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Reversing land degradation through grasses: a systematic meta-analysis in the Indian tropics

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Abstract

The present study critically analyzes the effect of grasses in reversing the process of land degradation using a systematic review. The collected information was segregated under three different land use and land management situations. Meta-analysis was applied to test the hypothesis that use of grasses reduce runoff and soil erosion. Effect of grasses was deduced for grass strip and in combination with physical structures. Similarly, the effects of grasses were analyzed in degraded pasture lands. The overall result of the meta-analysis showed that infiltration capacity increased approximately two-fold after planting grasses across the slopes in agricultural fields. Grazing land management through *cut and carry* system increased conservation efficiencies by 42% and 63% with respect to reduction in runoff and erosion, respectively. Considering comprehensive performance Index (CPI) it has been observed that hybrid napier (*Pennisetum purpureum*) and sambuta *(Saccharum munja*) seem to posses the best desirable attributes as effective grass barrier for western Himalaya and eastern Gahts while natural grass *(Dicanthium annulatum) and broom grass (Thysanolaena maxima)* are found to be most promising grass species for Konkan region of western Ghat and north eastern Himalayan region, respectively. In addition to these benefits, it was also observed that soil carbon loss can be reduced by 83% with the use of grasses. Overall, efficacy for erosion control of various grasses was more than 60% hence their selection should be based on the production potential of these grasses under given edaphic and agro-ecological condition.

Key-words

Contour grass barrier, Conservation efficiency, Grazing, Reverse land degradation, Soil erosion,

1 Introduction

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Water erosion is the main cause of land degradation affecting about 2 billion ha area throughout the world with a largest part in tropics which affect two most important natural resources, namely, soil and water (Mandal and Sharda, 2011a; De Oliveria et al., 2010; Keesstra et al., 2014; Novara et al., 2011; Seutloali and Beckedahl, 2015; Novara et al., 2016). Worldwide loss of water and sediment due to soil erosion is a major environmental threat (Prosdocimi et al., 2016; Pimentel, 1993). Soil erosion is accelerated due to high rainfall intensities (Keesstra *et al*., 2016), steep slopes (Beskow et al., 2009) and fragile nature of top soil (Lal, 1998; Rodrigo-Comino et al., 2016; Ochoa et al., 2016). Many parts of the tropics in India have high annual rainfall confined to only four to five months (June-September). During the seven to eight months dry period, scarcity of water causes a severe shortage of fodder in farmlands which leads to increase grazing pressure on forest and community lands. Nearly, a third of the fodder requirement in India is met from the forest resources in the form of grazing and cut fodder (MoEF, 1999). The process of land degradation in croplands and grasslands has been accelerated mainly by inappropriate land use (Nearing et al., 2005; Mandal et al., 2010) and mismanagement (Kagabo et al., 2013).

Generally, conservation planning needs the soil loss tolerance value which is considered as the higher limit of soil erosion rate that can be allowed without long term land degradation (Jha et al. 2009). Strategies to reverse land degradation are critical since soil is a non-renewable resource (Mandal and Sharda, 2011b; Mandal et al., 2010). Soil erosion rates more than tolerance values are considered non acceptable (Mandal and Sharda, 2013) which leads to irreversible land degradation and need to be reduced through appropriate soil conservation measures (SCM) (Biswas et al., 2015) The physical structures to check soil erosion are proven effective but are cost intensive. Biological methods of soil and water conservation, especially, grass based methods have been reported to be very cost effective and suitable for sloppy lands. Perennial grasses provide ground cover throughout the year and

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helps in reducing runoff and soil loss when used as barriers along the contour particularly in hill slopes (Dhruvanarayana and Ram babu, 1983). Grasses are the key component in many ecosystems of the world (Parras-Alcantara et al., 2015; Hu et al., 2016; Mekonnen et al., 2016).

Grass species, in particular, have tremendous potentialities in soil conservation as grass roots have a great binding influence on soil particles (Ovara et al., 2013; Ola et al., 2015). Due to resource scarcity and multiple competing enterprises that characterise most farming situations of rural India, farmers often lack adequate resource to invest in physical soil conservation structures. Thus, the usefulness of grasses as vegetative barrier is an alternative to the physical soil structures. Basically these contour vegetative barriers/grass filter strips help in reducing soil erosion by acting as porous barriers which subsequently slow down the flow of runoff (Angima et al., 2001; Mutegi et al., 2006).

The hilly region of India is characterized by geological fragility, land marginality and vulnerability (Mandal and Sharda, 2013). The croplands in sloppy areas suffer from excessive soil erosion and erosion induced nutrient depletion. Soil erosion in these areas ranges between 20-40 Mg ha^{-1} yr^{-1} as compared to the national average of 16.35 Mg ha^{-1} yr^{-1} (Dhruvanarayana and Ram babu, 1983). Such high rates of soil erosion result in considerable depletion of nutrients from the top soil which in turn causes poor productivity of crops. Research evidence from the land subjected to shifting cultivation reported that about 600 Mt (million tons) of soil is eroded annually which led to losses of 258,000, 73,000 and 179,000 tonnes of N, P_2O_5 and K_2O, respectively (Kumar, 2011). Soil erosion has been pointed as one of the important reason for the land abandonment by many farmers in sub-tropical hilly areas of India (Rao and Pant, 2001).

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The grasslands in middle and lower Himalayas are generally in the most neglected state with low productivity. In this predominantly grazing region, excessive reliance on animal husbandry under a growing population has exerted great pressure on the land. In tropical India, an average of 42 animals graze on a hectare of land compared to maximum threshold level of 5 (Sahay, 1999). Raising and maintenance of perennial grasses on degraded soils has been suggested as a means to improve soil quality and sequester carbon in the soil. Several studies have shown that the inclusion of grasses in the agricultural landscape often improves the productivity of system while providing opportunities to create carbon (C) sinks (Ghosh et al., 2009; Cogle et al., 2011; Huang et al., 2010; Mutegi et al., 2008). Soils typically account for 70-90% of the total carbon sequestered in a grassland ecosystem (Batjes, 2001).

In India most of the studies on the role of grasses as vegetative/filter strips have been done in isolation with fewer slope categories and with limited objectives restricting to soil erosion (Njoroge and Rao, 1994). Similarly, the studies on grazing land management are also very scarce. We present here an analysis on the potential of grasses for reversing land degradations for which the meta-analysis was carried out. The objective of this study is to determine the effect of grasses in arresting soil loss, runoff, moisture conservation and carbon build up in soils. Based on such information, conclusion regarding reversing land degradation through grasses can be drawn wherever similar land conditions are known.

2 Material and methods

Information on the usefulness of grasses in soil and water conservation was collected from published literature (Table 1 a and 1b). Keeping in view the role of grasses for arresting soil loss and runoff, all data were reoriented under three different categories viz; (i) role of grasses as vegetative barrier, (ii) complementary role of grasses with physical soil structures

Solid Earth Discuss., doi:10.5194/se-2016-143, 2016
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and (iii) management of grazing lands. A total of 83 studies comprising 19 different sites in varied agro-climatic region were included in the data set for the analysis (Table 1a and1b). Fifty four of these studies were related to contour grass barrier (CGB), 12 related to grazing and 17 related to complementary role of grasses.

Meta-analysis was applied to test the hypotheses about role of grasses in reducing soil erosion by combining data from several experiments. The technique has been extensively used in natural resource management studies (Ilstect et al., 2007, Poeplau and Don, 2015; Osenberg et al., 1999).

