology that enhances yields. It is the increase in yield that convinces the farmers of the value of soil conservation. Mats are more expensive than other erosion control measures, due to labour and material costs. Less longevity of the mats (due to their 100% biodegradability) further adds long-term expenditure. Kay (1978) reported that the application of geotextiles was limited by their cost (costs were at least four times as high as tacked straw) and effectiveness as they required high labour inputs for installation. Mats are generally not suitable for excessively rocky sites, or channels. Mats must be removed and disposed of prior to application of permanent soil stabilization measures. These mats also tend to be difficult to replant through because of their density and weight. Apart from the above-mentioned limitations, there are several unanswered questions related to the use of biogeotextiles in different agro-environmental situations. These are: (i) so far, little work has addressed issues of biogeotextile quality, production, durability and performance in both field and laboratory environments; (ii) limited studies are available on the ageing effects on physical and chemical properties of mats under diverse soil and climatic conditions; (iii) no studies are available on the impacts of indigenous mats in improving soil quality and possible agricultural use highlighting the yield enhancement of high value crops in erosion prone areas; (iv) limited data are available on the effectiveness of geotextiles as buffer strips or partial cover (as complete cover might be uneconomical); (v) research (despite the BORASSUS Project) and published data on socio-economic analysis of producing and using mats are limited and (vi) although effects of biogeotextiles in reducing soil loss by water has been widely studied, studies related to their effects on environmental protection (reducing nutrient concentration in sediment and runoff and effects of geotextiles on particle size in runoff water/sediment) are limited.

Functions, evaluation and applications of geotextiles

Soil erosion has been defined as the process of detachment and transportation of soil material by erosive agents (Ellison, 1947). In simple terms, erosion is the removal and loss of soil by the action of water, ice, gravity or wind. Interrill and rill erosion constitute the major source of soil lost from most upland areas of sloping land (Lattanzi *et al.,* 1974). Soil erosion proceeds in three stages: (i) separation of soil particles by the energy of raindrop impact; (ii) transport of these particles by surface runoff along the slope and (iii) deposition of erosional drift when transport energy reaches a low level (Römkens *et al.,* 2002). Each of these types of erosion involves the detachment, transportation and downstream/ downwind deposition of sediment. Erosion occurs when soil is exposed to rainfall energy.

Typical applications of geotextiles are: Retaining walls, landslide repairs, embankments on very soft soils, combined with vertical drains, reinforcement under tramways or railway ballast, roadway reinforcement, erosion control in vulnerable slopes and sea embankments, reinforcement or bridging over potential weak zones, voids or cavities, reinforcement of foundation layers and piled embankments with basal reinforcement. In environmental protection, geotextilte are mostly used in control of soil erosion by water. Geotextiles from palm leaves has been found to provide immediate erosion control, and increase the fertility of soil as well as its organic matter content. They are highly cost-effective and simple to manufacture because the raw materials are readily available. When applied for use in erosion control on a site in the UK, these materials reduced the sediment yield considerably compared with bare-soil control fields (Davies *et al.,* 2006).A study involving three natural fibre geotextiles and a bare soil control was carried out by simulating runoff and concentrated flow in a soil flume with different slope gradients. The results obtained showed an average of 60% reduction in the rate of erosion when using these materials (Smets *et al.,* 2009).

The performances of geotextiles in erosion control have been evaluated both quantitatively (few studies) and qualitatively (in most cases). Most of the studies on geotextile performance evaluation (Bhattacharyya *et al,* 2010a; 2010b; 2011; Alvarez-Mozos *et al.,* 2013) are based on observed field or laboratory data. Quantitative evaluation using erosion prediction models (Ayuba, 2013) has proved to be more efficient, straight forward and less time consuming. The work evaluated the use of the original (Morgan *et al*.,1984) and revised (Morgan,2001) versions of the Morgan, Morgan and Finney (MMF) erosion prediction model to estimate the performance of the four classifications of geotextile materials used in erosion control. A strong and positive correlation (Tables 2&3) was established between rates of erosion as observed in the field (in which these geotextiles were installed) and those predicted by the models (using geotextile properties as input parameters).

Material specifications for geojute used in India for slop stabilization in Indian Himalayan region found very suitable with following specification (Juyal *et al.,* 2011). Geotextile materials are generally available in rolls of 50 m length and 1.22 m width. Materials of following specifications may be used for slope stabilization and erosion control. Besides, Coir geonet (H2M8) may be used for stabilizing highly degraded sites (Table 4).

