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# An Experimental Study on Soil Erosion and Evaluation of Sustainable Soil Conservation Systems

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## ABSTRACT

Soil erosion, a complex phenomenon impacting the general land topography, essentially involves distinguishable stages such as detachment and transport of soil particles, storage and runoff of rainwater, and infiltration. Adoption of sustainable soil conservation measures suitable to the land use pattern are of great importance to arrest soil erosion. The present study deals with identifying the critical parameters affecting erosion from a cultivable farm land located in the southern rain-shadow area of Nilgiri Hills at Sathyamangalam. A series of rainfall simulations were performed under laboratory setup by varying rainfall intensity, soil texture, and conservation measures. Three types of soil conservation measures were practiced and tested for understanding water holding capacity and soil and erodability of the collected native soil. Results showed that mulching with dry leaves and growing of deep root vetiver plants could give relatively good and comparable results in terms of soil moisture content and percentage of fine particles retained. However, the soil treated with dry sludge collected from co-composting of faecal matter resulted in highest retention of soil moisture as well as fine particles. This can be attributed to the presence of higher organic matter present in the sludge which has the ability to absorb and hold water. Additionally, the soil amended with dry sludge is expected to improve the productivity of land, thereby minimizing the supply of artificial fertilizers. It can be concluded that erosion control by co-composted-dried sludge can be employed as a sustainable alternative for simultaneous erosion control and productivity enhancement of agricultural soil.

## INTRODUCTION

Soil erosion is a complex phenomenon with dynamic interactions between lithosphere, hydrosphere, atmosphere and biosphere, which can be basically conceived by some distinguishable stages such as detachment and transport of soil particles, storage and runoff of rainwater, and infiltration to the top soil layers. In order to improve the reliability, applicability and accuracy of erosion prediction and control, development of process-based models and relationships is of paramount importance (Romkens et al. 2002, Liu et al. 2011).

Several attempts have been made to control soil erosion such as planting wind breaks, preparing terraces and placing groynes (Campbell & Souster 1982, Battiston et al. 1987, Poesen & Lavee 1991, Meyer et al. 1999, Liu et al. 2011). Planting a thick row of bushes next to a field of plants can effectively stop water erosion as well as wind erosion. However, if the crops are growing on a slope, then contour planting has to be adopted rather than up and down. The vulnerability of soils to water erosion depends on rainfall intensity (erosivity), nature of the soil (erodibility), length and steepness of the slope (Bauer et al. 1979). Zuazo & Pleguezuelo (2007) suggested that plant covers can maintain biodiversity for steeply sloped areas based on the coexistence of sustainable interrelationship with soil properties. However, erosion is likely to be more affected by changes in rainfall and plant cover than runoff, though both are influenced. Dalton et al. (1996) studied that hedges made of vetiver grass can be an attractive soil control measure at land slopes between 0.5 and 2% where strip cropping or contour banks generally fail to perform.

If the soil is poorly structured, it is more prone to break up, and the impact of raindrops can be minimised by proper surface protective measures such as growing plants or applying litter cover (Meyer et al. 1999). Mermut et al. (1997) found that the amount of splashed soil and sediment load increased with increased rainfall intensity, even though the rate of splashing was decreased after wetting of the soil surface. Romkens et al. (2002) reported that soil water pressure in the subsurface can substantially affect the sediment concentration in runoff even though the runoff amount is only marginally impacted.

Application of jute geotextiles has emerged as a strong alternative to synthetic geotextiles for many civil engineering applications (Chandran et al. 2012, Ahmed & Rubel 2013). Due to their short life span, they are used as separator, vegetation growing mesh on slopes or as vertical drains. A recent study on the landslide prone areas of Ooty suggested that plantation and soil modification can enhance the performance of geo-textiles for erosion control (Thanaraj et al. 2015). Alternatively, Faucette et al. (2004) reported that use of compost or mulch blanket could reduce total solids loss in runoff as well as supplement soil fertility. However, protection cover is mandated to minimize erosion even while using composted materials as soil amendments.

Present study is focused on design and fabrication of experimental simulation setup in the laboratory for examining the pattern of soil erosion. In order to evaluate the critical soil parameters in a productive soil from an agricultural land, different surface modification techniques for controlling erosion were simulated and compared for their performance. It is important to draw basic understanding of the mechanisms of erosion in order to suggest suitable soil management options to the farmers.