We aim to synthesise and discuss the fact that can be drawn from the past scientific studies pertaining to the effect of grasses in arable and non-arable lands on one of the key determining soil processes, namely reduction in soil and water losses and enhancement of infiltration. We systematically used quality criteria to select studies to which we applied meta analysis in order to produce a combined data set with the condition that a reference bare land/fallow land had to be present with all the study sites. The reference sites were adjacent to the grass treated filed/plots within the same landscape and similar slope. Therefore, we excluded studies where the reference site was either missing or was away from the field study. The conservation use efficiency (CUE) was calculated by the following formula (Khola and Sastry, 2005).

$$\text{CUE} = \frac{(\text{The water or soil runoff rate before the conservation measure}) - (\text{The water or soil runoff after the conservation measure}) \text{ X } 100}{\text{The water or soil runoff rate before the conservation measure}}$$

Data were analyzed using the SPSS (version 17). The Analysis of Variance (ANOVA) was conducted to test the significant difference between different treatments. Initially, a t-test was conducted to test whether the impact of two treatments (without grass and with grass) were significantly different. Protected least significant difference (LSD) at P=0.05 was used to separate the means for all the three different categories of data (Fisher, 1935). A separate t-test was also used for different slope classes to evaluate the performance of CGBs on the reduction of soil and water loss and enhancing crop yield.

Relative performance of different grasses used as CGB was evaluated by using a comprehensive performance index (CPI). The following formula was used to compute CPI values of different grasses (Sudhishri et al., 2008).

$$CPI = \sum_{i=1}^{n} WiRi$$

Where CPI is comprehensive performance index of the grass species, *Wi* is weightage of the *i*th parameter, *Ri* is rating (scoring) of the *i*th parameter based on its observed value. A total of six attributes namely, infiltration rate, soil loss, root binding capacity, maximum sod forming depth, fodder/commercial value and cost of establishment (Table 2) were used for computing CPI.

Additionally, relative reversibility of erosion/water loss and relative yield gained due to adoption of CGBs were computed by using the following formulas, respectively.

Relative reversibility of erosion/water loss:

$$\Delta \text{ Erosion}/ \Delta \text{ Runoff} = \frac{\text{Erosion/ Water loss without CGB} - \text{Erosion/ Water loss with CGB}}{\text{Mean erosion/ Water loss}} \text{ X100}$$

Relative yield gain:

$$\Delta \text{ Yield gain} = \frac{\text{Mean yield with CGB} - \text{Mean yield without CGB}}{\text{Mean Yield}} \times 100$$

3 Results and discussion

3.1 Contour Grass Barrier (CGB)

India is the home of about 1225 species of grasses, majority of which grows well in tropical and subtropical region (Prakash et al., 1999). These grasses can be used as live bunds in arresting soil erosion. Efficacy of CGBs in increasing the opportunity time for infiltration and consequent profile recharge was also reported by other researchers (Sharma et al., 1997; Prakash et al., 1999). In this meta-analysis, based on 25 observations, we quantified the general potential of vegetative barriers to reduce run off and soil loss (Table 3). The overall result of the meta-analysis showed that infiltration capacity increased approximately two-fold after planting grasses across the slopes in agricultural fields (95% confidence level). However, it is interesting to note that the mean runoff values were statistically insignificant in case of combined treatment of grasses along with structural measures. This may be due to very high standard deviation (SD) values obtained for vegetative barrier. These higher values indicate lot of heterogeneity in the observation which needs to be verified. Although 70% data showed similar variation, however, few higher values were not in expected lines which might have caused this uncertainity. In case of Doon valley region, comparing the impacts on soil wetting pattern, infiltration rate and sorptivity, it was observed that *Chrysopogon fulvus* was most promising grass species. However, in Doon valley region *Panicum maximum* is identified as most effective grass barrier with maize, but more research is required with *Chrysopogon fulvus* because the rooting pattern, soil wetting, infiltration rate and other properties of this grass shows great potentiality to be used as contour grass barrier in valley as well as in hilly areas (Mandal and Jayaprakash, 2009). It was identified that *Saccharum munja* and *Eulaliopsis binata* are two most effective grasses for *Shivalik* region of Punjab and Haryana while hybrid napier and *Panicum maximum* are very effective in humid tropical regions of lower Himalaya.

Run off and soil loss values in CGB plots were lower than the control plots. The data show that run off varies between 11.26% and 62.60% with the mean value 37.71% and soil loss varies between 0.53 Mg ha^{-1} yr^{-1} and 30.90 Mg ha^{-1} yr^{-1} with the mean value 9.56 Mg ha^{-1} yr^{-1} in control treatments (Table 3). With CGB, the runoff data varies between 5.87% and 44.10% with the mean value 20.93% and soil loss varies between 0.50 and 18.70 Mg ha^{-1} yr^{-1} with the mean value 3.93 Mg ha^{-1} yr^{-1}. The study revealed that on an average the overland flow reduced by 45% compared to control. CGB facilitated the appearance of backed-up water above the filter strips, which resulted in sedimentation and substantial reduction in soil loss. The analysis of the data indicated that as the rain proceeded, overland flow moved down slope into the grass hedges and water backed-up behind them, giving more opportunity time for the water to infiltrate the soil. Experiments conducted by Becker (2001) reported reduced soil erosion by parallel strips of stiff-stemmed grass planted along the contour lines. Over and above, the amount of transported soil reduced by 59% in case of grass barriers than that of the control. A substantial reduction in runoff from 37.71% in control to 20.93% in CGB was observed. Vegetative barriers reduced the soil loss from 9.0 Mg ha^{-1} yr^{-1} to 3.0 Mg ha^{-1} yr^{-1}. The CUE of vegetative barrier was found to be 44.56 and 59.04%, for runoff and soil loss, respectively. These findings are in conformity with the results reported by Gilley et al. (2000) who have summarized that grass hedges have the potential to reduce runoff by 52% and soil loss by 53% under no-till conditions. Globally, most researchers in tropical region have used vetiver grass (*Vetiveria zizanioides*), eastern gamagrass (*Tripsacum dactyloides*) due to their special characteristics with stiff, erect and coarse stems (Rachman et al., 2004, 2005;

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Janushaj, 2005). Such species are perennial in nature thus show a good protective cover throughout the year in warm humid topics.

In terms of soil loss, the vegetative barrier of *Panicum maximum* showed promising performance with average rate of soil loss between 2.74 Mg ha^{-1} yr^{-1} and 7.93 Mg ha^{-1} yr^{-1} in north western Himalayan region which indicated that soil loss can be effectively brought below tolerance limit by adopting such SCM (Mandal et al., 2006). Considering the advantages of contour grass strips, over the mechanical measures, due to their less cost and minimum removal of the fertile top soil many organizations are promoting this practice as an effective measure to reduce erosion (ASAE, 1981; Hudson, 1981; Mulugeta, 1988; Turkelboom et al., 1994). Moreover, CGB is comparatively simple and easy to establish (Grunder, 1988), while mechanical measures are too expensive, are difficult to maintain in the long run (Rodriguez, 1997) and are time consuming (Tripathi and Singh, 1993). Additional advantages with regard to establishment and stabilization of the grass strip is that it needs very less attention to form a terrace while mechanical measures need regular maintenance to keep their effectiveness (Welle et al., 2006).

A study revealed that *Panicum maximum* provided 56% of coverage after three years of planting. The coverage increased progressively from 23% in 1st year to 56% in 3rd year. Similarly, Vetivercoverage increased from 29% in 1st year to 75% in 3rd year (Shrimali, 2000). Vetiver grass distinctively showed highest reduction in annual runoff and soil. This was attributed to the fact that the erect and rather stiff leaves and stems of vetiver grass retarded more runoff flow and acted as filter to more sediment. Similar performance level of vegetative barrier was also reported by Rao et al. (1991) and Laing and Rupenthal (1991). This is also in conformity with the results of Patil et al. (1995b), who recorded 41.4% lesser runoff for vetiver over control. Similar results had been obtained by Tangtumniyom *et al*. (1996) for a cassava crop on a 5% slope where vetiver was used as vegetative barrier. The

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effect produced by *Cenchrus ciliaris* planted at 10-m spacing was also comparable to that of vetiver at 10 m, which recorded a mean annual soil loss of 3.39 Mg ha^{-1} (Jagannathan et al., 2000).

