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Field instrumentation and monitoring of soil erosion in coir geotextile stabilised slopes—A case study

K.R. Lekha*

Centre for Water Resources Development and Management, Kunnamangalam P.O., Kozhikode-673 571, Kerala, India

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Abstract

Soil erosion along degraded hill slopes has been a problem of serious concern throughout the world. In India, about 5330 million tones (16.4 t/ha) of soil is being lost every year. Conventional methods of bench terracing coupled with dry rubble packed bunds are being used on steep slopes of plantation area situated along the Western Ghats, to reduce surface erosion. But these conventional methods prove unsuitable in many of the steep slopes which are highly susceptible to erosion. A permanent and self-propagating vegetal cover is found to be an ideal solution to 90% of the erosion problems. Stabilisation of soil along the hill slopes using natural and locally available materials such as coir is a recent technique. Natural and biodegradable fibres such as coir and jute in the form of nettings can aid in vegetative turfing along the slopes. These nettings are intended to protect the seeds and the soil until the sites are permanently stabilised with vegetal cover, by providing a physical barrier between the soil particles and rainwater. The coir netting spread over seeded slopes shields the soil and seeds from the impact of rain drops, minimise runoff and slows down its velocity, maintains the capacity of soil to absorb water, holds the soil particles and seeds in place and retains soil moisture. When seeds germinate, they grow through the gaps in the fabric and achieve a cover all over as the biodegradable coir netting begins to degrade. This technology is applicable to highly erodable slopes where mechanical methods such as tillage or terracing prove unsuitable. This paper presents the methodology followed in monitoring soil erosion in a hill slope stabilised by coir geotextile aided vegetative turfing. Improvement in various soil parameters

*Corresponding author. Tel.: +91-495-2355864; fax: +91-495-2357827.
E-mail addresses: lekharajendran@hotmail.com, lekha2003@eth.net (K.R. Lekha).

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in such a protected slope is analysed by a comparison of results from a similar unprotected slope.

Keywords: Soil erosion; Coir geotextiles; Vegetation; Hill slopes; Slope stabilisation

1. Introduction

Failure of natural slopes are mostly associated with human intervention either for urbanisation or for other developmental activities. But while planning for such works, the environmental instability likely to take place are hardly given importance. Unscientific measures of slope protection and improper design of structures will always have its consequence on the stability of slopes. A small initial movement in an unstable slope can trigger further soil water movement resulting in soil erosion and consequent landslides. The degree of stability of a given slope can vary widely depending on the conditions that exist in it at a given time. Control over the groundwater and seepage conditions deep within the slope by drainage is one of the best methods for improving the stability of earth slopes.

Conventional methods of bench terracing coupled with dry rubble packed bunds are being used on steep slopes to reduce surface soil erosion. But these conventional methods will not yield vegetation growth on steep slopes, which are denuded by erosion. Natural vegetation for sustainable erosion control and slope protection is a proven choice of soil conservation along hilly terrain. Vegetation growth in a troubled slope is occasionally met with problems like absence of initial binding material in the soil, washing away by runoff, etc. In such conditions, geotextiles serve the purpose of protecting the soil and the seeds in the initial stage of vegetative growth.

Natural geotextiles made of coir, jute, etc. are more preferred to synthetic fibres on account of the fact that the material is environment friendly and ecologically compatible as it gets degraded with the soil. In an age of growing environmental awareness, synthetic geotextiles have some disadvantages. They are polymeric materials which are not biodegradable and are likely to cause soil pollution. Further, their production process cause air and water pollution. Moreover, natural fibres are less costly and easily available in many parts of the world which make it a better choice compared to synthetic fibres. The ability of natural fibres to absorb water and degrade with time are its prime properties that give it an edge over synthetic geotextiles for slope stability applications.

Coir geotextile is a prominent natural fibre geotextile primarily applicable for temporary soil reinforcements and erosion control. Coir resembles natural soil in its capacity to absorb solar radiation. This means that there is no risk of excessive heating as happens sometimes in the case of synthetics. In application of erosion control, coir geotextiles serve the purpose of protecting the seeds and surface soil from being washed away in the initial stage and the finial stability of the slope is attained by the roots of vegetation and soil consolidation. This method is more appropriate in places where vegetation is considered to be the long-term answer to the slope stabilisation.