Table 2. Correlation analysis of predicted vs. observed relative rates of erosion- original MMF

Soil type	Rainfall	Treatment	Predicted (%)	Observed (%)	Regression equation
Clay loam	Low Intensity	Bare soil	100	100	y = 0.9858x – 15.975
		Enviramat	15.42	27.24	$R^2 = 0.8394$
		Geojute	12.63	29.26	R = 0.9162
		Enkamat	46.66	85.55	
		Geoweb	149.90	n/a	
	High Intensity	Bare soil	100	100	y = 0.6277x +2.7104
		Enviramat	15.42	35.61	$R^2 = 0.5851$
		Geojute	12.63	11.53	R = 0.7649
		Enkamat	46.66	113.92	
		Geoweb	149.90	n/a	
Sandy loam	Low Intensity	Bare soil	100	100	y = 0.17x +73.0.31
		Enviramat	38.07	30.45	$R^2 = 0.0216$
		Geojute	31.17	76.36	R = 0.1470
		Enkamat	99.40	253.76	
		Geoweb	166.58	51.36	
	High Intensity	Bare soil	100	100	y = 0.8378x +16.022
		Enviramat	38.07	24.97	$R^2 = 0.9091$
		Geojute	31.17	14.06	R = 0.9535
		Enkamat	99.40	130.09	
		Geoweb	166.58	154.76	

Source: Ayuba (2013)

Table 3. Correlation analysis of predicted vs. observed relative rates of erosion – revised MMF

Soil type	Rainfall	Treatment	Predicted (%)	Observed (%)	Regression equation
Clay loam	Low Intensity	Bare soil	100	100	y = 1.103x – 26.928
		Enviramat	0.25	27.24	$R^2 = 0.8708$
		Geojute	12.61	29.26	R = 0.9332
		Enkamat	46.60	85.55	
		Geoweb	187.10	0	
	High Intensity	Bare soil	100	100	y = 0.6887x +5.0854
		Enviramat	0.25	35.61	$R^2 = 0.5829$
		Geojute	12.61	11.53	R = 0.7635
		Enkamat	46.60	113.92	
		Geoweb	187.10	n/a	
Sandy loam	Low Intensity	Bare soil	100	100	y = 0.3393x +12.171
		Enviramat	0.49	30.45	$R^2 = 0.1755$
		Geojute	12.67	76.36	R = 0.4190
		Enkamat	40.40	253.76	
		Geoweb	47.15	51.36	
	High Intensity	Bare soil	100	100	y = 0.8378x +16.022
		Enviramat	0.49	24.97	$R^2 = 0.9091$
		Geojute	12.67	14.06	R = 0.9535
		Enkamat	40.40	130.09	
		Geoweb	129.68	154.76	

Source: Ayuba (2013)

Table 4. Geotextile materials specification used in Indian Himalayan region

Geotextile	Weight (g/m^2)	Mesh size
Geo-jute (soil saver)	500	16 mm × 22 mm
Coir geo-net		
a) H2M6	400	25 mm × 25 mm
b) H2M8	700	10 mm × 10 mm

In bare soil region use of biological geotextiles results in higher biomass yield. Increased biomass yield is attributed to soil and moisture conservation. Biological geotextiles results in significant increase in aboveground biomass production and to decreased soil loss under different soil and climatic conditions (Bhattacharya *et al.,* 2012). Coir geotextiles when coupled with existing soil conservation technique, can play an important role in protection against soil erosion in sloping lands (Anil *et al.,* 2012). A study conducted in temperate monsoon climate with hot, rainy summers and cold, dry winters evidenced that straw mat geotextile was best in runoff control between shade net, non-woven fabrics and straw mats,S traw mats resulted in the lowest runoff coefficient (10.9%) and sediment yield (8.5 g m$^{"2}$) (Luo *et al.,* 2013). The coir and jute geotextiles produced 2–3 times more runoff on both the 45° and 60° slopes. It was found that Geotextiles were more effective in reducing soil loss at 45° than at 60° slopes respectively. Surface-laid geogrid, was found to most effective with a median Soil Loss Reduction Effectiveness (SLRE) of 76% and 53% for the 45° and the 60° slopes, respectively (Álvarez-Mozos *et al.,* 2014).

Structural properties become important on steep slopes (Chen *et al.,* 2011). The biodegradation of sheep wool is a slow process and it occurs, much slower in comparison to the cellulosic materials. The slow biodegradation of the ropes enhances their protective potential for longer duration (Broda *et al.,* 2016). Geotextiles with dense covers were found to be especially ineffective in reducing runoff (Davies *et al.,* 2006; Mitchell *et al.,* 2003). Coir blanket when used as dense gotextiles, it resulted in reduced rain splash erosion (Rickson, 2006). But, as slope inclination increases, surface runoff might play a more important role in soil erosion than rain splash (Álvarez-Mozos *et al.,* 2014).

Conclusions

Performance of geo-textiles for slope stabilization and soil erosion control is now well proven technology in developed as well as in developing countries but still lot of research is needed in the area of use of geo-textiles in arable lands and to raise the income of farmers by enhancing cropping intensity. Another question mark is availability of these materials to farmers at affordable prices. These two important issues can only be solved through location specific research on geo-textiles by involving famers of a particular region. Additionally, international conferences, seminars, brain storming sessions etc. should be organised on use of geo-textiles in agriculture by government sectors to aware policy makers to provide subsidy to farmers for purchasing and manufacturing synthetic as well as natural geo-textiles. Extensive awareness should be created among the people about the application of geotextiles. To explore the potential of geotextile more researches are needed in this field around the world in different physiographic region.

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