The conservation of soil and water in CGB varies with grass types and site conditions in different regions. However, *Pennisetum purpureu*m, *Panicum maximum* and *Eulaliopsis binata* were very effective for lower Himalayan and Shiwalik region. Results from different studies across the country showed that due to the large amount of green phytomass, profuse tillering and dense rhizomatous network of roots, runoff and soil losses were significantly reduced with barrier of *Pennisetum purpureum.* For different regions of India including Andhra Pradseh, Haryana, Karnataka, Madhya Pradseh, Maharashtra, Orissa, Punjab, Tamilnadu and Uttarakhand suitable grasses for CGB are given in Table 4. In situation where fodder requirements are high *Pennisetum purpureum* mounted as a barrier would be beneficial, while in those areas where soil conservation is utmost important, *Eulaliopsiss binata* or aromatic grasses such as palmarosa (*Cymbopogon martinii*) or vetiver (*Vetiver zizanoides*) grass would be reasonable choice.

Analysis of variance through t-test of soil loss, run off and yields of crops indicated that loss of water was significantly less in CGB treated sites in <2% slopes (Table 5). The water loss provided by CGBs compared to control was 16% Vs 27% for < 2% slope. However, the similar trend was not observed in 2-4% slope range. Interestingly the soil loss was significantly less in CGB treated sites in higher slopes (2-4 and >4% slopes).

Variations in soil erosion amounts paralleled to some extent to those of runoff in all the slope classes except in lower slope range (Table 5). The protective action of various CGBs are very clearly shown by the soil loss values which reflect that between 141% and 107% reversibility in soil loss can be achieved through adoption of CGB. The relative reversibility of water loss provided by CGBs compared to control was 52.6% and 55.5% for < 2% and >4% slopes, respectively. Favourable soil condition created by CGBs resulted an increase in yield in all slope ranges. The significantly higher yield in CGB treated sites have resulted from either better moisture regime or higher nutrients or by both depending on the detention of runoff and deposition of fertile sediment by the CGBs. The relative yield gained by CGBs varied between 44% and 53% with highest value in 2-4% slope.

Clear picture about the relative merit of CGBs was determined through development of CPI for different grasses (Table 6). Hybrid Napier *(Pennisetum purpureum*) seems to posses the best desirable attributes for soil and water conservation with highest CPI value of 0.81. On the other hand *Saccharum munja* had fairly good merit (0.79) in conserving soil and water and has both fodder and commercial values. Similarly *Dicanthium annulatum* with CPI value of 0.77 has an edge over broom grass (0.72). However from farmer adaptation point of view, both *Saccharum munja* (0.79) and *Thysanolaena maxim*a (0.72) grass are most preferred species especially in shifting cultivation area of Eastern Ghats and north eastern hilly region of India.

3.2 Complementary role of grasses with physical soil structures

Grasses, shrubs and tree barriers in combination with structural measures (bioengineering measures) are known to be beneficial for soil and water conservation and have many relative advantages over structural interventions. Reinforcement by live roots which bind soil particles and underground decomposed biomass provides stability to aggregated soil. Plant detritus on the soil surface act as a cushion for dissipating kinetic energy of rain drops. This above ground biomass upon its subsequent decomposition also adds to the soil humus and increases infiltration, soil water holding capacity as well as stability of aggregates (Prakash *et al.*, 1999).

The data from Table 3 show that the use of grasses led to significant decrease in runoff from 25.53% in control to 9.37% with structural conservation measures. Soil loss also has significant decrease from 1.88 Mg ha^{-1} yr^{-1} in control to 0.73 Mg ha^{-1} yr^{-1} in structural conservation measures (Table 2). The run off varies between 17.00% and 48.50% with the mean value of 25.53% and soil loss varies between 1.53 Mg ha^{-1} yr^{-1} and 3.26 Mg ha^{-1} yr^{-1} with the mean value of 1.88 Mg ha^{-1} yr^{-1} in control. The runoff varies between 0.40% and 15.30% with the mean value of 9.37% in combined treatment (grass along with structural measures). Similarly, analysis of the data revealed that the impact of grasses was more pronounced along with soil and water conservation measures in minimizing the losses of soil and water. Over and above, the complimentary action shows water saving by 63% and soil saving by 61%.

Earthen bund and earthen bund with broom was found to be more effective in soil moisture conservation at 4% and 8% slope as compare to other treatments (Figure 1). In comparative study conducted on *Pennisetum* and *Arundinella* barriers in combination with soil conservation measures, a substantial reduction (65-88% and 15-38%, respectively) in overland flow compared to the control plots had been reported (Huong et al., 2010).

3.3 Management of grazing lands

In India about 12.0 m ha of area is represented by permanent pasture and grasslands, majority of which is confined to the tropical areas (Roy and Singh, 2013). Since this pastureland and grasslands are severely affected by soil erosion, special attention should be given to their management to reverse the process of degradation. Our synthesis of the meta analysis revealed that by managing the grassland with cut & carry system, rotational grazing and control grazing can greatly reduce the water and soil loss and helps in the reversing the land degradation process. Similar phenomena have been reported by Misri (2003) and Pathak and

Dagar (2015), especially, for the lower Himalayan and Shivalik grassland where severe biotic pressure is imposed by both sedentary and migratory graziers. The grazing intensity in the country is as high as 12.6 adult cattle units per hectare (ACU ha^{-1}) as against the carrying capacity 0.8 ACU ha^{-1} (GOI, 2015).

The data (Table 3) show that run off varies between 11.30% and 33.40% with the mean value 24.33% and soil loss varies between 1.52 Mg ha^{-1} yr^{-1} and 3.28 Mg ha^{-1} yr^{-1} with the mean value 2.58 Mg ha^{-1} yr^{-1} in control plots (without grazing management). The management of grazing lands (cut and carry system, rotational grazing and control grazing) significantly reduced the runoff ranging between 6.60% and 22.20% (with the mean value 14.12%) and soil loss ranging between 0.58 Mg ha^{-1} yr^{-1} and 1.30 Mg ha^{-1} yr^{-1} (with the mean value 0.95 Mg ha^{-1} yr^{-1}). A total of 12 studies on grazing land management revealed that the benefits of stall feeding and controlled grazing could save about 42% water loss and 63% soil loss in sloppy lands. The mean runoff in grazing management practices was significantly reduced from 24.33% to 14.12%. This may be due to higher green cover and biomas production under improved management. Grazing land management of *Chrysopogon fulvus, Heteropogon contortus* and *Panicum maximum* have shown potentiality to produce 40 t ha^{-1}, 8.5 t ha^{-1} and 110 t ha^{-1} green biomass yields, respectively (Rana, 1998; ICAR, 2006; Ghosh et al., 2009; Pathak and Dagar, 2015). The average soil loss was significantly reduced from 2.0 Mg ha^{-1} yr^{-1} to 0.95 Mg ha^{-1} yr^{-1} by the imposition of grazing and grassland practices. However, some researchers demonstrated that the grass steppe is more resistant to land degradation than shrub steppes (Palacio et al., 2014 and they contribute to increase the biodiversity and to improve the soil quality (Costa et al., 2105; Gao-Lin et al., 2016)