Various attempts are being made by researchers to study the mechanism of reinforcement using natural fibre geotextiles. Henderson (1982) presented the use of a knitted yarn interwoven strips of biodegradable paper, that is intended to protect exposed or disturbed soils until the sites are permanently stabilised with vegetal cover. Balan and Venkatappa Rao (1996) have shown that natural fibre geotextile can be used where soil surface need to be stabilised and protected from erosion by vegetative growth. Banerjee (1996) presented blended natural fibre geotextiles using coir and jute which is found to be a very versatile material. Venkatappa Rao and Balan (2000) have compiled state-of-the-art information on the emerging trends of coir geotextiles.

The present study illustrates the methodology and instrumentation adopted for quantification of soil erosion from a study plot in a sloppy terrain. Also, the advantages of coir geotextiles for stabilisation of hill slopes is studied by analysing various parameters such as soil moisture retention, organic carbon, vegetative growth, etc. The study was carried out in a highly erosion prone hill slope in the Attappady region of Kerala.

2. Location specific information

Kerala is a natural geographical region that lies in the west coast of India with a landscape that slopes from Western Ghats in the east to Arabian sea in the west. The region has highly undulating topography with a unique hydrology. Demographically, this state has three rain seasons, viz. pre-monsoon from February to May, monsoon from June to September and post-monsoon from October to January. The South west winds bring rain to Kerala during the monsoon period. The annual average rainfall in the state is about 3000 mm.

Attappady is located in the North-eastern corner of Palakkad district in Kerala between 10° 55′ and 11° 15′ N latitude and 76° 22′ and 76° 46′ E Longitude. This region with an aerial extent of 826 km^2 is an east sloping plateau and has a peculiar geographical location and physiography with a large number of tribal population. The Attappady region differs from the rest of the humid tropic areas in Kerala mainly because of its peculiar rainfall characteristics. This region is considered to be one of the driest part of the state and has an average annual rainfall of 1500 mm. Attapady valley is included in the manipulation zone of Nilgiri Biosphere Reserve (NBR) by the Department of Environment, Government of India.

3. Materials and methods

3.1. Materials

Coir geotextile is manufactured from coir fibre, which is obtained from the husk that surrounds the nut of the coconut plant. Coir fibre has a chemical composition of 40–45% lignin, 32–43% cellulose, 2.75–4% pectin and 1.44% ash. Fibre length varies from 10 to 200 mm and the diameter is about 0.3 mm. Inspite of the low cellulose content, coir has a very close fibre structure that account for its better durability compared to other natural fibres such as jute, sisal, etc. Coir matting is manufactured in Kerala from different types of coir yarns as Anjengo, Quilandy, Beypore, Vycome and Beach. The fabric is available in rolls of 1–2 m width and length of 50 m.

The mesh matting selected for the present study is designated H2M8 (MMA3) with a mesh opening of $6 \times 10.5\,mm^2$ and density $0.7\,kg/m^2$. Tensile strength of fresh coir netting was 18 kN/m.

3.2. Field layout and installation procedure

A total hill slope area of $1600\,m^2$ (0.16 ha) having an average slope of 26° was selected for erosion monitoring. Of this, an area of about $1360\,m^2$ served as a demonstration plot. There are three sets of twin plots (with each twin plot having one protected and one non-protected slope) covering a total area of $240\,m^2$ for erosion monitoring. Each individual plot is of dimension $22 \times 1.8\,m^2$ and had an average slope of 26°. A 20 cm high masonry boundary wall was constructed at the top of the plots in order to arrest the debris movement from entering the control plot and yet to provide sufficient drainage. In each pair of control plots, one was selected for protection using coir netting aided vegetative turfing and other was left non-protected with arrangements provided for erosion monitoring. The bottom end of each control plot is provided with angular tapering that leads the runoff to specially fabricated erosion drums. Schematic of the erosion monitoring arrangement is given in Fig. 1.

The method of installation is simple and straightforward. The area was first cleared of all vegetation. The control plot area including the demonstration plot was first levelled, graded and tamped to the desired shape. All protruding rocks, roots, slumps, etc. were removed since any projection left on the soil cutting allows water to flow under the netting and thus cause undercutting. The area was then seeded with

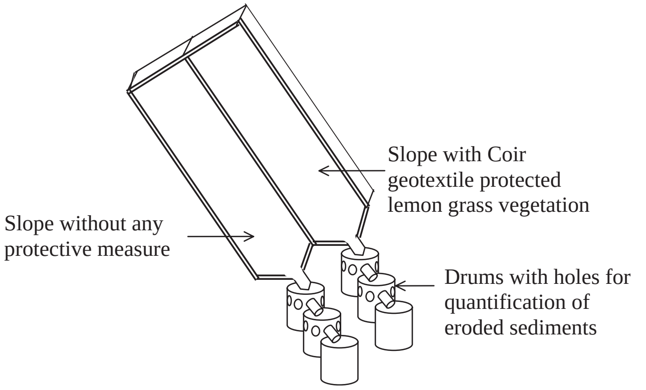

Fig. 1. Schematic of test plots with arrangements for collecting runoff and erosion debris.