## MATERIALS AND METHODS

**Details of the study area:** In order to simulate the features of existing land topography, field survey (contour survey) was conducted before downscaling to the experimental setup in the laboratory. The site selected was a cultivable farm land located in the southern rain-shadow area of Nilgiri Hills at Sathyamangalam with latitude 11°51' and longitude 77°26' (Fig. 1). From the reconnaissance survey and observations on the hill, more than five individual evidences of past landslides were recorded, including a few quite large failures. Remarks of most of the landslides were visible only on a small-scale map (with an error of a few meters), and the lengths of individual features cannot be shown accurately on the map as the terrain is often sub-vertical. The most distant rock falls and slides (mostly small) were identified to the southward direction from the hills near Sathyamangalam. The terrain is observed to be wide, slopy and remain uncultured despite the possibility of soil conservation measures. Based on the results of contour survey (with an interval of 4m), the average slope of the land was found to be 20 degrees.

**Laboratory scale experimental setup**: Based on the results of the topographic survey, a prototype was simulated in the laboratory replicating the field conditions. Wooden planks were used to construct a box with the dimension of 1.0m × 0.5m × 0.15m and placed at a horizontal slope of 20 degrees. Composite soil samples collected from the field were filled unevenly to mimic approximate field porosity of the soil (about 35%). The pattern of rainfall was simulated using a series of cross PVC tubes and parallel rubber tubes placed at a height of 1.5m, connected to a water supply line with the help of a flow control valve. In order to wet the soil equally in all the places, the flow rate was restricted to 500mm/h using a flow control valve. Excess water from flooding and erosion was collected from the bottom and used for further analysis. The experiment is preceded with three types of surface modification methods such as providing mulching with dry palm leaves, growing vetiver grass and adding dewatered sewage sludge as compost.

Fig. 1: Selected site for survey at Sathyamangalam.

Vetiver grass (*Vetiveria zizanioides*) is a tall (1-2m) and fast-growing perennial grass, native to south and south-east Asia, which form a dense hedge when planted closely in rows. Hedging with row grasses is now being practiced worldwide as a sustainable means of soil and water conservation and land stabilisation.

The dewatered and dried sludge from sewage treatment plant was used to prepare a co-composting unit. It includes organic matter such as vegetables, fruits and kitchen waste, and inorganic materials such as papers and saw dust. All the contents were mixed in a rectangular box, and kept under aerobic condition with frequent wetting with treated wastewater.

**Erosion control experiments:** Initially, the wooden box was completely filled with soil uniformly in such a way that size of soil particles are well graded throughout. The soil is placed in three layers with proper compaction at each stage. Soils from three portions were taken for sieve analysis to determine the amount of fines present. Artificial rain is simulated for a period of 30 minutes, followed by sample collection at a regular interval of 10 minutes. Finally, samples from the same three portions are taken for sieve analysis to compare the fines with the one that present before the precipitation. This will give the amount of fines that has been eroded. Also, 10 grams of soil from three portions are taken for laboratory to know the moisture content.

Further, the experiments were done under with control measures like mulching, vetiver grassing, and dry sludge covering (Fig. 2). For mulching, dry leaves were spread over the top layer to cover fully the top soil. Soils from three

Fig. 2: Simulation of mulching and dewatered sludge covering for erosion control.

points on the longitudinal section were taken for sieve analysis and estimation of moisture content. Artificial rain is simulated for a period of 30 minutes, followed by sample collection at a regular interval of 10 minutes.

## RESULTS AND DISCUSSION

**Erosion study with no control:** It was observed that greater amount of fines has been eroded since there is no control measures provided. Particle size less than 300mm (that is about 3.6% of the total surface soil cover) has been removed within first 30 minutes of rainfall simulation (Fig. 3). Near the outlet portion, the percentage of fines is greater in the sample taken before rain than the sample taken after the rain. This is due to the fact that once erosion occurs, it is obvious that at one place deposition will occur. The sample taken from that portion clearly indicates deposition of fine particles. However, whenever there is chance for long duration rainfall events such as flood, the downstream portion may also be anticipated to experience greater erosion than deposition.

It was observed that the variation in moisture content of samples collected 30 minutes after the precipitation events was between 15% and 22% (not shown). The amount of soil eroded for three samples was estimated for a period of one minute taken regularly after every 10 minutes interval. The result clearly shows that a greater amount of soil had been eroded when comparing with the other controlled experiments. The last sample taken after 30 minutes had eroded the maximum soil of about 6.7 grams per minute (Fig. 4). Following the rainstorm event, the impact of erosion on a dry soil can be inferred as increase aggregate slaking and breakdown due to air escape upon rapid wetting, enhancing soil detachment by raindrop impact and the subsequent transport by overland flow.

It is reported that existing subsurface moisture content and soil water pressure might have opposing effects on the processes of surface sealing, runoff generation and sediment production (Mermut et al. 1997, Meyer et al. 1999). However, since the water content is low in the present condition, comparatively large negative pressure of the pore water can increase the cohesiveness of the soil, resulting in a minimized detachability of soil particles.

Fig. 3: Simulated soil erosion without any control measures.