Dicanthium annulatum cover was found to reduce the runoff and soil loss by 35.45-51.40% and 71.90-81.08%, respectively, in slightly to severely degraded lands in lateritic soil of Konkan regions in India (Figure 2 and 3). In this region *Dicanthium annulatum* yielded about 25-30 t ha^{-1} of green biomass under improved management. The investigation further suggested that carbon loss can be reduced to the extent of 88.36 - 83.12 % in slightly and severely degraded lands in the same region (Figure 4). The study also indicated that carbon sequestration rate up to 100 kg ha $^{-1}$ yr^{-1} can be achieved by the use of grass strips running across the slope especially in laterite soils of *Konkan* region (Kale et al., 1993). About 6 fold increase of SOC content in soil has been observed in barren lands of *Shivalik* region through rehabilitation by *Arundo donex*. Grazing management typically leads to a 3% annual increase in soil carbon (Conant et al., 2001). Duran and Rodriguez (2008) highlighted that grasses provide perennial protection and minimal erosion as they provide complete ground cover (Brindle, 2003). In Mediterranean region, based on 20 paired plots study, Keesstra et al. (2016) reported that runoff sediment concentration was 45.5 times higher in cleaned cultivation plots compared to covered plots. They further reported that erosion rate was below the soil loss tolerance limits under surface covered conditions. It is noticeable that the loss of vegetation cover leads to increase surface instability and poor regeneration which in turn set a vicious cycle in motion.

In the hilly region of north-eastern Himalaya, the alternative land use systems help in reducing soil erosion systems and SOC loss to a substantial extent. Higher root-biomass of the grasses, particularly *Paspalum*, *Congosignal*, *Hamil* and *Makunia* due to greater water transmission resulted in higher SOC in the soil profile. Following addition of organic matter through continuous root decay of these grasses, water holding capacity of the soil increased as a result of the increased specific surface area. Additionally, these grasses helped in improving soil quality including soil hydro-physical characteristics and biological activities. Such improvement in soil properties have a direct bearing on C-sequestration (5 fold increase in SOC over control), long-term sustainability, reducing soil erosion (2-3 fold increase in structural stability over control) in a complex, risk prone fragile ecosystem (Ghosh et al., 2009)

4 Conclusions

Human induced changes due to land use intensification and overgrazing caused some severe and extreme state of land degradation that may prove to be more difficult to restore under the ongoing practices. The present meta-analysis clearly revealed that suitable conservation measures especially, the vegetative and biological practices greatly assist in reversing the land degradation process for both cropland and grasslands.

Most soil erosion control measures implemented on cultivated fields are physical structures. However, these physical structures were reported to be less acceptable due to high cost of their construction and maintenance. The Meta analysis clearly showed that grass barriers potentially reduce runoff and soil loss by up to 86.8% and 97.32 %, respectively. The relative yield gained of various crops through CGBs at different slopes varied between 44% and 53%. However, the effectiveness of grass barrier, as reported by several studies, is site-specific and depends mostly on slope gradient, runoff volume and flow rate, size and density of sediment particles, grass species, density, interval and width of grass strips, underlying soil properties, and rainfall intensity and duration. According to farmer's criteria based on comprehensive performance index, the study revealed that *Pennisetum purpureum* was most preferred grasses followed by *Saccharum munja* and *Dicanthium annulatum*. Considering the CPI values it is apparent that *Saccharum munja* (Sambuta) and *Thysanolaena maxim*a (hill broom) are two important bio-remediation options for reclamation of shifting cultivation of north eastern hill region and eastern Ghat of India.

The present analysis also indicated that grass must be used as vegetative strip to maintain soil quality in sloppy arable areas (8.5 m ha) of Indian hilly regions. Special emphasis on establishing grasses should be given to about 3 m ha degraded pasture lands and 3.5 m ha shifting cultivation areas in India to reverse the land degradation. Overall, we conclude that the use of grass barriers alone or in combination with structural measures and grassland management were effective and efficient for decreasing soil and water loss on sloppy croplands in tropical and sub-tropical regions of India. Thus, these practices should be intensively recommended and used widely in similar climatic regions. Similarly, the reduction in grazing intensity needs to be advocated for about 12 m ha of permanent pasture lands.

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Table 1a. Details of the experiments and sources of data used in the study

	With contour Grass barrier			Without Control Grass barrier		Soil type and climate	Source
Vegetative barrier	Name of grass	Soil Loss (Mg ha^{-1} yr^{-1})	Runoff (%)	Soil Loss (Mg ha^{-1} yr^{-1})	Runoff (%)		
	Dichanthium annulatum	1.0	-	16.68	-	Red soil (Rhodustalfs), Hot sub-humid	Lal et al., 2004
		4.2	33	10.8	48		
		0.1	7.7	6.35	64.8	Inceptisols, semi arid	Rao & Pande , 2014
						Red, hot sub-humid	Sharma, 1999
	(*Tripsacum laxum*)	-	19	19	29	Red(laterite), Warm sub humid	Madhu et al. 2004
	Panicum maximum	2.47	20.7	8.1	40.9	Alluvial, subtropical	Sharda et al., 2002
		5.62	34.3	20.6	48.3	Alluvial, subtropical	Ojasvi et al., 2000
		7.54	28.6	30.9	37.9	Alluvial, subtropical	Ojasvi et al., 2000
		7.93	17.04	15.26	22.79	Alluvial, Subtropical	Khola, 2000
	Natural	2.17	35.08	5.08	54.5	Laterite, Hot-sub-humid	Yadav et al., 2000
		0.5	22.7	1.05	49.6		Rao et al., 1998
		1.37	39.9	2.16	54.8	Laterite, Hot-sub-humid	Rao et al., 1998
		1.02	44.1	1.72	59.1		Rao et al., 1998
		0.59	5.87	3.12	12.08	Laterite, Hot-sub-humid	Kale et al., 1993
		0.76	10.2	4.4	16.95		Kale et al., 1993
		1.36	13.36	4.84	20.1	Laterite, Hot-sub-humid	Kale et al., 1993
	Cenchrus ciliaris	0.6	16.25	7.05	46	Black (Inceptisol)	Nalatwadmath & Rao., 2000
		0.81	21.9	1.39	29.5	Hot-semiarid	
		0.5	6.6	16.08	68.7	Red, hot sub-humid	Katiyar et al., 2007
							Sharma, 1999
	Vetiveria zizanioides	9.02	19.17	15.26	22.79	Alluvial, Subtropical	Khola, 2000
		0.29	7.29	0.53	11.26	Red, hot sub-humid	Katiyar et al., 2007
		1.29	25.4	6.35	64.8	Red, hot sub-humid	Sharma, 1999
		0.5	8.6	0.7	20.7	Red, hot sub-humid	Sharma & Bhatt, 1996
	Thysanolaena maxima (Broom)	15.7	14.2	19	17	Red laterite (Alfisol)	Sahoo & Adhikari, 2014
		18.7	17.3	23.9	23.5	Hot sub-humid	Sahoo & Adhikari, 2014
	Heteropogon hamata	0.59	20.8	1.39	29.5	Red laterite (Alfisoil) Hot sub-humid	Katiyar et al., 2007

Grassland management							
Grass	Grass improvement			Traditional Grass		Soil type and climate	Source
	Species	Soil loss (Mg ha^{-1} yr^{-1})	Runoff (%)	Soil Loss (Mg ha^{-1} yr^{-1})	Runoff (%)		
	Cynodon dactylon	0.06	35	3.28	54	Red, hot sub-humid	Hazra & Singh, 1987
	Cenchrus	0.13	33	3.28	28.12	Red, hot sub-humid	Hazra & Singh, 1987