lemongrass seeds at the rate of 8 gm/m^2. Lemon grass is a perennial grass with fairly good root system which can hold the soil in place once the coir gets completely degraded in the soil. Lemon grass also has the advantage of not being destroyed by grazing. Moreover, lemon grass oil has very high economical importance.

One end of the coir netting (which is in the form of rolls) is then inserted into the ground to a depth of 30 cm at the top end of the slope and hooked at intervals using iron hooks. The netting was then rolled down the slope and the bottom end is fixed to the ground using iron staples. The netting is then pinned to the slope surface at staggered intervals so as to ensure proper contact. Lemon grass seeds were again spread over the netting at the rate of 8 gm/m^2. After installation, the netting would be tamped flush with the soil surface. The field was finally irrigated to promote the growth of vegetation. The laying out of coir netting over seeded slope was carried out during 23–26 September 1997 before the onset of NE monsoon (post-monsoon period).

4. Monitoring of parameters

Data on various soil–coir–grass parameters were obtained from control plots in order to assess the efficiency of the technology. The runoff from control plots are collected and analysed for estimating the quantity of eroded sediments. Soil samples were collected periodically from the control plots and analysed for water content, soil moisture retention and organic carbon. The biodegradation of the coir fabric is assessed by periodic sampling of the coir from the control plot and tested for ultimate tensile strength.

4.1. Soil erosion

4.1.1. Instrumentation and monitoring

Erosion is monitored from the control plots using specially fabricated collection drums provided at the bottom of each control plot. For each plot, the instrumentation setup consists mainly of three drums arranged in sequential order so that the outflow from the first enters the second and that from the second enters the third drum. There are fixed number of holes of specified diameter on the walls of the first and second drums to enable quantification of sediments. The outflow from a single outlet is diverted to the next drum. A specially constructed outlet at the bottom end of each control plot diverts the runoff to the drums. Each of the drums is provided with a specially constructed cover made of tin metal to avoid the direct entry of rainfall. Plate 1 shows the drum arrangement for collection of runoff sediments. Field installation of coir geotextile and sowing of grass seeds were completed by the end of September 1997. Soil erosion was monitored for one full hydrologic year from February 1998 to January 1999 (starting with the pre-monsoon period). The total sediment eroded out from the control plot was quantified using specially fabricated instrumentation setup explained earlier.

Plate 1. Drum arrangement for collection of runoff and erosion debris from control plots.

4.1.2. Results and analysis

Runoff along with the eroded sediments from the entire area of each plot is collected in the first drum. Major sediments are settled out in the first drum. Excess water along with the suspended sediments from the first drum flows out to the second drum and from the second drum to the third one. Each time the third drum is full, 1 l sample is collected and the drum is cleaned. This procedure is repeated, till the first drum is filled up with major sediments. Once the first drum gets filled up, samples are taken from all the drums and the drums emptied. Quantity of major sediments in the first drum is calculated after determining the density of soil sample collected from it. Suspended sediments from water samples collected in 1 l cans are filtered using Whatman No. 1 filter paper, and the dry weight is determined. Similarly, suspended water samples from the second and third drums are filtered and the quantity of dry sediment is determined. The total sediments collected in the first drum is also added to get the total eroded sediments from one plot, which is expressed in tonnes/ha.

Monitoring of soil erosion was commenced from the next pre-monsoon period (February 98–May'98) and continued for one full hydrologic year till the end of January 1999 covering all the three seasons of pre-monsoon, monsoon and post-monsoon period. Fig. 2 shows a comparison of the seasonal and annual variations in soil erosion in the coir net aided vegetated slope and non-protected slope. The rainfall variation during the period under observation is also shown.