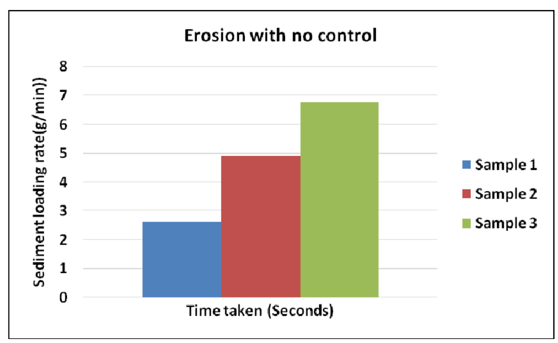


Fig. 4: Sediment loading rate from the soil with no control.

**Erosion study with control using mulches:** The experiment is again repeated with the soil sample covered with leaves i.e., mulching. Initially, the erosion was smaller when compared with soil having no control, then after satisfying the infiltration, overflow starts and fines starting to erode, however, the value is still smaller. With the sieve analysis results, it is clear that the erosion of fine particles was reduced by 15-20% when compared to experiment done un-

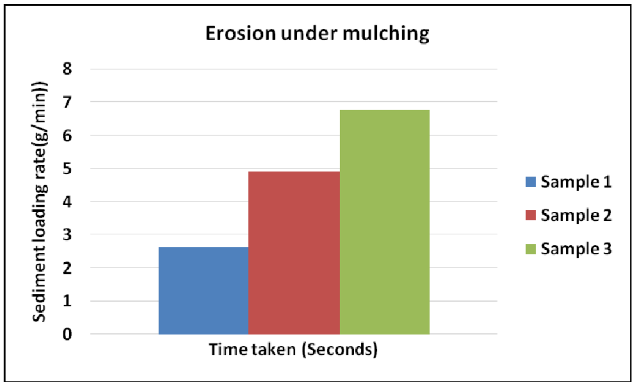


Fig. 5: Erosion for soil treated with mulches.

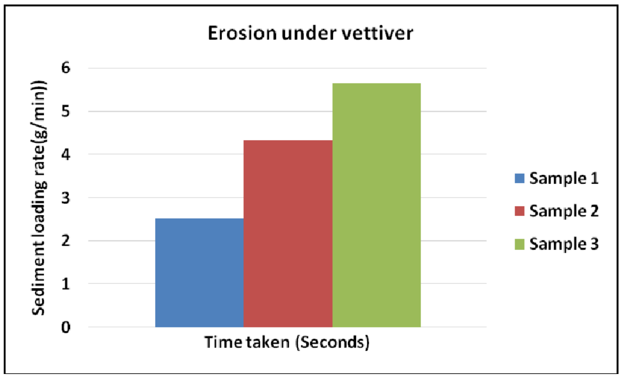


Fig. 6: Erosion of soil treated with vetiver.

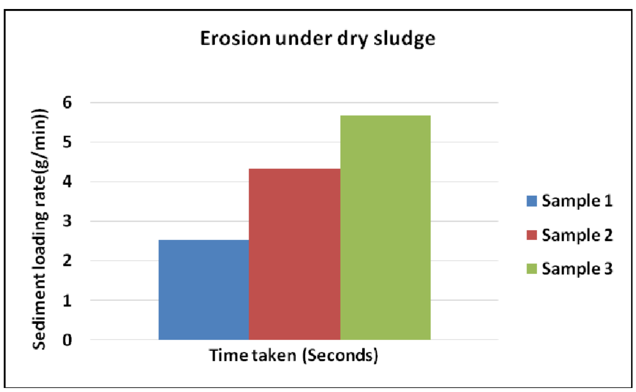


Fig. 7: Erosion of soil when treated with sludge.

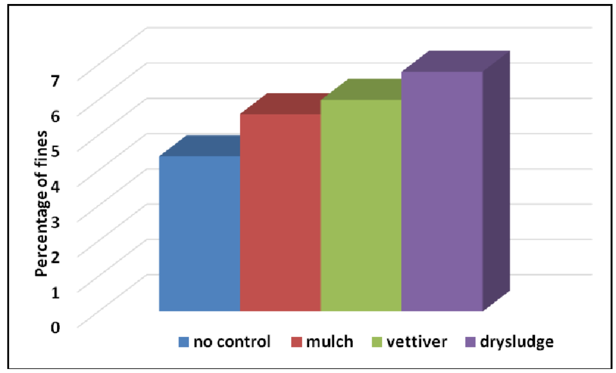


Fig. 8: Comparison of percentage of fines retained with different control strategies. (Sample 1)