Solid Earth Discuss., doi:10.5194/se-2016-143, 2016
Manuscript under review for journal Solid Earth
Published: 21 October 2016

ciliaris	2.14	16.8	3.33		Black, hot semi arid	Ilango et al., 2002
Panicum antidotale	0.43	36	3.28	54	Red, hot sub-humid	Hazra & Singh. 1987
Pennisetum polystachyon	0.07	27	3.28	54	Red, hot sub-humid	Hazra & Singh., 1987
Urochloa stolonifera	0.08	32	3.28	54	Red, hot sub-humid	Hazra & Singh., 1987
Cymbopogon martini	1.08	11.32	3.33	28.12	Black, hot semi arid	Ilango et al., 2002
Dicanthium annulatum	1.98	12.56	3.33	28.12	Black, hot semi arid	Ilango et al., 2002
Vetiver zizanioides	2.61	18.4	3.33	28.12	Black, hot semi arid	Ilango et al., 2002

Grazing	Open Grazing		Grazing Management		Soil type and climate	Source
Treatment	Soil loss (Mg ha^{-1} yr^{-1})	Runoff (%)	Soil Loss (Mg ha^{-1} yr^{-1})	Runoff (%)		
	2.35	27	0.85	19	Red, hot sub-humid	Hazra & Singh, 1986`
	3.28	22	0.58	11	Red, hot sub-humid	Hazra & Singh, 1986
	-	24	-	13.9	Alluvial, Hot sub	Bhatt, 2013
	-	11.3	-	6.6	humid	Bhatt, 2013
	1.52	21.6	1.52	10.2	Alluvial, Hot sub	Rao & Reddy, 1996
	3.26	29.34	0.84	15.35	humid	Rao & Reddy, 1996
		20.40	1.18	9.6	Black, Hot semi arid	Khola, 2004
		33.40		19.2	Black, Hot semi arid	Khola, 2004
		29.90		22.2	Black, Hot semi arid	Khola, 2004

Combination

	With Grass (SWC)		Without Grass (SWC)		Soil type and climate	Source
	Soil Loss (Mg ha^{-1} yr^{-1})	Runoff (%)	Soil Loss (Mg ha^{-1} yr^{-1})	Runoff (%)		
Trenching + Vegetative	-	3.4	-	27.6	Black, Hot semi- arid	Khola, 2004
barrier	-	10.5	-	48.5	Black, Hot semi- arid	Khola, 2004
	-	7.6	-	45.5		Khola, 2004
	0.84	10.2	1.53	21.6	Alluvial, Hot sub	Rao & Reddy, 1996
	1.18	15.5	3.26	29.3	humid	Rao & Reddy, 1996
	0.93	8.7	1.55	17.6	Vertisol , Hot semi-	Ali et al., 2014
	0.66	4.1	1.55	17.6	arid	Ali et al., 2014
	0.05	0.4	1.55	17.6		Ali et al., 2014
	6.4	10.8	19	17	Red laterite, hot sub	Sahoo & Adhikari, 2014
	14	12.7	23.9	17	humid	Sahoo & Adhikari, 2014
	9.9	13.4	19	23.5		Sahoo & Adhikari, 2014
	11	15.3	23.9	23.5	Red laterite, hot sub humid	Sahoo & Adhikari, 2014

Table 1b. Details of the experiments and sources of data used to assess relative merits of different contour grass barriers (CGBs)

<2% slope						
Contour grass barriers	Soil Loss (t ha^{-1})	Runoff (%)	Yield (Kg ha^{-1})	Crop	Soil type and climate	Source
Cynodon	3.01	18	1036	Rice	Red Laterite, Hot	Subudhi and Senapati. 1996
dactylon	5.51	16.83	1748	Rice	sub-humid	Subudhi et al. 1998
	4.73	15.59	1759	Rice	Red Laterite, hot	Subudhi et al. 1998
	4.81	15.67	1519	Rice	sub-humid	Subudhi et al. 1998
Pennisetum	2.68	17.4	1669	Rice	Red Laterite, Hot	Subudhi and Senapati. 1996
perpureum	3.05	18.1	1562	Rice	sub-humid	Subudhi and Senapati. 1996
	4.4	15.32	1828	Rice	Red Laterite, Hot	Subudhi et al. 1998
	4.42	15.01	1925	Rice	sub-humid	Subudhi et al. 1998
	4.41	15.17	1877	rice		Subudhi et al. 1998
Vetiveria	2.22	16.6	2133	Rice	Red Laterite, Hot	Sbudhi and Senapati. 1996
zizanoides	4.23	14.83	2042	Rice	sub-humid	Subudhi et al. 1998
	4.02	14.05	1976	Rice	Red Laterite, Hot	Subudhi et al. 1998
	3.96	13.88	2214	Rice	sub-humid	Subudhi et al. 1998
	7.1	34.63	2000	Maize	Red Laterite, Hot	Senapati and Sharma. 2007
	6.89	31.59	2022	Maize	sub-humid	Senapati and Sharma. 2007
	6.48	28.31	2053	Maize		Senapati and Sharma. 2007
	1.14	16.2	1377	Sorghum	Red Laterite, Hot	Prasad et al. 2005
	0.73	13.6	699	Sorghum	sub-humid	Prasad et al. 2005
Eulaliopsis	2.37	17.5	1436	Rice	Red Laterite, Hot	Subudhi and Senapati. 1996
binnata	4.82	15.87	1933	Rice	sub-humid	Subudhi et al. 1998
	5.5	16.32	1812	Rice		Subudhi et al. 1998
	5.54	16.2	1769	rice		Subudhi et al. 1998
Cymbopogon martinii	2.57	17.7	1911	rice	Red Laterite, Hot sub-humid	Subudhi and Senapati. 1996
Dicanthium	1.05	15.5	1364	Sorghum	Black soil, hot-	Prasad et al. 2005
annulatum	0.69	13.7	697	Sorghum	semiarid	Prasad et al. 2005
	0.18	7.1	808	Sunflower		Bhanavase et al. 2007
	0.85	40	-		Inceptisol, Black	Bhanavase et al. 2007
	0.26	12.2	-		sub-humid	Bhanavase et al. 2007
	0.3	12.5	-			Bhanavase et al. 2007
	0.52	28.14	-			Bhanavase et al. 2007
					Inceptisol, Black sub-humid	
Cenchrus	0.14	6.5	867	Sunflower	Inceptisol, Black	Bhanavase et al. 2007
ciliaris	0.74	34.8	-		sub-humid	Bhanavase et al. 2007
	0.21	11.6	-		Inceptisol, Black	Bhanavase et al. 2007
	0.22	11	-		sub-humid	Bhanavase et al. 2007
	0.46	24.12	-			Bhanavase et al. 2007
	1.01	15.8		Sorghum	Black soil, hot	Prasad et al. 2005
	0.77	13.9	1359	Sorghum	semi-arid	Prasad et al. 2005
			697			

Solid Earth Discuss., doi:10.5194/se-2016-143, 2016
Manuscript under review for journal Solid Earth
Published: 21 October 2016