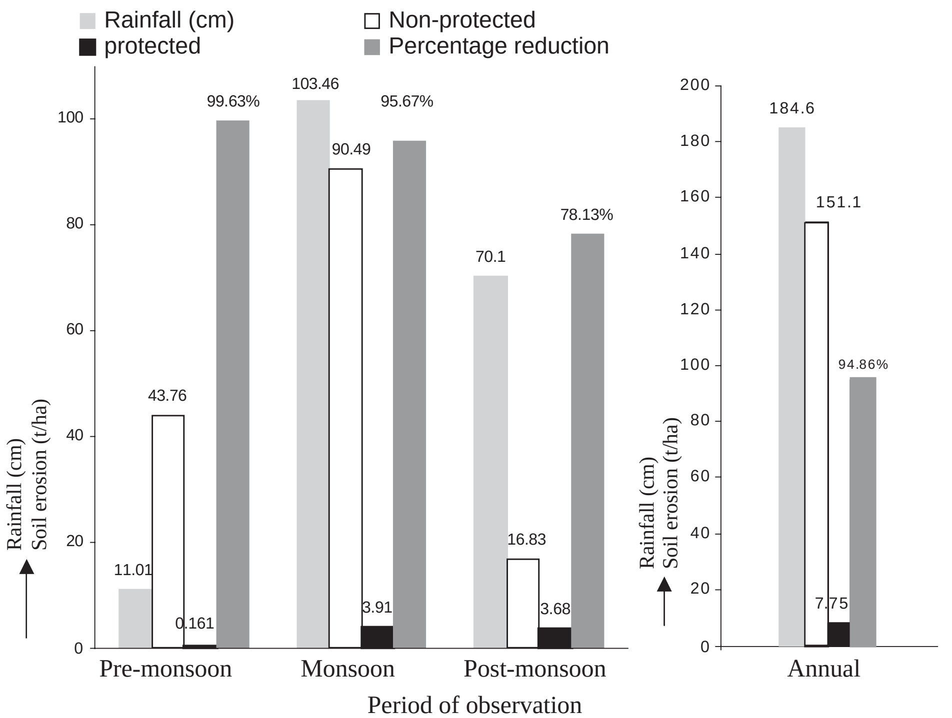

Fig. 2. Comparison of seasonal and annual soil erosion in protected and non-protected slopes.

During the pre-monsoon period (4 months after installation) with 6% rainfall, coir geotextile aided vegetative protection is found to reduce soil erosion by 99.63%. This is primarily because of the fact that during this period, there is very less rainfall contributing to erosion. Also in the case of coir net protected slope the netting offers maximum resistance against soil removal.

In the subsequent stage, i.e. monsoon period with 56% rainfall, coir geotextile aided vegetative protection is found to reduce soil erosion by 95.67%. At this stage, the two major factors contributing to maximum reduction in soil erosion in the protected slope are

(i) The coir net cover which is still remaining, though in degraded form; and
(ii) The average grown grass canopy and root system.

The combined action of the above two factors contribute to the maximum reduction in soil erosion in the protected slope.

In the next stage (post-monsoon) with 38% rainfall, the coir net protected vegetative measure is found to reduce soil erosion by 78% compared to the non-protected slope. The decrease in the observed effectiveness may be due to the improved stability of the non-protected slope by natural soil consolidation. Though the fully grown grass root system in the protected slope is extremely efficient in minimising soil erosion, during this period of one year, the soil in the non-protected slope also attain certain degree of stability naturally due to soil consolidation resulting in an apparent decrease in the percentage reduction of soil erosion in the protected slope.

4.2. Soil moisture retention

Soil moisture retention refers to the amount of soil moisture that is retained in the soil at a particular pressure. Retention at 0.3 bar refers to the field capacity and at 15 bar refers to the wilting point. Amount of water between 0.3 and 15 bar is the water available for plant growth. Soil samples were collected from the field every month at different depths. i.e., 30 cm, 60 cm and 90 cm since the field installation was completed. The period immediately followed after the field installation was a post-monsoon season (October 1997–January 1998). Observations were continued during the next pre-monsoon and monsoon seasons so as to complete monitoring for one full hydrologic year. Soil Moisture retention is determined using pressure plate apparatus.

The pressure plate apparatus enables the development of soil moisture characteristic curves in the higher range of matric potential (>1 bar) which is not possible on suction pipes. The apparatus consists of pressure plates or membranes of high air entry values contained in air-tight metallic chamber strong enough to withstand high pressure. The saturated soil sample along with porous plate is kept inside the apparatus and the desired pressure is applied on the soil. Water starts flowing out from the saturated soil sample through the outlet till equilibrium against the applied pressure is achieved. The soil sample is then taken out and oven dried to get the moisture content at the applied pressure.