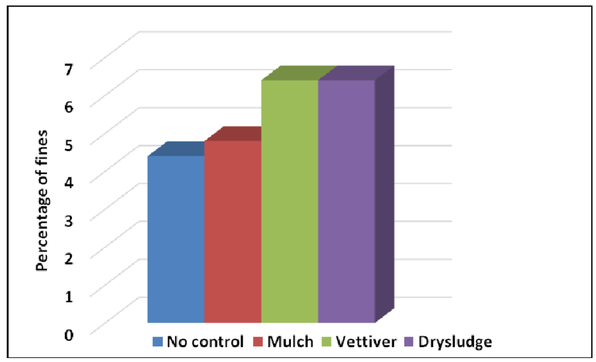


Fig. 9: Comparison of percentage of fines retained with different control strategies. (Sample 2)

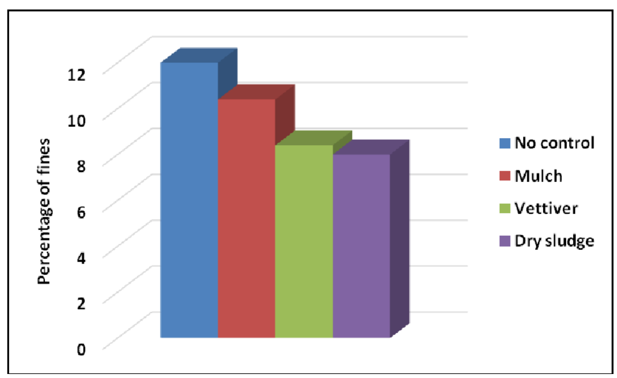


Fig. 10: Comparison of percentage of fines retained with different control strategies. (Sample 3)

der no control. Three samples each 10 grams from three different locations are used to analyse moisture content. The moisture content of three samples was found to be between 12% and 14%. The result clearly showed that considerable amount of soil (about 6.8 grams) had washed away in the last sample which is found to be lesser when comparing with no control (Fig. 5).

**Erosion study with control of vetiver:** The percentage of fines before and after the rain when the soil is treated with vetiver was analysed. The result shows that the erosion could be better controlled with vetiver grassing than previous methods. However, the result appears to be similar with the soil controlled using mulches. It was observed that the fines were removed only by small extent and were directly deposited at the bottom portion. The moisture content of three samples were also found to be between 11% and 13%. By calculating the sediment loading rate, it was found that only a lesser amount of soil (about 5.66 gram/minute) had eroded in the volume of 200mL sample (Fig. 6).

**Erosion study with control using co-composted dry sludge:** Control of erosion through dry sludge resulted as the most effective compared to other control methods adopted. This statement can be clearly understood from the comparison of dry sludge and the other control methods. The fraction of fines eroded and deposited was significantly reduced in this case. This method erodes only half the amount of soil when compared to zero control condition. The last sample taken after 30 minutes had eroded the minimum soil of about 3.1 grams/minute in the volume of 200mL which is the least among all the controlled experiments (Fig. 7). A combination of composting and grassing can reduce the vulnerability to erosion by at least 50 times than unprotected soil condition. Hence, this method proves to be an effective conservative method than all other methods.

The comparison of percentage of fines retained when the samples were collected from top of the sand box during each experiment (named as sample 1) was also analysed (Fig. 8). It is clear that large amount of fines have been eroded when the soil is left barren, but the rate of erosion could be reduced significantly by applying control mechanisms in increasing order starting from mulch, vetiver and dry sludge.

The Fig. 9 compares the percentage of fines when the sample collected from the middle portion (named as sample 2). It can be seen that soil which is left untreated behaves poorly during the precipitation. Thus, the soil treated with mulches proves to be an efficient one when comparing with the soil untreated. Comparing the above two methods, vetiver and dry sludge produce a similar and desired result in erosion control.

For the sample collected from the downward end of the box (named as sample 3), the percentage of fines deposited at the bottom portion after the precipitation (Fig. 10). It is clear that much amount of soil is deposited when the experiment is done under soil with no control, followed by the soil treated with mulches. Soil treated with dry sludge had deposited minimum when comparing with above three methods.

## CONCLUSIONS

Present study focused on comparative evaluation of various low cost indigenous erosion control measures by performing laboratory scale experiments with simulated rainfall conditions. From the study, it was observed that the vulnerability of unprotected soil is at least 50 times higher than any protected soil condition. The soil treated with conservative measures like mulching and deep root vetiver system gave relatively good, but similar results when comparing with the soil that is left unprotected. However, the soil which is treated with the dry sludge gives a fair result in controlling erosion. This is due to the presence of higher organic matter present in the sludge which has the ability to absorb and hold water. Also, when the soil is rich in sludge content, it will improve the productivity of land by replacing artificial fertilizers. Hence, a combination of composting and grassing proves to a better conservative practice in controlling soil erosion.

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