Saccharum	0.86	16.3	1355	Sorghum	Black soil, hot	Prasad et al. 2005
munja	0.7	13.4	674	sorghum	semi-arid	Prasad et al. 2005
Stylosanthes	8.92	33.52	1789	Maize	Red laterite, Hot	Senapati and Sharma. 2007
hemata	8.21	33.21	1766	Maize	sub-humid	Senapati and Sharma. 2007
	8.13	34.41	1733	Maize		Senapati and Sharma. 2007
	5.81	16.87	1777	Rice		Subudhi et al. 1998
	5.85	16.92	1775	Rice	Red laterite, Hot	Subudhi et al. 1998
	5.61	16.63	1803	Rice	sub-humid	Subudhi et al. 1998
	2.8	18.2	1280	rice		Sbudhi and Senapati. 1996
Pennisetum	8.01	34.01	2011	Maize	Red laterite, Hot	Senapati and Sharma. 2007
pedicellatum	7.01	30.98	1990	Maize	sub-humid	Senapati and Sharma. 2007
	6.97	31.64	1969	Maize		Senapati and Sharma. 2007
Cultivated	7.87	23.5		rice	Red laterite, Hot	Sbudhi and Senapati. 1996
fallow					sub-humid	
Control	3.47	21.4	1236	Rice	Red laterite, Hot	Sbudhi and Senapati. 1996
	10.39	19.94	1332	Rice	sub-humid	Subudhi et al. 1998
	7.54	19.02	1330	Rice	Red laterite, Hot	Subudhi et al. 1998
	7.24	19.18	1508	Rice	sub-humid	Subudhi et al. 1998
	8.45	40.18	1720	Maize		Senapati and Sharma. 2007
	9.22	42.32	1790	Maize	Red laterite, Hot	Senapati and Sharma. 2007
	9.02	42.6	1717	Maize	sub-humid	Senapati and Sharma. 2007
	1.89	22	1140	Sorghum	Black Soil, hot sub-	Prasad et al. 2005
	1.45	20.2	562	Sorghum	humid	Prasad et al. 2005
	0.22	10.12	618	Sunflower	Inceptisol, Black	Bhanavase et al. 2007
	1.15	53	-		sub-humid	Bhanavase et al. 2007
	0.4	15.2	-		Inceptisol, Black	Bhanavase et al. 2007
	0.5	16.2	-		sub-humid	Bhanavase et al. 2007
	0.8	40.2	-			Bhanavase et al. 2007
2-4% slope						
Vetiveria	2.54	16.27	1075	Blackgram	Red laterite, Hot	Mishra and Sahu. 2001
zizanoides	1.78	18.45	803	Blackgram	sub-humid	Mishra and Sahu. 2001
	3.5	27.4	5.9	Sorghum	Alluvial Soil, sub-	Chand and Bhan. 2000
	7.2	33	1900	Maize	humid	Bhardwaj and Sindhwal.
	9.8	43	2389	Maize	Alluvial, Sub-	2007
	8.6	42	2063	Maize	tropical	Bhardwaj and Sindhwal.
	6.9	40	2042	Maize	Alluvial, Sub-	2007
	2.9	22	3124	Maize	tropical	Bhardwaj and Sindhwal.
	5	30	3144	Maize	Alluvial, Sub-	2007
	5.5	27	2278	Maize	tropical	Bhardwaj and Sindhwal.
	6.72	35.1	2444	Maize		2007
						Bhardwaj and Sindhwal.
						2007
						Bhardwaj and Sindhwal.
						2007
						Bhardwaj and Sindhwal.
						2007
						Bhardwaj and Sindhwal.
						2007
Pennisetum	3.08	16.5	1002	Blackgram	Red laterite, Hot	Mishra and Sahu. 2001
perpureum	2.96	18.88	624	Blackgram	sub-humid	Mishra and Sahu. 2001

Solid Earth Discuss., doi:10.5194/se-2016-143, 2016
Manuscript under review for journal Solid Earth
Published: 21 October 2016

Solid Earth Discussions Open Access EGU

Eulaliopsis	3.15	18.24	836	Blackgram	Red laterite, Hot	Mishra and Sahu. 2001
binata	2.75	20.51	618	Blackgram	sub-humid	Mishra and Sahu. 2001
	7.9	34	1869	Maize	Alluvial, Sub-	Bhardwaj and Sindhwal.
	10.6	46	2333	Maize	tropical	2007
	12.4	49	1833	Maize	Alluvial, Sub-	Bhardwaj and Sindhwal.
	8.3	42	1961	Maize	tropical	2007
	3.6	25	2941	Maize	Alluvial, Sub-	Bhardwaj and Sindhwal.
	7.3	31	2839	Maize	tropical	2007
	7.3	32	2028	Maize	Alluvial, Sub-	Bhardwaj and Sindhwal.
	8.34	37.9	2296	Maize	tropical	2007
						Bhardwaj and Sindhwal.
						2007
						Bhardwaj and Sindhwal.
						2007
						Bhardwaj and Sindhwal.
						2007
						Bhardwaj and Sindhwal.
						2007
Heteropogon	0.08	5.5	523	Sorghum	Red soil, hot sub-	Narayan et al. 2014
contortus	0.6	15.9	-		humid	Narayan et al. 2014
	0.2	4.1	-			Narayan et al. 2014
Cenchrus	0.9	8.37	509	Sorghum	Red soil, hot sub-	Narayan et al. 2014
ciliaris	0.82	19.4	-		humid Red soil, hot	Narayan et al. 2014
	0.3	6.84	-		sub- humid	Narayan et al. 2014
	4	30.2	7.2	Sorghum	Alluvial Soil, sub-	Chand and Bhan. 2000
					humid	
Pannicum	6.12	33.3	2460	Maize	Alluvial, Sub-	Bhardwaj and Sindhwal.
antidotale	5.8	29	1911	Maize	tropical	2007
	8.1	41	2528	Maize		Bhardwaj and Sindhwal.
	7.6	38	2073	Maize	Alluvial, Sub-	2007
	6.2	39	2059	Maize	tropical	Bhardwaj and Sindhwal.
	2.9	23	3109	Maize		2007
	6.1	31	3089	Maize		Bhardwaj and Sindhwal.
	6.8	28	2138	Maize		2007
						Bhardwaj and Sindhwal.
						2007
						Bhardwaj and Sindhwal.
						2007
						Bhardwaj and Sindhwal.
						2007
						Bhardwaj and Sindhwal.
						2007
Saccharum	3.87	18.93	963	Blackgram	Red laterite, Hot	Mishra and Sahu. 2001
munja	3.07	21.04	603	Blackgram	sub-humid	Mishra and Sahu. 2001
Control	3.42	17.35	965	Blackgram	Red laterite, Hot	Mishra and Sahu. 2001
	3.27	20.75	603	Blackgram	sub-humid	Mishra and Sahu. 2001
	7.5	46.5	5.3	Sorghum	Alluvial Soil, sub-	Chand and Bhan. 2000
	46.28	18.04	-	Maize	humid	Bhardwaj and Sindhwal.
	0.41	19.8	480	Sorghum	Alluvial, Sub-	2007
	1.4	29.7	-		tropical	Narayan et al. 2014
	1	13.7	-		Red soil, hot sub-	

Solid Earth Discuss., doi:10.5194/se-2016-143, 2016
Manuscript under review for journal Solid Earth
Published: 21 October 2016

					humid	
>4% slope						
Thysanolaena maxima	6.92 6.02 7.16	13.85 13 14.06	891 1105 1045	Finger millet	Red laterite, Hot sub-humid	Sudhishri et al. 2008
Vetiver zizanioides	4.22 3.85 4.06 9.87	8.79 7.85 9.88 40.52	1092 1226 1346 2180	Finger millet	Red laterite, Hot sub-humid	Sudhishri et al. 2008
Saccharum munja	4.49 4.02 4.65	9.36 8.25 10.83	1045 1226 1427	Finger millet	Red laterite, Hot sub-humid	Sudhishri et al. 2008
Cynodon dactylon	2.1	27.1	4355		Alluvial (Entisols) sub humid tropical	Narain et al. 1994
Dicanthium annulatum	1.02 0.23	21.2 1.9	6805		Alluvial (Entisols) sub humid tropical	Narain et al. 1994
Eulaliopsis binnata	0.29	5.2	16290		Alluvial (Entisols) sub humid tropical	Narain et al. 1994
Chrysopogon fulvus	0.3	2.5	19170		Alluvial (Entisols) sub humid tropical	Narain et al. 1994
Control	83.04 18.45 92.42	32.6 16.2 71.1	- - -		Alluvial (Entisols) sub humid tropical	Narain et al. 1994 Narain et al. 1994 Narain et al. 1994
	13.9 13.7 14.28	26.02 24.84 26.78	607 676 682	Finger millet	Red laterite, Hot sub-humid	Sudhishri et al. 2008 Sudhishri et al. 2008 Sudhishri et al. 2008