Variations in soil moisture retention at both wilting point and field capacity are shown in Fig. 3. At both wilting point level and field capacity, soil moisture retention is higher in the protected plot than in the unprotected plot. It is seen that in the pre-monsoon period (dry season), the soil moisture retention in the coir net protected slope was increased by 13% at 0.3 bar and 22% at 15 bar pressure. Thus water availability for plant growth is very much improved in the protected plots. This is because of the water absorption quality of coir fabric and the ultimate reduction in soil erosion achieved using coir nets.

4.3. Soil water content

Coir netting spread over the slope acts as a shielding material for the surface soil thus improving the moisture content in the soil. Soil samples were collected from both the plots twice in a month from depths of 30, 60 and 90 cm. Water content was determined by gravimetric method and is presented in Fig. 4. It can be seen that the water content values are always higher in the protected plot than in the non-protected plot. In the protected plot, there is reduction in the surface runoff and the loose top soil allows for proper infiltration which contribute to improved water content in the soil. A 22% increase in water content was observed in the coir net aided lemon grass protected slope during pre-monsoon (dry) period.

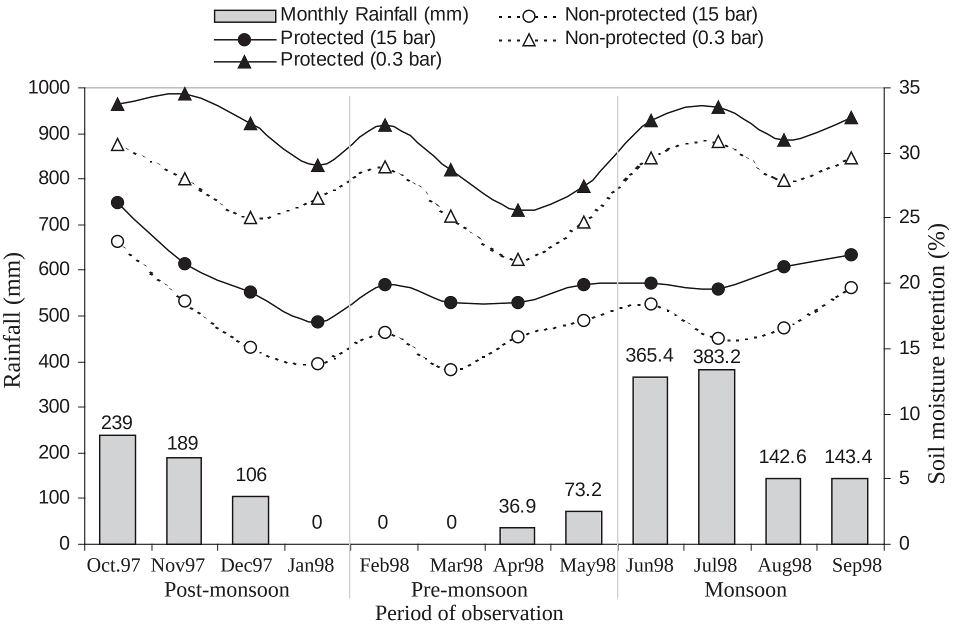

Fig. 3. Comparison of soil moisture retention in protected and non-protected slopes.

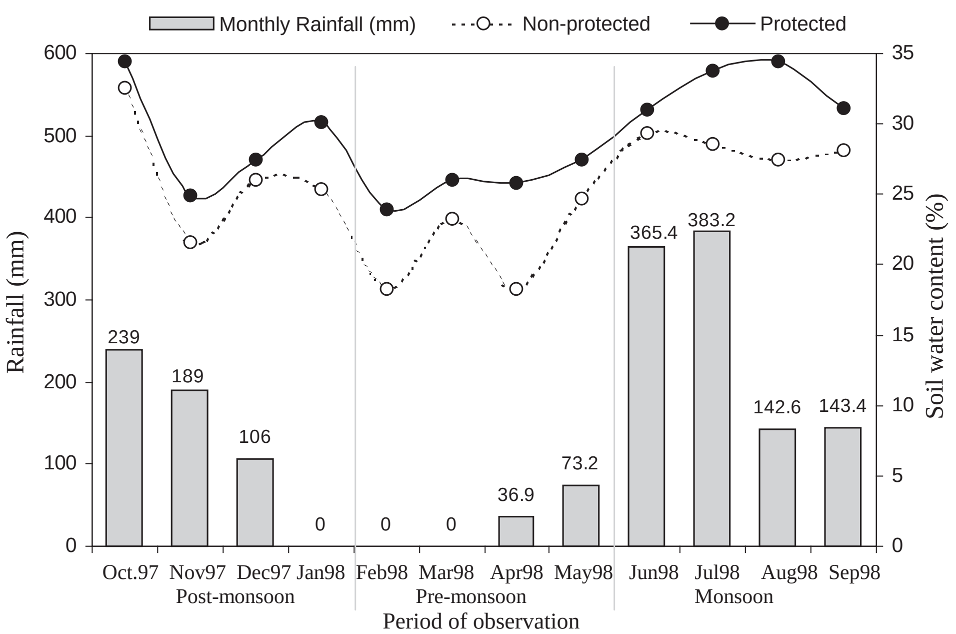

Fig. 4. Comparison of soil water content in protected and non-protected slopes.

4.4. Organic carbon

Soil organic matter plays a spectacular role in the maintenance and improvement of soil properties. Soil organic matter includes humus and humus-like substances in the soil. Because of the complex nature of soil humus which contains a wide variety of organic molecules, identification of such molecules is difficult. However attempts have been made from earlier times to quantify soil organic matter simply by determining the organic carbon content.

Susceptibility of soils to erosion depends to a large extent on the water stability of the soil aggregates and this is a function of the organic matter content and other cementing agencies. Soil samples were collected from protected and non-protected plots periodically. Dry soil was powdered well to pass through 0.5 mm sieve; 1 g of powdered soil was taken. Organic carbon content values corresponding to percent absorbance value for the soil samples were noted from the calibration chart. Walkely Black modified method using potassium dichromate solution and sulfuric acid was used for the test. Fig. 5 shows a comparison of the organic carbon content in the protected and non-protected plots. From the observations, it is seen that in the initial stage, organic carbon content in the protected plot is slightly less compared to that in the non-protected plot. This is because of the fast nutrient removal by the growing vegetation.

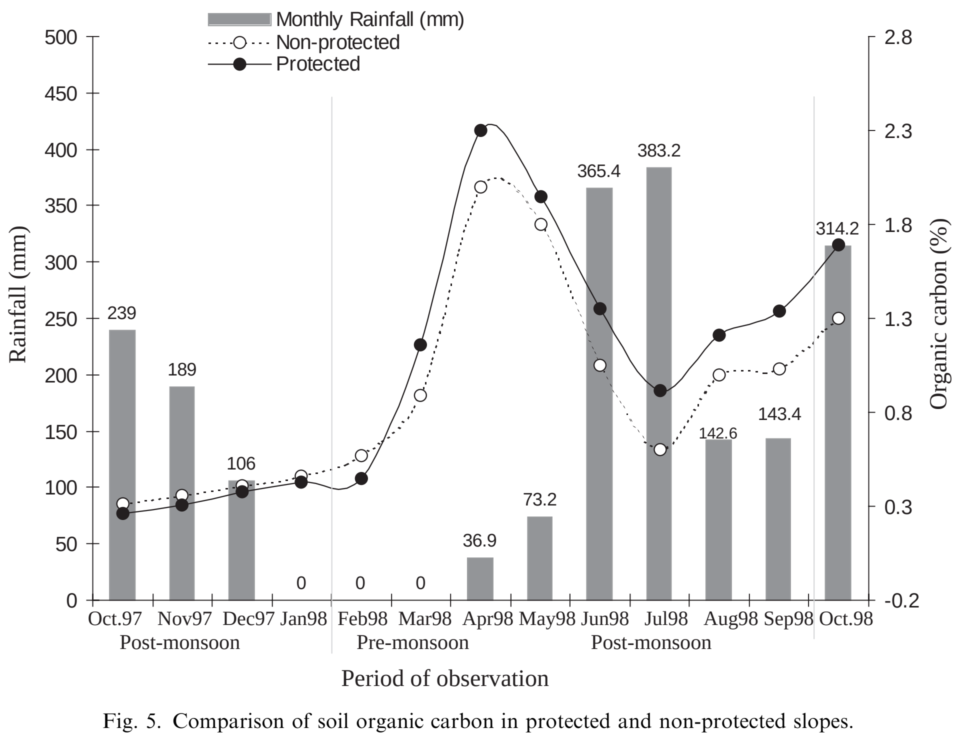

Fig. 5. Comparison of soil organic carbon in protected and non-protected slopes.

In the next stage which is a pre-monsoon period, there is a gradual increase in the organic carbon content in both the plots because of less rainfall and less runoff resulting in accumulation of the organic matter. Compared to non-protected plot, the coir protected plot has more organic carbon content during this period. The high accumulation of organic matter in the protected plot is due to the fact that the nutrients are preserved from leaching away due to the binding effect of plant and arresting of overland flow by the coir net. In addition, the biodegradation of the coir fabric adds to the organic content of the soil.