Solid Earth Discuss., doi:10.5194/se-2016-143, 2016
Manuscript under review for journal Solid Earth
Published: 21 October 2016

Table 2. Various attributes and normalized scores used for calculating CPI for different vegetative barriers

	Vetiver	Hy. Napier	Panicum	Dicanthium	Broom	Cymbopogon	congosignal	Eulaliopsis	Saccharum munja Sambuta
IR (cm ha^{-1})	7.5-11.6	11.08-13.26	7.68-8.21	7.12-8.02	14.42		20.06	7.7-8.6	12.7
Score	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Soil Loss (t ha^{-1})	1.0-9.8	2.96-3.08	2.9-8.1	0.2-1.02	6.02-7.16	1-2.57	6.0-8.0	2.75-12.4	4.02-4.7
Score	0.5	0.8	0.5	1.0	0.5	1.0	0.5	0.8	0.8
Soil binding (ml mm^{-2})	206-248	577-803	82-127	127-331	153-178	80-150	75-110	613-956	230-395
Score	0.2	1.0	0.2	0.2	0.2	0.2	0.2	1.0	0.5
Sod forming Soil depth (cm)	60-90	40-60	80-105	50-60	60-95	80-100	30-50	30-40	35-50
Score	0.8	0.5	1.0	0.5	0.8	1.0	0.5	0.2	0.2
Fodder or commercial value	Average	excellent	Very good	Excellent	Average	Average	Good	Very good	Average
Score	0.2	1.0	0.5	1.0	0.2	0.2	0.5	0.5	0.2
Cost of establishme-nt (Rs)	3500-4500	4000-6000	3000-5000	3500-4500	4000-5000	4000-6000	2500-3500	3500-5000	3000-4501
Score	0.5	0.5	0.5	0.5	0.5	0.5	0.8	0.5	0.8

Solid Earth Discuss., doi:10.5194/se-2016-143, 2016
Manuscript under review for journal Solid Earth
Published: 21 October 2016

Table 3. Impact of grasses in arresting Soil loss and Runoff

Treatment	Run off (%)	Soil loss (Mg ha^{-1} yr^{-1})	Number of Samples (n)
Vegetative barrier			
Control (Without Grass)	11.26 – 62.40 (37.71 ± 18.12)[a]	0.53-30.90 (9.56±8.79)[a]	25
With Grass	5.87 – 44.10 (20.93 ± 10.76)[b]	0.5-18.7 (3.93±5.03)[b]	25
Conservation use efficiency (CUE)	44.56	59.04	25
Along with Structural Conservation measures			
Control (Grazed)	17.0 – 48.5 (25.53 ± 10.88)[a]	1.53-3.26 (1.88±0.77)[a]	17
Combination	0.40 – 15.30 (9.37± 4.76)[a]	0.05-1.18 (0.73±0.42)[a]	17
Conservation use efficiency (CUE)	62.93	60.96	17
Grazing Management			
Control (Grazed)	11.30 – 33.4 (24.33 ± 6.55)[a]	1.52-3.28 (2.58±0.73)[a]	12
Management	6.60 – 22.2 (14.12 ± 5.23)[b]	0.58-1.3 (0.95±0.29)[b]	12
Conservation use efficiency (CUE)	42.01	63.18	12

Values in the parentheses are mean ± SD

Different letters in the same column are significantly different at $P<0.05$

Table 4. Site specific suitable grasses for Contour Vegetative Barriers

S.No.	State	Crop	Barrier
1	Andhra Pradesh	Sorghum/castor	*Cenchrus ciliaris (* Buffel grass)
2	Haryana	Urd Bajra and Wheat	Mixed barrier of *Vetiveria zizaniodes* (Vetiver) plus *Eulaliopsis binata* (Sabai grass)
3	Karnataka	Groundnut Finger millet Sorghum	*Vetiveria zizaniodes* (Vetiver) on contour Combination of graded bund and *Vetiveria zizaniodes* (Vetiver) Compartmental bunding with *Vetiveria zizanoides* (Vetiver)
4	Madhya Pradesh	Soyabean	*Cympogon martini* (Lemon grass/ Palmarosa)
5	Maharashtra	Sorghum, Cotton	*Vetiveria zizanoides* (Vetiver)
6	Orissa	Paddy Cowpea (green pond)	*Vetiveria zizanoides* (Vetiver) , *Cynodon dactylon* (Bermuda grass)
7	Punjab	Maize	*Saccharum sps.*
8	Tamil Nadu	Potato	*Pennisetum purpureum* (Napier/Elephant grass)
9	Uttarakhand	Corn	*Panicum maximum* (Guinea/buffalo grass)

Solid Earth Discuss., doi:10.5194/se-2016-143, 2016
Manuscript under review for journal Solid Earth
Published: 21 October 2016

Table 5. Relative merits of contour grass barrier (CGBs) in different land slopes

Treatment	Run off (%)	Soil loss (Mg ha^{-1} yr^{-1})	Yield	Number of Samples (n)
<2 % slope				
Control (Without Grass)	10.12 – 42.60 (27.10 ± 13.58) [a]	0.22 – 10.39 (5.03 ± 3.92) [a]	546 – 1717 (1179 ± 475.32) [a]	12
With Grass	13.88 – 16.92 (15.81 ± 1.06) [b]	3.82 – 5.85 (5.03 ± 0.69) [a]	1519 – 2214 (1843 ± 176.09) [b]	12
Relative reversibility	52.64 % (Δ RF)	Insignificant (Δ SL)	44 %(Δ Y)	
2-4 % slope				
Control (Without Grass)	13.20 – 71.10 (28.36 ± 15.36) [a]	0.41 – 92.42 (23.46 ± 32.54) [a]	345 – 965 (756 ± 341.17) [a]	12
With Grass	16.27 – 41.00 (24.65 ± 9.45) [a]	1.78 – 8.10 (4.24 ± 2.11) [b]	618 – 2528 (1257 ± 684.69) [b]	12
Relative reversibility	14.63 % (Δ RF)	141 % (Δ SL)	53 %(Δ Y)	
> 4 % slope				
Control (Without Grass)	24.84 – 71.10 (36.27 ± 19.70) [a]	13.70 – 92.42 (43.47 ± 40.53)[a]	558-682 (638 ± 53.80) [a]	5
With Grass	7.85 – 14.06 (11.51 ± 3.39) [b]	3.85 – 7.16 (5.63 ± 1.52) [b]	891 – 1226 (1071 ± 121.13) [b]	5
Relative reversibility	55.54 % (Δ RF)	107 % (Δ SL)	50.64 %(Δ Y)	

Relative reversibility of erosion/Water loss-

$$\Delta \text{Erosion}/\ \Delta \text{Runoff} = \frac{\text{Erosion/ water loss without CGB} - \text{Erosion/ water loss with CGB}}{\text{Mean erosion/ water loss}} \times 100$$

Relative yield gain -

$$\Delta \text{Yield gain} = \frac{\text{Mean yield with CGB} - \text{Mean yield without CGB}}{\text{Mean yield}} \times 100$$

Solid Earth Discuss., doi:10.5194/se-2016-143, 2016
Manuscript under review for journal Solid Earth
Published: 21 October 2016