In the next stage with the onset of monsoon, there is drastic decrease in organic carbon values in both the plots. This is due to the leaching away of the soil by high rainfall. Here again, the organic carbon content in the protected plot is higher than that in the non-protected plot. The biodegradation of the coir fabric and reduction in surface runoff contribute to this improvement in the organic content in protected plot.

It is observed that there is 32% increase in the organic carbon content in the protected slope compared to non-protected slope during the monsoon period, which is the most critical season as regards to the loss of nutrients. This is a clear indication of the improved organic content in the coir net protected slope.

4.5. Biodegradation of coir fabric

Being a natural fibrous material, coir net starts degrading due to the microbial action in the soil and due to the continuous action of rain and sun. Biodegradation of coir fabric was studied based on the tensile strength test on coir samples periodically collected from the site. The stress–strain observations were obtained and curve of ultimate strength vs. age of the coir sample is drawn which is shown in Fig. 6. The field laid coir netting is found to retain 22% of its initial strength at the end of seven months.

Balan and Venkatappa Rao (1996) have reported a case study with the same type of coir netting and penisettum grass. In their study, H2M8 coir netting was found to retain 56% of its original strength after seven months in the field. They have reported a tensile strength of 24.8 kN/m for the fresh coir and 13.8 kN/m for the field laid coir after 7 months of time. Various factors such as rainfall, type of vegetative cover, slope of the terrain, etc. can contribute to the life of the netting and also the growth of vegetation. Also, faster the growth of vegetation, faster will be the rate of degradation of coir. The loss of strength of the coir net is not of concern in this kind of applications wherein the coir is meant to serve its function only during the period till the vegetation is established. It may be noted that even if the netting looses its complete strength in a period of one year or so, it can absorb water thereby modifying the macroclimate suitable for the growth of vegetation.

4.6. Vegetative growth

Coir fibre installed in the soil helps to improve the organic content of the soil and hence can promote vegetal growth. Comparison of the vegetation growth in protected and non-protected plots show marked improvement in the protected plot.

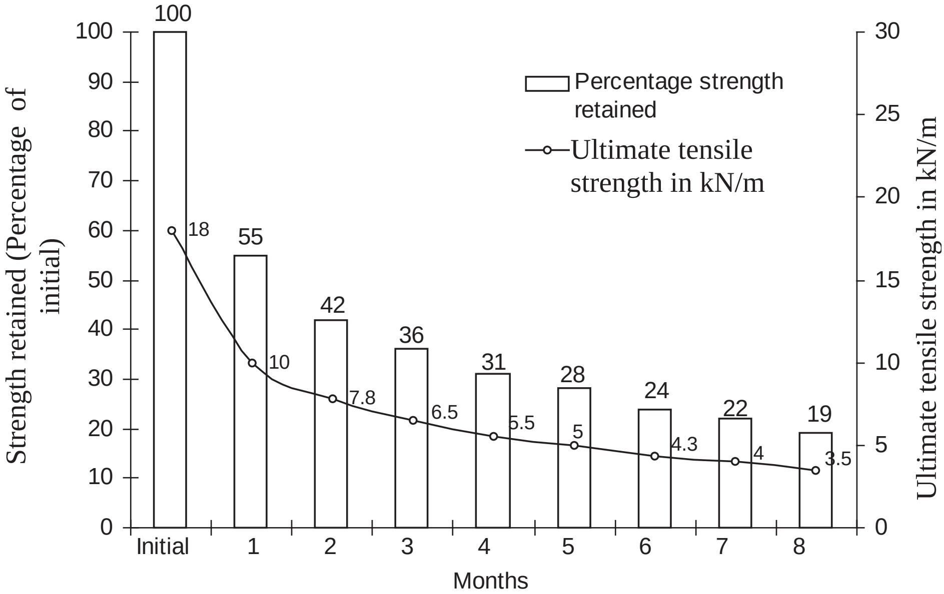

Fig. 6. Variation in the ultimate tensile strength of the coir net after field application.

Average length of sample leaves at any period is assumed to be indicative of the vegetation growth at that period. Improvement in the vegetal growth by installation of coir netting is noted from a comparison of the growth of grass in plots with and without coir net protection. It can be seen that the growth of vegetation is substantially higher in the coir laid plot compared to the coir unlaid plot, which is indicative of the improved nutrient status of the coir laid soil. Comparison of the vegetative growth in coir laid and plain soil is shown in Fig. 7. It is seen that at the end of 16 months, the vegetative growth in the coir net protected slope is 21% higher than in the slope without coir net protection.