Table 6. Comparative Comprehensive Performance Index of vegetative barrier

Wt.	Vetiver	Hy. Napier	Panicum	Dicanthium	Broom	Cymbopogon	Congosignal	Eulaliopsis	Sambuta
IR (0.2)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Wt x score	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Soil loss (0.2)	0.5	0.8	0.5	1.0	0.5	1.0	0.5	0.8	0.8
Wt x score	0.10	0.16	0.10	0.2	0.1	0.2	0.1	0.16	0.16
Soil binding (0.1)	0.2	1.0	0.2	0.2	0.2	0.2	0.2	1.0	0.5
Wt x score	0.02	0.1	0.02	0.02	0.02	0.02	0.02	0.1	0.05
Sod forming (0.1)	0.8	0.5	1.0	0.5	0.8	1.0	0.5	0.2	0.2
Wt x score	0.08	0.05	0.1	0.05	0.08	0.1	0.05	0.02	0.02
Fodder value (0.2)	0.2	1.0	0.5	1.0	0.8	0.2	0.5	0.5	1.0
Wt x score	0.04	0.2	0.1	0.2	0.16	0.04	0.1	0.1	0.2
Cost established (0.2)	0.5	0.5	0.5	0.5	0.8	0.5	0.8	0.5	0.8
Wt x score	0.1	0.1	0.1	0.1	0.16	0.1	0.16	0.1	0.16
CPI=Σ (Wt x score)	0.54	0.81	0.62	0.77	0.72	0.63	0.68	0.68	0.79

Values in the parentheses are weights assigned to the respective attributes

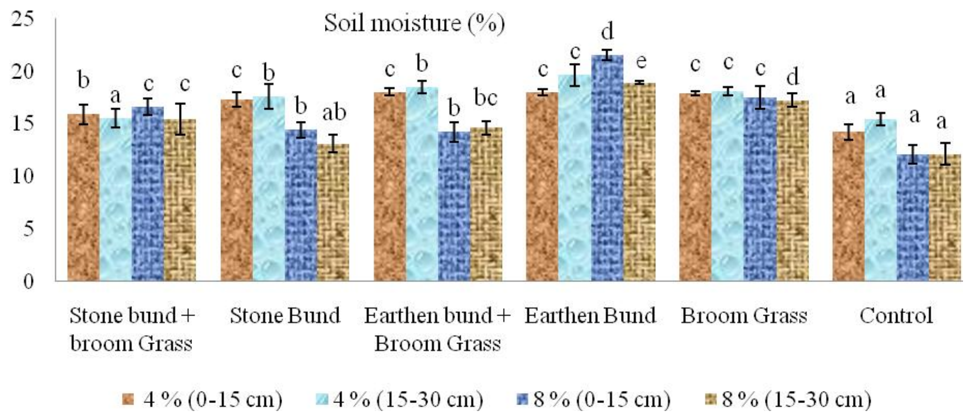

Figure 1. Complimentary role of grasses in enhancing soil profile moisture at 4 % and 8 % slope. Values with different letters are significantly different at 95% confidence level ($p \leq 0.05$; ANOVA-DMRT).

Solid Earth Discuss., doi:10.5194/se-2016-143, 2016
Manuscript under review for journal Solid Earth
Published: 21 October 2016

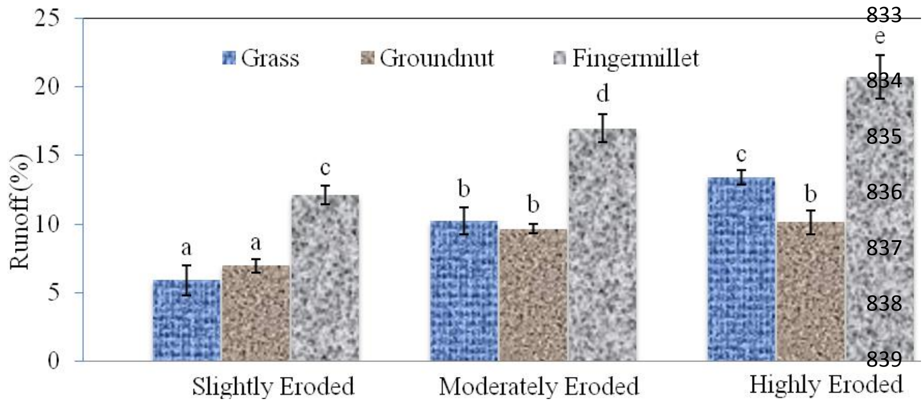

Figure 2. Impact of grasses in reducing runoff in lateritic soil. Values with different letters are significantly different at 95% confidence level ($p \leq 0.05$; ANOVA-DMRT).

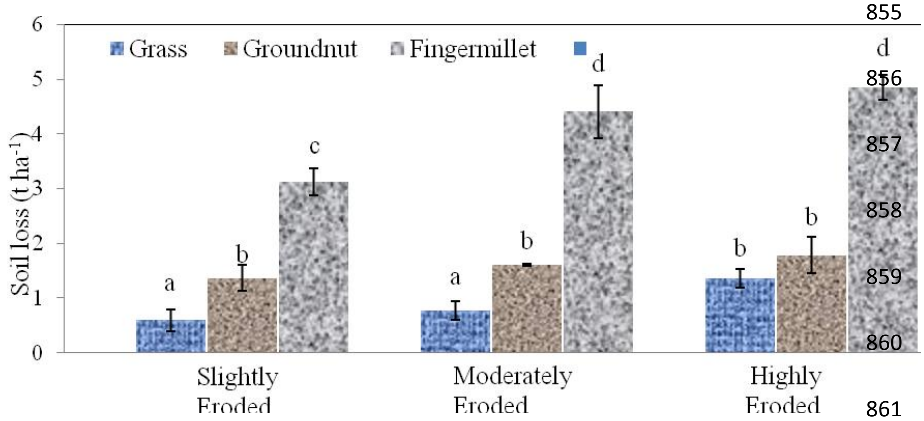

Figure 3. Impact of grasses in reducing soil loss in lateritic soil. Values with different letters are significantly different at 95% confidence level ($p \leq 0.05$; ANOVA-DMRT).

Solid Earth Discuss., doi:10.5194/se-2016-143, 2016
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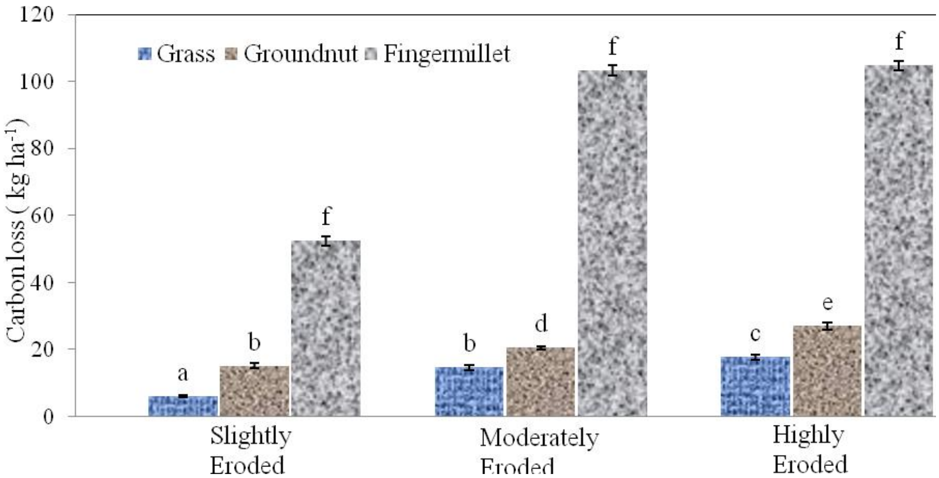

Figure 4. Impact of grasses in reducing carbon loss in lateritic soil. Values with different letters are significantly different at 95% confidence level ($p \leq 0.05$; ANOVA-DMRT).

Solid Earth Discuss., doi:10.5194/se-2016-143, 2016
Manuscript under review for journal Solid Earth
Published: 21 October 2016

List of Tables

List of Figures