5. Summary

This work forms one of the pioneering research attempts on the application of coir netting to aid in vegetative turfing for the control of soil erosion on the hill slopes. The project was implemented in a typical degraded hilly terrain in Kerala. The entire area is inhabited by tribals who form the most socially and economically weaker section of the society. A total hill slope area of about 0.4 ha owned by a tribal is selected for implementing the project. With the implementation of the project, soil erosion at the site was reduced substantially. Coir netting could promote the growth of lemongrass and a thick vegetative cover could be established in the area with in a period of one year. Plates 2 and 3 show the test plot after one month and one year of laying the coir net.

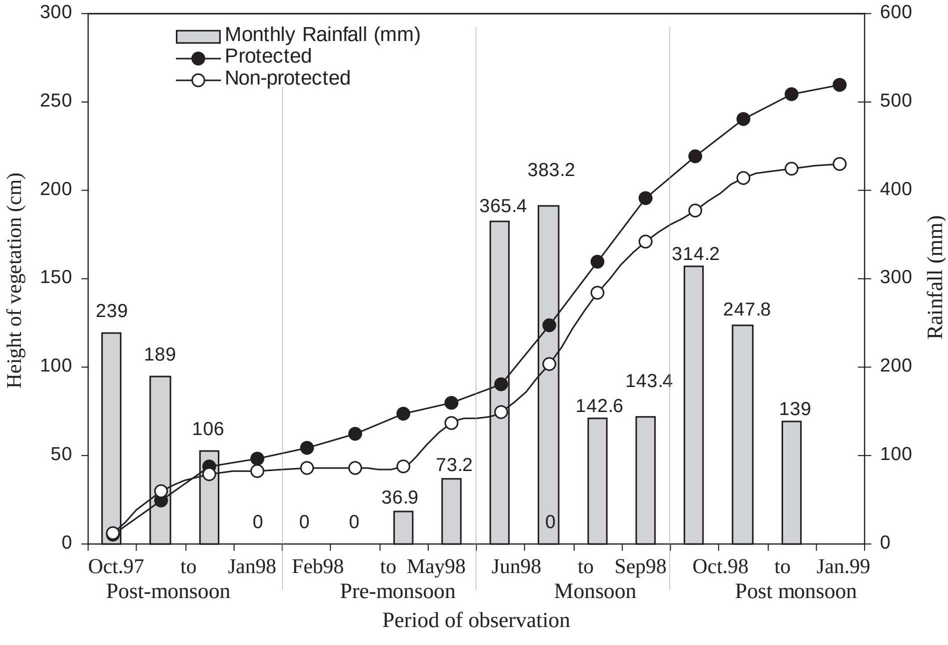

Fig. 7. Comparison of the vegetative growth in coir net laid and plain slopes.

Plate 2. View of the coir geotextile laid vegetated slope after one month.

Plate 3. View of the coir geotextile laid vegetated slope after one year.

6. Conclusions

- Coir, in the form of nettings has proved to be advantageous for controlling soil erosion in hill slopes since it protects the seeds in the initial stage of plant growth from being washed away and acts as a shielding material against the impact of rain, and wind.
- Lemongrass turfing with the aid of coir netting is found to reduce soil erosion substantially. The annual soil loss from one such protected plot is found to be 94.9% less compared to nearby non-protected plot.
- It is observed that soil erosion in the protected plot is reduced by 99.6% during the pre-monsoon, 95.7% in the monsoon and 78.1% during the post-monsoon compared to that in the non-protected plot. This is a clear indication that the technology is extremely efficient in minimising soil erosion in degraded hilly terrain
- Analysis of the ultimate tensile strength of coir netting shows that after seven months of laying, the field laid coir net has retained 22% of the strength of the fresh sample. This faster rate of biodegradation of the fabric is not of concern since the lemon grass could develop a well-defined root system and was able to adequately hold the soil in place within a period of six months. Moreover, the thickly grown canopy could reduce the impact of rainwater, reduce surface runoff and increase infiltration.
- The research further established that there is a substantial improvement in the parameters like organic carbon, soil water content, soil moisture retention and

vegetative growth. It may be concluded that this technology can be applied for the eco-restoration of the stretches of degraded wastelands in terms of land, water and bio biomass management.

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